

Design Manual

Removal of Arsenic from Drinking Water Supplies by Iron Removal Process

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Abstract

This design manual presents the steps required to design and operate a water treatment plant for removal of arsenic (As) from drinking water supplies using iron removal processes. It also discusses the capital and operating costs, including the many variables that can raise or lower costs for identical treatment systems.

Iron removal processes are generally simple, reliable, and cost-effective. Arsenic removal is accomplished by adsorption of As(V) onto ferric hydroxides formed in the iron removal process. Several iron removal treatment methods can remove arsenic from drinking water supplies to levels below the new arsenic maximum contaminant level (MCL) of 0.010 mg/L; these methods include oxidation and filtration, and the use of solid oxidizing media products and manganese greensand. Many existing water utilities have much if not all of the appropriate technology in place for iron removal, but may need to modify or adjust the processes in order to meet the new MCL.

Iron removal processes have operational options that vary with the oxidants used and the media selected for filtration. Selection of the most appropriate process for a water supply should be evaluated on a life-cycle basis. This design manual provides examples for performing an economic evaluation, including the development of an equivalent annual cost. The arsenic removal capacity may be affected by the raw water quality, particularly hydrogen sulfide, organics, and, in some cases, the pH of the water. Treatment processes incorporating oxidants require careful handling and storage of corrosive chemicals, such as chlorine and potassium permanganate.

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Acronyms and Abbreviations

ADA	Americans with Disabilities Act
ANSI	American National Standards Institute
APHA	American Public Health Association
ASME	American Society of Mechanical Engineers
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
Birm	Burgess Iron Removal Method
EDR	electrodialysis reversal
ETV	Environmental Technology Verification
FRP	fiberglass reinforced polyester
GFAA	graphite furnace atomic adsorption
GHAA	gaseous hydroxide atomic adsorption
gpd	gallons per day
gpg	grains per gallon
gpm	gallons per minute
HDPE	high-density polyethylene
HTH	calcium hypochlorite
HVAC	heating, ventilating, air conditioning
ICP-MS	inductively coupled plasma–mass spectrometry
MCL	maximum contaminant level
mgd	million gallons per day
NEC	National Electrical Code
NSF	National Sanitation Foundation International
NTNC	nontransient, noncommunity
NTU	nephelometric turbidity unit
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
P&ID	Process and Instrumentation Diagram
PLC	programmable logic controller
PPD	potassium permanganate demand
psi(g)	pounds per square inch (gage)
PVC	polyvinyl chloride

SDWA	Safe Drinking Water Act (of 1974)
SMCL	secondary maximum contaminant level
STP	stabilized temperature platform
U.S. EPA	United States Environmental Protection Agency
WEF	Water Environment Federation
WTP	water treatment plant

1.0 Introduction

1.1 Purpose and Scope

This manual presents up-to-date information on how iron removal processes can be designed, operated, and modified to effectively remove arsenic from drinking water supplies. The information provided is primarily for small central groundwater treatment plants ranging in capacity from 30,000 to 1,000,000 gallons per day (gpd). However, this manual also can be adapted to both larger and smaller systems. For very small systems having capacities of less than 30,000 gpd (20 gallons per minute [gpm]), some equipment may be different and less expensive (e.g., fiberglass reinforced polyester [FRP] tanks and automatic control valves likely would be used).

1.2 Background

The Safe Drinking Water Act (SDWA) of 1974 mandated that the United States Environmental Protection Agency (U.S. EPA) identify and regulate drinking water contaminants that may have adverse effects on human health and that are known or anticipated to occur in public water supply systems (Public Law, 1974). In 1975, under the SDWA, U.S. EPA established a maximum contaminant level (MCL) for arsenic at 0.05 mg/L (U.S. EPA, 1975). In 1996, Congress amended the SDWA to require that the U.S. EPA develop an arsenic research strategy, publish a proposal to revise the arsenic MCL by January 2000, and finalize the new rule by January 2001 (Public Law, 1996).

On January 22, 2001, U.S. EPA published a final Arsenic Rule in the *Federal Register* that revised the MCL for arsenic at 0.01 mg/L (10 µg/L) (U.S. EPA, 2001). Two months later, in March 2001, the effective date of the rule was extended to provide time for the National Academy of Science to review new studies on the health effects of arsenic and for the National Drinking Water Advisory Council to review the economic issues associated with the standard. After considering

the reports by these two review groups, U.S. EPA finalized the arsenic MCL at 0.01 mg/L (10 µg/L) in January 2002. In order to clarify the implementation of the original rule, U.S. EPA revised the rule text on March 25, 2003 to express the MCL as 0.010 mg/L (U.S. EPA, 2003). The final rule requires all community and non-transient, non-community (NTNC) water systems to achieve compliance with the rule by January 23, 2006.

1.3 Arsenic Speciation

Arsenic is a common, naturally occurring contaminant that originates from arsenic-bearing rocks and soils. It is transported to natural waters through erosion and dissolution and exists primarily in inorganic form. Common sources of contamination include the erosion of natural deposits, pesticide runoff from orchards, and runoff from glass and electronics production wastes. Inorganic arsenic is the form of arsenic most likely to cause regulatory concern.

The species and valence state of inorganic arsenic depend on the oxidation-reduction conditions and pH of water. In general, arsenite, the reduced, trivalent form [As(III)], is found in groundwater (assuming anaerobic conditions); and arsenate, the oxidized, pentavalent form [As(V)], is found in surface water (assuming aerobic conditions). This rule, however, does not always hold true for groundwater. Some groundwaters have been found to contain only As(III), others with only As(V), and still others with a combination of both As(III) and As(V). Arsenate exists in four forms in aqueous solution, depending on pH: H_3AsO_4 , H_2AsO_4^- , HAsO_4^{2-} , and AsO_4^{3-} . Similarly, arsenite exists in five forms: H_4AsO_3^+ , H_3AsO_3 , H_2AsO_3^- , HASO_3^{2-} and AsO_3^{3-} .

Until recently, studies on the preservation of arsenic species concluded that no effective methods exist to preserve As(III) and As(V) in water samples. Because of the lack of a good preservation method, field separation methods developed by Ficklin (1982), Clifford et al.

(1983), and Edwards et al. (1998), and modified by Battelle (U.S. EPA, 2000) have been used to separate As(III) from As(V). All of the methods use an anion exchange resin column and have been found to be effective for speciating. Their use is recommended to determine the oxidation state of arsenic in the source water to be treated. The speciation of arsenic is important because As(V) is more effectively removed by iron removal processes than As(III); therefore, if source water contains predominantly As(III), a strong oxidant must be added to convert As(III) to As(V) for more effective removal.

1.4 Arsenic Removal Options

Arsenic concentrations in surface water supplies normally are less than the finalized U.S. EPA MCL of 0.010 mg/L. However, groundwater supplies often have arsenic concentrations that are higher than the MCL due either to the exposure of water to arsenic-bearing geologic materials, or to contamination by arsenic-bearing water. Because of the revision of the MCL, a large number of utilities that previously have been in compliance will need to install new and/or modify existing arsenic removal systems to meet the new MCL. Many treatment options exist for the removal of arsenic from surface and groundwaters. They include coagulation/filtration using iron or aluminum salts; lime softening; ion exchange; adsorptive media; membrane processes (such as reverse osmosis [RO] and nanofiltration [NF]); electro dialysis reversal (EDR); and iron removal (U.S. EPA, 2000).

This design manual focuses on the removal of excess arsenic from source water using iron removal processes. The concepts and principles outlined in the manual can be adapted to several different types of iron removal treatment options:

1. Chemical oxidation followed by media filtration.
2. Solid oxidizing media filtration.
3. Manganese greensand filtration.

The variation among the different treatment options depend on site and water quality factors.

Two other processes that are particularly cost-effective for treatment of groundwater include ion exchange and adsorptive media; a design manual for each process has been published by U.S. EPA (Rubel, 2003a and 2003b).

Other non-treatment lower-cost options also exist for reducing the arsenic level in a water supply. One option is to locate an alternate water source within the service area that complies with the arsenic MCL, as it may be feasible to blend the two sources and achieve a combined water quality that complies with the arsenic MCL.

A second option (which includes an element of risk) is to drill a new well (or wells) within the service area. This approach should be attempted only when there is sound reason to believe that a sufficient quantity of acceptable water can be located. The costs (both capital and operating) of a new well should not exceed the costs of treating the existing source.

A third option is to pump water of good quality to the service area from another service area. This imported source either can be used alone or can be blended with the original source to achieve a combined water quality that meets the MCL. However, the costs of installing a delivery system and delivering the water become increasingly unfavorable as the distance increases, the rise in elevation increases, and/or the physical barrier exists. Factors to be considered are the reliability, the cost, and the assurance that the consumers will only use the imported/blended source.

2.0 Arsenic Removal by Iron Removal Treatment Methods

2.1 Introduction

This chapter provides an overview of the design considerations that are applicable to arsenic removal by use of iron removal treatment methods. Iron-based treatment technology options include chemical coagulation/filtration with iron salts, adsorptive media (iron-based products), and iron removal by oxidation and filtration (Gupta and Chen, 1978; Edwards, 1994; McNeill and Edwards, 1995; Scott et al., 1995; Holm, 1996; Hering et al., 1996; McNeill and Edwards, 1997; Chen et al., 2002). These processes are particularly effective at removing arsenic from aqueous systems because iron surfaces have a strong affinity to adsorb arsenic. The adsorption and coprecipitation of As(III) and As(V) on iron oxide surfaces have been investigated extensively (Manceau, 1995; Waychunas et al., 1996; Sun and Doner, 1998; Jain et al., 1999). Research also has shown that As(V) is more effectively removed by iron removal processes than As(III) (Edwards, 1994; Hering et al., 1996; Leist et al., 2000; Chen et al., 2002).

Many arsenic-containing groundwaters also may contain significant levels of iron and manganese due to natural geochemistry. Like arsenic, iron exists in two primary valence states: Fe(II) (ferrous iron) and Fe(III) (ferric iron). Manganese has many valence states: Mn(II), Mn(III), Mn(IV), Mn(VI), and Mn(VII). The reduced forms of both elements (i.e., Fe(II) and Mn(II) [manganous manganese]) are soluble. When oxidized, both elements are converted to insoluble forms and can cause serious aesthetic problems in drinking water. Because of these potential problems, secondary maximum contaminant levels (SMCLs) were established by U.S. EPA (1979) for iron (0.3 mg/L) and manganese (0.05 mg/L). Removing iron and manganese levels to below their SMCLs eliminates many of the taste, odor, and color problems caused by high concentrations.

Iron and manganese can be removed from source water by several technologies. The traditional removal method for both elements involves a two-step process: (1) oxidation of the soluble Fe and Mn forms to the common insoluble forms of $\text{Fe}(\text{OH})_{3(s)}$ and $\text{MnO}_{2(s)}$ and, (2) filtration of

these formed precipitates. Figure 2-1 shows a schematic of conventional iron removal by aeration.

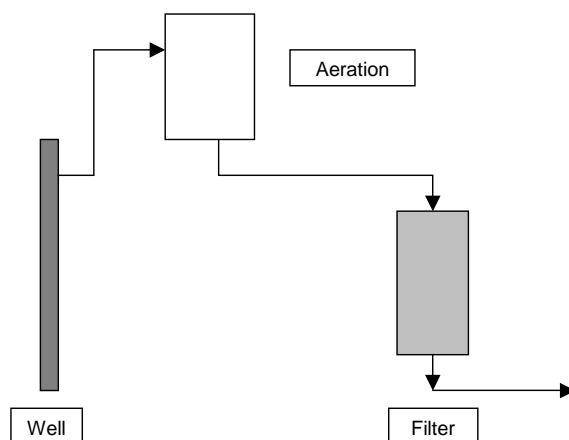


FIGURE 2-1. Conventional Iron Removal by Aeration

Note that, although manganese has properties similar to iron, it does not have a high capacity for arsenic removal. Thus, the amount of arsenic removed by processes designed to remove both iron and manganese depends primarily on the iron removed. Therefore, this manual has been devoted to iron removal processes.

Arsenic in source waters can be removed by taking advantage of the arsenic adsorptive capacity of natural iron particles formed following the oxidation of Fe(II) to Fe(III). Arsenic removal is achieved through two primary mechanisms: adsorption, which involves the attachment of arsenic to the surface of Fe(III) particles; and coprecipitation, which involves the entrapment of arsenic within growing Fe(III) particles by inclusion, occlusion, or adsorption (Benfield and Morgan, 1990; Chen et al., 2002). In essence, iron removal processes also can act as effective arsenic removal processes.

The capacity of a given iron removal process to remove arsenic and the potential to meet the new arsenic MCL depends largely on the amount of arsenic and natural iron in the source water. Sorg (2002) proposed an arsenic treatment selection strategy screening guide,

which is derived from the prediction that source waters having an iron to arsenic ratio of 20:1 are potential candidates for arsenic removal to below the MCL by removing the iron (U.S. EPA, 2001 and 2002). Converting this ratio into a removal guide indicates that 1 mg/L iron should be capable of removing 50 µg/L arsenic under optimum adsorptive and process operational conditions (Figure 2-2).

The actual capacity to remove arsenic via iron removal depends on several factors, including water chemistry, operating considerations, and the sequence of treatment processes. Studies have shown that the sorption of arsenic onto iron solids is affected by many factors, including the amount and form of As(III) and As(V) present; pH; water chemistry; amount and form of iron present; and the existence of competing ions, such as phosphate, silicate, and natural organic matter (Andreae, 1979; Azcue and Nriagu, 1993; Edwards, 1994; Al-Juaid et al., 1994; Borho and Wilderer, 1996; Chen et al., 2002). Redox relationships between arsenic, iron, and oxidants are particularly important to consider when optimizing the removal of arsenic via an iron removal process.

Several variations on traditional iron removal oxidation/filtration technology for groundwater exist; the basic process includes oxidation, contact time (optional), and filtration. The most common oxidants used for iron precipitation are oxygen, chlorine, and potassium permanganate; however, aeration is not an effective method for oxidizing arsenic (Frank and Clifford, 1986; Lowry and Lowry, 2002). To achieve arsenic removal by iron

removal, the use of a strong chemical oxidant is required. The oxidation step is usually followed by detention (contact time) and filtration.

Filtration options consist of sand (only), anthracite and sand (dual media), manganese greensand, and various synthetic filtration media. The manganese greensand media is a special media that removes iron and manganese by combination of oxidation, adsorption, and filtration all within the media itself. Oxidation and filtration processes as well as the significance of contact time and jar/pilot testing will be discussed in more detail in Sections 2.2 through 2.5.

2.2 Oxidation

When oxidizing iron and arsenic to optimize removal, one must consider (1) the addition of a strong oxidant, and (2) the point of chemical oxidant addition.

In general, arsenic in groundwater containing both arsenic and iron will exist in the reduced form, As(III). To optimize arsenic removal, neutrally charged As(III) needs to be oxidized to As(V). As(V) exists as a negatively charged ion and can be adsorbed onto positively charged surfaces of ferric hydroxide particles. Consequently, if the arsenic in the source water is predominately As(III), oxidizing As(III) to As(V) using a **strong oxidant** will result in a higher rate of arsenic removal by an iron removal process. Figure 2-3 shows the recommended sequence of steps for removing As(III) via iron removal using a strong chemical oxidant.

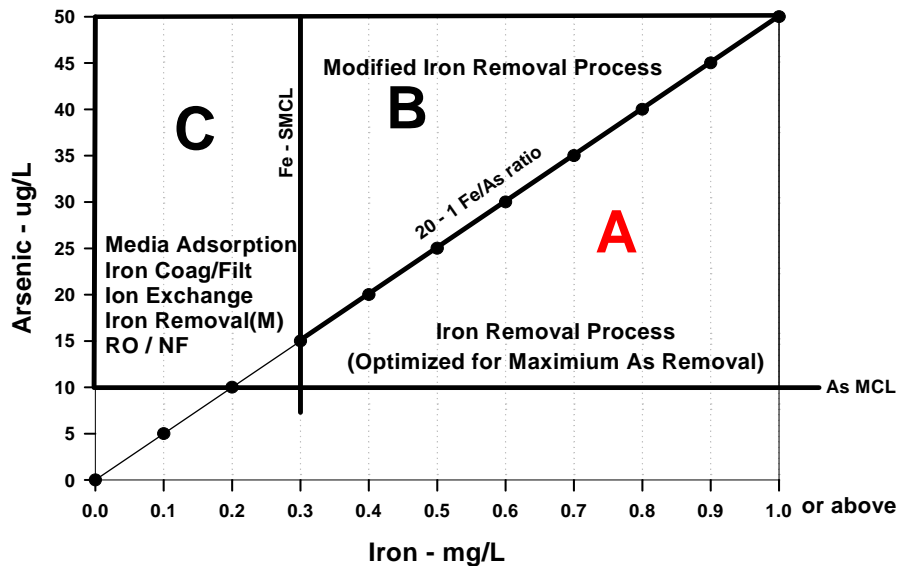


FIGURE 2-2. Arsenic Treatment Selection Strategy Guide (function of initial As and Fe content of water) (Sorg, 2002)

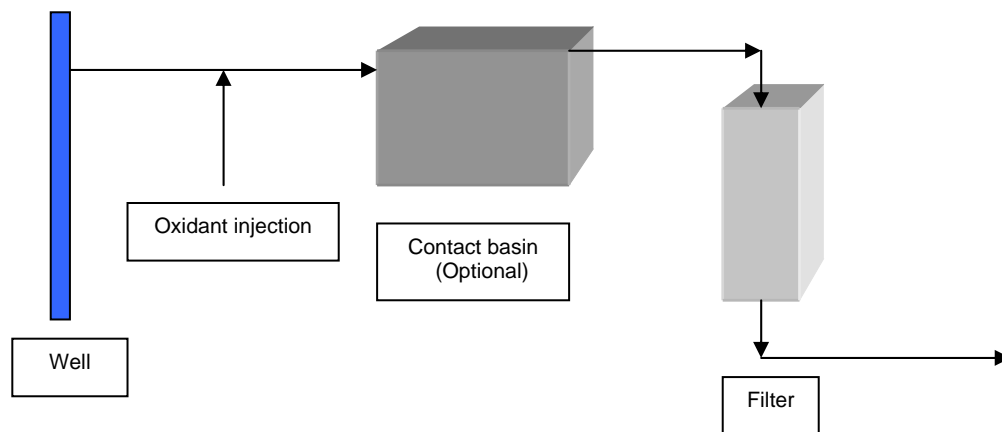


FIGURE 2-3. Recommended Steps for Arsenic(III) Removal Using an Iron Removal Process

2.2.1 Chemical Oxidants

As(III) can be easily converted to As(V) using chemical oxidants such as chlorine, potassium permanganate, and ozone, which are known to improve arsenic removal (Ghurye and Clifford, 2001 and 2004). The dosage of oxidants will depend on the concentrations of other substances in the source water, such as iron, manganese, sulfide, and dissolved organic matter. Oxidants that do not effectively convert As(III) to As(V) include oxygen (i.e., aeration), chlorine dioxide, and chloramine.

The effectiveness of various chemical oxidants for iron, manganese, and arsenic is shown in Table 2-1. The table lists the effectiveness of these oxidants for manganese because the oxidation option selected for arsenic removal may be determined by the need to oxidize both iron and manganese.

The stoichiometric amount of oxidant necessary to oxidize As(III), Fe(II), and Mn(II) is important when approximating chemical feed dosage in iron/arsenic removal systems. It is important not to under-dose on the oxidant because under-dosing can result in incomplete oxidation of As(III). Table 2-2 presents the stoichiometric relationships between relevant oxidants and Fe(II), Mn(II) and As(III). Note that the oxidant demand of Fe(II) and Mn(II) dominates relative to that of arsenic. Other water quality constituents also may have an oxidant demand (e.g., ammonia, dissolved organic matter). Thus, when determining the oxidant dose, the total oxidant demand of the source water must be determined.

The **point of chemical oxidant addition** also is critical in achieving optimal arsenic removal. Research has shown that pre-formed iron particles have less capacity to remove As(V) than iron particles that are formed in the presence of As(V). Edwards (1994) reported that

pre-formed iron hydroxides only reached a maximum adsorption density of 0.1 M As(V)/M hydroxide solid, compared to a maximum adsorption density of 0.5 to 0.6 M As(V)/M for iron hydroxides formed in the presence of As(V). The differences in adsorption densities were attributed to different adsorption mechanisms: strict surface adsorption of As(V) onto pre-formed iron hydroxides versus adsorption/co-precipitation with iron hydroxides formed in the presence of As(V).

