Enhanced Iron Removal for Recovery from Aerobic Ponds Using Retrofit Lasaire Aeration

FINAL REPORT

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EXECUTIVE SUMMARY

Passive treatment systems are used to treat high iron concentration AMD in Pennsylvania in order to remove iron (and other contaminants) that would degrade surface waters. A number of these iron removal passive treatment systems have been constructed on high flow discharges with varying success and performance. The focus of this study was to evaluate a new aeration system to improve and enhance iron removal that can be retrofit on passive treatment systems comprised of aerobic ponds treating alkaline discharges or aerobic ponds with an anoxic limestone drain (ALD) pretreatment.

Many high flow AMD discharges contain iron as the primary contaminant in the soluble ferrous iron form and contain sufficient alkalinity to neutralize the acidity associated with the removal of the soluble iron. In some cases, alkalinity is added to the AMD using the ALD, a type of pretreatment that adds alkalinity without precipitating the iron. In either instance, the AMD is treated with a passive treatment system known as an aerobic pond(s). An aerobic pond is a deep (5-6 feet) open water pond that provides detention time for the ferrous iron to oxidize, hydrolyze, flocculate and settle to the pond bottom where it gradually accumulates for future removal/recovery. While these ponds are effective at removal of iron, their performance varies depending on discharge chemistry and seasonal temperature changes. In addition, performance of aerobic ponds tends to gradually decline over their effective operational lifespan due to filling of the pond and/or declining alkalinity generation by the ALD.

This study was conducted for the Pennsylvania Department of Environmental Protection (DEP) under the OSM PA AMD(06) grant for innovative ex-situ AMD treatment and metal recovery systems for abandoned acidic mine drainage. This project evaluated new aeration equipment, known as Lasaire Aeration®, which is a bubble aeration system with low energy requirements that has been successfully used in other fields including industrial and municipal wastewater treatment as well as natural fishery ponds. This *in situ* aeration would provide both higher dissolved oxygen levels and increase pH to improve iron removal in existing systems and decrease the size of new installations. The aeration could also increase the amount of solids accumulating in the aerobic ponds between clean-out cycles.

Test studies were conducted at three (3) locations where aerobic pond performance is inadequate and/or where aeration could replace or reduce the use of high cost chemicals. The sites were: 1) the Wildwood Treatment system in Allegheny County where hydrogen peroxide is used to oxidize ferrous iron in a concrete tank system; 2) the Upper Latrobe site in Westmoreland County that involves the discharge of alkaline AMD from a pressurized and flow controlled drill hole to an aerobic pond; and 3) the Brandycamp discharge in Elk County that is treated with hydrated lime prior to iron removal in an active treatment system. The Wildwood and Upper Latrobe sites tested installed Lasaire Aeration® equipment and the Brandycamp site used a pilot steel tank aeration system. The focus of the aeration at the Wildwood and Upper Latrobe sites was improved iron removal. Aeration at the Brandycamp site focused on carbon dioxide (and associated acidity) removal in order to evaluate decreasing lime dose and solids production in the active treatment system.

Lasaire Aeration® at the Wildwood site was installed in the late Fall 2007. There were initial operational issues associated with the air delivery unit (i.e., blower) that resulted in drive motor and blower shut down. The components were repaired and the unit was modified in the Spring of 2008. No subsequent operational issues with the air delivery unit were encountered during the remainder of the study. Monitoring of the Wildwood site Lasaire Aeration® system was conducted through to late Fall of 2008. The results at the Wildwood site indicated the aeration increased pH (> 7.5) and dissolved oxygen (> 10 mg/L). Studies conducted with the hydrogen peroxide turned off resulted in complete oxidation of the ferrous iron, however, the

size of the concrete tank at the Wildwood site was insufficient to settle the particulate iron solids produced using aeration only; total iron decreased about 60% (effluent between 1.5 to 2.5 mg/L). Hydrogen peroxide treatment produced a corresponding effluent total iron less than 1 mg/L. The hydrogen peroxide appears to produce a better settling iron oxide which is likely a result of decreasing the surface charge of the particulate iron oxide allowing better flocculation and settling.

Lasaire Aeration® was installed at the Upper Latrobe site in the Spring of 2008. Monitoring at Upper Latrobe Lasaire Aeration® system was conducted through late Fall of 2008. The results indicated the Lasaire Aeration® systems increased the pH (~7) and dissolved oxygen (> 9 mg/L) of the AMD, which enhanced iron oxidation and iron removal. The results at the Upper Latrobe site indicated higher flows, approximately 4 to 5 times higher, could be treated by the aerobic pond with the Lasaire® Aeration system compared to the aerobic pond only. Maintenance procedures were developed for the Lasaire® Aeration system to maintain air flow due to iron clogging of the aeration tubing. Maintenance involved bi-weekly (i.e., once every two weeks) cleaning using pressurized air and acid injection into the tubing.

The Brandycamp aeration study was conducted in November and December 2008 using a pilot aeration system that used membrane fine and coarse bubble diffusers in a portable steel tank system with air delivered by a blower system. This was a modification to the project approach to address ongoing treatment difficulties at the Brandycamp AMD Treatment System. Water from the Brandycamp discharge was pumped into the aeration pilot system where the water was aerated to add dissolved oxygen and remove carbon dioxide (and associated acidity). Dissolved oxygen was also increased from less than 1 mg/L to greater than 10 mg/L (near 100% saturation). The aeration also resulted in greater than 50% removal of total acidity, which corresponded to nearly complete carbon dioxide acidity removal. There was also a measured decrease in the required lime dose that corresponded to the decrease in acidity. The decrease in total acidity and the lime (hydrated lime) dose required for treatment of the Brandycamp discharge equates to a potential cost savings of $50,000/year. The aeration could also decrease the volume of solids produced by as much as 50%, an effect of the high initial carbon dioxide that leads to the formation of calcium carbonate (calcite) precipitation.

INTRODUCTION

The discharge of AMD to surface waters in Pennsylvania (and other eastern coal region states) contaminates thousands of miles of surface waters resulting in their non-compliance with numerous Pennsylvania Water Quality Standards including, but not limited to, pH, total iron, suspended solids, and aesthetics. The AMD is a result of past (and unregulated) surface and underground coal mining, which exposes pyritic minerals to atmospheric oxygen and results in their oxidation and the production of AMD.

A number of AMD discharges consist of chemistry containing elevated ferrous iron concentrations and sufficient alkalinity (i.e., net alkaline) or sufficient alkalinity after pre-treatment in an anoxic limestone drain (ALD) for complete removal of iron and associated acidity. An ALD is a passive treatment system containing buried limestone that adds alkalinity through the dissolution of the limestone while maintaining anoxic conditions (i.e., no oxygen) to prevent the oxidation and precipitation of the ferrous iron. Where AMD discharge flow and land conditions permit, this type of AMD discharge can be treated with passive treatment, typically in one or more aerobic ponds. Aerobic ponds are open water ponds (5 to 6 feet deep) that provide natural aeration and long detentions times to facilitate ferrous iron oxidation to ferric iron, form a ferric hydroxide precipitate, and settle the particulate iron from the water to the pond bottom. A depiction of an aerobic pond is shown in Figure Lasaire FINAL-1. The success of aerobic ponds has varied considerable with the use of the existing surficial removal design criteria of 20 grams per day per square meter (Hedin *et al* 1994). Differences in AMD pH, alkalinity, ferrous iron concentrations, discharge temperature and designs have been the primary causes of the varying performance of aerobic ponds. In addition, the sizing criteria does not consider the effects of seasonal changes in temperature as well as the effect of the gradual accumulation of solids in the aerobic ponds on its overall performance.

This study was conducted to investigate a new and innovative aeration technology, known as Lasaire Aeration®, to enhance iron removal and metal recovery of AMD discharges that are currently ineffectively treated with aerobic ponds, use additional chemicals to achieve needed performance, or are constrained due to land area limitations. The study involved installation of aeration systems and monitoring at two locations to evaluate this new application of the Lasaire Aeration®.

Lasaire Aeration® was tested at two locations in southwestern Pennsylvania. The two locations were:

1. Wildwood AMD Treatment System near Gibsonia, Pennsylvania; and
2. Upper Latrobe Passive Treatment System near Latrobe, Pennsylvania.

The two locations are underground mine type discharges in the bituminous coal region. The locations were selected based on a number of factors including AMD chemistry, space limitations affecting overall performance, and the use of supplemental chemicals to achieve the desired performance.

A third location involved evaluation of aeration using a portable aeration pilot unit to remove total acidity, through carbon dioxide acidity removal, and lower lime (hydrated lime) dose and solids production. The third location was in north central Pennsylvania at the Brandycamp AMD Treatment System near Brockway, Pennsylvania. This is an active treatment system using lime dosing, aeration and clarification to remove iron and associated acidity from a deep mine discharge. The Barndycamp treatment system has operational and performance issues including high lime dose and high solids production. The issues limit the flow the active treatment system is able to treat. Discharge flow typically exceeds the capacity of the system during three to six months of the year.

The following provides a summary of the three project locations, background chemistry, overall effectiveness of the aeration, and an evaluation of the Lasaire Aeration® technology for future applications. The Brandycamp site involved a different type of aeration equipment and will be discussed separately.

LASAIRE AERATION STUDY

The following provides the technical background information for the Lasaire Aeration® projects for the aeration testing including project location, AMD characteristics at each site, background iron oxidation information, and an evaluation of the effects of the aeration on aerobic pond performance.

Lasaire Aeration® System

Lasaire Aeration® is a unique aeration technology that has been employed in wastewater treatment (e.g., aerated lagoons). The technology uses specialized manufactured tubing that contains a weight to keep the tubing fixed to the bottom, a hollow tube to deliver low pressure (< 10 psi) air, and drilled holes to provide fine bubble aeration to the water. Figure Lasaire-1 shows a section of the tubing used in this study with the various components identified.

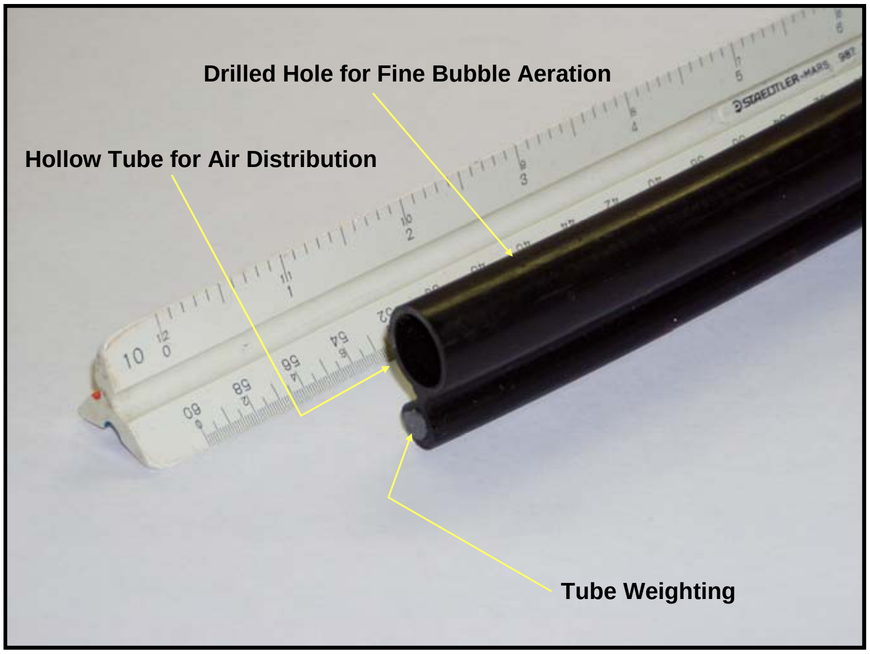


Figure Lasaire-1. Lasaire Aeration Tubing used in the study

Air is delivered to the Lasaire Aeration® tubing by a mechanical blower operated by an electric motor, and header pipes to deilver the air to the tubing. Figure Lasaire-2 shows the mechanical blower unit used at the Upper Latrobe site, which consists of an air intake, mufflers, blower motor unit, electric motor and pulleys (or shives) to drive the blower, an air pressure relief valve to prevent excess back pressure, and an air discharge line. Figure Lasaire 3 shows the header pipe system used to

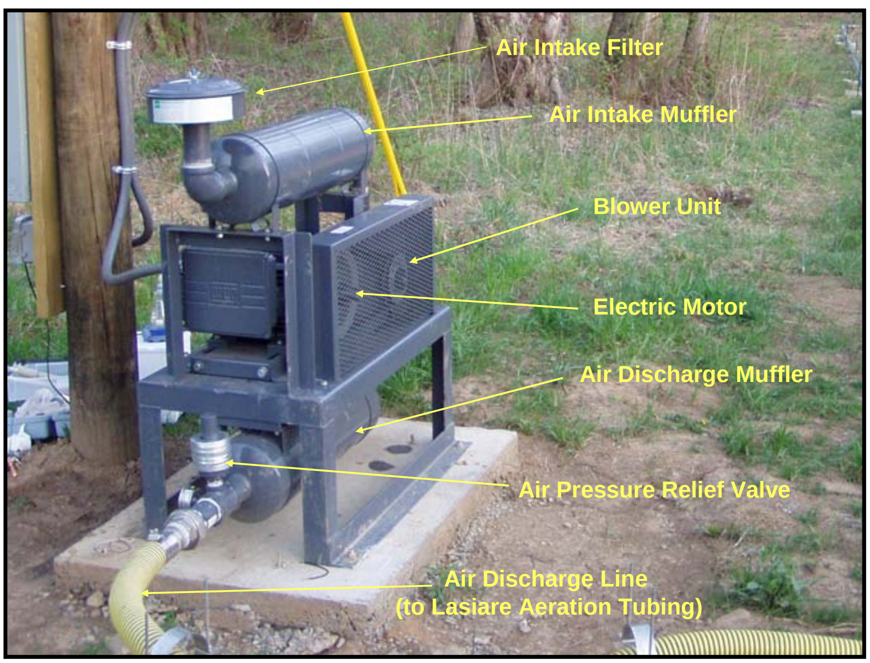


Figure Lasaire-2. Lasaire Aeration air delivery unit

distribute the air to the Lasaire Aeration® tubing. The header system consists of an air distribution header pipe, air line shut-off/isolation valves, high pressure clean-out tubing and valving, and the Lasaire Aeration® tubing connected to the header system with various connectors.

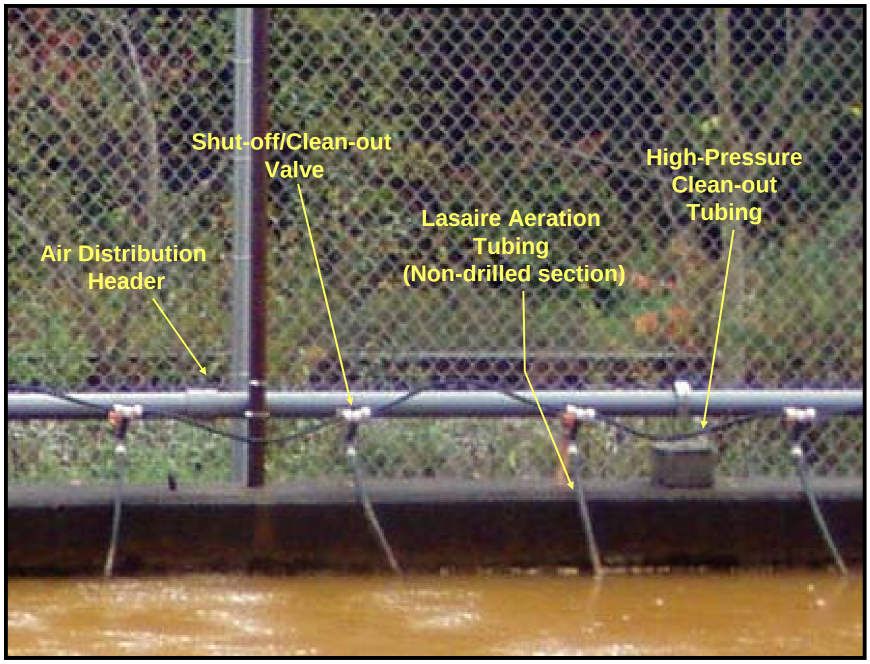


Figure Lasaire-3. Lasaire Aeration Header System

Selected Sites

The two sites selected for testing of the Lasaire® Aeration system in Pennsylvania were:

1. The Wildwood AMD Active Treatment System near Wildwood, PA; and
2. The Upper Latrobe Borehole AMD discharge and passive treatment system near Latrobe, PA.

The two locations are in western Pennsylvania are both underground mining type discharges in the bituminous coal region. The locations were selected based on review of numerous sites that either had inadequate overall performance or used supplemental chemicals to achieve the desired performance. Each of the sites is briefly described in the following paragraphs.

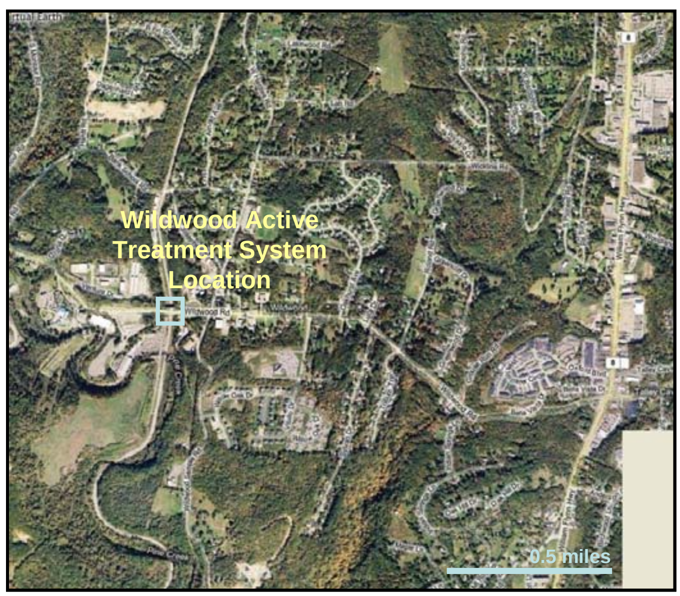


Figure Lasaire-4. Wildwood Active Treatment System Location

Wildwood AMD Active System

The Wildwood AMD Active System is located north of Pittsburgh, Pennsylvania in a residential/commercial area known as Wildwood. Figure Lasaire 4 provides the location of the Wildwood AMD Active Treatment System. The discharge and active treatment system are located adjacent to a railroad bed along on the west bank of Willow Run, a tributary to Pine Creek. Pine Creek is an important local trout stocked fishery. The discharge is piped underground from an abandoned bore hole to the active treatment system.

Figure Lasaire-5. Wildwood Active Treatment System.

The Wildwood Active Treatment System has been in operation since the 1960s and was installed to treat a deep mine discharge emanating from a bore hole. The discharge was degrading Pine Creek through deposition of iron oxides, “Yellowboy”, which threatened the stream as a trout stocked fishery. Figure Lasaire 5 shows the Wildwood Active Treatment System and the various system components. The Wildwood Active Treatment System consists of an inlet pipe to an aeration trough and a 45 feet wide and 260 feet long concrete settling basin. The basin is separated by membrane curtains spaced every 40 ft to 60 ft of basin length. The aeration trough provides aeration by cascading the AMD in a series of troughs before entering the settling basin. Although the AMD is aerated, the AMD is primarily treated by dosing hydrogen peroxide (H_2O_2) using metering pumps. The hydrogen peroxide is needed to oxidize the dissolved ferrous iron to insoluble ferric iron oxide and allow the particulate iron to settle in the concrete basin. The hydrogen peroxide is a high cost chemical that may not be needed if adequate aeration is provided to oxidize the ferrous iron and raise the pH to produce a rapidly settling particulate iron.

