Help Instruction File:

Hydrogen Peroxide 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).

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1.0 Objective

The objectives of this overview are to: (1) Provide an understanding of the application of Hydrogen Peroxide in mine drainage treatment and (2) Provide an overview of the Hydrogen Peroxide Module to guide users in developing an estimate of the cost to construct, operate, and maintain Hydrogen Peroxide treatment systems. The module can also be applied to reverse cost model existing system to establish and evaluate future financial and investment decisions. The information is presented in two sections, **Overview and Application** and **Hydrogen Peroxide Module Overview**.

2.0 Overview and Application

A basic understanding of the chemical and physical properties, the application, and equipment requirements of a Hydrogen Peroxide treatment system area required to develop a treatment strategy using the AMDTreat software. These topics are discussed below before discussing the Hydrogen Peroxide 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

Commercial strength concentrations (> 3 % solution strength) of Hydrogen Peroxide 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. Hydrogen peroxide is a danger in both liquid and vapor form. It should be noted that even when utilizing 50% peroxide in areas where summertime temperatures routinely exceed 90°F that storage facilities may be required to have external cooling systems to prevent catastrophic rapid decomposition of the chemical. A decomposition reaction of hydrogen peroxide is a highly exothermic and self-sustaining reaction that can result in devastating damage. Rapid decomposition of peroxide in storage tanks can result from incompatible materials and chemicals inadvertently introduced to storage facilities as well. Iron, copper and other transition metals, organic materials and incompatible chemicals such as sodium hydroxide (NaOH) and other alkali reagents must never come in contact with stored quantities of hydrogen peroxide. In Pennsylvania, seven hydrogen peroxide systems were constructed without external cooling systems; however, external cooling systems should be considered and consultation should be done with appropriate contractor to ensure appropriate safety protocols are in place. Please watch the peroxide safety training video listed in the references section below. Therefore, precautions must be considered and taken when utilizing hydrogen peroxide for mine drainage treatment.

Hydrogen Peroxide has a chemical formula of H_2O_2 and is manufactured via an auto oxidation process. The main steps of the process consist of: (A) hydrogenation of an anthraquinone [$C_{14}H_8O_2$], (B) oxidation of the resulting anthraquinol, (C) extraction of hydrogen peroxide solution, then (D) purification and concentration of hydrogen peroxide. Hydrogen Peroxide exists as a water-based solution and solution strengths are commonly specified as % by weight (mass of H_2O_2/mass solution). Attention to both solution strength and specification (by wt., by vol., by wt./vol) is necessary when purchasing and conducting price comparisons.

Hydrogen Peroxide is commercially produced and distributed in solution strengths ranging from 27% to 70% solution. Railroad tanker cars transport Hydrogen Peroxide as a 50% to 70+% solution and distributers dilute the solution to customer specifications. Therefore, for a number of reasons, a 50% solution is almost always the most cost effective due to the high percentage of active ingredient and the lack of a dilution step.

This help file and AMDTreat peroxide module does not comprehensively address the overall site safety precautions that must be considered when designing, operating or maintaining a hydrogen peroxide 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.

The common solution strengths used in mine drainage treatment are 35% and 50% (w/w). In general, there is not a concern for hydrogen peroxide regarding their freezing or boiling points; for example, the 50% solution has a freezing point of -52°C (-62°F) (Table 1). 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 peroxide solution as well. Table 1 provides characteristics of the common solution strengths.

Solution Strength (wt/wt)	Solution Density (lbs/gal)	lbs H_2O_2/gal solution	Freezing Point
35%	9.45	3.31	-34°C (-29°F)
50%	9.98	4.99	-52°C (-62°F)

Table 1: Specifications for common Hydrogen Peroxide Solution Strengths.

Ferrous Iron is the primary multi-valent contaminate in flooded underground coal mines in the eastern U.S., although a few underground mines require Manganese treatment. Historically, operators have used lime addition to adjust pH to increase to precipitate $Fe(OH)_2$ to achieve effluent standards (Figure 1). However, if mine drainage is net alkaline hydrogen peroxide can be used to oxidize ferrous iron and will drastically reduce chemical and operational costs, especially in instances of highly carbonated mine drainage. A plant in Pennsylvania reduced annual operational costs by $250,000 after switching to Peroxide. The cost savings stemmed from a decrease in annual chemical cost (H_2O_2 vs. $Ca(OH)_2$), sludge disposal (Peroxide creates only $Fe(OH)_3$ sludge, Hydrated Lime creates $Fe(OH)_3$, $CaCO_3$, plus other nuisance precipitates), and electrical costs (turning off 60 HP blowers used to pneumatically mix Hydrated Lime w/ mine water). It needs to be noted that Hydrogen Peroxide with not oxidize Manganese and its use should be restricted to net alkaline water where Ferrous Iron is the sole contaminate.

As indicated in Figure 1, a treatment strategy that utilizes peroxide (or another oxidizer) will increase the Eh and cause the oxidation of ferrous iron and the precipitation of $Fe(OH)_3$. 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). In addition, the capital and operational/maintenance costs are much less for Hydrogen Peroxide than alki chemicals, such as, Hydrated Lime.

