Passive, Periodic Flushing Technology for Mine Drainage Treatment Systems[1]

by

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Abstract. Investigators have recently identified issues that need to be addressed for the evaluation, improvement, and ultimate success of passive Abandoned Mine Drainage (AMD) treatment systems. One of the major issues identified is the plugging of Anoxic Limestone Drains (ALDs) and Vertical Flow Reactors (also known as Successive Alkalinity Producing Systems) with aluminum precipitates. A modified Vertical Flow Reactor design has been recently developed that maintains its treatment effectiveness by the manual flushing of aluminum precipitates out of the bed using the head provided by pooled water in the system. This design shows potential for maintaining the hydraulic conductivity and treatment performance of passive treatment systems. However, a drawback to the design is that it requires manual effort to open the valve and operational judgment to determine the appropriate length of the flush. The incorporation of a passive, periodic flushing mechanism in AMD treatment systems is described here to address this drawback and potentially improve the performance of passive treatment systems through increased frequency of flushing events. Passive, periodic flushing mechanisms called automatic dosing siphons are a common method used to flush wastes in animal barns. Automatic dosing siphons operate in two distinct phases, a fill phase and a drain phase. This type of automatic flushing mechanism has been applied to three different types of passive AMD treatment systems, including an open limestone bed, a Vertical Flow Reactor, and an ALD. These passive, periodic flushing treatment systems operate based on the same treatment principles as standard systems. However, because they operate in continual fill and drain cycles they have different liquid-solid contacting patterns and reactor types. The contacting pattern of passive, periodic flushing treatment systems combines both plug flow and batch treatment modes. A description of this technology along with design parameters is presented.

Additional Keywords: AMD, passive treatment, dosing siphon, flushing, aluminum

Introduction

Abandoned mine drainage (AMD) continues to be one of the greatest environmental problems in the US impacting over 14,000 km of US streams and rivers (EPA, 2000). AMD is formed when sulfide minerals are oxidized in the presence of oxygen and water (Skousen, 1995). The result is a highly acidic, high sulfate drainage that is often contaminated with dissolved iron, aluminum, and manganese (Hedin, Nairn, & Kleinmann, 1994). AMD formation can occur wherever sulfide minerals are exposed to oxidizing conditions. In the coal bearing regions of the US, pyrite and marcasite (FeS_2) are common metal sulfides that result in AMD (Skousen, 1995). Metal contaminant and acidity levels in AMD depend on the type and amount of sulfides present and the surrounding geology (Skousen, et al., 1998). However, AMD is often found to have pH less than 3.5, acidity greater than 500 mg/L as $CaCO_3$, and dissolved metals concentrations greater than 50 mg/L (Ziemkiewicz, et al., 1997).

AMD can be remediated by the addition of alkaline chemicals. Use of alkaline chemicals to raise the pH and neutralize acidity creates an environment where metal contaminants precipitate out of solution.

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Five chemicals are widely used to actively treat AMD: calcium carbonate, calcium hydroxide, sodium carbonate, sodium hydroxide, and anhydrous ammonia (Phipps, et al., 1995). The choice of a chemical for a specific situation is based upon technical factors such as acidity, flow rate, type and concentration of metal contaminants, rate and degree of treatment required, desired effluent quality, and the following economic factors: chemical price; labor rate; machinery and equipment costs; required length of treatment; sludge removal and disposal cost; and interest rate (Phipps, et al., 1995; Skousen, et al., 1998). Annual costs for chemical addition can be extremely high. Treatment costs for even moderately acidic AMD with a flow of 189 L/min and an acidity of 100 mg/L as $CaCO_3$ reported to be in the range of $11,525 to $22,344 per year in 1996 dollars (Skousen, et al., 1998).

High costs of active treatment represent a long-term liability that also limits its application in treating AMD from abandoned mine sites. Because of the drawbacks to active treatment, there has been interest in passive treatment systems that do not require continual chemical addition and have low maintenance requirements. In the last 15 years there has been considerable effort spent on developing passive systems for AMD treatment (Hedin, Nairn, & Kleinmann, 1994; Hedin, Watzlaf, & Nairn, 1994; Skousen, et al., 1992; Skousen, et al., 1998). These passive treatment technologies for the remediation of AMD have been developed to take advantage of naturally occurring chemical and biological processes (Hedin, Nairn, & Kleinmann, 1994; Skousen, et al., 1998). The objective of passive treatment is to enhance natural remediation processes within the treatment system and not in the receiving waters. The two factors determining treatment effectiveness are the kinetics of the contaminant removal processes and the hydraulic retention time of AMD within the treatment system (Hedin, Nairn, & Kleinmann, 1994).

