Help Instruction File:

Pre-Manufactured Hydrated Lime Slurry 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).

Pre-Manufactured Hydrated Lime Slurry Module Overview

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1.0 Objective

The objectives of this overview are to: (1) Provide an understanding of the application of Pre-Manufactured Hydrated Lime Slurry in mine drainage treatment and (2) Provide an overview of the module to guide users in developing a conceptual estimate of the cost to construct, operate, and maintain Pre-Manufactured Hydrated Lime Slurry treatment systems. This module, as well as most of the other AMDTreat modules, can also be applied to reverse cost model existing systems and system components to establish and evaluate future financial and investment decisions. The information is presented in two sections, **Overview and Application** and **Pre-Manufactured Hydrated Lime Slurry Module Overview**.

2.0 Overview

A basic understanding of the chemical and physical properties, the application, and equipment requirements of a Pre-Manufactured Hydrated Lime Slurry 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. **Users should also note that the Lime Products Help file contains an extensive discussion of dry lime products, Calcium Oxide (CaO) and Calcium Hydroxide ($Ca(OH)_2$) that are used to produce lime slurries on site, using storage, dispensing, mixing equipment and available on site process/potable water. Users should refer to the dry lime products help file for additional or ancillary information concerning all commonly used lime products for mine drainage treatment applications.**

This module discusses pre-manufactured lime slurry and its application in mine drainage treatment. This reagent is produced off site, typically at a commercial facility and delivered to the treatment site as a readily usable liquid/solid suspension. In addition to commercial manufacturing facilities, some state agencies and operators have envisioned and applied the concept of producing lime slurries at larger or centralized mine drainage lime treatment facilities that can then be transported to smaller and/or more remote treatment sites.

2.1 Physical and Chemical Properties

Pre-Manufactured Hydrated Lime Slurry is a low viscosity suspension of Calcium Hydroxide ($Ca(OH)_2$) in water. Calcium hydroxide is used to neutralize acidity (H^+) in mine drainage. First the calcium hydroxide dissociates in water then the hydroxyl alkalinity is available to react with the acidity in mine drainage.

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^- \rightarrow Ca^{2+} + 2OH^- + H^+ \rightarrow Ca^{2+} + H_2O$$

In mine drainage treatment applications, most commercial manufacturers produce what is termed as a “high density” slurry that contains approximately 30 to 38% solids (by weight). By comparison, lime slurry produced by on-site processes can have a much wider range of densities depending upon the type of slurry make-down equipment present. Both low density (<12% solids) and high-density on-site systems exist and are utilized at lime-based mine drainage treatment sites. As a rule, older lime treatment facilities most likely utilize a low-density process. Regardless of origin, high density lime slurries are in most instances much more advantageous that their lower density counterparts. High density (~35% solids) lime slurries are, for all practical purposes, are as easily pumped as low-density slurries and they offer significant additional advantages beyond just having a higher percent solids of calcium hydroxide per unit volume. For example, in the experience of the AMDTreat Development team, facilities utilizing high density lime slurry have little or no scaling issues in storage tanks, piping, valves or other dosing equipment as compared to low density slurry systems; therefore, maintenance requirements can be markedly reduced.

2.1.1 Hydrated Lime Slurry Chemical Characteristics

Hydrated Lime is relatively insoluble and consistent with exothermic reactions, solubility increases with decreasing temperature (Figure 1). At a temperature of 55 ^{0}F the solubility of $Ca(OH)_2$ is 1.2 g/L and will achieve a pH of 12.4 and dissolved alkalinity of 1,621 mg/L as $CaCO_3$ if dissolved into water containing a Total Inorganic Carbon (TIC) concentration of 2 mg/L (Figure 2). A saturated solution of Hydrated Lime is known as 'lime water'. Because of the low solubility of Hydrated Lime, the use of Lime Water would require large makeup water requirements and storage tanks. For example, a typical surface mine discharge of 20 gpm and acidity of 100 mg/L (as $CaCO_3$) would require 1,778 gallons/day of Lime Water. Thus, Hydrated Lime is mixed with water to create a slurry, which consists of a combination of Lime Water and suspension of unreacted Hydrated Lime particles. Modern Hydrated Lime systems and commercially available Pre-Manufactured Lime Slurry can yield slurry with up to 38% solids by weight. A 38% solids by weight slurry provides an additional 651,700 mg/L of alkalinity (as $CaCO_3$) in the form of suspended $Ca(OH)_2$ particles, which produces a highly concentrated product with a total alkalinity (dissolved + suspended) of 653,321 mg of $CaCO_3$ per liter of slurry. For perspective, the 1,778 gallons/day of Lime Water required in the example above would be reduced to 4.4 gallons/day of 38% slurry.

