Help Instruction File:

Permanganate Module Overview

Provided by the Office of Surface Mining Reclamation and Enforcement (OSMRE), the Pennsylvania Department of Protection (PADEP), the U.S. Geological Survey's (USGS) and the West Virginia Department of Environmental Protection (WVDEP).

Permanganate Module Overview

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1.0 Objective

The objectives of this overview are to: (1) Provide an understanding of non treatment specific infrastructure or costs that may be necessary for different treatment system sites and (2) Provide an overview of the Site Development Module to guide users in developing an estimate of the cost to construct, operate, and maintain additional treatment system infrastructure not covered in other modules. The module can also be applied to reverse cost model an existing system to establish and evaluate future financial and investment decisions. The information is presented in two sections, **Overview and Application** and **Site Development Module Overview**.

2.0 Overview and Application

In addition to treatment specific components covered in other AMDTreat modules, there are typically additional components that may be necessary to estimate costs for when considering A basic understanding of the chemical and physical properties, the application, and equipment requirements of a Permanganate treatment system are required to develop a treatment strategy using the AMDTreat software. These topics are discussed below before discussing the module interface and functionality to provide the necessary context. The Overview and Application section is organized into three parts: (1) Physical and Chemical Properties and (2) Benefits/Drawbacks, Equipment and Typical Treatment Configurations, and (3) Application and Financial Analysis.

2.1 Physical and Chemical Properties

Permanganate products are classified as a hazardous substance (oxidizer, corrosive, and irritant) by OSHA (Occupational Safety and Health Administration). Some of the hazards consist of (1) strong oxidizer, (2) cause fires or explosions, (3) cause severe skin burns, (4) serious eye damage/eye irritation, and (5) respiratory irritation/acute oral toxicity. Permanganate is a danger in both liquid and vapor form. Please see Safety Data Sheets for additional information on permanganate products. **This help file and AMDTreat Permanganate module does NOT comprehensively address the overall site safety precautions that must be considered when designing, operating or maintaining a Permanganate treatment system. System designers and operators must consult with qualified and knowledgeable chemical and equipment providers in order to adequately address site and personnel safety concerns.**

There are two chemical compounds that are considered ‘permanganate’, potassium permanganate [$KMnO_4$] and sodium permanganate [$NaMnO_4$]. Both are manufactured by using manganese oxide ore [i.e. pyrolusite, MnO_2], which is mined out of the ground. Potassium permanganate is fused with KOH and heated with a source of oxygen to form K_2MnO_4. Then the potassium manganate is converted to permanganate via electrolytic oxidation to form $KMnO_4$. Sodium permanganate is produced in a slightly different manner. It is prepared by heating manganese oxide with sodium hypochlorite (NaClO) and caustic soda (NaOH) as in the following equation:

$$2MnO_2 + 3NaClO + 2NaOH \rightarrow 2NaMnO_4 + H_2O$$

In general, sodium permanganate is more expensive to produce; therefore, may not be used quite as much as potassium permanganate. However, sodium permanganate has a much higher solubility (90g/100mL at

20°C) in water compared to potassium permanganate (0.06g/100mL at 20°C); therefore, a higher concentration (20% or 40% by weight/weight) of sodium permanganate can be prepared in concentrated liquid form. Compared to potassium permanganate, which is prepared in liquid form at a 1% to 3% by weight. Please note, in this module it is assumed that the sodium permanganate will be delivered in a pre-mixed solution at either 20% or 40% w/w. However, it is assumed the potassium permanganate will be delivered in a dry (solid) form and 'made-down' onsite, into either a 1%, 2%, or 3% solution (w/w). Please see Section 3.4 of Help File for assumptions. Attention to both solution strength and specification (by wt., by vol., by wt./vol) is necessary when purchasing and conducting price comparisons.

The solution strengths used in the AMDTreat program are 20% and 40% (w/w) for sodium permanganate and 1%, 2%, or 3% (w/w) for potassium permanganate. The module has an option to include a heating system; however, the purpose of this system is to prevent the water for the eye wash and safety shower from freezing, although a heated building would also help stabilize the viscosity of the Permanganate solution as well. Table 1 provides characteristics of the common solution strengths.

Solution Strength (wt/wt)	Solution Density (lbs/gal)	lbs of Permanganate/gal Solution
20% $NaMnO_4$	9.67	1.93
40% $NaMnO_4$	11.55	4.62
1% $KMnO_4$	8.40	0.084
2% $KMnO_4$	8.45	0.169
3% $KMnO_4$	8.51	0.255

Table 1: Specifications for common Permanganate solution strengths.

Ferrous Iron is the primary multi-valent contaminate in flooded underground coal mines in the eastern U.S.; although, additionally some underground mines require manganese treatment. Typically, if operators want to use an oxidant, they would use hydrogen peroxide; however, if manganese is present in the mine drainage water, hydrogen peroxide will not oxidize manganese. Therefore, an operator can consider using Permanganate in order to oxidize the ferrous iron (Fe^{2+}) and dissolved manganese (Mn^{2+}). Historically, operators have used lime addition to increase pH in order to first precipitate $Fe(OH)_2$, allow it to settle out, then increase the pH further (~9.0) and precipitate $Mn(OH)_2$ to achieve effluent standards (Figure 1). However, if mine drainage is net alkaline Permanganate can be used to oxidize these metals. In either case, with net alkaline drainage or drainage that is initially treated to adjust pH and produce net alkaline water, Permanganate can be used as a "second step" in the treatment process after alkaline conditions are achieved and ferrous iron has been oxidized. Permanganate added at this point will then only target primarily manganese oxidation. In many instances, this treatment strategy may be more cost effective given that Permanganate is a considerably more costly reagent than comparative chemicals that only target iron removal.

As indicated in Figures 2 and 3, a treatment strategy that utilizes Permanganate will increase the Eh and cause the oxidation of dissolved ferrous iron and manganese and the precipitation of $Fe(OH)_3$ and MnO_2. Utilizing a treatment strategy focused on increasing Eh instead of pH, avoids costly nuisance reactions such as calcite formation and the deprotonation of H_2CO_3 and reduces sludge production (see Decarbonation Help Files for additional information).

2.2 Benefits/Drawbacks, Equipment and Typical Treatment Configurations

This section summarizes some of the benefits, drawbacks, equipment, and treatment configurations of Permanganate at mine drainage treatment sites.