Rapid oxidation caused by Peroxide will result in a very small and highly charged $Fe(OH)_3$ floc that can be more difficult to settle compared to using alkali chemicals. Field trials should be conducted to identify and address any sedimentation issues. Seven treatment plants in Pennsylvania, ranging from 1,000 to 7,000 gpm, were converted from Hydrated Lime to Hydrogen Peroxide and all but one experienced settling issues. Most of the issues were due to a lack of produced solids after peroxide conversion but some of the issues were probably due to the surface charge on the $Fe(OH)_3$ floc from lack of pH adjustment. Five plants use clarifiers and the other two use ponds for sedimentation. After coverting to Peroxide most plants required both increased polymer dose and sludge recirculation rates to achieve clarity similar to Hydrated Lime treatment. Settling tests of the $Fe(OH)_3$ floc from peroxide treatment dosed with between 0.5 and 1.0 ppm of anionic polymer achieved settling rates that ranged from 2 to 8 gpm/ft^2. Optimized peroxide treatment using anionic polymer and sludge recirculation to increase produced solids concentration (~ 2,000 mg/L) achieved effluent iron concentrations of less than 0.2 mg/L in a clarifier designed at a settling rate of 0.5 gpm/ ft^2.

2.2 Benefits/Drawbacks, Equipment and Typical Treatment Configurations

This section summarizes some of the benefits, drawbacks, equipment, and treatment configurations of hydrogen peroxide with mine drainage treatment sites.

2.21 Benefits

The major reason why Hydrogen Peroxide is popular is because of its cost savings, both chemical cost and sludge produced. The benefits of using Hydrogen Peroxide as a mine drainage treatment oxidant include:

1. 100% soluble and quick reacting (< 20 sec);
2. Quick reacting and solubility allow for precise dosage and small reaction tanks;
3. Can be effectively mixed using passive mixing, like turbulent flow;
4. Specifically targets ferrous iron and avoids costly nuisance reactions like calcite ppt.;
5. Low sludge production since it primarily targets ferrous iron in eastern coal mine drainage;
6. Lower Capital and Maintenance costs than Lime Products;
7. Dosing can be performed manually without electricity or using metering pump;
8. Extremely low maintenance with the peroxide pump being the only mechanical part;
9. Relatively small equipment footprint, approximately 600 ft^2 storage building.
10. Relatively stable chemical allows for long-term storage in instances of ephemeral or periodic treatment;

2.22 Drawbacks

The drawbacks of using Hydrogen Peroxide 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 $Fe(OH)_3$.
3. Relatively high initial capital cost compared to sodium hydroxide or premanufactured lime slurry systems.
4. Not effective for the treatment of Manganese.

2.23 Equipment and Typical Treatment Configurations

The Hydrogen Peroxide treatment systems are automated (electrical) systems with safety as the most notable factor when considering peroxide at a site. The ideal configuration for hydrogen peroxide consists of the following: (1) storage building, (2) storage tank with secondary containment, (3) dosing skid/pump, (4) feeder line(s), (5) clean water & eye washing station (6) and electric heating system. This setup will allow for the safe storage and handling of the hydrogen peroxide.

Storage Tanks, Secondary Containment, and Storage Building

It is recommended that hydrogen peroxide tank(s) be placed within a storage building with secondary containment. In general, the module envisions the user selecting either a stainless-steel tank that includes a stainless-steel secondary containment (Figure 3) which would be housed in a storage building OR the user selecting the POLY tank, not including a storage building, but including the concrete secondary containment and exterior concrete pad. However, the module does allow the user to select a storage building with the POLY Tank with an option to add a cost for secondary containment. The system layout and tank material is largely controlled by site conditions and/or available capital.

Therefore, the module is setup for user to select between two storage tanks, a stainless-steel tank or POLY tank. Totes are not included as an option in the module, due to safety concerns and not being cost effective. The 5,600-gal stainless steel tank (Figure 3) and 4,500-gal POLY tank are used to take advantage of bulk deliveries and chemical pricing. Based on road weight restrictions, bulk deliveries of hydrogen peroxide are approximately 4,000 to 4,200 gallons, depending on the solution strength density. The storage tank sizes would permit bulk deliveries while providing reserve capacity. The POLY tank is comprised of double-walled plastic, such as, polypropylene or polyethylene (Figure 6 & 7). The pricing for both the stainless-steel and POLY double-walled tanks are based on previously installed tanks at seven sites in Pennsylvania. The default cost of $70,000 for the stainless-steel tank includes the delivery, installation, and steel secondary containment of a 5,600-gallon tank. The default cost of $18,500 of a POLY tank just includes the tank and delivery and does NOT include secondary containment. The user would have to include that option if considering a POLY tank.

The stainless-steel tank is oriented horizontally and the POLY tank is positioned vertically. A drainage valve should be located at the bottom to permit the tank to be fully emptied for inspection and cleaning. All tanks need level indicators for supply management (Figure 7 & 12). It is important to note that tanks, feeder lines, and fittings cannot be made from aluminum, copper, zinc, galvanized steel, lead, brass, or bronze. Feeder line, valves, and fittings having to be constructed of stainless-steel or polypropylene (Figure 8, 9, & 10). In addition, all valves must be vented as a safety precaution. In addition, all new stainless tanks and appurtenances must be passivated with a nitric acid solution prior to the initial fill in order to remove manufacturing residues such as oil films and other residual materials, which if present could cause a serious adverse reaction with the peroxide (see section 2.1 above). The Passivation process also creates an oxidation barrier on the surface of the stainless steel as an added protection against corrosion and etching of the stainless steel by the peroxide solution. Poly tanks must also be fully cleaned prior to the initial fill with peroxide for the same reason. Provisions for this to occur must be included in all systems designs. Contract specifications requiring equipment suppliers to both certify tank preparations and be present on site during initial tank fill-up will help ensure a safe start-up of the equipment.