The dissolved alkalinity in the Lime Water is immediately available for reaction, however, the majority of the alkalinity in Hydrated Lime slurry is in the form of suspended $Ca(OH)_2$ particles that require a dissolution step before being available to neutralize the acidity. In most cases, a mechanical mixing is required to help dissolve and promote reaction with the mine drainage. Mixing, promotes dispersion, prevents agglomeration and settling, and helps to continuously abrade particles to reveal fresh reactive surfaces that may become coated with mine drainage precipitate.

2.2 Benefits/Drawbacks of Lime Slurry

2.2.1 Benefits of Pre-Manufactured Hydrated Lime Slurry vs Dry Lime Products

The benefits of using Pre-Manufactured Lime Slurry as a mine drainage treatment alkali include:

1. The major reason Pre-Manufactured Lime Slurry is utilized is because of its convenience and flexibility.
2. The initial capital investment for on-site equipment can be much less compared to dry lime products.
3. Operational labor and maintenance cost are less compared to on-site lime systems.
4. Electrical power requirements and electrical power usage are significantly reduced. This type of system generally only requires the use of single-phase power and can even be deployed with solar power systems.
5. Consistent % solids of the slurry resulting in consistent dosage rates and target treatment pH control.
6. Eliminates fugitive dust and worker exposure to dry lime products.
7. Reduces the quantity and/or need for on-site process/potable water. A source of washdown water or PPE water supply is still necessary but could be provided by utilizing a storage tank.

2.2.2 Drawbacks of Pre-Manufactured Hydrated Lime Slurry vs Dry Lime Products

The drawbacks include:

1. Increased unit cost of the pre-manufactured product.
2. Increased cost associated with transport of a slurry product of which a significant portion is water.
3. Limited number of suppliers can result in both the absence of competitive pricing and product availability.
4. High volume and or high acid load discharges will likely result in making on-site lime slurry make-down systems a much more viable option.

2.2.3 Application, Equipment, and Typical Treatment Configuration

In Appalachia (Eastern U.S.) mine drainage discharges less than 250 gallons per minute (gpm) are typically treated with either caustic soda, lime slurry, soda ash, or passive treatment technologies. It is important to note the flow-based example is provided to give perspective and should not be considered guidelines. Treatment technology selection should be based on economics, site specific characteristics/limitations and the goal of the project. In some cases, more expensive treatment options are selected if they afford convenience or some other benefit important to the project.

Pre-Manufactured Lime Slurry equipment is modest compared to on-site lime slurry system make-down componentry. Figure 4 and 5 illustrate the components of a lime slurry treatment facility. Typically, only a storage tank, tank mixer/agitator, chemical metering pump (Figure 6), EDPM rubber tubing for dispensing, an insulation/heating blanket for the tank (unless within a heated facility) and heat tracing for the dispensing line are needed. Optional equipment includes a pH controller and remote telemetry. Also, some Pre-Manufactured Lime Slurry suppliers offer a complete turn-key system from a single manufacture. Finally, some suppliers offer portable systems mounted on trailers for short term treatment scenarios and/or testing purposes (Figure 3) is a photo of a portable unit set up on an PA anthracite region AML site that was used for testing and treatment watershed impact evaluation.

2.3 Financial Analysis between other Dry Lime Products and Pre-manufactured Hydrated Lime Slurry

As previously mentioned, treatment technology selection should be based on economics, site specific characteristics/limitations and the goal of the project. In some cases, more expensive treatment options are selected if they afford convenience or some other benefit important to the project. By utilizing and comparing the estimates provided by both the Dry Lime and Pre-Manufactured Lime Slurry Modules of the AMDTreat program in combination with the various financial forecasting tools, both the long- and short-term cost considerations of either selection can be compared. Additionally, other possible alternatives such as treatment with Caustic Soda (NaOH) can also be comparatively analyzed.