2.21 Benefits

The major reason why Permanganate is popular is because of its ability to oxidize both dissolved Fe and dissolved Mn, and the limited sludge produced. The benefits of using Permanganate as a mine drainage treatment oxidant include:

1. Quick reacting and solubility allow for precise dosage and small reaction tanks;
2. Can be effectively mixed using passive mixing, like turbulent flow;
3. Specifically targets ferrous Fe and dissolved Mn, and avoids costly nuisance reactions like calcite precipitation;
4. Low sludge production since it primarily targets ferrous iron and dissolved Mn;
5. Lower capital and maintenance costs than Lime Products;
6. Low maintenance with the dose pump and electric mixer being the only mechanical parts;
7. Relatively small equipment footprint.
8. Relatively stable chemical allows for long-term storage in instances of ephemeral or periodic treatment;

2.22 Drawbacks

The drawbacks of using Permanganate as a mine drainage treatment chemical include:

1. Safety concerns with handling; site safety, security and operator safety are key issues that must be considered.
2. Produces a low-density sludge that may be difficult to settle; therefore, requiring the addition of polymer and solids recirculation if using clarifiers. Pond clarification may require a polishing wetland to remove fine particulates of the metal oxides.
3. Due to the lack of a competitive market for Permanganate products, the cost of these products tends to be high, often making Permanganate cost-prohibitive for use in mine drainage treatment.
4. Permanganate will target iron oxidation before or simultaneously with manganese oxidation, consequently a treatment strategy that removes iron in a prior treatment step may be advantageous from a cost perspective.

2.23 Equipment and Typical Treatment Configurations

The treatment configuration will be slightly different when using the sodium permanganate versus the potassium permanganate. The module assumes the $NaMnO_4$ will be delivered in a pre-mixed solution compared to the $KMnO_4$ being delivered in a solid (sand) form. The potassium permanganate will have to be mixed onsite in a mix tank then subsequently placed in a dose tank. Compared to the sodium permanganate that would be stored directly in a dose tank. Then either solution would be dispensed via a dosing skid (i.e. electric pump) with appropriate length of piping/tubing to the specific location for addition to the mine drainage. The module provides the option for the user to include the following equipment: (1) Mix Tank and Electric Mixer System, (2) Dose Tank, Secondary Containment, Dosing Skid, (3) Storage Building and Safety Items. The following is a description of these items when considering Permanganate.

Mix Tank and Electric Mixer System

When considering sodium permanganate, the user would not be able to include a 'Mix Tank' and 'Electric Mixer' since that would only be required when utilizing potassium permanganate. In general, there are not many Permanganate treatment systems currently being utilized for mine drainage. Figure 4 is an image of a Mix Tank used at a potassium permanganate treatment site in Pennsylvania. At this treatment site, the Mix Tank consists of a steel tank with electric mixer motor mounted on top of the tank. The Permanganate module does not assume a particular tank type and/or electric mixer.

HDPE Double-Walled Dose Tank, Secondary Containment, and Dosing Skid

It is highly recommended that the Dose Tank(s) be placed within a secondary containment structure in case of any leaks or spills of the Permanganate solution. The Dose Tank assumed in this module consists of an HDPE double-walled tank; whereby the tank size (gallons) and unit cost can be adjusted to an appropriate volume and cost based on the mine drainage flow and raw water quality. It is assumed that the user would be able to purchase a custom tank size based on the specified volume required. Also, it is assumed that the dose tank sits in a vertical position. Figure 4 is an example of a HDPE double-walled dose tank that sits in a vertical position. A drainage valve should be located at the bottom to permit the dose tank to be fully emptied for inspection and cleaning. Dosing tanks need level indicators for supply management. Poly tanks must also be fully cleaned prior to the initial fill with Permanganate for the same reason. Provisions for this to occur must be included in all system designs. Contract specifications requiring equipment suppliers to both certify tank preparations and be present onsite during initial tank fill-up will help ensure a safe start-up of the equipment.

The secondary containment cost is calculated based on the dose tank size (i.e. diameter). It will consist of a concrete berm structure surrounding the dose tank. The volume and cost of the concrete is based on an assumed height of 4-feet and thickness of 4-inches, along with the appropriate length and width in order to surround the dose tank. The user needs to ensure that the secondary containment and storage building are sized sufficiently so the dose tank and secondary containment will sufficiently fit within the storage building. An error message will occur in the module if the square footage of the storage building is insufficient for the dose tank but **does not consider the size of the secondary containment if the user selects to include the secondary containment**.

The Dosing Skid that is assumed in the Permanganate module consists of a two-pump system (Figure 6 and 7). Two pumps are considered for redundancy purposes, allowing personnel to address any operation and maintenance issues that may arise. The tubing, fittings, gaskets, and lines must be constructed of an appropriate material to prevent the corrosion and potential leaks or spills of the Permanganate solution. The solution is pumped from the dosing tank, through the pumps, and out of the storage building to the treatment area (i.e. mixing/reaction tank). In addition, vents may be required in the storage building to ensure proper venting of the pumps.

Storage Building

The Storage Building is a simple concrete block and metal building with a concrete foundation and floor that will house the dose tank (Figure 5). The building will not contain insulation, lighting, heating, or any other service unless costs are included for these items. The default setting will be to include a storage building in the Permanganate module. The user can decide to uncheck the storage building option if it's not in the design. The default storage building size is 15-ft length, 15-ft width, 16-ft height (225 ft^2). The typical storage building would have a garage roll-up door for access and a standard side-door for entry. The system layout and tank material is largely controlled by site conditions and/or available capital.

Clean Water Tank, Eye Wash Station & Safety Shower, Building Heating System

Based on safety concerns when dealing with an oxidant like Permanganate, it is **strongly** recommended that users include the safety items that are included by default in this module. If a public water supply is not available at the site, the cost for installing a clean water tank can be included. It is assumed that the clean water tank will consist of a 500-gallon plastic tank and includes the excavation, ditching, plumbing, and electric hook-up. An eye-wash station and safety shower are assumed to be installed in the storage building (Figure 13) in order to provide an immediate source of water in case of an emergency spill and/or exposure to personnel onsite. The building heating system would ensure that the water supply and piping for the eye wash station and shower do not freeze during the colder winter months and help to stabilize the viscosity of the Permanganate solution.

