Help Instruction File:

Clarifier 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).

Clarifier Module Overview

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1.0 Objective

The objectives of this overview are to: (1) Provide an understanding of the application of Clarifiers in mine drainage treatment and (2) Provide an overview of the Clarifier Module to guide users in developing an estimate of the cost to construct, operate, and maintain clarifiers at mine drainage treatment sites. The information is presented in two sections, **Overview** and **Clarifier Module Overview**. It needs to be stressed the Clarifier module is a tool for reverse cost modeling or developing rough costs for the construction and operation of clarifiers and not for final design.

2.0 Overview

In the treatment of coal mine drainage in the eastern U.S., ponds and conventional clarifiers are the two common technologies used to separate suspended particles from water; a process known as clarification. Coal companies are more apt to use ponds for clarification, whereas government entities are more inclined to use clarifiers. However, in large pump and treat scenarios both entities commonly use clarifiers. Clarifiers are settling tanks used for solid-liquid separation and they also include a sludge management system .

A basic understanding of the data requirements and application of clarifiers is required to develop a treatment strategy using the AMDTreat software. These topics are discussed below to provide the necessary context before discussing the clarifier module interface and functionality. The Overview section first provides a description of how clarifiers are typically utilized to treat coal mine drainage in the eastern US which is then followed by additional sections: (1) Settling Tests and (2) Clarifier Options, and (3) Treatment Options.

2.1 Settling Tests

Understanding the relationship between the concentration and settling rate of precipitated particles and effluent clarity is important. Generally, low concentrations of precipitated particles (produced solids) result in a fast particle settling rate but will result in poor effluent clarity. When particle concentrations are low, flocculated particles tend to settle uninterrupted and without influence from other particles that result in a fast-settling rate. However, the low solids concentrations will result in infrequent collisions between particles and will result in both poor flocculation and effluent clarity. Particle collisions and interactions are needed to agglomerate smaller particles into large particles to produce low turbidity effluent. Alternatively, if the concentration of solids becomes too high, constant particle-to-particle interactions will hinder particle settling and result in a slow settling rate. On the other hand, the numerous particle interactions promote flocculation and produce a clear effluent. Therefore, the goal of settling tests is to identify the optimum balance between the concentration of solids required to produce clarity and settling rate to minimize the size of the clarifier.

It is important to note the term “solids concentration” refers to the total concentration of suspended solids entering the clarifier or settling basin. The suspended particles include the particles “produced” or precipitated during treatment reactions, particles of unreacted hydrated lime or other reagents, and the solids that are or planned to be recirculated from the clarifier underflow back to the reaction tank (external recirculation) or to the center well (internal recirculation).

In general, if the total suspended solids (precipitated + recycle + lime) predicted to enter the clarifier is:

- < 150 mg/L, there is a high likelihood of poor effluent clarity and solids from the clarifier underflow (sludge) will need to be recycled to the reaction tank (external recirculation) or internally recirculated within the clarifier to increase the total suspended solids concentration to achieve effluent clarity;

- > 150 < 800 mg/L, there may be enough produced solids to produce effluent clarity without the need of recirculating solids;

- >800 < 3000 mg/L, the optimal concentration of suspended solids to produce effluent clarity while producing a fast-settling rate; and

- > 3000 mg/L, will produce clear effluent but will have slow, hindered, settling rates and require high dose of polymer flocculant. May require dilution to lower solids concentration.

Bench-scale settling tests are used to determine the relationship between solids concentration, settling rate, and effluent clarity. The tests are used to determine the settling rate and thickening potential of the metal hydroxide particles precipitated during the treatment process. For settling to occur, the water velocity in the clarifier (rate of rise) must be less than the velocity (settling rate) required to settle the produced solids (solids produced during precipitation reactions) to achieve effluent standards.

Settling tests are performed by adding enough treatment chemical to a 2 L container of mine drainage to achieve the treatment pH required to meet effluent standards in a full-scale treatment system. Next, an anionic polymer flocculant is added to agglomerate particles into larger more settable solids. Lastly, the treated water is added to a 2000 mL cylinder to measure the bulk settling rate (Figure 1). The settling rate is measured and the clarity of the supernate is recorded. The solids are resuspended and sampled to determine the Total Suspended Solids (TSS) concentration. If the supernate is clear and the settling rate acceptable, the results can be used to size the clarifier. If clarity is poor, then the produced solids concentration will have to be increased by recirculating solids from the clarifier underflow (settled sludge) or increasing the treatment pH.

If the concentration of produced solids is low and/or the settling tests produced poor clarity, a series of settling tests are performed to identify the optimal concentration of solids. In settling test situations where raw water quality results in low produced solids, additional solids must be produced by treating tens or hundreds of gallons of additional mine drainage. The supernate is decanted and the additional settled solids are collected to perform the tests. A portion of settled solids is added to a 2000 mL beaker and the decanted supernate is added until 2000 mL is achieved. A polymer flocculant is added to agglomerate the particles and the flocculated solution is added to a 2000 mL graduated cylinder. The solution is gently mixed and a setting rate is measured. This test is repeated using differing concentrations of sludge to produce a graph of settling rate versus concentration of suspended solids (Figure 2). One goal is to determine the lowest concentration of suspended solids that will produce a clear supernate and fast settling rate. This will help determine the solids loading that will have to be pumped from the underflow of the clarifier back to the reaction tank or center well to achieve effluent clarity. Next a graph of settling flux is produced by multiplying the suspended solids concentration by the settling rate (Figure 3). This provides information on the optimal concentration range for flocculation that achieves the highest settling flux, or movement of solids through the clarifier. Figure 3 shows that the optimal settling flux was achieved with a solids concentration between 1,200-2,200 gm/L, which produces a rise rate of between 4 and 2 gpm/ft^2 or settling rates of 0.53 and 0.27 ft/min. This indicates the water velocity must be much less than 0.27 ft/min to provide a factor of safety.

Numerous settling tests have shown varying concentrations of ferruginous mine drainage treated with hydrated lime resulted in hydraulic loading ranging 2 to 7 gal/ft^2/day. Likewise, aluminum dominated mine drainage produced rise rates ranging from 1 to 7 gal/ft^2/day. After reviewing both bench scale testing and data from in-service clarifiers, the optimal suspended solids concentration for producing effluent clarity (Total Fe < 0.5 mg/L) appears to range from 1,500 to 2,500 mg/L for most coal mine drainage producing aluminum, iron, and manganese hydroxide sludges.

Settling tests are used as a proxy to simulate the behavior and characteristics of solids that will occur in a full-scale treatment system. Any bench-scale treatment used to create the produced solids must mimic the full-scale treatment strategy. Even with perfect bench scale testing, design and construction flaws in full scale treatment systems, like issues with flocculation, floc shearing, or hydraulic issues, can cause disparity between settling tests results and the actual performance. Thus, it is important to use safety factors to adjust bench scale results. It is common practice to multiply the settling rates from bench tests by, <u>at least</u>, 0.5 to compute the maximum design settling rate.

Many industrial settings have a design advantage in that designers know and can control the water quality characteristics of the produced wastewater stream before designing a clarifier. In mining scenarios, treatment systems may have to be constructed before mining commences and water quality is known. In addition, the pumped water quality is often unknown for Abandoned Mine Land (AML) projects. In these instances, the water quality of the surface discharge may be different than the quality deeper in a chemically stratified mine pool; thus collecting water from the discharges may not be appropriate to conduct settling tests. Piezometers can be installed near the proposed pumping site to try to better characterize the water for settling tests, but, even then, the final chemical composition of the water that will be pumped is unknown since the capture zone will be an amalgamation of different water qualities throughout a stratified mine pool. There are many nuances that can affect the concentration of produced solids, such as the concentration of carbon dioxide in the water, that is hard to characterize when proposing to treat a chemically stratified mine pool. The preceding discussion provides the reasoning to justify the use of robust safety factors for design criteria in many mine drainage treatment scenarios.

2.1 Clarifier Options: Conventional versus Solids Contact

While there are many types of clarifiers, over 99% of the ones used to treat coal mine drainage in the eastern U.S. are conventional clarifiers. There are at least two solids contact clarifiers in existence to treat mine drainage and there have been attempts to use inclined plate clarifiers, however, problems with iron hydroxide and calcite scale on the plates eventually caused the decommissioning of at least one of the incline plate clarifiers. AMDTreat offers users the ability to cost model two types of clarifiers, conventional and solids contact.

2.1.1 Overview of Conventional Clarifiers

Within the context of AMDTreat, conventional clarifiers describe circular settling tanks with the mechanical means to continuously manage and remove sludge (Figures 4 & 5). Typically, conventional clarifiers receive pH or Eh adjusted mine drainage that has been dosed with a polymer flocculant prior to entering the clarifier. There are a few situations where a tank is used to mix polymer and mine drainage to promote flocculation before discharging to the clarifier. However, it is more common to add polymer at a “hydraulic jump” or turbulent point in a conveyance trough or pipe that transports the water from the reaction tank to the center well of the clarifier (Figure 6). The center well acts as an inlet feed system to feed the water to the clarifier at an optimal velocity and flow distribution. Since many mine drainage treatment systems do not use external flocculation tanks, “flocculating” center wells are often incorporated into the clarifier design (Figure 7). Flocculating center wells are often larger than traditional center wells are sized to promote the agglomeration of flocculated particles. Water should flow out of the center well in an even radial fashion. If the velocity of the water is less than the settling velocity of the suspended particles, then settling is initiated. If not, solids are discharged from the clarifier. The zone of active settling and high suspended solids concentration is called the sludge blanket (Figure 8). Suspended particles that rest on the bottom of the clarifier make up the sludge bed. A raking and sludge pump (sludge removal) system is used to manage solids inventory. The raking system consists of plows attached to steel armatures that extend radially from the center of the clarifier (Figure 9). A geared drive system provides the rotational force needed to move the rake assembly through the sludge bed. The rake plows are used to transport the sludge toward the sludge sump, also sometimes referred to as a sludge cone, located at the bottom center of the clarifier (Figures 10 & 11). Sludge sumps are typically 100 to 500 gallons and will completely fill within a few minutes when treating in the thousands of gallons per minute range and producing low density sludge (< 1.0% solids by wt.). If the sludge pumping schedule is less frequent than the time it takes to fill the sludge sump, a sludge bed will form that extends laterally out to the side walls of the clarifier. Infrequent sludge pumping will cause the buildup of the sludge bed and the raking system will no longer effectively transport sludge to the sump until pumping occurs. Instead, the rakes will continue to rotate through the sludge bed and agitate and stir the sludge particles. The agitation facilitates sludge thickening, a process that involves the rearrangement of particles into a more compact arrangement by displacing water contained in the sludge. The thickening process increases sludge density and will reduce the volume of the sludge bed and lessen the frequency of sludge pumping. Deciding how to manage solids inventory to control thickening and the sludge blanket is a major objective of plant operators. Some operators chose to periodically dewater and clean the clarifier. Figure 12 shows an operator using a hose connected to a pump to pressure wash the clarifier walls, floor, and rakes. Figure 10 was taken after the clarifier shown in Figure 12 was cleaned.

When starting up a newly constructed treatment system or after changing treatment chemicals or strategy, a clarifier may become disrupted (Figure 13) and require troubleshooting. Troubleshooting usually starts with evaluating whether polymer is being properly dispensed and distributed in the wastewater stream. The sludge pumping plan is also evaluated to ensure the solids inventory is being properly managed. Dye tests are used to identify flow distribution, velocity, and retention time issues (Figures 14, 15, 16, 17). Simple devices that show the position of the rakes are useful in troubleshooting the formation of clouds of suspended solids (Figures 17 & 19). For both newly constructed and older clarifiers, laundering weirs should be inspected for levelness to prevent preferential flow paths. Scrapping or rubbing sounds may indicate the rakes are misaligned. Frequent visual checks of the torque indicator meter helps to monitor whether excess torque is being applied to the drive system.