The decision to design a Lime plant to produce lime slurry onsite or to use pre-manufactured lime slurry can be a difficult decision.

To provide perspective on the potential for cost savings, consider the treatment scenarios shown in Tables 1 and 2.

System	Flow (gpm)	Acidity (mg/l $CaCO_3$)	Capital Construction Cost	Annual Chemical Cost
On-site Hydrated Lime	300	150	\$613,000.00	\$14,300.00
Pre-Manufactured Lime Slurry	300	150	\$93,000.00	\$23,600.00

Table 1: Treatment scenario evaluating the cost of using Hydrated Lime vs. Lime Slurry for treatment. While there are more in-depth approaches for analyzing the payback, this simple analysis shows there is potential cost savings for utilization of Pre-manufactured Lime Slurry for moderately sized treatment projects. Even though annual chemical costs are significantly more for pre-manufactured lime slurry, the \$9300.00 per year chemical cost savings afforded by an on-site system would require ~50 years till the cost differential for the initial capital investment was offset.

System	Flow (gpm)	Acidity (mg/l $CaCO_3$)	Capital Construction Cost	Annual Chemical Cost
On-site Hydrated Lime	2000	300	\$613,000.00	\$219,000.00
Pre-Manufactured Lime Slurry	2000	300	\$93,000.00	\$323,000.00

Table 2: Treatment scenario evaluating the cost of using Hydrated Lime vs. Lime Slurry for treatment.

While there are more in-depth approaches for analyzing the payback, this simple analysis shows that the increased capital expenditure associated with an on-site hydrated lime system would be recovered in a little over five years of operation given the $104,000.00 per year chemical cost savings afforded by an on-site system.

3.0 Pre-Manufactured Lime Slurry 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) Pre-Manufactured Hydrated Lime Slurry Information, (3) Chemical Consumption, (4) Equipment, (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 *Net Acidity* and AMDTreat calculates the annual acidity loading. Then select the % solids of the Pre-Manufactured Hydrated Lime Slurry, along with the *purity* and *mixing efficiency, specific gravity* and *unit cost delivered to the site*. Next select the method to estimate Chemical Consumption (*Stoichiometric, Titration,* or *User-Specified Quantity*). AMDTreat uses this information along with the acidity load to estimate the annual consumption. Users select the *Equipment and System Installation* heading to select and size treatment options. Additionally, users can use this section to specify the operational frequency and hours of operation of the treatment system so 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 chemical consumption and reserve capacity. The estimated cost to construct and operate the Pre-Manufactured Lime Slurry 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 the 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 Net Acidity values. These values are used to (1) estimate the annual chemical consumption and (2) estimate the size of various equipment, such as, chemical storage volume and refill frequency.

The definitions for *Typical Flow* and *Net Acidity* 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.

Net Acidity represents the acidity released and neutralized when the base is added to achieve the treatment pH. For eastern coal mine drainage, the acidity producing species will be the hydrolysis of Al^{3+}, Fe^{2+}, Fe^{3+}, and Mn^{2+}, the precipitation of $CaCO_3$, the deprotonation of H_2CO_3 and HCO_3^-. For treatment pH > 10, the hydrolysis of Mg^{2+} and hydroxylation of cations need to be considered. Net Acidity is best determined by performing a cold acidity titration in the field to preserve WQ characteristics. This method is described in Titration Section 3.2.3.2 under the Chemical Consumption heading.

3.2.2 Pre-Manufactured Lime Slurry Information: Users can select to estimate the chemical consumption and cost. The *Purity* of the chemical and *Mixing Efficiency must be specified.* Lime Slurry producers can provide potential purchasers with the purity for their product. Default purity is 93%.

Mixing Efficiency is used to simulate the percentage of chemical being dosed that is dissolving or participating in treatment reactions. Unlike Caustic Soda, Lime is mostly a solid suspension in water and requires mixing to promote and accelerate dissolution. If Lime Slurry is dosed without mechanical mixing or agitation, maybe only 50% of the slurry solution may dissolve and the remaining will be unavailable to further react since it will be removed during the solid/liquid separation stage. Therefore, the *Mixing Efficiency* may be estimated at 50% to properly estimate chemical consumption. Mixing efficiency can be measured by collecting total and dissolved water samples before chemical addition and right before settling and the difference between total and dissolved calcium provides insight to the *Mixing Efficiency*.

