Help Instruction File:

Lime Products 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).

Lime Products Module Overview

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1.0 Objective

The objectives of this overview are to: (1) Provide an understanding of the application of Lime products in mine drainage treatment and (2) Provide an overview of the Lime Module to guide users in developing an estimate of the cost to construct, operate, and maintain Lime treatment systems and also aid in reverse cost modeling of existing systems. The information is presented in two sections, **Overview** and **Lime Module Overview**.

2.0 Overview

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

The two main Lime products used in mine drainage treatment are Lime and Hydrated Lime. In 2019, 18 million tons of Lime products were produced by 28 companies at 84 plants in 36 States. However, only 18 companies produced Lime for commercial resale and the remaining was produced for internal use (USGS, 2020). Table 1 provides several characteristics for Lime products.

Parameter	High Calcium Lime	High Calcium Hydrated Lime
2020 Unit Cost (Pa)	$145	$160
lbs of $CaCO_3$ /lbs reagent	1.79	1.35
$/lb	$0.08	$0.073
$/Ton Alkalinity	$81.20	$118.40
Typical Purity	90 to 94%	94 to 97%
Specific Gravity*	3.2	2.3
Bulk Density (lbs/gal)*	7.35 (Pebble)	3.34
Angle of Repose*	55^{o}	70^{o}

Table 1: Costs and characteristics of Lime products (* National Lime Association, 2020)

2.1.1 Lime (CaO)

Lime is produced by calcining high-Ca content limestone, containing less than 5% Mg, in horizontal or vertical kilns at temperatures between 1,832 and 2,372 °F (above the theoretical calcination temperature of 1,568 °F) for rapid decomposition and evolution of CO_2 (Means et al., 2014) (Figures 1 & 2). The chemical formula below indicates a maximum of 56 tons of CaO and 44 tons of $CO_{2(g)}$ is produced from calcining 100 tons of $CaCO_3$.

$$CaCO_3 + Heat = CaO + CO_{2(g)} \tag{1}$$

The resultant product, CaO, is often referred to as by the chemical formula name, Calcium Oxide, but also referred to by a variety of common names including, Lime, Quicklime, Burnt Lime, HiCal Lime, Caustic Lime, and Calcium Lime. Herein, CaO will be referred to as Lime. It is important to note that agriculture lime or ag lime is a variety of crushed limestone ($CaCO_3$) and is not, and should not be confused with, Lime (CaO).

Lime is a whiteish mineral containing a crystalline structure. The purity of Lime (% CaO by wt.) is a function of the limestone feedstock quality and the effectiveness of calcining, however, most Lime used in mine drainage treatment is between 92 and 95% pure. Lime is produced in various form factors depending on the application and is mostly sized as Pebble (1/4" to 2 1/2"), Ground (< ¼"), or Pulverized (100% through a No. 20 sieve). Most lime plants using CaO use the Pebble gradation (Pebble Lime). Some Lime treatment plants directly dose Pebble Lime into mine drainage, but most plants first slake the Lime to produce Slaked Lime (Hydrated Lime) before application.

The motivation to directly dose Lime into mine drainage was mostly due to a lack of electricity at a site. Generally, sites with no electricity were forced to use Caustic Soda (NaOH) due to its ability to be manually dosed and passively mixed, but, the high chemical cost made treatment financially unreasonable for large acidity loads. Operators and equipment manufacturers developed systems capable of dispensing Lime using water, solar, or battery power. Being able to dispense Lime without the need for commercial electric allowed Operators to take advantage of low cost of Pebble Quicklime ($/ton alkalinity) and avoid dependence on Caustic Soda at remote sites.

While these systems are generally dependable and able to achieve effluent standards, the dosing of pebble-sized lime directly into mine drainage without mechanical mixing resulted in poor dissolution and increased sludge mass due to unreacted Lime. This resulted in two issues. First, poor dissolution limits the amount of Lime available to react, causing the operator to increase Lime dosing at several times the theoretical amount to compensate and overcome the inefficiency. There are several causes that explain the poor dissolution, including the small surface area of the Pebble size, particle agglomeration, poor dispersion due to Lime settling to bottom of reaction ditch, and the incomplete hydration (slaking). Lime must hydrate (discussed later) before participating in treatment reactions and directly mixing Pebble Lime to large volumes of mine drainage will hydrate the outer layer of the Pebble, which will act as a barrier for water to penetrate and hydrate the interior. All these issues contribute to poor dissolution, increased Lime consumption, and increased chemical cost.

The second issue is the unconverted and unreacted Pebble Lime ends up as sludge in the settling pond. The resultant sludge is very difficult to pump, and extra steps are required for desludging that increase cost. A settling pond must be decanted to expose the sludge and then water must be pumped and mixed with the Pebble Lime sludge to produce a favorable % solids slurry capable of being pumped. The increased cost and effort of desludging caused some operators to abandon the direct application of Lime to mine drainage. Additionally, unreacted Pebble Lime will accumulate in conveyance ditches resulting in significantly increased maintenance cost.

Both issues, increased chemical and sludge costs, have caused some operators to install an electrically driven Lime plant to properly "slake" the lime before dosing to improve reactivity. The process of slaking involves converting Lime to Hydrated Lime. Lime is mixed with water and "hydrated" or "slaked" to produce Hydrated Lime before mixing with mine drainage for treatment.

$$CaO + H_2O = Ca(OH)_2 + 490\ BTU/lb\ Heat \qquad (2)$$

Equation (2) shows the process of hydrating CaO to form $Ca(OH)_2$ is strongly exothermic and care is required when mixing Lime with water. Furthermore, stoichiometric relationships in equation (2) show 1 ton of pure CaO requires 640 lbs of water to produce 1.32 tons of $Ca(OH)_2$. Hydrated Lime is a diluted form of Lime and contains 25% less CaO than Lime on a weight basis.