2.1.2 Overview of Solids Contact Clarifiers

Solids Contact Clarifiers (SCC) are also known as a Sludge Contact and Draft Tube Clarifier (Figures 20, 21, & 22). SCC provide two main benefits; enhanced flocculation and combination of several treatment processes into a single component. SCC increases effluent clarity by using a centrifugal impeller pump to lift sludge from the bottom of the clarifier, through a draft tube where recycled sludge is mixed with the raw/influent water and chemical reagent before being discharged at the top of the center well (Figure 23). At this point, polymer flocculant is added and the water flows from the top of the center well down through the surrounding solids contact reaction well where flocculation occurs before entering the settling zone (Figure 24). The process of increasing the suspended solids concentration to enhance flocculation is further explained in Section 2.2.2.

Another key feature is a SCC provides the flexibility to be operated as a chemical reactor, flocculation tank, and settling tank. Ph or Eh adjusting chemicals can be injected into the draft tube or influent line and the center well/reaction skirt will serve as a reaction tank to mix the influent water, chemical, and recycled sludge. Polymer flocculant can be injected at the top of the center well and the solids contact skirt acts as a slow mix flocculation tank. While all these processes can be completed within a SCC, some operators may prefer to use external chemical reactors and polymer flocculant mix system to separate the processes to aid in operational control and troubleshooting.

Lastly, another important distinction between SCC and conventional clarifiers is the sludge thickening process. Sludge is not thickened, or is minimally thickened, in a SCC due to the pump continuously disturbing the sludge at the bottom of the clarifier and lifting it through the draft tube. It is common practice in the coal fields of the eastern U.S. to inject sludge back into the underground mine being pumped and treated. Thus, a drawback of not being able to thicken sludge is having to frequently pump a large volume of low-density sludge/water back into the mine that increases inflow. A SCC in Pennsylvania produces a 0.2 % solids sludge (by wt.) and must pump sludge to the underground mine at 200 gpm every few minutes to manage solids inventory.

It needs to be noted that the settling and clarity performance offered by a SCC can be achieved by combining a conventional clarifier with external sludge recirculation to a reaction tank (pumping sludge from clarifier to reaction tank to increase suspended solids). See Section 2.2.2 on Enhanced Flocculation.

<u>Advantages of a SCC compared to a conventional clarifier:</u>

- Improved settling rates which result in a smaller and less expensive clarifier;
- Improved effluent clarity due to increased TSS loading in center well;
- Provides the ability to be a turn-key treatment system that acts as a chemical reactor, flocculator, and sedimentation tank; and
- A low-density unthickened sludge will increase the longevity of injection wells into underground mines or surface mine backfill.

<u>Disadvantages of a SCC compared to a conventional clarifier:</u>

- Does not appreciably thicken sludge, which can affect the operation and final density if dewatering devices are required (e.g. presses, centrifuges);
- Produces a low-density unthickened sludge. The constant recirculation of sludge from the bottom up through the draft tube for solids contact prevents thickening. This is a drawback for treatment systems injecting sludge into the same mine they are pumping from since it adds significant

amounts of water back into the mine.

- May produce poor water quality during initial startup until enough sludge is produced to achieve appreciable solids contact and enhanced flocculation.

- While the overall cost is less due to size, the cost of the clarifier internals is more expensive; and

- Due to their decreased size, the sludge blanket may rapidly expand upwards and be hard to control if large fluctuations in influent flow is experienced.

2.2 Treatment Options

2.2.1 High Density Sludge

The High-Density Sludge (HDS) process was developed in the late 1960s by Bethlehem Steel researchers P.D. Kostenbader and G.F. Haines. The first described the process in a 1970 Coal Age article titled, " High-Density Sludge Treats Acid." The paper describes the laboratory testing conditions and the demonstration project at the Mine 32 treatment plant, located near Johnstown, Pa, that was used to optimize and refine the process. The process involves recirculating a portion of the clarifier underflow (settled sludge) back to a small reactor where hydrated lime is added to the sludge to generate a pH 11 to 12.4 sludge/hydrate slurry mixture. Presumably, the high pH condition creates an overall negative charge on the surface of the metal hydroxide sludge. The sludge/slurry mixture is then mixed with the raw water and cations, ferrous and ferric iron, are adsorbed and then precipitated onto the surface of recirculated metal hydroxide sludge. Dissolved pollutants adsorbing and precipitating onto the surface of recycled sludge creates a denser sludge then the precipitation of individual particles of sludge in a water column that may or may not aggregate into larger denser particles. The Kostenbader paper provides some useful design criteria including a recycled sludge and lime mixing time recommendation of one minute in a reactor and a solids recycle ratio of between 20 to 30 (lbs recycled sludge/lbs precipitated sludge). Conventional mine drainage treatment produces sludge that ranges from 0.2 to 6% solids (by wt.) whereas HDS typically produces 20 to 40 % solids.

<u>Advantages to producing high density sludge include:</u>

- Improved settling rates, thus smaller clarifiers;

- Improved effluent clarity due to increased TSS loading in center well;

- Decrease in sludge pumping time due to increase in sludge density;

- Less water being returned to the mine if injecting into underground mine workings;

- Provides opportunity to redissolve and use unreacted lime or calcite in sludge during recirculation process;

- Effective in removing trace elements;
- Decrease in diameter of sludge pumping lines; and
- May not require (or minimize) a polymer flocculant to achieve TSS standards.

Disadvantages to producing high density sludge include:

- Sludge injection wells may be more prone to clogging or have a shortened life span due to decreased flowability of the sludge;
- A possible decrease in the service life clarifier rake drive mechanisms due to increased torque imparted by the higher density solids

The equipment for a HDS system typically consists of a sludge line that pumps sludge from the sludge sump in the clarifier, a sludge pump with a variable frequency drive to control recirculation rate, and a tank or conveyance trough capable of mixing hydrated lime with the sludge. HDS equipment can be included in a treatment design and only used if it is required to achieve effluent standards. For a relatively low cost, it provides operators with flexibility to achieve compliance in variable conditions or if treatment standards change in the future.

Many designs specify using a small mix tank to mix the recirculated sludge and lime for 1 to 5 minutes (Figures 25 & 26). However, some operators have complained about the maintenance caused by calcite scaling and other issues with the mixer and tank. There are instances where operators separated the recirculated sludge from the lime slurry to minimize the maintenance (Figure 27), which probably stopped the formation of HDS. While the Kostenbader paper discusses the Bethlehem Steel HDS design as using a conditioning tank to mix the sludge and lime, the majority, if not all, of Bethlehem's HDS plants eliminated the conditioning tank and used a trough to dose the recirculated sludge with hydrated lime (Figure 28). The sludge recirculation line transitions to a trough directly under the lime dispenser and lime is dispensed directly into the trough. The sludge/lime slurry mixture flows about 30 feet before discharging into the reaction tank. The trough uses passive mixing and virtually eliminates maintenance issues encountered with the tank and mechanical mixer. While retention time in the trough is only seconds, it appears to be sufficient to condition the sludge for adsorption processes. The trough HDS systems that mimic the Bethlehem design have produced sludges that range from 35 to 40% solids by wt. Lastly, a common myth is the iron sludge needs to be oxidized as $Fe(OH)_3$ (red sludge) for the HDS process to work. Many HDS plants in Pennsylvania, including the Bethlehem Mine 31 plant, recycle unoxidized $Fe(OH)_2$ (green sludge) and generate sludge up to 40% solids by wt.

2.2.2 Enhanced Flocculation Sludge Recirculation System

Arguably, the most difficult challenge in operating a treatment system with a clarifier is to manage the suspended solids concentration of the effluent, especially for sites that generate produced solids concentrations of less than 200 mg/L. The term "produced solids" refers to the concentration of solids that is generated during the treatment process and flows to the clarifier for solid/liquid separation. The primary source of those produced solids results mostly from precipitation reactions and unreacted chemical. For example, if 60 mg/L of ferric iron is expected to precipitate as $Fe(OH)_3$, then the produced solids concentration for iron would be 114.8 mg/L. If it is predicted that 50 mg/L of Hydrated Lime will recarbonate to calcite during the treatment process and remain suspended, then the produced solids from this reaction will be 67 mg/L. If these are the only two reactions that produced solids, then the total produced solids concentration is 182 mg/L (114 mg/L of $Fe(OH)_3$ and 67 mg/L of $CaCO_3$).

Before entering a discussion on how to enhance sedimentation of a low produced solids waste stream, it is useful to define how the terms flocculation and agglomeration are defined and used in this help file. For the purposes of this help file, the process of flocculation includes using both a mixing strategy to promote collisions between particles and the addition of a polymer flocculant to aggregate individual particles into large particles to increase settling rates. While flocculation is used to describe both the particle mixing and bonding strategies, agglomeration is used to just describe the process of aggregating individual particles to form a single larger particle.

For mine drainage sites that use clarifiers, a general rule of thumb is a produced solids concentration of less than 150 mg/L may result in poor effluent clarity. Low concentrations of produced solids inhibit the agglomeration of particles by lowing the probability of particle collisions, even in well mixed situations. Upon initial precipitation, particles are less than 1μm in size and, if conditions are favorable, some of the individual particles will combined to form large aggregates due to the attractive nature of Van der Waals forces. Under this scenario, the low concentration of large aggregates will settle discretely and freely, without influence from adjacent particles. The aggregates have fast settled rates since their settling is not influenced or hindered by other particles in these solutions of low particle concentrations. On the other hand, the low concentration of particles means the remaining unaggregated micron-sized particles left in suspension will cause poor effluent clarity. In situations of low concentrations of produced solids, the Enhanced Flocculation (EF) process can be used to increase the concentration of produced solids to improve particle aggregation and effluent clarity. The EF process augments the produced solids concentration by recirculating solids from the clarifier sump back to the reaction tank to increase the probability of particle collisions (Figure 29). EF is like the HDS process in that sludge is recirculated back to the reaction tank but differs in that no chemical is added to condition the sludge to a high pH like in the HDS process. Sludge is simply recirculated to increase the produced solids concentration to improve the flocculation process.

While increasing the concentration of solids improves effluent clarity by promoting particle interactions and agglomeration, the increased particle interactions prevent the free and discrete settling of individual particles that produce fast settling rates. Instead, as particle concentrations increase, the interactions between neighboring particles hinders discrete particle settling and causes the particles to settle as a group. Group settling has a lower settling rate than free settling due to particle collisions redirecting particles from the settling direction, upward velocities caused from settling particles displacing water, and from changes in viscosity when particle concentrations transform the solution to a slurry. The agglomeration that occurs during group settling produces good effluent clarity but slows the overall settling rate. There is a point when the particle concentration increases, and the slurry is effectively "hindered" from settling in any reasonable time. The rate of hindered settling may become slower than the rate of rise in the clarifier and particles will be discharged from the clarifier. Therefore, managing an EF system is a balancing act of finding a center well concentration that achieves low turbidity but still produces acceptable settling rates.

In mine drainage, hindered settling typically occurs when center well concentrations approach 5,000 to 10,000 mg/L. A rule of thumb is to adjust the sludge recirculation pump to achieve a produced solids concentration of 2000 to 2500 mg/L in the center well. Typically, this level of EF produces an optimal balance between effluent clarity and settling rates. Operating clarifiers with EF within this range typically produce effluent suspended iron concentrations of 0.2 to 0.6 mg/L.

**The Enhanced Flocculation option is only available to conventional clarifiers since Solids Contact Clarifiers inherently contain enhanced flocculation through internal recirculation of sludge particles.