Upper Latrobe AMD Site

The Upper Latrobe site is located in the town of Latrobe, Pennsylvania. Figure Lasaire 6 provides the location of the Upper Latrobe site. The discharge and passive treatment system are located on the west bank within the floodplain of the Loyalhanna River. The location is within a meander of the river and results in a nearly flat site location. The entire site, as well as much of Latrobe, is underlain by a flooded abandoned deep mine complex. At this location the deep mine pool has several feet of pressure head above the surface elevation.

Figure Lasaire-6. Upper Latrobe Site Location.

As part of a several projects to lower the mine pool pressure head and minimize AMD outbreaks at various locations along the Loyalhanna River, the Loyalhanna Watershed Association (LWA) undertook a project at the Upper Latrobe Site that involved drilling a well into the mine pool and construction of a passive treatment system. The well was capped and valved to permit regulation of the flow with the intent to divert AMD flow (and lower the mine pool pressure) to this location where the AMD could be treated with passive treatment. A passive treatment system was constructed at the site. Figure Lasaire 7 shows the location of the well and the passive treatment system. The passive treatment system is an rectangular aerobic pond with membrane baffles installed to improve plug flow and detention time in the aerobic pond. The aerobic pond is approximately 37,000 ft^2 with areas ranging between 6,000 ft^2 and 9,000 ft^2 in each baffled area of the aerobic pond.

Figure Lasaire-7. The Upper Latrobe Site Passive Treatment System.

Based on the size of the aerobic pond and the iron removal criterion of 20 gr/day/m^2 of iron removal (Hedin *et al* 1994) the pond should be able to treat an AMD flow of 280 gpm. However, LWA has indicated the passive system is limited to about 50 gpm of AMD flow before effluent water quality begins to deterioate. This is likely due to low pH and minimal natural aeration (flat landscape) at the passive treatment system.

AMD Characteristics

The AMD discharge chemistry for the Upper Latrobe and Wildwood AMD discharges are summarized in Table Lasaire - 1. Evaluation of the AMD chemistry is an integral component in determining treatment and aeration requirements.

Table Lasaire - 1. Average AMD Discharge Characteristics

Site	Wildwood	Upper Latrobe
pH	6.9	6.1
Dissolved Oxygen (mg/L)	0.80	0.15
Temperature (ºC)	12.0	12.5
Alkalinity (mg/L as $CaCO_3$)	360	150
CO_2 Acidity (mg/L as $CaCO_3$)	225	500
Total Fe (mg/L)	8.5	45
Ferrous Fe (mg/L)	8.5	45
Total Mn (mg/L)	0.2	4.5
Total Al (mg/L)	0.1	0.1
Sulfate (mg/L)	120	600

Both the anoxic discharges contain ferrous iron (Fe^{2+}). The ferrous iron concentration is important since it is the oxidation of ferrous iron that is the controlling step in iron removal from mine drainage. Iron oxidation and removal will be evaluated using the abiotic model in Sung and Morgan (1980) and the grams per day per square meter (GDM) criterion from Hedin *et al* (1994).

Alkalinity was evaluated to determine whether there is adequate alkalinity for the removal of iron from the mine drainage. The oxidation and precipitation of 1 mg/L of ferrous iron will consume 1.8 mg/L of alkalinity. Both the discharges have adequate alkalinity to completely oxidize and precipitate ferrous iron.

Carbon dioxide (CO_2) acidity data was calculated based on pH and alkalinity, which is important in determining the amount of aeration needed to remove the CO_2 and evaluate the likely pH and ferrous iron oxidation in the system. While dissolved oxygen is important in the oxidation of ferrous iron, the pH of the water controls the overall rate of iron oxidation and iron removal. In aqueous chemistry, carbon dioxide acidity is present in water as carbonic acid (H_2CO_3). The pH of water is determined by the concentrations of bicarbonate (HCO_3^-), which is alkalinity, and H_2CO_3 according to the following relationship:

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+, \qquad (1)$$

The pK_a of this equilibrium is 6.4. This 6.4 would also be the pH at which the H_2CO_3 and HCO_3^- concentrations would be equal. This means an alkalinity (HCO_3^-) of 230 mg/L (as $CaCO_3$) would have to have an equal CO_2 acidity (H_2CO_3) of 230 mg/L (as $CaCO_3$) to have a pH of 6.4. The CO_2 acidities calculated for the various discharges are provided in Table 1, which indicates there is considerable CO_2 acidity. The source of this acidity is chemical neutralization reactions in the deep mine pool as well as decomposition reactions. If this CO_2 acidity is removed through aeration, the pH of the water will rise. As an example, if 80% of the carbon dioxide acidity is stripped from the Upper Latrobe AMD discharge through aeration, the pH will increase from 6.1 to 6.9.

This summarizes the chemistry evaluation for the discharges. As previously indicated, this evaluation is an integral component in determining the amount of aeration required to achieve the desired treatment levels in aerobic ponds.

Background Process Chemistry

AMD treatment requires a number of chemical and physical processes including ferrous iron oxidation, particulate iron settling, and passive/active aeration for dissolved oxygen addition and carbon dioxide removal (i.e., pH adjustment).

Ferrous Iron Oxidation in AMD Treatment

The treatment of many AMD discharges requires iron removal and this iron removal is a multi-step process involving:

1. Oxidation of dissolved ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+});
2. Hydrolysis of ferric iron to form insoluble ferric oxide ($Fe(OH)_3$);
3. Flocculation of tiny (sub micrometer - µm) iron oxide particles to form larger (micrometer - µm) iron oxide particles;
4. Settling of suspended iron oxide particle from solution.

Depending on the type of treatment, one or more of the above processes will control the removal of iron. In passive treatment, the oxidation (Step 1) of ferrous iron is very slow and determines iron removal and thereby determines the size of the passive treatment system. In chemical treatment at high pH (> 8), the settling (Step 4) typically controls iron removal.

The oxidation of ferrous iron is the first and most crucial step in the removal of iron. Without the oxidation step, ferrous iron would remain in solution (except at very high pH where it precipitates as ferrous hydroxide) and removal of iron from AMD would not be possible. There are two types of ferrous iron oxidation in water, which are:

1. ***Homogeneous Ferrous Iron Oxidation*** – is the long established oxidation process occurring in solution and involves the reaction of dissolved ferrous iron (Fe^{2+}) with dissolved oxygen. *(discussed below)*
2. ***Heterogeneous Ferrous Iron Oxidation*** – is a newly identified oxidation process occurring on the surface of iron oxide solids and involves the sorption of ferrous iron and dissolved oxygen followed by the rapid catalytic oxidation on the surface of the iron oxide. *(beyond scope of this project)*

With respect to aerobic ponds, the homogeneous ferrous iron oxidation process is the dominant process and controls iron removal. The passive treatment design/sizing of 20 grams per day per square meter (GDM) from Hedien *et al* (1994) is a zero order removal rate. The criterion is based on empirically derived average removal of iron from past operating systems and does not consider differences in AMD chemistry (e.g., iron concentration, alkalinity, pH and temperature), differences in designs (e.g., shallow vs. deep water), and critical conditions (e.g., low winter temperatures and summer stratification). Another tool to estimate ferrous iron oxidation is the long established homogeneous oxidation rate equation (Sung & Morgan 1980):

$$R(M \cdot s^{-1}) = -\frac{\partial[Fe(II)_{diss}]}{\partial t} = \frac{k_{Ho2} \times [Fe(II)_{diss}] \times [O_2]}{\{H^+\}^2} \qquad (2)$$

This equation determines the oxidation of ferrous iron as a function of time and according to first-order reaction rates. The equation is complex and considers the affects of ferrous iron concentration $[Fe(II)_{diss}]$, dissolved oxygen $[O_2]$ and pH $\{H^+\}$ on the rate of ferrous iron oxidation and removal. Temperature is an integral part of the equation by its affects on the reaction rate constant (k_{Ho2}), with a decrease in temperature causing a decrease in the oxidation rate. Two factors in the above equation can be affected by aeration: the dissolved oxygen concentration; and pH as expressed by the $\{H^+\}$. The equation indicates as the dissolved oxygen increases the oxidation rate will increase and as the pH increases (or $\{H^+\}$ decreases) the oxidation rate will also increase. Increases in the dissolved oxygen from 4 to 8 mg/L will double the oxidation rate. Increases in pH from 6.2 to 6.5 (halving of the $\{H^+\}$) will quadruple the rate because of the square power on the $\{H^+\}$. Increasing the pH from 6.2 to 6.9 will increase the rate 25-fold. In AMD treatment the increase in pH is from CO_2 removal through either active or passive aeration.

Dempsey *et al* (2001) found the homogeneous rate equation to accurately predict iron removal in passive treatment systems with varying design and AMD quality; demonstrating the limiting step in passive treatment is ferrous iron oxidation. The equation is much more reliable design tool than the 20 GDM approach because the equation can be used to predict iron removal for 1) different AMD chemistry, 2) factors in iron removal under critical operating conditions (e.g., low temperature), and 3) address differences in treatment cell design (i.e., treatment cell depth) and pre-treatment (i.e., aeration).

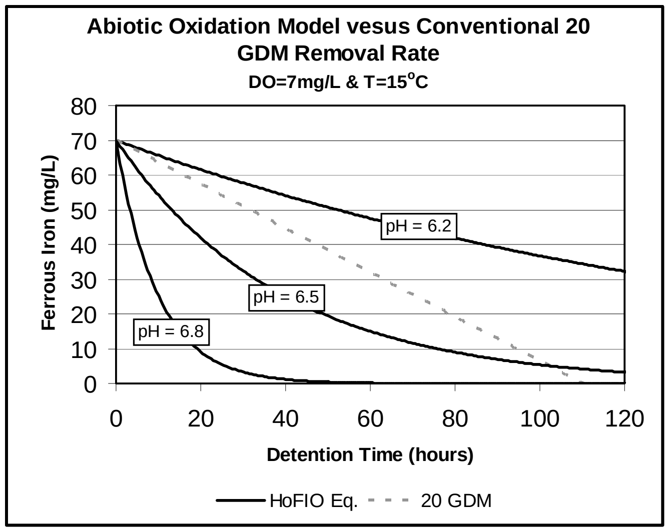


Figure Lasaire-8. Comparison of Ferrous Iron Oxidation Rates at Different pH.

The Figure Lasaire 8 provides a comparison of the removal rate (20 GDM) versus the actual oxidation using the homogeneous equation for various pH encountered in passive treatment systems. The figure shows the initial ferrous iron oxidation is much faster than the removal rate approach, but as ferrous iron concentration decreases the ferrous iron oxidation rate decreases. The pH 6.5 homogeneous oxidation curve and the 20 GDM removal rate straight line intercept at approximately 100 hours and at a ferrous iron concentration of approximately 5 mg/L. The oxidation line for pH 6.8 is similar to what might occur in the passive treatment system with pre-aeration and shows much higher oxidation rates and near complete oxidation in about 40 hours as compared to greater than 120 and 250 hours for pH 6.5 and 6.2, respectively.

Aeration in AMD

Aeration in AMD treatment is important to add dissolved oxygen necessary for the oxidation of ferrous iron and remove carbon dioxide resulting in an increase in pH. Aeration in passive treatment occurs at the surface of the water and where the water is agitated, such as channels and spillways. Figure Lasaire 9 shows the relationship between air and water and that the aeration occurs only at the water

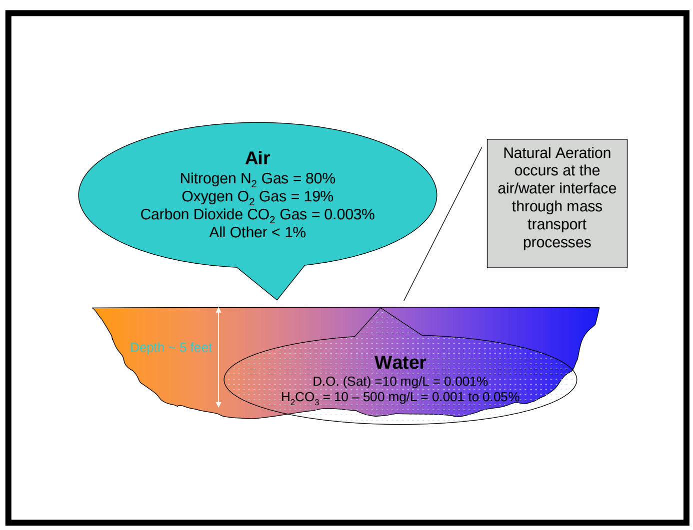


Figure Lasaire-9. Natural Pond Aeration Schematic.

surface interface. This aeration is generally slow and can be affected by a number of factors including air and water temperature, wind, surface films, and thermal stratification.

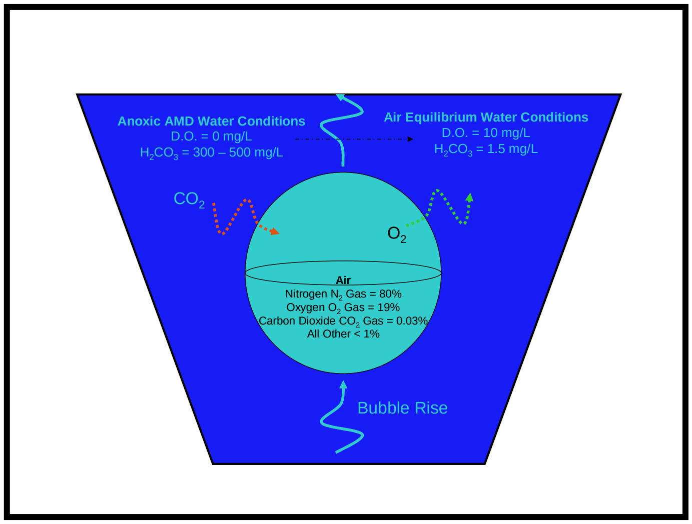


Figure Lasaire-10. Mechanical Bubble Aeration Schematic.

Active aeration is accomplished with mechanical mixers that agitate the surface of the water or with bubble aeration where air is delivered to the water through diffusers and mechanical blowers. Both processes increase the surface area contact between the water and the air and results in greater mass transport of gases to or from the water. Figure Lasaire 10 shows a schematic of an air bubble in the water column. Anoxic mine water generally is low in dissolved oxygen and high in carbon dioxide, which is produced from oxidation/neutralization reactions and decomposition reactions by bacteria in the mine pool. Air bubbles are pockets of air trapped in the water that have the same composition as the atmosphere containing high oxygen and low carbon dioxide concentrations. As shown in Figure Lasaire 10, dissolved oxygen will transport across the bubble into the water forming dissolved oxygen in the water and carbon dioxide will transport from the water to the air bubble. The carbon dioxide is then released to the atmosphere once the bubble reaches the surface. The bubble size is minimally affected by this transport due to the bulk of the air is comprised of nitrogen.

By adding air bubbles the surface of water in contact with the air is increased by orders of magnitude over passive aeration at the pond surface. As an example, to provide a one (1) acre pond surface area in bubbles only requires an aeration volume of 230 ft^3 (~1,700 gallons), based on calculated surface area of fine bubbles (Diameter < 0.1 cm).

There are number of factors that affect the gas transport to and from the air (or air bubble). Overall the process of whether gas is transported to or from the bubble and to what final concentration is determined by Henry's Law:

$$K_{Hx} = P_x \div C_x \tag{3}$$

where K_{Hx} is the Henry's Law constant for the gas (e.g., oxygen or carbon dioxide), P_x is the partial pressure of the gas in the atmosphere, and C_x is the concentration of the gas in water. In anoxic mine water oxygen is dissolved in the water and carbon dioxide is removed from the water by aeration. Factors affecting gas transport to and from bubbles into water include: 1) the relationship of the concentration of the gas in the air relative to the concentration in the water; 2) the temperature of the water (and air), which affects the Henry's Law Constant; 3) the area of the water and air interface, related to bubble size and volume; and 4) the detention time of the aeration basin. Bubble size is important as it affects both the air:water surface area interface and the velocity at which the bubble rises.

Wildwood Site

The existing Wildwood Active Treatment System consisted of a concrete settling basin with a surface area of approximately 12,000 ft^2 with a depth between 9 and 10 feet. The settling basin was divided with membrane baffles into six zones with areas ranging between 1,800 ft^2 and 2,500 ft^2. The Wildwood System receives AMD from a sealed mine opening that is piped to the treatment system. Reported flow for the AMD discharge, as measured by DEP at the effluent from the basin, vary from 200 to 1,400 gpm. Highest flows typically occur in the spring and early summer. The treatment of the discharge currently uses hydrogen peroxide to oxidize the ferrous iron to insoluble ferric iron, which is then collected in the basin.

Figure Lasaire-11. Lasaire Aeration System at the Wildwood Treatment System.

The goals and objectives of the Lasaire® aeration study at the Wildwood Treatment System were two-fold. First, the system was to provide aeration to increase the dissolved oxygen and remove carbon dioxide (i.e., raise pH) to increase the rate of ferrous iron oxidation in the settling basin without the use of hydrogen peroxide. Secondly, the removal of carbon dioxide from the aeration would raise the pH to produce a settleable iron oxide solid. The improved settling is needed because iron oxide particles are positively charged at circumneutral, which prevents rapid flocculation to form larger more rapidly settling particles. By increasing the pH the iron oxide particles should become less charged allowing improved flocculation and settling.

System Installation

The operational Lasaire© Aeration System at the Wildwood System is depicted in Figure Lasaire 11. The Lasaire© Aeration System was installed in the first two baffled areas of the basin in November 2007. Initial installation consisted of: 1) adding electrical service to electrical panel on the outside of the pump building; 2) removal and addition of a new fence section along the access road to allow installation of a header pipe; 3) pouring a concrete pad for the blower unit; 4) anchoring an one hundred (100) standard cubic feet per minute (SCFM) Blower Package (Purestream, Inc.) to the concrete pad. Once the blower was placed, header piping was assembled and anchored along the first and second baffled areas of the concrete basin. Lasaire aeration tubing (27 tubing runs) was installed across the first and second baffled areas.

The system was initially operated from December 3rd through late December, 2007. However, an operational problem occurred with the blower unit resulting in its shutdown in late December, 2007. The electrical motor in the blower unit failed. It was later determined the failure was due to an overheating issue, which took several months to identify and retrofit the the blower unit motor with modifications as well as replace the motor. The blower unit was restarted on April 16th, 2008 and operated until June 9th, 2008. During this period the blower appearred to deliver inadequate air flow. The blower unit seized in this fist part of June 2008, probably a result of overheating during the previous electric motor failure. The blower unit was rebuilt and once again restarted in August 2008 and ran without problems through the completion of testing in (date).

The Wildwood Lasaire Areation System blower back pressure increased over a short period of time, approximately four (4) weeks, during this operational period (August 27 through September 23, 2007). A cleaning procedure (developed for the Upper Latrobe site) was employed at the Wildwood site. The cleaning procedure developed for the mine drainage application consisted of injecting 100 mL of muriatic acid into an individual Lasaire tubing line followed by connection and delivery of high pressure air to the tubing from a portable (rental) compressor. The procedure was repeated for each line in the system. The procedure takes approximately one to two hours of time.

