Help Instruction File:

Caustic Soda Module Overview

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

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Table of Contents

4.0 FIGURES 17

1.0 Objective

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

2.0 Overview and Application

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

Caustic Soda, also known as Sodium Hydroxide, has a chemical formula of NaOH and is produced as a co-product in the production of chlorine. Caustic soda exists as a solid but is highly soluble in water and is almost exclusively sold as a solution for mine drainage treatment. Solution strengths can be specified as percent (%) by weight, % by volume, or % by weight/volume. Attention to how the solution strength is specified is required when purchasing caustic soda and conducting price comparisons. The industry standard in mine drainage treatment is to discuss solution strengths in terms of % by weight (weight of caustic soda/weight of solution [w/w]).

Caustic soda is commercially produced and distributed as a 50% solution. Railroad tanker cars transport caustic soda as a 50% solution and distributers dilute the solution to customer specifications. Therefore, a 50% solution is always the most cost effective due to the high percentage of active ingredient and the lack of a dilution step. The common solution strengths used in mine drainage treatment are 20, 25, and 50% (w/w). While a 50% solution is the most cost effective, it begins to crystallize (freeze) at 54º F and solidification will plug containers and supply lines. In northern climates, 20 or 25% (w/w) solution strengths are used since they freeze at -12 and 0º F, respectively. A cost-conscious treatment strategy is to use 50% solutions during the summer months and a 20 or 25% solution during the colder months. Alternatively, it may be cost effective to store a tank of 50% solution in a heated building that maintains a temperature of at least 65º F, if the chemical cost savings from using 50% can offset the cost of heating the building. Maintaining a temperature of at least 65º F generates a favorable viscosity for dosing a 50% Caustic Soda solution. Table 1 provides characteristics of the common solution strengths.

Solution Strength (wt/wt)	Specific Gravity	Solution Density (lbs/gal)	lbs NaOH/gal solution
20%	1.226	10.215	2.430
25%	1.281	10.677	2.669
50%	1.537	12.804	6.402

Table 1: Specifications for common Caustic Soda Solution Strengths.

While Sodium Hydroxide is highly soluble, most transitional metal hydroxides are insoluble, therefore, Caustic Soda is used to adjust pH and precipitate dissolved transition metals found in mine drainage (Figure 1).

The two main alkali reagents used in mine drainage treatment are Caustic Soda and various manufactured derivatives of limestone, such as Lime (CaO), Hydrated Lime [$Ca(OH)_2$], and Pre-Manufactured Lime Slurry [Water + $Ca(OH)_2$, commonly produced between 30 and 38% solids by wt.]. Treatment professionals need to understand the relationship between neutralization capacity and price between different reagents to make informed treatment decisions. Table 2 provides neutralization characteristics of commonly used Caustic Soda solutions relative to lime-based reagents. The table shows a 50% Caustic Soda Solution has more neutralization capacity than an equivalent amount of Lime Slurry (38%), but lags well behind the capacity of Lime and Hydrated Lime.

	NaOH 20%	NaOH 25%	NaOH 50%	Lime Slurry (38%)	$Ca(OH)_2$	CaO
mg of $CaCO_3$ /mL reagent	306.0	399.8	959.0	680.2	3,165.0	6,080.1
lbs of $CaCO_3$ /gal reagent	2.55	3.34	8.00	5.68	26.41	50.74
lbs of $CaCO_3$ /lbs reagent	0.25	0.31	0.63	0.51	1.35	1.79
Gallons reagent/Ton Acidity ($CaCO_3$)*	783	599	249	352	75	39
lbs reagent/Ton Acidity ($CaCO_3$)*	8,001	6,401	3,200	3,731	1,542	1,204

* Represents the amount of reagent required to neutralize one ton of acidity ($CaCO_3$)
Note: CaO and $Ca(OH)_2$ assumed to be 93 and 96% pure

Table 2: Neutralization characteristics of various Caustic Soda solutions compared to other common alkaline treatment reagents

Unlike caustic soda, Lime products are insoluble and require mixing with water to create a slurry for transport to the dosing location and to improve dispersion and mixing with mine drainage. Most of the neutralization potential in the slurry is contained in the suspended hydrated lime particles and not dissolved in the alkaline solution. Thus, lime products require an additional step of dissolving the suspended particle before hydroxyl ions are available for mine drainage neutralization. In this regard, caustic soda has an advantage over lime products. caustic soda is highly soluble, quick reacting and requires little mixing. Simply dripping a caustic soda solution directly into turbulent flowing mine drainage provides sufficient mixing for treatment. A solution of Caustic Soda is denser than water so dripping the solution directly into a pond or very slow-moving water may result in the accumulation of chemical at the pond bottom and cause chemical inefficiency (actual dose > theoretical dose).