3.0 Clarifier Module Overview

The module provides a capital, annual, and recapitalization (net present value) costs for a clarifier and sludge handling and disposal activities. AMDTreat estimates the diameter of the clarifier after users specify the *Design Flow*, suspended metal concentrations, a *Hydraulic Loading value* and selects a type of clarifier (*Conventional* or *Solids Contact)*. Under the *Clarifier Design* section, users can specify the clarifier tank be constructed from concrete, welded steel, or bolted steel that sits atop of a concrete floor. Under the *Equipment* heading, users can specify whether to include a protective coating for the tank and either accept default values or specify unit costs for items like the overflow weir, catwalk, and density current baffle. In addition, users must specify the power requirement for motors to facilitate the calculation of the annual electrical cost to operate the clarifier. For *Conventional Clarifiers*, users can opt to include a *High-Density Recirculation Pump* or an *Enhanced Flocculation* system. The power requirement and number of sludge disposal pumps must also be determined along with the cost estimate for the clarifier and sludge pump foundations under the *Equipment* heading.

Next, the *Sludge Disposal Pipeline (HDPE)* section is used to specify the characteristics of the buried HDPE pipeline that will transport sludge from the clarifier to be disposed of in injection boreholes or dewatered in geotubes (filter bags) and disposed of in a landfill.

The *Other Capital Items* section is used to account for items and costs that are not included in the module.

The *Annual Cost Input* section contains a list of items that affect the annual cost estimate. Users can specify the *Operational Time* of the clarifier, which is important in instances, like mine pool management, where the clarifier is not constantly operating. The *Operational Time* will affect the estimates of sludge production, pumping, disposal, and electrical costs to operate the clarifier. The *Sludge Generation* section is where users characterize the sludge that will affect annual sludge handling and disposal costs. Users must estimate the percent solids (by wt.) of the thickened sludge and specify whether minerals other than aluminum, iron, and manganese (specified in the *Water Quality and Flow Input* section) will add mass to the sludge. AMDTreat allows users to specify the amount of calcite that will precipitate and the mass of other nuisance minerals, such as, $Mg(OH)_2$ that will increase sludge mass and volumes. Finally, Annual Cost Input contains a Sludge Disposal section that allows users to determine whether sludge from the clarifier (underflow) will be disposed of in an injection well into an underground coal mine or pumped into a geotube, allowed to dewater, and excavated, transported, and disposed of in a landfill.

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) Clarifier Design, (3) Equipment, (4) Sludge Disposal Pipeline (HDPE), (5) Other Capital Items, (6) Annual Cost Input, and (7) Other Annual Items. The workflow for the module is for users to start at the top left-hand side. Enter the *Design and Typical Flow* and *Suspended metal concentration of the produced solids*. In other words, these are the concentration of solids precipitated from the raw water after chemical addition (pH/Eh adjustment). These concentrations should not include concentrations from recirculating clarifier underflow. The suspended metal concentrations can be obtained from treatability tests after adjusting the raw water to a target treatment pH or Eh. AMDTreat will assume the metals precipitate as metal hydroxides (e.g. Fe^{2+} as $Fe(OH)_2$, Fe^{3+} as $Fe(OH)_3$, Al^{3+} as $Al(OH)_3$, Mn^{2+} as $Mn(OH)_2$).

Next, select either a conventional or solids contact clarifier and specify a hydraulic loading and construction material (e.g. steel or concrete clarifier) under the *Clarifier Design* section. AMDTreat uses the information to determine the size of the clarifier. Then specify equipment options and costs for items like Tank protective coatings and catwalks and determine whether High Density Sludge (HDS) or Enhanced Flocculation (EF) is necessary. The *Sludge Disposal Pipeline (HDPE)* section is used if users plan to pump the clarifier underflow through a buried HDPE pipeline. Users select a Nominal Pipe Size and SDR ratio and specify a total static head and pipeline length and AMDTreat estimates the fluid pressures and velocities provides an error message if the design criteria are outside acceptable limits. Errors can be fixed by changing the pipe size, SDR ratio or water quality (affects fluid viscosity, which affects pressure). Users then use the *Annual Cost Input* section to specify unit costs and make selections that affect annual costs. Users can specify the operational time of the clarifier for sites that do not continuously operate. The operational time is used to refine estimates of annual costs and sludge volumes. The *Annual Cost Input* section also includes sections for *Sludge Generation* and *Sludge Disposal*. Users must specify the predicted % solids (by wt.) of the underflow (sludge) and specify the amount of calcite or other miscellaneous precipitate that will add to the mass of sludge beyond aluminum, iron, and manganese. The *Sludge Disposal* section offers the ability to estimate the cost to use sludge injection boreholes to dispose directly into an underground mine or pump to a geotube for dewatering to haul for offsite disposal. 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 clarifier dimensions, center well suspended solids concentrations, and sludge production estimates. The estimated cost to construct and operate the Clarifier 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 Help files located on AMDTreat's website and 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 Design and Typical Flow and Metal Concentrations. These values are used to estimate (1) the size of the clarifier and (2) annual sludge volumes.

The definitions for *Design* and *Typical Flow* and *Metal Concentrations* 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, *Design Flow* is used to size the clarifier and *Typical*

Flow is used to calculate annual sludge estimates and costs. *Design Flow* is the maximum flow the clarifier can accept and *Typical Flow* is the flow rate "typically" experienced at the site. *Ferrous Iron*, *Ferric Iron*, *Aluminum*, and *Manganese* represent the concentrations of suspended metals predicted to be removed by the clarifier. While users input the concentration of the suspended metal, AMDTreat assumes they are precipitated as metal hydroxides (e.g. the value entered for suspended Fe^{2+} is recalculated as $Fe(OH)_2$) for calculating the mass and volume of sludge.

3.2.2 Clarifier Design:

3.2.3.1 Conventional – This option is used to size a Conventional clarifier (see section 2.1.1 for description). A default value of 0.50 gal/min/ft^2 is used to represent the *Hydraulic Loading* required to size a conventional clarifier without recirculating underflow solids back to the reaction tank to increase solids loading. The default value has been used to successfully size several large, hydrated lime treatment plants with > 600 mg/L of suspended (metal hydroxide) solids entering the center well, however, users are encouraged to conduct setting tests to characterize site specific conditions. The *Hydraulic Loading* value could be equal to the value used for a *Solids Contact* clarifier if the *Enhanced Flocculation Sludge Recirculation System* is selected under the *Equipment* section. Adding external recirculation of underflow solids to a *Conventional* clarifier approximates the performance of a *Solids Contact* clarifier.

The *Design Flow* rate is divided by the *Hydraulic Loading* value to calculate the surface area of the clarifier.

When a *Conventional* clarifier is selected, the *Impeller Motor* options under the *Equipment* section is deactivated since impeller motors are unique to solids contact clarifiers.

3.2.3.2 Solids Contact – This option is used to size a Solids Contact clarifier (see section 2.1.2 for description). A default value of 0.70 gal/min/ft^2 is used to represent the *Hydraulic Loading* (rise rate) required to size a *Solids Contact* clarifier, however, users are encouraged to conduct setting tests to characterize site specific conditions.

The *Design Flow* rate is divided by the *Hydraulic Loading* value to calculate the surface area of the clarifier.

When a *Solids Contact* clarifier is selected, the *High-Density Sludge Recirculation Pump* and *Enhanced Flocculation Sludge Recirculation System* options under the *Equipment* section are deactivated.

3.2.3.3 Clarifier Construction Material – Users can opt to develop cost estimates for clarifiers tanks constructed of concrete, welded steel, or bolted steel. Regardless of tank construction material, AMDTreat assumes all clarifiers have a concrete floor (Figure 30). Figure 11 shows a newly constructed concrete walled clarifier with a concrete floor and Figure 31 shows a welded steel concrete clarifier with a concrete floor.

In general, a concrete-walled clarifier is the most expensive to construct but the most durable (Figures 4 & 6), while bolted steel is the cheapest to construct but may require increased maintenance due to the potential for corrosion to occur at each bolt location. Welded Steel clarifiers are more maintenance than concrete clarifiers, due to periodic sandblasting and painting, but are more durable than bolted steel clarifiers. Figures 32 through 34 show the construction of a welded steel clarifier.

Users can select to include cost estimates to include protective tank coatings under the *Equipment* section that may extend the lifecycle and lessen the maintenance of a clarifier.

3.2.3.4 Clarifier Water Height, Freeboard, and Sludge Blanket Depth – Users must specify a water and freeboard depth to allow AMDTreat to calculate the dimensions of the clarifier. The *Sludge Blanket Depth* is an optional parameter that does not affect cost calculations.

3.2.4 Equipment: This section has two subsections: *Tank Coatings, Motors, Pumps, etc.* and *Foundation*.

3.2.4.1 Tank Coatings, Motors, Pumps etc.: This section is used to specify the unit costs for various parts of the clarifier and to specify or estimate power requirements.

Overflow Weir Unit Cost – Users can specify the unit cost of a peripheral overflow (laundering) weir located around top of the clarifier wall. The overflow weir transports water from inside to outside of the clarifier. Figure 6 shows a blue saw toothed overflow weir directly inside of the concrete wall. Figure 35 is an up-close photo of an iron coated overflow weir. Coatings of iron, calcite, algae, leaves, or other debris will lead to short circuiting to unclogged sections of the weir and will cause settling problems. Figure 36 shows an operator ready to both clean the inside of the clarifier and brush the overflow weir to remove the iron coating.

It is highly recommended to use stainless steel bolts to fasten the center well structure and overflow weir when treating mine drainage. Figure 37 shows workers replacing the steel bolts that fasten the yellow saw-toothed overflow weir to the concrete wall at the Hollywood AMD treatment plant in Pennsylvania. Note the ladder is resting on the saw-toothed weir and the yellow weir is resting on and bolted to the steel beam extending from the concrete wall. Figure 38 shows the corrosion of the bolts that attach the steel support beam to the weir and to the concrete wall. Some of the steel bolts corroded to the point of failure and half of the weir disconnected and fell into the water causing a short circuit and elevated suspended solids in the effluent (Figure 39). The clarifier was in its 9th year of operation when the failure occurred.

Catwalk with Handrail Unit Cost – The Catwalk with Handrail is used to walk across the top of the clarifier to access the center well to work on the drive system and possibly sludge recirculation lines and or pumps. AMDTreat offers the ability to calculate the cost of a Catwalk extending from the outside clarifier wall to the center well (Half Length) or across the entire top of the clarifier (Full Length). The unit cost can be set to $0.0 to eliminate the cost. Figures 10 and 14 show examples of a steel catwalk with handrailing extending half the diameter of the clarifier.

Density Current Baffles – Density Current Baffles are used to disrupt density currents caused by differences in suspended solids concentrations and temperatures within the clarifier (Figures 31 & 40). Temperature differentials along the outside wall, bottom, and top of the clarifier will change viscosity and create areas of different velocities, which will affect particle settling. In winter conditions, surface cooling may cause vertical convection currents that will hinder particle setting. Decreases in water temperature will increase viscosity and may lead to an increase in suspended particles in the effluent. Likewise, the momentum and suspended solids concentration of the water exiting the bottom of the center well may cause a density current near the top of the sludge bed which may concentrate lighter solids. Density current baffles have a proven track record of successfully reducing effluent suspended solids concentrations in a number of Pennsylvania mine drainage treatment systems.

Tank Protective Coating – Users can opt to include tank coatings to prevent corrosion and extend the life cycle of the clarifier. The tank coating affects the life cycle assigned to the clarifier under the *Net Present Value* section. Manufactures recommend periodically reapplying coatings for full protection.

Impeller Motor – This option is only available when Solids Contact is selected. The impeller motor draws solids from the bottom of the clarifier up the draft tube to be mixed with the influent water and increase the solids loading to improve flocculation. The horsepower of the Impeller Motor is required to estimate the annual electricity cost. AMDTreat can estimate the power requirement of the Impeller Motor based on the size of the clarifier or users can specify the motor power.