The Storage Building option can be for either the stainless-steel tank or POLY tank. The Storage Building is a simple concrete block and metal building with concrete foundation and floor that will house the hydrogen peroxide tank (Figure 4 & 5). The building will not contain insulation, lighting, heating, or any other service unless costs are included for these items. The default will be to include a storage building in the AMDTreat program. The user can decide to uncheck the storage building option if it's not in the design. The storage building size default (600 ft^2) is based on previous experience. The building size is: 30-ft length, 20-ft width, 14-ft wall height. The storage building would have a garage roll-up door for access and a standard side-door for entry. It is assumed that if a user selects the stainless-steel tank, they will also construct a storage building; therefore, the exterior concrete pad option is only for the POLY tank.

Hydrogen Peroxide is corrosive and can etch the tanks at the fill level, if the maintained for an extended period. A drainage valve should be located at the bottom to permit the tank to be fully emptied for inspection and cleaning.

Dosing Skid

The Dosing Skid that is assumed in the Hydrogen Peroxide module consists of a two-pump system (Figure 8 & 9). Two pumps are considered for redundancy purposes, allowing personnel to address and operation and maintenance issues that may arise. The tubing, fittings, gaskets, and lines all need to be appropriate material (i.e. stainless steel) to prevent the corrosion and potential leaks or spills of the hydrogen peroxide. The solution is pumped from the hydrogen peroxide tank, through the pumps, and out to the treatment area (i.e. mixing/reaction tank). Figure 12 is a photo of the stainless-steel line and peroxide solution being added to the mine drainage in a mixing tank. In addition, vents may be required in the pump to ensure proper venting in the pump.

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

Based on safety concerns when dealing with hydrogen peroxide, it is **strongly** recommended that users include the safety items available in this module. If 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 tank will consist of a 500-gallon plastic tank and includes the excavation, ditching, plumbing, and electric hook-up for the clean water tank. 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 be to ensure that the water supply and piping for the eye wash station and shower do not freeze during the colder winter months.

2.3 Application and Financial Analysis

Hydrogen Peroxide is typically used to oxidize ferrous iron in net alkaline mine drainage. The hydrogen peroxide is used to quickly oxidize the ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) in the alkaline mine drainage in order for Fe^{3+} to undergo hydrolysis to form the solid precipitate $Fe(OH)_3$. While many people have historically used lime products and a mixing/aeration tank to achieve oxidation and formation of $Fe(OH)_3$, hydrogen peroxide can be used in lieu of or in combination with the lime. Hydrogen Peroxide is typically selected as the oxidation reagent for a site based on:

1. Convenience of use (requires little mixing, fast reacting, etc);
2. Cost effectiveness versus aeration/mixing & lime products.

3.0 Hydrogen Peroxide 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) Hydrogen Peroxide 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* and *Ferrous Iron* and AMDTreat calculates the annual ferrous iron loading. Then select the *Hydrogen Peroxide Solution* strength, along with the *purity* and *mixing efficiency* and select the method to estimate the hydrogen peroxide consumption (*Stoichiometric* or *Titration*). AMDTreat uses this information along with the ferrous iron load to estimate the annual H_2O_2 consumption. Next, users use the *Equipment and System Installation* heading to select and size treatment equipment. The stainless-steel tank or POLY tank options, along with dosing skid, storage and handling, and safety items can all be specified. The *Annual Input* section allows the user to specify chemical unit cost, operational periods, and additional items that would be considered annual costs to ensure chemical consumption and electrical costs are correctly modeled. 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 Hydrogen Peroxide treatment system is provided under the *Capital Cost* and *Annual Cost* headings. Lastly, users can opt to conduct a Net Present Value (NPV) 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 and Ferrous Iron values. These values are used to (1) estimate the annual chemical consumption and (2) estimate the size of various equipment, such as, chemical storage tanks.

The definitions for *Typical Flow* and *Ferrous Iron* 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 amount of the dissolved ferrous iron (Fe^{2+}) in 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, properly preserved, and analyzed by the laboratory.

3.2.2 Hydrogen Peroxide Information

3.2.2 Hydrogen Peroxide Information: Users can select from the two common *Hydrogen Peroxide Solution* strengths used to treat mine drainage, 35% or 50% by weight. The handling and storage, consumption, pricing, refill frequency, etc. will determined which wt% solution the user may select. Since hydrogen peroxide is highly reactive, it is assumed 100% of the dosed H_2O_2 reacts in the mine drainage; therefore, mixing efficiency is not a parameter that is considered in the Hydrogen Peroxide module.

3.2.3 Chemical Consumption: The *Chemical Consumption* section offers users two methods to estimate the annual chemical consumption, *Stoichiometric* and *Titration*. The user does have the option to enter the dollar ($) amount for chemical in the Annual Output section of the module. **Please note, the chemical consumption output takes into account the Peroxide System Operational Time input parameters. However, the Hydrogen Peroxide Dose (ml/min) output does not take into account the Operating Time (hr/day, days/yr) input parameters. The Hydrogen Peroxide Dose is an output parameter to assist the user on obtaining the chemical dosing rate (based on flow input and ferrous iron concentration) to oxidize the ferrous iron using either the stoichiometric method or the titration method.**

3.2.3.1 Stoichiometric – This method estimates the hydrogen peroxide dosage and the hydrogen peroxide consumption by using the user-specified information under the *Water Quality & Flow Input, Hydrogen Peroxide Information,* and *Operational Time* headings. First, the stoichiometric method uses the values from *Typical Flow* and *Ferrous Iron* to calculate the loading in moles per minute of Fe^{2+} in equation (1):

$$Fe^{2+}\ Loading = \left(Flow\ \frac{gal}{min}\right) * \left(Fe^{2+}\ \frac{mg}{L}\right) * \frac{3.785\ L}{gal} * \frac{1\ g}{1000\ mg} * \frac{1\ mole}{55.65\ g} \qquad \textbf{(1)}$$