2.3 Application and Financial Analysis

Permanganate is typically used to oxidize ferrous iron and dissolved manganese in mine drainage. It is used to quickly oxidize the Fe^{2+} and Mn^{2+} in order to undergo hydrolysis and form the solid precipitates $Fe(OH)_3$ and MnO_2. While many people have historically used lime products and a mixing/aeration tank to achieve oxidation and formation of metal oxides, Permanganate can be used in lieu of or in combination with the alkaline product. Permanganate is typically selected as the oxidation reagent for a site based on:

1. Dealing with mine drainage containing both dissolved Fe and dissolved Mn;
2. Fast reacting;

3.0 Permanganate Module Overview

3.1 Layout and Workflow

In general, inputs are on the left-hand side of the module and calculated outputs are on the right. The module inputs on the left-hand side are arranged into six sections: (1) Water Quality and Flow Input, (2) Permanganate Information, (3) Equipment and System Installation, (4) Annual Cost Input, (5) Other Capital Items, and (6) Other Annual Items. The workflow for the module is for users to start at the top left-hand side. Enter the *Typical Flow*, *Ferrous Iron, Dissolved Mn* and AMDTreat calculates the annual ferrous iron and dissolved Mn loading. Then select the specific *Permanganate Product ($KMnO_4$ or $NaMnO_4$), Non-Bulk* or *Bulk Delivery,* and *Concentration of Solution*. AMDTreat uses this information along with the calculated loading to estimate the annual chemical consumption, based on the specified Operational Time. Next, users can use the *Equipment and System Installation* section to select and size the Permanganate treatment equipment. If potassium permanganate is selected, input for a *Mix Tank* and *Electric Mixer* is to be specified. The dosing tank options, along with secondary containment, dosing skid, storage building, and safety items can all be specified. The *Annual Input* section allows the user to specify the chemical unit cost, operational periods, and additional items that would be considered annual costs to ensure chemical consumption and electrical costs are correctly estimated. Finally, users can specify additional capital and annual costs not considered by the module under the *Other Capital Items* and *Other Annual Items* headings.

Module output is provided on the right-hand side of the module. Module outputs on the right-hand side are arranged into four sections: (1) *Sizing Summary*, (2) *Capital Cost*, (3) *Annual Cost*, and (4) *Net Present Value*. The *Sizing Summary* section provides estimates of solution pricing, dose rate, chemical consumption, and storage tank refill frequency for the system. The estimated cost to construct and operate the Permanganate treatment system is provided under the *Capital Cost* and *Annual Cost* headings. Lastly, users can opt to conduct a Net Present Value (NPV) analysis to obtain the total cost to operate and maintain a treatment system for a defined time period.

A general overview of the module input and output sections is presented below, however, users are directed to the numerous tool tips located in the module that provide additional detailed information, such as definitions of terminology. In most cases, the tool tips are accessed by clicking on the information icon ( ) in each of the subheadings in the module.

3.2 Module Inputs

3.2.1 Water Quality and Flow Input: The Water Quality and Flow Input section is where users specify the Typical Flow, Ferrous Iron, and Dissolved Mn values. These values are used to (1) estimate the annual chemical consumption and (2) estimate the size of various equipment items such as chemical storage (dose) tanks.

The definitions for *Typical Flow*, *Ferrous Iron, Dissolved Mn* can be found in the tool tip for this section. Click on the information icon ( ) on the right side of the Water Quality and Flow subheading. In short, *Typical Flow* is the flow rate "typically" experienced at the site. This flow rate is used to calculate the annual chemical consumption so one must take careful consideration to calculate this value.

Ferrous Iron: represents the concentration of the dissolved ferrous iron (Fe^{2+}) in the water. The user needs to make sure that the total Fe is not used as the input parameter. For instance, the water sample would have been field filtered if applicable, properly preserved, and analyzed by the laboratory. The 'raw water' being defined as the water entering the Permanganate component of the treatment system, which may not necessarily be the raw water entering the treatment system if the design consists of having several treatment components prior to the Permanganate component.

Dissolved Manganese: represents the concentration of dissolved manganese in the raw water. The 'raw water' being defined as the water entering the Permanganate component of the treatment system, which may not necessarily be the raw water entering the treatment system if the design consists of having several treatment components prior to the Permanganate component.

3.2.2 Permanganate Information: Users can select from the two Permanganate products (sodium permanganate and potassium permanganate) and then select the *Concentration of Solution* strengths used to treat mine drainage, 20% or 40% (w/w) for $NaMnO_4$, or 1%, 2%, or 3% for $KMnO_4$. For sodium permanganate the *Non-Bulk* and *Bulk* delivery options consist of 263-gallon (totes) or 3,500-gallon delivery, respectively. Sodium permanganate will be delivered in liquid form. For potassium permanganate the *Non-Bulk* and *Bulk* delivery options consist of 55-lb bags and 330-lb drums, respectively. This module assumes potassium permanganate will be delivered in a solid form that requires mixing onsite. The handling and storage, consumption, pricing, refill frequency, etc. will determine which wt% solution the user may select. Since Permanganate is highly reactive, it is assumed 100% of the dosed $NaMnO_4$ or $KMnO_4$ reacts in the mine drainage; therefore, mixing efficiency is not a parameter that is considered in this module.

The chemical consumption is calculated via the Stoichiometric method for the Permanganate module. This module does not offer other 'Sizing Methods' like the titration and user-specified quantity sizing methods found in the Caustic Soda module.

3.2.3.1 Stoichiometric – This method estimates the annual chemical consumption by using the user-specified information under the *Water Quality & Flow Input* and *Permanganate* headings. The method uses the values for *Typical Flow*, *Ferrous Iron, Dissolved Mn* to calculate the required amount of permanganate in milligrams per liter (mg/L) to neutralize the metal loading. Equations 1, 2, 3, 4 and 5 are an example using the 20% $NaMnO_4$ solution and how the AMDTreat program calculates the chemical consumption:

$$Dose_{Na} = \left(\frac{Mn(\frac{mg}{L})}{54.94g} \div 1.50 * \frac{141.93\ g}{mole}\right) + \left(\frac{Fe(\frac{mg}{L})}{55.85g} \div 3.03 * \frac{141.93\ g}{mole}\right) \quad \textbf{(1)}$$

Where:
Mn = Dissolved Mn concentration in mg/L
Fe = Ferrous Fe concentration in mg/L
54.94 = Atomic weight of Manganese
1.50 = Number of Dissolved Mn moles oxidized by 1 mole of permanganate
141.93 = Atomic weight of $NaMnO_4$
55.85 = Atomic weight of Iron.
3.03 = Number of Ferrous Fe moles oxidized by 1 mole of permanganate
$Dose_{Na}$ = Dosage in mg of $NaMnO_4$ per liter of mine drainage required to neutralize the ferrous iron and dissolved manganese load.