Rake Drive Motor – User must specify the horsepower of the rake drive motor for AMDTreat to calculate the annual electrical cost to transport sludge to the sludge sump.

3.2.4.2 Solids Recirculation Options – Users can opt to include the High Density Sludge process or Enhanced Flocculation in a conventional clarifier. Both methods require users to specify the difference in water elevation between the water elevation in the clarifier and the reaction tank to estimate the power requirement to pump underflow from the bottom of clarifier back to the reaction tank. Users must specify the elevation difference at the top of the *Solids Recirculation Options* section.

High Density Sludge Recirculation Pump: Selecting this option adds the cost of incorporating a slurry pump to pump the underflow back to the reaction tank. The High-Density Sludge (HDS) process is explained in Section 2.2.1. Users must specify the difference in elevation between the water level in the clarifier and the reaction tank to activate the HDS option. In addition, users can have AMDTreat estimate the size of the HDS slurry pump or opt to specify the capacity of the pump. For AMDTreat to estimate the pump capacity users must specify the Sludge Recycle Ratio. The value represents the ratio of the iron loading being pumped from the underflow back to the reaction tank to the iron loading in the untreated water. P.D. Kostenbader and G.F. Haines (1970) recommended an iron recycle ratio of between 20 and 30 to optimize density. Both the AMDTreat estimate, and the User Specified method uses the difference in water elevation and the

HDS pump capacity (gpm) to estimate the capital cost of the pump and the annual electrical cost associated with the HDS system.

Enhanced Flocculation Sludge Recirculation System: Users can opt to include an Enhanced Flocculation Sludge Recirculation System into a conventional clarifier to approximate the flocculation and clarity of a Solids Contact clarifier. While a Solids Contact clarifier recycles solids within the clarifier, the enhanced flocculation pumps underflow from a conventional clarifier back to the reaction tank to achieve a desired suspended solids concentration in the center well. Users specify the desired suspended solids concentration in the center well and AMDTreat uses this value along with the values for Typical Flow and Ferrous and Ferric Iron concentrations to calculate the flow rate of the underflow required to achieve to achieve the center well concentration. AMDTreat estimates the horsepower required to calculate the estimated annual electrical cost.

3.2.4.3 Sludge Disposal Pumps – Users specify the number of horizontal centrifugal sludge pumps, which should be at least two for redundancy. Users can opt to have AMDTreat estimate the size and capacity of the pumps or users can specify a capacity. If users choose to have AMDTreat estimate the pump capacity, users must specify the *Desired Time to Pump Sludge each Day* and the *Safety Factor* under the *Sludge Disposal Pump Sizing* heading and specify the *Total Static Head*, sludge *Pipeline Length* and *Nominal Pipe Size* under the *Sludge Disposal Pipeline* section.

AMDTreat uses four steps to estimate the power requirement of the sludge disposal pump.

Step #1: Determine Density and Specific Gravity of Solids within the Sludge

Mine drainage sludge is a composition of water and precipitated minerals, such as oxides, hydroxides, and carbonates (Figure 41). The first step is to determine a weighted density and specific gravity of the composite precipitated solids. AMDTreat assumes the dissolved metal concentrations entered into the *Water Quality & Flow Input* section are precipitated as the hydroxide solids shown in Figure 1. AMDTreat converts 100% of each metal concentration to the equivalent concentration of a precipitated solid. AMDTreat calculates the % mass of each of the precipitated solids relative to the total mass of precipitated solids. The percent mass of each solid is multiplied by the corresponding specific gravity to determine the weighted density of each precipitate. The weighted density of the precipitates is summed to calculate an overall weighted density and specific gravity for the composite precipitated solids (Figure 42).

The composite sludge density is used to calculate the composite specific gravity of the solids in the sludge. After the composite sludge density is determined, AMDTreat uses the *Typical Flow* and the concentration of sludge to calculate the daily solids load that makes up the sludge. Recall, sludge consists of mineral solids and water. At this point, the daily solids load is characterizing the daily mass of the solid precipitate and does not include the water portion of the sludge. The daily solids load is divided by the composite density to determine the daily volume of sludge produced.

Users can also include additional mass due to the precipitation of calcite or other miscellaneous precipitated solids. If Calcite is expected to precipitate, users can specify the precipitation concentration under the *Sludge Generation* heading of the *Annual Cost Input Section* and it will be included in the estimate of daily sludge production. If other minerals are expected to precipitate, users enter the concentration of the precipitated form of the mineral in the *Miscellaneous Solids* input field along with a density under the *Sludge Generation* heading of the *Annual Cost Input Section*. For example, if bench scale testing showed 100 mg/L of Mg^{2+} will precipitate as a hydroxide, users can specify that 242 mg/L, in this case $Mn(OH)_2$, of *Miscellaneous Solids* will precipitate and be added to the mass of sludge. AMDTreat will use the *Miscellaneous Solids* value along with the *Miscellaneous Solids Density* to calculate mass of the additional sludge.

Step #2. Calculate the Specific Gravity and Density of the Sludge

Sludge is a combination of mineral precipitate and water. Sludge is often characterized by specifying the *% Solids* of the sludge by weight. 100 grams of sludge that is 10% solids by wt. contains 10 grams of precipitated mineral and 90 grams of water. Users can specify the expected *% Solids by wt*. of the sludge under the *Sludge Generation* heading of the *Annual Cost Input* section. The *% Solids* should represent the solids content of the thickened sludge being pumped from the clarifier. The values for % Solids and the specific gravity of the composite precipitated solids (solid content of the sludge) is used to calculate the specific gravity of the Sludge:

$$SG\ Sludge = \frac{SG_{solids}}{SG_{solids} - (\frac{\%\ solids}{100} * (SG_{solids} - 1))}$$

The specific gravity of the sludge is multiplied by 8.43 lbs/gal to calculate the sludge density.

Step #3: Calculate Daily Sludge Production

The cumulative concentration of precipitated solids (Step #1) is multiplied by the Typical Flow rate to calculate the daily loading of precipitated solids. The daily loading is divided by the Sludge Density (Step #2) to calculate the daily volume of sludge produced.

Step 4: Calculate the Power Requirement of the Sludge Pump

The flow capacity of the sludge pump is determined by dividing the daily sludge volume by both the *Sludge Pumping Time* and *Safety Factor*, which are specified by the user under the *Equipment* heading. The Horsepower of the pump is calculated by:

$$HP = \frac{Flow * Density * 144 * Total\ Dynamic\ Head}{2.3 * 7.48 * 60 * 555 * Efficiency * Safty\ Factor * 8.43}$$

HP = Horsepower of sludge pump
Flow = Required Flow Rate of sludge pump
Total Dynamic Head = (Dynamic Pipe Losses + Static Head)(1+(% Incidental Head Losses/100)*
Efficiency = The Pump Efficiency is used to describe the how efficient the pump is at converting all the electrical power to pumping power. It is expressed as a decimal.
Safety Factor = Expressed as a decimal

AMDTreat uses the information to estimate the pumping power (HP) required transport the sludge through the pipeline. The variables describing the pipeline are described in the *Sludge Disposal Pipeline* section and the variables presented in the *Sludge Disposal Pump Sizing* heading are described here.

> *Safety Factor*: The *Safety Factor* is convenient way to increase the overall capacity of the pump. If AMDTreat estimates the need of a 20 HP pump, a *Safety Factor* of 2.0 will increase the pump estimate to 40 HP.
>
> *Pump Efficiency and Pump Safety Factor*: The *Pump Efficiency* is obtained from the manufacture is expressed as a decimal. The *Pump Efficiency* is used to describe the how efficient the pump is at converting all the electrical power to pumping power. The *Pump Safety Factor* is a way to increase the capacity of the pump to overcome any uncertainty with the assumed percent solids (by wt.), viscosity of the sludge or estimates in head loss or pressure drops over time. The estimated pump capacity is divided by both the *Pump Efficiency* and *Safety Factor*. For example, assume a user specifies a Pump Efficiency of 0.75 and a Pump Safety Factor of 0.85 and AMDTreat estimates an 82 HP pump is required to achieve the flow rate and head pressure in the sludge line. The final pump size would be 129 HP or 56% larger since 82/0.75/0.85 = 129 HP. The Safety Factor and the Pump Safety Factor may be redundant, and users can simply use a Pump Safety Factor of 1.0 to eliminate redundancy.

3.2.4.4 Foundation – This section affects both the foundation of the clarifier and the concrete pad that houses the sludge disposal pumps. The first step in estimating the capital cost of the foundation 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. Next, users must specify a *Site Solids Condition* of *Poor*, *Average*, or *Excellent* (Poor = 1,500 lbs/ft^3, Average = 3,500 lbs/ft^3, Excellent = 4,500 lbs/ft^3). The specified soil condition is used to determine the foundation area. The user should be aware that mine subsidence concerns are not addressed in the AMDTreat foundation design and that these concerns if applicable need to be addressed separately by the system designers with the appropriate input from qualified Geotechnical Engineers.

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 per yd^3.

3.2.4 Sludge Disposal Pipeline (HDPE):

The sludge disposal pipeline is used to transport sludge from the bottom of the clarifier to either an injection borehole or to a geotube. AMDTreat assumes the construction of the pipeline consist of excavating a trench and installing a bed of gravel on the floor of the trench to cushion the pipe. HDPE pipe is installed on top of the gravel bed and the trench is backfilled and compacted. Users can opt to include the costs of air/vacuum release assembles to prevent air locks and pig launchers to unclog the pipeline.

The width of the trench is calculated by adding 24” to the outside diameter of the pipe selected by the user. Trench depth is determined by adding 42” to the diameter of the pipe. The trench wide and depth are multiplied to determine the cross-sectional area of the trench. This area is multiplied by the user-specified length of the pipeline to estimate the excavation volume and cost. The volume and mass of gravel bed is determined by first multiplying the length of the pipeline by two since the width of the trench is ~ two feet. This determines the area of the bottom/top of the gravel bed. This value is multiplied by the user-specified pipe bedding thickness to estimate the volume of the gravel bed. two the user-specified pipe bedding thickness. A bulk density of 95 lbs/ft^2 is used to convert the bed volume to a mass of gravel.

3.2.4.1 Pipe Selection and Sizing- The HDPE pipeline can be sized with a 1.5-, 2.0-, 3.0-, 4.0-, or 6.0-inch nominal pipe size. Users must also select a Standard Dimension Ratio (SDR) for the pipe. SDR describes the correlation between the outside diameter of the pipe and the pipe wall thickness (SDR = outside diameter / wall thickness). SDR is used for pressure rating pipe with lower SDR numbers having higher pressure ratings. Table 1 provides the relationships between pipe dimensions and SDR Rating.

HDPE Pipe Specifications (Perforance Pipe Inc.)	Pressure Rating (PSI)	SDR Schedule	Nominal Outside Diameter of Pipe (inches)				
			1.5"	2"	3"	4"	6"
	335	7	1.325"	1.656"	2.44"	3.137"	4.62"
	250	9	1.453"	1.815"	2.675"	3.44"	5.07"
	200	11	1.533"	1.917"	2.826"	3.633"	5.35"
	160	13.5	1.601"	2.002"	2.951"	3.794"	5.58"
	125	17	1.7"	2.078"	3.063"	3.938"	5.8"
			Inside Diameter of Pipe (inches)				

Table 1: Relationship between Nominal Pipe Diameter, SDR, Pressure Rating, and Inside Pipe Diameter (Courtesy of Performance Pipe Website).

3.2.4.2 Pipe Sizing Evaluation and Error Routine - In addition to specifying the pipe size and SDR, the total static head, pipeline length and incidental head losses must be specified.

> *3.2.4.2.1 Total Static Head* - The total static head is the difference in elevation between the outlet (discharge head) and the inlet (suction head).
>
> *3.2.4.2.2 Pipeline Length* - The pipeline length is the distance between the clarifier and the injection borehole or geotube.
>
> *3.2.4.2.3 Incidental Head Losses* – The loss in head (pressure) as the fluid flows through the pipeline due to friction caused by pipes, valves, fittings, bends, and tees.