Where:
Fe^{2+} Loading = Fe^{2+} in moles/min
Flow = Typical Flow in gal/min
Fe^{2+} = Ferrous Iron in mg/L

The program then calculates the pounds of H_2O_2 in one gallon of peroxide solution based on the solution density and wt%, prior to calculating the hydrogen peroxide dosage required for the ferrous iron load. Whereby, 35% solution would have a density of 9.45 lbs/gal and 50% solution would have a density of 9.98 lbs/gal. Equation (2) is an example using the 35% hydrogen peroxide solution.

$$H_2O_2\,\frac{lbs}{gal} = \left(\frac{9.45\ lbs}{gal}\right) * 0.35 = 3.30\ lbs\ of\ H_2O_2\ per\ gallon\ of\ peroxide\ solution \qquad \textbf{(2)}$$

After the moles/min of Fe^{2+} and lbs/gal of H_2O_2 in the specified peroxide solution is determined, the program uses the stoichiometric relationship between Fe^{2+} and H_2O_2 to re-express the load in terms of dosage or ml/min of H_2O_2.

$$Dose = \frac{2\ Mole\ Fe^{2+}}{1\ Mole\ H_2O_2} * \frac{34.02g\ H_2O_2}{1\ Mole\ H_2O_2} * \frac{1\ lb}{453.59g} * \frac{1\ gal}{3.30\ lbs} * \frac{3.785\ L}{1\ gal} * \frac{1000mL}{1\ L} \qquad \textbf{(3)}$$

Where:
Dose = Dosage in ml/min of H_2O_2 required to oxidize the ferrous iron load.

Finally, the program uses the user specified Operational Time to calculate the hydrogen peroxide consumption in gallons/day and gallons/year.

Equations (4) and (5) are used in order to account for the user specified Operational Time to determine chemical consumption, hours per day and days per year.

$$H_2O_2gpd = Dose * 60\left(\frac{min}{hr}\right) * OpHrs \div 1000\left(\frac{ml}{L}\right) \div 3.785\left(\frac{L}{gal}\right) \qquad \textbf{(4)}$$

Where:
H_2O_2gpd = H_2O_2 in gallons per day.
Dose = ml/min of H_2O_2
OpHrs = User Specified Operational Time (hrs/day) of Hydrogen Peroxide system

In order to calculate the gallons per year of hydrogen peroxide consumption, the gallons per day of hydrogen peroxide is multiplied by the user specified days per year the hydrogen peroxide system is operated, Equation (5).

$$H_2O_2gpy = H_2O_2gpd * OpDays \qquad \textbf{(5)}$$

Where:
H_2O_2gpy = H_2O_2 in gallons per year.
H_2O_2gpd = H_2O_2 in gallons per day.
OpDays = User Specified Operational Time (days/yr) of Hydrogen Peroxide system.

3.2.3.2 Titration - This method estimates the hydrogen peroxide dosage and the hydrogen peroxide consumption by using the user-specified information *Typical Flow, Titration* input (gal/gal), and *Operational Time* headings. First, the titration method uses the values from *Typical Flow* and *Titration* to calculate the dosage output parameter, equation (1). Please note, similar to the Stoichiometric method, the dosage (ml/min) output does not account for the Operational Time; however, the chemical consumption calculation does account for user specified Operational Time.

$$Dose = Titration * Flow * 60\left(\frac{min}{hr}\right) * 24\left(\frac{hrs}{day}\right) * 3785\left(\frac{ml}{gal}\right) \div 1440\left(\frac{min}{day}\right) \qquad \textbf{(6)}$$

Where:
Dose = Dosage in ml/min of H_2O_2 required to oxidize the ferrous iron load.
Titration = User specified titration amount (gallons) to oxidize ferrous iron in one gallon of mine water.
Flow = Typical Flow in gal/min

The daily and annual hydrogen peroxide consumption is calculated by accounting for the Operational Time, equation (7) and equation (8).

$$H_2O_2gpd = Titration * \ Flow * 60 \left(\frac{min}{hr}\right) * OpHrs \qquad \textbf{(7)}$$

$$H_2O_2gpy = \ H_2O_2gpd * OpDays \qquad \textbf{(8)}$$

Where:
H_2O_2gpd = H_2O_2 in gallons per day.
Dose = ml/min of H_2O_2
OpHrs = User Specified Operational Time (hrs/day) of Hydrogen Peroxide system
OpDays = User Specified Operation Time (days/year) of Hydrogen Peroxide system

3.2.4 Equipment and System Installation: This section allows users to design and select a Hydrogen Peroxide treatment system setup. The majority of Hydrogen Peroxide treatment systems used in mine drainage treatment are fairly simplistic, so users are only faced with making two important choices, whether to use a stainless-steel tank with associated storage building or POLY tank with secondary concrete containment and exterior concrete pad. In addition, the user can decide to include the safety features (i.e. clean water, eye wash station, heating system).