Then the amount of the solid sodium permanganate (lbs) per day required to neutralize the Fe and Mn loading is calculated using the following equation:

$$Daily\ Dose_{lbs} = \left(\frac{Dose_{Na} * Flow(gpm)}{1000\ mg/g} \div 453.59\ \frac{g}{lb} * \frac{3.785L}{gal} * \frac{60min}{hr} * OpHrs\right) \quad \textbf{(2)}$$

Where:
$Dose_{Na}$ = Dosage in mg of solid $NaMnO_4$ per liter of mine drainage required to neutralize the ferrous iron and dissolved manganese load
Flow = Typical flow of the mine drainage (gallons per minute)
453.3 = Grams to pounds conversion
3.785 = Liters to gallons conversion
OpHrs = User specified Operational Time of the treatment system (hours/day)
$Daily\ Dose_{lbs}$ = Dose (lbs/day) of solid sodium permanganate to neutralize the Fe and Mn load

Then the amount of the solid sodium permanganate (lbs) per year required to neutralize the Fe and Mn loading is calculated using the following equation:

$$Annual\ Dose_{lbs} = Daily\ Dose_{lbs} * OpAnnual \quad \textbf{(3)}$$

Where:
Daily $Dose_{lbs}$ = Dose (lbs/day) of sodium permanganate to neutralize the Fe and Mn load Flow
OpAnnual = User specified Operational Time of the treatment system (Days/Year)
Annual $Dose_{lbs}$ = Dose (lbs/year) of solid sodium permanganate to neutralize the Fe and Mn load

Then the required amount of solid sodium permanganate is converted to the liquid solution and the appropriate percentage solution. The amount of pounds in one gallon of 20% solution (Table 1) is used to obtain the required gallons per day of Permanganate solution. In this example we are converting the 20% sodium permanganate:

$$Daily\ Vol_{Na} = \frac{Daily\ Dose_{lbs}}{20\%\ NaMnO_4\ lbs} \qquad \textbf{(4)}$$

Where:
Daily $Dose_{lbs}$ = Daily Dose in pounds of $NaMnO_4$ required to neutralize the ferrous iron and manganese load
20% $NaMnO_4$ lbs = lbs of $NaMnO_4$ in one gallon for 20% sodium permanganate solution (Table 1)
Daily Vol_{Na} = Dosage in gallons per day of 20% sodium permanganate solution required to neutralize the ferrous iron and dissolved manganese load.

The required annual amount of liquid (20% solution) sodium permanganate is then calculated with the following equation:

$$Annual\ Vol_{Na} = Daily\ Vol_{Na} * OpAnnual \quad \textbf{(5)}$$

Where:
Daily Vol_{Na} = Dosage in gallons per day of $NaMnO_4$ required to neutralize the ferrous iron and dissolved manganese load.
OpAnnual = User specified Operational Time of the treatment system (Days/Year)
Annual Vol_{Na} = Annual volume of 20% sodium permanganate required to neutralize Fe^{2+} and dissolved Mn loading.

In the above example a 20% solution of sodium permanganate was used to neutralize the metal loading. The same equations would be used for a different percent solution of sodium permanganate and different percent solution of potassium permanganate by substituting the values for two variables. For example, if a 2% solution of potassium permanganate was used, the atomic weight of $KMnO_4$ (158.034 g/mole) would be substituted in equation 1; and, the

0.169 lbs of $KMnO_4$ in one gallon of the Permanganate solution (Table 1) would be substituted in equation 5.

3.2.3 Equipment and System Installation

3.2.3 Equipment and System Installation: This section allows users to design and select a Permanganate treatment system setup. Permanganate treatment systems are fairly straightforward, after the user decides which Permanganate product to utilize, then the user will decide which equipment items to include as part of the design. The following subsections discuss these items.

3.2.3.1 Mix Tank and Electric Mixer System: The module assumes that if the user selects potassium permanganate that the solid Permanganate will be mixed onsite; therefore, this item is only available when the user selects potassium permanganate. The volume of the mix tank is estimated by taking the required daily volume (gal/day) of selected % solution of Permanganate to neutralize the metal loading multiplied by a conservative error factor of 1.2, using Equation (6).

$$Mix\ Tank\ Volume = Daily\ Vol_K * 1.2 \qquad \textbf{(6)}$$

Where:
Daily Vol_K = Dosage in gal of $KMnO_4$ of specified % solution required to neutralize the ferrous iron and dissolved manganese load.
Mix Tank Volume = Calculated volume of mix tank for potassium permanganate.

The user also has the option to 'edit' this calculated mix tank volume by selecting the edit checkbox and adjusting the gallons up or down. The user also can edit the mix tank unit cost and the electric mixer unit cost accordingly in order to get an accurate capital cost for these items.

3.2.3.2 HDPE Double-Walled Dose Tank, Dosing Skid, and Secondary Containment:

Dose Tank
The tank options only consist of one tank type, a HDPE double-walled tank. The default volume is 500-gallons for potassium permanganate and for the non-bulk sodium permanganate delivery option. However, the default volume of 4,500-gallon dose tank is used for the bulk delivery option of sodium permanganate. It is a greater volume for the bulk delivery (~3,500-gal) of sodium permanganate due to the fact that this would be delivered in a tanker truck. The user can adjust this default tank volume up or down according to site conditions.

Dosing Skid (pump, valves, & piping)
By default, a dosing skid is included for the system equipment. The user can choose to uncheck the box to not include the dosing skid. The default cost for the dosing skid is $5,000 but can be adjusted appropriately. The dosing skid consists of a two-pump dispensing diaphragm system, valves, and 3/8-inch stainless-steel piping to dispense the chemical within 40-ft of the dose tank. Figures 5 and 6 are examples of a two-pump system albeit for the hydrogen peroxide treatment facility in Pennsylvania. The two pumps allow for a backup in case of pump maintenance, failure, replacement, variable flow of mine drainage or other issues that arise. The user can also adjust the default unit cost for the dosing skid accordingly.

AMDTreat estimates the volume of concrete used for the secondary containment by first taking the volume of the specified dose tank and dividing by the default 5,500-gallon bulk dose tank and then multiplying it by $18,500. The $18,500 is a known cost of previously installed concrete secondary containment structure for a 5,500-gallon tank. Please note, the default tank size in the module is 4,500-gallons; however, currently this calculation uses a 5,500-gallon tank size. Therefore, the default capital cost will be less than $18,500 if the tank size is not adjusted from 4,500-gallons.