AMDTreat uses the input values to calculate the pressure within the sludge pipeline during pumping. To calculate the pressure, AMDTreat first calculates the required flow rate of the sludge pump (see section 3.2.4.3, Step 4). Next, it uses the flow rate, along with the inside diameter and length of the sludge pipeline to estimate the Dynamic / Frictional Head Pipe Losses. These losses are added to the Total Static Head and Incidental Head Losses to determine the Total Dynamic Head. The Total Dynamic Head is used to calculate the Total Dynamic Head (TDH) Pressure within the pipeline.

AMDTreat performs four error checks and one warning check to ensure the sludge pipeline is sized properly. Error messages require users to change input values to eliminate the errors before AMDTreat will proceed with cost estimations. Warning messages are designed to notify users of a potential issues but AMDTreat will continue to conduct cost estimation without changes to input values.

The four error checks are:

1. Compare the calculated THD pressure to the pressure rating of the pipe show in Figure 3. If the calculated pressure exceeds the allowable pressure, the following error message is displayed, and users will have to change input variables to prevent the exceedance:

   "*The pressure for the SDR selected has been exceeded. Increase in pipe diameter to decrease pressure or a decrease in SDR to increase the allowable pressure.*"

2. If the calculate THD pressure is greater than 335 psi, which is the maximum pressure for the SDR piping in AMDTreat, the following error message appears:

   "*Maximum pressure for HDPE pipe has been exceeded. Increase pipe diameter or decrease flow rate to decrease pressure, or design project using steel or some other high-pressure pipe.*"

3. If the calculated velocity of the pumped sludge is greater than 15.0 ft/sec, the following error message appears and users will have to change input variables to reduce the flow velocity:

   "*Pipe Fluid Velocity is greater than 15 ft/s, which results in excessive wear and head loss. Increase pipe diameter or decrease flow rate.*"

4. If the calculated velocity of the pumped sludge is less than 2.0 ft/sec, the following error message appears, and users will have to change input variables to prevent the possibility of sludge settling within the pipeline:

   "*Pipe Fluid Velocity is less than 2 ft/s which creates the possibility of sludge settling in line. Decrease pipe diameter or increase flow rate.*"

The one warning message is:

1. If the user selects a pipe diameter and SDR value that has a pressure rating that is much higher than the calculated pipe pressure, AMDTreat will provide a warning message to the user notifying them a pipe with a higher SDR number, which is less expensive due to a thinner wall thickness, could be selected without errors. Users do not have to change any input values and can disregard the warning message. The warning message is:

   "*Selected SDR is heavier than required. Consider increasing SDR to use a lower pressure rated pipe which results in decreased costs.*"

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 Annual Cost Input: This section contains the variables and activities that affect the annual treatment costs.

3.2.6.1 Electric Unit Cost - Users must specify the unit cost of electricity for the site they are interested in evaluating in order to estimate the annual cost to operate the motors and pumps associated with the clarifier. The true cost of electricity includes taxes, transmission, and distribution fees; therefore, one should take the total cost of a monthly electrical bill and divide by the kWh used to determine the electrical unit cost. This cost is used to calculate the annual electrical cost of all electrical components for a clarifier, including the rake motor drive, HDS pump, enhance flocculation pump, sludge pump impeller motor, etc.

3.2.6.2 Clarifier Operational Time- Some mine drainage treatment systems do not continuously operate. For example, many underground mines have pump and treat systems that are designed to maintain a certain mine pool elevation to prevent a surface discharge. During dry climatic conditions, a mine pool may not have to be pumped for weeks until it fills to an elevation that triggers pumping. The Operational Time annual cost input provides users with the ability to specify the time period the clarifier operates. Changes to the operational time will affect the annual electricity cost and the estimated sludge production.

3.2.6.2 Sludge Generation- The clarifier module calculates the annual sludge production to estimate the annual costs associated with pumping and disposing of the sludge. Under this subheading, users can specify values for variables that affect annual sludge production.

% Solids of the sludge underflow – This percentage represents the mass of solids relative to the mass of sludge being pumped from the clarifier for disposal. The annual sludge production estimate is very sensitive to this value, so it is important to properly characterize the % solids to produce accurate cost estimates.

Calcite as $CaCO_3$ – AMDTreat allows users to specify the concentration of aluminum, iron, and manganese that will contribute to sludge. In addition, calcite is a common precipitate especially in instances where lime or hydrated lime is being used for pH adjustment or in waters with elevated Total Inorganic Carbon containing a treatment pH > 7. Kinetically, calcite does not precipitate to equilibrium as quick as the metal hydroxides so it can be difficult to estimate the amount of calcite that will precipitate before the water is discharged from the treatment systems. Users can enter the estimated concentration of calcite that will precipitate during treatment and AMDTreat will include the mass in the annual sludge production estimate.

Miscellaneous Solids – There are instances where precipitates other than aluminum, iron, manganese, and calcite contribute to sludge generation. For example, magnesium will precipitate as $Mg(OH)_2$ if the treatment pH is > 10. Users can enter the concentration of miscellaneous solids that are predicated to precipitated and AMDTreat will use the concentration and the specified *Miscellaneous Solids Density* to add it to the sludge volume. If 100 mg/L of Mg is predicted to precipitate as $Mg(OH)_2$, users would enter a value of 239 mg/L for *Miscellaneous Solids*.

Miscellaneous Solids Density – Users must specify a density representative of the *Miscellaneous Solids* predicted to precipitate.

3.2.6.3 Sludge Disposal – The capital and annual costs associated with sludge handling, dewatering, and disposal of sludge is organized under the *Annual Cost Input* section. AMDTreat offers two methods for sludge handling and disposal for a clarifier, *Injection Borehole* and *Geotube*.

Injection Borehole - The most common method for sludge handling and disposal when operating a mine drainage treatment facility is to pump the sludge from the clarifier sump to a borehole that injects the sludge into an abandoned underground coal mine (Figure 43). Ideally, the borehole is installed into a different mine complex than the one being pumped and treated; however, this is not always possible, and it is common to pump and inject within the same mine complex. In any case, the injection borehole must be located into a portion of a mine that minimizes communication with the pumping well (e.g., downdip and into a non-subsidence area) (Figures 44, & 45). In addition, the mine pool must be circumneutral pH to prevent the redissolving sludge back into the mine pool.

A best practice is to always have two sludge injection boreholes installed and connected to the treatment system and a third borehole sited with all necessary access easements. The two installed boreholes provide redundancy, and the pre-determined location of the third borehole allows for easy implementation when one of the primary boreholes eventually fail.

The *Underground Mine Disposal Borehole* section provides users with the ability to model the capital cost of installing up to three sludge injection boreholes. Users select the desired borehole diameter and the borehole multiplier. The multiplier increases the size of the borehole to accommodate casing and grout. Next, the depth to the mine is entered and users can either accept the default drilling and installation cost or specify a cost. AMDTreat multiplies the borehole depth by the installation cost to determine the capital cost. The annual cost of electric to pump to the borehole is determined by the electrical unit cost and the sludge pumping frequency.

Geotube Disposal - In instances where injection to an unground mine is not possible, geotubes can be used to dewater and temporary store sludge (Figures 46 & 47). Sludge is periodically pumped from the clarifier sludge sump and dosed with additional polymer flocculant as a thickening agent before being pumped into a geotube (Figure 48). The flocculant aggregates the particles to a size larger than the pores of the geotube fabric so the sludge is retained within the geotube while the water can discharge through the fabric (Figure 49). Operationally, geotubes are often used in parallel where one bag is filled with sludge and allowed to dewater while the other bag is filled (Figure 50). If sludge pumping is daily, several bags operating in parallel may be needed as it often takes 24 to 48 hours to dewater and generate the space to accept additional sludge. After completely filling a geotube, it may take several weeks or a month to dewater and produce a sludge capable of being excavated from the geotube and transported in a dump truck. A rule of thumb is that sludge must be at a minimum of *20% solids by wt.* before it can be excavated from the geotube. There are geotubes that are made to fit inside a roll of container and, once filled, a roll off container truck can simply transport the geotube to the landfill for disposal. However, it is more common to use an excavator to remove the dewatered sludge from the geotube and use a dump truck to transport the sludge to a disposal location.

The annual cost to use geotubes to handle sludge is determined by having users estimate the dewatered solids content of the sludge before it is excavated for disposal. The default assumption is the sludge will be 40% solids by wt. Users can also specify the size of the geotube and AMDTreat uses the information to estimate the annual number of geotubes. This module assumes the polymer equipment sized and specified in the *Polymer* module will be primarily used to flocculate particles flowing from the reaction tank to the clarifier. It is assumed the same equipment will be used to dose the sludge when it is pumped form the clarifier to the geotube. The polymer model accounts for the cost to dose the produced solids flowing into the clarifier and the *Clarifier* module accounts for the annual polymer used to dose the sludge flowing to the geotube. Therefore, users are required to specify the type of polymer (emulsion or dry), the % active ingredient, the dose, and the unit cost and the clarifier module will predict the annual amount and cost of polymer. Finally, users must specify the roundtrip distance, excavator and transportation unit costs, and Landfill tipping fee. AMDTreat uses the information to estimate the annual excavator time required to remove the dewatered sludge from the geotube and load the dump truck. Then AMDTreat estimates the annual time and cost to transport the sludge to the disposal site. Users can specify any disposal cost in the *Landfill Tipping Fee* section.

3.2.7 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.

3.2.8 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 sizing characteristics of the clarifier and estimated sludge production. Most of the sizing summary outputs are self-explanatory, however, there are a few that warrant further explanation.

Sludge Production @ Typical Flow Rate & Operational Time – Sludge loading rates shown under this heading are calculated using the "*Typical Flow Rate*". The reported values represent the sludge production for the specified Operational Time located in the *Annual Costs Input* section of the module. For example, if a mine pool management plan only requires a pool to be pumped and treated for six months annually, users would enter 24 hrs/day and 182.5 days/year into the input fields for Operational Time. AMDTreat would use the information to compute the sludge production at the *Typical Flow* rate for six months of treatment.

Est. Sludge Pumping Time @ Operational Time – Values reported under this subheading represent the required sludge pumping based on the *Operational Time* users specified under the *Annual Cost* Input section. The reported value for *hours/day* represents the amount of daily sludge pumping required while the treatment plant is operating. For example, if a user specifies the Operational Time is 6 hours/day for 365 days/year, the reported value for *hours/day* represents the daily sludge pumping time during the 6 hrs of daily operation. The *hours/year* represents the cumulative hours of pumping on an annual basis.

Calculated Pressure Class – AMDTreat uses the user-specified input and calculates the highest SDR rating (lowest pressure class) for the set of conditions. AMDTreat compares the Calculated Pressure Class to the SDR selected by the user as part of error checking. If the user selects a pressure class of SDR pipe higher than the calculated, AMDTreat produces a Warning Message informing the user they can use a thinner, and less expensive, pipe.

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 Clarifier 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 clarifier component of the treatment system. The annual Maintenance 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 contained in the clarifier.

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

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

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

- <u>Inflation Rate</u>: Represents the average price increase of goods and services over time. AMDTreat uses the inflation rate to calculate the future cost of the annual operation and maintenance (O&M) and recapitalization items.

- <u>Rate of Return</u>: Describes the expected profit on an investment.

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

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

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

To determine the NPV to recapitalize rebuilding of the motor, AMDTreat calculates the future cost to rebuild the motor at each life cycle, 20 and 40 years. The program uses the *Inflation Rate* to inflate the present-day default cost to rebuild the motor in 20 and 40 years from now. While the present-day cost to rebuild the pump motor is $20,000, the future cost to rebuild the motor in 20 years at a 5.0% *Inflation Rate* is $53,065 and $140,799 in 40 years (Equation 8). 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 =

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

- 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.