Hering et al. (1996) examined the water quality factors that affect arsenic removal during iron coagulation and adsorption to pre-formed hydrous ferric oxides. Based on experimental results and surface complexation modeling, the authors demonstrated that, although it is an important mechanism, adsorption is not the only mechanism controlling arsenic removal during coagulation. Similar results were found at an iron removal treatment plant that used aeration to oxidize iron, followed by chlorination or potassium permanganate to oxidize As(III); this was another situation where iron particles were formed prior to arsenic oxidation. Lytle and Snoeyink (2003) observed that arsenic removal would be lower during this sequence of treatment steps, as opposed to the preferred process of oxidizing both Fe(II) and As(III) at the same time. Consequently, **oxidation of iron and arsenic should occur at the same time to achieve optimal arsenic removal.**

2.2.1.1 Chlorine

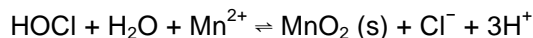
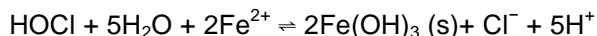
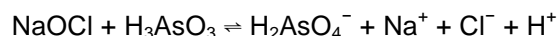
Chlorine has long been used as the disinfectant of choice for most drinking water supplies. The oxidizing power of chlorine is not only effective with iron, but also with many other contaminants found in raw water, both organic and inorganic. Chlorine also effectively oxidizes As(III), Fe(II) and Mn(II). The simple oxidation reactions between chlorine and arsenic, iron, and manganese are as follows:

TABLE 2-1. Relative Effectiveness of Various Oxidants

Oxidant	Iron (Fe)	Manganese (Mn)	As(III)
Oxygen (aeration)	Effective	Not effective	Not effective
Chlorine	Effective	Somewhat effective	Effective
Chloramine	Not effective	Not effective	Not effective
Ozone	Effective	Effective	Effective
Chlorine dioxide	Effective	Effective	Not effective
Potassium permanganate	Effective	Effective	Effective

TABLE 2-2. Stoichiometry of Various Chemical Oxidants

Oxidant	Iron (Fe) (mg oxidant/mg Fe)	Manganese (Mn) (mg oxidant/mg Mn)	As(III) (µg oxidant/µg As[III])
Chlorine (Cl ₂)	0.64	1.29	0.95
Chloramine (NH ₂ Cl)	0.46	0.94	0.69
Ozone (O ₃)	0.43	0.88	0.64
Chlorine dioxide (ClO ₂)			
1-electron transfer	-----	2.45	1.80
5-electron transfer	0.24	-----	0.36
Potassium permanganate (KMnO ₄)	0.94	1.92	1.40



Oxidation of As(III), Fe(II), and Mn(II) by chlorine occurs fairly rapidly in pH ranges of 6.5-8.0. To determine the dosage of chlorine, 0.64 mg/L of chlorine (as Cl₂) is needed to oxidize 1.0 mg/L of iron. However, because other materials in the source water may have a chlorine demand, this dose rate may need to be increased. For example, water with manganese requires 1.29 mg/L of chlorine (as Cl₂) to oxidize 1.0 mg/L of manganese. Arsenic typically is present at microgram levels, so negligible amounts of additional oxidant are required. It is common practice to use the stoichiometric value plus 10% when establishing initial dosages.

In recent years, the use of chlorine gas has come under increased scrutiny for safety reasons; sodium hypochlorite and calcium hypochlorite are two common alternatives, especially in smaller plants.

Chlorine gas is delivered by tanker cars (either truck or rail) for very large plants; 2,000-lb containers are used by most cities. For smaller plants, 150-lb cylinders are more typical. The gas is drawn by a vacuum into the water, and the resulting solution is injected into the raw water stream to oxidize iron. Typically, this oxidation step takes place in 10 to 15 seconds (Sommerfeld, 1999).

Note that the use of chlorine gas requires the ability to isolate chlorine leaks. At treatment plants, this normally involves the use of specially modified rooms with appropriate safety gear, ventilation systems, and, in some cases, gas scrubbers.

Sodium hypochlorite is delivered in bulk by tankers or in smaller quantities such as carboys and 5-gallon cartons. It is pumped directly into the raw water stream to oxidize soluble iron. One of the other results of adding sodium hypochlorite to hard water is the formation of caustic soda that tends to soften the water and precipitate calcium and magnesium. These precipitates can harden onto pipe walls and eventually restrict pipe flow if not maintained. Careful consideration to the point of application must be given for maintenance reasons. Shelf life is diminished at higher temperature readings and when exposed to sunlight. Control of off-gassing is another design issue.

Calcium hypochlorite is provided in a dry form and is typically used in low-flow applications. It can be provided in tablet form for use in automatic feed equipment or in a dry powder. Degradation occurs over time. It is the most expensive of the three forms of chlorine and can lead to scale formation in hard waters.

2.2.1.2 Potassium Permanganate

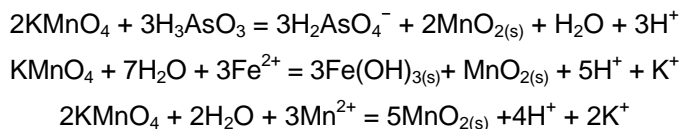
Potassium permanganate (KMnO₄) is a strong chemical oxidant. When dissolved in water, it imparts a pink to purple color depending on the concentration. Potassium

permanganate is similar to chlorine in being able to oxidize Fe(II), Mn(II), and As(III). The chemical also has been used for taste and odor control.

The most common application of potassium permanganate in water treatment is as an oxidant for iron and manganese. A byproduct of this oxidation step is insoluble manganese dioxide. Potassium permanganate can be used in combination with either gravity filters or pressure filters. The most popular type of pressure filter media used is manganese greensand.

Potassium permanganate also is effective at oxidizing As(III) to As(V), which then readily adsorbs to iron particles (not manganese dioxide particles) in water; these iron particles are of a size that can be filtered for removal. Therefore, filtration must follow oxidation to remove the insoluble iron and manganese particles.

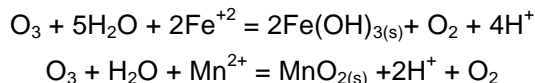
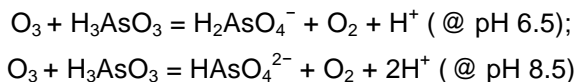
The simple oxidation reactions between potassium permanganate and arsenic, iron, and manganese are as follows:



Potassium permanganate normally is purchased as dry solid crystals in bulk or in drum containers. The chemical is mixed with water and the solution is pumped directly into a raw water line. The maximum solubility of potassium permanganate is about 6.5% at 20°C. After the dry crystals are added to the water, the solution should be mixed for at least 15 minutes with a mechanical agitator. Continuous mixing is recommended.

2.2.1.3 Ozone

Ozone (O₃) has been shown to effectively oxidize iron and manganese at the same time removing arsenic and other metals to below detection limits. An ozone generator can be used to make ozone, which can then be dispensed into a water stream to convert Fe(II) to Fe(III) and As(III) to As(V). It is also a potential disinfectant, but unlike chlorine, ozone does not impart a lasting residual to treated water. Research has shown that the effectiveness of ozonation can be significantly affected by the presence of organic matter and sulfide (S²⁻) (Ghurye and Clifford, 2001 and 2004). The simple oxidation reactions between ozone and arsenic, iron, and manganese are as follows:



2.2.2 Solid Oxidizing Media

Current studies indicate that some solid oxidizing media, such as Filox-R and Pyrolox, will oxidize As(III) to As(V) (Ghurye and Clifford, 2001 and 2004; Lowry et al., 2005). Although both media have been used primarily for filtration, Filox-R has been used to oxidize As(III) as a pre-treatment step before anion exchange treatment for As(V) removal (Lowry et al., 2005). However, stand-alone solid oxidizing treatment is better suited for small treatment plants with low iron concentrations. The removal capacity of solid oxidizing media depends largely on the type of media used and the dissolved oxygen concentration and sulfide levels in the source water. A more detailed discussion on solid oxidizing media is provided in Section 2.4.2.

2.3 Contact Time

Strong chemical oxidants oxidize As(III) and Fe(II) very rapidly (AWWARF, 1990; Ghurye and Clifford, 2001 and 2004), thus contact time generally is not a critical factor for optimizing arsenic removal. Lytle and Snoeyink (2004) report that a majority of arsenic is incorporated into Fe(III) particles during the first several minutes following oxidant addition. Relatively small amounts of additional arsenic adsorption/removal may occur with extended contact time. Extended contact time may provide some benefit to particle development and filterability, and should be considered particularly when anticipated arsenic removal is not achieved. Cost savings can be achieved by eliminating the need for contact basins. Also, a detention/settling tank can help reduce the filter load and increase filter performance and run time.

2.4 Filtration

After the oxidation step (with or without a detention or settling tank), the source water is filtered through a filter media in either a pressure vessel or a gravity filter to remove the iron/arsenic solids formed in the water. A typical layout for pressure vessels is shown in Figure 2-4.

The filtration media in these systems may consist of sand, sand and coal anthracite (dual media), or proprietary/patented products, such as Pyrolox, Filox-R, Birm, and manganese greensand. Table 2-3 provides the costs and physical properties of several commercially available iron removal media. Effective removal of iron particles is critical to good arsenic removal because all iron particles in the filter effluent contain (adsorbed) arsenic.

Some media, such as manganese greensand, have the ability to both oxidize and filter iron and manganese effectively and at the same time. Manganese greensand, pyrolusite, Birm, or any media coated with manganese dioxide has the capacity to oxidize iron and manganese and filter the insoluble precipitates with the filter bed. These media also have some, but limited, capacity for As(III) oxidation and arsenic adsorption.

2.4.1 Anthracite/Sand

Anthracite and sand usually are used in gravity filters to remove particles. A coarse anthracite bed in the size range of 0.80-1.20 mm generally will capture ferric hydroxide solids. Anthracite is generally used in a 12-18 inch depth followed by 12-18 inches of sand ranging from 0.45-0.55 mm. Sand alone may be used without the anthracite cap, but terminal head loss may develop sooner, requiring more frequent backwashing.

Iron and arsenic leakage or breakthrough of the filter can be caused by a number of factors, including:

- Inadequate oxidation that may allow soluble Fe, As(III), and As(V), to pass through the filter media;
- Improper backwashing that does not adequately remove the captured solids containing iron and arsenic, causing them to be “pushed” through the filter when it is put back into service;
- Waiting too long to backwash a filter, which can cause iron and arsenic particles to leak through the filter as the bed becomes packed with these particles; and
- Operating a filter at high loading rates or excessive pressure across the filter.

Properly trained operators can control these factors with regular cleaning and maintenance. Cleaning of the filter media is accomplished through a water backwash. The need for backwashing a gravity filter is usually prompted by one of three factors:

- Head loss up to 8-10 ft due to a “dirty” filter.
- Turbidity breakthrough or other deterioration of the effluent quality.
- Filter run time exceeding a predetermined limit, often set at 80-120 hours.

Fluidization of the bed is accomplished by an upward flow of water through the media of sufficient velocity to suspend the grains in water. This flowrate generally begins at 4-6 gpm/ft² and proceeds up to 15 gpm/ft². The resulting collision of particles and scrubbing action loosens the trapped precipitates, and the carrying velocity of the water removes the particles to a waste stream. Expansion of the filter media varies according to media particle size, specific gravity, and uniformity coefficient. For example, a rate that expands the sand media 30-35% may expand the anthracite 50%. Actual backwashing rates should be determined for the type of media used. If pressure vessels are used, adequate freeboard within the filtration vessels must be designed so that media is not carried out to waste.

For pressure filters, dual media filtration rates are typically in the range of 3 to 5 gpm/ft². Filter run times may be affected by the type of media, filtration rate, and the levels of iron being removed. Some treatment units operating at a high filtration rate (>4 gpm/ft²) and removing high concentrations of iron (3-10 mg/L) may require backwashing daily. Other filters with lower levels of iron being removed and lower filtration rates may not need to be backwashed for several days. In those cases, good operation generally initiates a backwash between 80-120 hours of operation to prevent potential bacteria growth in the filter bed.

2.4.2 Solid Oxidizing Filtration Media

Two media that are gaining wider acceptance for filtration use in iron and manganese removal are pyrolusite and Birm. Pyrolusite is manganese dioxide in a granular form that can be used within a pressure vessel for filtration. Birm, on the other hand, is a manufactured material that begins with a base material coated with manganese dioxide.

Both types of media oxidize iron on the media surface and trap ferric hydroxide particles in the filter bed. Some As(V) can be adsorbed to the ferric hydroxide solids, which then are backwashed out of the filter. The use of oxidizing media should be considered only as a pre-treatment step to remove iron solids and convert As(III) to As(V). As such, it is recommended that processes such as adsorptive media or ion exchange resins be used as a polishing step to remove As(V).

2.4.2.1 Pyrolusite

Pyrolusite is the common name for naturally occurring manganese dioxide and is available in the United States, United Kingdom, South America, and Australia. It is distributed under brand names such as Pyrolox, Filox-R,

PRESSURE VESSEL CONFIGURATION (TYPICAL)

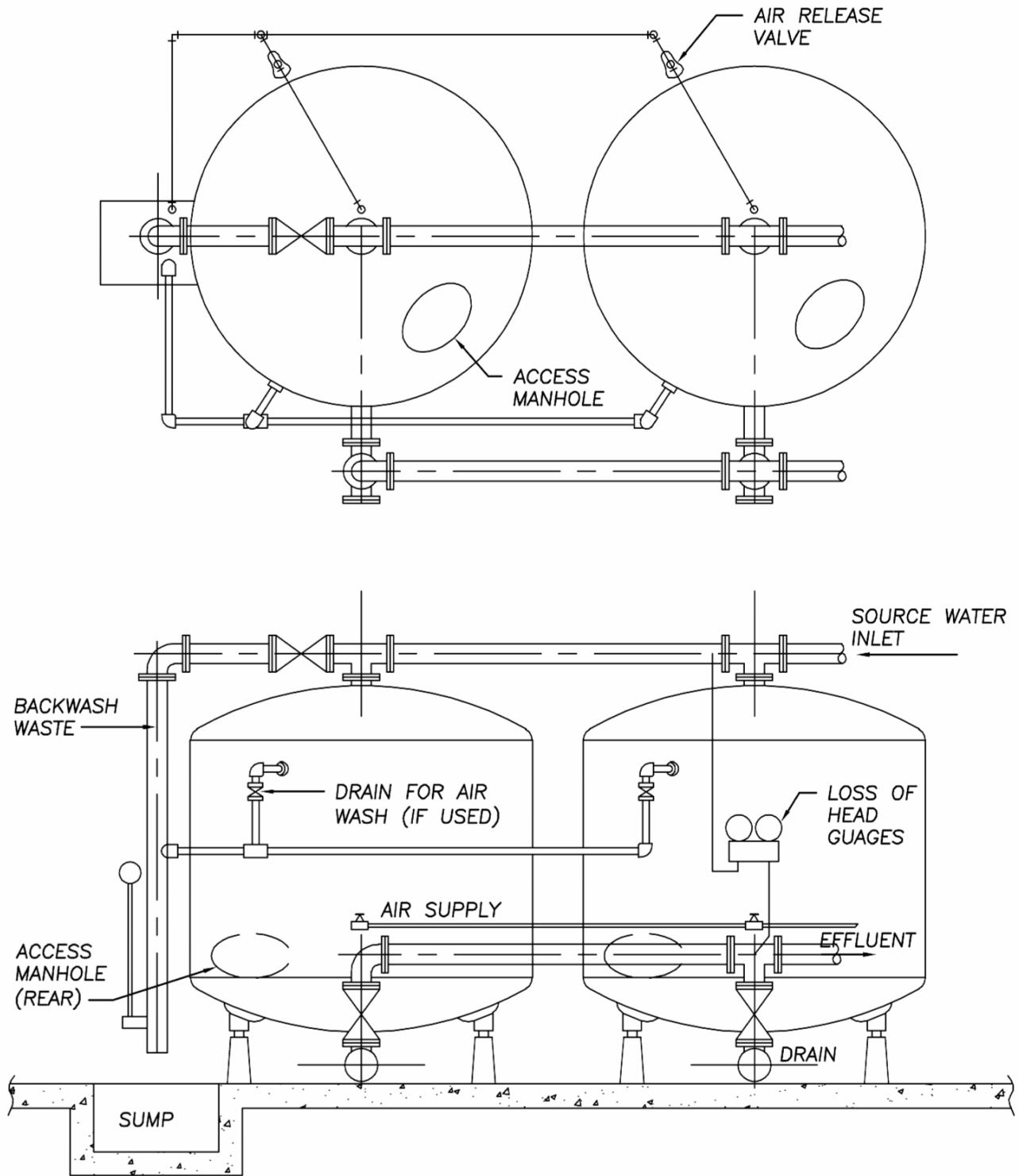


FIGURE 2-4. Typical Layout of Pressure Vessels Used for Filtration

TABLE 2-3. Characteristics of Filter Media for Iron Removal^(a)

Media	Color	Cost ^(b) (\$/ft ³)	Filter Rate (gpm/ft ²)	Specific Gravity (g/cm ³)	Bulk Density (lb/ft ³)	Effective Size (mm)	Uniformity Coefficient	Mesh Size	Chemical Regeneration	pH	Air Scouring	Backwash Rate (gpm/ft ²)	Backwash Bed Expansion (% of bed depth)	Freeboard (% of bed depth)
Manganese greensand	Black	84-90	3.0-5.0	2.4-2.9	85	0.30-0.35	1.3	16 - 60	1.5-2.0 oz (by weight) of KMnO ₄ per ft ³	6.2-8.5	Required	10-12	40	50
Anthracite	Black	8-15	5.0	1.6	50	0.8-1.2	< 1.65	Varying	Not required	Inert	Not required	12-20	50	50
Silica sand	Light brown	5-10	3.0-5.0	2.6	120	0.45-0.55	1.62	16 x 50	Not required	Inert	Not required	10-20	30-35	50
Macrolite	Taupe, brown to grey	220	8.0-10.0	2.1	54	0.25-0.35	1.1-1.2	40 x 60	Not required	Inert	Required	8-10	100	100
Pyrolusite "Pyrolox" "Filox-R"	Black	92 263	5.0	3.8-4.0	125	0.51	1.7	8 x 20 20 x 40	Not required	6.5-9.0	Recommended	25-30	15-30	40
Birm	Black	56-65	3.5-5.0	2.0	40-45	0.48	2.7	10 x 40	Not required	6.8-9.0	Not required	10-12	20-40	50
Granular manganese dioxide "MTM"	Dark brown	70-78	3.0-5.0	2.0	45	0.43	2.0	14 x 40	1.5-2.0 oz (by weight) of KMnO ₄ per ft ³	6.2-8.5	Not required	8-10	20-40	50

Note: Information compiled as of January 2004.

(a) Some media are available in various mesh sizes. Contact vendors for more information.

(b) Costs may vary with the order size.

and MetalEase. It is a mined ore consisting of 40 to 85% manganese dioxide by weight. The various configurations of pyrolusite provide extensive surface sites available for oxidation of soluble iron and manganese. Removal rates of iron in excess of 20 mg/L are achievable.

Pyrolusite is a coarse oxidizing media available in 8 to 20 mesh with a high specific gravity of about 4.0. Like silica sand, pyrolusite is a hard media with small attrition rates of 2-3% per year. Pyrolusite may be used in the following two ways: (1) Mixing with sand, typically at 10-50% by volume, to combine a filtering media with the oxidizing properties of pyrolusite; (2) Installing 100% pyrolusite in a suitably graded filter to provide oxidation and filtration. Maximum hydraulic loading rates of 3-5 gpm/ft² should be the basis of design for a pressure vessel. No chemical regeneration is required.

Backwash is critical for proper operation. Attrition during backwash can be a benefit as it exposes more surface sites for oxidation of soluble iron and manganese. The density of pyrolusite is in the range of 120 lb/ft³, requiring a backwash rate of 25-30 gpm/ft² to fluidize the bed, scrub the media, and redistribute the media throughout the bed. Air scour and backwashing are recommended in simultaneous mode. If water backwash alone is used, air scour prior to backwash is recommended with a water backwash designed for 30 gpm/ft² in order to fluidize the bed at least 30%. If a gravel support over the underdrain is used, a gravel retaining screen should be included in the design. The manufacturer recommends daily backwashing to maintain the effectiveness of the media for oxidizing and removing iron.

2.4.2.2 Birm

Birm is an acronym that stands for the "Burgess Iron Removal Method" and is a proprietary product manufactured by the Clack Corporation in Wisconsin. Typical applications have been point-of-use treatment, but it has been used in municipal treatment plants. Birm has the capacity to oxidize iron, but is not very effective at oxidizing As(III) to As(V).

Birm is produced by impregnating manganous salts to near saturation on aluminum silicate sand, a base material. The manganous ions then are oxidized to a solid form of manganese oxide with potassium permanganate. This process is similar to that used to manufacture manganese greensand. The manufacturer indicates that the presence of dissolved oxygen is necessary for Birm to function as an oxidizing media for iron oxidation.

Birm is available in a 10 × 40 mesh with an effective size of 0.48 mm and a specific gravity of 2.0. To be effective, it must be used in water with a pH range of 6.8-9.0.

Alkalinity should be greater than two times the combined sulfate and chloride concentration. Injection of compressed air ahead of the media to maintain a dissolved oxygen content of at least 15% of the iron content may be required, especially for source water with iron at concentrations of 3 mg/L or greater. The dissolved oxygen oxidizes iron with Birm media serving as a catalyst that enhances the reaction between dissolved oxygen and dissolved iron and manganese in the water. Further, formed ferric hydroxide attracts oxidized arsenic, which then is captured in the filter bed.

Filter loading rates should be between 3.5-5.0 gpm/ft² with a bed depth of 30-36 inches. Birm is not suitable for use with water containing hydrogen sulfide or organic matter exceeding 4-5 mg/L. Chlorination greatly reduces Birm's effectiveness and at high concentrations can deplete the catalytic coating. Polyphosphates can coat the media, thus reducing its effectiveness for iron removal. Manufacturer information is available at www.clackcorp.com.

No chemical addition or regeneration is required for Birm. Backwash rates should be controlled in the range of 10-12 gpm/ft² in order to achieve suitable bed expansion of approximately 30% for cleaning. An excessively high backwashing rate and air scour should be avoided to minimize attrition loss. Underdrains may include a gravel support bed or may be of the gravel-less type. Figures 2-5 and 2-6 provide information for normal service pressure drops and backwash bed expansion characteristics for Birm and manganese greensand.

2.4.3 Manganese Greensand

Another media that converts soluble forms of iron and manganese to insoluble forms that can then be filtered is manganese greensand. Manganese greensand has been used in North America for several decades and is formed from processed glauconite sand. The glauconite is synthetically coated with a thin layer of manganese dioxide, which gives the dark sand a definite green color and thus its name. There is only one North American manufacturer of manganese greensand and it is located in New Jersey. Limitations for manganese greensand include a maximum limit of 5 mg/L of hydrogen sulfide removal and 15 mg/L for iron removal; also, water pH should be in the range of 6.2-8.5 (Zabel, 1991).