3.2.3.3 Storage Building: A storage building is included by default for the system equipment. However, the user can choose to uncheck the box to not include a storage building. The cost is either estimated using a price per square foot and the user-specified square footage of the building or if the user specifies a total cost of the storage building. An error message will be presented if the storage building square footage is not big enough for the specified dose tank. This cost will be included in the Capital Cost. Please note, the user should ensure the building design is sufficient for the size of storage tank.

3.2.3.4 Clean Water Tank: By default, the Clean Water Tank will be included as part of the module. The user can select not to include a clean water tank. The main purpose for clean water is to provide a source of water for spill control, eye wash station, and safety shower. Additionally, many bulk chemical suppliers will insist upon the presence of an on-site clean water supply as a required condition for site delivery. This option should be considered for locations that do not have a public water supply available. The default cost of $5,000 is assumed to be for a 500-gallon plastic tank and includes the excavation, ditching, plumbing, and electric for a 500-gallon clean water tank.

3.2.3.5 Eye Wash Station & Safety Shower Cost: By default, the Eye Wash Station and Safety Shower will be included as part of the Permanganate module. The user can unselect the checkbox to not include this item. The default total cost ($1,700) for an eye wash station and safety shower includes the installation and unit cost. This is based on a previously installed system at the Lancashire treatment facility in Pennsylvania (Figure 8).

3.2.3.6 Electric Heating System (Building): By default, the heating system is included as part of the module. The user can select not to include the electric heating system for the storage building if appropriate. The purpose of the heating system is for the water supply (eye wash & safety shower) and not allowing it freeze during the colder months. The default cost for the heating system is $1,000 and is based on previously installed heating systems.

3.2.4 Other Capital Items: The *Other Capital Items* section allows users to capture the capital cost of equipment and other items that are not included in this module. For example, a small number of Permanganate treatment systems have electronic surveillance to notify authorities if unauthorized persons attempt to interfere with the equipment. Since this is uncommon it was not included in the module, however, users who want to include this capability can input the cost into the *Other Capital Items* section to capture the capital cost for such a system.

3.2.5 Other Annual Items: The *Other Annual Items* section allows users to capture the capital cost of equipment and other items that are not included in this module. For example, users could include the annual subscription cost to conduct electronic surveillance on the treatment system in the *Other Annual Items* section.

3.3 Module Outputs

3.3.1 Sizing Summary: The Sizing Summary section displays important calculated module outputs, such as the estimated chemical consumption, storage tank refill frequency, and operational time of the dosing skid pumps. The dose tank refill frequency provides users with an estimate of how often the dose tank will need refilled based on the tank volume and estimated chemical consumption.

3.3.2 Capital Cost: This section provides the estimated costs for the various user-specified components and the total estimated cost to construct the Permanganate system. Users can opt to estimate the installation cost by specifying it as a percentage (cost-multiplier) of the capital cost or by entering a user-specified cost.

3.3.3 Annual Cost: The annual cost section provides an estimate of the annual cost to operate and maintenance the Permanganate component of the treatment system. Users can select to have AMDTreat estimate the annual chemical cost or specify an annual chemical cost. Specifying an annual chemical cost is often used when AMDTreat's Net Present Value calculations are being used to estimate water treatment liability. The annual operation and maintenance for the Permanganate treatment component can either be specified by the user or estimated by assuming it is a percentage of the capital cost. The latter method assumes that more expensive systems are more costly to maintain.

3.3.4 Net Present Value: The Net Present Value (NPV) section determines the cost to operate a treatment system component over a specified time period. The NPV calculates the present-day financial investment required to generate the income to pay for future operation and equipment/materials replacement costs. Both **Financial Variables** and **Cost Categories** are required to calculate the NPV.

3.3.4.1 Financial Variables - The *Term of Analysis*, *Inflation Rate*, and *Rate of Return* are three variables used in the NPV calculations. The default values for these terms are shown under the *Net Present Value* section of each module. Users must access the *Net Present Value* menu at the top of the main user interface to change the default values as they would apply to all modules used for an entire treatment system. While NPV is determined for each AMDTreat module activated by the user, the goal is to determine a total NPV for an entire mine drainage treatment system project (a collection of cost estimates for individual modules creates a treatment system project in AMDTreat). Therefore, a single value for *Term of Analysis*, *Rate of Return*, and *Inflation Rate* is applied to all modules and cannot vary between modules.

- Term of Analysis: The time period used by the NPV calculation to determine the financial investment required to pay for all future costs of the treatment system.
- Inflation Rate: Represents the average price increase of goods and services over time. AMDTreat uses the inflation rate to calculate the future cost of the annual operation and maintenance (O&M) and recapitalization items.
- Rate of Return: Describes the expected profit on an investment.

3.3.4.2 Cost Categories - For each treatment module, AMDTreat provides a list of recommended equipment and materials that require recapitalization. In addition, AMDTreat provides recommendations (default values) for life cycle and replacement percentage. Users can click on the default values for *Life Cycle* or *Replacement Percentage* and use the +/- buttons to change the default values. In addition, users can select *Custom Cost* and enter a new cost to represent the current cost of the equipment. Users can add new recapitalization items or deactivate/delete existing items for calculating the NPV.

An example of how the recapitalization variables are used to determine NPV is to consider the following hypothetical scenario. Assume a vertical turbine pump has a life cycle of 50 years but requires the pump motor to be rebuilt every 20 years. Assume the present-day cost to purchase the motor is $500,000, and the cost to remove, rebuild, and reinstall the pump motor is $20,000. Now assume we want to determine the amount of investment required today (NPV) to generate the income to pay for the future cost of rebuilding the pump motor over a 50-year *Term of Analysis*, which is also equal to the life cycle of the pump. Assume an *Inflation Rate* of 5.0% and *Rate of Return* of 8.1%. The goal is to place the money in a relatively secure investment vehicle to generate 8.1% annually. The NPV will calculate the size of investment required to generate income for future costs.

There are several ways to model the replacement cost. One way is to replace 4% of the present-day cost of the pump (4% of $500,000 = $20,000) with a life cycle of every 20 years. If the *Term of Analysis* is 50 years, then the entire pump would not require recapitalization since the life cycle of the pump is 50 years. However, the motor would require two replacements (50 years / 20 years = 2.5 rounded down to 2).