Passive AMD treatment technologies include constructed wetlands, anoxic limestone drains, Vertical Flow Reactors or Successive Alkalinity Producing Systems (SAPS), limestone ponds, and open limestone channels (Skousen, et al., 1998). Constructed wetland passive treatment systems are generally built as either aerobic wetland systems or anaerobic wetland systems. Aerobic constructed wetlands are relatively shallow (<30 cm) basins planted with wetland vegetation in impermeable substrates comprised of soil, clay, or minespoil. Aerobic wetlands are designed to provide high hydraulic residence time and aeration to promote metal oxidation and hydrolysis and subsequent metal precipitation and settling. Anaerobic constructed wetlands are relatively deep (>30 cm) basins planted with wetland vegetation in permeable substrates of soil, peat moss, sawdust, or other organic materials, which are typically mixed with limestone. Anaerobic wetlands are designed with a horizontal water flow path and generate alkalinity through limestone dissolution and bacterial sulfate reduction. Also, the water surface of anaerobic wetlands provides aeration for metal oxidation and precipitation and the organic substrate provides sites for metal exchange and complexation reactions (Skousen, et al., 1998).

Anoxic limestone drains (ALDs) are buried limestone trenches or beds that are designed to add alkalinity and raise the pH of AMD. ALDs were initially developed and described by the Tennessee Valley Authority and the Tennessee Division of Water Pollution Control in the late 1980s and early 1990s (Skousen, 1991; Turner & McCoy, 1990). AMD that is anoxic and has dissolved iron that is only in the ferrous form (Fe^{2+}) is treated in an ALD by the dissolution of limestone, which adds alkalinity and raises the pH. Because ferrous hydroxides do not precipitate under anoxic conditions at pH<8, the surface of the limestone does not become coated with iron precipitates. ALDs are designed to add alkalinity exclusively and they are not intended to promote metal oxidation, precipitation, and settling. ALDs can be subject to clogging if ferric iron or aluminum is present in the AMD. Dissolved ferric iron or aluminum will form metal hydroxides when they come in contact with limestone, even under anoxic conditions (Hedin, Nairn, & Kleinmann, 1994). Formation of iron hydroxides will coat limestone surfaces and aluminum precipitate formation may clog the bed pore spaces. Clogging or coating of ALDs with metal precipitates affects both the operational lifespan and treatment performance of the ALD (Hedin, Nairn, & Kleinmann, 1994; Skousen, et al., 1998). Water discharged from ALDs is often followed by a pond and/or aerobic constructed wetland for metals oxidation, precipitation, and settling.

Vertical Flow Reactors (VFRs) are a passive treatment constructed wetland in which AMD is directed downward through a layer of organic matter, then through a bed of limestone, and out a bottom drainage system. VFRs are often referred to as Successive Alkalinity Producing Systems (SAPS) or Alkalinity Producing Systems (APS). VFRs minimize some of the limitations of the ALD by using the organic layer to remove oxygen and reduce ferric iron to ferrous iron. Alkalinity is produced in a VFR through sulfate reduction in the organic layer and limestone dissolution in the limestone bed (Faulkner & Skousen, 1995). Typically 0.3–3 m of water is ponded over a 0.1–1.0 m deep organic layer, which covers

0.5–1.5 m of limestone and the underdrain system. Metal oxidation and precipitation is avoided in a vertical flow system so that the limestone does not become coated and the organic layer and limestone bed do not become plugged. Similar to ALDs, VFRs are often followed by ponds and/or aerobic constructed wetlands for metals oxidation, precipitation, and settling (Skousen, et al., 1998).

Limestone ponds are open water limestone pond structures which treat AMD by the dissolution of limestone to add alkalinity and raise pH. AMD is typically introduced into the limestone pond at the bottom of the pond structure and is forced to flow upward through the limestone bed and out a high-level discharge point. Limestone ponds have been used to treat AMD seeps and underground discharges. Limestone ponds typically provide 1–2 days of hydraulic retention and have a 1–3 m deep clear zone of water over 0.3–1.0 m of limestone. Limestone ponds are recommended for AMD with no ferric iron or aluminum. A major advantage of limestone ponds is the ability to visually observe the formation of metal precipitates in the pond to determine maintenance requirements (Faulkner & Skousen, 1995; Skousen, et al., 1998).