While the terms hydrating and slaking can be used interchangeably, the term hydrating is generally reserved to describe the process where minimal water is used to create a low moisture powered form of Hydrated Lime. Slaking is used to describe the process when excess water is used to produce a wet slurry of Hydrated Lime (Slaked Lime). Dry hydration is conducted by manufactures to produce commercially saleable Hydrated Lime ($Ca(OH)_2$), which is discussed in the Hydrated Lime Section 2.13. Wet hydration or slaking is conducted onsite by treatment plant operators using equipment called a slaker. Since wet hydration involves the purchase of Lime (CaO) it will be discussed later in this section, which is devoted to Lime. The reason why the discussion is separated is because choosing between designing a Lime plant, which will slake Lime onsite to produce Hydrated Lime, or designing a plant to use manufactured Hydrated Lime is a very important decision that warrants separate detailed discussions. Designers and Operators need to understand the benefits and drawbacks of each approach to make an informed decision.

The reason why Lime is slaked before treatment is to avoid the issues previously discussed when Lime is directly dosed to a wastewater stream. Lime is hydrated to improve reactivity and dissolution efficiency mainly due to the increased specific surface area of Hydrated Lime. Murry (1956) found specific surface area of similar sized particles ranged from 0.67 to 1.30 m^2/g for Lime and from 13 to 26 m^2/g for Hydrated Lime. Boynton (1980) found that surface area is the most significant physical property in the reactivity of Hydrates, even more than particle size. Similar-sized Hydrated Lime particles, created from differing feedstock and/or under differing conditions, will result in particles of differing shapes and porosities that can significantly affect surface area. An increased specific surface area allows more of the particle to be available for reaction with the wastewater, thus increasing efficiency. Therefore, specific surface area, not particle size, is the most important attribute to promote reactivity.

2.1.1.1 Slaking Equipment and Process

Lime and Hydrated Lime treatment systems share many of the same componentry. Both products are stored in silos and use volumetric feeders dispense the product from the silo. At this point, Lime systems differ from Hydrated Lime systems in that the Lime is dispensed into a slaker, whereas, Hydrated Lime is dispensed into a slurry tank (see Section 2.121).

Slakers are equipment designed to mix Lime and water to hydrate the Lime to form Hydrated Lime to generate the increased surface area and reactivity (Figure 3). While the theoretical Lime to water ratio required for hydration is 3.1:1.0, slaking ratios are typically 1.0: 3.0-6.0. There are several types of slakers, including paste, detention/slurry, and ball mill and detention/slurry. Detention/slurry slakers are the most popular in mine drainage treatment. The basic operation of a slaker is for Pebble Lime to be dispensed in volumetric quantities and mixed with water in a reaction chamber to complete the hydration process (Figure 4). The reaction time for the hydration process varies between less than one minute and 10 minutes. A programmable logic controller (PLC) (or some other mechanism) monitors temperature in the reaction chamber to maintain a reaction temperature of 170 to 190 ºF by controlling water addition. The exothermic reaction from the slaking process produces the heat to achieve the desired reaction temperature. After the Lime is slaked, the newly formed Hydrated Lime flows into a grit separator where impurities, such as silicates, settle from suspension. The purified Hydrated Lime slurry flows to a slurry storage tank for dosing.

Slaking optimization involves completely hydrating the all Lime to create Hydrated particles that will fully and rapidly dissolve in water. This allows for small reaction tanks, mixers and lower annual costs. There is debate and conflicting information on how to achieve optimization for a given feedstock of Lime. Treatment plant operators should consult with their Lime producer to discuss the best slaking practices for their Lime. Lime manufactures have often tested their Lime and understand how to optimize for desirable characteristics, such as, particle size and surface area. In addition, some manufactures have technical assistance available to analyze slaking efficiency and optimize the process.

The potential cost savings makes onsite slaking attractive for large Lime consumers (discussed in Section 2.3), however, slaking does add complexity to the treatment process. Without a knowledgeable operator, the potential cost savings could be offset by inefficient slaking practices that lead to poor conversion and low surface area that increases the Lime requirement. The information provided below is aimed at making readers aware a few of the variables in the slaking process. Modern slaking equipment has largely automated the process; however, operators should still have a basic understanding of the factors that promote efficiency.

2.1.1.2 Limestone and Lime Characteristics

Many remote mine drainage treatment locations only have one Lime producer available, thus treatment plant operators lack the ability to evaluate and select from different Lime feedstock. Lime quality depends on the quality of limestone and the calcination process. The concentration of iron, aluminum, silica, and other impurities vary among quarries and affect the quality of the feedstock for Lime production. In addition to Limestone quality (ASTM C25), the production and preparation of Lime (calcination temp., particle size, etc.) affects the slaking process, which effects slaking time, particle size, surface area, purity, etc. If multiple Lime manufactures are available, potential consumers should request results of laboratory and slaking analysis of their Lime. For purity and surface area, there are several ASTM standards to measure Lime characteristics, including Gradation (E 11-70), Settling Rate, Slaking Rate (C 110) Water Treatment (C 53-63) and Industrial Waste Treatment (C 826-75), acid neutralization (ASTM C400-64), and there are other tests to measure slaking time, reactivity, and other qualities of interest.

2.1.1.3 Slaking Temperature

Slaking temperature is probably the most important variable that affects surface area and particle size. In general, higher slaking temperatures results in smaller particles with larger specific surface areas, however, slaking at temperatures near boiling can cause issues. Low slaking temperatures form large Hydrated particles with lower surface areas that are prone to agglomeration. Therefore, typical slaking temperatures range from 170 to 190 ºF.