The convenience afforded by the easy dosing, mixing, and quick reactions make Caustic Soda a very popular mine drainage treatment reagent. Caustic Soda is the most commonly used active treatment chemical in the Appalachian coal fields of the eastern U.S. according to the Office of Surface Mining Reclamation and Enforcement's (OSMRE) mine drainage inventory, On the other hand, Caustic Soda is a commodity, which in the past, has experienced large fluctuations in pricing that makes financial planning difficult (e.g. market price doubled within a year). Furthermore, caustic soda has the highest price-per-ton of alkalinity ($/ton of $CaCO_3$) of any of the popular mine drainage treatment alkaline reagents so there is a trade off between convenience and cost (Table 3). This is further discussed in the Application and Financial Analysis section.

	NaOH 20%	NaOH 25%	NaOH 50%	Lime Slurry (38%)	$Ca(OH)_2$	CaO
$/lbs	$0.101	$0.088	$0.093	$0.150	$0.080	$0.073
$/gal	$1.03	$0.94	$1.19	$0.60	$1.56	$2.06
$/Ton of Alkalinity*	$808.09	$563.26	$297.63	$212.67	$118.40	$81.20

*Alkalinity expressed as $CaCO_3$
Table 3: Bulk delivery pricing in Eastern U.S. for various alkaline chemicals (2020).

2.2 Benefits/Drawbacks, Net Alkaline Applications, Equipment and Typical Treatment Configurations

2.2.1 Benefits

The major reason why caustic soda is popular is because of its convenience and flexibility. The benefits of using caustic soda as a mine drainage treatment alkaline reagent include:

1. 100% soluble and quick reacting;
2. Reactivity and solubility allow for precise pH control;
3. Effectively mixed using passive mixing methods, involving turbulent flow;
4. Caustic Soda can be deployed and operated without electricity using manual drip addition or fully automated with electricity including use of a metering pump and pH controller;
5. Can be configured without any moving parts making it low maintenance;
6. Very small footprint, commonly less than 200 ft^2, and tanks can be set vertically to lessen footprint;
7. Caustic Soda can be stored and dosed from either a steel or poly tank capable of accepting bulk deliveries or from a delivered 275 or 330-gallon tote that is periodically replaced by a chemical distributor;
8. Caustic Soda is relatively stable, which allows for long-term storage in instances of ephemeral or periodic treatment;
9. Produces a low-density sludge that is easier to pump than Lime-generated sludge;
10. Can achieve > pH 13.0 treatment; and
11. Less prone to calcite precipitation and scale compared to the use of Lime products.

2.2.2 Drawbacks

The drawbacks of using caustic soda as a mine drainage treatment alkaline reagent include:

1. Safety concerns with handling and storage;
2. Pricing fluctuations make financial planning difficult;
3. Expense in terms of $/ton of alkalinity relative to Lime products; and
4. Typically produces a more voluminous sludge compared to Lime products, which may result in the need for more frequent sludge removal.

2.2.3 Net Alkaline Applications

Caustic soda is typically used to treat net acidic mine drainage; however, it can be used to treat net alkaline mine drainage. While many prefer to use passive treatment for treating net alkaline mine drainage, caustic soda is used in instances where ferrous iron and manganese cannot be removed because of land restrictions or in instances where the operator requires additional operational control to prevent effluent violations. Caustic soda is typically selected as the treatment reagent for a site based on:

1. Convenience of use (requires little mixing, fast reacting, etc);
2. Does not require electricity for use; and
3. Very low capital cost for equipment.

2.2.4 Equipment and Typical Treatment Configurations

The majority of caustic soda treatment systems in the Appalachian coal fields of the eastern U.S. are manually operated (non-electrical) systems that consist of three items: (1) a chemical storage tank/tote, (2) feeder line, and (3) a manually operated value to control reagent dosing. In most of these cases, caustic soda is selected because the remote mine site lacks electricity, which eliminates many Lime-based chemicals that require electric for dosing and operation.