Open limestone channels are open trenches lined with limestone designed to add alkalinity to AMD through the dissolution of limestone. Although open limestone channels typically become coated with metal precipitates, they continue to provide treatment through limestone dissolution at decreased rates (Ziemkiewicz, et al., 1997). Design of open limestone channels focuses on the length and slope of the channel. Increased channel slope provides higher velocities and increased turbulence that helps to prevent the coating of limestone by metal precipitates (Faulkner & Skousen, 1995; Skousen, et al., 1998).

Recently Skousen, et al. (1998) identified issues that need to be addressed for the evaluation, improvement, and ultimate success of passive AMD treatment systems. One of the major issues identified is the plugging of ALDs and SAPS with aluminum precipitates. Kepler and McCleary (1997) have also identified the plugging of ALDs and SAPS with aluminum precipitates as a serious concern for the success of passive AMD treatment systems. Watzlaf, et al., (1994) has documented the drop in permeability through an ALD when aluminum precipitates form in the pore spaces of an ALD. Flow through the Jennings Environmental Center ALD dropped from 94% to 10% of the total AMD flow over a four-month period. This reduction in permeability corresponded with increased aluminum retention in the ALD. Partial excavation of this ALD revealed gelatinous aluminum hydroxide deposits within the ALD (Watzlaf, et al., 1994).

Kepler and McCleary (1997) have developed a modified SAPS, the Aluminator©, which includes the ability to periodically flush and remove aluminum deposits. The Aluminator© introduces AMD onto the surface of the SAPS and directs it downward through the treatment column of a clear zone of pooled water (0.5–2.0 m) above an organic compost layer (0.1–0.3 m) above a bed of limestone (0.5–1.3 m) (Figure 1). The organic layer serves the purpose of removing oxygen and reducing ferric iron to ferrous iron. The limestone layer increases the pH, adds alkalinity, and retains aluminum. This modified SAPS design maintains treatment effectiveness by manual flushing of aluminum precipitates out of the bed using the head provided by the pooled water. Manual flushing is accomplished over a period of a few hours by utilizing a control valve on the underdrain piping system (Kepler and McCleary, 1997).

Aluminators© show potential for maintaining the hydraulic conductivity and treatment performance of passive treatment systems. Greater than 80% of collected aluminum can be removed from the system in a single flushing event (Kepler and McCleary, 1997). However, manual flushing requires a few hours to complete. The incorporation of a passive, periodic flushing mechanism would address this drawback and potentially improve the performance of SAPS through increased frequency of flushing events.

Technology Description

Passive, periodic flushing mechanisms called automatic dosing siphons are a common method used to flush wastes in animal barns. Other methods of flushing animal wastes in barns include tipping buckets and gated flush tanks (Mensch, 1985; NRCS, 1996; Overcash, et al., 1983). Minimum frequency for flushing waste collection channels is twice per day, but can range up to 48 times per day. Design of flushing channels and systems for animal barns is well developed and considers channel length, width, slope, flushing water depth, total required daily flushing water volume, flushing frequency, flushing duration, and flushing discharge rates (Mensch, 1985; NRCS, 1996; Overcash, et al., 1983).

An automatic dosing siphon is comprised of a reservoir tank containing a bell compartment which is hydraulically connected to the liquid in the reservoir tank (Hazen, 1974). An open vertical pipe underneath the bell compartment has a small opening for constantly supplying liquid to the trap element.

Improvements and changes to the design of dosing siphons have been made over the years (Hazen, 1975; George, 1981; Patterson, 1999). Dosing siphon technology has also been applied to the distribution of septic tank effluent (Ball, 1984). A schematic of a commercial automatic dosing siphon is shown in Figure 2.

Automatic dosing siphons operate in two distinct phases, a fill phase and a drain phase (Figure 3). During the fill phase the reservoir tank is filled with liquid and the liquid level in the tank and under the bell compartment rise at the same rate (1). When the water level in the tank covers the bell compartment air-vent piping, an air seal is created between the liquid level in the bell and the liquid level in the trap (2). The liquid level in the tank continues to rise, which compresses the air trapped between the bell and trap water levels. The liquid level in the bell compartment rises much slower because of the air pressure created. The air pressure forces the water level in the trap downward towards the invert of the trap (3). As the liquid continues to rise to the high water level, the water in the bell compartment approaches the top of the vertical pipe and air pressure forces the water level in the trap to the trap invert (4). The siphon triggers as a bubble of air is forced around the trap invert through the discharge end of the pipe. The escaped air releases the pressure within the bell compartment, and liquid fills the vertical pipe starting the siphon and beginning the draining of the reservoir tank (5). The drain phase begins as the siphon is activated and liquid drains out of the reservoir tank through the vertical pipe and trap (6). The liquid continues to drain from the tank until the liquid level reaches the bottom of the bell compartment. Once the liquid level reaches the bottom of the bell compartment the siphon stops as air is drawn into the bell (1). The cycle then begins again as the liquid level in the reservoir begins to rise (Fluid Dynamic Siphons, Inc., 1990; Parker, et al., 1976).