The combination of a strong oxidant and manganese greensand filtration media for iron removal is commonly referred to as the "Manganese Greensand Process." Either potassium permanganate or chlorine can be used to effectively regenerate manganese greensand filters. However, if chlorine is used alone, it may be necessary to periodically regenerate the manganese greensand

SERVICE FLOW PRESSURE DROP SHOWING GREENSAND & BIRM

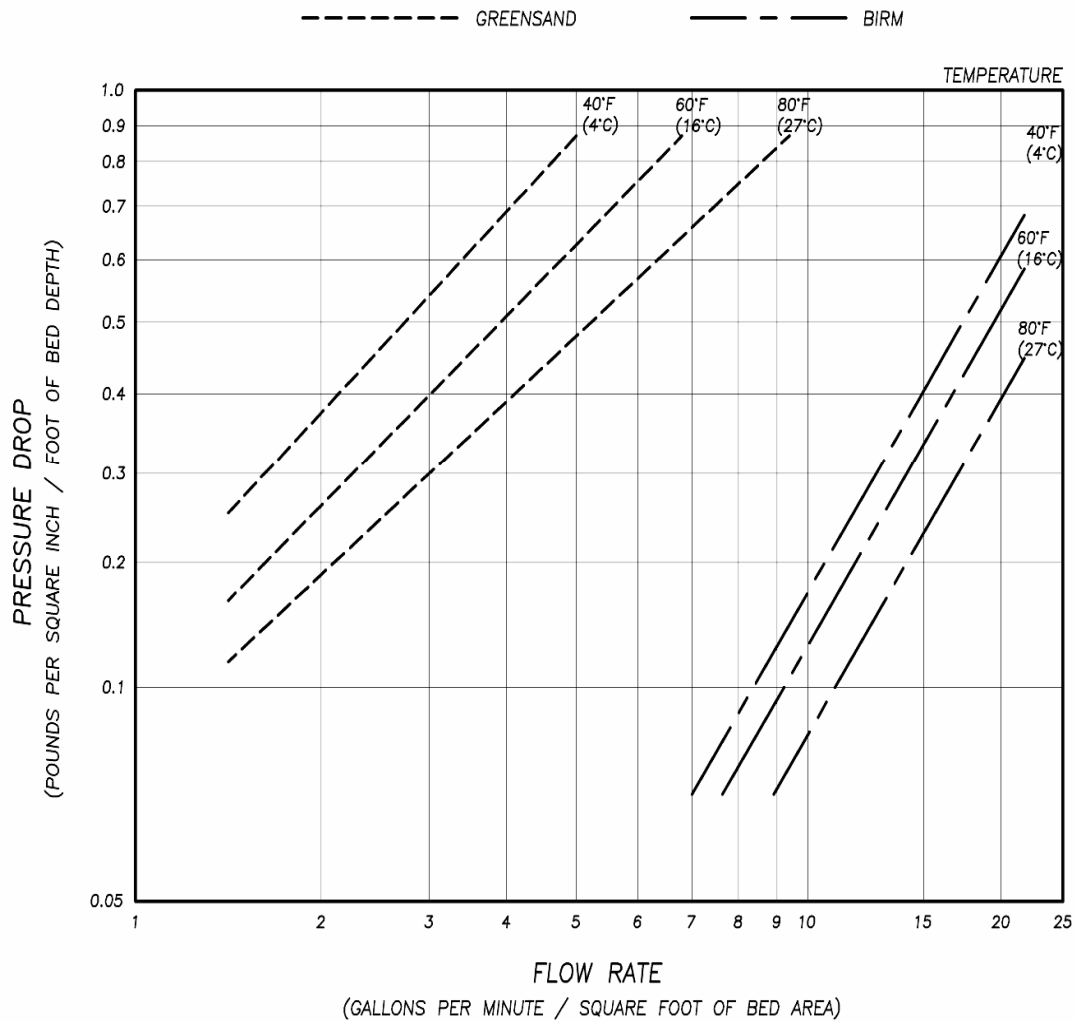


FIGURE 2-5. Service Flow Pressure Drop through Greensand and Birm Media
(Source: Hungerford & Terry, Inc. and Clack Corporation)

using potassium permanganate by a batch process in order to maintain optimum effectiveness of the media. Prechlorination is often recommended if iron levels are significantly greater than 1 mg/L in order to reduce the need for the more expensive potassium permanganate.

Continuous regeneration of greensand with a strong oxidant serves two purposes: (1) it reactivates the manganese dioxide on the greensand and (2) it oxidizes Fe(II) and As(III). This allows the newly formed As(V) and any residual As(V) to adsorb to the ferric hydroxide particles, which then are captured in the filter bed. Potassium permanganate should be fed in the piping far enough ahead of the filter to allow mixing and contact for several

seconds before entering the filter. Figures 2-7 and 2-8 illustrate continuous versus batch regeneration.

Manganese greensand is somewhat smaller than typical filter sand, with an effective size of 0.30-0.35 mm and a specific gravity of about 2.4. The density of greensand at 85 lb/ft³ is considerably lower than pyrolusite, but greater than Birm. A vigorous backwash with air scouring is recommended. Backwash rates typically are in the range of 10-12 gpm/ft² and should be preceded by an air scour of the media to attain at least 30% bed expansion. A gravel support bed with a gravel retaining screen is recommended over the underdrain system.

BACKWASH BED EXPANSION SHOWING GREENSAND & BIRM

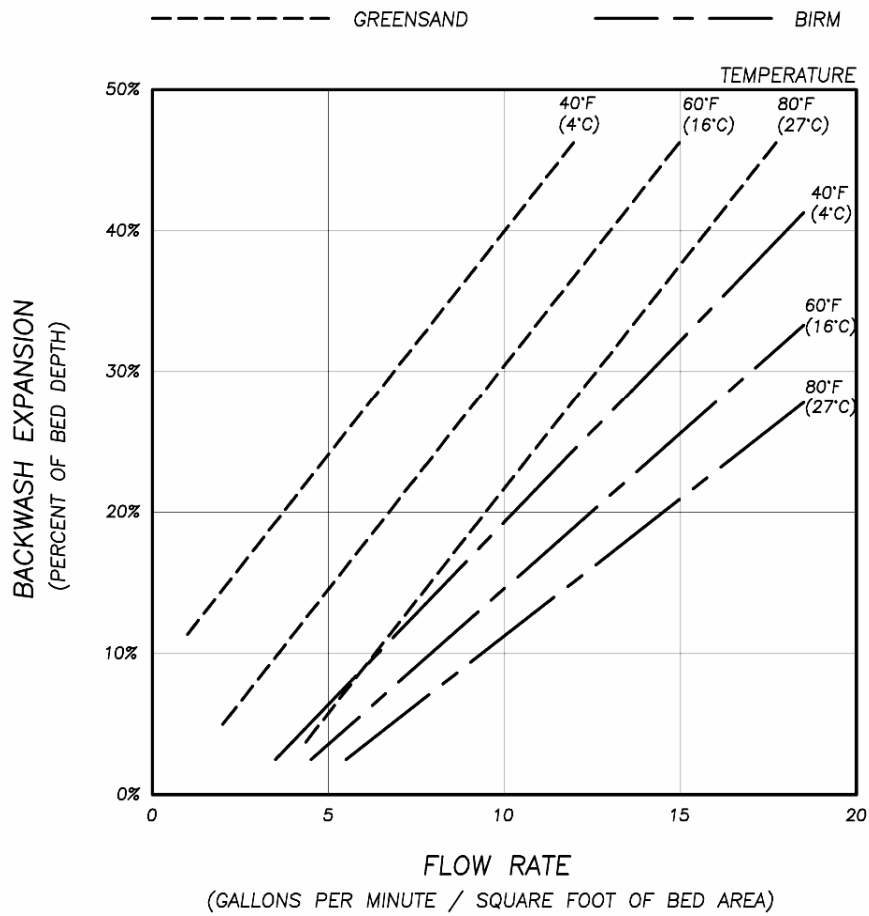


FIGURE 2-6. Backwash Bed Expansion Characteristics for Greensand and Birm
(Source: Hungerford & Terry, Inc. and Clack Corporation)

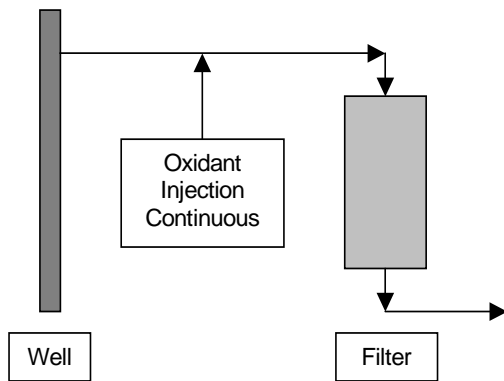


FIGURE 2-7. Manganese Greensand Process with Continuous Regeneration

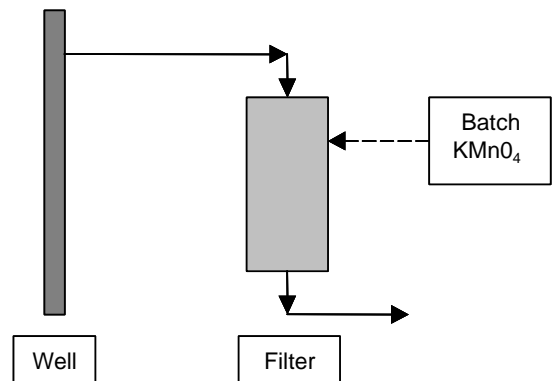


FIGURE 2-8. Manganese Greensand Process with Batch Regeneration (ineffective for As removal)

It is common to implement a dual media system for iron and arsenic removal that consists of anthracite followed by manganese greensand. Anthracite readily captures most of the iron hydroxides containing As(V). The water then passes through the manganese greensand, which oxidizes and precipitates any residual iron and manganese. Similar to conventional dual media filters, it is common to have a 12-18 inch depth of anthracite (with a size range of 0.80-1.20 mm) followed by at least 15-24 inches of greensand.

Greensand can be used without an anthracite cap, but filter runs may be shortened significantly. The actual depth of manganese greensand will depend on the oxidizing capacity desired of the media. As a rule of thumb, oxidizing capacity of 1 ft³ of manganese greensand media for raw water with 1 mg/L of iron is exhausted after 10,000 gallons of throughput. Therefore, a filter with 3 ft³ of greensand filtering a raw water with 1 mg/L of iron would need to be backwashed after filtering 30,000 gallons. However, because the continuous regeneration system is recommended for removing arsenic, the oxidizing function of the greensand is not critical to the process.

2.4.4 Other Media

A variety of filtration media are available for iron-removal systems, and some companies have developed their own

proprietary filtration media. One example is the Macrolite media used by Kinetico of Newbury, OH. Macrolite is a patented ceramic, round-shaped media with a diameter of 0.215 mm. The media is marketed as having the ability to operate at a filtration rate of 10 gpm/ft² to have an indefinite service life. It is always good to research the different types of filtration media and their ability to meet the treatment objectives.

2.5 Jar Testing/Pilot Plant Studies

Jar tests and pilot plant studies are important tools in drinking water treatment design, process control, and research. In the drinking water field, jar tests often are used as a “bench-scale” simulation of full-scale water treatment processes. Although more commonly associated with coagulation/flocculation/sedimentation of surface waters, jar tests can successfully simulate iron, manganese, and arsenic removal. Jar tests are relatively simple, low-cost, and can be completed in a short time frame (Lytle, 1995). These procedures are highly recommended as they can provide very valuable information to address arsenic removal efficiency, oxidant type, contact time, filtration media removal efficiency, and other water quality issues well before full-scale removal systems are planned. Small pilot studies may be very valuable in some cases to evaluate the filtration system for iron removal.

3.0 Central Water Treatment Plant Design

3.1 Introduction

When designing a central water treatment plant, the design engineer typically divides the project into three phases:

1. General Plan – This is the conceptual design with basic design information and is often required for regulatory agency review.
2. Preliminary Design – This typically includes the completion of 30% of system design drawings, which are used to establish a cost estimate and select potential major equipment suppliers.
3. Final Design – This is the completion of the contract documents, which are used to bid and construct the central treatment plant, subject to regulatory agency review and approval.

The concepts and principles outlined in this chapter can be adapted to the design of several different types of iron removal treatment systems including:

1. Chemical oxidation followed by media filtration.
2. Solid oxidizing media filtration, including pyrolusite, Birm, and other solid oxidizing media filtration processes.
3. Manganese greensand filtration.

3.2 General Plan

The General Plan is prepared to provide background information on the project and outline specific issues that must be addressed in order to treat the source water. The General Plan should summarize the basis of design for all elements of the project and evaluate those against any regulatory standards to make sure that regulatory compliance will be met. Key elements of the plan include an analysis of the source water, reliability of supply,

evaluation of the appropriate treatment process, establishment of design data in accordance with regulatory requirements, and conceptual layout. Budget cost estimates are derived using general guidelines with conservative contingencies provided for unknown items, which may be determined during the preliminary and final design.

An analysis of the raw or source water is perhaps the most critical consideration during this phase of system design. The data from the source water analysis will impact all aspects of system design, from treatment selection to labor and materials costs. An example of the different types of information required for a raw water analysis is provided in Figure 3-1.

Another major consideration at this phase is siting of the central water treatment plant. The treatment facility should be placed in such a location that expensive improvements do not need to be made in order to convey the water to the customers of the central water treatment plant. In some cases, the existing well pumps may be able to provide adequate flow and pressure through the central treatment plant to customers. The well pumps also may need to be modified to allow for the additional pressure required to pump the water through the treatment plant. Another option to consider is the possibility of providing storage at the water treatment plant site and re-pumping the finished water to the distribution system. In this case, the well pumps may need to be modified to reduce the pressure being discharged to the water treatment plant.

Other items that need to be determined in the General Plan include the following:

- Hours of operation and whether the facility will be automatically or manually operated. With manual operation, personnel must be available or on site during operation of the water treatment plant. Automatic operation can save labor costs if designed properly.

Report of Water Analysis

Name and Address:								
Container:								
Sample Date:								
Taken By:								
Analysis *	#1	#2	#3	#4	#5	#6	#7	#8
Calcium								
Magnesium								
Sodium								
Potassium								
Total Cations								
Total Alkalinity (M)**								
Phenolphthalein Alkalinity (P)**								
Total Hardness**								
Sulfate								
Chloride								
Nitrate								
Phosphate (PO ₄)								
Silica (SiO ₂)								
Free Carbon Dioxide								
Hydrogen Sulfide								
Iron (Fe) Unfiltered								
Iron (Fe) Filtered								
Manganese								
Turbidity (NTU)								
Color (Units)								
Fluoride								
Total Arsenic								
Soluble Arsenic								
Particulate Arsenic								
Arsenic (III)								
Arsenic (V)								
pH (Units)								
Specific Conductance (micro-mhos)								
Temperature (°C)								
* All units reported in mg/L except as noted.								
** As CaCO ₃ .								

FIGURE 3-1. Example Report of Water Analysis

- Water storage facilities must be evaluated to balance the hours of operation against the sizing of the plant. In general, storage for an average day of use is desirable. This would theoretically provide complete turnover of the water and storage on a daily basis, thus preserving quality and providing quantity in case of an emergency.
- Construction materials must comply with Occupational Safety and Health Administration (OSHA) standards, local building codes, and health department requirements. Materials also must be suitable for the pH range of the water and be compatible with any pretreatment chemicals. Consideration for oxidants being used will determine the types of materials and ventilation system used in the treatment facilities. Both drinking water chemicals and system components should comply with NSF/ANSI STD 60 and 61, respectively.
- Treatment system equipment should be protected from ambient weather. It is recommended that the system be housed within a treatment building, although housing is not mandatory in some locations.
- The cost of wastewater disposal is a major consideration in the design of any central water treatment system. Wastewater resulting from backwash and regeneration of the treatment media can only be disposed of in a manner permitted by state and/or local regulatory agencies. Wastewater handling options should be carefully evaluated including performing a life-cycle analysis to determine the best options. Separate local and state regulatory reviews may be required for wastewater disposal. Quantifying the backwash waste and determining the disposal requirements also should be outlined.

A General Plan report containing all of this information as well as a preliminary project estimate and schematic drawings should be submitted for review and approval by the appropriate authorities. This document can be used to establish funding requirements for the project. A determination of what funding is available should be made before the project is authorized for preliminary and final design. If the preliminary estimate of project costs exceeds the available funds, adjustments should be made to increase the funding or reduce the scope of the project. Figure 3-2 illustrates the steps of the project development process from project authorization through final design.

3.3 Preliminary Design

Once funding is in place and the General Plan has been reviewed and approved by the appropriate authorities, preliminary design can begin on the project.

3.3.1 *Manual or Automatic Operation*

One of the first decisions to be made is whether the plant should be manually or automatically operated. In a manual operation, the plant operator personally performs all of the operating functions and makes all operating decisions. The treatment plant equipment does not accomplish any function independent of the operating personnel. The equipment is simple and performs the basic functions that the operator implements. Manual operation includes the following:

1. Motors (pumps, chemical pumps, etc.) with manual start/stop controls. Some motors have manual speed adjustment capability. Chemical pumps have manual speed and stroke length adjustment capability.
2. Valves with manual handle, lever, hand wheel, or chain wheel operators.
3. Instrumentation sensors with indicators. Instrumentation is installed in-line when operating data such as flowrates, total flow, pressure, pH and liquid levels are indicated. Besides the pump operations and the chemical feed adjustments, the biggest single function performed by the operator is the backwashing of the filters.

In the automatic operation of a treatment plant, computer controls will basically control the plant. Initial programming of the computer controls is done by an outside specialist who works with the treatment plant operator to program the plant. The equipment used by the operator during the performance of treatment plant functions is the operator interface and the printer.

Controls can be used for many other purposes to assist the operator in the proper operation of the plant. These controls can automatically shut down equipment or notify the operator of high/low pressure; levels control of tanks (high or low); problems with chemical feed equipment that can be automatically shut off; and other items particular to each individual system.

The addition of automatic controls increases the initial cost of the system, but the plant will require minimal operator attention (i.e. decreases associated operation costs). For remote treatment plants or where operator

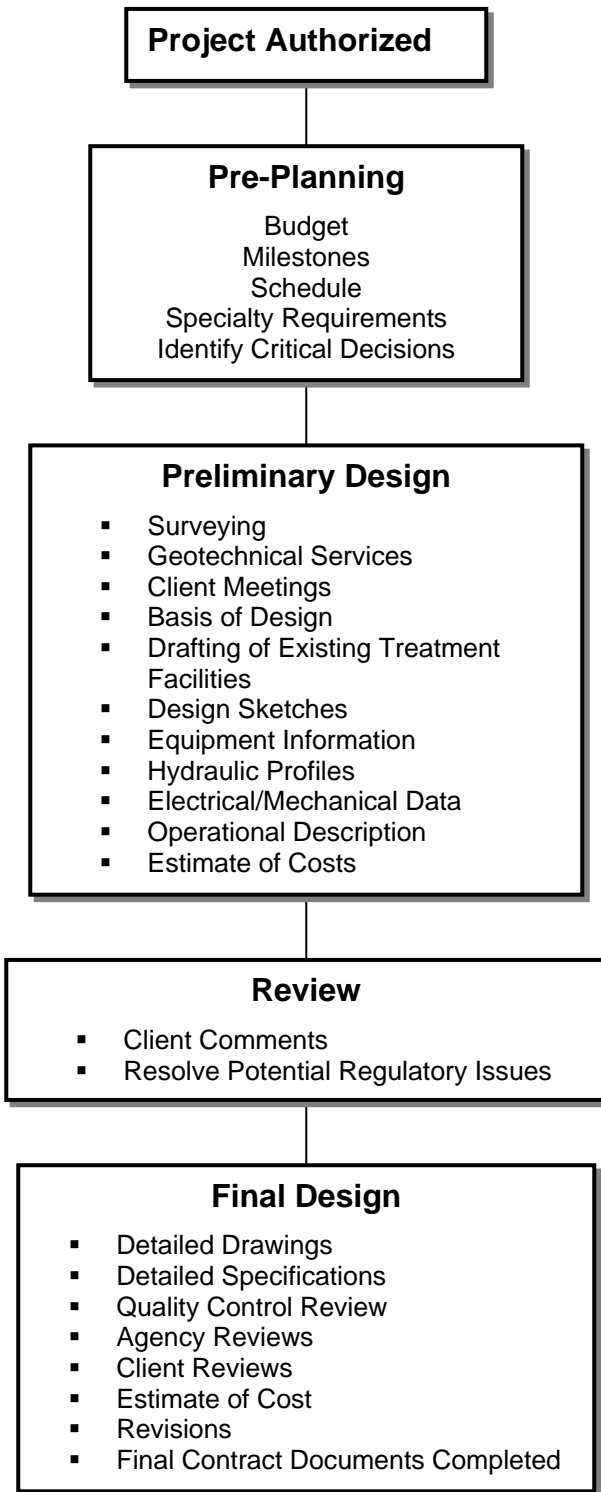


FIGURE 3-2. Project Development Process

availability is limited, automatic operation can be a great advantage.

Automatic operation includes the following:

1. Motors for pumps, chemical pumps, air compressors, etc. are automatically turned on and off and may have speed adjustment controls. Chemical pumps may have a manual stroke length adjustment but can be paced by the flow and on/off operation of the plant.
2. Valves with either pneumatic/hydraulic or electric operators are required on the equipment. Valves require manual overrides during startup, power failure, or compressed air failure. Valves should have opening and closing speed controls to prevent water hammer during automatic operation, especially on pump systems.
3. Instrumentation may be electronic, pneumatic, or a combination of both. The instruments and controls should always be capable of transmitting and receiving electronic information to and from the computer system. Backup manual instruments are recommended to provide verification of automatic instrumentation. Comprehensive automatic alarms that notify operators and/or shutdown key components of the system are necessary and need to be incorporated in the design.
4. Filter backwashing also can be accomplished by automatic controls. However, systems can be modified so that major operations will not occur without operator initiation. For example, when a filter needs to be backwashed, a warning or an alarm can be provided to notify the operator that a filter needs to be backwashed. The operator then can choose to continue to run the filter, take it offline, or backwash the filter. At that point, the operator would initiate backwashing by giving the command through the computer system to do so.

It is the responsibility of an operator to calibrate and check all components of the automatic operating equipment system on a routine basis. Regular maintenance by the operator or a qualified instrumentation and control specialist should be performed. The person responsible for maintenance should also be capable of emergency repair of all components. Every function included in an automatic system should be capable of manual operation by the operator.