<u>Storage Totes & Tanks and Fittings</u>

For low acidity loading mine discharges, many operators choose to store and dose from either 275 or 330-gallon storage totes that are delivered and periodically replaced by the chemical supply company (Figure 3). The totes are portable and easily moved around onsite using a skid steer, tractor, or truck mounted crane. Operators typically store several totes at a site to ensure ample supply in case of inclement weather or other delivery issues. Feeder line is attached to the tote via the 2-inch threaded camlock valve at the bottom of the tote (Figures 4 & 5) and extended to the application location where a valve is used to control the dose of caustic soda into the mine drainage. As a tote nears empty, treatment operators simply disconnect the feeder line from the camlock valve assembly and reconnect to a full tote. The chemical supply company removes the empty tote while delivering a new tote. While using totes supplied by the chemical distribution company is convenient, the unit cost for Caustic Soda delivered in this manner is generally higher since it is considered a non-bulk volume. Therefore, totes are only used for small acidity loading dischargers or in cases of intermittent flow.

For larger acidity loading discharges, 5,000-gallon storage tanks are used to take advantage of bulk deliveries and the discounted chemical pricing. Based on weight restrictions of public access roads, bulk deliveries of caustic soda typically range from 3,000 to 4,000-gallons, depending on the solution strength density. A 5,000-gallon caustic soda storage tank allows for bulk chemical deliveries while providing reserve capacity. Bulk storage tanks are commonly comprised of double-walled plastics, such as, polypropylene or polyethylene (Figures 6 & 7) or carbon steel (Figures 8 & 9). Caustic Soda is corrosive, and flakes of corroded iron will contaminate the solution unless the steel tank is epoxy lined (especially when using 50% Caustic Soda), however, unlined steel tanks are commonly used in mine drainage treatment. Steel tanks are commonly constructed from 1/4“steel plate, which provides for a 1/8” allowance for corrosion. It is important to note that storage tanks, feeder lines, and any fittings cannot be made from aluminum, copper, zinc, galvanized steel, lead, brass, or bronze. Feeder lines and fittings are commonly constructed of black iron, steel, CPVC, or polypropylene. Be sure to select Caustic Soda compatible PVC cements to avoid leaks at joints (Figure 10).

Storage tanks can be positioned horizontally or vertically and all tanks should have the discharge orifice located 3 to 6" from the tank bottom to allow for the accumulation of impurities. A drainage valve should be located at the bottom to allow the tank to be fully emptied for inspection and cleaning. All storage tanks need level indicators for supply management (Figure 11); however, the solution level is typically visible through the sidewalls of poly tanks (Figure 6). Needle valves are commonly used for chemical dosing in mine drainage treatment to provide precise pH control, although ball valves can also be used when treating high flow conditions. Needle valves are operated by turning a wheel that raises or lowers a needle to open or restrict flow through the feeder tubing (Figures 12 & 13).

While the majority of caustic soda systems in the Eastern U.S. are manually operated and dosed, manual systems require daily adjustment to prevent over or under treatment when the acidity loading of the mine drainage changes. A manual system is not an issue while the mine site is active and personnel are present, but the daily or every other day site visits become more costly after the site is reclaimed and unmanned. In addition, several sites have received regulatory violations for discharging pH > 9.0 water in their outfall because the caustic soda dose was not adjusted when the mine drainage acidity loading decreased. As a result, there is an increase in pH-controlled dosing systems using metering pumps that automatically change dose to maintain a pH set point and, in some instances, reduce the need for daily site visits.

Whether the caustic soda system is manually or automatically dosed, nearly 100% of the systems use passive mixing where the reagent is dosed directly into flowing water, mostly in a ditch, and allowed to mix and react for less than a minute before entering a settling pond for sedimentation.

2.3 Application and Financial Analysis

The benefit of cost savings generally outweighs the benefits of convenience and simple cost evaluations that prove Caustic Soda is best suited for treating low to moderate acidity loading discharges (e.g., <105 tons of $CaCO_3$/yr). The major chemical competitor of caustic soda is Pre-Manufactured Lime Slurry (Lime Slurry) because both systems are relatively simple, have a small footprint and low power requirements, which is a benefit at rural mine sites. Like caustic soda, lime slurry is purchased from a chemical distributor ready to dispense and does not require any additional equipment to prepare the chemical for use (unlike dry lime products).