Passive, Periodic Flushing of Vertical Flow Wetlands

Automatic, periodic flushing mechanisms can be applied to passive AMD treatment systems. The modified SAPS system described by Kepler and McCleary (1997) can directly employ this type of passive, periodic flushing to remove aluminum deposits from the limestone bed and maintain system permeability. The design of a modified SAPS or VFR, including the passive, periodic flushing technology is very similar to a standard design. AMD is introduced onto the surface of a clear zone of pooled water (0.3–3.0 m) over an organic layer (0.1–0.3 m), over a limestone bed (0.5–1.3 m) and underdrain system. The underdrain system is connected to a sump that contains the automatic dosing siphon. The elevation of the low water level of the dosing siphon is set to approximately 0.1–1.0 m above the organic layer. This depth must be adequate to provide a minimum positive water head for adequate flow through the organic layer. Additional pooled water also ensures that the organic layer and limestone bed are not exposed to air. The berms encompassing the VFR must be designed to accommodate the high water level of the siphon (Figure 4).

The passive, periodic flushing VFR is based on the same treatment principles as a standard VFR. The organic layer removes oxygen from the AMD and creates a reducing environment to reduce ferric iron to ferrous iron. The limestone bed is intended to increase the pH, add alkalinity, and retain aluminum precipitates. However, a primary difference between a standard SAPS, Aluminator©, and the passive, periodic flushing VFR is its liquid-solid contacting pattern or reactor type. Both SAPS and Aluminator© systems are steady state plug flow. AMD passes through the treatment matrix with a flat velocity profile with progressive treatment along a longitudinal axis. In the passive, periodic flushing VFR, the reactor characteristics are more complex. AMD enters the system after a flushing and begins to pool on top of the organic layer. The level of AMD over the organic layer rises until it reaches the high water level of the automatic dosing siphon. The dosing siphon triggers and the AMD pooled over the organic layer flows downward through the organic layer and into the limestone bed. AMD that had previously been in the limestone bed is flushed from the system carrying with it aluminum precipitates collected in bed pore spaces. The automatic dosing siphon stops siphoning as the water level drops to the siphon low water level. AMD that had been pooled over the organic layer then resides in the organic layer and limestone bed for treatment during the next entire fill cycle. This contacting pattern combines both plug flow and batch treatment modes. During the siphon's drain cycle, AMD flows vertically through the organic layer and the limestone bed, and approximates plug flow operation. However, because the flow through the siphon is dependent upon the head pressure, the flow at the beginning of a drain cycle is greater than at the end of a drain cycle. This results in a time dependent velocity profile with higher velocities at the beginning of a cycle than at the end. However, the majority of time the passive, periodic flushing VFR operates in batch mode with AMD in static contact with the organic layer and limestone. It should be noted that the bulk liquid (AMD) is not actively mixed and may not have a uniform composition throughout. This deviates from an ideal batch reactor characterized by being well mixed and having a uniform composition (Levenspiel, 1972; Levenspiel, 1996).

Passive, Periodic Flushing of Limestone Ponds

Another application of automatic dosing siphon technology for passive AMD treatment is in limestone ponds treating AMD with little or no dissolved iron and high dissolved aluminum levels. AMD with high dissolved aluminum and low dissolved iron may be considered for treatment in limestone ponds because the coating of limestone with iron precipitates is not a major concern. However, reduced permeability of the system due to plugging of the limestone matrix with aluminum precipitates is a concern. Employing passive, periodic flushing mechanisms in limestone ponds may help remove aluminum precipitates from the limestone bed and maintain system permeability. The design of a modified limestone pond including passive, periodic flushing technology is different from standard limestone ponds described by Faulkner and Skousen (1995) or limestone leach beds described by Black, et al. (1999). In this modified limestone pond design, AMD is introduced into the limestone pond structure where it collects in a bed of limestone (typically >1.0 m) which covers an underdrain system. The underdrain system is connected to a sump containing an automatic dosing siphon. In a fully draining system the low water level of the siphon is set to just at or below the elevation of the underdrain system and the high level of the siphon is set to just cover the limestone bed. In a partially draining system the low water level of the siphon is set to an elevation within the limestone bed and the high level of the siphon is set to just cover the limestone bed (Figure 5).