To determine the NPV to recapitalize rebuilding of the motor, AMDTreat calculates the future cost to rebuild the motor at each life cycle, 20 and 40 years. The program uses the *Inflation Rate* to inflate the present-day default cost to rebuild the motor in 20 and 40 years from now. While the present-day cost to rebuild the pump motor is $20,000, the future cost to rebuild the motor in 20 years at a 5.0% *Inflation Rate* is $53,065 and $140,799 in 40 years (Equation 6). Assuming an 8.1% *Rate of Return*, the 50-year NPV for the pump is $17,422. In other words, an initial investment of $17,422 is needed at an annual *Rate of Return* of 8.1% to generate the investment income required for the two motor rebuilds over the 50-year life cycle of the pump.

$$\begin{aligned}&Cost\ to\ rebuild\ pump\ motor\ in\ 20\ years = \\ &Present\ Day\ Cost\ \times (100\% + Inflation\ Rate)^{20} = \$20{,}000 \times (100\% + 5\%)^{20} = \$53{,}065 \quad \textbf{(7)}\end{aligned}$$

- <u>Annual Operation and Maintenance Cost</u>: By default, AMDTreat transcribes the annual O&M cost from the Annual Cost section to the Net Present Value section. The program assumes the module is being used to first estimate the annual cost for a treatment system component, so it automatically transcribes the annual cost to the NPV section. If this is not the case or the user wants to use some other annual cost, the “Use Custom” box can be selected to allow the user input of a different annual cost to utilize in the NPV calculation.

- <u>Recapitalization Cost</u>: Certain treatment system components, especially mechanical and water conveyance equipment, require periodic replacement. The recapitalization cost of an item is an estimate of the amount of money required to pay for future replacement costs for the item. In addition to the Financial Variables described above, three additional values are required to calculate the NPV of recapitalization costs, the Present-Day Equipment Cost, the Life Cycle, and the Replacement Percentage.

- Default Cost: This represents the current cost to purchase the equipment or material.

- Life Cycle: The time frame between equipment or material replacement is termed as its Life Cycle. Some equipment manufacturers provide recommended life cycles for their equipment to provide consumers with an estimate of how long the equipment is expected to be operational. Some life cycles, such as those used for treatment media (limestone), are based on best professional judgement. Some operators prefer to periodically purchase and replace equipment before failure to preserve the continuity of operations, while others wait until failure to replace an item.

- Replacement Percentage: The Replacement Percentage is an adjustment factor to the default cost to accommodate situations where the entire piece of equipment or all of the material does not require recapitalization. For example, a passive treatment component may be designed to contain enough limestone to neutralize the acidity load for 20 years, however, the accumulation of metal hydroxide precipitates within the void space of the limestone layer may require that 25% of the limestone be replaced every 7 years to prevent hydraulic failure such as plugging or short-circuiting. For this scenario, the initial cost of the limestone making up the limestone layer is discounted by 75% and assigned a life cycle of 7 years to determine the amount of money required to cover the cost of replacing 25% of the limestone layer every 7 years over the Term of Analysis.

3.3.4.3 Rationale for Recapitalization Recommendations:

Recapitalization recommendations are based on professional experience of the AMDTreat Team and may not apply to all situations. Users are encouraged to customize the recapitalization assumptions to their treatment scenario. AMDTeat Team members are located in Pennsylvania and West Virginia and have collective experience in design, funding, and/or operation/maintenance for over 100 passive treatment systems. The AMDTreat Team held discussions on personal experience to develop a list of recapitalization recommendations. Users may have different experience and opinions than those listed.

By default, AMDTreat includes a list of nine recapitalization items in the Permanganate module. However, based on the items the user selects to include in the module will determine which ones are included in the NPV section. Users can delete or modify any of the default Recapitalization items by either deselecting the item or by setting the Replacement % to zero. If the item is deselected the Total Cost for the item will still be shown but the cost will be subtracted from the Net Present Value Cost, shown in the Net Present Value Heading. For example, the default value for the life cycle of an HDPE dose tank is 12 years due to degradation from ultraviolet light. However, users may opt to increase the life cycle if the tank will be housed in a building. Users are free to fully customize the replacement items, including adding new items or deleting default items.

Mix Tank: The mix tank default life cycle is 12 years with 100% replacement. This will depend on the tank type and material. The user can adjust these values accordingly.

Electric Mix Motor: The electric mix motor default life cycle is 12 years. The life cycle may be adjusted based on the quality of the motor.

Dose Tank: The HDPE double-walled dose tank default life cycle is 12 years with 100% Replacement. This value was determined after discussing tank longevity with chemical distribution companies and tank manufactures. This shorter life cycle is due to the material and the fact that these poly tanks may be placed outside and open to the atmosphere, and not in a storage building. Ultraviolet light will degrade poly tanks. The user can adjust the life cycle of any tank if determined and site conditions deem appropriate.

Dosing Skid (Pump): Since their use in our industry is still infrequent and relatively recent, the AMDTreat Team cannot offer their experience to suggest a life cycle. However, after conducting some research, we are recommending a life cycle of 5 years before the equipment requires replacement. The oxidant will tend to corrode or wear-out the parts within the pump and may need replaced on a frequent basis.

Storage Building: The Storage Building default life cycle is 50 years at 100% replacement. Since the simple structure would consist of a concrete foundation, concrete walls, and metal siding and roof there is potential that the structure could last longer than 50 years.

Concrete Secondary Containment: The default life cycle is 50 years for the concrete secondary containment at 100% replacement. However, the user should probably consider if this concrete structure is outside in the elements or maybe (but unlikely) in a storage building. This may have an impact on the life cycle of the concrete structure.

Clean Water Tank: The default life cycle is 50 years for the Clean Water Tank at 100% replacement. The user should consider adjusting these defaults depending on tank type (i.e. poly) and whether the tank is placed subsurface or above ground.

Eye Wash Station and Safety Shower: The default life cycle is 50 years for the Eye Wash Station at 100% replacement. The user should consider adjusting these defaults depending if it's a portable system or part of the safety shower.

Building Heating System: The default life cycle is 15 years for the building heating system at 100% replacement.

3.4 Assumptions of Design Sizing and Costs

AMDTreat is a cost estimation model that uses assumptions to provide treatment sizing and both capital and annual cost estimates. While there are many assumptions in the program, the assumptions that follow are important for the Permanganate module.