A basic financial analysis helps to illustrate why caustic soda is best suited for low to moderate acidity loadings. In most cases a simple manual caustic soda system can be purchased and installed for less than $10,000. A Lime Slurry system can be purchased and installed for $100,000 assuming electricity is available. This analysis assumes both systems use turbulent water flow for mixing and both labor and maintenance costs are similar, even though most Lime Slurry applications use mechanical mixing resulting in higher maintenance costs. Assuming a $90,000 difference in capital cost and chemical pricing is shown in Table 3, Figure 2 shows it would take 20 years before the cost savings of installing a Lime Slurry system would be realized over installing a 50% Caustic Soda system for an annual acidity load of 65 tons ($CaCO_3$). At an annual acidity loading of 100 tons ($CaCO_3$), more than 10 years of treatment would be required before a Lime Slurry would be less expensive to operate than a 50% Caustic Soda treatment system. Generally, mine drainage treatment is a long-term endeavor; however, many operators make decisions using a 5 to 10-year payback analysis. Many operators will not invest in a cost effective, but more expensive, treatment system unless the system will pay for itself within 10 years. Table 4 shows the annual acidity loadings required to pay off the capital investment for a Lime Slurry system within 10 years. Table 4 shows a 20% Caustic Soda system would be less expensive to treat a 15 ton/year acid load up until 10 years, however, after 10 years a Lime Slurry system would be less expensive.

Annual Acidity loading required to achieve a 10-year payback compared to Pre-Manufactured Lime Slurry

	Annual Acidity Loading*
20% NaOH	15
25% NaOH	25
50% NaOH	105

*Tons $CaCO_3$/yr

Table 4: Annual acidity loading required to achieve a 10-year payback of installing a Pre-Manufactured Lime Slurry system vs 3 different Caustic Soda solutions.

3.0 Caustic Soda 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-hand side. The module inputs on the left-hand side are arranged into six sections: (1) Water Quality and Flow Input, (2) Caustic Soda Information, (3) Chemical Consumption, (4) Equipment and System Installation, (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. Next, the user selects the *Caustic Soda Solution* strength, along with the *purity* and *mixing efficiency* and select the method to estimate the caustic soda consumption (*Stoichiometric, Titration,* or *User-Specified Quantity*). AMDTreat uses this information along with the acidity load to estimate the annual caustic soda consumption. Next, the *Equipment and System Installation* section allows the user to select and size the treatment system equipment. Additionally, users can use this section to specify the operational frequency and duration of the treatment system to ensure chemical consumption and electrical costs are correctly estimated. Finally, users can specify additional capital and annual costs not considered by the module under the *Other Capital Items* and *Other Annual Items*.

Calculated 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 storage tank refill frequency for the system. The estimated cost to construct and operate the caustic soda treatment system is provided under the *Capital Cost* and *Annual Cost* headings. Lastly, users can choose to conduct a Net Present Value (NPV) analysis to obtain the total cost to operate and maintain a treatment system for a defined time period.

A general overview of the module input and output sections is presented below, however, users are directed to the numerous tool tips located in the module that provide additional detailed information, such as definitions of terminology. In most cases, the tool tips are accessed by clicking on the information icon ( ) in each of the headings and subheadings within 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 for the mine drainage. 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 include 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 the hydroxylation of cations need to be considered as well.

3.2.2 Caustic Soda Information: Users can select from the three common *Caustic Soda Solution* strengths used to treat mine drainage, 20, 25, or 50% by weight. In addition, users can specify the purity and mixing efficiency of the Caustic Soda solution. In the past, there have been instances where operators have purchased caustic soda that was previously used to clean rail cars and other containers due to favorable pricing. The caustic soda contained a higher concentration of impurities but was still useable to treatment mine drainage. *Purity of Caustic Soda* can be adjusted to represent the solution purity. In most cases, the default value of 99% should be used. *Mixing Efficiency* is used to simulate the percentage of chemical being dosed that is actually dissolving or participating in the treatment reactions. For example, the *Mixing Efficiency* may be 50% if Caustic Soda is dosed directly into a pond and not mixed. In this case, Caustic Soda would quickly sink to the bottom of the bond and not comingle with untreated water so it would require dosing at much higher rates than the theoretical requirement to compensate for the mixing inefficiency. If the Caustic Soda *Mixing Efficiency* is set to 50%, the estimated dose will be twice the theoretical amount.

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 *Caustic Soda Information* headings. The method uses the values for *Typical Flow* and *Net Acidity* to calculate the annual acidity loading in Calcium Carbonate Equivalents.