3.3.2 Basis of Design

The Basis of Design is a document, outline, or strategic plan that is developed early in a water treatment system

project in order to record and summarize decisions that have a major and extensive impact on project design and implementation. The Basis of Design also helps minimize late changes, additions, or modifications to the project, as well as minimize the high expenses commonly associated with late changes. The following subsections discuss elements that should be addressed in a Basis of Design.

Note that the development of the Basis of Design should not be performed solely by the Project Manager; the owner of the water treatment system must have opportunity to review and comment on the content of each design element.

3.3.2.1 General

1. State the purpose of the project (i.e., what problem the project is designed to correct?).
2. Identify areas of new or unique design and provide criteria.
3. Identify areas where evaluation of alternatives must first be completed before initiating final design. Identify alternatives to be evaluated.
4. Identify critical structures, processes, or complex areas that require early engineering and design effort to avoid later delays.
5. State major constraints such as maximum construction cost, and court-imposed or client-imposed deadlines.
6. Note availability of prior drawings and dates when previous on-site project work was done.
7. Note major potential trip-up items (i.e., flood plain location? historic register? property or easement availability? financing?).
8. Identify provisions to be made for future construction and expansion, beyond present scope, for sizing of or location of structures or equipment.
9. Note who has jurisdiction for permit approvals (i.e., plumbing, electrical, building, elevator, elevated tank, groundwater protection, U.S. EPA, etc.).
10. Identify unusual situations that will affect design (i.e., rock, unstable soil, high groundwater, corrosion).
11. List specific points where client has expressly requested to be advised of design decisions, or where client will require involvement of staff in decision-making.

12. Identify hazards or hazardous areas (i.e., asbestos, windowless building story, confined space, fire, NEC explosion areas, corrosion, fumes, dust, odor). For asbestos, determine responsibility for discovery, arrange testing, and determine level of abatement required.
13. Identify large or complex structures that will require special building code compliance review prior to initiating final design.

3.3.2.2 Project Scope

1. Provide a schematic process flow diagram (i.e., show such items as water or wastewater flow, chemical feed, site sanitary sewer, and drain piping).
2. Provide a list of building, structures, and equipment.
3. Based on client's input, identify major equipment or brands of equipment to be used or not used.
4. Prepare tentative list of plan sheets.

3.3.2.3 Process Design Data Summary

1. List design data summary. Note average, maximum, and peak hydraulic flowrate capacities. Define concentrations and loading to be removed or treated. Identify "Design Parameters" and "Units Furnished" for each unit process or major equipment item.

3.3.2.4 Site

1. Provide a simple site plan with locations of existing and new structures, including sanitary and stormwater pumping stations as applicable.
2. Note any special consideration related to design (i.e., location in flood plain, dike construction, location to adjacent residential areas or parks, requirements for site clearing, major underground facilities that will affect location of new improvements).
3. Summarize concept for removing stormwater from site.
4. Identify any site constraints (i.e., required area set aside for future expansion, other client land uses).
5. Identify structures to be demolished.
6. Determine general fencing requirements and whether motorized gates are desired.
7. Identify extent of landscaping if desired by client.
8. Identify 100-year flood plain elevation if applicable.

3.3.2.5 Layout of Structure

1. Identify approximate structure size and preliminary location of rooms and/or major equipment on a floor plan.
2. Determine building(s) use group, fire resistance ratings, ceilings, stairwells, height and area restrictions, special fire and life safety requirements, and means of egress strategy to at least the level that they will affect preliminary building layouts and costs. Address requirements of the Americans with Disabilities Act (ADA).
3. Coordinate location and layout of chlorine rooms.
4. Identify particular client preferences early for architectural details.
5. Determine architectural style and requirements, with consideration to insulation requirements:
 - a. Wall construction (i.e., brick and block, concrete block, glazed structural block, sound block, metal siding, pre-engineered, aggregate panels).
 - b. Roof construction (i.e., pre-cast concrete, poured-in-place concrete, steel deck and bar joists, wood trusses). Consider type of structure and its interior use (i.e., wet areas, chemical feed area, etc.).
 - c. Roofing materials (i.e., single-ply ballasted or adhered membrane, built up, shingles, metal).
 - d. Windows (i.e., natural light, ventilation, aesthetics). Match or replace existing windows: material (i.e., aluminum, steel, wood, vinyl) and/or finish (i.e., anodized, painted, primed).
 - e. Doors. Match or replace existing doors: material (i.e., hollow metal, aluminum, FRP, stainless steel, wood, acoustical).
 - f. Overhead and/or roll-up doors. Identify electric operator versus manual lift doors.
6. Provide room finish schedules based on client input. Items to include are listed as follows:
 - a. Interior wall construction (non-load bearing); material (i.e., concrete block, glazed block, steel or wood stud walls); finishes (i.e., unfinished, painted, gypsum board, wallpaper, paneling, chair railing, molding at ceiling and floor).
 - b. Flooring. Unfinished or sealed concrete, seamless floor covering, vinyl, carpeting, tile (i.e., thin-set or thick-set), terrazzo, applied composite

material with urethane overcoats, embedded steel mats where heavy steel wheel loads are anticipated (i.e., dumpster containers).

c. Ceilings. Material and finishes.

7. Identify stair type (i.e., concrete pan, metal, cast in place).
8. Identify method of removing rainwater from roofs of each building and point of discharge (i.e., roof drains, gutters and downspouts, roof scuppers discharging to ground, or storm sewers).
9. Identify locations of rest rooms (for both genders) in building.
10. Identify locations of drinking fountains and coolers.
11. Identify areas where service sinks or portable sampler wash down basins will be provided.
12. Specify grating material (i.e., aluminum, steel, FRP such as in certain chemical feed and fill areas).
13. Determine extent of laboratory improvements.
14. Identify any existing structures to be re-roofed or re-painted.
15. Write preliminary outline of requirements for OSHA (i.e., signing, color coding, fire extinguishers) and ADA.

3.3.2.6 Structural

1. Identify local code requirements for seismic design, frost depths, wind loads, and snow loadings.
2. Identify design of live load requirements for stairway, office, and corridor floors. Also floor loadings for operating and storage areas.
3. Identify design for water, earth, and live load requirements for foundation walls.
4. Identify likely areas where peripheral drains and hydrostatic pressure relief valves will be necessary to prevent flotation and reduce exterior pressures (if high groundwater conditions are known to exist prior to obtaining soil boring data).
5. Identify requirements for protection of existing adjacent structure foundations that could be damaged during excavation.

6. Identify any material handling that is required (monorails, crane, davit, dock access, eyebolts) and approximate lifting capacities.
7. Identify major equipment and provide approximate weights (i.e., pumps, blowers, generators, engines).
8. Note any structural repairs required in existing buildings or any new or enlarged wall or floor openings. Note any concrete repairs or masonry rehabilitation and coordinate with client.
9. Identify design strength criteria for reinforced concrete and steel.

3.3.2.7 Mechanics

1. For heating, ventilating, and air conditioning (HVAC) and other mechanical building systems, identify any special or specific expectations or the client.
2. Identify energy source(s) to be used for providing building heat (i.e., natural gas or electric) and supplier(s).
3. State method of providing heat to each structure, building, or section of building such as a lab or office area. Identify preliminary location of central heating and cooling facilities.
4. Identify ventilation method for each building and preliminary location of exhaust fans, louvers, air handling systems and ventilation rate criteria (air changes, cfm/ft², cfm/person).
5. Provide conceptual strategy for dealing with dust control, explosion resistance, fire protection, humidity control, emergency showers and/or eyewash, and hazard detection interlocks with ventilation. Describe equipment to be provided.
6. Identify mechanical building system requirements for generator and engine rooms (ventilation, combustion air, cooling system strategy, fuel system and storage, and drainage).
7. Identify areas to be air conditioned or de-humidified.

3.3.2.8 Electrical

1. Provide any special or specific expectations of the client. Note any problems with existing equipment, if applicable, or certain manufacturer's equipment to be used or not used.
2. Identify power supply source.

3. Identify source and location of emergency power generator if required.
4. Provide general control descriptions that will be used to develop loop descriptions for automatic controls.
5. Complete an "Equipment and Controls Listing" as completely as possible.
6. Confirm instrumentation and control philosophy with the client (i.e., completely manual, data acquisition and logging with manual control, automated control of specific equipment or processes, or completely automated).
7. Identify work required at remote site from the project site (i.e., lift stations, well sites, booster stations, elevated tanks, other plants).
8. Identify equipment that is to be driven by variable speed systems.
9. Determine whether plant power distribution is to be overhead and/or underground.
10. Identify if existing lighting is to be revised with the client.
11. Identify method of providing outdoor lighting (i.e., high mast lights, pole-mounted street lights, or wall-mounted exterior building lights).
12. Identify whether Process and Instrumentation Diagram (P&ID) drawings are required and how many there will be.
13. Identify areas where electrical equipment including computers must be located in rooms with special temperature or humidity environments.
14. Identify pumps requiring seal water systems with solenoid valves, pressure switches, and controls for alarm/lockout.

3.3.3 Treatment Equipment

From the General Plan, the basic treatment equipment has been determined from one of the following treatment alternatives:

1. Chemical Oxidation and Filtration – Elements comprising this alternative include aeration (optional); chemical oxidant addition (chlorine); and filtration (sand and anthracite).
2. Solid Oxidizing Media Filtration – Elements comprising this alternative include filtration with the solid

oxidizing media. Depending on the media used, the addition of air may be required to maintain manufacturer suggested dissolved oxygen levels in the source water.

3. Manganese Greensand Filtration – Elements comprising this alternative include continuous chemical oxidant addition (potassium permanganate and/or chlorine) with time for mixing followed by manganese greensand filtration.

For each alternative, disposal of backwash waste streams is a design consideration to be addressed.

A general discussion of treatment equipment in this section should be applied to the appropriate alternative selected. Certain elements, such as aeration, do not apply to each alternative, but a discussion of the filtration pressure vessel does.

3.3.3.1 Aerator

For aeration, in most cases, one aerator is required along with one detention tank and a bypass around both the aerator and detention tank to the filters. A minimum of two filters must be provided so that the peak flow can be met if the largest filter goes out of service. Depending on the configuration constraints, the designer should determine how many filters need to be provided for the project.

3.3.3.2 Treatment Vessels

Treatment vessels generally are piped in parallel with a downflow treatment mode through the filters. Up to a diameter of approximately 12 ft, most pressure vessels are vertical but horizontal pressure vessels can be used as well. Treatment vessel piping should be configured to provide for media backwashing up through the filters. The materials of construction are generally FRP or carbon steel with fabrication, assembly, and testing that complies with the American Society of Mechanical Engineer's (ASME) code section VIII, Division 1. The interior should be lined with abrasion-resistant vinyl ester or epoxy coating. Interior lining material should be NSF-certified for potable water application and suitable for pH range of 2.0-13.5. Vessel pressure rating should be 50 pounds per square inch gage (psig) or the minimum necessary to satisfy the system requirements. In general, the rating should be at approximately 25 psig greater than the normal service pressure. Other vessel materials of construction for the internal components of the vessels should take into consideration the abrasion and corrosive atmosphere that the components will face. Materials such as abrasion-resistant epoxy, rubber, stainless steel, brass, and fiberglass all can be used within the pressure vessel.

Depending on the depth of media selected and the type of space requirements available, underdrain systems should be evaluated for the vessels. Underdrains can be of a slotted nozzle type installed on a plate and installed with or without gravel supporting media to the sand and anthracite. Other systems including header laterals systems with a gravel supporting bed may be used. Unused areas below the underdrain system, which could potentially hold stagnant water, should be filled with concrete. Fabrication of pressure vessels is typical in 6-inch increments over a range of diameters from 6 inches up to several feet in diameter.

Distribution of water in the pressure vessels typically is done through a header system in the top of the pressure vessels that distributes the water evenly over the top of the media. A system of collection pipes also should be available to allow the backwash waste to go through this piping during the backwash sequence.

Placement of air release valves on the highest point of the piping at each vessel needs to be considered so that air binding will not occur. This air release piping can either be automatic or manual. The discharge from the air release valves should be piped to waste because of the spray, which will occur as the vessel dispels air. Cross-connections must be avoided. At least two access ports of sufficient size to meet OSHA requirements should be provided for entrance into the pressure vessel as well as for providing a means of changing media.

3.3.3.3 Process Piping Material

When considering process piping for use in conveying the water between treatment units and connecting pressure vessels and pumping systems, selection of materials becomes critical. For piping 4 inches and larger in diameter, ductile iron is recommended. For smaller diameters, polyvinyl chloride (PVC), FRP, carbon steel, and copper may be used as long as the limitations of each of the types of piping are evaluated for plant-specific conditions. If temperature conditions vary dramatically or if temperatures in a treatment facility exceed 99°F, then PVC materials should be avoided due to their loss in strength and thermal expansion features. FRP may be a better choice for the strength and support that is required at elevated temperatures. Carbon steel may present a corrosion concern and copper may not be strong enough for the type of piping necessary. Care should be taken to economically match the right piping system with the application.

3.3.3.4 Control Valves

Isolation and process control valves may be wafer style butterfly type, except in low-flowrate systems where small pipe size dictates the use of true union ball valves.

The use of inexpensive, easily maintained valves that operate manually provide minimum capital costs. The valves can be automated by the inclusion of pneumatic, hydraulic, or electric operators. Valves on the face of pressure vessels, which are automatically operated, may include pneumatic-type diaphragm valves. These valves are somewhat more expensive than butterfly valves, but give a positive control and are very reliable. As a part of the preliminary design, the electrical and instrumentation needs should be analyzed and summarized in tables to determine the power requirements and the monitoring and control points in the system. One-line diagrams and process and instrumentation diagrams should be provided at this stage.

3.3.4 Layout of Facilities

Once all of the individual components have been determined and preliminary choices have been made, the pieces need to be laid out and assembled in an efficient design that will meet the needs of the operator. It is recommended that the operator and those responsible for maintaining the facility provide design input to address the needs of the treatment system operators. Sufficient space for proper installation, operation, and maintenance of the treatment system needs to be evaluated. Clearances and constructability reviews should be performed to determine the adequacy of the building. Items such as workshops, storage facilities, and maintenance facilities are sometimes overlooked but add significant costs to the project when included. The layout also should include a projection of potential future expansion at the site. Factors such as duplicating facilities and the design of the external components of the building (e.g., driveways and utility locations) also should be evaluated.

The type of building used needs to meet the requirements of the local personnel maintaining the facility. Protection from the elements will depend on the climate. Standard pre-engineered steel buildings may be adapted for use, as well as concrete block or other masonry type structures. Standard building dimensions should be used with adequate access doors, lighting, security, ventilation, emergency showers, and laboratory facilities to monitor and control the process.

3.3.5 Preliminary Project Cost Estimate

A preliminary cost estimate for the treatment facilities can be made once the following has been completed:

- The Basis of Design is finished;
- Preliminary drawings have been completed that show the layout of the building, the selection of

building materials, and an inventory of the power supply needs and instrumentation points; and,

- The preliminary selection of equipment and capital cost quotes of the equipment from manufacturers and suppliers is completed.

This preliminary cost estimate should be within approximately 20% of the final cost estimate. A full discussion of key cost factors is provided in Section 4.2 of this manual.

3.3.6 Revisions and Approval

To complete the preliminary design process, additional floor plans and even sections of the proposed treatment facility should be completed. Specialty items should all be compiled and summarized in a detailed design memo with the drawings and cost estimate, and explained to the client. These specialty items can include checking for natural gas for heating purposes; subsurface investigation to determine foundation requirements; and disposal requirements that may require special permitting. Upon review of the preliminary design by the client, revisions should be incorporated for which the final scope of design details can be determined. With these revisions, a final design can be drafted and authorized.

3.4 Final Design

After completion of the preliminary design and approval by the client, the final design can be drafted. The final design includes a detailed design of all process equipment and piping, a complete process system design with all of the chemical feed equipment incorporated, building modifications, and site work. The final capital cost should be within 10% of the estimated final cost and should include a 15% contingency allowance.

The deliverable items at the completion of final design include a set of contract documents containing the construction drawings and specifications, and a final capital cost estimate. The final design includes treatment system equipment; continues with the building specifications including heating, cooling, painting, lighting, utilities, laboratory, personnel facilities, etc.; and finishes with the site specifications, including outside utilities, drainage, paving and landscaping.

3.4.1 General Guidelines

Some ways to simplify the final design and keep costs under control include minimizing the amount of customized details on the project; allowing shop fabrication of

platforms, pipe supports, and other items which then would not have to be done in the field; providing skid-mounted equipment where feasible; and using the inherent heating and cooling capabilities of groundwater with the treatment vessels in the building system. Humidity issues must be considered, but heating and cooling may be tempered by allowing the pressure vessels to moderate the indoor temperature of the facilities.

The drawings and specifications should provide all information necessary to manufacture and install the treatment system equipment. The general principle is to provide enough information on the drawings and in the specifications that a contractor can clearly determine what is intended and needs to be accomplished. It is up to the contractor to provide the means and the methods for finishing the project.

The specifications should include spare parts as part of the deliverables during the construction project for the equipment. All specialty tools such as forklifts or barrel dollies, or other such items which may not be common to most utilities, should be included as well.

3.4.2 Plan Content Guidelines

To receive competitive bids and to avoid costly change orders during construction, it is important to provide sufficient information in the final design to accurately portray what is intended by the design. Duplication of information can be a hindrance as it provides opportunities for errors. The following guidelines should be used by the designer to be accurate without duplicating unnecessary information.

3.4.2.1 Structural

1. Use bold lines for walls, slabs, etc. where new concrete is proposed.
2. Where drawings become complex, use separate drawings to show reinforcing steel.
3. Try to limit showing re-steel to section views. Only show re-steel on sectional plans when necessary to cover changes in steel shown in sections. Where possible to identify re-steel clearly, do so via plan notes covering bar size and spacing and do not show lines and dots in walls, slabs, etc.
4. Provide required job-specific structural notes on drawings when additional drafting can be minimized. Make use of specifications for notes that do not relate directly to the drawings.

3.4.2.2 Schedules

1. Use room finish schedules to eliminate separate call outs, which tend to clutter drawings.
2. Develop schedules and details for doors, windows, louvers, vent fans, meters, valves, pipe support beams, room finish, and ladders, and locate these in one specific location in a drawing set rather than scattered throughout the drawings.

3.4.2.3 Miscellaneous

1. Avoid excessive call outs of items that appear more than once on a sheet, such as piping sizes, grating thickness, downspouts, gutters, types of masonry walls. Label items once.
2. Reduce the amount of detail shown on existing structures to avoid clutter on drawings, which confuses bidders and causes wasted time during bidding. For example, for existing wall sections where no work is being done, just show wall outlines and eliminate all the fill-ins depicting the type of wall construction.
3. With existing structures, do not dimension and call out items within these structures if no work is to be performed or if the information is not related to the new construction proposed.
4. For site plans, show building outlines only if there are specific areas where new construction is to connect to existing construction.
5. Avoid excessively precise depictions of building materials such as shingles, grating and checker plate hatching, brick, block, and filter media. The lines clutter the drawings and make it difficult to assess the quality of materials.
6. Avoid showing unnecessary background information when cutting sections. Only show background information not shown in other views or to avoid interferences.
7. Avoid repeating details of similar structures in plan views or site plans. Actually, it is not necessary to

show the “inner workings” of any treatment tanks on site plans. Only the outside wall lines of the tanks are of interest to the contractor.

8. Do not overly detail layouts or dimensions for manufactured items such as pumps, motors, blowers, couplings, etc. Let the specifications describe these products.
9. Reduce the amount of dimensioning to avoid clutter and confusion and reduce possibility for error. For vertical dimensioning, if slab thicknesses and slab elevations are provided, do not add more dimensions. Also reduce repetition on dimensioning. Do it once for a section, plan, or sectional plan, but unless dimensions change, do not repeat dimensions on the same sheet or another sheet where a similar view is shown.
10. On the Location Plan, show a street address for the job site and provide a statement noting the city or county the project is located in.
11. Do not provide roof plans of simple structures if sections cut through the building convey adequate information concerning the dimensions and construction of the roof.
12. Leave details of equipment off drawings that are made to show other information on the structure and piping within it.

3.4.2.4 Piping

1. Do not overly detail small piping layouts. Leave the small piping off structure plan views and sections. Small piping could be defined as 2-inch-diameter and less for water supply and process piping. Show this piping on piping schematics for each structure.

3.4.2.5 Electrical

1. Do not show electrical conduit routes on bidding documents. Use one-line diagrams for clarity and simple understanding of the project. Use schedules to illustrate what electrical components (such as motor control centers and lighting panels) are to be installed in each location.

4.0 Central Water Treatment Plant Capital Costs

4.1 Introduction

This chapter discusses factors that affect the capital costs of an iron removal treatment plant, and provides an example economic evaluation between two iron removal system alternatives. The owner of a central water treatment plant should be provided with the most cost-effective iron/arsenic removal system possible, one that can remove the excess arsenic from a sufficient quantity of water but that also will satisfy all water consumption requirements.

4.2 Cost Variables

An economic evaluation should include the initial capital costs, operation and maintenance (O&M) costs, and replacement costs over a 20-year period. The water treatment design flowrate is the major variable affecting capital costs. Other factors which have varying impacts on the capital costs include, but are not limited to, the following:

1. Existing and planned (future) potable water system parameters:
 - Number of wells, location, storage, distribution
 - Water storage (amount, elevation, location)
 - Distribution (location, peak flows, total flow, pressure, etc.)
 - Consumption (daily, annual)
2. Raw water arsenic and iron concentrations
3. Chemical and physical parameters including but not limited to pH, alkalinity, iron, manganese, hydrogen sulfide, hardness, silica, sulfate, sodium, and turbidity
4. Stability and/or pH adjustment of water supply
5. Media selected for treatment system

6. Chemical and media supply logistics
7. Manual versus automatic operation
8. Backwash wastewater disposal
9. Climate (temperature, precipitation, wind, etc.)
10. Seismic zone
11. Soil conditions
12. 100-year flood elevation
13. Financial considerations (cost trends, capital financing costs, cash flow, labor rates, utility rates, chemical costs, etc.).