Since controlling water input controls the slaking reaction temperature, source water that experiences large temperature fluctuation throughout the year can make maintaining a constant slaking temperature challenging. In remote settings groundwater can be used as hydration water and equation (2) indicates 1.0

lbs of CaO would raise the temperature of 3.9 lbs of water from 55 to 180ºF, assuming no thermal loss from the reaction tank. In most instances, either potable "municipal" water is plumbed to the site and purchased for slaking or clarified water is pumped from the top of the clarifier and used for slaking.

2.1.1.4 Slaking Water Quality

Boynton (1980) and others have reported the effect of water quality on the slaking process. Mine drainage contains two water quality variables that will affect the slaking process, dissolved CO_2 and sulfate.

Dissolved Carbon Dioxide

It is common for Appalachian underground mine water to contain hundreds of mg/L of dissolved CO_2 from the reaction between acidic water in the mine pool mixing with alkaline recharge water. If treated mine water is used for slaking the CO_2 content should be determined and evaluated for use. High concentrations of CO_2 can cause recarbonation of the Lime to form $CaCO_3$ during the slaking process, which leads to an inefficiency that will increase use and cost

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Dissolved Sulfate

Boynton (1980) recommended not using water that contains sulfate concentrations > 500 mg/L for slaking. He provided data to show elevated sulfate affects and slows the hydration process. Presumably, a gypsum coating forms a shell around the Lime particle and retards the penetration of water molecules to slake the particle interior.

The effect of sulfate on slaking has always been a concern in mine drainage treatment since sites are remote and often treated water is the only source water for slaking. The author had a unique experience to compare Lime consumption slaked with low sulfate municipal water against clarified treated water pumped from the top of the clarifier. The treated water contained a sulfate concentration of 1,100 mg/L. The large treatment plant pumps at a constant rate and the mine pool water quality is stable with an iron concentration of 160 mg/L. The treatment plant consumes almost 20 tons of Lime per day.

The treatment plant was designed to be able to switch between using municipal and process water for slaking. The plant was operated for a month using municipal water and a month using process water. Flow and mine pool chemistry was monitored to explain any change in Lime use and the treatment pH remained constant and controlled by the PLC. The PLC did not record any significant change in Lime usage and the plant continues to use process water. Laboratory analysis may have been able to detect effects on the slaking process, however, practically speaking, there was no observed difference that could justify the cost of purchasing municipal water. There may have been noticeable effect if sulfate concentrations were higher.

2.1.2 Hydrated Lime ($Ca(OH)_2$)

Hydrated Lime, also known as Calcium Hydroxide, has a chemical formula of $Ca(OH)_2$. The proceeding paragraphs discuss commercially available Hydrated Lime produced by "Dry Hydration" and sold as a dry powder in 50 lb bags or 23-ton bulk deliveries. Unlike Wet Hydration, Dry Hydration involves the use of minimal water and the process is highly individualized by the manufacture. Small consumers choose Hydrated Lime over Lime due to the capital cost and increased complexity of operating a slaker.

Hydrated Lime is relatively insoluble and, consistent with exothermic reactions, solubility increases with decreasing temperature (Figure 5). 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 6). 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 make up water requirements and storage tanks. For example, a typical surface mine discharge of 20 gpm and acidity of 100 mg/L (as CaCO3) would require 1,778 gallons/day of Lime Water. Thus, Hydrated Lime is mixed with water to create a slurry, which consists of Lime Water and suspension of unreacted Hydrated Lime particles. Modern Hydrated Lime systems can produce Slurry with up to 38% solids by weight. A 38% slurry provides an additional 651,700 mg/L of alkalinity (as $CaCO_3$) in the form of suspended $Ca(OH)_2$ particles to produce 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 for reaction. 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.

2.1.2.1 Hydrated Lime Equipment and Process

Hydrated Lime is delivered to treatment sites by semi-truck, and pneumatically transferred from the truck to the storage silo (Figures 7 through 11). Storage silos commonly range from 30 to 120 tons and are sized from consumption estimates to hold Hydrated Lime for up to a month to prevent recarbonation and "bridging" and compaction issues in the silo. Vibratory mechanisms are placed near the bottom of the silo and periodically shake the silo to maintain free-flowing Hydrated Lime and to prevent compaction (Figure 12). Compaction will change the mass of Lime dispensed by the volumetric screw feeders. The volumetric screw feeders at the base of the silo dispenses Hydrated Lime directly into mine drainage, known as dry application, or into a slurry tank to produce a Hydrate slurry for wet application.

<u>Dry Application of Hydrated Lime</u>

Dry application involves feeding Hydrated Lime from the silo directly into mine drainage located underneath or adjacent to the silo (Figures 13 & 14). There has been considerable debate over the merits of dry vs wet application. Dry application is often selected for smaller treatment systems where the goal is to maintain low capital cost and simplicity or in situations where water is not available to make a slurry and the treated process water contains sulfate concentrations that are too high to avoid gypsum formation. In these cases, Hydrated Lime is directly dispensed into mine drainage by a belt or screw feeder and mixing is accomplished by passive (water turbulence) or mechanical means. For sites that afford onsite sludge disposal, the cost of installing and operating mechanical mixers may not offset the cost of inefficient dissolution of particles and additional sludge handling costs caused by unreacted Hydrated Lime particles. Historically, dry application system has been plagued with poor pH control caused by variability in volumetric dosing if the bulk density of Hydrate changes in the silo (e.g. compaction). Advancements in technology over the past decade have eliminated this concern and there are several highly efficient and effective dry application systems in the eastern U.S. Dry application systems do eliminate maintenance issues related to making (water requirement), mixing (mechanical mixers), and pumping (pumps and line clogging) of Hydrated Lime slurry.