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

Where:
A.L. = Annual Acidity Load in grams $CaCO_3$/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 NaOH to re-express the acidity load in terms of NaOH.

$$NaOH_L = \left(A.L.\frac{g\ CaCO_3}{yr}\right) * \frac{Mole\ CaCO_3}{100\ g} * \frac{2\ Mole\ H^+}{1\ Mole\ CaCO_3} * \frac{Mole\ NaOH}{1\ Mole\ H^+} * \frac{40\ g}{1\ Mole\ NaOH} \quad \textbf{(2)}$$

$NaOH_L$ = Annual Acidity Loading in grams/yr expressed as NaOH

Finally, the program uses an appropriate solution density for the user-selected Caustic Soda solution strength to determine the annual amount of Caustic Soda required to neutralize the acidity load. The annual amount will be adjusted for the user-specified values for the *Purity* and *Mixing Efficiency* of the Caustic Soda solution.

$$\frac{6.402\ lbs\ NaOH}{Gal\ 50\%\ NaOH\ Solution} = \frac{12.804\ lbs}{gallon\ of\ 50\%\ NaOH\ Solution} * \left[\frac{50\%\ NaOH\ Solution\ by\ wt.}{100}\right] \quad \textbf{(3)}$$

$$NaOH_{gal} = \left(NaOH_L\ \frac{g}{yr}\right) * \frac{1\ lbs}{454\ g} * \left[\frac{1\ gallon\ 50\%\ NaOH\ Solution}{6.402\ lbs\ NaOH}\right] \quad \textbf{(4)}$$

$$Adjusted\ NaOH_{gal} = \frac{NaOH_{gal}\frac{gal}{yr}}{\frac{Purity\ of\ Cuastic\ Solution * Mixing\ Efficiency\ of\ Cuastic\ Solution}{100}} \quad (5)$$

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.

Users must enter the results of the titration data in terms of gallons of Caustic Soda required to treat a gallon of mine drainage. Since the Caustic Soda solution strength and purity is inherently contained in the titration input value, AMDTreat does not use values for *Caustic Soda Solution* strength or *Purity* when the Titration method is selected. However, users can enter *Mixing Efficiency* values if they feel the actual mixing efficiency will differ from the efficiency experienced during the titration.

$$Adj.NaOH_{gal} = \left(Flow\ \frac{gal}{min}\right) * \left(Titration\frac{gal\ NaOH}{gal\ AMD}\right) * \frac{60min}{hr} * \frac{24\ hr}{day} * \frac{365\ day}{yr} * \frac{1}{\frac{Mix\ Eff.}{100}} \quad \textbf{(6)}$$

Where:
Mix Eff. = Mixing Efficiency
Adj. $NaOH_{gal}$ = Annual Caustic Soda Consumption adjusted for Mixing Efficiency

3.2.3.3 User-Specified Quantity - This method allows users to specify the annual Caustic Soda consumption, which is most common for an existing treatment system where the annual quantity of chemical usage is well known. This AMDTreat method is typically used to evaluate long-term water treatment liability using the *Net Present Value* calculations.

3.2.4 Equipment and System Installation

3.2.4 Equipment and System Installation: This section allows users to design and select the components of a Caustic Soda treatment system. The majority of Caustic Soda treatment systems used in mine drainage treatment are fairly simplistic, so users are only faced with making two important choices, whether to install an automated or manually operated system and the volume and material of a Caustic Soda storage tank.

3.2.4.1 Automated System: If the checkbox for Automated System is not selected, AMDTreat assumes the Caustic Soda System will be a manual system. By selecting the checkbox, users can include the cost of a Proportional Integral Derivative controller (PID), a pH probe, and a chemical metering pump to automatically control the Caustic Soda dose. The PID control is a control loop mechanism that continuously evaluates the treatment pH against the pH set point and automatically adjusts the Caustic Soda pump dosing to minimize the difference. This type of system is very effective at maintaining a set treatment pH that can automatically adjust to changes in flow and/or acidity.

If an automated system is selected, users can specify the Daily and Annual Operational Period. These inputs capture the frequency and duration of operating the treatment system. This information is used to determine the operating cost of the chemical metering pump.

3.2.4.2 Tank Volume and Tank Type: Users need to specify the volume of the chemical storage tank. Users should use the estimate of the annual chemical consumption to help size the storage tank. In addition, users need to specify whether they want a Poly or Steel storage tank.