The passive, periodic flushing limestone pond is based on the same treatment principles as standard limestone ponds or limestone leach beds. The limestone bed is intended to increase the pH and add alkalinity to the AMD being treated. The modified limestone pond also retains aluminum precipitates during a siphon fill cycle and flushes them during a siphon drain cycle. The liquid-solid contacting pattern or reactor type is similar to that previously described for a passive, periodic flushing VFR, employing both plug flow and batch modes. AMD enters the limestone pond after a flushing and begins to fill the limestone bed pore spaces. The level of AMD in the limestone bed rises until it reaches the high water level of the automatic dosing siphon. The dosing siphon then triggers and the AMD in the limestone bed flows downward through the limestone and out the underdrain system, carrying with it metal precipitates collected in the bed pore spaces. The automatic dosing siphon stops siphoning when the water has drained from the limestone bed and reaches the siphon low water level. The majority of the time AMD is treated in a batch mode with AMD in static contact with limestone. However, during a drain cycle AMD flows vertically through the limestone, approximating plug flow operation.

Passive, Periodic Flushing of Anoxic Limestone Drains

It may be feasible to utilize automatic dosing siphon technology for passive AMD treatment in ALDs. ALDs are typically limited to treating AMD with little or no ferric iron, dissolved oxygen, and aluminum. Use of ALDs for AMD treatment with high aluminum is typically not considered due to the collection of aluminum in the pore spaces of the limestone bed resulting in reduced permeability of the system. Employing passive, periodic flushing mechanisms in ALDs may help remove aluminum precipitates from the limestone bed and maintain system permeability. The design of a modified ALD including passive, periodic flushing technology is more complex than standard ALDs. One design option incorporates a layer of porous sandstone (typically 0.3–1.0 m), above a thin layer of compost material (typically 0.1–0.5 m), above the limestone bed (typically >1.0 m). In this modified ALD design, AMD in an anoxic or oxygen deficient condition is collected in the stone filled area with an underdrain system. The compost material may serve two functions: removing the remaining oxygen from the AMD; and/or adding carbon dioxide during the decomposition process. The addition of carbon dioxide may increase the dissolution rate of the limestone. The underdrain system is connected to a sump containing an automatic dosing siphon. The low water level of the siphon is set above the top elevation of compost layer and the high level of the siphon is set to the top of the sandstone layer (Figure 6).

The passive, periodic flushing ALD operates based on similar treatment principles as standard ALDs with some important exceptions. The limestone bed is intended to increase the pH and add alkalinity. The modified ALD retains aluminum precipitates during a siphon fill cycle and flushes them during a siphon drain cycle. The liquid-solid contacting pattern is similar to that previously described for a passive, periodic flushing VFR, employing both plug flow and batch modes. AMD enters the sandstone bed after a drain cycle and begins to fill the sandstone bed pore spaces. The level of AMD in the sandstone bed rises until it reaches the high water level of the automatic dosing siphon. The dosing siphon then triggers and the AMD in the sandstone bed flows downward through the compost layer, to the limestone bed, and out the underdrain system, carrying with it metal precipitates collected in the bed pore spaces. The automatic dosing siphon stops siphoning when the water reaches the siphon low water level above the compost layer. The majority of the time AMD is treated in a batch mode with AMD in static contact with limestone. However, during a drain cycle AMD flows vertically through the limestone, approximating plug flow operation.

The designer must consider what may fill the void spaces in the sandstone during a drain cycle. In the case of an underground mine source, oxygen deficient gas, AMD under hydraulic pressure, or oxygen rich air from the surface or the underground mine may enter the void spaces. It may also be possible for a vacuum to be created which may cause the siphon to lose its air seal. The optimum condition is for oxygen deficient gas to enter the void spaces. The material expected to enter the void spaces may determine feasibility of utilizing a passive, periodic flushing ALD verses a passive, periodic flushing VFR.