3.2.3 Chemical Consumption: The *Chemical Consumption* section offers users three methods to estimate the annual chemical consumption, *Stoichiometric*, *Titration*, and *User-Specified Quantity*. The sizing summary expresses both the gallons of Pre-manufactured Lime Slurry and the equivalent quantity of Dry Calcium Hydroxide ($Ca(OH)_2$) consumed on both a daily and annual basis.

> *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 Pre-Manufactured *Lime Slurry Information* headings. The method uses the values for *Typical Flow* and *Net Acidity* to calculate the annual acidity loading in Calcium Carbonate Equivalents.

$$A.L. = \left(Flow\ \frac{gal}{min}\right) * \left(Acidity\ \frac{mg\ CaCO_3}{L}\right) * \frac{3.785\ L}{gal} * \frac{1\ g}{1000\ mg} * \frac{60 min}{hr} * \frac{24\ hr}{day} * \frac{365\ day}{yr}$$

Where:
A.L. = Annual Acidity Load in g $CaCO_3$/yr

Flow = Typical Flow in gal/min
Acidity = Net Acidity in mg/L as $CaCO_3$

After the Annual Acidity Load is determined, the program uses the stoichiometric relationship between $CaCO_3$ and $Ca(OH)_2$ to re express the acidity load in terms of $Ca(OH)_2$.

$$HL = \left(A.L\ \frac{g\ CaCO_3}{yr}\right) * \frac{Mole\ CaCO_3}{100\ g} * \frac{2\ Mole\ H^+}{1\ Mole\ CaCO_3} * \frac{2\ Mole\ Ca(OH)_2}{2\ Mole\ H^+} * \frac{74\ g}{1\ Mole\ Ca(OH)_2}$$

HL = Annual Acidity Loading in g/yr expressed as $Ca(OH)_2$

Finally, annual amount will be adjusted for the user-specified values for the *Purity* and *Mixing Efficiency* to determine the annual Pre-Manufactured Hydrated Lime Slurry Consumption.

$$Adjusted\ Ca(OH)_2 = \frac{HL\frac{g}{yr} * \frac{1\ lb}{454\ g} * \frac{1\ ton}{2000\ lbs}}{\frac{Purity\ of\ Caustic\ Solution * Mixing\ Efficiency\ of\ Caustic\ Solution}{100}}$$

3.2.3.2 Titration – The titration method allows users to input the results of field or bench acidity titrations that empirically determine the required dose to achieve effluent standards. The “treatment” acidity or net acidity is best determined by field conducing a cold acidity titration using the same treatment chemical that will be used in the final treatment system. A cold acidity “treatment” titration is performed by filling a 1 Liter beaker with fresh mine drainage and immediately titrating to various pH endpoints. The beaker contains a pH probe and magnetic stirrer. At each pH endpoint, a filtered sample is collected and sent for laboratory analysis. The information is used to determine the pH at which effluent standards will be achieved and the corresponding chemical dose is used to determine the treatment (or net) acidity. For Lime Slurry products, AMDTreat requires the treatment acidity to be entered as lbs of Lime products per gallon of mine drainage treated. Since the purity is inherently contained in the titration input value, AMDTreat does not use values for *Purity* or *Mixing Efficiency* when the Titration method is selected.

$$Annual\ H.L. = \left(Flow\ \frac{gal}{min}\right) * \left(Titration\frac{lbs\ Ca(OH)2}{gal\ AMD}\right) * \frac{60min}{hr} * \frac{24\ hr}{day} * \frac{365\ day}{yr} * \frac{1\ ton}{2000\ lbs}$$

Where:

Annual H.L = Annual Hydrated Lime in tons/yr

3.2.3.3 User-Specified Quantity - This method allows users to specify the annual Pre-Manufactured Lime Slurry consumption. This method is typically used when AMDTreat is being used to evaluate long-term water treatment liability using the *Net Present Value* calculations.

3.2.4 Equipment: This section has two subsections: *Storage and Dispensing System* and *Tank Foundation and Pump Housing*.

3.2.4.1 Storage and Dispensing System – Users may select from the following options within the *Storage and Dispensing System*:

Electric Rate: This rate should include all costs associated with the electric bill (fees, taxes, etc)

Slurry Storage Tank: A default storage tank of 8,800 gallons with a 10 ft diameter and 15 ft height. This tank size is common in the Eastern U.S. Coal Fields and can take advantage of bulk delivery and pricing of slurry. Users can enter their tank volumes ranging from 1,000 to 12,000 gallons.