Ideal conditions for designing and operating an effective, minimum-cost iron/arsenic removal water treatment system would resemble the following:

1. Well capacity for peak consumption day
2. Raw water quality presents no problem (moderate temperature, adequate alkalinity, moderate iron levels, no interference of treatment due to hydrogen sulfide, organics, sulfate, etc.)
3. Existing wastewater disposal capability adjacent to treatment site
4. Warm moderate climate (no freezing, no high temperature, minimal precipitation, no high wind)
5. No seismic requirements
6. Foundation on well compacted, high-bearing-capacity soil
7. Secure site not in a neighborhood
8. Low-cost utilities

9. Accessibility for deliveries

10. Financial capability.

The more these ideal conditions exist, the more favorable and significant the cost savings are.

4.2.1 Existing and Planned (Future) Treatment Plant Parameters

Many existing and planned (future) plant configurations can influence capital costs. The most important factors are discussed in this section.

4.2.1.1 Number and Location of Wells

When only one well requires treatment, the removal of arsenic from source water should be accomplished prior to the water entering the distribution system. Theoretically, treatment can occur before or after entering storage. Practically speaking, treatment prior to entering storage is much easier to control because the treatment plant flowrate will be constant. If treatment takes place after storage, or if there is no storage, the treatment flowrate is intermittent and variable, and pH control is only achievable using a sophisticated automatic pH control/acid feed system.

When more than one well requires treatment, it must be determined whether a single plant treating water from all wells manifolded together is more efficient and cost-effective than operating individual treatment plants at each well. Factors such as distance between wells, distribution arrangement, system pressure, and variation in water quality should be evaluated for that decision. If all of the wells are in close proximity and pump similar quantity and quality water, a single treatment plant serving the entire system is preferable. When wells are widely dispersed, manifolding costs become prohibitively expensive, so individual treatment plants must be installed at each well. Frequently, the distances may be such that the decision is not clear; in that case, other variables should be evaluated such as water quality, system pressure, distribution configuration, and land availability.

Systems that require multiple treatment plant installations can achieve cost savings by employing an identical system at each location. This results in an assembly-line approach to procurement, manufacture, assembly, installation, and operation. Material cost savings, labor reduction, and engineering for a single configuration will reduce costs for the individual plant.

4.2.1.2 Potable Water Storage Facilities

The number, size, and location of storage tanks can affect treatment plant size (flowrate) and capital costs. If there is no storage capacity in the water treatment system, the well pump should be capable of delivering a flowrate equal to the system's momentary peak consumption; this could be many times the average flowrate for a peak day. Therefore, if no storage capacity exists, a storage tank should be added to the system for storage of treated water. Otherwise, automatic disinfection and pH instruments and controls will be required to pace chemical feedrates to the varying process water flowrates.

Most water treatment systems have an existing storage capacity. The storage may be underground reservoirs, ground-level storage tanks, or elevated storage tanks (located on high ground or structurally supported standpipes). The first two require repressurization; the latter does not. The elevated storage tanks apply a back-pressure on the ground-level treatment system, requiring higher pressure (and more costly) construction of treatment vessels and piping systems.

The amount of storage capacity also affects treatment system costs. The larger the storage capacity (within limits), the lower the required treatment plant flowrate (and resulting costs). Some regulatory agencies require a one day, average day storage capacity. A minimum storage capacity of one-half of a system's peak day consumption is recommended.

4.2.1.3 Distribution and Consumption

The factors that determine the sizing of the treatment system are the well (or feed) pump flowrate, the storage capacity, and the system consumption characteristics. Those factors should be coordinated to provide a capacity to deliver a peak treated water supply to satisfy all possible conditions of peak consumption. If there is adequate storage capacity, the momentary peaks are dampened. The peak day then defines the system capacity. The well (or feed) pump should be sized to deliver the peak daily requirement and the treatment system in turn should be sized to treat the volume of water that the well (or feed) pump delivers.

The distribution system may anticipate future growth or increased consumption. The well (or feed) pump then either should pump a flow equal to or greater than the maximum anticipated peak daily flows, or should be able to adjust to future increased flowrate. The treatment plant in turn should incorporate capacity to treat the ultimate peak flowrate or include provisions to increase the treatment capacity in the future.

4.2.2 Water Chemistry

Water chemistry can affect both capital and operating costs. With a clear understanding of the raw water quality, its possible variations, and adverse characteristics, the effect on capital costs can be determined readily. Required pH adjustment to make the water treatable or to stabilize the treated water before distribution can add significantly to chemical costs and, therefore, the capital costs for equipment. Treatment for hydrogen sulfide, organics, or other contaminants may require additional treatment processes such as aeration and/or significantly escalated oxidant chemical requirements. High hardness levels may require an additional softening treatment process to bring water to acceptable quality parameters. In addition, byproducts from the additional treatment processes may significantly impact waste disposal requirements.

Each of the physical and chemical characteristics of the raw water should be evaluated. The technical as well as the economic feasibility for the entire project could hinge on these factors.

4.2.3 Chemical Supply Logistics

Chlorine in its various forms (gas and liquid) varies in price depending on the quantities involved. For example, a Midwest survey in 2002 of gas chlorine costs found that ton containers were approximately \$0.24/lb and 150-lb cylinders were approximately \$0.40/lb. The same survey revealed that sodium hypochlorite delivered in 4,000-gallon bulk trucks was \$0.70/gal; partial bulk truckload deliveries were \$0.75/gal; and 330-gallon totes were \$0.90/gal. In very small plants, the cost of storage tanks for those volumes is not justified and, therefore, smaller volumes with higher unit prices should be procured.

For small applications, potassium permanganate is available in 25-kg (55-lb) pails made of high-density polyethylene (HDPE). Most commonly, steel containers weighing 150 kg (331 lb) are provided in drums about 20 inches in diameter and 30 inches high. Large quantities in 1,500-kg (3,307-lb) bins are available as well as bulk shipments up to 48,000 lb. The price of potassium permanganate averaged approximately \$1.35/lb in 2002.

4.2.4 Manual Versus Automatic Operation

Automatic operation is feasible, but semi-automatic operation is most common in iron removal treatment systems. However, the presence of an operator is required periodically in any mode of operation. The capital costs

of automation (computer hardware/software, valve operators, controls, instrumentation, etc.) as well as maintenance costs may exceed budget limits that the client can accept. Therefore, either manual or semiautomatic operation may be more economical. The advantages and disadvantages of manual, automatic, and semi-automatic operation require careful evaluation.

4.2.5 Backwash and Regeneration Disposal Concept

Disposal of waste backwash water and waste solids is not included in the scope of this manual. Depending on wastewater discharge limits established by U.S. EPA, state, and local regulatory agencies, wastewater disposal is a significant cost item that should be evaluated in the capital (and operating) cost projection. Requirements can vary from zero discharge to discharge into an existing and available receiving facility. If the regulatory agency permits disposal by conventional methods (such as surface discharge and percolation), the disposal costs are minimal. The total volume of wastewater backwash generally is 100-300 gal/ft³ of filter media when washed on a daily basis for the types of iron removal systems outlined in this manual. Compared to filtration daily volumes of 4,000-7,000 gal/ft³ of filter media, the waste disposal requirements range from 2-7% of filtered water flows.

4.2.6 Climate

The installation costs for the buildings along with their associated civil work are a major portion of the overall capital cost. Care in interpreting the climatological conditions and their requirements is necessary. Temperature extremes, precipitation, and high wind will necessitate a building to house the treatment system equipment. High temperature and direct sunlight adversely affect the strength of plastic piping materials. Freezing can damage piping and in some extreme cases can damage treatment vessels. Temperature variation introduces requirements for special thermal expansion/contraction provisions. A building with heating and/or cooling and adequate insulation will eliminate these problems and their costs, but will increase the cost of the building. The building cost should accommodate wind and snow loads as well as thermal and seismic requirements. Operator comfort in place of economic considerations may dictate the building cost.

4.2.7 Seismic Zone

Compliance with the seismic design requirements of the local building codes can impact capital costs. Buildings and tall slender equipment are vulnerable to seismic

loads. The magnitude of seismic design requirements should be determined. In zones of extreme seismic activity, low-profile equipment and buildings are recommended.

4.2.8 Soil Conditions

Unless soil boring data are already available for the treatment plant site, at least one boring in the location of the foundation for each heavy equipment item (treatment vessels, chemical storage tanks, and backwash waste tank) is required. If the quality of the soil is questionable (fill, or very poor load-bearing capacity), additional soil borings should be obtained. Poor soil may require costly excavation/backfill and foundations.

Combinations of poor soil with rock or large boulders can make foundation work more complex and costly. Rock and boulders in combination with extreme temperatures can result in very high installation costs for sub-surface raw, treated, and wastewater piping.

4.2.9 100-Year Flood Plain

For water treatment facilities located within a 100-year flood plain, the entire site should be relocated to another site outside of the 100-year flood plain, be elevated 3 ft above the 100-year flood level, or be protected on all sides by a dike system that extends a minimum of 3 ft above the 100-year flood level.

4.2.10 Financial Considerations

Many financial factors should be considered by the treatment plant designer and the owner. The client can impose financial restrictions (beyond any of the technical factors mentioned above), which result in increased (or decreased) capital costs. These restrictions include, but are not limited to, the following: inflationary trends, interest rates, financing costs, land costs (or availability), cash flow, labor rates, electric utility rates, chemical costs, and auxiliary features to the basic building required. If interest rates are low, inflation is anticipated, cash is available, and labor and electric utility rates are high, the designer and the owner may consider increasing capital investment and reducing operating costs; or the opposite can be true.

4.3 Example Economic Evaluation

This section provides an example cost evaluation for two hypothetical iron/removal treatment systems. For this example, the costs to design and operate two 500,000-gpd iron removal treatment plants over a 20-year period were evaluated and compared. One system is based on

aeration and chlorination followed by filtration for the treatment process, and the other is a manganese greensand filtration plant. Simple floor plans for each are shown in Figure 4-1, and were used as a basis for developing cost estimates outlined in Figures 4-2 and 4-3. A detailed breakout of the design data and equivalent annual cost calculations for each system is included in Appendix A.

Estimated costs were organized into three categories: capital, O&M, and replacement costs. Assumptions made for the analysis were:

- Iron levels at 1.0 mg/L, arsenic at 0.03 mg/L, and manganese at 0.1 mg/L
- Backwash holding tank sized to hold two backwashes
- Building on concrete slab with metal siding and shingles
- Maximum flowrate is 500,000 gpd and average is 250,000 gpd
- Normal plant operation is 12 hours at 500,000 gpd rate
- High service pump discharge is 60 psi at 500,000 gpd
- O&M costs average increase 3% annually
- Chemical feed and high-service pumps replaced after 15 years
- Filter media replaced after 10 years
- All other equipment assumed to have a life of 20 years
- 20-year analysis using federal interest rate of 5½%.

The capital cost for the manganese greensand filtration plant is slightly less than the aeration/filtration plant. The manganese greensand system had an Equivalent Annual Cost of \$165,774, which is 4% higher than the aeration/filtration treatment plant cost of \$159,611. The difference was due to the impact of the slightly higher operational cost for the manganese greensand plant on a 20-year basis. Overall, the two treatment plant options are within 10% on an equivalent annual cost basis, making them essentially equal from an economic perspective.

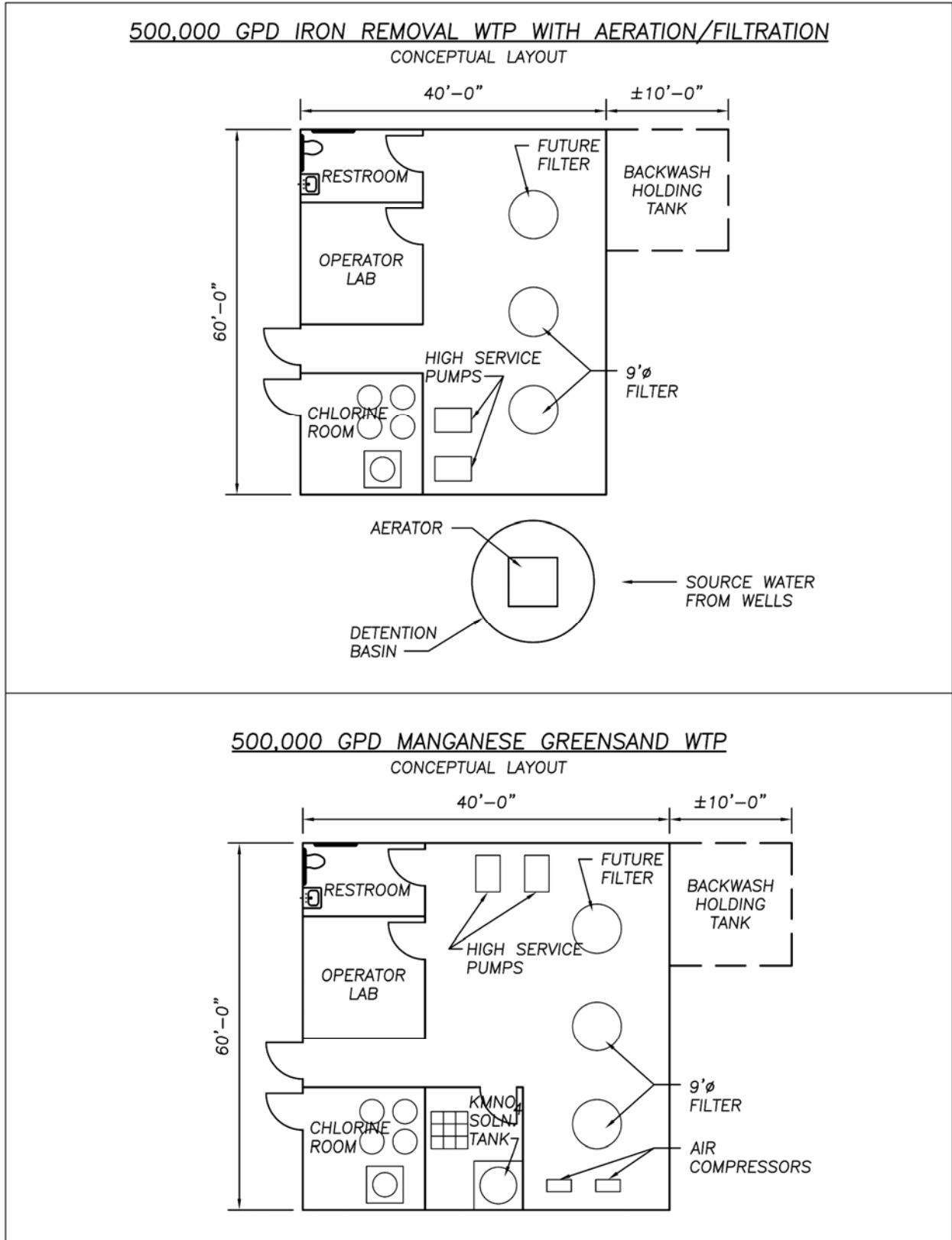


FIGURE 4-1. Two Conceptual Iron Removal Water Treatment Plant Floor Plans for Cost Estimates

	QTY	UNIT	Unit (\$)	Total (\$)
Building/Structure				
Building	2400	SF	\$100	\$240,000
Backwash holding tank, 25,500 gal, concrete	1	LS	\$30,000	\$30,000
Laboratory casework and equipment	1	LS	\$10,000	\$10,000
Clearwell, 10,500 gal, steel	1	LS	\$15,000	\$15,000
HVAC and Plumbing	1	LS	\$8,000	\$15,000
Electrical	1	LS	\$30,000	\$30,000
Civil Site	1	LS	\$20,000	\$20,000
				\$360,000
Process Equipment - 20 Yr				
Aerator and detention tank	1	EA	\$30,000	\$30,000
Vertical pressure filters, 9 ft diameter, w/o media	2	EA	\$125,000	\$250,000
Blower and air piping	1	LS	\$6,000	\$12,000
NaOCl drum scale	1	EA	\$2,500	\$2,500
NaOCl day tank	1	EA	\$1,500	\$1,500
Piping and valves	1	LS	\$25,000	\$25,000
				\$321,000
Process Equipment - 15 Yr				
NaOCl feed pumps	2	EA	\$2,500	\$5,000
				\$5,000
Auxiliary Equipment - 15 Yr				
High service pumps	2	EA	\$10,000	\$20,000
				\$20,000
Auxiliary Equipment - 10 Yr				
Filter Media, sand and anthracite	1	LS	\$17,500	\$17,500
				\$17,500
Subtotal				
				\$723,500
Contingency	15%			\$108,525
Total - Preliminary Construction Cost Opinion (nearest \$1000)				
				\$832,000

FIGURE 4-2. 500,000-gpd Iron Removal Water Treatment Plant with Aeration Followed with Filtration

	QTY	UNIT	Unit (\$)	Total (\$)
Building/Structure				
Building	2400	SF	\$100	\$240,000
Backwash holding tank, 25,500 gal, concrete	1	LS	\$30,000	\$30,000
Laboratory casework and equipment	1	LS	\$10,000	\$10,000
Clearwell, 10,500 gal, steel	1	LS	\$15,000	\$15,000
HVAC and Plumbing	1	LS	\$8,000	\$15,000
Electrical	1	LS	\$30,000	\$30,000
Civil Site	1	LS	\$20,000	\$20,000
				\$360,000
Process Equipment - 20 Yr				
Vertical pressure filters	2	EA	\$125,000	\$250,000
Blowers and air piping	1	LS	\$6,000	\$12,000
KMnO ₄ mixing tank and mixer	1	LS	\$2,000	\$2,000
NaOCl drum scale	1	EA	\$2,500	\$2,500
NaOCl day tank	1	EA	\$1,500	\$1,500
Piping and valves	1	LS	\$25,000	\$25,000
				\$293,000
Process Equipment - 15 Yr				
NaOCl feed pumps	2	EA	\$2,500	\$5,000
KMnO ₄ Feed Pumps	2	EA	\$2,500	\$5,000
				\$10,000
Auxiliary Equipment - 15 Yr				
High service pumps	2	EA	\$10,000	\$20,000
				\$20,000
Auxiliary Equipment - 10 Yr				
Greensand Filter Media	1	LS	\$30,500	\$30,500
				\$30,500
Subtotal				\$713,500
Contingency	15%			\$107,025
Total - Preliminary Construction Cost Opinion (nearest \$1000)				\$821,000

FIGURE 4-3. 500,000-gpd Iron Removal Water Treatment Plant with Manganese Greensand Filtration

5.0 Central Water Treatment Plant Operation

5.1 Introduction

Upon completion and approval of the final water treatment plant design package (plans and specifications), the owner/client proceeds to advertise for bids for construction of the treatment plant. The construction contract normally is awarded to the firm submitting the lowest qualified bid.

Upon award of the construction contract, the engineer may be requested to observe the work of the construction contractor in order to notify the client of the compliance or lack of compliance with the design. This responsibility may be limited to periodic visits to the site to assure the client that the general intent of the design is being fulfilled; or it may include day-to-day field observation and reporting of the work as it is being performed. Payment to the contractor should be made by the client after receiving the written review of the pay estimate by the engineer. The engineer should state that the amount is in accordance with the construction completed and with certifications from the contractor that he has paid all subcontractors and suppliers for the work completed. The engineer should review all shop drawings and other information submitted by the contractor. All acceptable substitutions should be approved in writing by the engineer.

Upon completion of the construction phase of the project, the engineer normally is requested to perform a final inspection along with the client before final payment is made. This entails a formal approval indicating to the client that all installed items are in compliance with the requirements of the design. Any corrective work required at that time is covered by a punch list and/or warranty. The warranty period (normally one year) commences upon final acceptance of the project by the client from the contractor. Final acceptance and final payment usually take place upon completion of all major punch list items.

Preparation for treatment plant startup and operation is important, but training for these functions may or may not be included in the construction contract. Before system

startup, it is essential that system operating supplies, such as treatment chemicals, laboratory supplies, and recommended spare parts, are procured and stored on site. The treatment plant operating and maintenance instructions (or O&M Manual) also should be available for use. Included in the O&M Manual are diagrams and operational procedures for basic operation, maintenance, and troubleshooting of equipment. Valves, pumps, and other similar equipment should be identified by a numbering system for ease of correlation with the O&M Manual. For example, valves may be designated as "V-1", "V-2", etc. which corresponds to identification tags on the valves (see Figure 5-1). A valve directory should be included in the O&M Manual and reference made to these numbers in the explanation of operating procedures (see Table 5-1).

The following sections discuss the activities and events that lead up to routine plant startup and operation. They also address different process elements of the three alternative treatment types (i.e., oxidation and filtration, solid oxidizing media filtration, and manganese greensand filtration). Note that discussion of pressure filters operation applies to all three treatment types. Appendix B provides operation procedures for iron removal plants.

5.2 Chemical Treatment Equipment

Proper training and instruction in the handling and use of chemicals at a water treatment plant is critical for operators. Appropriate protective apparel and safety stations which include eyewashes or showers in the event of a spill need to be a part of the treatment facility. Maintenance of chemical storage areas to prevent contamination and appropriate isolation is to be observed.

Chemical storage tanks should be clearly labeled or color coded, indicating the chemical contained within the tank. The piping, valves, pumps, etc., also should be clearly labeled or color coded. It is the responsibility of the client to properly label or color code the storage tank, pump, and associated equipment in accordance with the plant color system or labeling.