Design Factors

Incorporation of automatic dosing siphons for passive, periodic flushing VFRs, limestone ponds, and ALDs requires consideration of new design parameters not previously taken into account in passive AMD treatment system design. Specifically, the use of automatic dosing siphons requires the consideration of high and low water levels within the system, the differential between the high and low water levels, the siphon discharge rate at the beginning of a drain cycle, the siphon discharge rate at the end of a drain cycle, the average siphon discharge rate, diameter of the siphon piping, and siphon housing and installation. Also, because the modified designs result in a change in reactor contacting pattern from steady state plug flow to plug flow combined with batch treatment, some of the established design parameters for passive AMD treatment must be re-evaluated to ensure proper system operation.

The passive, periodic flushing VFR design sets both the high and low water levels in the clear zone of pooled water on top of the organic layer. However, the specification of the elevation of the low water level is very important. The low water level must be set far enough above the level of the organic layer to ensure that adequate water head is available to provide flow through the organic layer at the end of a drain cycle. If flow through the organic layer is restricted, then any water differential between the level in the siphon sump and the SAPS system will increase, causing the siphon to break prematurely. A water level differential will exist due to head losses in the organic layer, limestone bed, and underdrain system, but this should be minimal. Providing a water depth to organic layer depth ratio of at least 2:1 should allow flow through the end of a drain cycle.

In addition, the flow through the organic layer in a VFR utilizing a dosing siphon should account for the increased flow at the beginning of a drain cycle. At the beginning of a drain cycle pooled water that had been over the organic layer will flow through the organic layer at a high flow rate. A designer must account for this high flow rate and specify the thickness of the organic layer so that there is adequate hydraulic retention time in this layer for removal of oxygen and reduction of ferric iron to ferrous iron.

Another design consideration is redistribution of the flush flow from the siphon to the rest of the passive treatment system. Most pond and wetland system design criteria are based on some combination of retention time, loading rates, and surface area. Flows during a flush cycle are typically 10 times or more the average flow rate of the seepage flow to the system. Therefore, in order to meet design criteria based on retention time or surface area, it may be necessary to redistribute the flow. This can be accomplished using a retention pond. The retention pond should be capable of capturing the entire flush volume and discharging at a rate approximately equal to the seepage rate into the system. This results in a more even flow through the system of ponds and/or wetlands following the redistribution pond.

Hubler Run Field Application

Hubler Run is a tributary of Alder Run, and subsequently the West Branch of the Susquehanna River in Clearfield County, Pennsylvania. Hubler Run is impacted by diffuse AMD seeps emanating from a mine spoil pile. The area adjacent to Hubler Run had been surface mined in the 1960's, reclaimed, and planted with conifers. However, the AMD impacting Hubler Run has degraded its water quality and also contributes to the larger AMD problem in Alder Run. The seeps are divided into two distinct discharges with various seeps creating a marsh area that drains directly into Hubler Run and various seeps collecting into an unnamed tributary that drains into Hubler Run. The marsh seeps have an average combined flow rate of 70 liters per minute with an acidity of 115.2 mg/L, a dissolved iron content of less than 1 mg/L, a dissolved aluminum content of 17.0 mg/L, and a dissolved manganese content of 14.3 mg/L. The unnamed tributary has an average flow of 66 liters per minute with an acidity of 78.5 mg/L, a dissolved iron content of 2.3 mg/L, a dissolved aluminum content of 6.0 mg/L, and a dissolved manganese content of 15.4 mg/L. These AMD discharges and another set of acidic drainages, have degraded Hubler Run to the point where it has an average pH of 3.7, an acidity of 71.2 mg/L, a dissolved iron content of 3.3 mg/L, a dissolved aluminum content of 11.5 mg/L, and a dissolved manganese content of 11.8 mg/L.

This project incorporates passive, periodic flushing technology to maintain the hydraulic conductivity and treatment performance of an open limestone pond system. The treatment system directs both the marsh seeps and the unnamed tributary to independent open limestone cells for alkalinity addition. The limestone cell for the marsh seeps is a 25-year design limestone channel that contains 790 tons of limestone in a 3-foot deep bed. The limestone cell for the unnamed tributary is a 25-year design limestone pond that contains 765 tons of limestone in a 3 foot deep bed. Each limestone cell contains an automatic dosing siphon (Fluid Dynamic Siphons Model 836, Steamboat Springs, CO, USA) within a manhole. Each manhole and dosing siphon is hydraulically connected to its limestone cell by a network of underdrain piping. The system operates in fill and drain cycles: AMD enters the limestone cell and fills up the channel or pond until it reaches a water level where the dosing siphon activates and a siphon is started, draining AMD through the underdrain and siphon and into the wetland cells. The estimated fill times are 42 and 46 hours for the marsh seep channel and unnamed tributary pond, respectively. The estimated drain times are 51 and 50 minutes, respectively. Two wetland cells in series receive AMD from the limestone cells. These wetland cells are designed for settling of precipitated metals. The first wetland cell also acts as a redistribution pond. The second wetland discharges the treated water back into Hubler Run.