Wet Application of Hydrated Lime

Wet application involves dispensing Hydrated Lime from a silo into a tank and mixed with water to create a slurry (Figure 15) . Treated mine water, either from a clarified portion of a settling pond or from the top of a clarifier, is the common source of slurry make up water if sulfate concentrations will not invoke gypsum precipitation. Some sites purchase municipal water and even fewer sites use a ground water well. A pump connected to a pH controller in the reaction tank controls the pumping of slurry to the dose point to maintain a pre-determined pH set point. Wet application has been far more popular than dry and is required if the dosing point is higher than the bottom of the silo or far away from the silo. Additionally, maintaining precise pH control is easier since pumps are generally more precise than various types of dry feeding systems.

2.2 Benefits/Drawbacks, Equipment and Typical Treatment Configurations

2.2.1 Benefits of Lime (CaO) vs. Hydrated Lime ($CaOH_2$)

The major reason why Lime is popular is because of its convenience and flexibility. The benefits of using Lime as a mine drainage treatment alkali include:

1. Lime costs between 10 and 20% less than Hydrated Lime, depending on price negotiation and market conditions;
2. CaO contains 25% more Lime than $Ca(OH)_2$ since it is anhydrous ;
3. The bulk density of Lime is approximately twice that of Hydrated Lime;
4. The practical effect of benefits #1 through #3 listed above include decreased chemical and transportation costs and storage requirements (smaller silo);
5. Lime is less dusty than Hydrated Lime;

2.2.2 Drawbacks

The drawbacks of using Lime vs. Hydrated Lime, include:

1. Increased capital cost of slaker equipment;
2. Increased operator knowledge to effectively operate slaker;
3. Increased operation and maintenance of slaker; and
4. Inefficient slaking will lead to increased Lime demand, and increased sludge generation which can delay or null equipment payback.

2.2.3 Application, Equipment, and Typical Treatment Configurations

Lime and Hydrated Lime treatment systems in Appalachia (Eastern U.S.) are typically used to treat high acidity load discharges despite the fact that they have significantly higher capital cost than Caustic Soda, Soda Ash, or Pre-Manufactured Lime slurry systems. Lime and Hydrated Lime systems contain much more sophisticated mechanical and electrical systems. They also require additional site attendance and maintenance. However, these extra costs and effort are quickly offset by the low cost per ton of alkalinity of Lime and Hydrated Lime that quickly make these two products the most economical choice for discharges containing a large acidity load. Unless dealing with extremely acidic low flow discharges, Hydrated Lime treatment systems start to be an option once flow rates exceed 250 gpm and become a very common treatment option for discharges that exceed 500 gpm. Discharges less than 250 gpm are typically treated with Caustic Soda, Pre-manufactured Lime Slurry, Soda Ash, or Passive Treatment technologies. It is important to note the flow-based criteria are provided to provide perspective and should not be considered guidelines. Treatment technology selection should be based on economics 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.

As previously described, Lime and Hydrated Lime equipment are very similar except for Lime systems contain slakers and Hydrated Lime systems contain slurry make down equipment, unless it is a dry feed Hydrated Lime system. Both use storage silos, dust control systems and electrical control panels, and silo dispensing mechanisms. It is common to purchase a complete turn-key system from a single manufacture. The turn-key systems contain the silo, silo dispensing equipment, slaker/slurry system, electrical control panel, all enclosed in a building under the silo. The system is delivered as a completed unit and erected using a crane by the manufacture. The operator is responsible for the foundation and electrical connections to the unit.

2.3 Financial Analysis between Lime and Hydrated Lime

The decision to design a Lime plant to slake Lime onsite or a Hydrated Lime plant can be a difficult decision. The decision to slake or not is largely determined based on whether the potential cost savings of using Lime is outweighs the convenience afforded by Hydrated Lime.

To provide perspective on the potential for cost savings, consider the treatment scenario showed in Table 2.

Flow	Acidity	Lime Purity	Hydrated Lime Purity	Est. Annual Lime Consumption	Est. Annual Hydrated Lime Consumption
5000 gpm	100 mg/L as $CaCO_3$	93%	96%	660 tons	845 tons

Increase in Capital Cost for Slaker	Lime Unit Cost	Hydrated Lime Unit Cost
$250,000	$140/ton	$160/ton

Lime Unit Cost	Hydrated Lime Unit Cost	Annual Chemical Cost savings using Lime
$92,505	$135,278	$42,773

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

The discharge characteristics and costs are reasonable for an abandoned mine pump and treat project in Pennsylvania. Assuming the increased capital cost associated with purchasing a slaker is $250,000 and the annual chemical cost savings is $42,773, it would take approximately six years to payback the investment in Lime treatment, assuming the operation and slaking process was efficient. While there are more in-depth approaches for analyzing the payback, this simple analysis shows there is potential cost savings for moderately sized treatment projects.

3.0 Lime Products 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) Dry Lime 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 Hydrated Lime or Lime, along with the *purity* and *mixing efficiency* and *unit cost*. 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 use the *Equipment and System Installation* heading to select and size treatment equipment. 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 silo refill frequency. The estimated cost to construct and operate the Lime 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 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 tanks.

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 Lime Information: Users can select to estimate the consumption and cost of either Hydrated Lime ($CaOH_2$) or Dry Lime (CaO). For either chemical, users must specify the *Purity* of the chemical and *Mixing Efficiency.* Lime producers can provide potential purchasers with the purity for either product. Hydrated Lime is refined from Lime, thus purer. Default purity for Hydrated Lime is 96% and 93% for Dry Lime. The impurities in Hydrate and Lime are typically consist of silicate and oxide minerals and will not dissolve and end up as grit (during slaking) or sludge.

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 a solid and requires mixing to promote and accelerate dissolution. If Lime is dosed without mechanical mixing or agitation, maybe only 50% of the Lime will 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*.