Slurry Refill Volume: Users can choose between 2 standard refill volumes of either 4,800 gallons or 3,900 gallons based upon tanker truck type. (4,800 gallons for Semi Truck tank trailers or 3,900 gallons for Straight Truck Triaxle tank trucks). A user defined volume option is also available. These data are used to provide refill frequency and reserve capacity of the slurry system and are shown as part of the sizing summary output.

EPDM Rubber Tubing to dispense Slurry: Users specify the distance between the slurry tank and the dose point and the material unit cost to estimate the quantity of Ethylene Propylene Diene Monomer (EPDM) tubing required.

Stainless Steel Slurry Agitator: A mechanical mixer/agitator is contained in the slurry storage tank and is used to prevent liquid / solid separation of the slurry. The user cans specify run time and motor horsepower to estimate the annual electrical usage and cost.

Chemical Metering Pump: A peristaltic metering pump equipped with a Variable Frequency Drive (VFD) is the default selection for AMDTreat. Most systems deploy an additional pump unit to serve as a backup in the case of either failure or needed pump maintenance. Users can specify the number of pumps, horsepower rating and operational timeframes.

Hach se 200 pH-based dosing controller: Users can opt to include the cost of a dispensing controller and pH probe. This can be a significant savings in both chemical consumption and corresponding sludge production by helping to avoid overtreating especially if discharge flow and or acid load is variable.

Cellular Telemetry and Fees: Users can opt to include the cost of telemetry for remote monitoring of the system

Silicon Rubber Heat Blanket: SRP heat blankets are attached to the slurry storage tank and thermostatically controlled to prevent freezing. Four (4) 2’ x 3’ blankets are required for the standard 8800-gallon storage tank. Users can specify the number of hours per day of operation at temperatures less than 40 degrees F.

Tubing Heat Trace: Heat Trace is necessary for the EDPM rubber dose tubing to prevent freezing in winter months at temperatures less than 40°F. Users can specify the number of hours per day of operation

3.2.4.2 Tank Foundation and Pump Housing – This section allows users to develop cost estimates for the slurry tanks concrete foundation and also for a shed/control structure to house electrical panels, pumps and controllers.

Slurry Tank Foundation and Foundation Area: Users have the option to either specify the foundation size or have AMDTreat estimate the foundation area. The size and cost information is reported in the sizing summary portion of the module. AMDTreat assumes the foundation is square shaped having a width and length that is 2 feet more than the tank diameter. Users also specify the concrete thickness and the program then provides a calculated foundation volume.

Pump and Electrical Control Panel Housing: This equipment can either be specified for outdoor use or AMDTreat has an optional prefabricated wooden structure to house electrical control panels.

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 Lime 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, Lime Slurry tank refill frequency requirements and reserve capacity, and foundation size. The calculations indicating the days of treatment afforded by each truckload delivery of Lime slurry and reserve tank capacity provides users with an estimate of how often the storage tank will be refilled based on the tank capacity 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 Lime Slurry system. Users can opt to estimate the installation cost by specifying it as a percentage of the capital cost or by entering a cost. The default installation cost is 40% of the capital but users can either change this percentage or enter a specific user 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 for an existing treatment system. 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. Finally, users can specify the annual electric cost or AMDTreat will estimate the annual electric cost for all the electrical equipment described under the *Storage and Dispensing System* section.

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.

- <u>Term of Analysis</u>: The time period used by the NPV calculation to determine the financial investment required to pay for all future costs of the treatment system.

- <u>Inflation Rate</u>: 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.

- <u>Rate of Return</u>: 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. 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.

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

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

- <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 in Pennsylvania and West Virginia and have collective experience in design, funding, and/or operation/maintenance of Pre-manufactured Hydrated Lime Slurry 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 eight recapitalization items for the pre-manufactured Hydrated Lime Slurry treatment systems. Items included are; Slurry Storage Tank, Tank Agitator/Mixer, Chemical Dosing Pump, pH Controller, pH Probe, Heat Blanket/Tracing Tape, Pump Housing (storage shed) and Annual O&M. 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 Lime Slurry storage tank is 25 years assuming it is exposed to weather conditions normally experienced in the northern Appalachian Region. However, if the the tank is located inside a building or in a different climate, users may opt to increase or decrease the Lifecyle. Users are free to fully customize the replacement items, including adding new items or deleting default items.