1. The Stoichiometric method used to estimate the annual chemical consumption relies on a properly determined value for Typical Flow, Ferrous Iron (Fe^{2+}, dissolved iron) and

Dissolved Mn. Many people would field filter and preserve the iron sample prior to sending the water sample for laboratory analysis. User would not want to use a total iron or manganese laboratory result in this module to determine chemical consumption. In addition, this module assumes the mine water is void of Permanganate consuming species other than Ferrous Iron and Dissolved Mn, such as, organic matter or other oxidizable species.

4.0 References

LabChem Safety Data Sheet, Potassium Permanganate.

5.0 Figures

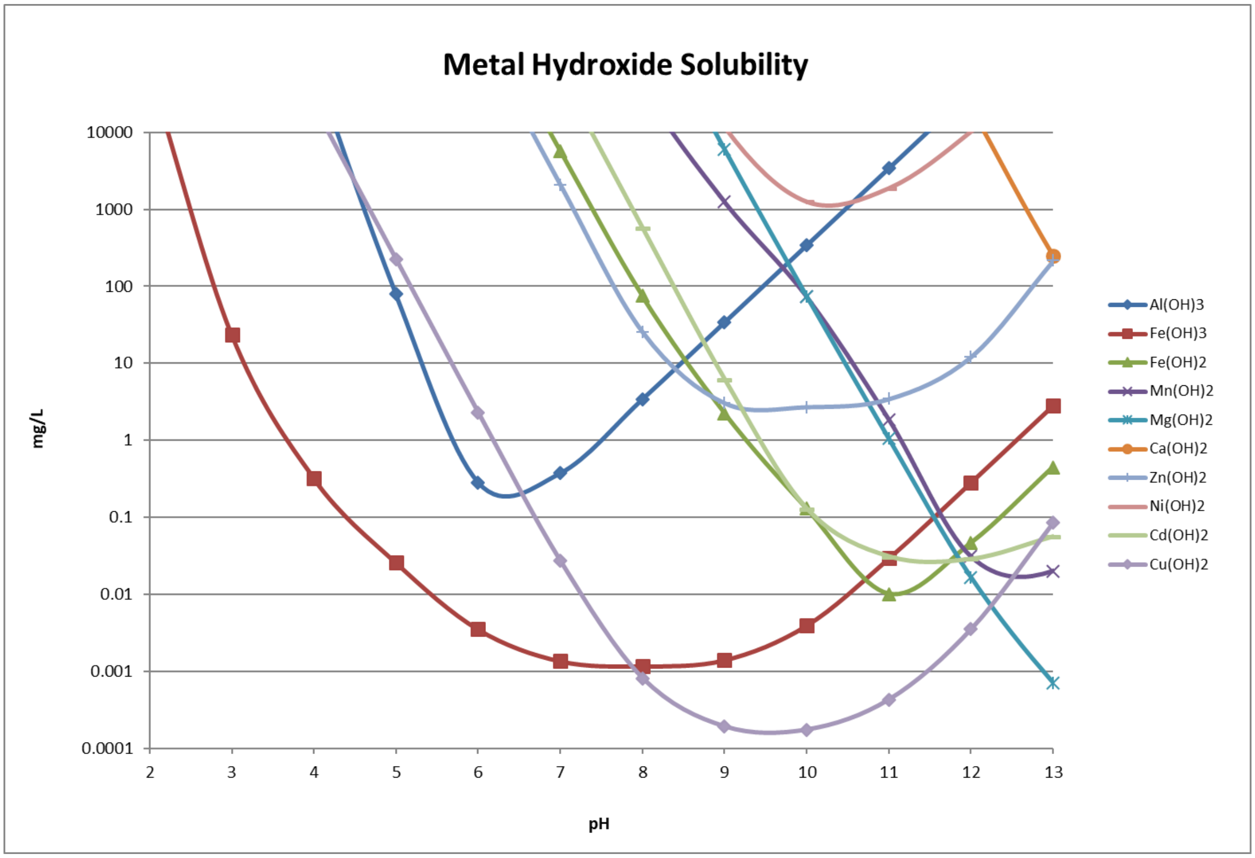

Figure 1: Solubility of transition metal hydroxides.