Upper Latrobe Borehole Site

The Upper Latrobe Borehole passive treatment system consisted of an aerobic pond with a surface area of approximately 37,000 ft^2 with a depth between 3 and 5 feet. The aerobic pond was divided with membrane baffles into five zones with areas ranging between 6,000 ft^2 and 9,000 ft^2. At the time of the evaluation, the aerobic pond was receiving approximately 50 gpm of AMD flow from the borehole. The flow rate from the borehole is adjustable by opening and closing a valve. Flow rates can be increased to greater tha 500 gpm, although the long term sustainability of this high flow is uncertain because the mine pool is under pressure and could potentially be drawn down at higher flow rates. The 50 gpm flow into the aerobic pond was established by LWA as the maximum flow the aerobic pond could treat without deterioration of effluent quality.

During the site review it was found the pond embankments were leaking as the inflow rate was greater than the effluent flow; approximately 20 gpm was measured at the outflow from the aerobic pond compared to 50 gpm inflow. Locations of potential leakage were identified, which were near the first baffle in the aerobic pond. The bottom of the aerobic pond was not lined and embankment material was comprised of alluvial (floodplain) soils that are likely to

Figure Lasaire-12. Lasaire Aeration System at the Upper Latrobe Borehole.

be slightly to moderately porous. During the Fall of 2007 the DEP-BAMR Maintainance Staff improved the access road by placing stone in wet areas and attempted to minimize the embankment leakage by adding and compacting the embankment soils.

System Installation

The operational Lasaire© Aeration System at the Upper Latrobe Borehole passive treatment system is depicted in Figure Lasaire 12. The Lasaire© Aeration System was installed in the first baffled area of the aerobic pond in the Spring of 2008 (March-April 2008). Initial installation consisted of: 1) placing a electrical pole adjacent to the first baffled area; 2) installation of electrical service to the site by Allegheny Power; 3) pouring a concrete pad adjacent to the pole; 4) anchoring an eighty (80) standard cubic feet per minute (SCFM) Blower Package (Excelsior Blower Systems, Inc.) to the concrete pad. Once the blower was placed, header piping was assembled and anchored along the embankment of the first baffled area. Lasaire aeration tubing (15 tubing runs) was installed lengthwise in the first baffled area. In addition to the aeration installation, the AMD was piped from the borehole to the passive treatment system in order to eliminate any aeration in the inflow channel.

The system was initially operated from April 10th through June 9th, 2008. The AMD flow was regulated between 125 gpm and 250 gpm during this initial period. There was one shut down on of the blower in April during this period due to a power outage. The unit was restarted and was operational. The Lasaire Aeration system was effective at increasing dissolved oxygen and pH during this study period. However, the blower back pressure increased in a short period of time, less than two (2) weeks, during the operational period. This was due to some form of clogging in the tubing. The normal cleaning cycle in wastewater applications is between 4 and 8 weeks depending on the characteristics of the wastewater (e.g., hardness). Initial efforts to clean the system using compressed air were of limited success. In order to further investigate the clogging issue the system was shutdown and tubing was removed and sent out for microscopic inspection.

The results of the microscopic inspection indicated the clogging issue was related to iron oxide precipitation in the air hole of the tubing. This accumulation could be a result of: 1) accumulation of iron oxide deposits on top of the tubing; and/or 2) direct oxidation and precipitation of the iron oxide at the air hole of the tubing. To address this clogging issue an alternative cleaning procedure was developed using both high pressure air and muriatic acid. Also, during this shutdown period: 1) the intake and first baffle were moved to increase horizontal velocity through the aeration zone by decreasing the volume of the first cell; and 2) aeration tubing were bundled in groups of three (3) to increase vertical velocities creared by the aeration. These steps were taken to reduce/eliminate iron oxide accumulation on top of the aeration tubing. The Lasaire© Aeration System was cleaned with the new procedure and restarted on August 25, 2008 after the modifications were completed.

The Upper Latrobe system was operated continuously after the modifications until November 26, 2008. This was the end of the monitoring period to assess the performance and operation requirements of the system. Flows tested during this monitoring period were between 200 gpm and 350 gpm. The new orientation of the tubing did not reduce the clogging issue of the system, which indicates it cloggging is due direct oxidation and precipitation of the iron oxide in the air hole of the tubing and not due to accumulation of settled iron oxides on top of the tubing. In addition, the new cleaning procedure was effective at restoring air flow to the aeration system and lowering the back pressure.

The cleaning procedure to maintain air flow through the aeration tubing at the Upper Latrobe site was required every 10 to 14 days; a relatively shorter period than is required in wastewater applications. The cleaning procedure developed for the mine drainage application consisted of injecting 100 mL of muriatic acid into an individual Lasaire tubing line followed by connection and delivery of high pressure air to the tubing from a portable (rental) compressor. The procedure was repeated for each line in the system. The procedure takes approximately one to two hours of time.

Figure Lasaire-13. Sample picture showing short-circuiting through and under a baffle.
(Location: Brandycamp Active Treatment System)

There was one operational issue with the Upper Latrobe passive treatment system that was documented through sampling and photography. As inflow was increased to the system there was a gradual increase in total iron in the last baffle area that was substantially greater than the two upflow adjacent baffle area. While initially believed to be a leak, this problem was most likely a result of short-circuiting under the baffles along the bottom of the aerobic pond. While this was not observed nor specfically proven, it is highly likely. The photograph in Figure Lasaire 13 shows an AMD inflow through a settling pond at the Brandycamp Active Treatment System. Note the flow follows a straight line directly through and under the baffle. This is likely explained by temperature differences (or thermal stratification) in the surface water versus the discharge during the summer period. Typically the discharge is cooler in temperature compared to the warmer surface water in the pond and sinks to the bottom. The cold discharge water is then likely to follow a path of least resistance along the bottom of the pond, potentially short-citcuiting the treatment pond and with minimual aeration. The higher the inflow rate the greater likelihood the AMD will create a channel in the sludge accumulkated in the pond bottom.

System Monitoring

Monitoring of the two systems occurred weekly during the periods the aeration systems were operating. Parameters monitored and methods used are summarized in Table Lasaire – 2. Sampling locations at each system included influent, end of aeration zone, effluent and intermediate points in the system. In the case of the Wildwood system monitoring was conducted with the hydrogen peroxide dosing to evaluate performance of the aeration system and prevent potential excess iron loading to the receiving stream. Once the performance of the system was documented the hydrogen peroxide was turned off and the system monitored over a short period to determine if the aeration was adequate to remove iron from the discharge in the existing basin. This was approach was used to prevent potential excess iron loading to the receiving stream in case the aeration was not able to remove the iron in the existing basin; Pine Creek is an important local trout fishery and upset could have negative impacts on the stream.

Table Lasaire - 2. Field monitoring methods for samples collected during the studies at each location.

Parameter	Units	Method Description	Equipment
pH	s.u.	Electrode	Accumet AP61
Alkalinity	mg/L as $CaCO_3$	Potentiometric Titration	Hach Titrator
Dissolved Oxygen	mg/L	Electrode	YSI 550A
Temperature	°C	Electrode	YSI 550A
Total Iron	mg/L	Ferrover	Hach Colorimeter
Ferrous Iron	mg/L	0.2 µM Filtration & Ferrover	Hach Colorimeter

In addition to water quality, flow and temperature were monitored. At the Upper Latrobe site flows were measured after setting the borehole valve and periodically to determine if flows from the borehole were unchanged. A continuous measurement temperature sensor was also installed in the effluent from the Upper Latrobe system to evaluate daily and seasonal temperature variability. At the Wildwood site, flows were measured at the effluent weir during sampling events. A continuous measurement temperature sensor was also installed at the effluent end of the basin.

System Results

Data were collected on a weekly basis during operational periods for the two Lasaire© Aeration Systems. Field analysis was conducted at AMD influent, end of aeration zones, effluent from the system and intermediate points in the system. Data collection included pH, dissolved oxygen, temperature, ferrous iron, total iron, and alkalinity. At the Wildwood site the flow was measured at the outlet weir box. At the Upper Latrobe site flow was set by adjusting the borehole valve with flow either measured at an intake weir or the outlet pipe. The following provides the results collected for each of the sites.

Wildwood Site

As indicated the Wildwood Lasaire Aeration System was installed in November 2007 with operation initiated in December 2007. Initial operation was to evaluate the affects of the aerations on increasing pH as well as dissolved oxygen. Table Lasaire – 3 contains the results of the initial startup. Initial results indicated the aeration increased dissolved oxygen to near saturation and pH to greater than 7.5. However in late December 2007 the blower motor ceased functioning due to a drive motor failure. This apparently occurred during a warm period. An investigation was initiated to determine the cause of the failure that included contacting the supplier and sending out the motor for inspection. After the investigation it was determined the motor failure was due to an overheating issue related to the sound proof cover included in the blower system. The motor was replaced under warranty and corrective measures were installed to minimize overheating of the motor.

Table Lasaire – 3. Lasaire Aeration Monitoring at the Wildwood Site during initial startup.

Sample Location	pH	Temp ºC	Dissolved Oxygen mg/L	Total Iron mg/L	Dissolved Iron mg/L	Alkalinity mg/L
December 5, 2007 @ 12:30 (Air Temp. -2ºC)						
Influent	6.87	12.1	0.01	7.4	7.4	373
end cell 1	7.39	11.4	9.5			
end cell 2	7.50	11.2	10.0			
system outfall	7.58	9.6	10.7	1.20	0.02	358
December 15, 2007 @ 10:00 (Air Temp. -3ºC)						
end cell 1	7.25	11.0	8.5			
start cell 2	7.40	10.8	9.5			
system outfall	7.38	9.6	9.8			
Uneven Air Distribution Noted						
Blower Failure on or about December 28, 2008 due to overheating issue with blower enclosure design						

After motor replacement and modifications to the blower unit, the system was restarted in April 2008. Table Lasaire – 4 contains the results after the April startup. The aeration system once again was able to increase dissolved oxygen and pH of the discharge. However, the dissolved oxygen and pH increases were not as great as initial startup. Several field monitoring events indicated poor air distribution in the Lasaire tubing with a possibility of low air flow from the blower. In late May 2008, the blower unit (the air delivery unit) of the blower system seized. This was determined to be a latent affect of the previous drive motor overheating. The blower motor was repaired and reinstalled on the blower unit.

The blower unit operational issues were not anticipated. Due to the experimental nature of the project only a single blower unit was installed to minimize costs while evaluating the efficiency of the Lasaire Aeration System to achieve the desired treatment goals. In normal installation, two blower units would be installed as an operating and a backup unit. This would have allowed continuous operation of the system in the event of a single unit failure. In addition, the failure of the blower unit at the Wildwood location led to indentifying an alternative manufacture of blower units, which was installed at the Upper Latrobe location.

The Lasaire Aeration System was once again restarted in August 2008, after the rebuilt blower motor was re-installed in the blower system. Table Lasaire – 5 provides the results after this restart of the system. The system was operated for several months to determine if the blower unit operational issues had been resolved and identify any other maintenance operation concerns with the system. As shown in the tables, the restarted system was able to increase the dissolved oxygen to near saturation and increase the pH to greater than 7.5 and at times approaching 8.0. The blower system operated continuously during this period with no operational issues. However, back pressure increased in the Lasaire tubing causing blow off. The back pressure

Table Lasaire – 4. Lasaire Aeration Monitoring at the Wildwood Site.						
Sample Location	**pH**	**Temp ºC**	**Dissolved Oxygen mg/L**	**Total Iron mg/L**	**Dissolved Iron mg/L**	**Alkalinity Mg/L**
April 15, 2008 @ 13:30 (Air Temp. 10ºC)						
Influent	6.59	12.6	0.00			
end cell 1	7.25	12.3	7.07			
end cell 2	7.33	12.2	8.35			
end cell 3	7.37	12.4	8.55			
April 18, 2008 @ 11:00 (Air Temp. 20ºC) Flow = 820 gpm						
influent	6.95	12.0	0.03	7.40	7.40	353.00
end cell 1	7.28	12.3	8.02			
end cell 2	7.36	12.5	8.35			
effluent	7.36	12.4	8.55	1.36	0.02	
April 22, 2008 @ 16:30 (Air Temp. 15ºC) Flow = 1125 gpm						
influent	6.92	12.0	0.60	5.35	5.35	343.00
end cell 1	7.22	12.2	7.85			
end cell 2	7.44	12.3	8.62			
effluent	7.30	12.5	8.24	2.21	0.02	336.00
April 30, 2008 @ 11:00 (Air Temp. 20ºC) Flow = 960 gpm						
influent	6.97	12.0	0.35	5.70	5.75	342.00
end cell 1	7.32	12.0	7.30			
end cell 2	7.39	12.0	7.60			
effluent	7.45	11.8	7.80	1.50	0.06	332.00
May 20, 2008 @ 09:30 (Air Temp. 10ºC)						
influent	6.68	13.0	0.00			
end cell 1	7.35	12.1	5.83			
end cell 2	7.41	11.9	6.04			
end cell 3	7.44	11.6	5.74			
Blower Failed on May 29, 2008 Due to Blower Unit Seized from previous overheating						

Table Lasaire – 5. Lasaire Aeration Monitoring at the Wildwood Site.						
Sample Location	pH	Temp ºC	Dissolved Oxygen mg/L	Total Iron mg/L	Dissolved Iron mg/L	Alkalinity mg/L
August 27, 2008 @ 14:00 (Air Temp. 20ºC) Flow = 320 gpm						
influent	6.58	14.2	0.2			
end cell 1	7.45	12.9	10.45			
end cell 2	7.49	12.9	10.50			
end cell 3	7.68	12.5	9.90			
end cell 4	7.70	12.6	9.20			
end cell 5	7.65	12.4	9.60			
effluent	7.62	12.5	9.21			
September 3, 2008 @ 15:00 (Air Temp. 20ºC) Flow = 320 gpm						
influent	6.65	12.2	0.2	8.6	0.03	
end cell 1	7.35	13.1	9.90			
end cell 2	7.40	13.0	10.27			
end cell 3	7.40	13.2	10.45			
end cell 4	7.50	13.3	10.53			
end cell 5	7.58	13.1	10.55			
effluent	7.47	13.3	10.70			
September 11, 2008 @ 15:30 (Air Temp. 15ºC) Flow = 320 gpm						
influent	6.99	12.0	0.85			
end cell 1	7.61	12.9	10.95			
end cell 2	7.69	13.0	11.19			
end cell 3	7.92	13.0	11.26			
end cell 4	7.97	12.9	11.12			
end cell 5	7.80	12.7	11.42			
effluent	7.79	12.7	10.48			
September 23, 2008 @ 11:00 - Power Outage. Blower Reset						
September 30, 2008 @ 14:00 (Air Temp. 10ºC)						
end cell 1	7.40	12.3	9.76			
end cell 2	7.49	12.4	9.85			
end cell 3	7.66	12.4	9.03			
end cell 4	7.69	12.4	8.88			
end cell 5	7.73	12.5	8.93			
effluent	7.66	12.3	9.50			
October 6, 2008 @ 14:00 (Air Temp. 10ºC)						
end cell 1	7.45	12.3	9.45			
end cell 2	7.54	12.3	9.45			
end cell 3	7.62	12.3	9.33			
end cell 4	7.82	12.2	9.49			
end cell 5	7.83	12.2	9.29			
effluent	7.78	12.2	9.77	1.01		

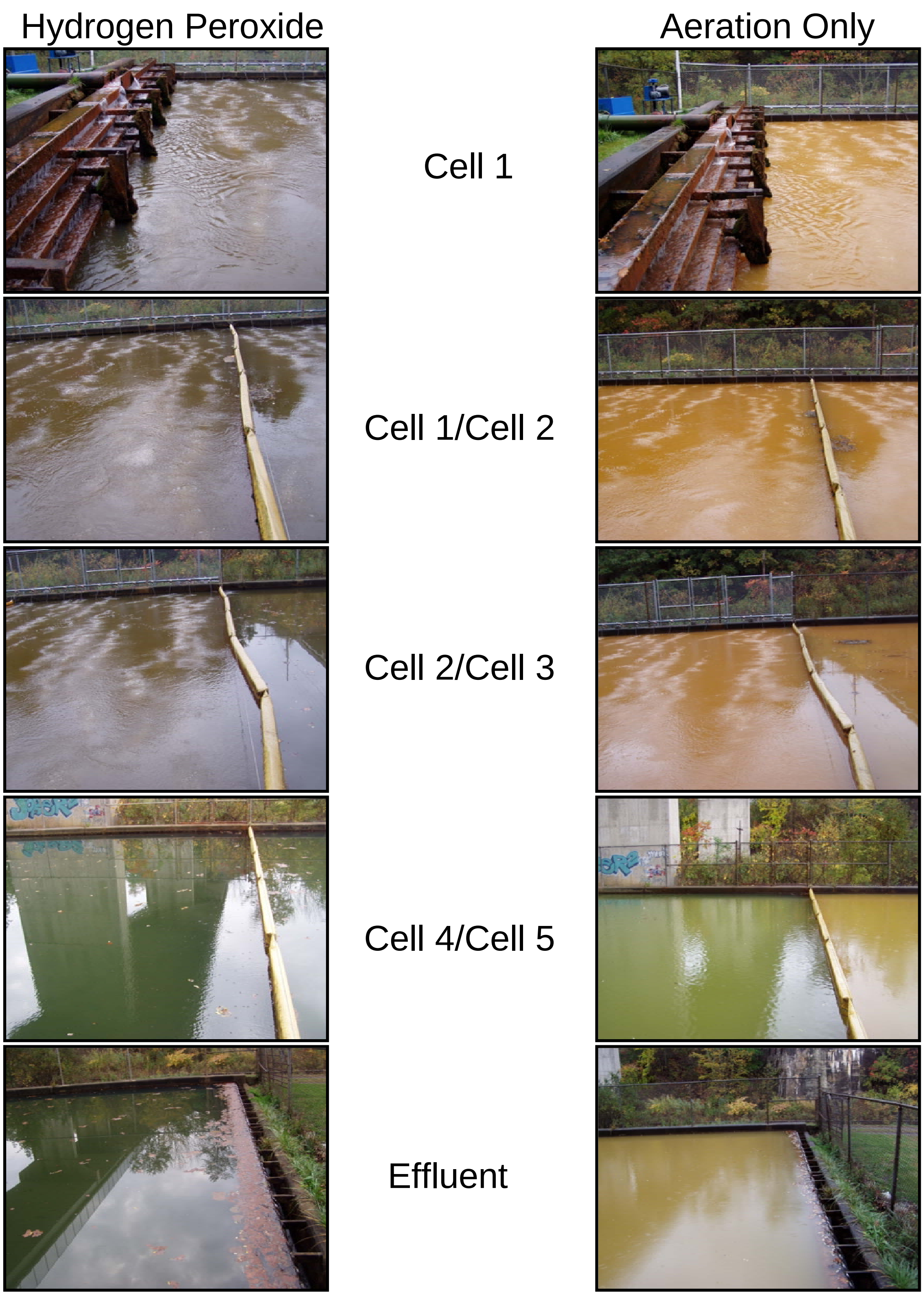
increase was not unexpected since routine maintenance in wastewater applications occurs due to calcite buildup at the air hole. Generally the routine maintenance is required every 4 to 6 weeks of operation using high pressure air (> 120 psi) from an alternative source, such as a compressor. It was determined during the operational period the high pressure air alone was inadequate to clean the Lasaire tubing. A methodology was developed that involved injection of muriatic acid (available over the counter) followed by the high pressure air was needed to clean the aeration tubing. This cleaning procedure was also found to be required every 3 to 4 weeks at the Wildwood location. This cleaning procedure may be needed to not only remove calcite scale but also iron oxide deposits forming at the air hole of the tubing; high pressure air may be adequate to remove the calcite scale but may not be adequate to remove iron oxide scale. Based on the three month period from August to October 2008 this methodology was successful at maintaining the air flow through the system.