3.2.4.1 Storage Tank Size, Type, and Secondary Containment: The user is required to select either the stainless-steel tank, POLY tank, or the User-Specified Tank & Secondary Containment option. The secondary containment is included with the stainless-steel tank option. The user can select the checkbox under POLY Tank option to include a concrete secondary containment. If this is selected, AMDTreat estimates the volume of concrete used for the secondary containment by first estimating volume needed for containment (4,500 gallons) with 10% added to the tank volume as a safety factor. The POLY tank dimensions, 9.6-ft diameter and 8.5-ft height, are the dimension of a previously installed tank at the Monview treatment facility in Pennsylvania (Figure 2). The formula used to estimate the side length of the square secondary containment structure is $Volume = Height * Length^2$, where *Height* is 4-feet high, then the equation is rearranged to solve for *Length*. Therefore, one of the concrete berm lengths of the secondary containment is calculated using the formula:

$$Length\ of\ concrete\ berm\ (ft) = \sqrt{\frac{4{,}950gal}{7.48gal/ft^3}} \div 4 = 12.9ft \qquad (9)$$

Subsequently, and assuming a 4-inch (0.33ft) berm thickness the concrete volume is calculated; then, multiplied by the unit cost to get the total cost (delivery and installation cost) of the concrete secondary containment:

$$Cost\ of\ Concrete\ Secondary\ Containment = \frac{(12.9ft * 4ft * 0.33ft) * 4}{27ft^3/yds^3} * Concrete\ Unit\ Cost \quad (10)$$

3.2.4.2 Dosing System: The users can choose to check the box to include the Dosing Skid. The default cost for the pump is $5,000 but can be adjusted appropriately. This 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 tank. Figure 4 is an example of two-pump system at the Lancashire treatment facility in Pennsylvania. The two pumps allow for a backup in case of pump maintenance, failure, replacement, mine drainage variable flow, or other issues that arise.

3.2.4.3 Storage Building: The user can click the checkbox to include a storage building. The cost is either estimated using a price per square foot and the user-specified square footage of the building. An error message will be presented if the storage building square footage is not big enough for the specified storage tank. The other option is to enter a user-specified storage building cost. 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.

3.2.4.4 Exterior Concrete Pad for POLY Tank: The user can select to include an exterior concrete pad for the POLY Tank and estimate this cost by specifying the concrete unit cost ($\$/yds^3$) and the square footage of the concrete pad. The unit cost should include the delivery and installation of the concrete pad. In addition, it is assumed that the concrete pad is 10 inches thick when estimating the volume of concrete. The user also has the option to enter an user specified total cost for the concrete pad. Please note, the user should ensure the concrete pad design is sufficient for the size of storage tank.

3.2.4.5 Clean Water Tank: By default, the Clean Water Tank will be included as part of the module. The user can select to not 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. This option should be considered for locations that do not have 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.

3.2.4.6 Eye Wash Station & Safety Shower Cost: By default, the Eye Wash Station and Safety Shower will be included as part of the Hydrogen Peroxide module. The user can unselect the checkbox to not included 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 previously installed system at the Lancashire treatment facility (Figure 6).

3.2.4.7 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 heating system purpose 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 the previously installed heating systems.

3.2.5 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 Hydrogen Peroxide 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 the cost module, however, users who want to include this capability can input the cost into the *Other Capital Items* section to capture the capital cost.

3.2.6 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 storage tank refill frequency provides users with an estimate of how often the storage tank will be 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 Hydrogen Peroxide system. Users can opt to estimate the installation cost by specifying it as a percentage (cost-multiplier) of the capital cost or by entering an user-specified cost.

3.3.3 Annual Cost: The annual cost section provides an estimate of the annual cost to operate and maintenance 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 Maintenance for the treatment system can either be specified by the user or estimated by assuming it is a percentage of the capital cost. The latter method assumes the more expensive system 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.

$$\textit{Cost to rebuild pump motor in 20 years} =$$

$$Present\ Day\ Cost\ \times (100\% + Inflation\ Rate)^{20} = \$20{,}000 \times (100\% + 5\%)^{20} = \$53{,}065 \quad \textbf{(11)}$$

- <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.

- <u>Default Cost</u>: This represents the current cost to purchase the equipment or material.

- <u>Life Cycle</u>: 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.

- <u>Replacement Percentage:</u> 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. 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 lifecycle of a POLY storage tank is 12 years due to degradation from ultraviolet light. However, users may opt to increase the Lifecyle if the poly tank will be housed in a building. Users are free to fully customize the replacement items, including adding new items or deleting default items.

Storage Tank: The Life Cycle of the Stainless-Steel Tank is assumed to be 50 years but could last much longer. The AMDTreat team decided on a 50-year life cycle mostly because of the unpredictability of events like vandalism and freak accidents that have a chance to occur over such a long-time frame. Without budgeting for the possibility of these situations, fixed financial instruments used to fund treatment could become underfunded and affect treatment longevity. On the other hand, one could assume the tank will require some repair from some type of damage in the future and assume any holes or compromised areas could be cut, removed, and rewelded with a new sheet of stainless steel. It should be noted a fenced stainless-steel Hydrogen Peroxide tank was installed in the early 1970s and is still in operation today with minimal repairs.

The POLY tank default Life Cycle is 12 years. 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 are likely 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 either 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 hydrogen peroxide will tend to corrode or wear-out the parts within the pump and may need replaced on frequent basis.

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

Exterior Concrete Pad: The exterior concrete pad default Life Cycle is 50 years with 100% Replacement. If the concrete pad begins to crack and/or subside a new pad would need to be poured in order to ensure the hydrogen peroxide tank is safe and no issues with being level. The exterior concrete pad would very likely be an item at a site with a POLY Tank.

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 Hydrogen Peroxide module.