If users do not select an Automated System, then a manually operated system is assumed and users need to specify the number of valves and length of chemical feeder line required. The primary equipment for a manual Caustic Soda system requires a storage tank, dosing valve, and feeder line. Examples of this type of manual system are shown in Figures 5 through 9.

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 Caustic Soda treatment systems have electronic surveillance to notify authorities if unauthorized persons attempt to interfere with the equipment/system. Since this is uncommon it was not included in the module, however, users who want to include this capability or any other equipment/item can input the description, quantity, and unit 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 annual cost of equipment and other items/services that are not included in this module. For example, users could include the annual subscription cost to conduct electronic surveillance on the treatment system in the *Other Annual Items* section.

3.3 Module Outputs

3.3.1 Sizing Summary: The Sizing Summary section displays important calculated module outputs, such as the estimated chemical consumption, storage tank refill frequency, and operational time of the chemical metering pump (if the Automated System check box is selected under *the Equipment and System Installation* section). The storage tank refill frequency provides users with an estimate of how often the storage tank will need refilled based on the selected tank volume and estimated chemical consumption.

3.3.2 Capital Cost: This section provides the estimated costs for the various user-specified components and the total estimated cost to construct the Caustic Soda system. Users can estimate the installation cost by specifying it as a percentage of the capital cost or by entering a known installation cost. Likewise, users can have the program estimate the capital cost of the Caustic Soda storage tank or specify the known cost.

3.3.3 Annual Cost: The annual cost section provides an estimate of the annual cost to operate and maintain the Caustic Soda treatment system. Users can select to have AMDTreat estimate the annual chemical cost or specify a known annual chemical cost. Specifying a known annual chemical cost is often used when AMDTreat's Net Present Value calculations are being used to estimate water treatment liability. The annual Operation & Maintenance (O&M) 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 systems are more costly to operate and maintain.

3.3.4 Net Present Value: The Net Present Value (NPV) section determines the cost to operate a treatment system component over a specified time period. The NPV calculates the present-day financial investment required to generate the income to pay for future O&M 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 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, please 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 1). 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.

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

- 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. AMDTreat Team members are located in Pennsylvania and West Virginia and have collective experience in design, funding, and/or operation/maintenance for well over 100 passive treatment systems. The AMDTreat Team held discussions on personal experience to develop a list of recapitalization recommendations. Users may however have different experiences and opinions than those listed.

By default, AMDTreat includes a list of four recapitalization items for Automated Caustic Soda systems (if Automated System checkbox is selected) and two items for manual systems (if Automated System checkbox is not selected). Users can delete or modify any of the default recapitalization items by either deselecting the item or by setting the Replacement % to zero. If the item is deselected the Total Cost for the item will still be shown but the cost will be subtracted from the Net Present Value Cost, shown in the Net Present Value heading. For example, the default value for the life cycle of a Plastic (poly) storage tank is 10 years due to degradation from ultraviolet light. However, users may opt to increase the life cycle if the poly tank will be housed in a building. Users are free to fully customize the replacement items, including adding new items or deleting default items.

Storage Tank: The life cycle of a steel storage tank depends on how well the bottom of the tank is protected from ground moisture, how often it is sandblasted and painted, and whether the tank is vandalized. After considering the condition and life of many steel tanks, the AMDTreat team feels 30 years is a good estimate as long as the tank is on a concrete or gravel foundation/pad or on wooden cribbing to prevent contact with ground moisture. A much longer life cycle may be appropriate if the storage tank is cleaned, primed, and painted when corrosion becomes visible.

The default life cycle for a poly tank is 10 years. This value was determined after discussing tank longevity with chemical distribution companies and tank manufactures assuming the tank would be placed outside and open to the atmosphere. Ultraviolet light will degrade poly tanks.

PID pH Controller: PID pH controllers are being more popular to control caustic soda dosing. Since their use in our industry is still infrequent and relatively recent, the AMDTreat team cannot offer their experience to suggest a life cycle. However, after conducting some research, we are recommending a life cycle of 10 years before the equipment requires replacement.

Chemical Pump: Determining the life cycle of a chemical pump can be difficult as it depends on many factors including the quality and maintenance of the pump. Furthermore, some pumps are not replaced but rather are periodically rebuilt and placed back into operation. After speaking to treatment operators and using personal experience, we recommend a life cycle of 5 years for the type of pump presented in the module.