Table Lasaire – 6. Lasaire Aeration Monitoring at the Wildwood Site during no hydrogen peroxide dosing.

Sample Location	pH	Temp ºC	Dissolved Oxygen mg/L	Total Iron mg/L	Dissolved Iron mg/L	Alkalinity Mg/L
October 15, 2008 @ 20:00 (Air Temp. 15ºC) Flow = 680 gpm						
influent	7.09	12.1	0.20	6.25	6.25	
end cell 1 - right	7.68	12.1	10.65			
end cell 1 - left	7.68	12.1	10.95	6.75	0.05	
end cell 2 - right	7.73	12.1	11.10			
end cell 2 - left	7.72	12.1	11.10	6.5	0.01	
effluent	7.70	12.3	10.91	0.82	0.02	
October 16, 2008 @ 08:00 - Shut off Hydrogen Peroxide						
October 16, 2008 @ 18:30 (Air Temp. 12ºC)						
end cell 1	7.61	12.3	10.20	7.25	0.15	
end cell 2	7.67	12.4	10.70	5.6	0.01	
end cell 3	7.70	12.3		4.4		
end cell 4	7.75	12.3		2.09		
end cell 5	7.74	12.4		0.79		
effluent	7.74	12.6	11.10	0.8	0.01	
October 17, 2008 @ 08:00 (Air Temp. 5ºC)						
end cell 1	7.64	12.2	10.10	6.25	0.35	
end cell 2	7.74	12.1	10.50	6.6	0.08	
end cell 3	7.74	12.2	10.40	5.25	0.01	
end cell 4	7.80			0.9		
end cell 5	7.78			0.87		
effluent	7.77	12.3	11.10	1.75	0.01	
October 17, 2008 @ 09:00 - Hydrogen Peroxide turned Back On						

Table Lasaire-6 contains the results of testing conducted with the hydrogen peroxide pumps turned off. This test was conducted to evaluate whether the aeration only could increase pH and dissolved oxygen to levels that would successfully achieve the needed oxidation of the ferrous iron to ferric iron and provide conditions to effectively flocculate and settle the iron oxide solids

Figure Lasaire-14. Comparison of Wildwood System with hydrogen peroxide dose and Aeration Only



within the Wildwood system. This was a short term test in order to minimize any potential iron oxide deposits, if iron removal deteriorated in the system, from impacting the receiving stream.

As can be see in Table Lasaire-6, the aeration system continued to increase the dissolved oxygen to near saturation (>10 mg/L) and increased pH to greater than 7.7 due to the removal of carbon dioxide acidity. The results also indicate the oxidation of the ferrous iron was rapid with near complete oxidation (<0.11 mg/L) by the end of the aeration zone (i.e., end cell 2) and complete oxidation by the end of the system. However, effluent total iron gradually increased from the Wildwood system after the hydrogen peroxide was turned off to as level of 1.75 mg/L at the end of the study period, slightly greater than the detention time of the concrete basin. This effluent iron is slightly more than twice the effluent iron using peroxide.

A visual comparison of the Wildwood basin with hydrogen peroxide dosing and with the Lasaire Aeration only is shown in Figure Lasaire-14. This is a side by side comparison of the baffled cells in the basin. It is apparent there is a very different coloration in the iron oxide solids produced in the presence of hydrogen peroxide and with aeration only. The hydrogen peroxide iron oxide solids are a darker brown compared to the orange solids produced with aeration only. This suggests the hydrogen peroxide may affect the solids formed and their surface charge potentially producing a more settleable iron oxide. The settleability of the solid is shown in the pictures of the effluent where there is approximately 0.8 mg/L with the hydrogen peroxide dose and 1.75 mg/L with the Lasaire aeration only.

Figure Lasaire-15. Wildwood Seasonal Effluent Temperature

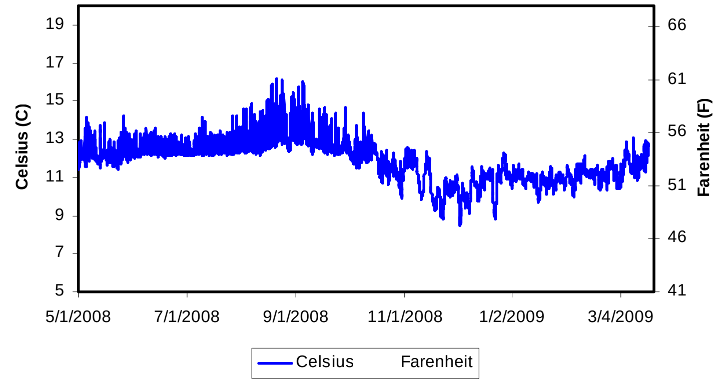
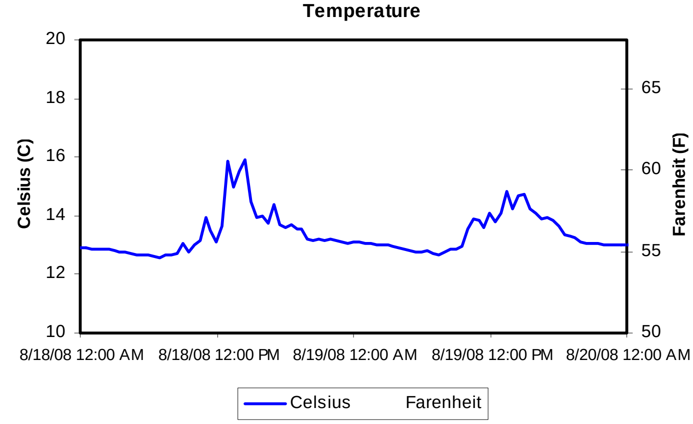


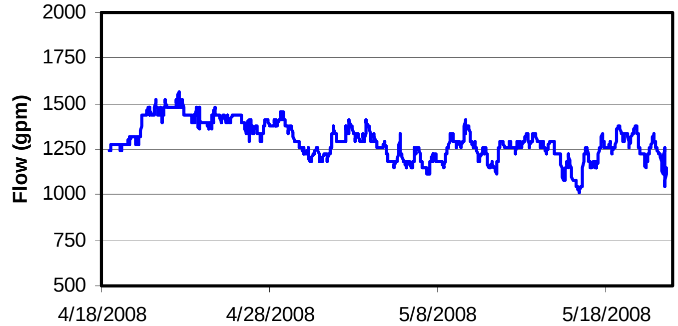
Figure Lasaire-16. Wildwood Effluent Summer Diurnal Temperature



Temperature was collected continuously at the discharge end of the Wildwood system. Figure Lasaire-15 provides the temperature data collected over the study period. As can be seen there is a seasonal fluctuation in the discharge temperature ranging from a low of 8.5ºC (47.3ºF) to a maximum of 16.2ºC (61.2ºF). However, field sampling indicated the discharge temperature varied little with temperature ranging from 12.0 to 12.4ºC (53.6 to 54.3ºF). The fluctuation in temperature was the result of seasonal heating and cooling of the water while in the basin. Figure Lasaire-16 provides the summer diurnal fluctuation observed in the discharge from the Wildwood system. As can bee seen the peak temperatures occurred between

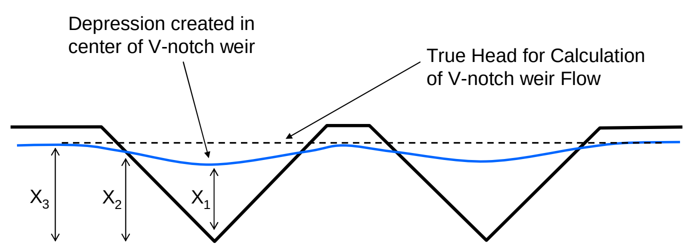
2:00 and 4:00 PM when solar influence would be the greatest. Overall the maximum diurnal fluctuation was less than 4ºC (7.2ºF). It should be noted the change in temperature of the discharge is minimal due to the short detention time (<20 hours) in the system, as well as the shaded location and the depth of the Wildwood concrete tank.

Figure Lasaire-17. Wildwood continuous flow data for April through May 2008



Flow data were also collected continuously to evaluate short term changes in flow in response to storm events. Figure Lasaire-17 provides several months of the flow data measured in the effluent of the Wildwood system using a recording pressure transducer. The transducer was calibrated to field measurements taken at the system effluent weir. As can be seen there is some fluctuations in the Wildwood discharge flow. The short term (hourly) fluctuations are noise. However, the multi-day fluctuations are likely in response to rain events recharging the deep mine. These fluctuations are relatively small indicated there is minimal storm event response in the discharge. Also note, the discharge flow gradually decreases over the two months from a flow of 1,500 gpm in April to 1,000 gpm in May. This likely reflects baseflow recession, or decreasing pool elevation, of the deep mine storage.

Figure Lasaire – 18. Comparison of measurement differences for calculation of flow in a v-notch wier.



There is one other issue at the Wildwood system related to the historically measured discharge flow and which may have caused an under design of the Lasaire Aeration system. The measured flow at Wildwood is based on a single measurement in the center of one of the 68 V-notches. Figure Lasaire-18 shows various Measuring in the center of the V-notch (X_1) can dramatically underestimate the actual flow as there is a slight depression of the water level due to over flow at this location. To lower the error, field measurements collected as part of this study were measured at the side of the v-notch (X_2) or by placing a calibrated staff a distance away from the V-notch (X_3). To evaluate the differences several measurements were made including the center of the V-notch a depth measurement based on the angle of the V-notch, and an effluent channel measurement using depth, width and a velocity meter. The three measurements resulted in 375 gpm, 500 gpm, and 650 gpm, respectively. This indicates the actual discharge flow is 80% greater than the historical flows provided for the design of the Lasaire Aeration system and the ability of the system to achieve pH greater than 8. However, as noted in the no hydrogen peroxide test, the hydrogen peroxide affected the surface charge of the iron oxide resulting in a more settleable solid. Aeration alone may not have been adequate to achieve this benefit. Table Lasaire-7 provides a corrected flow value, based on the field measured flows versus the center of the V-notch as the measurement location. The adjusted flows may be more accurate and provide a more reliable estimate of long term and average flows. This would provide for better estimates of current and future treatment costs and comparison to other treatment methods for the Wildwood system.

Table Lasaire-7. Current and Adjusted Wildwood Flow Values using the center of the V-notch as a measurement.

Depth Feet	Current (DEP) Value gpm	Adjusted Value gpm
0.09	<200	<350
0.10	234	440
0.11	268	540
0.12	402	650
0.13	469	760
0.14	603	880
0.15	670	1000
0.16	804	1130
0.17	871	1260
0.18	1005	1390
0.19	1180	1520
0.2	1370	1650

Upper Latrobe Site

As indicated the Upper Latrobe Lasaire Aeration System was installed in March/April 2008 with operation initiated in April 2008. Initial operation was conducted at a low flow (125 gpm) to evaluate the affects of the aerations on increasing pH and dissolved oxygen prior to increasing flows. Table Lasaire – 8 contains the results of the initial startup. Under the startup flow conditions, the initial results indicated the aeration increased dissolved oxygen from 0 to 10 mg/L, approximately 95% of saturation. The pH increased from 6.1 to 6.9 which equated to 90% removal of carbon dioxide acidity. In addition, the ferrous iron was decreased from 40 mg/L to 20 mg/L in the aeration zone. This aeration resulted in a complete oxidation of the ferrous iron by the end of cell 2 with a total iron of less than 0.5 mg/L. A slight increase in total iron was observed in the system discharge, but was still less than 1 mg/L.

Table Lasaire – 8. Lasaire Aeration Monitoring at the Upper Latrobe Site. Influent Flow Set at 125 gpm.						
Sample Location	**pH**	**Temp ºC**	**Dissolved Oxygen mg/L**	**Total Iron mg/L**	**Dissolved Iron mg/L**	**Alkalinity mg/L**
April 15, 2008 @ 16:00 (Air Temp. 10ºC)						
influent	6.24	12.8	0.00			
end cell 1	7.57	16.1	11.13			
system outfall	7.56	15.8	11.67			
April 18, 2008 @ 14:30 (Air Temp. 12ºC)						
influent	4:04	12.8	0.10	40.0	40.8	150
end cell 1	6.85	16.1	11.9	20.4	0.07	
end cell 2				1.34		
system outfall	7.49	19.9	10.9	0.68	0.01	77
April 22, 2008 @ 18:45 (Air Temp. 14ºC)						
influent	6.15	12.6	0.17	42.40	40.40	148
end cell 1	6.86	16.5	9.73	20.40	0.21	
end cell 2	7.54	20.2	9.38	0.42	0.01	
system outfall	7.53	18.9	9.69	0.69	0.01	75

The flow to the Upper Latrobe system was doubled to 250 gpm after this initial period. The results of this flow test are contained in Table Lasaire-9. Based on the results from April 30th, and May 29th, the results indicate the aeration increased the dissolved oxygen to 9 mg/l, approximately 85% saturation. The pH increased across the aeration from 6.1 to 6.6. While this is a lower pH increase it does equate to 87% carbon dioxide acidity removal. In addition, approximately 10 to 20 mg/L of ferrous iron was oxidized in the aeration zone. There was also a noticeable increase in total iron from the end of cell 3 (0.2 mg/L) to the effluent from the system (2.6 mg/L). This may have been from some partial short-circuiting within the Upper Latrobe system. Toward the end of this test a significant amount of back pressure on the aeration system began to occur, which resulted in a decrease in air flow through the aeration system. The decrease in air flow affected the performance of the aeration as shown on the June 9th sampling. A maintenance cycle was performed on the system using the recommended compressed air. However, the normal operating back pressures were not achieved and blow off occurred a few days after the maintenance cycle. The system was shut down and an investigation was conducted to determine the causes of the backpressure, the poor performance of the compressed air to clean the system, and identify alternative maintenance procedures to clean the Lasaire aeration system.

A section of the Lasaire tubing microscopically examined and the drilled holes were found to contain particles of iron oxide. There were two potential sources of the iron oxide in the drill holes, which were 1) direct oxidation and precipitation of the iron in the hole; and 2) settling of iron oxide particles onto the tubing and into the hole. It was also determined based on field efforts that the high pressure air was not adequate to remove the iron oxide. Based on these findings several steps were taken. First, a new more rigorous cleaning procedure was developed involving use of muriatic acid injected directly into the tubing followed by high pressure air from a compressor. Second, the Lasaire aeration system was reconfigured and involved: 1) strapping three tube lengths together to create greater air flow and shear over the tubing to prevent iron oxide settling; and 2) the first baffle was moved to narrow the aeration zone to increase horizontal velocities to decrease iron oxide settling in the aeration zone (this also decreased the detention time in the aeration zone). The modifications were completed in July 2008 and the system was restarted on August 18th.

Table Lasaire – 9. Lasaire Aeration Monitoring at the Upper Latrobe Site. Influent Flow Set at 250 gpm.

Sample Location	pH	Temp ºC	Dissolved Oxygen mg/L	Total Iron mg/L	Dissolved Iron mg/L	Alkalinity mg/L
April 30, 2008 @ 13:30 (Air Temp. 20ºC)						
Influent	6.20	12.8	0.20	39.8	40.8	132
end cell 1	6.62	12.9	9.02	30.4	6.90	
end cell 2	6.92	15.8	9.18	4.75	0.06	
end cell 3	6.95	15.1	9.75	2.01	0.01	
System outfall	7.02	14.2	9.77	2.12	0.01	67
May 29, 2008 @ 14:30 (Air Temp. 22ºC)						
Influent	6.16	12.6	0.12	38.6	38.0	140
end cell 1	6.45	16.2	8.32	16.50	0.76	
end cell 2	6.65	21.8	8.25	3.20	0.19	
end cell 3	6.91	21.0	9.05	1.28	0.01	
System outfall	6.81	20.8	8.40	2.86	0.01	70
June 9, 2008 @ 14:00 (Air Temp. 32ºC)						
Influent	6.07	12.8	0.15	39.00	39.40	136.0
end cell 1	6.35	19.1	6.55	29.60	0.38	
end cell 2	6.30	21.0	6.65	6.75	0.05	
end cell 3	6.75	28.4	7.10	0.22	0.01	
System outfall	6.60	26.3	7.50	2.60	0.01	68.0

Table Lasaire-10 summarizes the Upper Latrobe system results following the restart of the Lasaire aeration system. Initial results show dissolved oxygen and pH increases across the aeration zone (first cell) similar to previous results. During this initial period the system was evaluated to determine if the rapid increase in back pressure was decreased. Unfortunately the increase in back pressure and air blow off occurred in about a two week period. This is seen in the September 3rd results where the ferrous iron (dissolved iron) increased from 0.15 mg/L to 2 mg/L when blow off began to occur. The cleaning procedure using muriatic acid and high pressure air from a compressor was used and found effective at restoring normal operating conditions. This was required on an every other week basis to maintain adequate air flow through the system. The last two dates in Table Lasaire-10 show the difference between the conditions prior to cleaning when there is substantial loss of air (approximately 40% of the air flow) and just after cleaning when there is no loss of air in the system. With no loss of air the aeration increasing dissolved oxygen top greater than 8 mg/L and pH from 6.1 to greater than 6.6. With the air loss the dissolved oxygen is only increased to about 4.5 mg/L and pH only to 6.3. The performance of the aeration also results in slightly lower dissolved oxygen and pH than previously reported in Table Lasaire-9, but is expected because of the reconfiguration that decreased the detention time in the cell 1 aeration zone (by approximately 40%) than the results in decreased. Under optimal aeration the dissolved iron was decreased by 20 mg/L at the end of cell 1 with complete oxidation occurring by the end of cell 3. The aeration resulted in total iron decreasing to slightly greater than 1 mg/L by the end of cell 4. With significant loss of air the performance deteriorated with dissolved iron of 5.5 mg/L still present at the end of cell 4. It should also be noted the total iron increased between the end of cell 4 and the system outfall under the new configuration, which is likely due to some short circuiting of the baffles within the Upper Latrobe system, as was found previously.

Table Lasaire – 10. Lasaire Aeration Monitoring at the Upper Latrobe Site. Influent Flow Set at 200 gpm.