1. The Stoichiometric method used to estimate the annual chemical consumption relies on a properly determined value for Typical Flow and Ferrous Iron (Fe^{2+}) (dissolved iron). Many people would field filter and preserve the iron sample prior to sending water sample for the laboratory analysis. User would not want to use a total iron laboratory result in this module to determine chemical consumption. In addition, this module assumes the mine water is void of Peroxide consuming species other than Ferrous Iron, such as, organic matter or other oxidizable species.

4.0 References

Evonik Corp. Hydrogen Peroxide Safety Training Video https://youtu.be/RlafB5adtlQ.

Means, B.P., Beam, R.L., "Optimization of a High-Density Sludge Mine Drainage Treatment Facility" Paper published and presented at the 2014 International Water Conference, San Antonio, TX., November 17, 2014

Means, B.P., Beam, R.L. "Operational Studies of Hydrogen Peroxide versus Hydrated Lime and Hydrogen Peroxide versus Sodium Hydroxide at Selected Pennsylvania Mine Drainage Treatment Sites" presented at the NAAMLP Conference, Glade Springs WV, September 2013.

Means, B.P., Beam, R.L., Charlton, D. "Treatment Plant Optimization and Cost Reduction Strategies at Selected Bankruptcy Mine Sites in Pennsylvania" Presented at the 37th annual West Virginia Mine Drainage Task Force Symposium, March 29-30, 2016, Morgantown WV

C.A. Cole, Molinski A.E., Reig, 1977, "Peroxide Oxidation of Iron in Coal Mine Drainage" WPCF Journal July 1977 pp 1616 – 1620

5.0 Figures

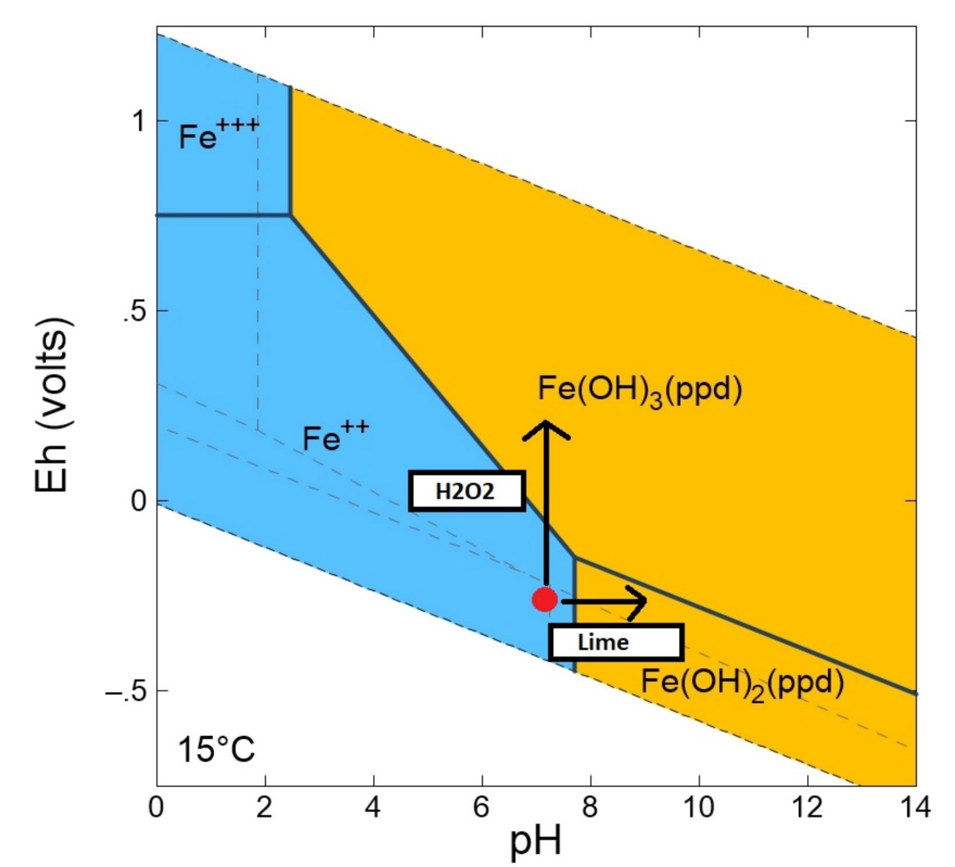

Figure 1. Eh – pH diagram illustrating the contrasting approaches of pH adjustment treatment strategy (lime or other alkali chemical addition) vs. an Eh adjustment treatment approach (peroxide or another oxidizing chemical). The blue areas of the diagram indicate stability fields where the dominate form of iron is dissolved. The tan areas of the diagram indicate Eh and pH conditions where iron is precipitated from solution.