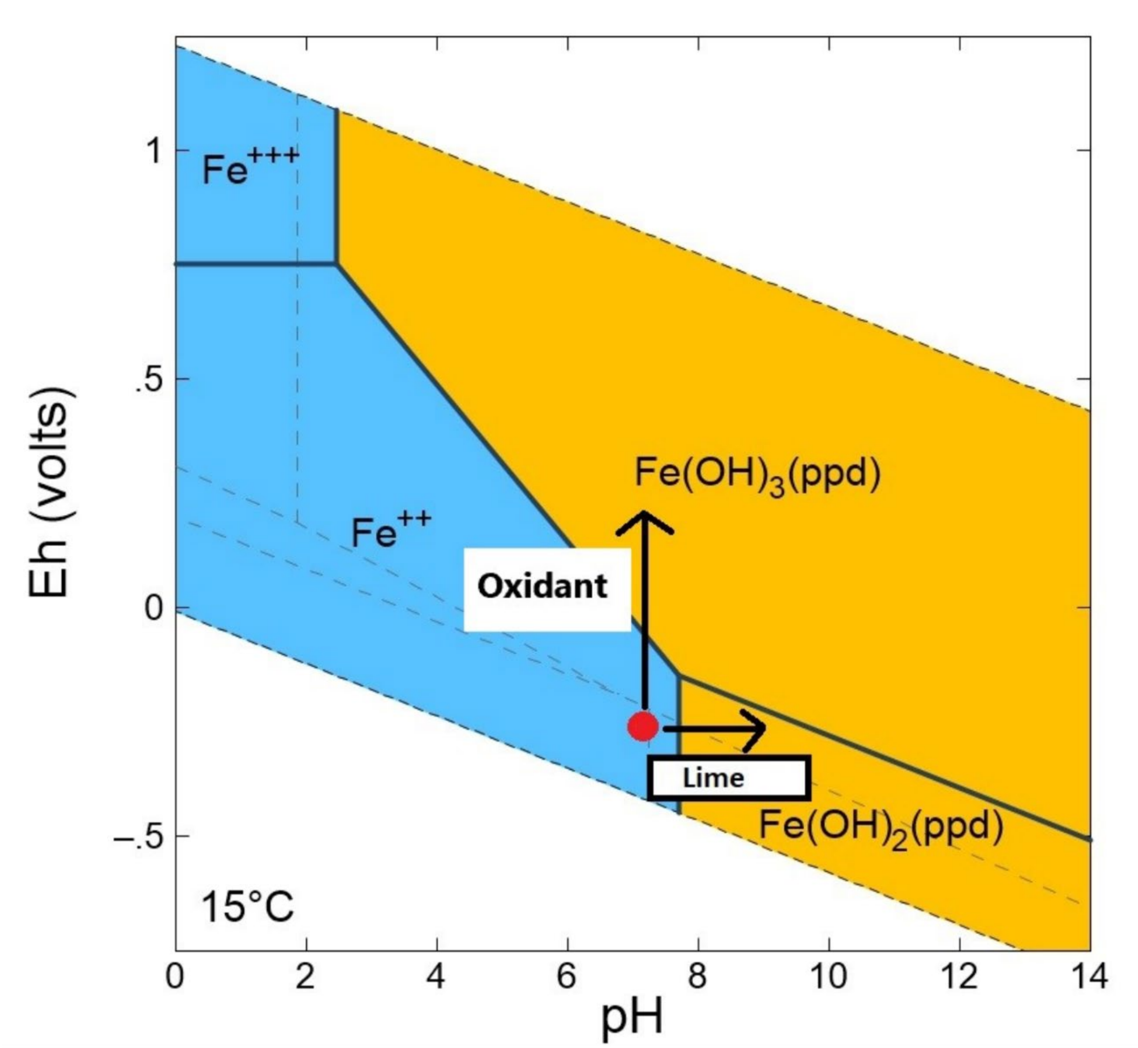

Figure 2. Eh – pH diagram illustrating the contrasting approaches of pH adjustment treatment strategy (lime or other alkali chemical addition) vs. an Eh adjustment treatment approach (permanganate or another oxidant). The blue areas of the diagram indicate stability fields where the dominate form of iron is dissolved. The tan areas of the diagram indicate Eh and pH conditions where iron is precipitated from solution.

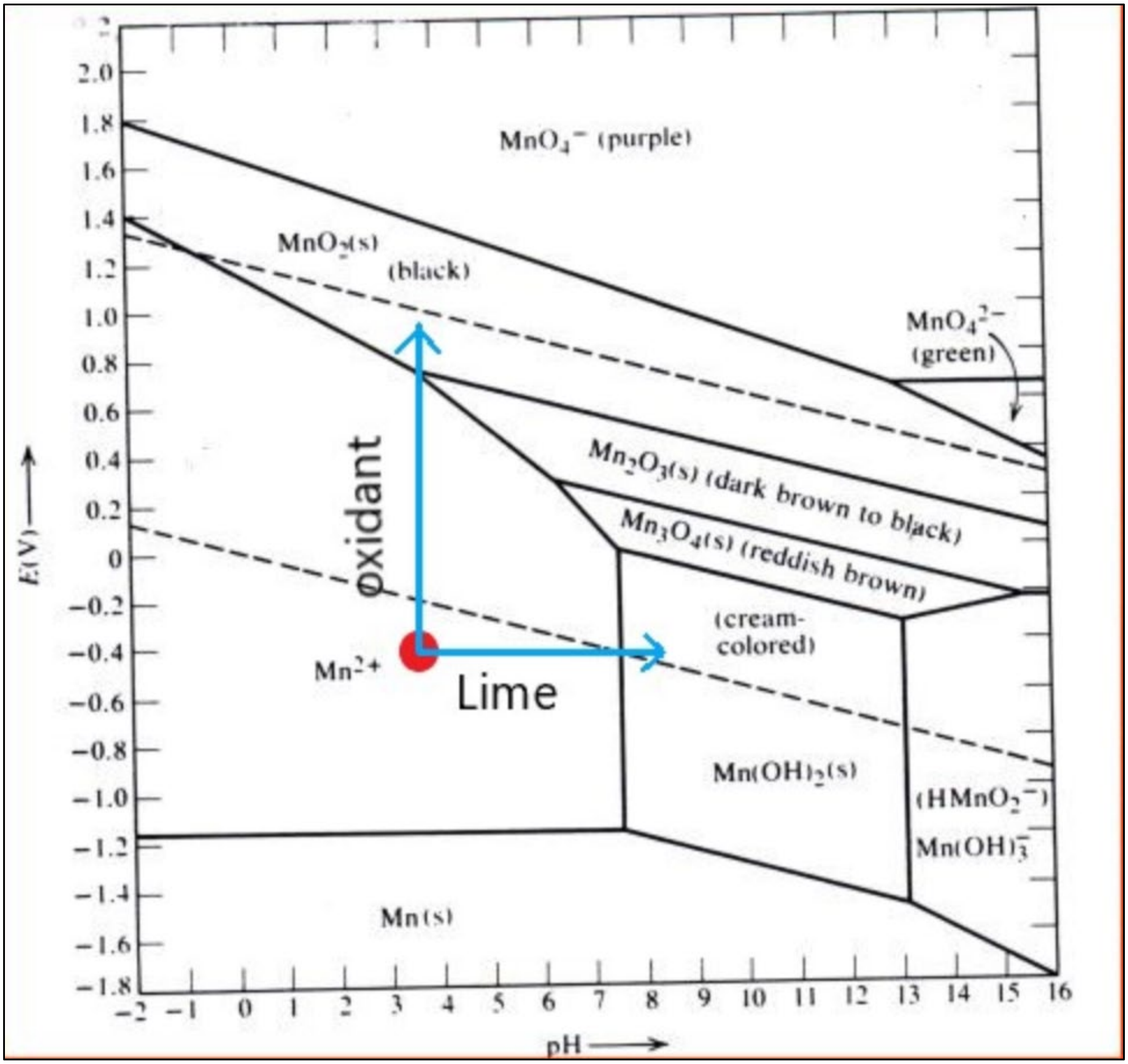

Figure 3. Pourbaix Diagram for Manganese with added arrows for either Lime addition or permanganate (oxidant) addition.

Figure 4. Mix Tank for a Potassium Permanganate treatment system.

Figure 5. Photo of a HDPE Double-Walled dose tank.

Figure 6. Photo of a Dosing Skid with Two Pumps in Red Circle. The chemical storage containers (tote) would represent the Non-Bulk Container for Sodium Permanganate.

Figure 7. Photo of a Dosing Skid with Two Pumps.

Figure 8. Photo of an Eye-Wash Station and Shower.