Sample Location	pH	Temp ºC	Dissolved Oxygen mg/L	Total Iron mg/L	Dissolved Iron mg/L	Alkalinity Mg/L
August 27, 2008 @ 10:30 (Air Temp. 20ºC)						
Influent	6.10	14.9	6.40	38.0	38.2	
end cell 1	6.85	14.9	7.45	35.2	1.14	
start cell 2		17.3	6.20			
end cell 4	7.04	19.9		1.75	0.15	
system outfall	6.60			7.20	7.00	
September 3, 2008 @ 10:00 (Air Temp. 20ºC)						
end cell 1	6.36	15.0	6.20	28.6	19.6	
start cell 2		16.9	5.25			
end cell 4		18.9	5.80	3.70	2.03	
system outfall	6.20			12.3	7.65	
September 11, 2008 @ 12:00 (Air Temp. 20ºC)						
influent	6.20			30.8	30.8	
end cell 1	6.66	14	8.10	12.0	9	
end cell 4	6.80	17.7	6.30	0.25	0.01	
system outfall	6.35			5.6	0.6	
September 23, 2008 @ 10:00 (Air Temp. 15ºC)						
influent	6.12			44.6		143
end cell 1	6.15	13.1	6.69	22.0	16	125
end cell 4	6.56	15.9	5.24	2.48	0.08	90
September 30, 2008 @ 11:30 (Air Temp. 10ºC)						
end cell 1	6.12	13.1	5.80	44.4	31.5	132
end cell 4	6.50	15.8	5.50	1.87	0.68	75
October 6, 2008 @ 14:00 (Air Temp. 25ºC)						
end cell 1	6.30	12.8	4.50	40	31.9	135
end cell 4	6.50	12.8	4.65	13	5.5	85
October 9, 2008 @ 16:00 (Air Temp. 20ºC)						
end cell 1	6.62	14.2	8.11	34.2	21.7	130
end cell 2	6.69	17.00	8.00	4.40	0.34	
end cell 3	6.68	14.40	8.80	1.93	0.01	
end cell 4	6.79	16.9	9.30	1.38	0.01	
system outfall	6.65	15.5		4.53	1.20	92

The discharge flow was increased to 350 gpm to evaluate the effects of the aeration system at this higher flow, likely to be the maximum effective flow rate for the Lasaire aeration system. The results are summarized in Table Lasaire-11. Two dates were sampled, October 15th represents the performance of the system shortly after a cleaning cycle and the October 21st represents the performance after about two weeks during which significant air loss was occurring. During optimal performance the aeration increased the dissolved oxygen to 8 mg/L and the pH to 6.6, which is similar to the 200 gpm test. At suboptimal conditions, the Lasaire aeration only increased the dissolved oxygen to 7 mg/L and the pH to 6.4. The difference of the aerations affect shown in the dissolved iron (ferrous) at the end of cell 4 which was 0.65 mg/L at optimal aeration and 7.1 mg/L at suboptimal conditions. The aeration also affected the total iron under the two conditions which were 4.3 mg/L and 17.7 mg/L, respectively. Note the total iron concentration measured from the system outfall increased well above the total iron measured at the cell 4 location as the flow rate to the system increased from 200 to 350 gpm. This may be due to short circuiting in the Upper Latrobe system.

Table Lasaire – 11. Lasaire Aeration Monitoring at the Upper Latrobe Site. Influent Flow Set at 350 gpm.

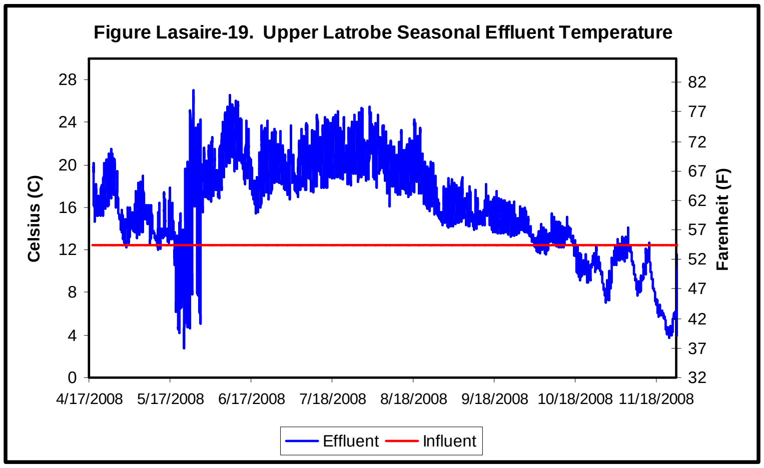
Sample Location	pH	Temp ºC	Dissolved Oxygen mg/L	Total Iron mg/L	Dissolved Iron mg/L	Alkalinity mg/L
October 15, 2008 @ 13:00 (Air Temp. 20ºC)						
influent	6.25	12.9	0.1	42.6	42.4	153
end cell 1	6.65	14.1	8.5	42.6	36.2	
end cell 2	6.65	14.1	8.3	16.6	11.0	
end cell 3	6.54	17.7	7.1	21.2	13.8	
end cell 4	6.69	15.1	6.5	4.35	0.65	
system outfall	6.65	15.0		22.3	16.6	
October 21, 2008 @ 10:00 (Air Temp. 20ºC)						
end cell 1	6.40	12.4	7.20	36.6	31.5	138
end cell 4	6.55	10.8	7.26	17.7	7.1	92

After the high flow test the influent flow was decreased to 200 gpm. This was done to evaluate performance of the system under cold weather condition. As can be seen in Table Lasaire-12 the temperature of the water in the Upper Latrobe system decreased from influent to effluent. This was due to the colder air temperatures during this period causing heat loss from the water in the system. Under optimal operating conditions the Lasaire Aeration system increased the dissolved oxygen to greater than 8 mg/L and pH to near 6.7, similar to previous results. However, also similar to previous results the aeration system deteriorated in less than two (2) weeks resulting in a decline in its performance and effluent quality, as can be seen in the November 5th sampling. The November 11th sampling was conducted several days after a cleaning cycle and shows the aeration system performance returned to optimal conditions, reflecting the cleaning procedure was effective.

Table Lasaire – 12. Lasaire Aeration Monitoring at the Upper Latrobe Site. Influent Flow Set at 200 gpm.						
Sample Location	**pH**	**Temp ºC**	**Dissolved Oxygen mg/L**	**Total Iron Mg/L**	**Dissolved Iron mg/L**	**Alkalinity mg/L**
October 28, 2008 @ 17:30 (Air Temp. 4ºC)						
end cell 1	6.67	11.2	8.7	38.6	24.5	
end cell 2	6.64	10.6	7.75	18.4	2.13	
end cell 3	6.82	10.2	8.5	7.85	0.11	
end cell 4	6.85	9.9	9.05	4.2	0.01	
system outfall	6.95	9.7	9.74	2.68	0.01	
November 5, 2008 @ 10:00 (Air Temp. 10ºC)						
end cell 1	6.35	11.6	6.15	42.8	40.2	137
end cell 4	6.70	10.9	4.94	12.7	0.51	80
November 11, 2008 @ 10:00 (Air Temp. 3ºC)						
influent	6.21	12.9	0.1	43.2	43.2	147
end cell 1	6.48	11.1	8.48	36.6	24.8	
end cell 2	6.68	10.1	8.25	23.5	6.35	
end cell 3	6.7	9.6	8.6	13.7	0.18	
end cell 4	6.98	8.4	9.45	8.9	0.04	
system outfall	7.1	8	11.05	4.0	0.01	79

The final test shown in Table Lasaire-13 was conducted at 50 gpm and with the Lasaire Aeration system turned off. The results show the systems effectiveness under cold weather conditions and at the 50 gpm flow. The dissolved oxygen gradually increased across the passive system from influent conditions to 80% saturation in the effluent. The pH also increased across the system to 6.8, which reflects a 90% decrease in carbon dioxide acidity. The performance of the Upper Latrobe system under this 50 gpm flow condition is similar to the performance of the system at 200 gpm with the Lasaire Aeration system operating. Greater temperature decreases across the system shown in Table Lasaire-13 at 50 gpm versus decreases shown in Table Lasaire-12 at 200 gpm are due to the lower discharge flow and not differences in ambient air temperature.

Table Lasaire – 13. Lasaire Aeration Monitoring at the Upper Latrobe Site. Influent Flow Set at 50 gpm. No Aeration.						
Sample Location	**pH**	**Temp ºC**	**Dissolved Oxygen mg/L**	**Total Iron mg/L**	**Dissolved Iron mg/L**	**Alkalinity mg/L**
November 26, 2008 @ 09:00 (Air Temp. 10ºC)						
influent	6.12	12.5	0.1	46.2	45.2	153
end cell 1	6.32	10.6	4.6	41.6	37.2	
end cell 2	6.44	8.6	5.9	25.2	15.6	
end cell 3	6.69	7.4	6.8	14.4	6.19	
end cell 4	6.63	6.5	7.7	9.2	0.47	
system outfall	6.8	5.4	9.8	5.3	0.07	81



Temperature was monitored continuously in the effluent from the Upper Latrobe System during the study from April through November 2008. As can be seen in Figure Lasaire-19, there was significant seasonal and daily variation in temperature from the system. The period shortly after May 17th where temperatures decrease below influent temperatures and with large diurnal variation was the result of the removal of the temperature monitor from the effluent by unknown persons. There are several periods of interest on the figure. By comparing the effluent temperatures during June 9th through August 20th (low flow and no aeration) to temperatures between August 20th and September 20th (high flow and aeration) indicates there are higher effluent temperatures and greater diurnal fluctuation during the summer in a conventional passive treatment system than one equipped with aeration. This is related to the flow into the system, which shortens detention times and decreases heating of the water within the system. Also, by examining October effluent temperatures (high flow with aeration) to mid-November effluent temperatures (low flow with no aeration) it is apparent the opposite occurs during cold periods; that is, the effluent from a conventional passive treatment system has lower winter temperatures than the aerated water. This is once again related to flow with the shorter detention times at the higher flow and aerated water having less cooling than would occur in the long detention times of a conventional passive treatment system.

Based on the results of the Upper Latrobe site Lasaire Aeration System the effectiveness of the aeration increased the capacity of the aerobic pond by between a factor of 4 to 5 depending on the season. There was required maintenance every 10 to 14 days needed to maintain the performance of the system and prevent degradation of the effluent.

Lasaire Aeration Operation & Maintenance Requirements

The Lasaire Aeration systems were operated at both the Wildwood and Upper Latrobe sites for extended periods. There was some startup issues at the Wildwood site related to a failure of the blower. This was found to be related to the blower enclosure design that resulted in poor air circulation, overheating of the drive and blower motors and their subsequent failure. After modifications to the design of the blower, no further overheating occurred. In addition, the blower unit at the Upper Latrobe site, a different design and manufacturer, did not have any overheating operational issues.

Routine maintenance of the Lasaire Aeration systems was required. The Lasaire tubing required regular cleaning, every 10 to 14 days, in order to prevent back pressure and maintain air flow through the system. Without this maintenance the air flow would decrease and the performance of the aeration system and the aerobic pond (based on the Upper Latrobe site) would deteriorate resulting in discharge of high dissolved and total iron concentrations. A cleaning procedure was developed for the tubing for mine drainage treatment applications and included: 1) injection of 100 mL of muriatic acid into each tubing length followed by, 2) use of high pressure air from a compressor to blow the acid and remove iron oxide solids from the holes in the Lasaire tubing. The frequency of this maintenance would require including a compressor unit on-site with the Lasaire Aeration system. Injection ports on the tubing would also be needed to facilitate the injection of the muriatic acid.

The blower units also require routine maintenance that includes checking oil levels (weekly), changing oil (monthly), greasing the units (monthly), changing air filters (every three months), inspecting drive belt (monthly), and replacing drive belt (annually).

Aerobic pond maintenance would involve inspection of inflow and outfall structure to prevent clogging with debris and monitoring of iron oxide accumulation. Based on the increased treatment flow and iron removal at the Upper Latrobe site, iron accumulation would be increased four to five fold necessitating shortening the cycle required for iron removal. However, the area involved would be decreased potentially decreasing the costs of iron removal. With respect to the quality of the iron oxides, no changes in characteristics are expected based on the water quality results from the Upper Latrobe system as the pH remained acidic (i.e., less than 7), thereby preventing the contamination of the solids with calcite (calcium carbonate). This is also supported by the alkalinity monitoring, which did not show any decreases in alkalinity (from calcite precipitation) over the stoichiometric alkalinity consumption from iron removal.

Lasaire Aeration System Costs

The Lasaire Aeration System capital costs and installation costs for the project included electrical service, site preparation, Lasaire Aeration equipment, mechanical blower, installation of equipment and fencing (if required). This was an investigation that did not include all the equipment needed to operate and maintain the equipment. As an example, a second blower would be needed to provide a backup unit in case of failure of one of the blowers. This would require a control panel to allow switching between blowers. In addition, remote locations may require and backup generator in case of power failure. Additional items that would be needed based on the study includes an on-site high pressure and high volume compressor for regular maintenance (every 10 to 14 days) and injection ports in the Lasaire Aeration system to permit rapid muriatic acid injection into the tubing. A building would also be needed to house the various equipment and protect it from adverse conditions. Based on the results of the study Table Lasaire-14 summarizes the capital costs for a typical 0.5 MGD system.

Table Lasaire-15 provides an estimate of O&M Costs for a 0.5 MGD Lasaire Aeration System and Aerobic Pond includes labor, operating and maintenance costs. The operation and maintenance costs were based on estimates from actual costs and included time and materials. The largest item is the labor to maintain and operate the Lasaire Aeration system. The labor cost is due to the level of maintenance required to routinely clean the tubing to maintain the necessary air flow. The effect of the system on the costs of the recoverable iron is likely to be related to the frequency of the solids removal cycle and in a smaller foot print. Based on the iron removal increase, the frequency of occurrence would be shorter with the aeration system decreasing the timeframe four to five fold. Evaluation of the cost benefits associated with the increase in frequency is beyond the scope of the project due to uncertainties in future value and market of the iron oxides.

Table Lasaire-14. Capital Costs for a 0.5 MGD Lasaire Aeration System for an Aerobic Pond (0.5 acres)

Item No.	Description	Quantity	Cost
1	Electric Service (varies depending on site)	1	$5,000
2	Site Preparation (fencing included)	1	$5,500
3	Lasaire Aeration System	1	$18,000
4	Blowers	2	$8,400
5	Air Compressor	1	$10,000
6	Building	1	$8,000
7	Installation	1	$3,500
	TOTAL COSTS		**$58,400**

Table Lasire-15. Treatment System Operating Cost Estimates for a 0.5 MGD Lasaire Aeration System

Item	Cost $/yr
O&M Electricity ($/yr)	$3,400
Maintenance Materials ($/yr)	$600
Personnel O&M Costs ($/yr)	$10,500
Total O&M Costs	**$14,500**

Using the capital costs for installing a Lasaire Aeration system and the expected maintenance costs, an overall cost of treatment was estimated for the Lasaire Aeration system (based on a 15 year replacement cycle). The cost per 1,000 gallons of treated mine water is approximately $0.10 and only includes the Lasaire Aeration costs. The costs of the passive treatment system would be decreased due to the smaller footprint needed, about a factor of four to five smaller. This would equate to a passive treatment construction cost savings.

Summary

Two Lasaire Aeration systems were installed as part of this project and tested to evaluate the effectiveness of this innovative *insitu* approach. The systems were installed at the Wildwood treatment system, an active chemical oxidation system, and the Upper Latrobe passive treatment system.

The Lasaire Aeration system was installed at the Wildwood location in November/December 2007. Initial equipment issues were encountered that were resolved. The results for the Wildwood Lasaire Aeration system indicated the aeration:

1. Increased dissolved oxygen substantially and to near saturated conditions
2. Increased the pH to greater than 7.7 through the removal of carbon dioxide (and carbonic acid) under tested flow conditions.
3. Achieved complete oxidation of ferrous iron to ferric iron within the aeration zone.

However, the concentration of iron in the mine drainage and the charge of the iron oxide solids formed from aeration alone would not flocculate and settle as effectively as the iron oxide solids produced from the hydrogen peroxide dosing. As a result, the hydrogen peroxide dosed treatment was found to produce a better quality effluent. Either additional settling basin would be required to achieve effluent quality with Lasaire Aeration or the aeration would have to be substantially increased to achieve the needed pH increase for iron oxide particle charge neutralization at the Wildwood site.

The Lasaire Aeration system was installed at the Upper Latrobe location in March/April 2008. The system was operated for several months during which back pressure in the system occurred after a short time of operation (~2 weeks). Normal cleaning with high pressure air was expected every 4 to 8 weeks depending on a number of factors, however, high pressure air was inadequate to return system to normal operating backpressures. The backpressure problem was identified as iron oxide buildup in the aeration holes of the tubing. A cleaning procedure was developed involving injection of muriatic acid followed by the normal high pressure air cleaning. This procedure was needed every 10 to 14 days. The Upper Latrobe Lasaire Aeration system was operated using this cleaning procedure for several months and at various mine discharge flows. There was also a short circuiting issue identified within the system that resulted in abnormal levels of effluent total iron while lower total iron levels were found at intermediate sampling points. Based on the monitoring the Upper Latrobe Lasaire Aeration system results indicate the aeration:

1. Increased dissolved oxygen to between 80 and 90% saturation.
2. Increased the pH to greater than 6.7 through the removal of 80 to 90% of the carbon dioxide (carbonic acid) in the mine water.
3. Achieved complete oxidation of ferrous iron to ferric iron within the remaining passive treatment system.
4. Effective at removing total iron (> 95%), with the exception of the short circuiting.
5. Provided treatment of increased flows approximately 4 to 5 times greater than the passive treatment without aeration could achieve.

Based on the results of this study, the use of Lasaire Aeration can be employed at active mine sites where there is personnel available to conduct the required regular cleaning and maintenance of the system. However, Lasaire Aeration can not be recommended on existing or future passive treatment systems where personnel availability is limited and seasonal conditions may constrain access to the system.

BRANDYCAMP PRE-AERATION STUDY

The Brandycamp AMD Treatment Plant is an active treatment system that uses hydrated lime to treat the Brandycamp deep mine discharge. The treatment facility has operated effectively for the flows that the system is capable of treating. However, historically the treatment facility has not had adequate dosing capacity for seasonal (late winter/early spring) high flows resulting in significant bypass of the treatment system. In addition, recent changes in the spring of 2008 resulted in both flow and chemistry changes that have increased the required lime dose further limiting the volume of the discharge that can be treated; less than 50% of the flow could be treated at maximum flow conditions.

An aeration study was recommended and conducted at the Brandycamp AMD Treatment Plant to assist DEP-BAMR in decision making for improving operational performance of the facility; i.e., treat greater flows and/or lower treatment costs. The proposed aeration is pre-aeration prior to lime dosing. The aeration could have the potential of lowering the required lime dose per volume treated and thereby decreasing treatment costs and/or increasing the volume of the Brandycamp discharge that can be treated. Additional benefits of the pre-aeration could include improved iron oxidation in the remaining treatment facilities and decreases in sludge volumes produced by the hydrated lime treatment.

The following provides the technical background information for the Brandycamp AMD discharge, background aeration information as it relates to the Brandycamp discharge and treatment facility, and an evaluation of the effects of the pre-aeration on the Brandycamp discharge and its treatment.

Brandycamp AMD Discharge Characteristics

The Brandycamp AMD discharge is a deep mine discharge that exist the deep mine under pressure through an abandoned air portal. The historic and current characteristics of the Brandycamp AMD discharge are summarized in Table Brandycamp-1.

Table Brandycamp-1. Historic and Current (during aeration study) Brandycamp AMD Discharge Characteristics

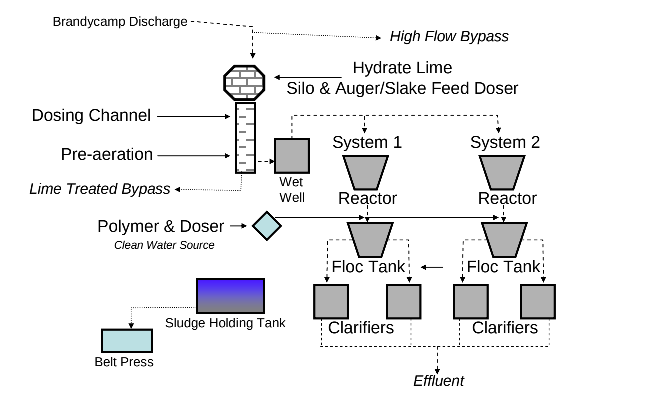
Site	Historic	Current
pH	5.2	4.8
Dissolved Oxygen (mg/L)	--	0.3
Temperature (ºC)	--	10.0
Alkalinity (mg/L as $CaCO_3$)	20	10
"Hot" Acidity (mg/L as $CaCO_3$)	110	250
Total Acidity (mg/L as $CaCO_3$)	--	480
Total Fe (mg/L)	56	102
Ferrous Fe (mg/L)	53	101
Total Mn (mg/L)	9.0	10.0
Total Al (mg/L)	6.0	8.0

The discharge is characterized as a moderately acidic containing high iron concentration, which comprise the majority of the “hot” acidity. “Hot” acidity is a measure of the acidity associated with pH and metals (i.e., iron, aluminum and manganese). Total acidity is a measure of nearly all the “hot” acidity as well as the carbon dioxide acidity in the water. As can be seen in Table Brandycamp-1, there is considerable carbon dioxide acidity in the Brandycamp AMD discharge. The concentration of carbon dioxide acidity will affect the lime dose needed to achieve a pH greater than 8, which is necessary for rapid iron removal, and can also result in substantial solids formation from calcite precipitation caused by the reaction of the carbon dioxide and calcium in the lime.