Cold Stream Chiller Seeps Field Application

The Cold Stream watershed is located south of the Borough of Philipsburg, Centre County, Pennsylvania. Cold Stream lies within the Moshannon Creek watershed and is listed as impaired by the Pennsylvania Department of Environmental Protection as a result of acid mine drainage which enters Cold Stream. The lower half of the watershed lies within the bituminous coalfields. From the early 1900's, the area was both surface and deep mined for coal. The upper half of the watershed is a high quality cold water fishery.

A significant source of pollution to the Cold Stream Watershed, the Chiller Seep, flows at an average rate of 230 liters per minute with average metal concentrations of 13 mg/L iron and 39 mg/L aluminum. A passive treatment system design was completed for the Chiller Seep using a modified Vertical Flow Reactor (VFR). The VFR passes water through a layer of compost to strip oxygen from the water followed by contact with limestone to impart alkalinity. The net alkaline water is then routed through pond and wetland cells for precipitation of metals.

A 25-year design time required approximately 2,500 metric tons of limestone. An automatic dosing siphon passively flushes aluminum through the voids in the limestone. The dosing siphon will take approximately a day to complete a fill cycle and approximately one hour to complete a flush cycle. The dosing siphon is placed in a manhole which is hydraulically connected to the limestone channel by a piping network. The discharge from the siphon enters a series of two ponds and two wetlands for metals precipitation. The first pond also serves to redistribute and equalize flows to the second pond and the wetlands using an in-line control structure. The pond is designed similar to a retention basin with a capacity to completely retain the flush volume. Holes are placed in the weir boards which allow the flush volume to discharge to the second pond at approximately the average of the seep flow. An aeration drop is also provided between the cells. The water level in the wetlands can be controlled using in-line control structures. The wetland cell water levels can be adjusted in response to buildup of sediment and/or metal accumulation. System installation began in the fall of 2000 with work scheduled for completion in the spring of 2001.

Indian Creek Sagamore #2 Field Application

A seep from the Sagamore #2 underground mine air shaft drains to Indian Creek in Fayette County, Pennsylvania. The Sagamore #2 seep is one of numerous seepage locations identified and sampled as part of the overall Indian Creek watershed restoration efforts. The original conceptual design combined the marginally acidic Sagamore #2 seep with the net alkaline Sagamore #1 seep. During the sampling period of May 1998, to June 1999, the average Sagamore #2 seep discharge quality was approximately 20 liters per minute, 16.6 mg/L acidity, 1.6 mg/L iron, and 1.1 mg/L aluminum. Starting in August of 1999, the acidity, iron, and aluminum increased to levels resulting in net acid water if Sagamore #1 is combined with Sagamore #2 seep. Therefore, a treatment system was devised to increase alkalinity of the Sagamore #2 discharge prior to combining with Sagamore #1.

The general concept used a modified ALD to capture water from Sagamore #2 and add alkalinity to the water through limestone dissolution (Figure 6). One challenge was to flush aluminum from the voids in the limestone. Water is introduced into a layer of porous sandstone approximately 0.5 m thick. The porous sandstone was used for multiple reasons. Some oxygen may enter the system during the flush cycle. If limestone is used, it is likely that it would coat with iron. In addition, sandstone was approximately ½ the cost of the limestone in this geographic location. A layer of straw bales was placed at the sandstone limestone interface in an attempt to strip oxygen (if present) and encourage carbon dioxide production. It is hoped that the presence of carbon dioxide may increase alkalinity production rates. The limestone thickness used in this application was approximately 1.2 m. An automatic dosing siphon was included to passively flush aluminum from the ALD. The water fluctuation zone was designed entirely within the sandstone layer. Water exiting the dosing siphon was then routed to the existing wetland cells to be combined with the alkaline discharge from Sagamore #1 for precipitation of metals. Additional aeration was provided at the wetland cells by windmill driven aerators at the pipe discharge location from Sagamore #2 and at the entrance to the second wetland cell.

This treatment technique was designed as an experimental system. In the event oxygen is introduced to the ALD and iron coating of the limestone occurs, the projected alkalinity generation should still result in a net alkaline discharge when Sagamore #2 is combined with Sagamore #1. Adequate limestone (approximately 300 metric tons) was included in the modified ALD to last 25 years at the predicted maximum alkalinity production rate. The system was constructed in the fall and winter of 2000/2001. Results from the system are expected in 2001.