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 Caustic Soda 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) analytical procedure to determine Net Acidity. In most instances, a Hot Acidity titration result will not accurately describe the base requirement to achieve effluent standards. A cold acidity titration is the best method to determine the Net Acidity encountered during treatment.

4.0 Figures

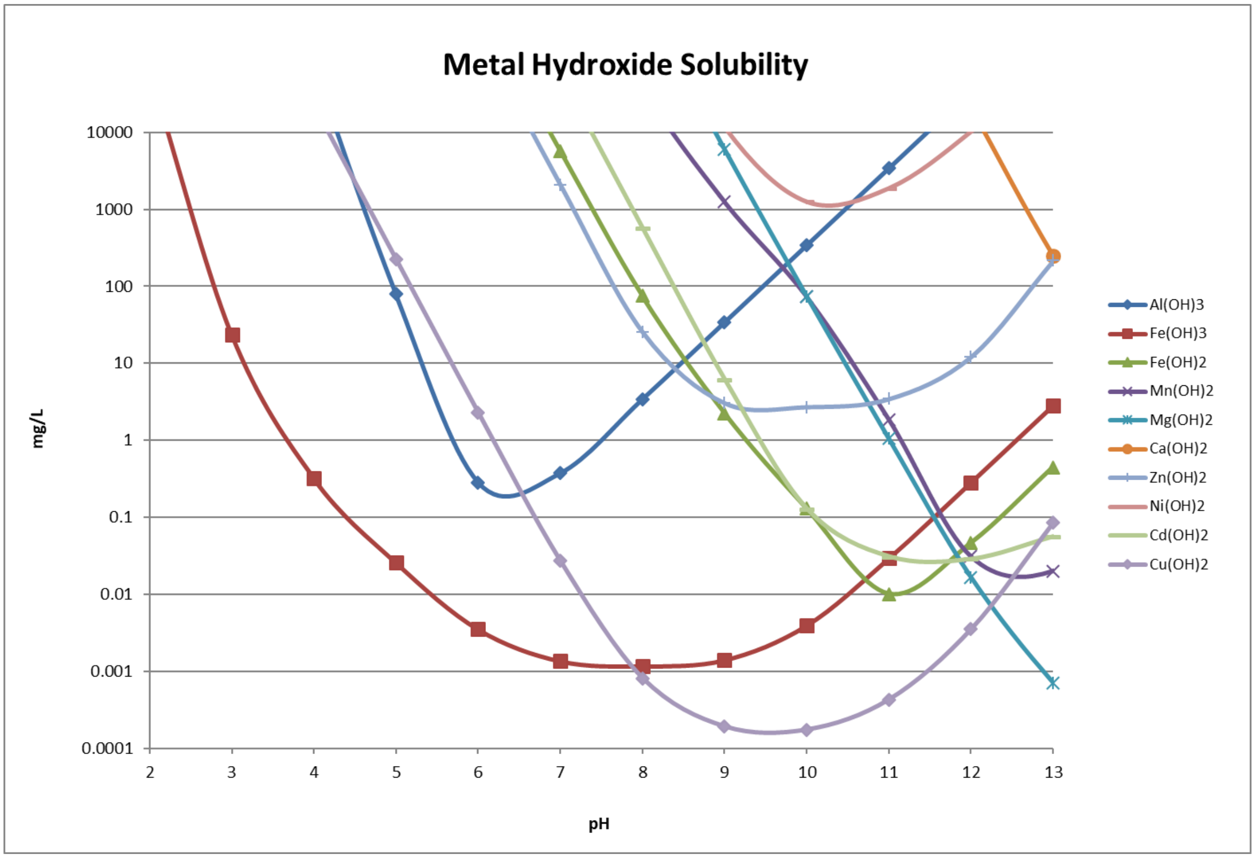

Figure 1: Solubility of transition metal hydroxides

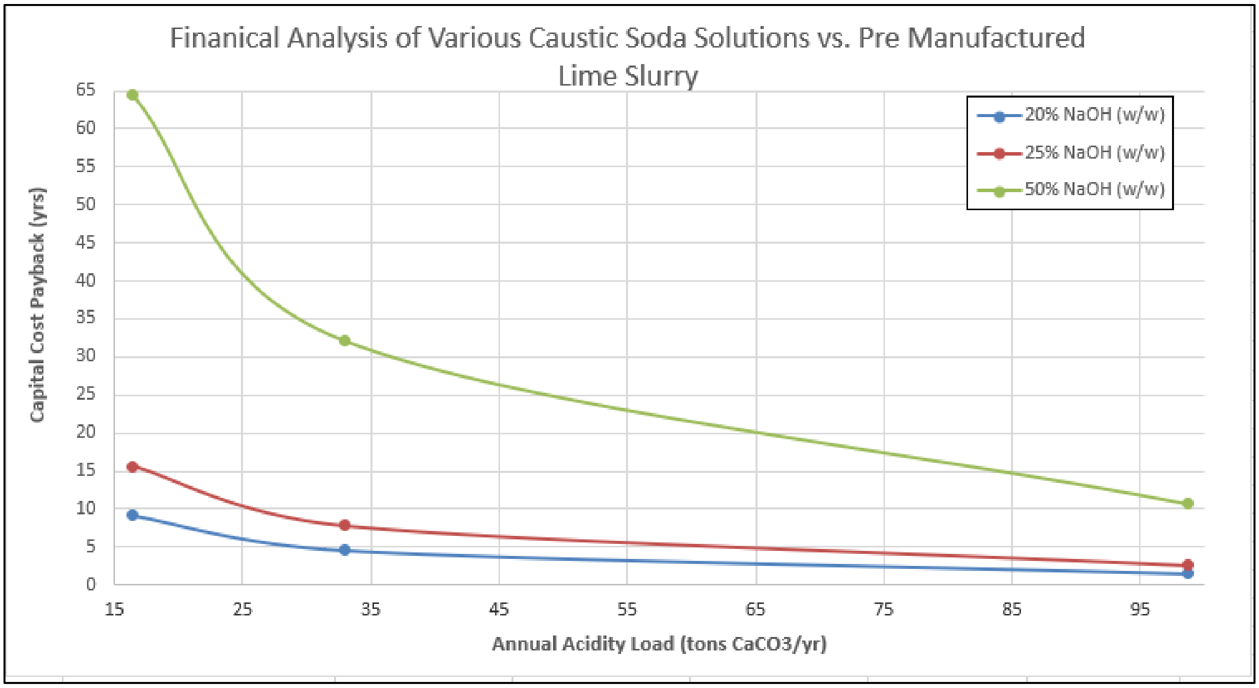

Figure 2: Financial analysis comparing the cost to purchase, install, and operate a Pre-Manufactured Lime Slurry treatment system to operating a Caustic Soda system at 3 different solution strengths for a variety of annual acidity loadings.

Figure 3: Caustic Soda being dispensed directly from a 330-gallon chemical storage tote. A poly feeder line and valve are attached to the tote for manual dosing.

Figure 4: Picture of the 2-inch camlock valve assembly for connecting hoses and lines to Caustic Soda totes. The camlock is used for quick connects to hoses while the NPT threaded connection is used for connecting to poly feeder line.

Figure 5: Picture of a 330-gallon tote of 25% Caustic Soda Solution being dosed from the 2-inch camlock valve assembly through poly feeder tubing. Note the reserve totes in the background.