Existing Brandycamp AMD Treatment System

A flow diagram of the overall Brandycamp AMD Treatment System is depicted in Figure Brandycamp-1. The existing Brandycamp AMD Treatment System consists of a 1) collection channel, 2) hydrated lime silo and slaking system for dosing a lime slurry to the AMD, 3) multiple inlet pumps at the end of the channel to lift the lime-dosed AMD into the remaining treatment system; 4) two parallel iron oxidation and clarification systems; 5) sludge storage of produced solids; and 6) a belt press to concentrate the liquid solids into a paste. Each parallel iron oxidation systems consists of 1) a 5,000 gallon aeration tank; 2) a 5,000 gallon flocculation tank into which polymer is dosed; and 3) two (2) inclined plate clarifiers in each parallel treatment system.

Figure Brandycamp - 1
Brandycamp Treatment System Flow Path



The original Brandycamp AMD Treatment consisted of on only one treatment system. A second was added several years ago because the original system could not adequately treat the high flows of the Brandycamp AMD discharge, resulting in significant bypass of flows around the system. During seasonal high flow periods and the recent changes in AMD chemistry there are substantial bypasses of the AMD around the treatment system. The bypasses have had negative impacts on the Toby Creek downstream of the discharge. In addition, there are significant operational problems at the Brandycamp AMD Treatment System related to 1) difficult iron removal during high flows and the recent chemistry change; 2) substantial production of sludge at volumes that can exceed sludge handling capacity; 3) scale formation on pumps and inside pipes of the treatment system.

Background Information

Carbon Dioxide Acidity

The Brandycamp AMD historic and chemistry during the aeration study is contained in Table Brandycamp-1. As can be seen, the discharge contains considerable “hot” and total/cold acidity. The “hot” acidity is a titration method involving titration with an acid to pH less than 4, addition of hydrogen peroxide to oxidize metals, heating to assist in the oxidation as well as remove any carbon dioxide, and titration with a base to an endpoint pH of 8.0 to 8.3. Typically, the “hot” acidity titration estimates the acidity associated with pH and hydrolysable metals only. The following equation can also be used to calculate/estimate “hot” acidity for mine drainage.

“hot” acidity (mg/L as $CaCO_3$) = $(50{,}000 \times 10\text{-pH}) + (1.8\times(C_{Fe(II)} + C_{Mn(II)})) + (2.7\times C_{Fe(III)}) + (5.6\times C_{Al})$ (1)

The C_i represents the various dissolved metal concentrations in mg/L units. In many cases this estimation method provides a more reliable “hot” acidity measurement.

The total/cold acidity method involves titration with a base directly to an endpoint pH of 8.0 to 8.3; that is, it does not include an acid titration, addition of hydrogen peroxide, or heating. As such, the method may not include the acidity associated with all hydrolyzable metals, particularly manganese. However, the method will include the acidity associated with aluminum, ferric iron, and most of the ferrous iron, depending on the initial ferrous iron concentration; i.e., the greater the initial ferrous iron the greater the percentage of acidity associated with the ferrous iron will be measured. In addition to the metals and because the method does not include acid titration or heating, the total/cold acidity method will contain carbonate acidity (i.e., carbon dioxide acidity). This carbonate acidity is commonly found in deep mine sources of AMD and is from a number of sources including organic carbon decomposition, pyrite oxidation, and neutralization of AMD acidity by bicarbonate alkalinity. A reasonable estimate for the carbon dioxide acidity is shown in the following equation.

CO_2 acidity (mg/L as $CaCO_3$) = “cold” acidity - $(50{,}000\times 10^{-pH}) - (2.7\times C_{Fe(III)}) - (1.8\times C_{Fe(II)}) - (5.6\times C_{Al})$ (2)

or

CO_2 acidity (mg/L as $CaCO_3$) = “cold” acidity – (“hot” acidity - $(1.8\times C_{Mn(II)})$) (3)

Equation 2 does not include manganese because the Mn(II) is soluble and must go through an oxidation step, which does not ostensibly occur at the endpoint pH and duration of the titration. Ferrous iron acidity, Fe(II), is be included because the solubility is substantially decreased (< 2 mg/L) at pH greater than 8.0. Therefore, as long as the titration time is short and an endpoint is between 8.0 and 8.3, the equation should yield a reasonable approximation of carbonate acidity. This was the calculation used to estimate the carbonate acidity in the Brandycamp AMD.

As can be seen in Table Brandycamp-1 the total/cold acidity in the Brandycamp AMD is nearly twice the “hot” acidity indicating the carbon dioxide acidity is approximately 230 to 250 mg/L.

The carbon dioxide acidity is important because it will have the opposite affect as alkalinity; that is the carbon dioxide acidity will buffer against pH increases. As a result, the carbon dioxide acidity will affect the lime dose needed to neutralize the acidity and achieve the pH needed for adequate treatment (i.e., iron oxidation and removal). This is seen in the following equation:

$$2CO_2 + Ca(OH)_2 \rightarrow Ca^{2+} + 2HCO_3^- \qquad (4)$$

Based on the equation the Brandycamp AMD will need a minimum lime dose of between 500 and 600 mg/L (as $CaCO_3$) to neutralize the carbon dioxide acidity (250 mg/L), the "hot" acidity (250 mg/L), and an additional amount to achieve a pH greater than 8.5, and maintain an effluent alkalinity. This acidity equates to a hydrated lime dose between 400 and 500 mg/L in the current treatment system. Based on a maximum dose rate with the existing auger dosing system (~ 3 tons per day) the maximum volume of the Brandycamp AMD that can be treated is between 700 and 800 gpm, depending on the required pH in the remainder of the existing treatment system.

There is one additional complication in the current treatment system approach involving calcium and the operating pH. According, to the above equation the dosing should produce an effluent with approximately 300 mg/L alkalinity from the conversion of carbon dioxide acidity to bicarbonate alkalinity. This concentration can not be achieved because calcium also has a pH dependent solubility. Figure Brandycamp-2 shows calcium solubility as a function of pH and the following equation describes the solubility reaction between dissolved calcium and carbonate.

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_{3(s)} \qquad (5)$$

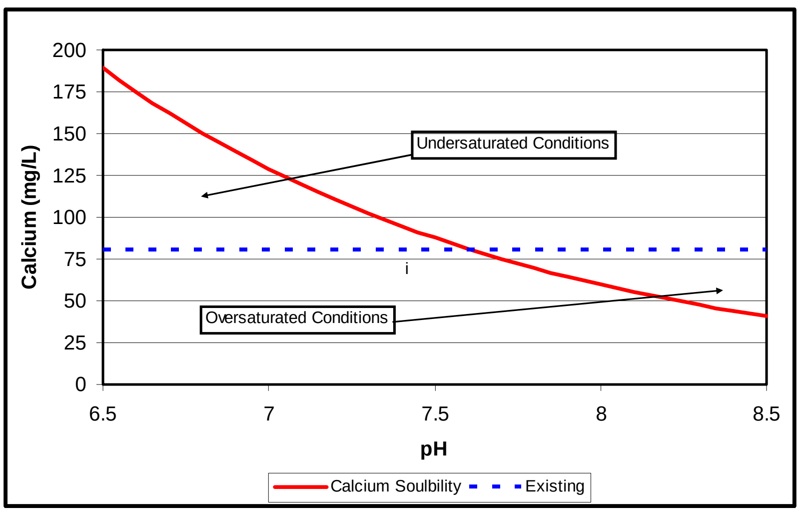


Figure Brandycamp-2. Solubility of calcium (calcite) as a function of solution pH.

The figure indicates approximately 15 mg/L of calcium, in the presence of carbonate, is soluble at pH 9.0, the minimum operating pH of the Brandycamp AMD treatment system. This calcium equates to an alkalinity of approximately 25 mg/L. The actual solubility of calcium and alkalinity concentration may vary depending on the final ion composition (and strength) of the discharge. Field sampling indicated the effluent from the existing clarifiers had approximately 15 to 30 mg/L alkalinity measured during the aeration study, which is closer to the predicted alkalinity based on the solubility of calcium carbonate than the alkalinity based on the conversion of carbon dioxide acidity to bicarbonate (~ 300 mg/L of alkalinity dosed). This confirms that the calcium carbonate solubility limits the alkalinity 1) that can be achieved in the current Brandycamp treatment system, and 2) the excess lime dose is primarily converted to insoluble calcium carbonate in the existing treatment system. The formation of insoluble calcium carbonate has implications regarding the solids produced, the solids handling, and the maintenance requirements in the various treatment system components due to calcite scale formation.

Ferrous Iron Oxidation & Solubility

The existing system was evaluated for its ability to remove ferrous iron from the AMD through oxidation and solubility processes. Based on the appearance of "greenrust", a ferrous hydroxide precipitate, the solubility of ferrous iron was first evaluated. The solubility of ferrous iron is described by the following equation.

$$Fe(OH)_{2(s)} + 2H^{+} \rightarrow Fe^{2+} + H_2O \qquad (6)$$

The solubility of ferrous hydroxide is determined using the solubility product (K_{sp}) of $10^{12.85}$ (Stumm and Morgan 1996). The equation also shows the solubility is highly pH dependent. Table Brandycamp-2 summarizes the approximate ferrous iron solubility at various pH.

Table Brandycamp-2. Solubility of ferrous iron as a function of pH

pH	Fe(II) mg/L
7.0	3,500
7.5	350
8.0	35
8.5	3.5
9.0	0.35

The observed pH in the lime dosing zone was approximately 9 and the aeration reactor pH was approximately 8.5. This indicates the removal of ferrous iron in the system, as currently operated, is controlled by the solubility of ferrous iron, as it relates to pH. This may also have implications with the rate at which ferrous iron is oxidized as a solid and the solids formed because ferrous hydroxide is known to form low density sludge.

The oxidation of ferrous iron in solution is well documented and occurs by the following equation:

$$\textit{HoFIO rate}\ (M \cdot s^{-1}) = -\delta[Fe(II)]/\ \delta t = k_{Ho1} \times [Fe(II)_{diss}] \times [O_2]\ /\ \{H+\}^2$$

The homogeneous ferrous iron oxidation (HoFIO) rate is dependent on the dissolved ferrous iron concentration $[Fe(II)_{diss}]$, dissolved oxygen $[O_2]$, and hydrogen ion concentration $\{H^+\}$ or pH ($\{H^+\} = 10^{-pH}$). The change in pH has a substantial affect on the oxidation rate with a 0.3 unit pH change will double the oxidation rate. The ferrous iron oxidation rate is also affected by temperature, as expressed in the activation energy of the rate constant (k_{Ho1}), with a change in temperature of 2.2°C causing the oxidation rate to change by a factor of 2. Based on the HoFIO equation the oxidation rate should increase as pH increases over all pH. However, Millero *et al.* (1987) found the ferrous iron oxidation rate leveled off (i.e., did not continue to increase) at pH greater than 7.8, which was attributed to the formation of particulate ferrous hydroxide, $Fe(OH)_2$ and a slower oxidation of the solid phase ferrous iron.

The field evaluation indicated the presence of "green rust" or ferrous hydroxide solids, as a result of the high pH in the lime dosed area. In addition, "green rust" was also measured in the aeration reactors of the treatment system, based on extractable ferrous iron from the collected iron oxide solids; the two reactors had 12.9 and 19.4 mg/L of ferrous iron remaining in the solid phase, based on acidified samples taken from the reactors. However, there was less than 0.2 mg/L of dissolved ferrous iron measured in the aeration reactors. This demonstrates the primary iron removal process in the Brandycamp treatment systems is the formation of ferrous hydroxide solid followed by the oxidation of the solid phase ferrous hydroxide to ferric hydroxide. The oxidation is not likely to be complete within the reactor and clarification system, but is likely to be completed within the sludge holding tank. Additional increases in pH would not likely benefit oxidation or the volume of AMD flow that can be treated because of the leveling off of the ferrous iron oxidation at pH greater than 7.8.

During the field investigation DEP staff indicated the original design called for ferrous iron oxidation to occur in the aeration reactors at a pH of 7.5. This pH would be beneficial by minimizing the formation of "green rust" solid (ferrous solubility) as well as decreasing the formation of calcite solid (calcium solubility – see above discussion). Table Brandycamp-3 provides an evaluation of detention times in two types of reactors, 1) continuously stirred and 2) batch, at various pH between 7 and 8, the discharge temperature, and for pre-existing and current Brandycamp discharge conditions. The last line provides the oxidation detention times if the water temperature was 25°C.

Table Brandycamp-3. Summary of Required Detention Times to oxidize ferrous iron to less than 0.5 mg/L for discharge conditions (Discharge Temp. = 10.3°C).

pH	Complete Mix Reactor DT (hours)	Batch Reactor DT (hours)
Current Discharge Conditions (Ferrous Iron = 110 mg/L)		
7.00	1080	28
7.50	110	2.7
8.00	11.3	0.28
Pre-Existing Discharge Conditions (Ferrous Iron = 60 mg/L)		
7.00	612	24.6
7.50	61	2.5
8.00	6.1	0.25
Pre-Existing Discharge Conditions (Ferrous Iron = 60 mg/L) @ 25°C		
7.5	2.0	0.08 (5 minutes)

As can be seen, there is a substantial difference in the detention times required for a complete mix reactor versus a batch reactor for the oxidation of ferrous iron. The complete mix reactor is the type of reactor present at the Brandycamp treatment system and the batch reactor would be similar to a bench-scale test. The current aeration reactor detention time, based on a volume of 6,000 gallons and current operating conditions, is about 25 minutes. As can be seen, the required detention time at a pH of 7.5 in a complete mix reactor and batch reactor are greater than 60 and 2.5 hours, respectively. The 25 minute detention time is achieved only in the batch reactor when the water temperature is increased to 25°C. Analysis at pH greater than 8 is not necessary because the ferrous iron oxidation levels off at pH greater than 7.8 (Millero *et al* 1987).

The evaluation of ferrous iron solubility and oxidation indicates the current Brandycamp treatment system will need to be run at a high pH, greater than 8.5, to remove ferrous iron and that the removal is based on the solubility of ferrous hydroxide, or “green rust”, and not the oxidation of ferrous iron. The size of the reactor limits the ability to utilize oxidation of the ferrous iron as a primary mechanism of iron removal. In order to utilize the homogeneous ferrous iron oxidation (HoFIO) process at a lower pH (~7.5) as the primary mechanism of iron removal, substantial modifications to the existing system would be needed. As a result, a high lime dose is needed to raise the pH to levels where ferrous hydroxide will precipitate, which is approximately 9. This pH results is substantial lime doses to overcome the carbonate acidity and produces additional solids from the precipitation of calcium as calcite.

Solids Production

The solids produced by the current treatment system are associated with the precipitation of iron and aluminum in the form of hydroxides. In addition, the required pH of the treatment process will result in the precipitation of calcium in the form of a calcium carbonate (see above discussion of calcium solubility). Table 2 provides estimates of the solids that are currently produced by the Brandy Camp treatment system based on the volume of water treated (approximately 600 gpm), the AMD characteristics, and the effluent quality from the treatment system. Iron and aluminum solids produced prior to the change in chemistry area also provided in the table.

Table Brandycamp-4. Summary of Estimated Current Solids Produced by the flow treated in the Brand Camp Treatment System.

	Units	Iron $Fe(OH)_3$	Aluminum $Al(OH)_3$	Calcium $CaCO_3$	Total Solids
Dry Weight	lbs/day	1,575	375	2,150	4,100
Belt press (20% Solids)	tons/day	3.9	0.9	5.4	10.2
Clarifier (2% Solids)	gal/day	9,500	2,250	12,900	24,650
Pre-existing Discharge Conditions					
Clarifier (2% Solids)	gal/day	5,000	500	3,000	8,500

The current conditions indicate the volume of sludge produced by the treatment system approaches 25,000 gallons per day (~5 gpm per clarifier pump). Also, the lime dosing data and effluent alkalinity data indicate approximately 50 percent of the total sludge volume currently being produced are calcium solids. The calcium solids produced is a direct result of the initial carbonate acidity and the pH required to effectively remove the ferrous iron as a ferrous hydroxide. Decreasing the initial carbon dioxide acidity and/or lowering the required pH would decrease the solids produced by decreasing the formation of calcium carbonate precipitate, potentially decreasing the solids produced by approximately 50%.

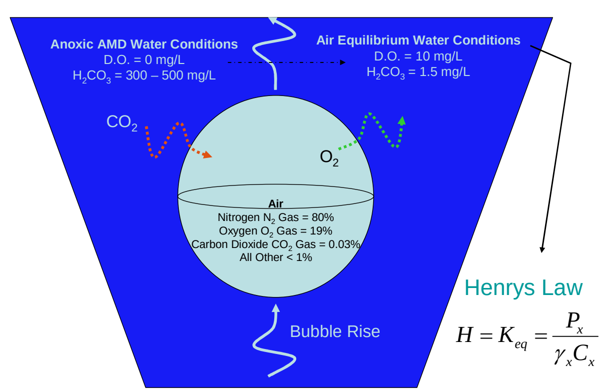
Gas Transport

Carbonate acidity in waters is the result of excess carbon dioxide in the form of carbonic acid (H_2CO_3). The carbonic acid is formed as a result of various biotic oxidation reactions (e.g., oxidation of pyrite and organics) and abiotic reactions associated with precipitation of metals. The result is AMD can contain carbonic acid concentrations, and carbonate acidity, orders of magnitude greater than the carbonic acid typical of surface waters in equilibrium with atmospheric carbon dioxide; therefore, the AMD would be supersaturated with carbonic acid. This carbonic acid would be gradually dissipated to the atmosphere as carbon dioxide through natural aeration processes or more rapidly with mechanical aeration systems. The carbonic acid is removed as carbon dioxide based on the following equilibrium reaction.

$$H_2CO_3 \leftrightarrow H_2O + CO_2$$

The carbon dioxide is released to the atmosphere through transport across the air and water interface. In mechanical aeration this is schematically shown in Figure Brandycamp-3, as well as introduction of dissolved oxygen into the water, where the carbon dioxide is transported from the water to the gas bubble. The solubility of the gases in water is determined by Henry's Law. This equation determines the final concentration of the carbon dioxide in the water, but not the rate at which it is removed from the water to the air. Based on Henry's Law, water in equilibrium with the atmosphere will contain approximately 2 mg/L of carbonic acid (as $CaCO_3$ acidity). In comparison, the Brandy Camp AMD contains approximately 400 mg/L of carbon dioxide acidity.