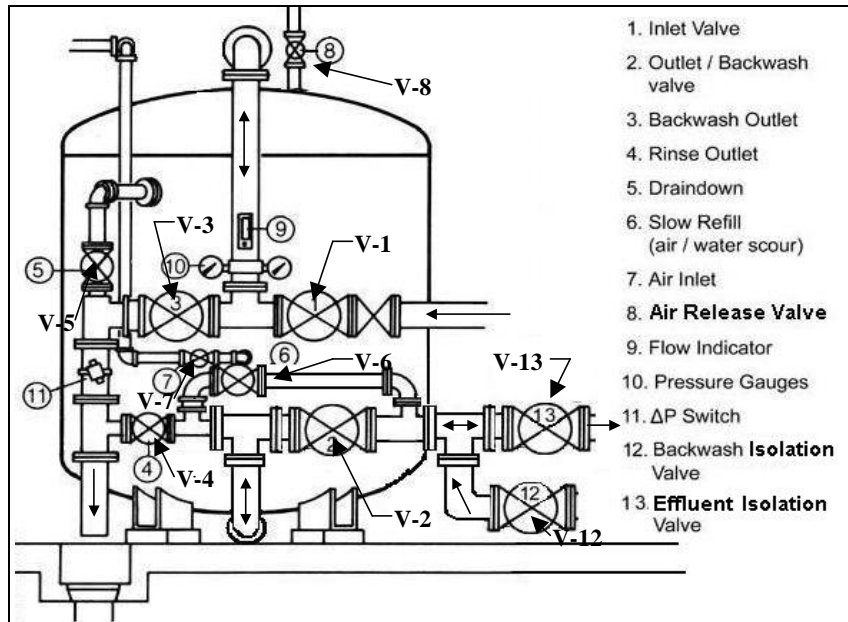


FIGURE 5-1. Valve Number Diagram on a Typical Pressure Filter

TABLE 5-1. Valve Operation Chart for Pressure Filters with Air Wash^(a)

Mode	Valve No.										
	1	2	3	4	5	6	7	8	12	13	
Treatment – in service	•	•	x	x	x	x	x	x	x	•	
Backwash											
Draindown	x	x	•	x	•	x	x	•	x	x	
Air/Water Wash	x	x	•	x	x	•	•	•	•	x	
Refill	x	x	•	x	x	•	x	•	•	x	
Fast Wash	x	•	•	x	x	x	x	•	•	x	
Slow Wash	x	•	•	x	x	x	x	•	•	x	
Bed Settle	x	x	x	x	x	x	x	x	•	x	
Rinse	•	x	x	•	x	x	x	x	x	x	
Treatment Start											
Treatment – offline	x	x	x	x	x	x	x	x	x	x	
Treatment – in service	•	•	x	x	x	x	x	x	x	•	

(a) Refer to Figure 5-1 for valve location.
Legend: x = valve closed; • = valve open.

Maintenance personnel should be familiar with the safety precautions associated with the chemical contained in the system and warned about the potential hazards before starting to work.

If a color coding system is used, the personnel should be familiar with the system so they know what chemical is contained within the equipment on which they are about to work.

5.2.1 Chlorination Equipment

Gas chlorination operation should only be accomplished by trained personnel. Training includes proper procedures

in connecting gas cylinders; repair and maintenance practices for piping, chlorination equipment, and safety equipment, including ventilation; proper use of safety equipment; and a thorough understanding of an emergency plan in the event of a leak.

Liquid chlorination systems with the use of a sodium hypochlorite or a calcium hypochlorite solution need to be maintained in the proper environment to preserve shelf life. These systems typically are comprised of a day tank on a scale with a chemical feed pump to withdraw the solution to an application point. If calcium hypochlorite (HTH) is supplied in dry powder, then mixing the powder into a solution tank will be required. Typical

available chlorine is about 65% in a calcium hypochlorite solution. Sodium hypochlorite is delivered in liquid form within a range of 5-15% available chlorine.

To calculate the pounds of calcium hypochlorite required on a daily basis, the following equation may be used:

$$\text{lb/day hypochlorite} = \frac{\text{(million gallons per day) (8.34) (mg/L)}}{\text{(percent available chlorine in hypochlorite)}}$$

To determine the amount of HTH required at 65% strength for treated water flow of 80,000 gpd (0.080 million gallons per day [mgd]) and a dosage of chlorine required of 3.0 mg/L, the calculation is:

$$0.08 \text{ mgd} (8.34)(3.0 \text{ mg/L}) / 0.65 = \mathbf{3.1 \text{ lb/day of HTH}}$$

5.2.2 Potassium Permanganate Feed Equipment

Similar to liquid chlorination systems, potassium permanganate systems typically are comprised of a day tank on a scale with a chemical feed pump. It is important to maintain a fixed and uniform concentration of the solution in the tank by accurate addition of the chemical and frequent stirring. A 1% solution can be prepared by dissolving one ounce of potassium permanganate in one gallon of water:

$$\mathbf{1 \text{ oz. KMnO}_4 \text{ (dry weight) per gallon of water}}$$

One of the common maintenance problems is the occasional plugging of chemical feed pumps with permanganate crystals. This is usually the result of inadequate stirring in the day tank. Many operators keep a continuous stirring of the day tank to insure chemical dissolution. If crystal formation continues, then it is possible that the solution strength is too high and better accuracy in the solution preparation is required.

Cleaning and flushing of permanganate systems is easily accomplished with water. Hot water will dissolve any residues or buildups more quickly.

5.2.3 Chemical Feed Pumps

For chemical pumping systems, it is most common to use either piston stroke pumps or, for smaller applications, electronic pulse pumps. For piston stroke pumps, chemical feed adjustment is by the length of the piston stroke on the pump. The stroke length is adjusted by a lever or knob, graduated from 0% to 100% of stroke. For electronic pulse pumps, the number of pulses per minute

can be set on a keypad to control chemical feed. Pump instruction manuals should be used for complete O&M details.

5.3 Pressure Filters

The filter vessel and piping should be disinfected in accordance with American Water Works Association standard procedures (AWWA, 1984 and 1999) and as outlined in the specifications. The media then is placed in the treatment vessels and is ready for operation.

There are two basic modes of operation: treatment and backwash. Slight variations to each mode depend on the media being used and the use of air scouring during backwash. Operating details for each of these modes are discussed as follows.

5.3.1 Treatment (Filtration) Operation

Figure 5-1 shows the position of the valves on a typical pressure filter. During normal filtration, water is routed through Valve No. 1 to the influent distribution header. The influent distribution header is a large-diameter, low-velocity piping array at the top of the filter vessel designed to evenly distribute the water over the surface of the media. It also serves as a collection header for wash water during the backwash cycle.

The water moves through the media at an approved rate (depending on media type). After filtration, the water is collected by the underdrain system. The underdrain system is designed to collect filtered water and to evenly distribute backwash water across the bottom of the media. After being collected by the underdrain system, the water exits the bottom of the filter and passes into the finished water piping through Valve No. 2.

While in operation, the influent pressure above the media and the effluent pressure below the media are indicated on pressure gauges (Valve No. 10 in Figure 5-1; a photo is provided as Figure 5-2). For plants monitored or controlled automatically, the lines connecting the gauges to the influent and effluent pipes also connect to pressure transducers at the filter. These devices convert the pressures to electrical signals that are monitored by a programmable logic controller (PLC) inside the control panel. The pressure drop indicated by these gauges (Influent-Effluent) should be monitored regularly. The filter must not be operated if the differential pressure is in excess of 8-10 psi. This condition will result in fracture to some media types. For accuracy, gauges should be selected to have normal operating points in the mid-range of the gauge.

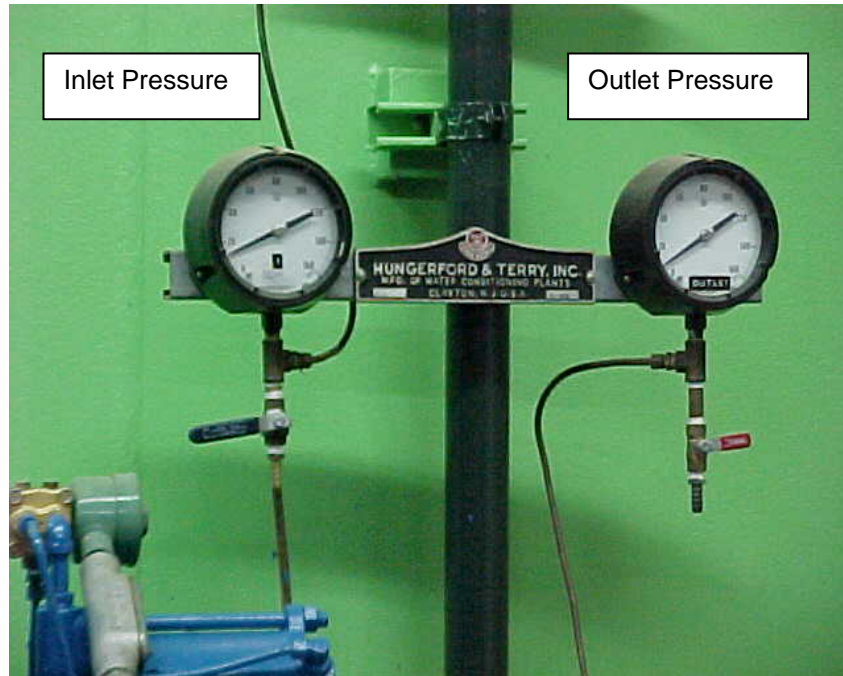


FIGURE 5-2. Pressure Filter Loss of Head Gauges

Filter effluent flow is used to balance the flow between the filters. Each effluent pipe is equipped with a flow meter, such as depicted in Figure 5-3. The signal from this meter is used by the PLC to control the motorized operator and position of the valve on each effluent pipe.

Additionally, these meters provide a direct display of the present flow and provide totalized flow with reset. This feature is useful for manual initiation of backwash based on gallons filtered. For automatic operation, totalized flow resets automatically upon backwash initiation.

5.3.2 Backwash Operation

The importance of proper backwashing of the filter media cannot be overemphasized. Backwashing is essential to maintaining the efficiency of the filter media and the quality of the finished water.

The backwash process can vary slightly depending on whether the use of air scouring is employed in backwashing. Some media, such as Birm, do not require nor can it withstand the turbulent collision of particles, which occur during an air scouring operation. Other media, such as manganese greensand, require air scouring to clean the media. In general, the backwash sequence can be broken into seven stages:

- Draindown
- Air/Water Wash

- Refill
- Fast Wash
- Slow Wash
- Bed Settle
- Rinse.

5.3.2.1 Draindown

During draindown, the water level in the filter is lowered to approximately six inches above the media. To do this Valve No. 1 (the influent valve), Valve No. 2 (the effluent valve), and Valve No. 6 (the slow wash/refill valve) are closed, isolating the filter from the rest of the system. Once these valves are closed there will be a programmed delay of one minute. Then, Valve No. 5, the draindown valve, and Valve No. 3, the backwash outlet valve, are opened. The draindown valve is programmed to remain open for five minutes. While draindown is in progress, Valve No. 8 (the air release valve) will allow air to enter the top of the filter (see Figure 5-4).

5.3.2.2 Air/Water Wash

This phase of the backwash process mixes air with water under the media, agitating the media and causing the media grains to rub together producing a very efficient scrubbing action. During this phase, the blower and the backwash pump are used (see Figures 5-5 and 5-6). The valves will be configured as follows: Valve No. 6 (the slow wash valve), Valve No. 7 (the air wash valve),



FIGURE 5-3. Filter Effluent Flow Meter



FIGURE 5-4. Air Release Valve

and Valve No. 12 (the wash water isolation valve) are opened. Valve No. 3 (the backwash outlet valve) remains open, while Valve No. 13 (the effluent isolation valve) and Valve No. 5 (the draindown valve) are closed.

Once the valves are properly configured, the blower will start. At the same time, the backwash pump will start and its rate is held by the backwash control valve at

approximately one-third of the maximum backwash rate used in the fast wash sequence. In automatic mode, this low rate is monitored by the backwash flow meter reading, and is controlled by the backwash rate valve. This process is programmed to continue for a short period, usually about three minutes. During this time the filter will partially refill.



FIGURE 5-5. Air Wash Blower and Motor



FIGURE 5-6. Air Wash Blower Controls

5.3.2.3 Refill

After the air/water wash the blower stops and Valve No. 7 closes, the wash water will continue for two more minutes. This ensures that there is sufficient water above the media to prevent any initial surges in the fast wash flow from disrupting the media.

5.3.2.4 Fast Wash

During the fast wash, water is forced through the media counter to its normal flow at velocities sufficient to expand the media to the desired level, usually 30-40% depending on the manufacturer's recommendation. This allows the previously entrained filtered particles to be suspended and then flushed from the filter by the backwash water. After refill, the backwash rate control is stepped from the refill rate to a maximum rate prescribed for the media type. For example, manganese greensand would typically have a refill rate of 4 gpm/ft², and the maximum backwash rate would be 12 gpm/ft². Wash water leaving the filter should be checked periodically for the presence of anthracite. If anthracite is present in more than trace quantities, the fast wash flow may need to be lowered. This phase of the backwash cycle is typically programmed to continue for 20 minutes.

5.3.2.5 Slow Wash

After the fast wash has ended, the backwash rate is decreased to the refill rate for one minute. This low rate allows the media to reclassify and settle evenly inside the filter.

5.3.2.6 Bed Settle

After the slow wash has ended, all wash water flow to the filter is stopped and the media is allowed to settle for approximately two minutes.

5.3.2.7 Rinse

This stage also is referred to as filter-to-waste. During this phase Valve No. 2 (the filtered effluent valve), Valve No. 3 (the backwash outlet valve), Valve No. 6 (the slow wash/refill valve), and Valve No. 12 (the backwash water isolation valve) are closed; and Valve No. 1 (the raw influent valve) and Valve No. 4 (the rinse valve) are opened. The filter is operated at its normal filtration rate with the effluent going to waste. The purpose for this is to make sure any particles dislodged but not removed from the lower portion of the media go to waste rather than into the finished water.

5.3.3 Filter Loadings and Run Termination

For treatment systems involving solid oxidizing media filtration (i.e., pyrolusite and Birm), daily backwashing is recommended for optimal filter efficiency. For oxidation and filtration as well as manganese greensand systems, three methods can be used to assess the need for backwashing this type of filter:

- Gallons treated
- Filter run time
- Pressure drop across the media.

5.3.3.1 Gallons Treated

The “gallons treated” method is used because the total volume of water filtered can be directly converted to the quantity of iron and manganese precipitated. When this reaches a predetermined limit, backwash is initiated. This method is used most frequently for filtration media that filters the precipitates, such as dual media anthracite and silica sand or anthracite and manganese greensand. Iron and manganese precipitates often are extremely small and will move down into the media bed rather than being stopped on the surface of the bed. When the precipitates collect evenly throughout the depth of the media, there will be only a slight pressure drop across the media, compared to the pressure drop encountered when the precipitates collect primarily in the upper three to four inches of the bed. As such, breakthrough may occur without significant pressure buildup through the filter.

For a manganese greensand system, the filter run between regenerations/backwashes can be calculated based on the potassium permanganate demand (PPD) of the water and the PPD capacity of greensand (Ficek, 1994). The PPD of water is defined as the stoichiometric amount of KMnO_4 necessary to oxidize Fe(II) and Mn(II) (see Table 2-2), as calculated using the following equation:

$$\text{PPD} = \text{Fe as mg/L} + (2 \times \text{Mn as mg/L}) = \text{mg/L Fe and Mn} \\ \text{mg/L Fe and Mn} / 17.1 = \text{gpg Fe and Mn}$$

Concentrations of iron and manganese are expressed as mg/L, which can be converted to grains per gallon (gpg) by dividing by 17.1.

According to the greensand manufacturer, one cubic foot of greensand has about 300 grains (or 19.4 grams) of manganese removal capacity. Since two parts of permanganate are required to oxidize each part of manganese, the PPD capacity of greensand is twice that for manganese or 600 grains (or 38.8 grams).

The following calculations are an example of how to determine the gallons filtered between regenerations/backwashes for a manganese greensand system. For a water containing 1.5 mg/L Fe, 0.5 mg/L Mn, and no other oxidizable contaminants, the PPD is:

$$\text{PPD of water} = 1.5 \text{ mg/L} + (2 \times 0.5 \text{ mg/L}) = 2.5 \text{ mg/L} \\ 2.5 / 17.1 = \mathbf{0.146 \text{ gpg}}$$

Assuming that greensand has a PPD capacity of 600 grains per cubic foot, a filter with an area of 50 ft^2 (8-ft-diameter pressure vessel) and an 18-inch media depth has a total capacity:

$$600 \text{ gr/ft}^3 \times 1.5 \text{ ft} \times 50 \text{ ft}^2 = \mathbf{45,000 \text{ grains}}$$

If each gallon of raw water contains 0.146 grains of KMnO_4 demand, the number of gallons of water a filter can treat would be:

$$45,000 \text{ grains} / 0.146 \text{ gpg} = \mathbf{308,219 \text{ gallons}}$$

This is the amount of water that may be treated before the filter would require regeneration and backwashing.

5.3.3.2 Filter Run Time

Filter run time can be used to initiate backwash when the filter is operated at a constant flowrate. This allows the run time to be directly converted to volume throughput. Using the previous example that determined 308,219 gallons of water treated between two backwash cycles, and filtering at a 3.0 gpm/ft^2 rate, the filter run time is:

$$3.0 \text{ gpm/ft}^2 \times 50 \text{ ft}^2 = 150 \text{ gpm} \\ 308,219 \text{ gallons} / 150 \text{ gpm} = \mathbf{2,055 \text{ minutes.}}$$

This would allow for a run time of:

$$2,055 \text{ minutes} / 60 \text{ minutes per hour} = \mathbf{34.2 \text{ hours.}}$$

5.3.3.3 Pressure Drop

Pressure drop is used to initiate a backwash when the pressure difference between the inlet and outlet pressure reaches 8-10 psig. As larger precipitates accumulate on the top of the media bed, the head loss through the filter increases. Depending on the size of the precipitates, the filter run time could be significantly shorter than that calculated based on the gallons filtered method.

When the head loss across the filter reaches 10 psig, a backwash cycle must be initiated regardless of the gallons that have been filtered. Monitoring the head loss across the filters also can be used to identify operating problems with the filter. As the media ages, it will generally decrease in size and the difference between the smallest grains and the largest grains will increase. This condition will cause the filter to exhibit higher initial head loss under clean bed conditions.

5.3.4 Filter Operation

Filters may be operated manually or automated through a PLC in the filter control panel (see Figure 5-7). The startup and shutdown of plant production and filter operation are typically based on the level of water storage facilities. An example of a common sequence of operation is described as follows:



FIGURE 5-7. Typical Two-Filter Control Panel

- When the storage tank falls below a pre-designated low level 1, the well pump control panel starts the well pump(s) designated under a LEAD/LAG matrix.
- If the storage tank continues to fall until it reaches low level 2, additional well pump(s) designated under the LAG steps of the matrix will be started.
- When the pumps are started, the filter control PLC will configure the influent and effluent valves for normal filtering.
- This process continues as the storage tank level rises. When the storage tank level reaches high level 1, the LAG pump(s) will stop. When the storage tank level reaches high level 2, the LEAD pump(s) will be signaled to stop.

<u>Two-Filter Control Panel</u>			
Effluent Rate Meters	Influent Meter	Disconnect	
Filtering/Washing Indicators	Plant Effluent	Backwash Flow	
Filtering—Washing			
Inlet Valve Switches OPEN—CLOSE—AUTO	Blower Motor Switch HAND—OFF—AUTO		
<u>Valve Position Meters As %</u>			
Effluent Valve Switch OPEN/CLOSE/AUTO	Bank A Backwash Full Flow—Low Flow—Close—Auto	Bank B Backwash	
Backwash Inlet Valves OPEN—CLOSE—AUTO	Hypochlorite Pump #3	Filter PLC Interface	
Backwash Outlet OPEN/CLOSE/AUTO	Unit Select Auto/ 1-2-3-4-5-6	Air/Water Wash INCLUDE OMIT	Wash Start PUSH TO START
Rinse Outlet Valves OPEN/CLOSE/AUTO	Backwash Resume PUSH TO START	Backwash Stopped	
Draindown Valves OPEN/ CLOSE/AUTO	Filter Sequence/ Time Control Prolong—Auto	Backwash Pump HAND/OFF AUTO	
Air Wash Inlet Valves OPEN—CLOSE—AUTO			

Displayed on the control panel are the vital flow parameters which consist of:

- Flow from each filter
- Plant effluent and influent
- Backwash flow
- Filter effluent valve positions.

Provisions are made available on the panel for both the manual and automatic operation of the following system components and operations:

- Filter valves
- Individual filter backwash operations
- Air wash operations.

An operator interface is provided for control and adjustment of automatic filter operations. The PLC has an

operator interface on the right side of the panel (see Figure 5-7), providing direct access to the control panel.

Valves operated with pneumatic or hydraulic actuators can be either open or closed (see Figures 5-8 and 5-9). The switches present on the control panel for electric operators will allow the plant operator to manually open

or close the valves. Additionally, the controls on the filter control panel should be designed to allow the plant operator to open and close the valve. Valves operated with electrical operators may be positioned at any point between fully opened and fully closed. The position of these valves is indicated as to what percentage the valve is fully opened (see Figure 5-10).