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 Lime module.

1. The Stoichiometric method used to estimate the annual chemical consumption relies on a properly determined value for Typical Flow and Net Acidity. Many people use the Standard Method 2310 (Hot Acidity) procedure to determine Net Acidity. In most instances, a Hot Acidity titration result will not accurately describe the base requirement to achieve effluent standards and could over or underestimate chemical costs. A cold acidity titration is the best method to determine the Net Acidity encountered during treatment.

4.0 References

United States Geological Survey, 2020, National Minerals Information Center Website (https://www.usgs.gov/centers/nmic/lime-statistics-and-information?qt-science_support_page_related_con=0#qt-science_support_page_related_con)

Boynton, R.S., (1980) Chemistry and technology of lime and limestone, 2nd edn. Wiley, New York.

Means, B., Beam, R, and Mercer, J., 214. Analysis of Hydrated Lime Consumption in Circumneutral Underground Coal Mine Drainage Treatment. Mine Water and the Environment.

Murray, J., 1956. Summary of Fundamental Research on Lime. National Lime Association.

National Lime Association, 2020, Lime Fact Sheet, https://www.lime.org/documents/publications/free_downloads/fact-properties2007rev.pdf

5.0 Figures

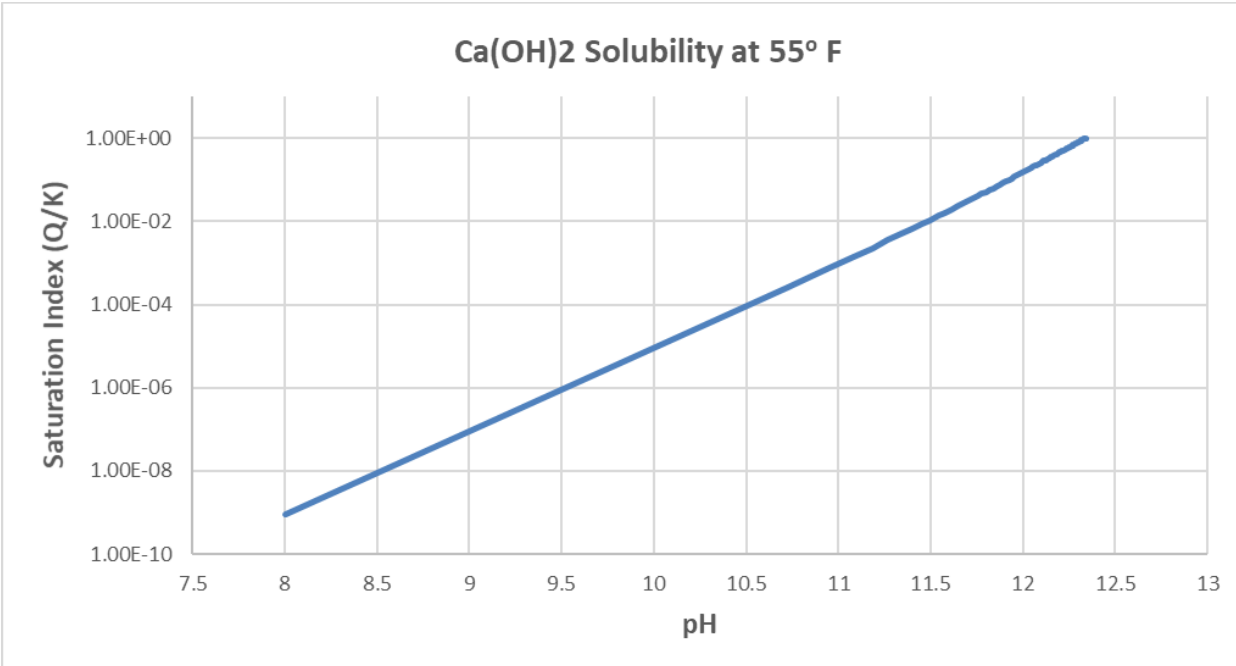

Figure 1: Graph showing saturated solution of $Ca(OH)_2$ is achieved at a pH of 12.4 at 55 °F.