Figure Brandycamp-3. Gas Transport from and to Air Bubbles



Removal of the carbonic acid prior to lime dosing would provide the greatest benefit for decreasing the lime dose per volume of AMD treated and the calcium solids produced. Removal of the carbonic acid will require mechanical aeration to lower the carbon dioxide in the AMD. Aeration removes the dissolved carbon dioxide by transport from the solution to the air bubbles, which are than released to the atmosphere. As with dissolved oxygen aeration to water, fine bubble diffused air will be the most efficient method of removing the excess carbon dioxide.

Pre-Aeration Study at the Brandycamp System

System Description

A portable aeration pilot treatment was mobilized and setup at the Brandycamp Treatment System adjacent to the concrete channel into which the hydrated lime is dosed. The pilot system is the portable unit used in the AIS Pilot Studies that were conducted for DEP-BAMR by IOT. The system setup at the Brandycamp location is shown in Figure Brandycamp-4. The pilot unit consists of two aeration reactors followed by a flocculation tank and clarifier. The two aeration reaction reactors were used to evaluate pre-aeration affects on the Brandycamp AMD discharge chemistry (e.g., total acidity).

Electrical connections needed to operate pumps, blowers, mixers and dosers were made from existing facilities at the Brandycamp Treatment System. A 1 HP submersible water pump was placed in the discharge channel above the lime silo and connected to the pilot unit using flexible pipe. The 1 HP pump provided excess flow to the pilot unit, which was directed to either the pilot unit or bypassed by adjusting plates on the inlet weir box. Both the aerated water and bypass water were conveyed by gravity back to the concrete channel below the lime silo using flexible pipe.

Figure Brandycamp-4. Pilot System Setup at the Brandycamp AMD Treatment System

Analytical Testing

A number of parameters were field tested during the pre-aeration study at the Brandycamp AMD Treatment System. Parameters and methods used are summarized in Table Brandycamp–5. Total acidity is the important parameter in the testing as a reduction in total acidity from aeration represents carbon dioxide and associated acidity removal. A pH 8.0 and 8.3 endpoint were used for the total acidity titration. The endpoints will likely include all acidity in the discharge (i.e., pH, iron, aluminum and carbon dioxide), with the exception of acidity associated with dissolved manganese. Sampling locations in the pilot unit included influent, effluent from each aeration tank, and final effluent.

Table Brandycamp-5. Parameter and methods for samples collected during the aeration study at the Brandycamp AMD treatment System.			
Parameter	**Units**	**Method Description**	**Equipment**
pH	s.u.	Electrode	Accumet AP61
Alkalinity	mg/L as $CaCO_3$	Potentiometric Titration	Hach Titrator
Total Acidity	mg/L as $CaCO_3$	Potentiometric Titration	Hach Titrator
Dissolved Oxygen	mg/L	Electrode	YSI 550A
Temperature	°C	Electrode	YSI 550A
Total Iron	mg/L	Ferrover	Hach Colorimeter
Dissolved/Ferrous Iron	mg/L	0.2 µM filtration and Ferrover	Hach Colorimeter
Dissolved Aluminum	mg/L	0.2 µM filtration and Aluver	Hach Colorimeter

In addition to the above water quality sampling, the AMD discharge and effluent from the pilot system were periodically collected and used to conduct a hydrated lime titrations. This testing was conducted on a 5 gallon sample. The sample was placed in a 5 gallon bucket and hydrated lime was gradually added until a pH of 8.0 and 8.5 were reached, as measured using the pH meter in the above table. The sample was mixed with a hand held mixer (i.e., drill) and a mixing blade. This testing was conducted to confirm the measured decrease in acidity equated to a decrease in hydrated lime dose.

Aeration Testing

Aeration testing using the pilot unit consisted of varying AMD and aeration flow. AMD flow was varied from 30 to 90 gpm and air flow was varied from 10 to 20 cfm. Fine bubble diffused and coarse bubble diffused aeration was also investigated to evaluate the potential benefits of using fine bubble diffused air versus coarse bubble diffused air. This was accomplished by switching diffuser heads in the aeration tanks; a relatively simple procedure accomplished without draining the tanks by turning off the air flow to an individual tank, removing the dropouts, replacing the membrane diffuser head, and replacing the dropout. The aeration testing at Brandycamp was conducted for a five week period during November and December 2008.

Pre-Aeration Results

Results of the routine sampling are provided in Table Brandycamp-6 through Table Brandycamp-11. The tables also provide the operating conditions under which the data were collected. The results indicate aeration lowered the total acidity in the Brandycamp discharge, based on the measured "cold" acidity titration. This decrease in total acidity was from the removal of carbon dioxide (CO_2), as shown by the decrease in calculated CO_2 acidity. There was also a modest increase in pH as well as a slight decrease in dissolved aluminum from the aeration. Despite the increase of dissolved oxygen from the aeration to near saturation, there was no measurable decrease in ferrous iron, as measured by dissolved iron. This is a result of the low pH associated with the discharge (i.e., less than 5.5) and the corresponding slow oxidation of ferrous iron at this pH.

Table Brandycamp-6. Summary of analytical results from aeration testing (Test A1) at Brandycamp Treatment System for AMD Flow = 65 gpm and fine bubble Air Flow = 18 cfm started on November 10, 2008 at 4:00 PM.

Location	pH	Temp. °C	Total Acidity mg/L	CO_2 Acidity mg/L[1]	Alkal. mg/L	Diss. Oxygen mg/L	Diss. Iron mg/L	Diss. Aluminum mg/L
November 12, 2008 at 9:30 AM								
Inflow	4.80	10	390	185	11	2.9	103	--
React 1	5.04	10	300	74	10	9.3	103.5	--
React 2	5.09	9.8	272	42	7	10.8	102.5	--
Clarifier	5.07	--	273	40	8	--	--	--
November 14, 2008 at 12:05 AM								
Inflow	4.74	10.2	440	200	10.4	3.0	102.5	6.2
React 1	4.97	10.2	315	75	8.2	9.4	--	--
React 2	5.01	10.4	284	44	6.7	10.8	--	--
Clarifier	5.01	10.4	280	40	6.8	10.8	102.5	3.0

[1] Calculated from total acidity and metal acidity.

Table Brandycamp-7. Summary of analytical results from aeration testing (Test A2) at Brandycamp Treatment System for AMD Flow = 31 gpm and fine bubble Air Flow = 18 cfm started on November 14, 2008 at 3:00 PM.

Location	pH	Temp. °C	Total Acidity mg/L	CO_2 Acidity mg/L[1]	Alkal. mg/L	Diss. Oxygen mg/L	Diss. Iron mg/L	Diss. Aluminum mg/L
November 17, 2008 at 9:30 AM								
Inflow	4.79	9.9	430	190	13.7	3.5	102.5	6.3
React 1	5.18	9.6	279	38	7.9	10.1	--	--
React 2	5.16	9.2	250	14	4.9	11.0	--	--
Clarifier	5.12	8.8	232	0	5.0	11.5	100.0	3.0
November 19, 2008 at 4:30 PM								
Inflow	4.65	10.0	473	233	13.8	3.3	101.0	7.1
React 1	5.01	9.6	278	90	9.0	10.6	--	--
React 2	5.05	9.2	254	68	5.0	11.6	--	--
Clarifier	5.05	8.9	240	0	4.7	11.5	101.5	4.0

[1] Calculated from total acidity and metal acidity.

Table Barndycamp-8. Summary of analytical results from aeration testing (Test A3) at Brandycamp Treatment System for AMD Flow = 95 gpm and fine bubble Air Flow = 18 cfm started on November 19, 2008 at 5:00 PM.								
Location	**pH**	**Temp. °C**	**Total Acidity mg/L**	**CO_2 Acidity mg/L[1]**	**Alkal. mg/L**	**Diss. Oxygen mg/L**	**Diss. Iron mg/L**	**Diss. Aluminum mg/L**
November 21, 2008 at 10:00 AM								
Inflow	4.81	10.0	472	232	13.1	0.5	101.5	5.8
React 1	5.01	9.9	330	90	10.5	9.3	--	--
React 2	5.05	9.6	308	68	7.9	10.8	--	--
Clarifier	5.05	9.4	300	60	7.2	10.4	102.0	5.4
November 24, 2008 at 9:00 AM								
Inflow	4.72	10.0	525	285	13.3	2.0	100.0	--
React 1	4.98	9.8	401	161	10.2	9.4	--	--
React 2	5.02	9.7	330	90	8.5	10.6	--	--
Clarifier	4.97	9.5	315	94	7.4	10.6	101.0	--

[1] Calculated from total acidity and metal acidity.

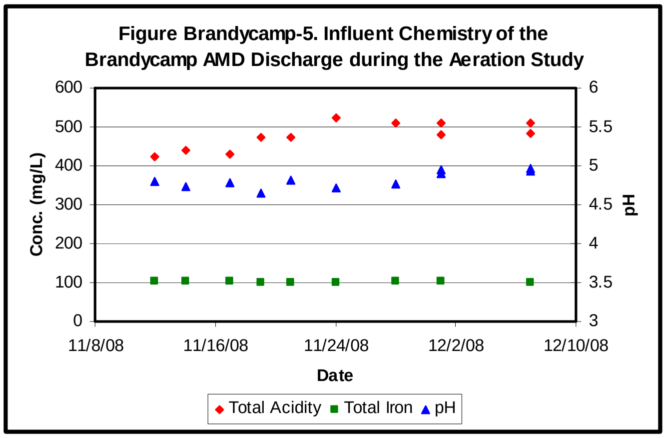
Table Brandycamp-9. Summary of analytical results from aeration testing (Test A4) at Brandycamp Treatment System for AMD Flow = 65 gpm and fine bubble Air Flow = 10 cfm started on November 24, 2008 at 12:00 PM.								
Location	**pH**	**Temp. °C**	**Total Acidity mg/L**	**CO_2 Acidity mg/L[1]**	**Alkal. mg/L**	**Diss. Oxygen mg/L**	**Diss. Iron mg/L**	**Diss. Aluminum mg/L**
November 28, 2008 at 12:00 PM								
Inflow	4.76	10.0	470	240	12.8	0.3	102.5	--
React 1	5.00	9.8	349	123	9.6	9.8	--	--
React 2	5.04	9.7	315	90	9.4	10.3	--	--
Clarifier	5.01	9.5	302	75	7.1	10.2	104.0	--
December 1, 2008 at 11:00 AM								
Inflow	4.90	9.9	510	270	13.3	--	100.0	5.0
React 1	5.06	9.7	357	117	10.7	--	--	--
React 2	5.03	9.5	328	88	8.7	--	--	--
Clarifier	5.04	9.5	315	75	8.9	--	103.5	4.7

[1] Calculated from total acidity and metal acidity.

Table Brandycamp-10. Summary of analytical results from aeration testing (Test A5) at Brandycamp Treatment System for AMD Flow = 65 gpm and coarse bubble Air Flow = 20 cfm started on December 3, 2008 at 12:00 PM.								
Location	pH	Temp. °C	Total Acidity mg/L	CO_2 Acidity mg/L[1]	Alkal. mg/L	Diss. Oxygen mg/L	Diss. Iron mg/L	Diss. Aluminum mg/L
December 7, 2008 at 10:00 AM								
Inflow	4.94	10.0	510	270	14	--	103.5	6.8
React 1	5.04	9.8	384	144	11	--	--	--
React 2	5.10	9.6	315	75	8	--	--	--
Clarifier	5.08	9.3	305	65	8	--	101.5	4.6

[1] Calculated from total acidity and metal acidity.

An important consideration in the aeration study was the variability of the influent over the course of the aeration investigation. Influent conditions sampled during the study are shown in Figure Brandycamp-5. The influent data shows the total iron did not change over the course of the study and this metal is the largest contributor to "hot" acidity on the discharge. Both the pH and the total acidity increased slightly over the course of the aeration study, which was likely related to a decrease in the discharge flow over the period and/or the gradual change in discharge chemistry from the early spring 2008 change in discharge chemistry event. Based on the analysis the increase in total acidity would be the result of an increased in CO_2 acidity of between 25 and 50 mg/L, or approximately a 10 % increase. This indicates that any decrease in total acidity was a result of carbon dioxide removal by aeration, which was measured as a decrease in CO_2 acidity, and not a change in the discharge chemistry.



Based on the no measured change in influent conditions, the pre-aeration results also show the amount of CO_2 acidity removed was related to the operating conditions (i.e., AMD flow, air flow, and bubble type) of the pilot pre-aeration unit. The percent CO_2 acidity removed along with the operating conditions are summarized in Table Brandycamp-11. This table shows that for fine bubble aeration CO_2 acidity removal 1) approached 100 % at a detention time of approximately 2 hours, 2) was approximately 80% at 1 hour detention time, and 3) decreased to 65% at 0.7 hours detention time. The CO_2 acidity removal rate as a function of detention time decreased non-linearly according to 1st order reaction kinetics. This non-linear relationship is demonstrated by comparing CO_2 acidity removal of 82% from Test A1 at a detention time of 1 hour to 95% from the Test A2 at a detention time of 2 hours. If the relationship was linear than Test A1 CO_2 acidity removal should be less than 50%. This 1st order reaction kinetics will be an important consideration in the design of a full-scale system.

Table Brandycamp-11. Summary of CO_2 Acidity Removal during Brandycamp Treatment System aeration tests (Test A1 through A5).					
Test	**AMD Flow gpm**	**Air Flow cfm**	**Air Type**	**Detention Time Hrs**	**% CO_2 Acidity Removal**
Test A2	31	18	Fine	2.11	95.8
Test A2	31	18	Fine	2.11	94.2
Test A1	65	18	Fine	1.00	82.5
Test A1	65	18	Fine	1.00	81.7
Test A3	95	18	Fine	0.69	71.2
Test A3	95	18	Fine	0.69	62.5
Test A4	65	10	Fine	1.00	62.5
Test A4	65	10	Fine	1.00	63.3
Test A5	65	20	Coarse	1.00	68.8

Table Barndycamp-11 also provides a comparison of fine and coarse bubble aeration showing a CO_2 acidity removal of 82% for fine bubble in Test A1 and 66% for coarse bubble Test A5 for the same air flow and AMD flow. While this is a significant difference, approximately 15% at the same air flow, there may be advantages for the coarse bubble aeration. As an example, blower horsepower and air flow is a function of the air pressure so that coarse bubble aeration, operating at a lower pressure and greater air flow, would likely achieve the same CO_2 acidity removal based on horsepower of the blower. The type of aeration will be evaluated based on operation and maintenance of the aeration and blower system.

Table Barndycamp-12 contains the results of the hydrated lime dose testing conducted during the aeration study. As can be seen by comparing inflow to outflow lime dose test results, the aeration decreased the required lime dose to reach a pH of 8.5 in all tests ranging from 38% to 58% lime dose decrease, depending on test conditions. For example, the results show the decrease in hydrated lime dose in the fine bubble detention time tests (A1 through A3) were dependent on the detention time, which corresponds to the CO_2 acidity removed. Based on the lime dose testing, pre-aeration will decrease the required lime dose to treat the Brandycamp AMD discharge by approximately 50% and will depend on the operating conditions; i.e., detention time, air flow and air type.

With respect to the total acidity measured during each test, the hydrated lime dose was comparable to the total acidity and decrease in total acidity. As an example, using outflow results of Test A3, the lime dose added to reach a pH of 8.5 was 261 mg/L hydrated lime ($Ca(OH)_2$) dose, which converts to 353 mg/L as $CaCO_3$ compared to the total acidity titration of 308 mg/L. The decrease in total acidity measured in Test A3 was from 499 mg/L to 308 mg/L, a decrease in 38%, compared to the lime dose decrease of 44% indicated measured total acidity decreases are similar to the hydrated lime dose test decreases.

Table Brandycamp-12. Summary of analytical results from hydrated lime dose tests conducted at Brandycamp Treatment System during aeration tests (Test A1 through A5).

Date	Test	Location	Hydrated Lime Dose mg/L		Final Alkalinity mg/L	Lime Dose Reduction %
			pH=8.0	pH=8.5		
11/14/2008	A1	Inflow	502	545	--	43
11/14/2008	A1	Outlet	--	311	--	
11/17/2008	A2	Inflow	449	502	220	58
11/17/2008	A2	Outlet	196	214	--	
11/17/2008	A2	Outlet	217	228	29	
11/19/2008	A2	Inflow	425	465	304	56
11/19/2008	A2	Outlet	196	205	26	
11/21/2008	A3	Inflow	427	450	245	44
11/21/2008	A3	Outlet	242	254	57	
11/24/2008	A3	Inflow	455	483	280	43
11/24/2008	A3	Outlet	261	269	63	
11/28/2008	A4	Inflow	468	512	306	48
11/28/2008	A4	Outlet	257	267	73	
12/1/2008	A4	Inflow	385	406	225	38
12/1/2008	A4	Outlet	238	254	68	
12/7/2008	A5	Inflow	418	446	241	42
12/7/2008	A5	Outlet	249	260	68	

An additional advantage of the pre-aeration was on the ferrous iron oxidation during the test. This is shown in Figure Brandycamp-6, which displays photographs of the lime dose tests on the inflow and aerated AMD. As can be seen, the inflow hydrated lime test produced a green precipitate characteristic of a ferrous hydroxide solid versus the aerated test was orange characteristic of a ferrous hydroxide solid. This indicates the pre-aeration will result in more effective oxidation of the ferrous iron contained in the Brandycamp AMD, which could have the added benefit of improved operating conditions in the remaining system and potentially provide a more settleable solid as well possibly allowing increased AMD flow into the treatment system.

Figure Brandycamp-6. Comparison of hydrated lime dose tests during Brandycamp aeration study with AMD inlet on left and aerated AMD on right.

Table Brandycamp-12 also shows results of the alkalinity in the hydrated lime dosed water for both inflow and outflow to the aeration system. There was substantially greater alkalinity in the lime dosed inflow water, which is the result of the formation of carbon dioxide in the AMD with the hydroxide in the lime to form carbonate alkalinity (see equation 4). This alkalinity would not be stable at the pH of the lime test (> 8.0) due to the limited solubility of calcium carbonate at this high pH (see equation 5 and Figure Brandycamp-2). The presence of the high alkalinity concentrations is likely the result of the lack of nucleation of particulate calcium carbonate in the short duration of the tests (< 10 minutes). This was evaluated by examining the alkalinity from the Brandycamp Treatment System during the aeration tests (i.e., same dose and operating conditions), which are provided in Table Brandycamp-13. The results indicate an effluent alkalinity of 25 mg/L, which likely indicates the high alkalinity from the hydrated lime dose is converted to insoluble calcium carbonate. This can be seen in Figure Brandycamp-2, which shows the calcium solubility would decrease to about 25 mg/L (60 mg/L alkalinity) as the pH approaches 9.0. It was likely a higher pH was present in the Brandycamp Treatment System after hydrated lime dosing, which was then lowered through the aeration reactor by the addition of carbon dioxide from the air. Crystalline calcium carbonate is present in the Brandycamp Treatment System solids, based on communications with Daryle Fish, Ph.D. (St. Vincent College), who used and tested the solids during a nutrient study. This indicates that while the hydrated lime tests conducted as part of the aeration study show higher final alkalinity in inflow water than the pre-aeration waters, the length of react time in the existing Brandycamp Treatment System would result in the removal of much of the alkalinity to an alkalinity that would be more consistent with alkalinity in the pre-aerated water.

Table Brandycamp-13. Results from the Brandycamp AMD Treatment System on November 24, 2008.