FIGURE 5-8. Pneumatically Operated Draindown Valves

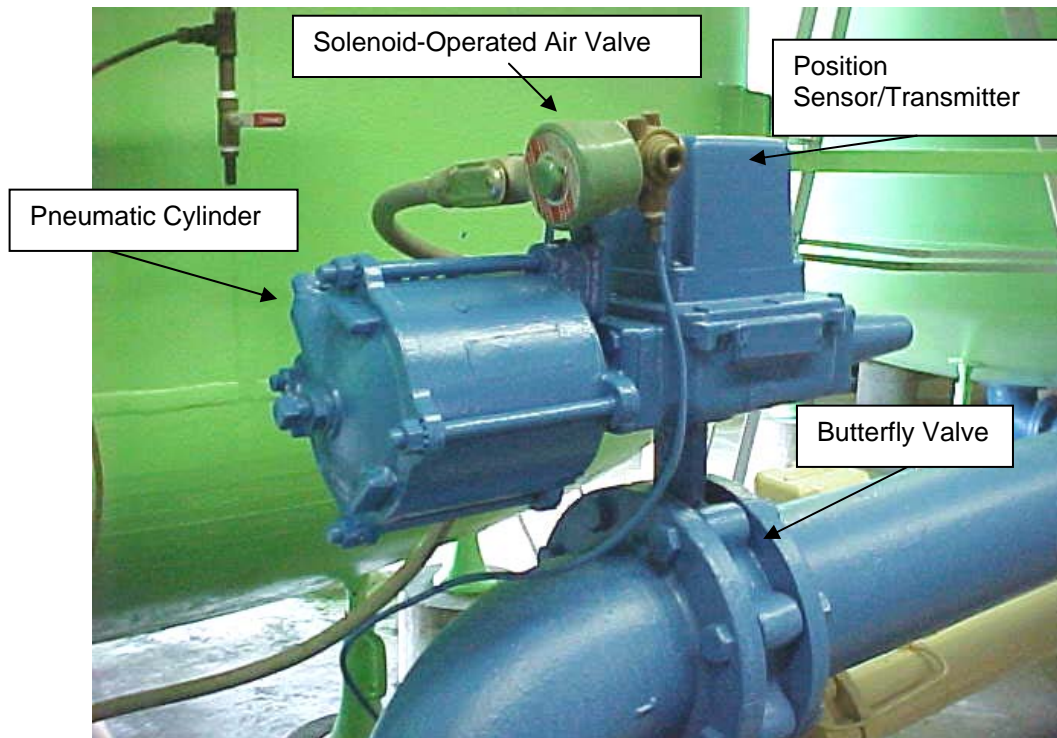


FIGURE 5-9. Filtered Effluent Pneumatically Operated Butterfly Valve

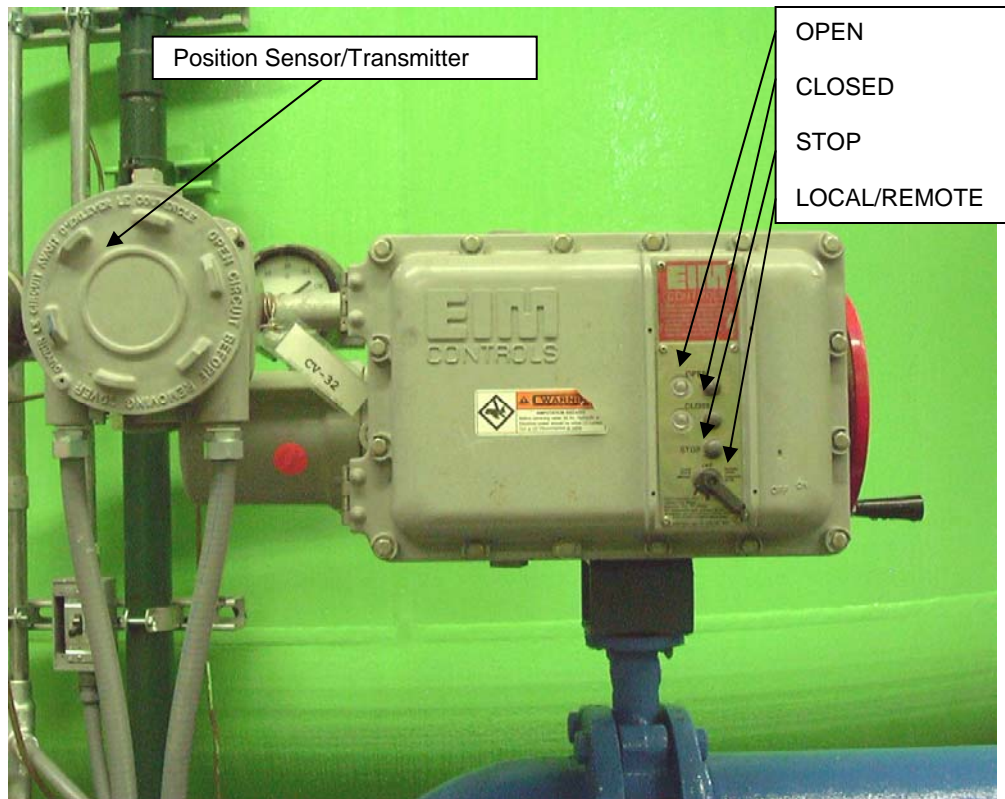


FIGURE 5-10. Electric Valve Operator

5.4 Media

The placement of the media in the treatment vessel, which takes place immediately prior to initial startup or during replacement of spent media, is a critical step in the future system performance. The media is usually delivered in bags on pallets. The volume of the media is determined on a dry weight basis.

5.4.1 Support Media

Some filters are designed to have an underdrain system that does not require support media; these are usually of a porous plate or strainer nozzle design. For an underdrain system that requires support media (e.g., gravel, garnet, and/or torpedo sand), care must be taken in the placement of the support media.

Before packing the support media, it is important to be sure that the interior of the tank is clean and that the underdrain is clear and secure. The support media then is placed around and over the underdrain system and each gradation is measured for proper depth. Support media should be properly leveled before adding the next size layer.

For vessels with air scour, the air distribution laterals should be inspected to ensure that the openings are facing downward into the support media. Gravels in 3/16-inch, 10 mesh then are placed in the tank to cover the air wash distributor. Care must be taken to prevent debris from entering the tank, as it may cause interference with the air distribution.

Air scour systems which require a gravel retaining screen should place the screen at the junction where the top layer of gravel will be leveled off and the layer of green-sand will be started. In packing the last layer of gravel, it must be mounded slightly above the top of the screen support angle so that, when the screen is installed, the gravel will be tight underneath the screen.

5.4.2 Filter Media

The filter media should be packed under water. With water available to the unit, clean water is fed to the tank until it stands about 12-18 inches deep above the supporting bed. The filter media may be placed in the filter tank by pouring it through the tank opening until the required amount is packed. Care should be taken to prevent bags or any portion of the shipping containers

from entering the tank, as this could cause excessive pressure loss and/or channeling of water through the bed during the service run.

After the required filter media has been placed in the tank and leveled, the filter must be given a conditioning backwash and the fines must be skimmed from the bed surface. The filter then should be backwashed at the flowrate required to achieve bed fluidization for at least 15 minutes. Following this backwash, the filter should be given a short downflow rinse, and then the filter should be backwashed again.

Following this second backwash, the filter should be drained completely. An inspection will show a layer of fine material on the bed surface from ½-inch to ¾-inch thick, which must be removed with a flat trowel or flat shovel and discarded. It is important not to rake or scrape this material across the bed surface, as this will only push the fines down into the bed.

For dual media filters, anthracite may be added after the fines have been skimmed from the bed. Water should be allowed to enter the filter until it stands about 6-8 inches above the bed. Anthracite then is placed into the filter to the required depth. Caution should again be exercised to prevent debris from entering the tank. After the required amount of anthracite has been placed into the tank, the filter may be backwashed again until the water passing to waste is clear and clean. Anthracite should be skimmed to remove fines. A short rinse should then be performed before the unit is drained.

While the unit is draining, it is important to observe the draindown and close the rinse valve when the water level is about 12 inches above the bed surface. The filter then is ready for conditioning (if required) and disinfecting.

5.4.3 Limitations and Precautions

Depending on the filter media, certain limitations and precautions should be observed.

5.4.3.1 Anthracite Caps

When using anthracite, the backwash wastewater should be monitored closely to determine media loss. Because anthracite is more easily fluidized than other media, it is more likely to experience a greater rate of attrition and carryover in the backwash waste. Also, it may be more likely to fracture under air scour or high rate backwashing, thus reducing its effective size and beginning to plug the filter bed, resulting in higher head loss through the filter. Besides periodically taking samples of backwash waste during high-rate backwashing, annual inspection

of the anthracite cap is recommended to determine the depth and effective size of the media.

5.4.3.2 Pyrolusite

Along with silica sand, pyrolusite is among the most durable of the available iron filter media. However, because of its high specific gravity, backwash rates must be able to redistribute the pyrolusite evenly throughout the sand filter bed. Using water alone for backwash requires 25-30 gpm/ft², a rate difficult to achieve for many smaller treatment plants. The use of air scour with water backwash is best in redistributing the pyrolusite. If iron removal effectiveness begins to decline, it may be due to uneven distribution of the media, and backwashing practices should be examined.

5.4.3.3 Birm

The effectiveness of the Birm media is compromised when it is operated outside of defined ranges. Free chlorine concentration in backwash water should not exceed 0.5 mg/L (as Cl₂). Water containing hydrogen sulfide or polyphosphates will reduce the oxidizing capacity of the media and must be avoided. During installation, disinfection of the treatment tank with chlorine should take place just prior to the addition of the Birm media. The tank should be thoroughly rinsed of any chlorine residue before placing the media. Careful placement of media to avoid contamination must be observed.

5.4.3.4 Manganese Greensand

Before manganese greensand is placed into service, it must be conditioned and disinfected. Conditioning is accomplished by filling the filter until the water level is approximately 12 inches over the bed. In accordance with the manufacturer recommendation, a prescribed amount of potassium permanganate is dissolved in water and then added to the filter by any convenient means (bucket or pump) through the tank top opening. It is important to prevent undissolved crystals of permanganate from entering the tank. The tank top opening should then be closed and the tank completely filled with water. With all valves closed, the inlet valve should be opened, followed by the slow opening of the rinse valve. Rinsing should continue until the rinse water tests free of iron and manganese. The filter then is ready for service.

Sometimes it is impractical to add potassium permanganate in solution. Although it is not desirable to add permanganate crystals because they dissolve very slowly, if necessary, they may be added to the 12 inches of water over the bed. The time required for rinsing may be extended considerably if potassium permanganate crystals are added.

5.5 Operator Requirements

A qualified operator for an arsenic removal water treatment plant, licensed in accordance with any regulatory requirements, should have thorough arsenic removal process training, preferably at an existing treatment plant. The operator should be able to service pumps, piping systems, instrumentation, and electrical accessories. The operator should be fully informed about the safety requirements and physical/chemical characteristics of all chemicals required for use at the plant. Corrosive chemical safety requirements for clothing, equipment, antidotes, and procedures must be thoroughly understood. The operator should be thoroughly trained to run routine water analyses including the method for determining arsenic levels. The operator should be well grounded in mathematics for operation cost accounting and treatment run recordkeeping. The operator, above all, should be dependable and conscientious.

5.6 Laboratory Requirements

In addition to the O&M Manual, the treatment plant should have the latest edition of *Standard Methods for the Examination of Water and Wastewater* prepared jointly by the American Public Health Association–American Water Works Association–Water Environment Federation (APHA-AWWA-WEF). This manual supplies the plant operators with necessary information for acceptable methods for analyzing water. A recommended list of items for analysis is illustrated in Figure 3-1. The primary requirement is accurate analysis for arsenic, iron, manganese, and pH. As long as pH meters are calibrated and cleaned regularly, high precision measurements are easily obtained. Care should be exercised to prevent contamination of pH buffers.

Total arsenic can be preserved effectively in field samples and analyzed by several analytical methods to the MCL of 10 µg/L or less. Preservation of total arsenic is accomplished by acidifying the sample to pH <2. The Arsenic Rule lists four U.S. EPA-approved analytical methods:

- Inductively coupled plasma–mass spectroscopy (ICP-MS),
- Graphite furnace atomic absorption (GFAA),
- Stabilized temperature platform (STP) GFAA, and
- Gaseous hydride atomic absorption (GHAA).

These methods are U.S. EPA-approved for compliance requirements and require expensive analytical equip-

ment that is found only at large water treatment plants or laboratories. During the past several years, several companies have developed portable test kits for field analysis of arsenic.

Several arsenic tests kits have been evaluated under the U.S. EPA Environmental Technology Verification (ETV) program by the Advanced Monitoring Systems Center managed by Battelle in partnership with U.S. EPA. These kits were tested for monitoring arsenic in the 1 to 100 µg/L range. Information on the test kits can be found on the internet (<http://epa.gov/etv/verifications/vcenter1-21.html>). Although they may be adequate for monitoring process performance, these test kits are not U.S. EPA-approved methods for use in reporting MCL compliance data. For regulatory data, water samples must be analyzed by U.S. EPA and state-certified testing laboratories employing U.S. EPA-approved methods.

5.7 Operating Records

A system of records should be maintained on file at the treatment plant covering plant activity, plant procedures, raw water chemical analyses, plant expenditures, and inventory of materials (spare parts, tools, etc.). The plant operators should have the responsibility of managing all aspects of the treatment plant operation. The operators are accountable to the water system management. The recommended record system should include, but not be limited to, items described below.

5.7.1 Plant Log

A daily log should be maintained in which the plant operators record daily activities at the plant. This record should include a listing of scheduled maintenance, unscheduled maintenance, plant visitors, purchases, abnormal weather conditions, injuries, sampling for state and other regulatory agencies, etc. This record should also be used as a tool for planning future routine and special activities.

5.7.2 Operation Log

The operators should maintain a log sheet for each treatment run for each treatment unit, so that a permanent plant performance record will be on file. Figure 5-11 illustrates a copy of a suggested condensed form.

5.7.3 Water Analysis Reports

It is recommended that the plant operators run an analysis of raw and treated arsenic levels once each week for each unit, and a total raw water analysis once per month. Changes in raw water may necessitate changes

WATER TREATMENT PLANT

FILTER OPERATION LOG

DATE: _____

FILTER NO. _____

Time	Rate of Flow (gpm)	Head Loss (psi)	Hours in Service	Total Volume Filtered	Filter Loading (gpm/ft ²)	Backwash Start	Backwash Finish	Backwash (gallons)	Percent Waste (%)	Raw Arsenic (mg/L)	Treated Arsenic (mg/L)	Raw Iron (mg/L)	Treated Iron (mg/L)

DATE: _____

FILTER NO. _____

Time	Rate of Flow (gpm)	Head Loss (psi)	Hours in Service	Total Volume Filtered	Filter Loading (gpm/ft ²)	Backwash Start	Backwash Finish	Backwash (gallons)	Percent Waste (%)	Raw Arsenic (mg/L)	Treated Arsenic (mg/L)	Raw Iron (mg/L)	Treated Iron (mg/L)

FIGURE 5-11. Typical Water Treatment Plant Filter Operation Log

in the treatment process. Raw water changes that can impact the treatment process include, but are not limited to, pH, alkalinity, arsenic, iron, manganese, hardness, phosphate, silica, sulfate, total dissolved solids, and turbidity. Figure 3-1 illustrates a copy of a suggested water analysis form. A permanent file of these reports can be a valuable tool.

5.7.4 Plant Operating Cost Records

Using accounting forms supplied by the water system’s accountants, the plant operators should keep a complete record of purchases of all spare parts, chemicals, laboratory equipment and reagents, tools, services, and other sundry items. This should be supplemented by a file of up-to-date competitive prices for items that have been previously purchased.

5.7.5 Correspondence Files

The plant operators should retain copies of all correspondence pertaining to the treatment plant in chrono-

logical order. Included would be intradepartmental notes and memos in addition to correspondence with other individuals and/or organizations. Faxes and copies of emails should be part of the file.

5.7.6 Regulatory Agency Reports

The plant operators should maintain a complete file of copies of all reports received from state, county, or other regulatory agencies pertaining to the treatment plant. In addition, training records of plant staff should be maintained to demonstrate compliance with license and other certification requirements.

5.7.7 Miscellaneous Forms

The operators should have an adequate supply of accident and insurance forms.

5.8 Treatment Plant Maintenance and Housekeeping

The maintenance concept for the water treatment plant is to isolate the equipment to be serviced by means of shutoff valves, vent and drain lines (as required), repair or replace equipment, fill lines, open valves, and start treatment service. All system components are equipped with isolating valves and all piping systems have vents at high points and drains at low points to improve maintenance efficiency.

Equipment manufacturers' recommended spare parts should be stocked at the treatment plant to avoid lengthy maintenance shutdowns.

Bypassing of components in the plant should be provided for periods of maintenance on those components. However, care should be taken to avoid bypassing treat-

ment and sending untreated water with excessively high arsenic to distribution, an event that should not occur and would result in a violation of primary drinking water standards.

A preventive maintenance program should be implemented to sustain the reliability of the plant and reduce operating costs. Scheduled maintenance should be planned and actual maintenance recorded in a systematic manner.

The plant operator should wash down all equipment at least once per month. Floors should be swept. Bathroom and laboratory fixtures should be cleaned once per week. All light bulbs should be replaced immediately on failure. Emergency shower and eyewash stations should be tested once per week. Any chemical spill should be neutralized and cleaned up immediately. Equipment should be repainted at least once every five years.

6.0 Central Water Treatment Plant Operating Costs

6.1 Introduction

The primary objectives in central water treatment plant design are to provide the owner/client with a low-capital cost installation that works efficiently and reliably; is simple to operate; and is inexpensive to operate. Iron removal systems include chemical pretreatment, filtration, and/or disinfection, and each system should be designed with maximum capability and flexibility.

Similar to capital costs, many variables affect operating costs. This chapter discusses the types of operating costs that are evaluated during each stage of the design phase of the project and the operation of the treatment plant. The costs include:

1. Treatment chemicals
2. Operating labor
3. Utilities
4. Replacement of equipment and media, and miscellaneous materials
5. Waste disposal (not included in this manual).

Operating costs normally are passed directly onto the water user in the monthly water bill. As the consumer's water bill normally is based on metered water consumption, the costs for treatment are prorated on the unit of volume measurement. The unit of volume is usually 1,000 gal, or 100 ft³ (750 gal). The rate units employed in this design manual is \$/1,000 gal. Some systems do not meter consumption; instead, they charge a flat monthly rate based on the size of the branch connection to the water main. Although this latter mode of distribution saves the cost of meters as well as the reading of meters, it does not promote water conservation. Therefore, far more water is pumped, treated, and distributed, resulting in a net increase in operating costs.

The common denominator that applies to both the operating costs and the bill for water consumption is the unit of volume, 1,000 gal. Each operating cost factor can be reduced to cost/1,000 gal. The sum total of the annual operating costs based on total water production yields the cost per 1,000 gallons.

Treatment system size is another variable that impacts costs. Operating labor requirements do not vary directly with the size of the system, but do vary with the type of operation; smaller systems would tend to employ the simplest operation. In general, the labor cost per 1,000 gallons of water is less for larger plants. For example, if it takes the same amount of labor to operate a 50,000-gpd plant as it does a 500,000-gpd water plant, the labor cost will be ten times less per 1,000 gallons for the larger plant.

Besides treatment system size, other variables that influence the costs of operation are the source water concentrations of iron, arsenic, and other contaminants that must be removed. Increased chemical addition and numbers of backwash cycles per 1,000 gallons increase when iron concentrations are higher. For example, water with 1 mg/L of raw iron may require chlorination of 1 mg/L and will not load filter media as quickly as raw water with 3 mg/L, which may require 3 mg/L of chlorine for oxidation.

The costs of treatment chemicals, utilities, waste disposal, and availability of operating personnel vary with geographic locations and may be deciding factors in the best treatment option available for a particular treatment system.

6.2 Treatment Chemicals

The treatment chemicals discussed in this chapter are limited to chlorine in its various forms and potassium permanganate. Both are oxidants and are highly corrosive, requiring compatible materials of construction, containment provisions, safety provisions, weather protection,

and operator training. Although special precautions and training are required, they are routinely accomplished. Other chemicals may be used for other requirements, such as corrosion inhibition or pH adjustment; however, such site-specific requirements are not covered in this manual.

The chemicals used for treatment of water for public consumption require NSF/ANSI STD 61 certification by most state regulatory agencies. It also is recommended that the chemical supplier be required to certify that the containers used to store and deliver the chemicals have not been used for any other chemical; or if they have, that they have been decontaminated according to procedures required by the governing regulatory agency.

Chemical costs are variable; recently these costs have been volatile. Like all commodities, there is sensitivity to the supply and demand fluctuation of the marketplace. The geographic location of the treatment plant site in relation to that of the supplier has an impact on the delivered cost. In some cases, the delivery costs are greater than the costs of the chemical. The conceptual design evaluates the chemical logistics and determines the most cost-effective mode of procurement as well as whether chemicals for pH adjustment are economically feasible.

Chemical costs are sensitive to the volume and containment mode of the commodity purchased. In general, gas chlorine is shipped in either 2,000-lb containers or smaller 150-lb cylinders. Liquid chlorine (sodium hypochlorite and calcium hypochlorite) come in various containers from bulk deliveries to small containers. Because commodity handling is minimized, bulk tank truck quantities entail the least cost.

Bulk deliveries require chemical storage tanks within containment basins located at the treatment plant site with necessary safety provisions and weather protection. The same commodities can be routinely purchased in drums (55-gal or 30-gal), totes, carboys, gallon jugs, etc. These packaged quantities result in much higher unit prices than bulk quantity. The drum and other small container prices also depend on the quantity procured at one time. Small containers also introduce additional handling requirements for the treatment plant operator. For small treatment systems, bulk procurement and storage of liquid chlorine can be a limiting factor.

Potassium permanganate is delivered in a dry, crystal form and can be shipped in 48,000-lb bulk shipments but more commonly is provided in 330-lb steel drums or 55-lb high-density polyethylene (HDPE) pails.

The following provides an example operational cost evaluation for a hypothetical manganese greensand iron removal treatment plant. For this example, it is assumed that the system that has an average flow of 500,000 gpd and uses chlorine and potassium permanganate as oxidants. Concentration of raw iron is 1.5 mg/L, and raw manganese is 0.10 mg/L.

The quantity of chlorine and potassium permanganate required can be calculated as follows:

$$\text{mg/L chlorine} = \text{mg/L iron} \\ \text{mg/L KMnO}_4 = 0.2 \times \text{mg/L iron} + 2.1 \times \text{mg/L Mn}$$

With no chlorine, the potassium permanganate demand is:

$$\text{mg/L KMnO}_4 = 1.1 \times \text{mg/L iron} + 2.1 \times \text{mg/L Mn}$$

Given:

Flowrate = 500,000 gpd
 Raw Iron = 1.5 mg/L
 Raw Manganese = 0.10 mg/L
 Chlorine (gas) = \$0.40/lb
 Potassium Permanganate = \$1.35/lb

Then:

Chlorine lb/yr:
 $(1 \times 1.5 \text{ mg/L}) \times 0.5 \text{ mgd} \times 8.34 \times 365 = 2,283 \text{ lb/yr}$

Potassium permanganate lb/yr:
 $[(0.2 \times 1.5 \text{ mg/L}) + (2.1 \times 1 \text{ mg/L})] \times 0.5 \text{ mgd} \times 8.34 \times 365 = 776 \text{ lb/yr}$

Chlorine cost:
 $2,283 \text{ lb/yr} \times \$0.40/\text{lb} = \$913/\text{yr}$

Potassium permanganate cost:
 $776 \times \$1.35/\text{lb} = \$1,048/\text{yr}$

Total chemical cost = \$1,961/yr

Total gallons water produced:
 $500,000 \text{ gpd} \times 365 \text{ days/year} = 182,500,000 \text{ gal/year}$

Chemical Cost/1,000 gallons:
 $\$1,961 / (182,500) = \$0.01/1,000 \text{ gallons}$

6.3 Operating Labor

Operating labor costs are difficult to quantify. The operators are required to be dependable and competent; however, the positions are not always full-time. Depending on the size of the system and the other duties available

for the operators, the operators' time should be distributed over several accounting categories. Automatic backwashing of filters can significantly reduce the time required at the plant.