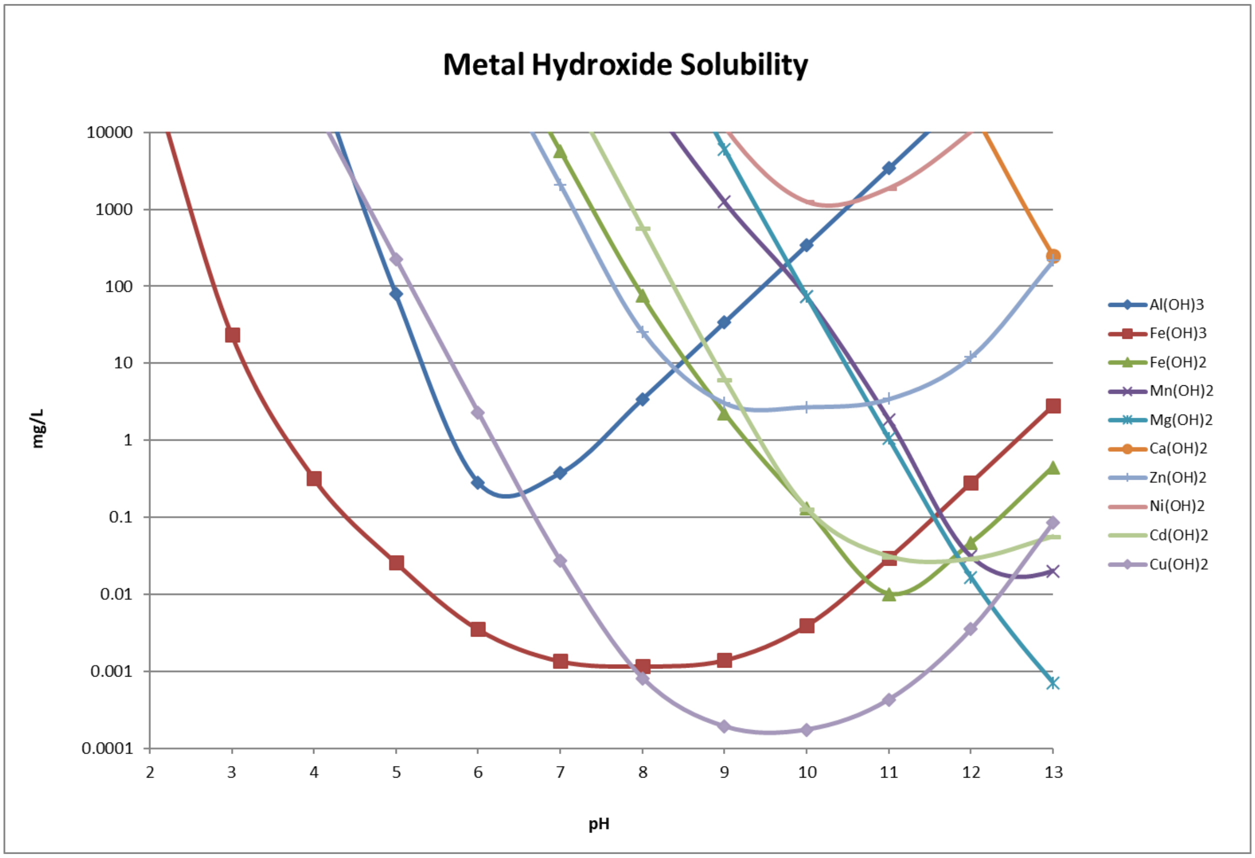

Figure 2: Solubility of transition metal hydroxides.

Figure 3. Stainless Steel Storage Tank for Hydrogen Peroxide with steel secondary containment. Note the ventilation fan in the upper portion of the photo. In the event of a leak ventilation fans will greatly assist in removing peroxide vapors from the building atmosphere.

Figure 4. Photo of the construction of a concrete block storage building with stainless steel tank located in the building.

Figure 5. Photo of a Storage Building that would house the hydrogen peroxide tank, dosing skid, eye wash station & safety shower.

Figure 6. Double-walled POLY Tank and associated two-pump Dosing Skid. Storage Tank is placed on exterior concrete pad within concrete block structure.

Figure 7. Photo of POLY double-walled hydrogen peroxide tank with level indicator in red circle.

Figure 8. Picture of stainless-steel and polyethylene tubing associated with Dosing Skid. Note pumps and piping are mounted inside the secondary containment structure.