- 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, the clarifier assumes the Sludge Recirculation Pump will be rebuilt every five years at a cost of 17% of the purchase price.

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 large treatment systems using clarifiers. The AMDTreat Team held discussions on personal experience and spoke to manufactures to develop a list of recapitalization recommendations. Users may have different experience and opinions than those listed.

By default, AMDTreat includes a list of eight recapitalization items for clarifiers. 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 Catwalk is 20 years assuming it is not sandblasted and repainted at first sight of corrosion. However, if a catwalk is 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.

Clarifier Tank and Internals: A Clarifier Tank consists of the outer wall and concrete floor. The Internals consists of the drive mechanism, rakes, and center well. The Life Cycle of a Clarifier Tank and Internals depends on the type of construction material. A concrete clarifier is likely to last much longer than a bolted or welded steel tank. There are concrete clarifier tanks that are over 65 years old still in operation. Likewise, there are welded steel clarifiers that are 50 years old still in operation, however, they are sandblasted and painted every 7 to 10 years at a significant cost. After a discussion with a clarifier manufacture, the AMDTreat team recommended a lifecycle of 75 years for concrete clarifiers and 35 years for steel clarifiers. The 35-year recommendation assumes the steel will not be maintained through sandblasting and painting. The lifecycle recommendations can be adjusted to reflect a planned maintenance strategy.

Catwalk: AMDTreat assumes the installation of painted steel catwalk and handrailing. A life cycle of 20 years is recommended for situations where the catwalk will be allowed to corrode without maintenance. If the catwalk is periodically sandblasted and painted, the life cycle can be increased. There are some well maintained catwalks that are 50 years old. The replacement life cycle can be increased if an aluminum catwalk is installed, like in many municipal situations.

Tank Protective Coating: Protective coatings are applied to clarifier outer walls during installation to slow corrosion and increase longevity. Protective coatings can be periodically reapplied to manufacture recommendations. AMDTreat includes the manufacture's recommended life cycle for each type of protective coating.

Sludge Disposal Pump Rebuild and Replacement: The AMDTreat team has personal experience with operating mine drainage plants and held discussions with plant operators to try to estimate the life cycles for sludge disposal pumps. In general, sludge pumps are commonly rebuilt or repaired numerous times before being replaced. The Team decided a five year rebuild/repair schedule and 20 year replacement life cycle.

Sludge Disposal Borehole: Sludge boreholes are used to dispose of sludge into underground coal mine voids or into the backfill of reclaimed surface mines. There are several way to try to increase the longevity of disposal boreholes including trying to prevent sludge thickening before pumping and pumping clean water for several minutes after injection to clear the borehole of any sludge. However, eventually sludge boreholes lose capacity to accept sludge and new holes must be drilled. While it is impossible to accurately predict the longevity of a borehole, we recommend a 15-year replacement assumption unless there is other information available.

Clarifier Cleanout: Some operators prefer to periodically dewater and clean the clarifier to prevent scale from accumulating on the rakes and potentially increasing torque and damaging the drive unit. Many operators clean the clarifier by using pressurized water to abrade the solids and scale from surfaces and a trash pump is placed in the sludge sump to remove the abraded solids from the clarifier. Cleaning the surfaces provide an opportunity to inspect the rakes to look for signs of corrosion.

5.0 Figures

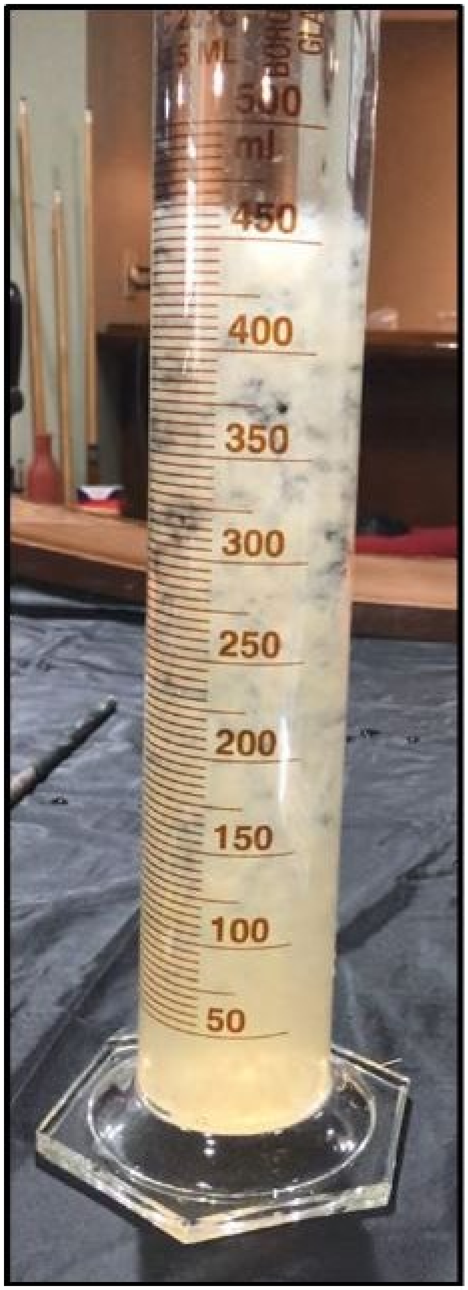

Figure 1: Settling test determining the settling rate for a specific concentration of flocculated aluminum hydroxide produced solids.

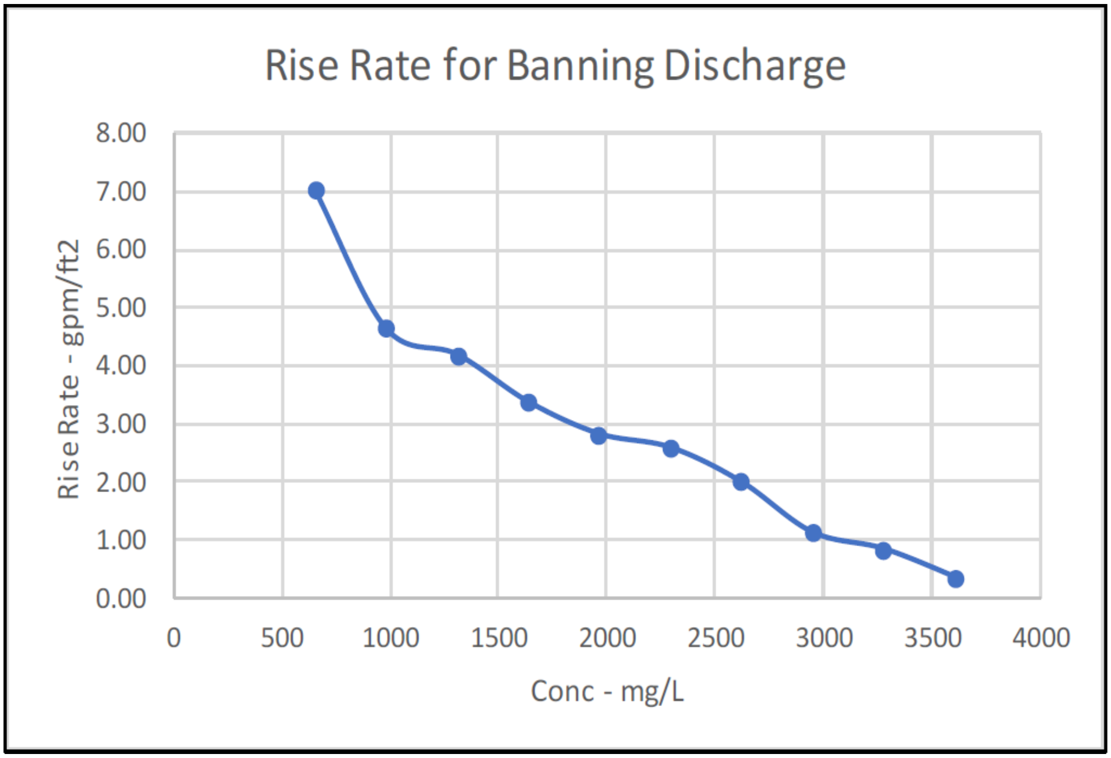

Figure 2: Results of ten settling tests to relate the rise rate to the concentration of produced solids.

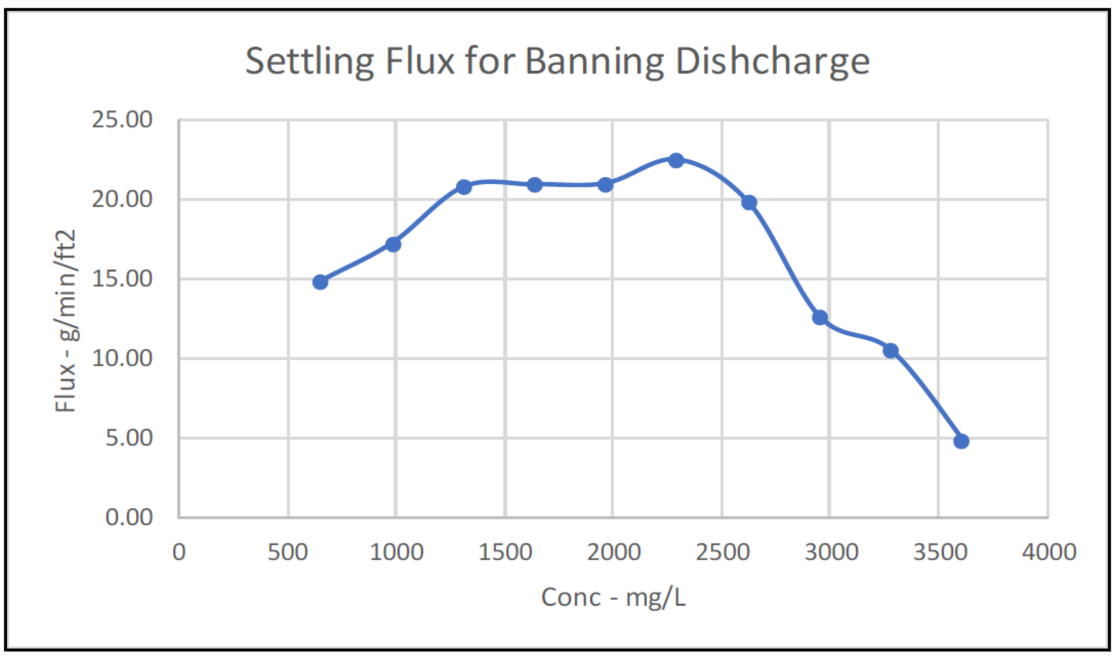

Figure 3: The settling flux rate characterizes the optimal solids loading.

Figure 4: Typical concrete conventional clarifier used to in mine drainage treatment in the eastern U.S.

Figure 5: Hydrated Lime mine drainage treatment plant using two conventional clarifiers operating in parallel.

Figure 6: Concrete-walled conventional clarifier. Note the open trough located under the walkway (catwalk) to the center well. Diluted polymer flocculant is added at hydraulic jump in the trough where the water falls by six inches to provide the mixing necessary to disperse the diluted polymer throughout the waste stream. Particle-to-particle interactions occur within the center well to promote agglomeration of particles.

Figure 7: Example of a flocculating center well. Polymer flocculant is added to pH-adjusted mine drainage at a hydraulic jump in the conveyance trough. The center well is designed to dissipate flow velocity and promote agglomeration of particles. Note transport rakes, located 20 ft under the water surface can be seen (see red arrow).

Figure 8: Photo of a 110 ft diameter conventional clarifier. Note red-colored sludge blanket is within five feet of the surface indicating the need to pump sludge. Reducing the volume of the sludge bed allows the sludge blanket to reposition lower in the clarifier.