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 *Lime 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 Hydrated Lime Consumption.

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

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 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 Lime 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 *Foundation*.

Users use the *Storage and Dispensing System* to select the size of a “turnkey” Lime/Hydrated Lime treatment system to determine capital cost and specify the operational time for electric components to accurately estimate annual electric costs. allows users to: (1) Size and cost a "turnkey" Lime or Hydrated Lime treatment system, and (2) Specify operational time for various electrical equipment to accurately estimate electrical costs. Users size and estimate the foundation size for the Lime treatment system using the *Foundation* subsection.

3.2.4.1 Storage and Dispensing System *Lime/Hydrated Lime Treatment System Sizing*: Users can size a "turnkey" Lime or Hydrated Lime treatment system in 30, 60, 90, or 120-ton silo sizes (Figure 8) (See Section 3.2.4.2 for information on silo diameter and foundation size). The term "turnkey" refers to the purchase of a complete Lime/Hydrate system that includes everything needed to slake Lime or produce Hydrated Lime slurry. The system includes the pricing for the purchase and delivery of a single unit system that includes the silo, silo dispensing system, slaker or Hydrate slurry system, Slaked Lime/Hydrate slurry pump system (Figure 16), electrical panel (Figures 17, 18, & 19), and controls all enclosed in the base of a skirted silo for protection. The cost of a foundation and installation are not included by AMDTreat offers the ability to capture those costs

3.2.4.1 Storage and Dispensing System *Operational Time for Electrical Components*: The turnkey Lime and Hydrated Lime system contains several electrical components that require the user to specify the motor power and operational time to accurately model annual electrical costs. The operational time reflects the time period the component is turned on and drawing electricity. The following electrical components are included in the turnkey system:

1. Dust Collector Blower: The Dust Collector Blower is used to control Lime dust when the silo is replenished with Lime or Hydrated Lime (Figures 10 & 11). It will only operate while the semi-truck pneumatically pumps Lime into the silo. The annual electrical cost to operate the blower is calculated by using the *Silo Refill Frequency*, provided under Sizing Summary, to estimate the number of times each year the silo will be refilled. Users specify the amount of time it takes to refill the silo and it is multiplied by the number of silo refills to determine the hours of operation each year. The Blower motor horsepower along with the operational time and electric rate to calculate the annual electrical cost.

2. Bin Activator/Vibrator: The Bin Activator is a device attached to the bottom cone of the storage silo and periodically vibrates the side walls of the silo to prevent Hydrated Lime from "bridging" across the silo and to keep the silo free flowing. Users specify the motor power and the vibration frequency to estimate the annual electrical consumption and cost. (Figure 12)

3. Screw Feeder: The Screw Feeder is used to volumetrically dispense Lime products from the bottom of the silo to either a slaker or slurry make down system. The screw feeders only operate when the control system calls for Lime products. The default operational time is assumed to be 18 hr per day.

4. Slurry Mixer and Pump: Hydrated Lime systems have tank that mixes water with Hydrated Lime to produce slurry. The slurry mixer keeps the slurry mixed and homogenized (Figure 20). The pump is used to pump slurry from the tank to the point where it is dosed with mine water (Figure 16). The pump is usually controlled by a pH controller. Both devices are operating when the plant is treating mine water .

5. Silo Exhaust Fan: The Silo Exhaust Fan is located within the silo skirt and keeps fresh air within the silo (Figures 20 & 21). The 18x18" fan can be thermostatically controlled to help lower the temperature within the silo skirt during the summer months if a slaker is used.

6. Silo Space Heater: Space heaters are used heat the skirted silo space where the slaker/slurry system are located. The heats provide a comfortable environment for workers but also prevent slurry water pipes from freezing. The heaters are thematically controlled are only operated when temperatures drop below 40 degrees. Users should estimate the number of days the heater will be used to accurately estimate electrical costs.

3.2.4.2 Foundation: The first step in estimating the capital cost of the foundation for the turnkey Lime/Hydrate treatment system is to specify, or accept the default, *Concrete and Material Placement* unit cost used to calculate the cost to purchase, deliver, and form (including rebar) the concrete foundation. The second step is to either have AMDTreat estimate the required foundation volume by select *User-Specified* and specify the foundation volume. AMDTreat estimates the foundation area using the information in Table 3. Foundation thickness depends on soil quality selected. For "*Poor*" quality soils (1500 lbs/ft^2), foundation thickness is determined by multiplying the "standard thickness" show in Table 3 by 1.5 to achieve a 5.25 ft thick foundation. For "*Average*" quality soils (3000 lbs/ft^2), foundation thickness is the 3.5 ft shown in Table 3. For "*Excellent*" quality soils (4500 lbs/ft^2), foundation thickness is determined by multiplying the "standard thickness" show in Table 5 by 0.75 to achieve a 2.6 ft thick foundation.

For either sizing method, the foundation volume is multiplied by the *Concrete and Material Placement Unit Cost* to estimate the capital cost of the foundation. If no foundation is required, users can make the *Concrete and Material Placement* \$0.0 or enter a \$0.0 yd^3 for the *User-Specified* foundation volume.

Silo Size (ton)	Silo Diameter (ft)	Foundation Area (ft^2)	Foundation Thickness* (ft)
30	12	220	3.5
60	12	220	3.5
90	16	315	3.5
120	16	315	3.5

* Thickness will vary based on specified soils quality. See Section for more detail

Table 3: Relationship between user selected Silo size and foundation area.

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, storage silo refill frequency, and foundation size. The storage silo refill frequency provides users with an estimate of how often the storage tank will be refilled based on the silo capacity and estimated chemical consumption. This information is useful to help size a silo to hold a delivery of Lime for no more than 45 days to prevent recarbonation and bridging issues.