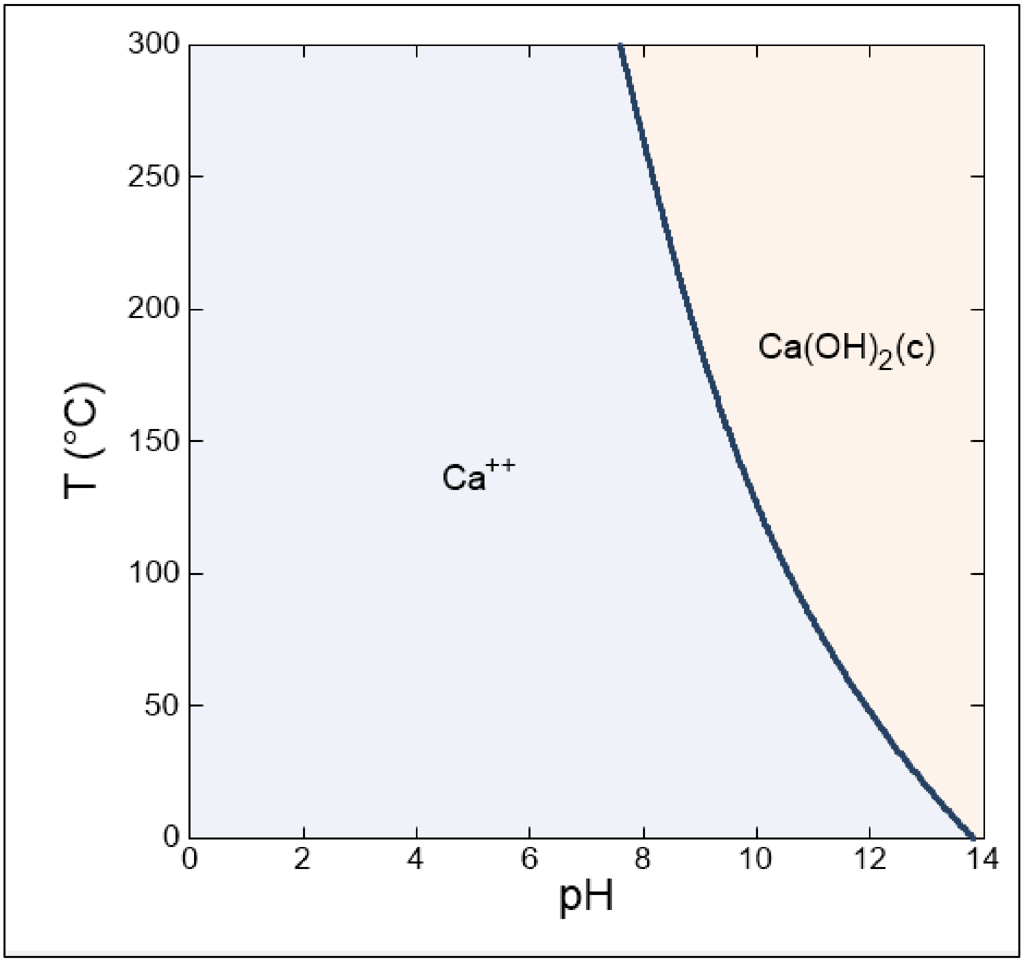

Figure 2: Graph showing the inverse relationship between solution temperature, pH, and solubility of $Ca(OH)_2$.

Figure 3: Portable lime slurry system in use at a PA Anthracite AML Discharge (Quakake Tunnel Discharge) to evaluate watershed impacts in consideration of a full scale permanent

Figure 4: Pre-manufactured Lime slurry system in use at a PA Bituminous Mine Site. 8800 gallon insulated storage tank, shed for dosing pump and electrical controls and a standby diesel generator.

Figure 5: Pre-manufactured Lime slurry system in use at a Northern PA Bituminous Mine Site. 8800-gallon insulated storage tank, shed for dosing pump and electrical controls. Blower units shown on the right-side concrete pad are used for a reaction tank.

Figure 6: Two examples of lime slurry metering/dosing pumps

Figure 7: VFD Control units for lime slurry metering/dosing pumps

Figure 8: pH Controller (Hach 200) for lime slurry metering/dosing pumps

Figure 9: Lime Slurry (small red rubber tube) introduced to mine water in a mixing channel.