Figure 9: Photo a center well and rake drive system that is over 55 years old. The center well is the large circular steel structure that extends approximately 6 ft below the water and the smaller diameter cylinder that extends through the center well to the bottom is the rake drive system. The steel armatures that extend outward from the rake drive to the outer wall is the rake. The angled plows attached to the bottom of the rake are used to transport settled sludge to the center of the clarifier for evacuation using a sludge pump.

Figure 10: A different angle of the same clarifier shown in Figure 5. Note the rectangular sludge sump located in the bottom center of the clarifier along with the steel sludge line embedded into the concrete flow of the clarifier. A sludge pump housed in the operations building pumps sludge from the sludge sump through the sludge line to an injection borehole that terminates in an underground mine. Also note the corrosion on the steel catwalk and handrailing extending to the center well.

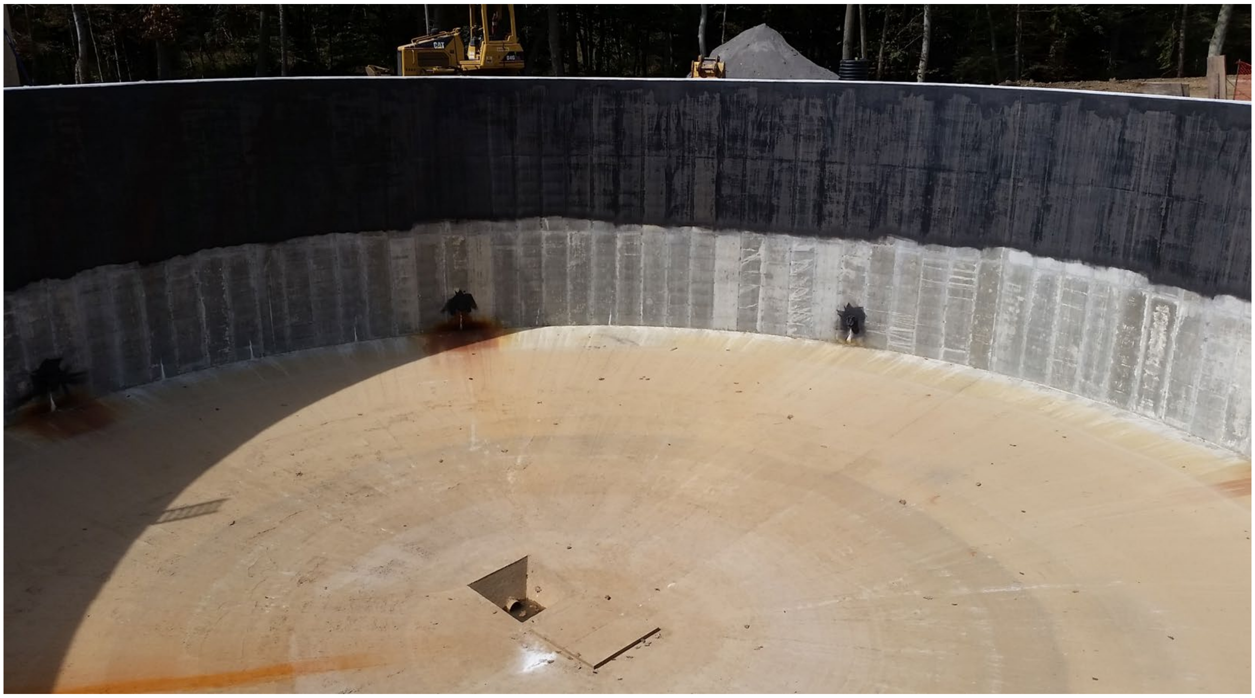

Figure 11: A newly constructed concrete clarifier showing the sloped floor and the sludge sump and sludge pump line extending under the floor.

Figure 12: Photo of an operator using a pressurized hose to clean iron hydroxide scale from the walls, floor, and rakes of the clarifier. Notice the lack of scale to the left of the operator compared to the right. Figure 9 shows the empty clarifier after it was cleaned.

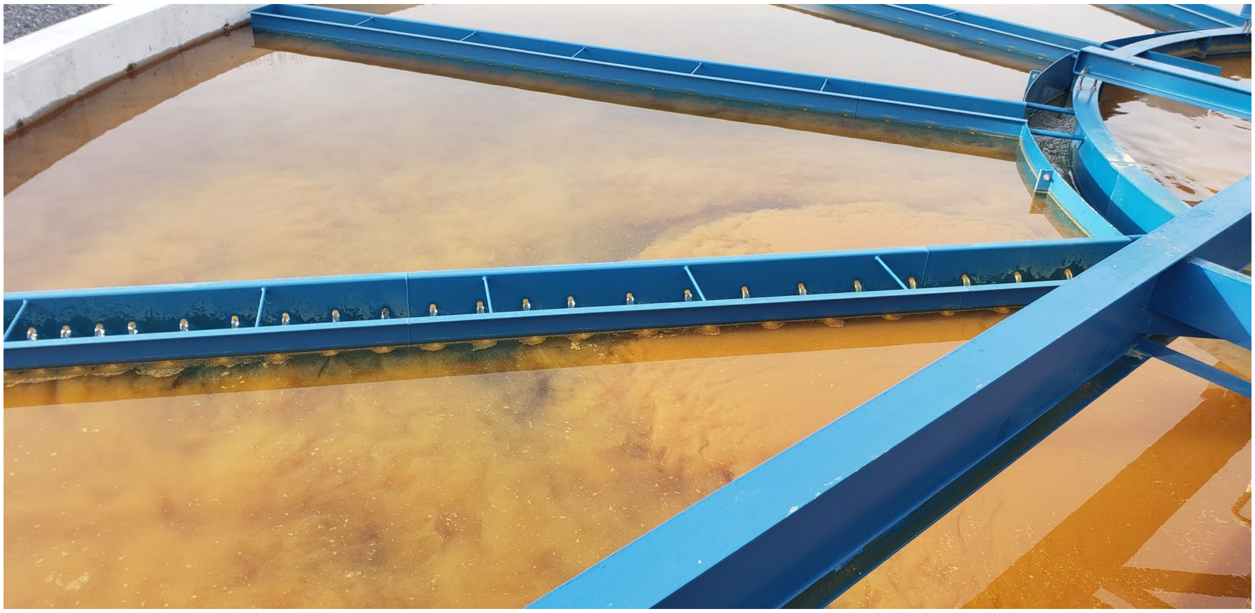

Figure 13: Photo of a disrupted clarifier discharging the sludge blanket due to an incorrect solids inventory handling plan. A change to both the elevation to maintain the sludge blanket and the sludge pumping schedule fixed the issue.

Figure 14: Bright green dye introduced into conveyance trough that connects the reaction tank to the center well of the clarifier. The open conveyance trough is located under the catwalk to the center well. Also, note the corrosion of the steel catwalk and handrailing extending to the center well.

Figure 15: Dye showed a preferential flow path of water on one side of the clarifier that increased water velocity causing poor settling and turbid effluent. Metal baffles were welded into the center well to improve flow distribution. This created a radial flow path emanating from the center well and resulted in improved effluent clarity. into the center well to redistribute the watering flowing down through the clarifier.

Figure 16: Alternative view of dye test shown in Figures 14 and 15. Before the installation of the flow baffle in the center well, dye preferentially flowed on one side of the clarifier.

Figure 17: Dye test on a large 220 ft diameter steel clarifier. Note rotation caused by rake movement.

Figure 18: A 5-gallon jug tied to a rake arm informs the operator the position of the rakes. The treatment strategy was changed from hydrated lime to hydrogen peroxide, which produced a less dense sludge. Soon after the conversion, a cloud of suspended iron solids appeared (Figure 19) and followed the floating jug indicating the rake speed was resuspending the less density peroxide sludge. A variable frequency drives connected to the drive motor was used to slow the speed of the rakes to fix the issue.

Figure 19: Cloud of suspended iron hydroxide that followed the rake rotation after conversion from hydrated lime to hydrogen peroxide.

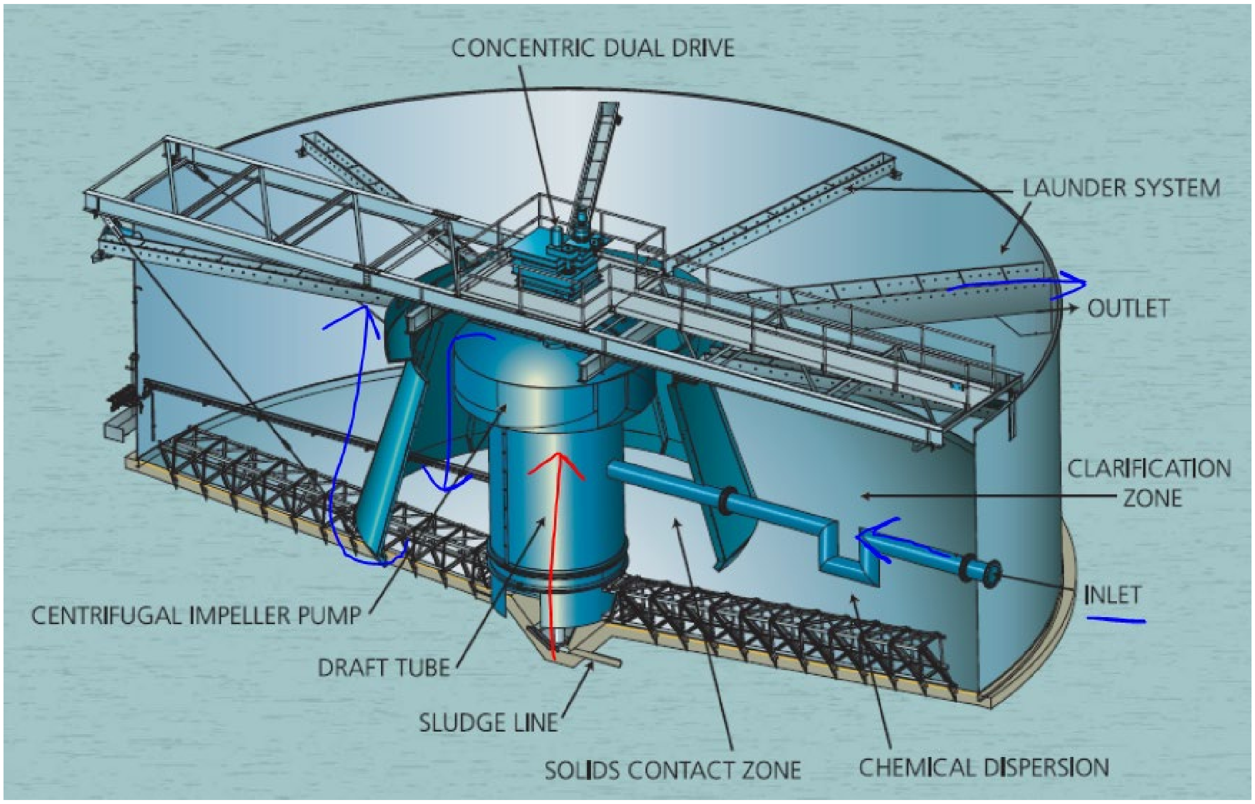

Figure 20: Schematic of a Solids Contact Clarifier (courtesy of Westech Engineering). Blue arrows signify the flow of water and the red arrow indicates how the sludge is pulled back to the surface to mix with raw water.

Figure 21: Concrete walled solids contact clarifier. Draft tube and reaction skirt/well are underwater and not visible.

Figure 22: Arial view of newly constructed concrete-walled Solids Contact Clarifier treating ferruginous mine drainage. Sludge pumps are housed in the white building and the effluent is discharged from silver piping into a wetland where total Fe is reduce4d from 0.5 to 0.03 mg/L.