Figure 6: Photo of a 2,500-gallon poly tank filled with 20% NaOH. Note the fill level can easily be seen through the poly tank. The unit cost of Caustic Soda will be more since this is less than a bulk delivery. Having two sites that use 2,500-gallon tanks will allow for a split delivery to obtain optimal pricing.

Figure 7: Photo of a 500-gallon poly tank. Mine drainage is in the black corrugated pipe and is dosed with Caustic Soda at the area circled in red.

Figure 8: Photo of a "typical" manually operated steel tank Caustic Soda treatment system. A 6,000-gallon steel tank is set on wooden cribbing to prevent contact between ground moisture and the tank. A red circle highlights the poly feeder line and manually adjusted valve that doses the mine drainage below.

Figure 9: A steel tank capable of accepting bulk deliveries of Caustic Soda. A dosing line and valve are secured in place by a wooden trough. Note the whitish-colored aluminum hydroxide precipitate forming at the point of addition, which illustrates the quick precipitation reaction.

Figure 10: Steel Caustic Soda storage tank and poly feeder line. Note the lack of vegetation indicating a Caustic Soda leak.

Figure 11: Photo of a 10,000-gallon steel Caustic Soda storage tank with caustic level sight tubing

Figure 12: Grey needle valve used to control Caustic Soda dose into mine drainage. Notice a ball valve is located before the needle valve to prevent pressured flow to the needle valve to provide better control when a low dose is required.

Figure 13: Another example of a needle valve being used for precise control of Caustic Soda dose.