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 system. Users can opt to estimate the installation cost by specifying it as a percentage of the capital cost or by entering a 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.

- 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 3). 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.

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

$$\textit{Present Day Cost} \times (100\% + \textit{Inflation Rate})^{20} = \$20{,}000 \times (100\% + 5\%)^{20} = \$53{,}065 \quad (3)$$

- Annual Operation and Maintenance Cost: 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.

- Recapitalization Cost: 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 more than 20 large Lime/Hydrated Lime 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 ten recapitalization items for Lime and nine for Hydrated Lime treatment systems. 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 steel storage Silo is 40 years assuming it is not sandblasted and repainted at first sight of corrosion. However, if a Silo will be periodically repainted, users may opt to increase the Lifecyle. Users are free to fully customize the replacement items, including adding new items or deleting default items.

Silo: The Life Cycle of a Steel Storage Silo depends on how well the Silo is maintained to prevent corrosion. Silos that sandblasted and repainted at the first sight of corrosion have been known to last more than 60 years. On the other hand, Silos that are not maintained and allow corrosion to spread have required replacement after 30 years. After considering the condition and life of many steel Silos, the AMDTreat team feels 40 years is a good estimate without being able to predict the maintenance commitment. The estimate was developed after consultation with a Silo manufacture.

Bin Activator, Screw Feeder, Slurry Mixer, Slurry Pump, Silo Space Heater, and Slurry Tank: There are many factors that affect equipment longevity; however, a major Lime/Hydrated equipment manufacture and numerous plant operators were requested to provide "typical" estimates for longevity for a variety of Lime system components. The AMDTreat Team used the information to develop default Lifecycles for the major Lime/Hydrate componentry.

Hardware/Software: Many modern Lime and Hydrated Lime plants use automation and are computer controlled. The AMDTreat team have worked at several treatment plants where issues developed in the automation and hardware and software that was 15 years old was obsolete and could no longer be replaced or fixed. The rapid advancement in software and hardware can lead to significant costs to upgrade the system if issues arise. The AMDTreat team decided computer automation software and hardware become obsolete after 15 years and will require replacement if an issue arises.

Slaker: If Lime treatment is selected, AMDTreat automatically includes the slaker as equipment that requires recapitalization. After consultation with a major manufacture of Slakers, a Lifecyle of 25 years is assumed.

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

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5.0 Figures

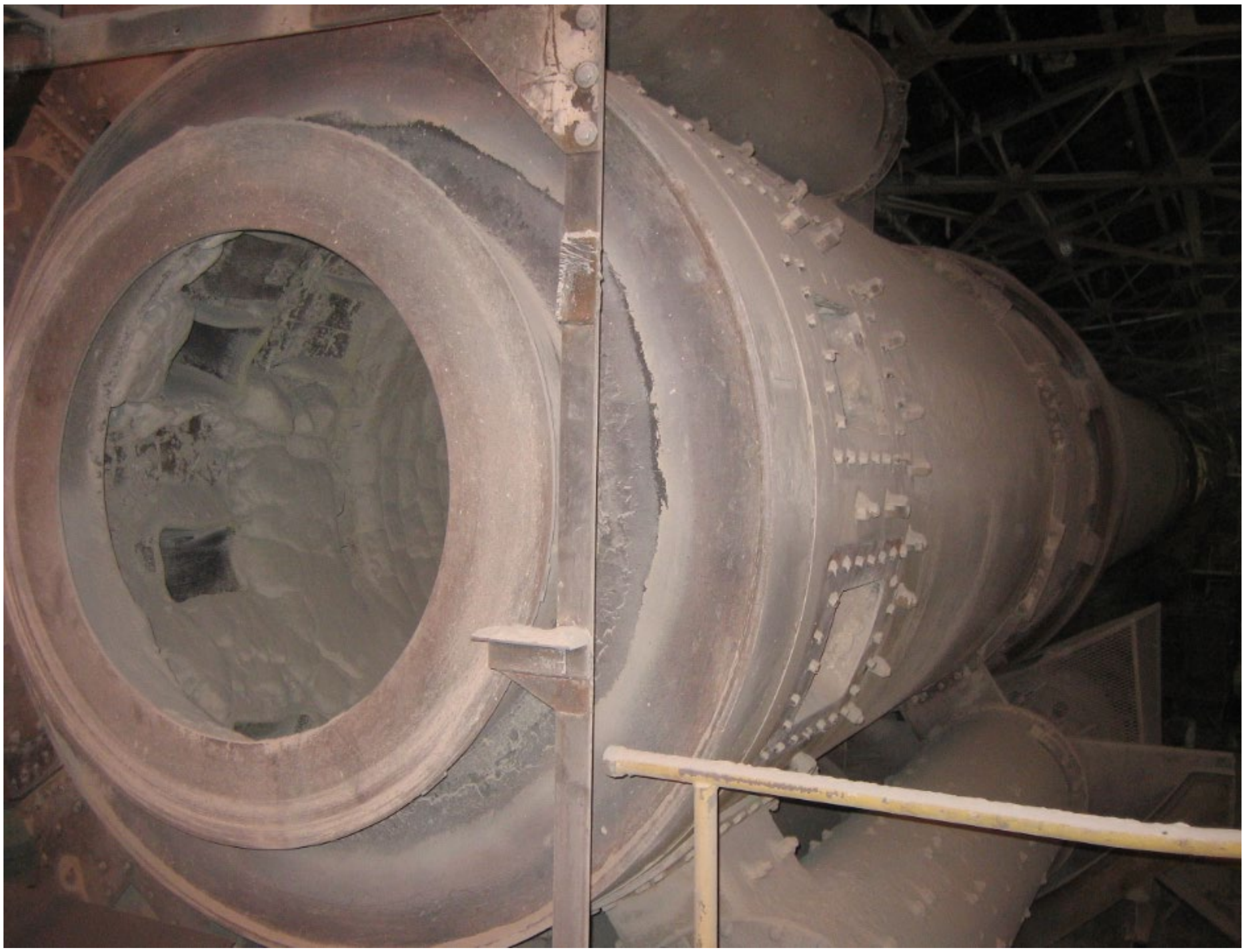

Figure 1: Rotary Kiln to produce Lime at a plant near Harrisburg, Pa

Figure 2: Alternative view of horizontal rotary kiln used to make Lime.