Location	pH	Temperature ºC	Dissolved Oxygen mg/L	Alkalinity mg/L
New-Clarifier	9.09	10.1	10.6	24
Old-Clarifier	8.95	10.2	10.3	27

The formation of calcium carbonate (calcite) solids in the existing Brandycamp Treatment System is an additional issue that would be minimized through pre-aeration. Based on an average alkalinity of 260 mg/L in the lime dose tests on the inflow water (see Table Brandycamp-12) and the average alkalinity of 25 mg/L in the effluent from the Brandycamp Treatment System (see Table Brandycamp-13) there is approximately 230 mg/L of calcium carbonate solids produced. Comparing this to the 200 mg/L of solids produced from the 100 mg/L of ferrous iron in the Brandycamp AMD indicates that over 50% of the solids formed at the Brandycamp Treatment System are from the hydrated lime added to overcome the carbon dioxide acidity and raise the pH to where iron can be rapidly removed. By removing the carbon dioxide the hydrated lime dose will be decreased along with the resulting calcium carbonate solids. Based on the hydrated lime dosed per-aerated water alkalinity of approximately 60 mg/L and the Brandycamp Treatment System effluent alkalinity of 25 mg/L there would still be some calcium carbonate solids produced, approximately 15% versus greater than 50%.

Conceptual Pre-Aeration System

Two alternatives for pre-aeration at the Brandycamp Treatment System were evaluated including 1) a steel tank system placed along side the existing concrete conveyance channel as a minimal invasive modification that could be accomplished without interruption of treatment; and 2) a concrete tank system to replace the existing concrete conveyance channel as a more substantial modification that would be more consistent with existing facilities and may require interruption of treatment or significant operational changes during construction.

The steel tank system location is depicted in Figure Brandycamp-7, which shows the tank system installed adjacent to the existing concrete channel. The Brandycamp discharge would be diverted into the tank where aeration would be provided to remove the CO_2 acidity. The volume in the steel tank would be 55,000 gallons providing approximately one hour detention time at a flow of 1,000 gpm. The steel tank dimensions would be 12 feet wide, 11 feet deep, and 69 feet long. The water depth in the tank would be 9.5 feet. Aeration (800 cfm) will be provided to the system by positive displacement blowers, one operating and one backup. Galvanized steel piping would deliver the air to coarse bubble diffusers located on removable drop outs in the tank. A conceptual cross section of the tank system is shown in Figure Brandycamp-8.

The concrete tank system location is depicted in Figure Brandycamp-9, which shows the tank system installed at the location of the existing concrete channel. The Brandycamp discharge would be diverted into the concrete where aeration will be provided to remove the CO_2 acidity. The volume in the concrete tank would also be 55,000 gallons. The concrete tank dimensions would be 12 feet wide, 12 feet deep, and 56 feet long. The water depth in the tank would be 11 feet. Aeration would be similarly provided to the system by positive displacement blowers, one operating and one backup. Galvanized steel piping would deliver the air to coarse bubble diffusers located on removable drop outs in the tank. The cross section of the tank system would be similar to the cross-section shown in Figure Brandycamp-8.

Cost vs. Benefit Analysis

The Pre-Aeration Tank treatment unit to achieve a minimum of 75 percent carbon dioxide acidity removal has been determined. The Pre-Aeration Tank will contain approximately 55,000 gallons of water volume and will be equipped with coarse bubble diffusers to deliver approximately 800 cfm of air. Table Brandycamp- 14 and 15 summarize the cost of the steel and concrete Pre-Aeration Tank system, respectively. As can be seen the concrete tank option is approximately $100,000 more expensive than the steel tank option. In addition to the above equipment costs, there will be additional costs associated with the Pre-Aeration system. The additional costs include IOT, LLC proprietary engineering design fees, treatment system installation engineering fees, and installation costs. The IOT, LLC proprietary engineering design fees are estimated at $7,500.00

Figure Brandycamp-7. Pre-Aeration steel tank system

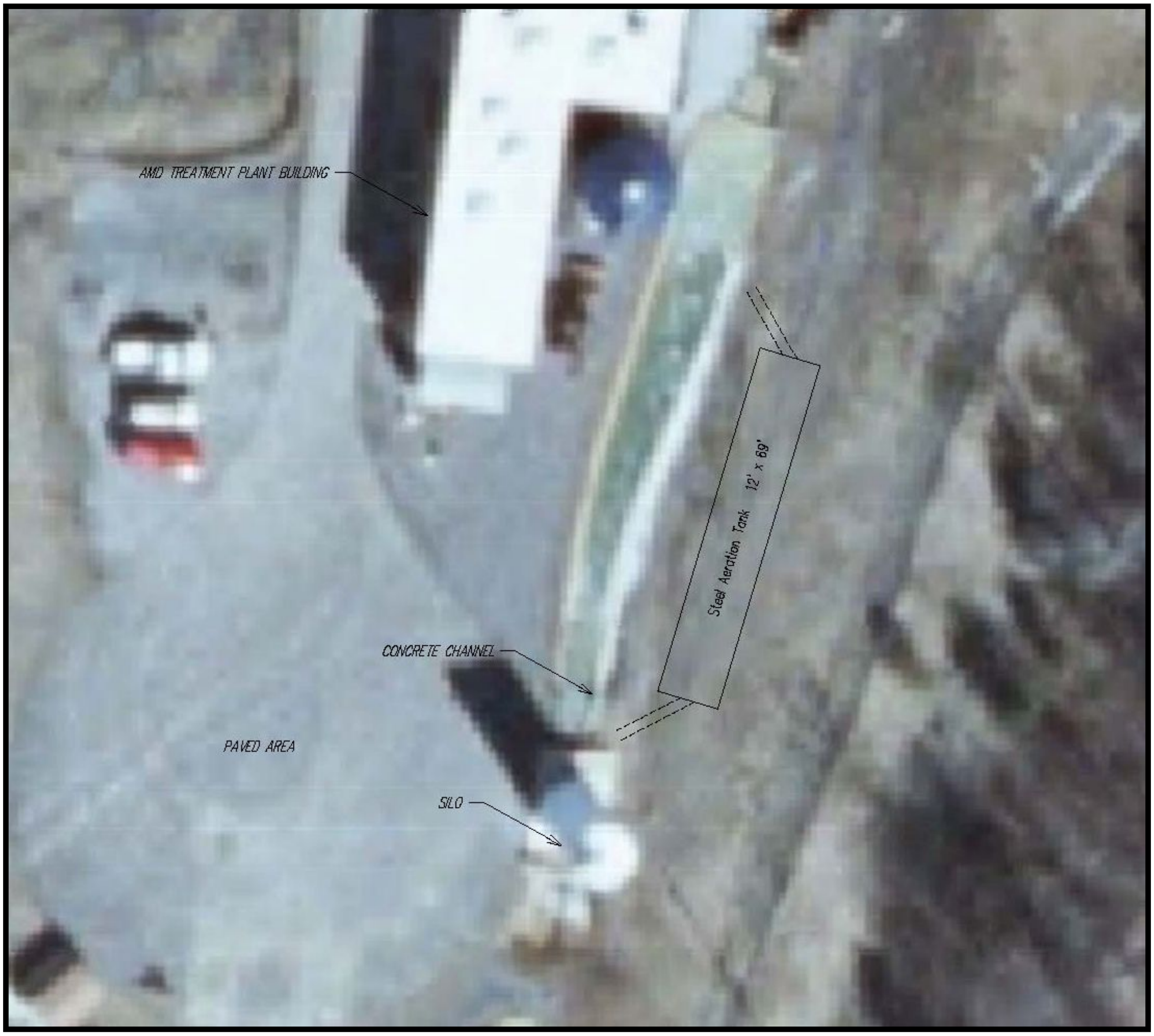
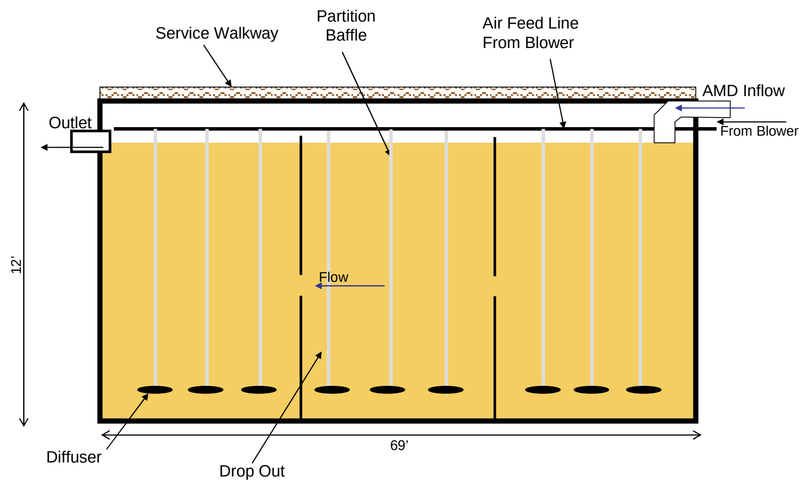


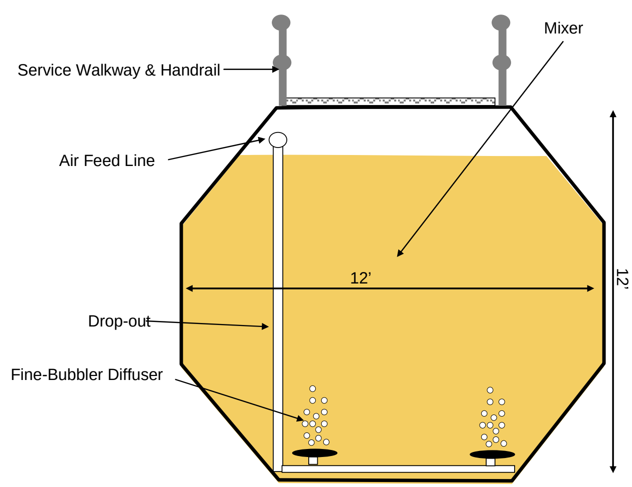
Figure Brandycamp-8
Aeration Tank Conceptual Layout

Side View



Not-to-Scale

Cross-Section View



Not-to-Scale

Figure Brandycamp-9. Pre-Aeration concrete tank system

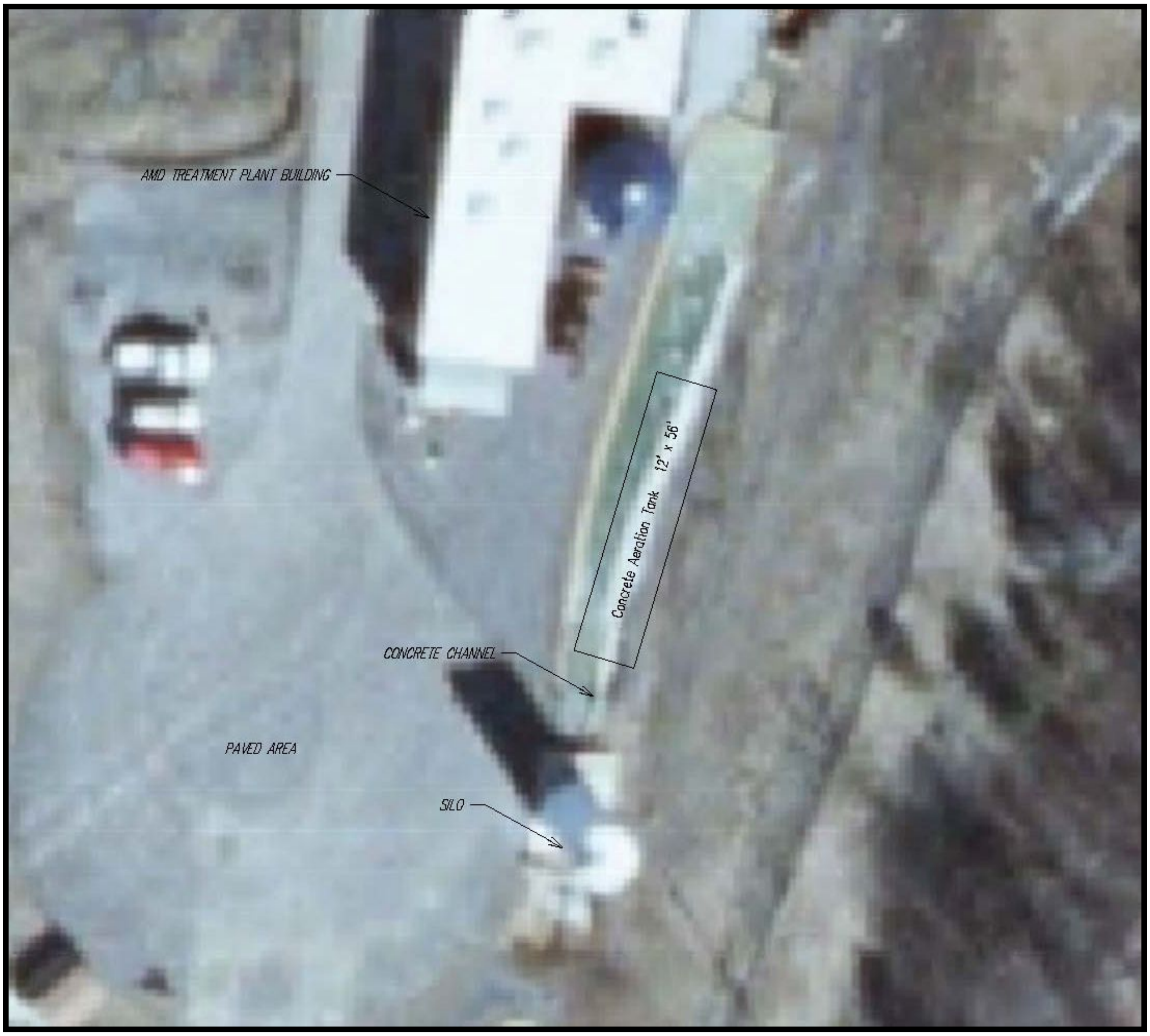


Table Brandycamp-14. Cost Estimate for the Brandy Camp Steel Tank Pre-Aeration Unit to Remove Carbon Dioxide Acidity.	
Item	**Cost**
Pre-Aeration Tank Unit 55,000 gallon Steel Tank – In Ground Reinforced Epoxy Painted External Coal-Tar Epoxy Painted 800 cfm Coarse Bubble Diffuser System Full Service Grating	$84,500.00
Blower System – Three Phase System One (1) Operating 30 HP Blower One (1) Back-up 30 HP Blower Control Panel	$23,500.00
Blower Option #1 – Optional Sound Enclosures	*$6,500.00*
Estimated Freight	$7,500.00
Estimated Installation Costs	$25,000.00
Total Equipment Cost	**$140,500.00**

Table Brandycamp-15. Cost Estimate for the Brandy Camp Concrete Tank Pre-Aeration Unit to Remove Carbon Dioxide Acidity.	
Item	**Cost**
Pre-Aeration Tank 55,000 gallon Concrete Tank Perimeter Safety Railing	$162,500.00
800 cfm Aeration Equipment Galvanized Steel Piping Galvanized Steel Dropouts Coarse Bubble Diffusers	$16,000
Blower System – Three Phase System One (1) Operating 30 HP Blower One (1) Back-up 30 HP Blower Control Panel	$23,500.00
Blower Option #1 – Optional Sound Enclosures	*$6,500.00*
Estimated Freight	$2,500.00
Estimated Installation Costs	$30,000.00
Total Equipment Cost	**$234,500.00**

The Pre-Aeration Tank Unit has been sized to provide a minimum of 75 percent removal of the carbonic acid (or carbonate acidity). Based on the field lime dosing tests the 75 percent removal will lower the hydrated lime dose by approximately 45 percent. Based on the 480 mg/L lime dose for the inlet water, 1,000 gpm of treated flow without pre-aeration requires 2.4 tons per day and with pre-aeration will require 1.3 tons per day. Based on the decrease in carbonic acid from the pre-aeration the lime dose should be lowered by 1.1 tons per day. Based on a current cost for hydrated lime is $130 ton, there would be a decrease in lime costs of approximately $143 per day or $52,000 per year.

There will also be a decrease in sludge production due to the decrease in calcite precipitation. Based on the decrease in lime dose and reduction in calcite formation, there should be a decrease in sludge production of 15,000 gallons per day (at 2 percent solids). This sludge decrease will decrease the labor required for dewatering in the belt press and decrease the sludge accumulation in the overflow settling ponds. The labor costs for belt press sludge dewatering will be minimal due to staffing requirements for the treatment facility. Decrease in sludge accumulation in the overflow settling ponds will be beneficial by decreasing the sludge pumping frequency from the ponds. Based on the sludge volume decreases the frequency of the pond sludge pumping will be almost double the current frequency. This decrease equates to approximately $15,000 per year.

The Pre-Aeration Tank System will have costs associated with operation and maintenance. Operational costs will be associated with electricity consumption to operate the 30 Hp 800 cfm blower to deliver air to the Pre-Aeration Tank. There will also be routine maintenance of the system to service the blower, monitor and replace diffuser heads, cleanout of inlet and outlet facilities, and painting and maintenance of the steel tank. The routine maintenance is not expected to increase labor requirements at the Brandy Camp treatment facility. Electricity costs for the operation of the Pre-Aeration Tank was determined based on assumptions including 30 horsepower (Hp) requirement for the blower (actual will be approximately 27 Hp) and an electricity cost of $0.08 per kilowatt-hour (kwH). Based on above assumptions the electricity costs associated with the Pre-Aeration Tank unit will be $43.20 per day or $15,800 per year.

Table Brandycamp-16 summarizes the various savings and costs associated with operation of the Pre-Aeration Tank unit, based on a treated flow of 1,000 gpm. The anticipated cost savings of the Pre-Aeration System is approximately $50,000 per year. This indicates the costs of the installation will be recovered in approximately 3 years, depending on the final installation costs.

Table Brandycamp-16. Summary of Costs (decreases and increases) Associated with the Brandy Camp Pre-Aeration Tank Unit.

Item	Without Pre-Aeration	With Pre-Aeration	Cost ($/yr)
Hydrated Lime (tons/day)	2.4	1.9	-$52,000
Sludge Production (gal/day)	38,500	22,500	*-$15,000*
Electricity (kwH/day)	0	540	+$15,800
Change in Operating Cost			**-$51,200**

Summary

The Brandycamp Aeration study provided conclusive results as to the effectiveness of aeration to remove carbon dioxide acidity and decrease the required lime dose at the Brandycamp AMD treatment system. With the aeration provided, the lime dose decreased by greater than 50% and produced a ferric iron oxide (orange solid) versus ferrous hydroxide (green rust) due to the improved dissolved oxygen concentration and ferrous iron oxidation associated with the aeration. Based on the performance of the existing system the lower lime dose would also produce less calcium carbonate (calcite) precipitation with anticipated solids reduction at the facility approaching 50% by weight. Effluent alkalinity with pre-aeration (between 25 and 70 mg/L) is not expected to change substantially from existing effluent alkalinity (approximately 25 mg/L) because of the nucleation and precipitation of calcite at the high operating pH (>9) in the existing system. The aeration system costs have been estimated for two alternatives, steel tank installation adjacent to the existing channel and concrete tank within the existing channel, which are $140,500 and $234,500, respectively. At the average annual flow of 1,000 gpm (2006 average annual flow), the lime dose cost savings would be approximately $52,000 per year and the sludge volume savings (from dredging pond) would be approximately $15,000. The added electricity costs associated with aeration would be approximately $15,800 per year, which equates to a net operating savings of $51,000 per year. This indicates the capital costs of the project would be recovered in 2 to 5 years depending on the aeration system selected for installation. This indicates a pre-aeration system would be a reasonable retrofit to the Brandycamp treatment System that would lower overall operation costs and potentially increase the volume of AMD the system is capable of treating.

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