On routine operating days, the operators check the system to see that equipment is operating properly, take and analyze water samples, check instruments (flow, temperature, pressure), and make entries in daily logs. Other activities, which may occur on a less frequent basis, include, but are not limited to, arsenic analyses in the treatment plant laboratory, equipment maintenance, and chemical tank truck deliveries. During the remainder of the time, the operators are able to operate and maintain other systems (distribution, pumps, storage, etc.), read meters, or handle other municipal responsibilities (e.g., operate sewage treatment plant). Backup operators should always be available to take over in case of an emergency. Those individuals should be well versed in the operation of the plant.

Assuming that the plant operations are charged an average of 20 hours per week for labor, the cost of operational labor will be as follows (it is assumed that the hours not used for treatment plant operation will be efficiently used on other duties):

Given:

Annual average use = 20 hr/wk
Operator annual salary = \$35,000
Overhead and fringe benefits = 30%
Available Annual Hour = 2,040 hr

Then:

Total plant operator time:
20 hr/wk × 52 wk/yr = 1,040 hr
Operator hourly rate: 35,000/2,040 = \$17.16/hr
30% (overhead and fringe benefits): = \$ 5.15/hr
Operator Rate: \$22.31/hr

Total operator cost:
1,040 hr/year × \$22.31/hr = \$23,200/yr

Total gallons water produced:
= 182,500,000 gal/yr

Labor cost/1,000 gal:
\$23,200/182,500 = \$0.13/1,000 gallons

If the operators had no other responsibilities and the operator's entire salary were expended against this treatment plant operation, the operating labor cost would become \$0.25/1,000 gal. Depending on the operational philosophy of the designer/planner/manager, the operating labor

costs can be minimized or maximized over a very broad range. In the case of a very high production plant, the operating labor requirement is not significantly larger than that for a very small treatment plant. Therefore, depending on relative salaries, the resulting cost per 1,000 gal can range from a few cents to more than a dollar.

6.4 Utilities

Utility costs normally are for electrical power, but can include costs for telephone and/or for oil or natural gas. Telephone service to the treatment building is recommended as a safety precaution in case of accident as well as operator convenience. Cost for that service should be the minimum available monthly rate. Depending on the local climate, the costs for heating can vary. The purpose of the building is to protect the equipment from elements (primarily freezing), not for operator comfort. Normally the treatment units act as heat sinks, maintaining an insulated building at a temperature near that of the raw water. In cold climates, the building should have an auxiliary heat source to prevent freezing of pipes in the event that the water is not flowing. If the client determines that the treatment building is to serve additional functions, heating and air conditioning to a comfortable temperature could be an additional required cost.

Electric power is needed for the following functions:

1. Chemical feed equipment
2. Instrumentation and controls
3. Pumps (well and high service)
4. Lighting
5. Office/lab/maintenance
6. Aerator
7. Air blowers
8. Backwash pump
9. Backwash waste holding pumps.

Items 1, 2, 4, and 5 are negligible. Item 3 is the largest use of power and the use of energy efficient motors is recommended. Item 6 is a relatively small load (1-3 hp blower motor). Items 7, 8 and 9 are intermittent loads, but significant.

Electrical utility rates also vary considerably from one geographic location to another. In 2002, rates varied from \$0.05 to \$0.20/kwh. The electrical utility cost can range from \$0.005 to \$0.02 per 1,000 gallon under normal conditions. Under abnormal conditions, the cost could be \$0.05/1,000 gallon or higher.

6.5 Media Replacement

Properly maintained media may be replenished annually due to attrition, but generally has a useful life of many years. It is not uncommon to use media for 10 years or longer before total replacement. Media is typically priced per cubic foot. Costs of media in 2002 were in the following ranges:

Silica sand	\$5-10/ft ³
Anthracite	\$8-15/ft ³
Pyrolusite	\$70-92/ft ³
Birm	\$56-65/ft ³

6.6 Replacement Parts and Miscellaneous Materials

This is a very small operational cost item. Replacement parts (e.g., chemical pump diaphragms, seals, and replacement pump heads) should be kept in stock in the treatment plant to prevent extended plant shutdown if a part is required. Also included are consumables such as laboratory reagents (and glassware), and recordkeeping

supplies. An operating cost allowance of \$0.01/1,000 gal of treated water is conservative.

6.7 Operating Cost Summary

The range of iron removal water treatment plant operating costs discussed above are impacted by the factors presented in Sections 6.2 through 6.6. For the manganese greensand water treatment plant example used in Section 6.2, the sum of the operating costs would be:

Chemical cost:	\$0.01/1,000 gallons
Labor cost:	\$0.13/1,000 gallons
Utility cost:	\$0.02/1,000 gallons
Miscellaneous cost:	\$0.01/1,000 gallons

Total Operating Cost: \$0.17/1,000 gallons

For an average flow of 500,000 gpd, the annual operating cost for the plant is \$31,025. This annual cost does not include waste disposal. Other water-related costs including distribution maintenance or administrative costs such as meter reading and billing are not included.

7.0 References

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Appendix A

Economic Evaluation Example

An economic comparison was made between a conventional iron removal water treatment plant (WTP) with aeration and a manganese greensand iron removal WTP. The following is a summary of the design data followed by an equivalent annual cost analysis.

Design Data Summary

Option 1: Iron Removal with Aeration WTP (500,000 gpd)

Process: Well Pumping → Aeration → Filtration → Disinfection → Clearwell → High Service Pumping → Distribution System

Flow:

Maximum day: 500,000 gpd (used to size process equipment)
Average day: 250,000 gpd (used to calculate chemical usage)

Pressure Filters*

Max flow, total: 500,000 gpd total (350 gpm)
Flow per filter: 175 gpm
Filtration rate: 3 gpm/ft²
Required filter area: 58.33 ft² (175 gpm / 3 gpm/ft²)
Filter diameter: 9'- 0" (nearest size exceeding required area)
Actual filter area: 63.62 ft² per filter

*actual allowable rate and filter redundancy requirements will vary among state regulatory agencies

Filter Media

Media depth: 36" (typical)
Media volume: 190.9 ft³ per filter (filter area × depth)
Media type: Sand and anthracite
Media cost: \$10-\$15 per ft³

Backwash Tanks

Backwash rate: 10 gpm/ft² of filter area
Backwash duration: 20 min
Required volume: 25,440 gallon*

* volume = (filter area) × (rate) × (duration) × (number of filters)

Clearwell Detention

Detention time: 30 minutes (groundwater)
Required volume: 10,500 gallon (350 gpm × 30 min)

Disinfection Chemical

Chemical:	Sodium Hypochlorite (NaOCl)
Delivery:	Liquid, 12.5% trade strength, no dilution
Dosage:	1.0 mg/L
Cl ₂ required/day:	2.1 lb/day (lb/day = 0.25 mgd x 1.0 mg/L x 8.34)
Cl ₂ from NaOCl:	Approximately 1 lb Cl ₂ per gallon 12.5% NaOCl
NaOCl required:	2.1 gallons/day
NaOCl cost:	\$1.00 to \$1.50 per gallon delivered

High Service Pumping

Pumping head:	60 psi (139 ft TDH)
Pumps:	Horizontal split case centrifugal
Power:	20 HP each pump*

$$* HP = \frac{\gamma QH}{550\eta};$$

where $\gamma = 62.4 \text{ lb/ft}^3$, H = head in ft, Q = flow in cfs, η = pump efficiency

Energy

Pumping:	kW = HP x 0.746
Heating/Ventilation:	Varies (typically 12.5 to 15.0 kW per 1,000 ft ²)
Lighting:	Varies (typically 0.75 to 1.5 kW per 1,000 ft ²)
Miscellaneous	Varies
Electric cost:	Varies (typically \$0.06 to \$0.12 per kW-hr)

Option 2: Manganese Greensand WTP (500,000 gpd)

Process: Well pumping → Chemical Oxidation → Filtration → Disinfection → Clearwell → High Service Pumping → Distribution system

Process calculations: same as for Option 1 except media type and chemical oxidation.

Filter Media

Media depth:	36" (typical)
Media volume:	190.9 ft ³ per filter (filter area x depth)
Media type:	Manganese greensand and anthracite
Media cost:	\$84-\$90 per ft ³

Chemical Oxidation

Chemical:	Potassium Permanganate (KMnO ₄) liquid
Dosage:	1.1 lb KMnO ₄ per lb Fe, 2.1 lb KMnO ₄ per lb Mn removed
Iron (Fe):	1.0 mg/L
Manganese (Mn):	0.1 mg/L
KMnO ₄ /day for Fe:	2.3 lb/day (lb/day = 0.25 mgd x 1.0 mg/L x 8.34 x 1.1 lb/lb)
KMnO ₄ /day for Mn:	0.4 lb/day (lb/day = 0.25 mgd x 0.1 mg/L x 8.34 x 2.1 lb/lb)
Total KMnO ₄ /day:	2.7 lb/day*
KMnO ₄ cost*:	\$3.50 to \$5.50 per lb in crystal form

*does not include periodic dosing of filter for media regeneration.

COST-EFFECTIVE ANALYSIS - DATA INPUT

Project Name: Project Economic Analysis

Alternative Name: Option 1 - Iron Removal with Aeration WTP

Planning Period in years: 20
 Initial Year of Planning Period: 0
 Construction Period, in years: 1.0

Interest Rate %: 5.875

Structures Value, year 0: \$360,000

Process Equipment

20 yr. Equipment Value, year 0: \$321,000
 15 yr. Equipment Value, year 0: \$5,000

Auxiliary Equipment

15 yr. Equipment Value, year 0: \$20,000
 10 yr. Equipment Value, year 0: \$17,500

Land Cost: \$0

Total Construction Cost: \$723,500

Contingences, % : 15.00

Technical Services, % : 0.00

Salaries and Administrative Cost, year 0 \$35,000
 year 20 \$63,000

Power and Gas? type Y, just Power? type P: P

Power Cost, year 0 \$28,000
 year 20 \$50,500

Chemical Cost, year 0 \$1,150
 year 20 \$2,100

Repair and Maintenance Cost, year 0 \$5,000
 year 20 \$9,000

Project Economic Analysis

Option 1 - Iron Removal with Aeration WTP

ESTIMATE OF OPERATION AND MAINTENANCE COST

Year	<u>0</u>	<u>20</u>
Salaries and Administrative	\$35,000	\$63,000
Power	28,000	50,500
Chemicals	1,150	2,100
Repair and Maintenance	5,000	9,000
	_____	_____
TOTAL O&M COSTS	\$69,150	\$124,600
TOTAL FIXED O&M	69,150	69,150
TOTAL VARIABLE O&M	\$0	\$55,450
Yearly Increase		\$2,773

Project Economic Analysis

Option 1 - Iron Removal with Aeration WTP

REPLACEMENT COST AND SALVAGE COST SUMMARY

	Initial Cost at <u>Year 0</u>	Replacement Cost at <u>Year 10</u>	Replacement Cost at <u>Year 15</u>	Salvage Value <u>Year 20</u>
A. Structures				
50 year life	\$360,000			
Salvage Value				\$216,000
B. Process Equipment				
20 year life	321,000			
15 year life	5,000			
Replacement Cost			5,000	
Salvage Value				3,333
C. Auxiliary Equipment				
15 year life	20,000			
10 year life	17,500			
Replacement Cost		17,500	20,000	
Salvage Value				13,333
D. Other Costs				
Contingencies	108,525			
Technical Services	0			
Land	0			0
TOTAL PROJECT COST	\$832,025			
TOTAL REPLACEMENT COST		\$17,500	\$25,000	
TOTAL SALVAGE VALUE				\$232,667

Project Economic Analysis

Option 1 - Iron Removal with Aeration WTP

AVERAGE EQUIVALENT ANNUAL COST DETERMINATION

COST AND OTHER DATA USED

Planning Period: 20 Years			
Initial Cost of Project:	\$832,025	Construction Period:	1.0 Year
Replacement Cost at Year 10:		\$17,500	
Replacement Cost at Year 15:		\$25,000	
Salvage Value at Year 20:			
Structures	-	\$216,000	
Process Equipment	-	3,333	
Auxiliary Equipment	-	13,333	
Land		0	
Total		<u>\$232,667</u>	
Constant Annual O&M Cost:			\$69,150
Variable Annual O&M Cost:			\$0 Year 0 to \$55,450 Year 20
Interest Rate:	5.875 %		

DETERMINE PRESENT WORTH AND AVERAGE EQUIVALENT ANNUAL COST OF THIS PLAN OVER 20 YEARS

Factors: (20 years at 5.875%, unless noted)	
Present worth (PW) of constant annual O&M cost:	11.5872
PW of variable annual O&M cost (annual increase):	88.5484
Present worth of replacement cost - Year 10:	0.5650
Present worth of replacement cost - Year 15:	0.4247
Present worth of salvage value:	0.3193
Interest during construction = Initial cost x (0.5) x Period of Construction (Years) x Interest rate.	
Equivalent annual cost = Total present worth x	0.0863

CALCULATIONS - PRESENT WORTH

1. Initial Cost		\$832,025
2a. Constant O&M		801,257
2b. Variable O&M		245,500
3. Replacement Cost		20,506
4. Salvage Value	(minus)	74,279
5. Interest During Construction		<u>24,441</u>
6. Total Present Worth		\$1,849,450

AVERAGE EQUIVALENT ANNUAL COST

<u>\$1,849,450 x</u>	<u>0.0863</u>	\$159,611
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COST-EFFECTIVE ANALYSIS - DATA INPUT

Project Name: Plant Economic Analysis

Alternative Name: Option 2 - Manganese Greensand WTP

Planning Period in years: 20
 Initial Year of Planning Period: 0
 Construction Period, in years: 1.0

Interest Rate %: 5.875

Structures Value, year 0: \$360,000

Process Equipment

20 yr. Equipment Value, year 0: \$293,000
 15 yr. Equipment Value, year 0: \$10,000

Auxiliary Equipment

15 yr. Equipment Value, year 0: \$20,000
 10 yr. Equipment Value, year 0: \$30,500

Land Cost: \$0

Total Construction Cost: \$713,500

Contingences, % : 15.00

Technical Services, % : 0.00

Salaries and Administrative Cost, year 0 \$35,000
 year 20 \$63,000

Power and Gas? type Y, just Power? type P: P

Power Cost, year 0 \$28,000
 year 20 \$50,500

Chemical Cost, year 0 \$6,100
 year 20 \$11,000

Repair and Maintenance Cost, year 0 \$5,000
 year 20 \$9,000

Plant Economic Analysis

Option 2 - Manganese Greensand WTP

ESTIMATE OF OPERATION AND MAINTENANCE COST

	<u>0</u>	<u>20</u>
Salaries and Administrative	\$35,000	\$63,000
Power	28,000	50,500
Chemicals	6,100	11,000
Repair and Maintenance	5,000	9,000
	_____	_____
TOTAL O&M COSTS	\$74,100	\$133,500
TOTAL FIXED O&M	74,100	74,100
TOTAL VARIABLE O&M	\$0	\$59,400
Yearly Increase		\$2,970

Plant Economic Analysis

Option 2 - Manganese Greensand WTP

REPLACEMENT COST AND SALVAGE COST SUMMARY

	Initial Cost at <u>Year 0</u>	Replacement Cost at <u>Year 10</u>	Replacement Cost at <u>Year 15</u>	Salvage Value <u>Year 20</u>
A. Structures				
50 year life	\$360,000			
Salvage Value				\$216,000
B. Process Equipment				
20 year life	293,000			
15 year life	10,000			
Replacement Cost			10,000	
Salvage Value				6,667
C. Auxiliary Equipment				
15 year life	20,000			
10 year life	30,500			
Replacement Cost		30,500	20,000	
Salvage Value				13,333
D. Other Costs				
Contingencies	107,025			
Technical Services	0			
Land	0			0
TOTAL PROJECT COST	\$820,525			
TOTAL REPLACEMENT COST		\$30,500	\$30,000	
TOTAL SALVAGE VALUE				\$236,000

Plant Economic Analysis

Option 2 - Manganese Greensand WTP

AVERAGE EQUIVALENT ANNUAL COST DETERMINATION

COST AND OTHER DATA USED

Planning Period: 20 Years			
Initial Cost of Project:	\$820,525	Construction Period:	1.0 Year
Replacement Cost at Year 10:			\$30,500
Replacement Cost at Year 15:			\$30,000
Salvage Value at Year 20:			
Structures	-	\$216,000	
Process Equipment	-	6,667	
Auxiliary Equipment	-	13,333	
Land	-	<u>0</u>	
Total	-	<u>\$236,000</u>	
Constant Annual O&M Cost:			\$74,100
Variable Annual O&M Cost:			\$0 Year 0 to \$59,400 Year 20
Interest Rate:	5.875 %		

DETERMINE PRESENT WORTH AND AVERAGE EQUIVALENT ANNUAL COST OF THIS PLAN OVER 20 YEARS

Factors: (20 years at 5.875 %, unless noted)	
Present worth (PW) of constant annual O&M cost:	11.5872
PW of variable annual O&M cost (annual increase):	88.5484
Present worth of replacement cost - Year 10:	0.5650
Present worth of replacement cost - Year 15:	0.4247
Present worth of salvage value:	0.3193
Interest during construction = Initial cost x (0.5) x Period of Construction (Years) x Interest rate.	
Equivalent annual cost = Total present worth x	0.0863

CALCULATIONS - PRESENT WORTH

1. Initial Cost	\$820,525
2a. Constant O&M	858,613
2b. Variable O&M	262,989
3. Replacement Cost	29,975
4. Salvage Value	(minus) 75,343
5. Interest During Construction	<u>24,103</u>
6. Total Present Worth	\$1,920,862

AVERAGE EQUIVALENT ANNUAL COST

\$1,920,862 x	0.0863	\$165,774
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Appendix B

Operations Procedures for Iron Removal Plants

- 1) When approaching the plant, first look to see if the lights are on around it or listen to hear if the generator is running. Check for power outages, integrity of fence, doors, windows, louvers, etc.
- 2) Once out of the vehicle, look to see if water is coming out from under the doors or up from the ground around the plant. Then look to see if everything else appears as it should.
- 3) Once inside, listen for familiar sounds:
 - Are the chemical feed pumps running?
 - Are the high service pumps running?
 - Are the backwash pumps running?
 - Are there any unusual sounds?
 - Is anything running that shouldn't be?
- 4) Check the control panel for alarms.
- 5) Check chart recorders for normal flow patterns and mark abnormalities.
- 6) Check the flow split between the filters.
- 7) Check totals on filters to see that they are backwashing as required.
- 8) Check the filters for anything unusual.

A common problem with filter systems that use a Venturi to measure flow is that the orifices in the tube will plug with a slime-like residue from the precipitated iron. In some cases the slime is caused by the iron-metabolizing bacteria.

One cure is to increase the chlorine feed if it is used or add a small amount of chlorine if aeration is used. If the chlorine feed is increased or started in a

softening plant, the carryover dose should not be greater than 0.1 mg/L.

The tubing from the Venturi to the sensor should be flushed regularly. Do not attempt to adjust the balance valves on the sensor.

If these procedures do not correct the problem, the Venturi will need to be removed and cleaned. All orifices and tubing should be cleaned and flushed and then reassembled.

- 9) When permanganate is being fed, a sample of the effluent from each filter should be analyzed daily for residual. This can be done quickly with a DPD colorimeter. The reading is multiplied by 0.891 to get the permanganate residual. A quick check method is to draw the effluent into a white styrofoam cup. If you see pink, you are overfeeding.

The concept of these filters is to remove manganese, so any carryover would be putting it back in.

Greensand media has an exchange capacity, so the best method of operation is to feed an amount of permanganate that is very slightly below the demand, and once a week increase the feed (KMnO_4) until pink is seen in the effluent, then turn the feed back down. This recharges the media.

- 10) When chlorine is used to oxidize iron, there should be a slight carryover to keep iron from fouling the greensand. This should be checked daily. If the filter is followed by softening, the residual must not be more than 0.1 mg/L on a continuous basis and not be allowed to exceed 0.3 mg/L. Most resins will tolerate 0.3 mg/L for *very short* duration peaks.
- 11) If filter backwashing or softener regeneration is set up for automatic operation, the operator should be at

the plant for several of these occurrences each week to make sure the different events are happening on schedule and to check the operation of the equipment involved.

A sample of the washwater should be taken and checked for washed out media.

The operation of the backwash pumps, valves, and flow meters should be checked.

- 12) If the different pumps are not controlled through a pump rotator, reset the LEAD/LAG sequence once a week.
- 13) Check chemical levels daily.
- 14) Check levels in waste holding tanks daily and monthly in waste-holding lagoons.
- 15) Check dehumidification equipment monthly.

16) Check air scour systems daily. It is not uncommon for water to leak past valves and flood the air blowers.

17) Compare tank level readings to the stop/start points of the equipment operated from those levels.

18) Open each filter annually and measure and core the media. While the filter is open, all of the other components should be checked.

19) Exercise and inspect all of the valves around each filter 2 to 3 times per year.

20) Depending on the types of valves in use, keep an assortment of repair parts on hand. Valves that are electric solenoids often have problems. For valves where the normal position of the valve requires the solenoid to be energized, regular failure of the coil can be seen. Coils are quickly and easily replaced. Also, repair kits for air switching valves need to be kept on hand at the plant.