Figure 3: Slaker at a mine drainage treatment plant near Johnstown, Pa

Figure 4: Slaking chamber where Lime and water are mixed with paddles at a constant temperature.

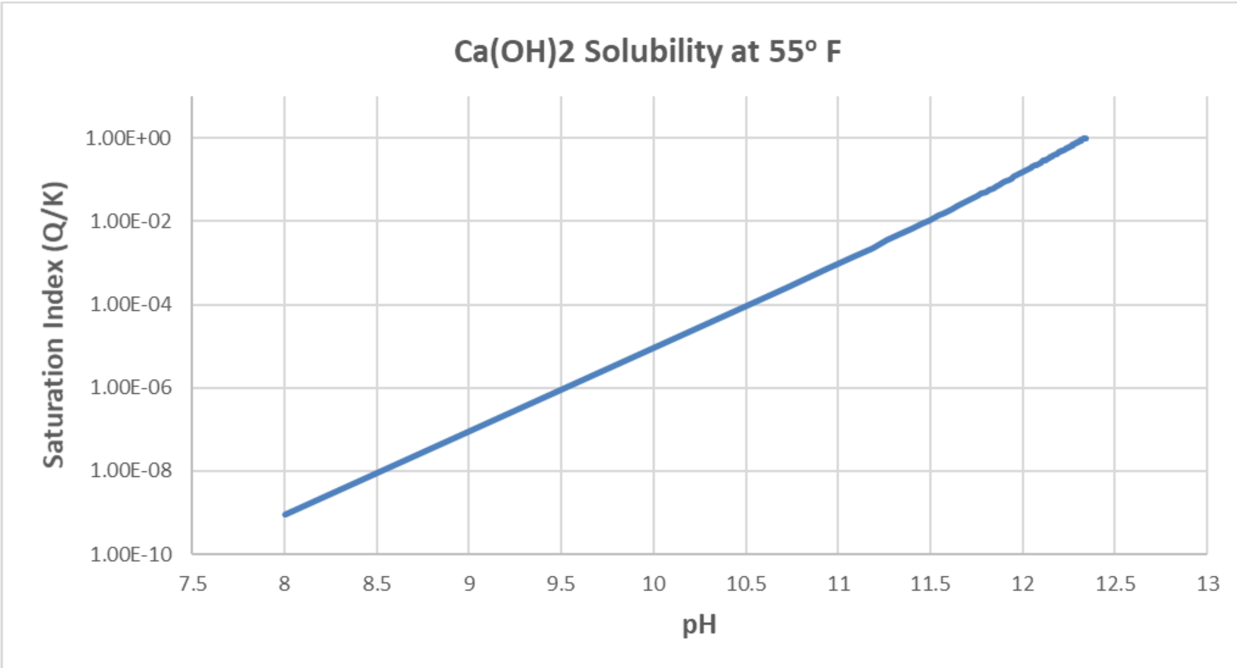

Figure 5: Graph showing saturated solution of $Ca(OH)_2$ is achieved at a pH of 12.4 at 55 °F.