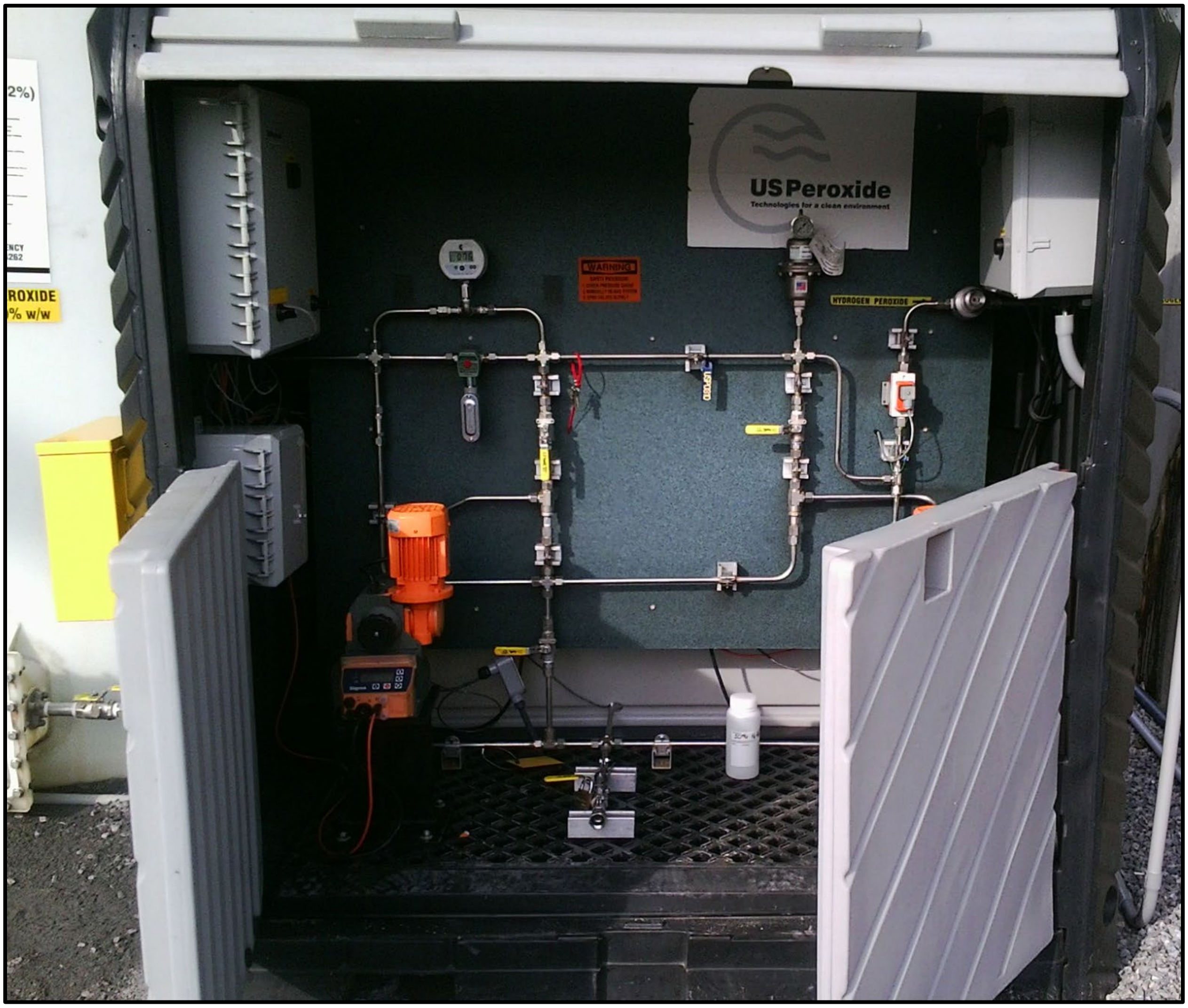

Figure 9. Photo illustrating the stainless-steel tubing used for hydrogen peroxide. Note the system has automated leak detection and the lower portion of the cabinet has a spill containment compartment.

Figure 10. Photo of a two-pump hydrogen peroxide dosing skid and associated polyethylene tubing. Note theses peristaltic pumps have automated leak detection systems that will stop the pump in the event of a tubing failure.

Figure 11. Photo of a two-pump hydrogen peroxide dosing skid and associated stainless-steel tubing. Note the presence of organic matter (leaves) in the vicinity of the diaphragm pumps. This is a situation should be avoided and immediate correct action is needed as a leak of peroxide will result in combustion of any exposed organic material.

Figure 12. Photo of the hydrogen peroxide dispensing (red arrow) into the mine drainage water. 90 gallons per day of 50% peroxide is being utilized to treat this 4500 gallon per minute abandoned underground mine discharge.

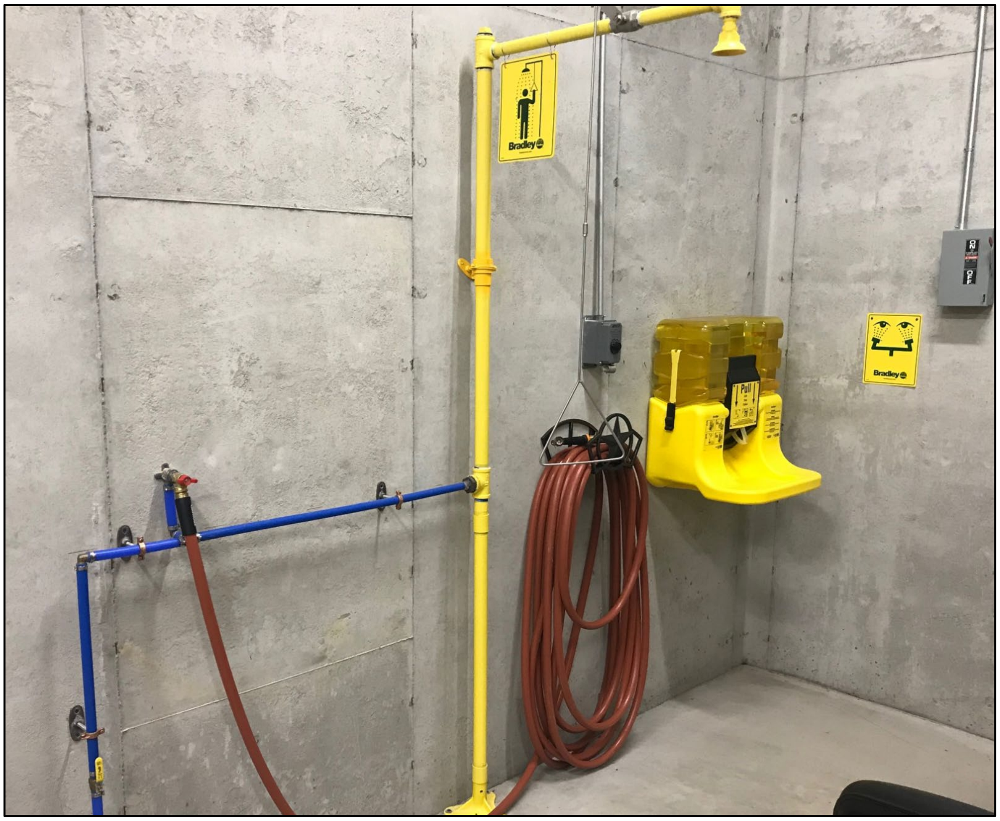

Figure 13. Photo of an Eye Wash Station and Safety Shower within a Storage Building.