Figure 23: Top view looking down at Center Well of a newly constructed Solids Contact Clarifier. The blue cylindrical tube in the middle of the photo that extends down to the concrete floor is the draft tube. The larger diameter blue cylinder on top of the daft tube is the impeller. The outer blue steel wall is the reaction well/skirt. The blue impeller spins and pulls settled sludge from the bottom up the draft tube where it is mixed and discharges it into the reaction well where the solids flocculated with the treated mine drainage. The mixture flows down the reaction well and into the settling zone of the clarifier.

Figure 24: A picture showing the reaction well of a newly constructed solids contact clarifier. The twelve-inch inlet pipe transports the raw mine drainage into the draft tube where it is reacted with hydrated lime and recycled sludge.

Figure 25: A steel mix tank to condition the recycled sludge with hydrated lime. The white pipe is the sludge recycle line and the smaller diameter black pipe entering the top right of the tank is the lime slurry line. A mechanical mixer is used to flash mix the sludge and lime slurry. The lime/sludge mixture is then discharged to the reaction tank where it reacts with the untreated influent water.

Figure 26: Outfall of sludge conditioning tank showing the sludge/lime slurry mixture being discharged into the reaction tank to react with the untreated influent.

Figure 27: The HDS conditioning tank was retrofitted to separate the lime slurry and sludge due to constant scaling and maintenance issues with the tank. The recirculated sludge is shown discharging from the blue pipe at the left of the photograph and the lime slurry is discharging from the conditioning tank.

Figure 28: HDS trough system developed by Bethlehem Steel. Lime slurry is dosed into the trough directly inside the building. The sludge/lime slurry mixture travels 30 feet before being discharged into the reaction tank to mix with the untreated influent water. The conditioned sludge in this photo has a higher percentage of lime since the photo was taken during a sludge pumping event. When sludge is pumped from the clarifier to an injection well, the amount of sludge recirculated decreases.

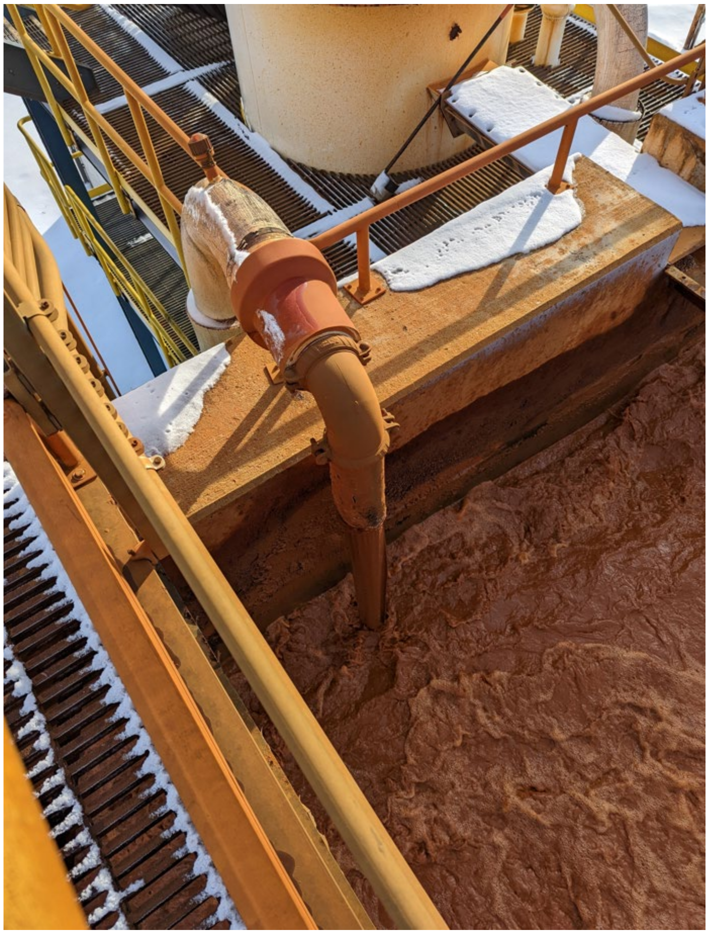
Figure 29: Example of an Enhanced Flocculation treatment system. Sludge from the clarifier is pumped back into the reaction tank where it is mixed with mine water treated with hydrogen peroxide. The pipe is recirculating approximately 250 gpm of 4% solids by weight back to the reaction tank.

Figure 30: Workers constructing a rebar form to pour a sloped concrete floor of a clarifier. The vertical form is to pour the concrete side walls.

Figure 31: A newly constructed welded steel conventional clarifier with a concrete floor. Note the greyish density curtain baffle extending the perimeter of the inside wall under the laundering weir.

Figure 32: The construction of a 220 ft diameter welded steel clarifier with a concrete floor. Note the missing steel panels that allow for equipment access into the clarifier during construction.


Figure 33: A viewpoint of the inside of the welded steel clarifier shown in Figure 31.


Figure 34: A viewpoint of the inside of the welded steel clarifier shown in Figures 31 & 32. Note the inside wall is in the process of being painted beige. A protective coating was also applied to the steel to retard corrosion. The steel panel weld marks are clearly visible on the unpainted section.

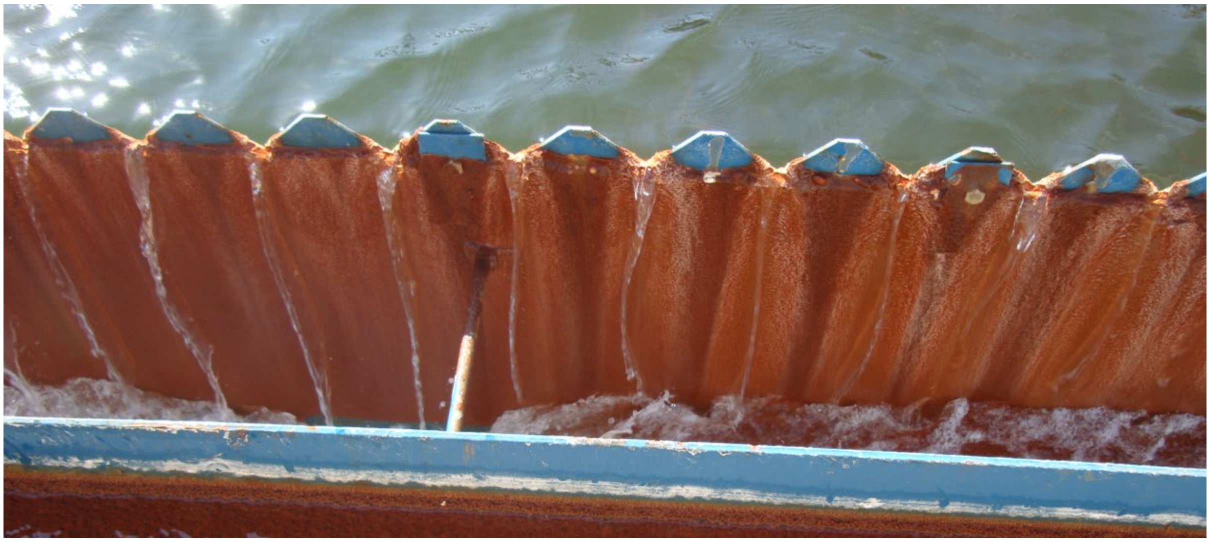

Figure 35: Photo showing a buildup of iron in the valleys of the sawtooth overflow weir.

Figure 36: Worker lowering pump to clean inside of clarifier. In addition, the iron-coated overflow weir and transport trough (working standing in trough) will be cleaned to restore an even distributed flow across the weir.

Figure 37: Works replacing the steel bolts that attach the overflow weir to the concrete wall with stainless steel bolts. The corrosion caused some of the bolts to fail causing the weir to fall into the clarifier (Figures 38 and 39). Stainless steel fasteners must be used when treating mine drainage. Note the top of the ladder is resting against the saw-toothed overflow weir and the weir is resting on support beams that secure the weir to the concrete wall.

Figure 38. Photo showing the corrosion of the fasteners that connect weir (top of photo) to the steel support beam and that connect the beam to the concrete wall. The steel fasteners were replaced with stainless steel.

Figure 39: Photo showing a portion of the yellow saw-toothed weir fell into the clarifier because corrosion from the mine drainage caused the fasteners to fail.

Figure 40: The blue fiberglass Density Current Baffle extends (courtesy of NEFCO) extends along the periphery of the outer wall just below the overflow weir.

Ion	Solid	S.G.
Al^{3+}	$Al(OH)_3$	2.42
Fe^{2+}	$Fe(OH)_2$	3.4
Fe^{3+}	$Fe(OH)_3$	4.25
Mn^{2+}	Mn(OH)2	3.25
	$CaCO_3$	2.71

Figure 41. Assumed solid phases and specific gravities for ions

Ion	mg/L	% Mass	Solid	S.G.	Weighted Density of Solids in Sludge (lbs/gal)
Al^{3+}	30	40%	$Al(OH)_3$	2.42	8.08
Fe^{2+}	15	20%	$Fe(OH)_2$	3.4	5.67
Fe^{3+}	20	27%	$Fe(OH)_3$	4.25	9.46
Mn^{2+}	10	13%	Mn(OH)2	3.25	3.62
$CaCO_3$	0		$CaCO_3$	2.71	
Misc. Solid	0				
Total	75	**Composite Solids in Sludge =**		**3.22**	**26.83**

Figure 42. Example of how a composite sludge density is calculated

Figure 43: Overland sludge pipeline to injection borehole. Most sludge lines are buried but this one is supported by wooden cribbing.

Figure 44: Raw water entering a reaction tank, showing clear, low total suspended solids water. The sludge injection well was located a few hundred feet from the raw water pumping well in a semi-isolated section of the mine. Sludge was successfully pumped for fifteen years without recirculating sludge back to the raw water pump. However, eventually the sludge disposal migrated to where the raw water pump recirculated sludge back to the reaction tank (Figure 45). A new sludge injection borehole was drilled a few thousand feet away in a more isolated and down-dip section of the mine.

Figure 45: Photo showing sludge injected in the underground mine is being captured by the raw water pump and recirculated with the raw water back to the reaction tank. See caption in Figure 44.

Figure 46: Large geotubes receiving sludge pumped from a clarifier. Eventually, the geotubes will be buried in place for final disposal.

Figure 47: Additional photo of geotubes show in in Figure 46. The geotubes will be buried in place as part of a reclamation plan to reclaim the highwall in shown in the photo. Soil will be placed over the final elevation of the geotubes and vegetated as part of the plan.

Figure 48: Sludge is pumped to the polymer mixer in the brown hose on the hillside. Polymer is added in the grey tubing near the sludge inlet and the polymer and sludge are passively mixed using a series of pipe bends. Two outlet hoses provide the flexibility to switch between two geotubes. When a geotube is filled, it is allowed to dewater and sludge is then pumped to the second geotube. The spigot is used to check the flocculation of the sludge to help calibrate the polymer dose. The PVC mixer can be constructed for a few hundred dollars.

Figure 49: Sludge is pumped through the red hose and into the geotube where the polymer flocculated particles are larger than pores in the geotube, which causes the solids to be retained in the bag while the water seeps through the fabric, dewatering the solids.

Figure 50: Geotubes being used in parallel. The geotube in the foreground was totally filled with sludge the previous day and is currently being allowed to dewater. Sludge will be pumped again in the next few days and the empty geotube will be used. The weekly sludge pumping will be alternated between geotubes to provide dewatering time. A gravel pad was constructed for the geotubes and has a 1% slope towards the perimeter ditching to capture the dewatering water. The geotubes are staked to the ground to prevent rolling as the tube is filled. In this photo, the sludge is being pumped from a pond and the variable sludge concentration during pumping makes it difficult to achieve a correct polymer dose. Thus, there are times where unaggregated particles leak through the pore space and into the perimeter ditch explaining the red coloration.