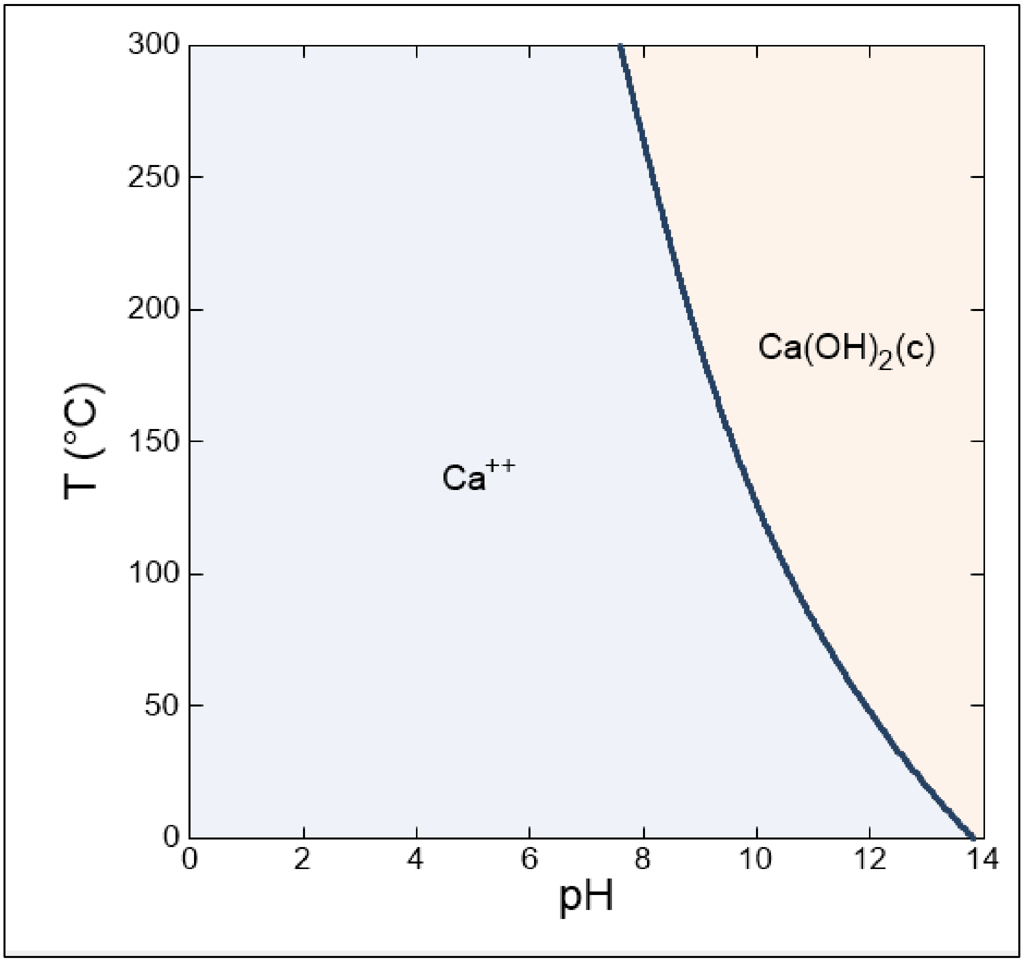

Figure 6: Graph showing the inverse relationship between solution temperature and solubility of $Ca(OH)_2$.

Figure 7: A 23-ton semi-truck pneumatically filling a 50- ton silo with hydrated lime. Note the fill line along the left side of the photo. Also, the fill line can be seen through the fence that connects the truck to the silo. Not the air exhaust line extending from the top of the right-hand side of the photo down to the reaction tank where the line is submerged to during filling to control lime dust. This 1960s-era silo lacks a filter bag air purification system onto of the silo.

Figure 8: 50-ton turn-key hydrated lime silo with bottom skirt that houses bin vibrators, electrical control panel, slurry tank, slurry mixers, slurry pumps, and electrical control panel (shown on silo). Note the fill line that connects to semi-trucks to pneumatically push 23-tons of hydrated lime up and into the top of the silo.

Figure 9: Photo of the fill line entering the top of the silo. Semi-Trucks carry approximately 23 tons of Hydrated Lime attach to the bottom of the fill line and pneumatically push the lime to the top of the silo. Note the blue housing that contains bag filters used to the evacuated exhaust air as lime is pushed into the silo during filling.

Figure 10: Alternative view of dust collection system on top of the silo. Motor and filter bags in blue housing remove hydrated lime exhaust dust during the filling of the silo.

Figure 11: Access to filter bag house to maintenance and replace filters on top of silo

Figure 12: Photo of dual silo cones beneath a 120-ton silo. The dual cones and hydrate feeder system provides redundancy incase the feeder system malfunctions. Note the orange 1-HP bin vibrator motors that vibrate the base of the silo to prevent lime from compacting and "bridging" across the base. The motors are time to vibrate the base of the silo for 30-secs every 5 minutes. The timers are adjustable.

Figure 13: Hydrated Lime silo and dispensing system “dry feeding” hydrate directing into mine drainage flowing underneath the system. This eliminates the need to make a slurry and pump a hydrate slurry to the dose point. Attention is required to ensure moisture from mine drainage doesn’t redecarbonate hydrate and cause feeding issues.

Figure 14: Simple hydrate system positioned overtop of a mine discharge to dry feed lime directly into the drainage flowing under the white building. A rock channel is used to create turbulence to aid in mixing and dissolving the lime into the drainage. Note the green ferrous iron hydroxide indicating the treatment pH is > 8.3.

Figure 15: Volumetric screw feed, hydrated lime slurry tank, and mixer positioned under the silo. Hydrated Lime and water are mixed in the slurry tank and pumped to the dose point.

Figure 16: Pumps used to pump Hydrated Lime slurry from the slurry tank, located under silo, through the red hose and to the dose point.

Figure 17: Electric control panel that controls dust collection bag filters that sit on top of silo and low and high silo fill alarms. This control panel is attached to the outside of the silo and operated when the silo is filled.

Figure 18: Electrical control panel located inside silo and controls slurry make up and pumping.

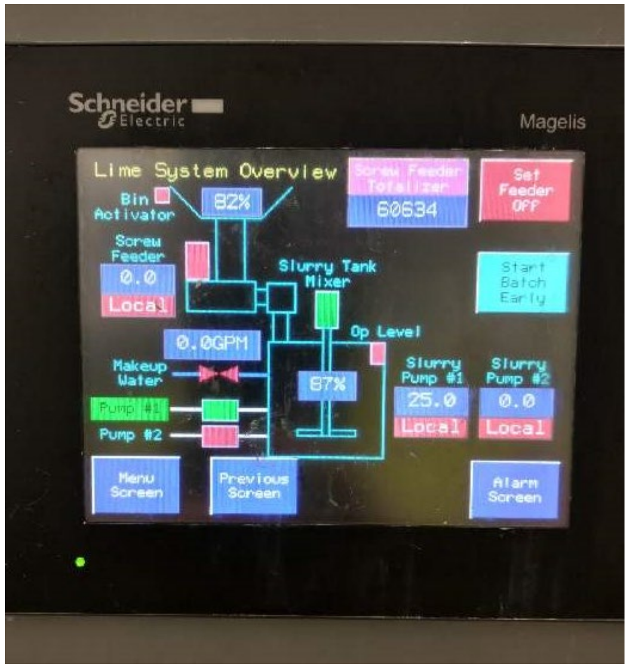

Figure 19: Close up of the touch screen attached to the face of the electrical control panel shown in Figure 18.

Figure 20: Mixer motor on top of Hydrated Lime slurry tank used to mix the hydrate with water. Note exhaust fan near top of photo to improve air quality within the skirt of the lime silo.

Figure 21: Exhaust fan shown near bottom of silo to remove hydrate dust and improve air quality within the silo skirt.