Conclusions

Incorporation of passive, periodic flushing mechanisms in AMD treatment systems may enhance the success of long-term, passive AMD treatment. ALDs, VFRs, and open limestone ponds are appropriate system designs for many AMD discharges. Addressing aluminum clogging with passive, periodic flushing may result in increased system performance and longevity. Three initial field applications of passive, periodic flushing cover a broad range of AMD water quality and hydraulics. Short-term and long-term monitoring of these sites will help determine the performance of passive, periodic flushing VFRs, ALDs, and open limestone ponds.

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Figure References

Figure 1. Aluminator© Cross-section (not to scale) (Kepler and McCleary, 1997)

Figure 2. Automatic dosing siphon (Courtesy of Fluid Dynamic Siphons, Inc., Steamboat Springs, CO USA)

Figure 3. Dosing siphon operation (Courtesy of Fluid Dynamic Siphons, Inc., Steamboat Springs, CO USA)

Figure 4. Modified VFR or SAPS incorporating an automatic dosing siphon (not to scale)

Figure 5. Modified limestone pond designs incorporating an automatic dosing siphon: A. Fully draining and B. Partially draining (not to scale).

Figure 6. Modified ALD incorporating an automatic dosing siphon (not to scale)

Figure 1. Aluminator© Cross-section (not to scale) (Kepler and McCleary, 1997)

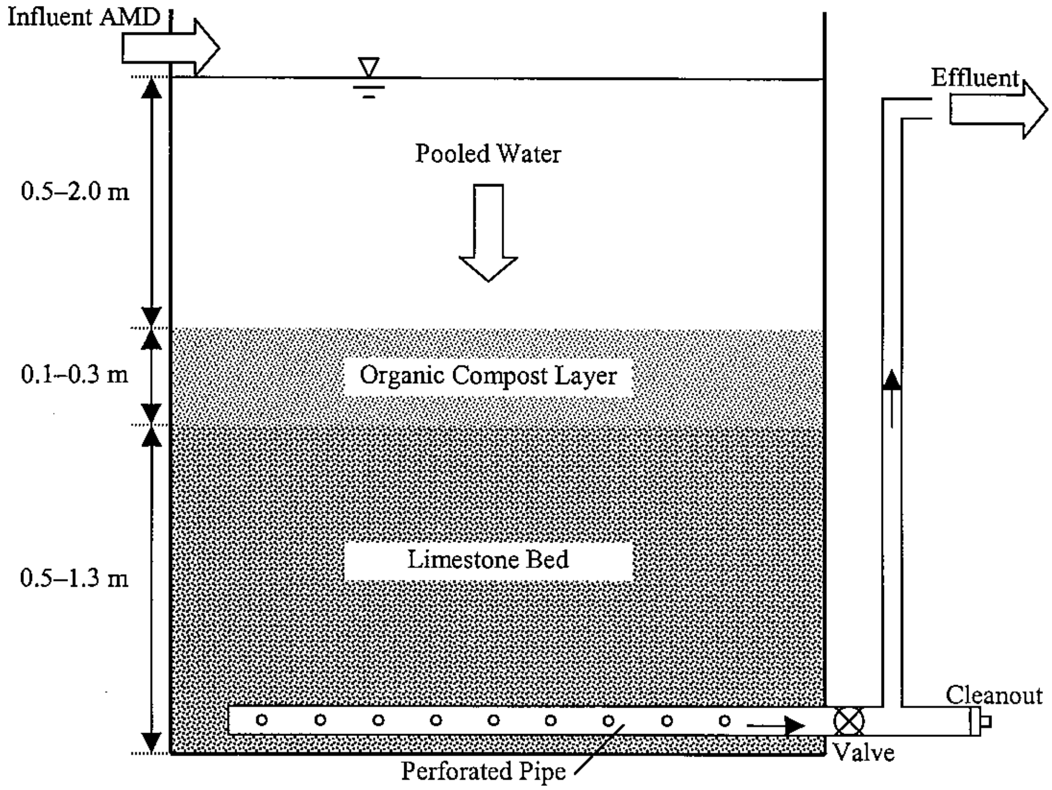


Figure 2. Automatic dosing siphon (Courtesy of Fluid Dynamic Siphons, Inc., Steamboat Springs, CO USA)

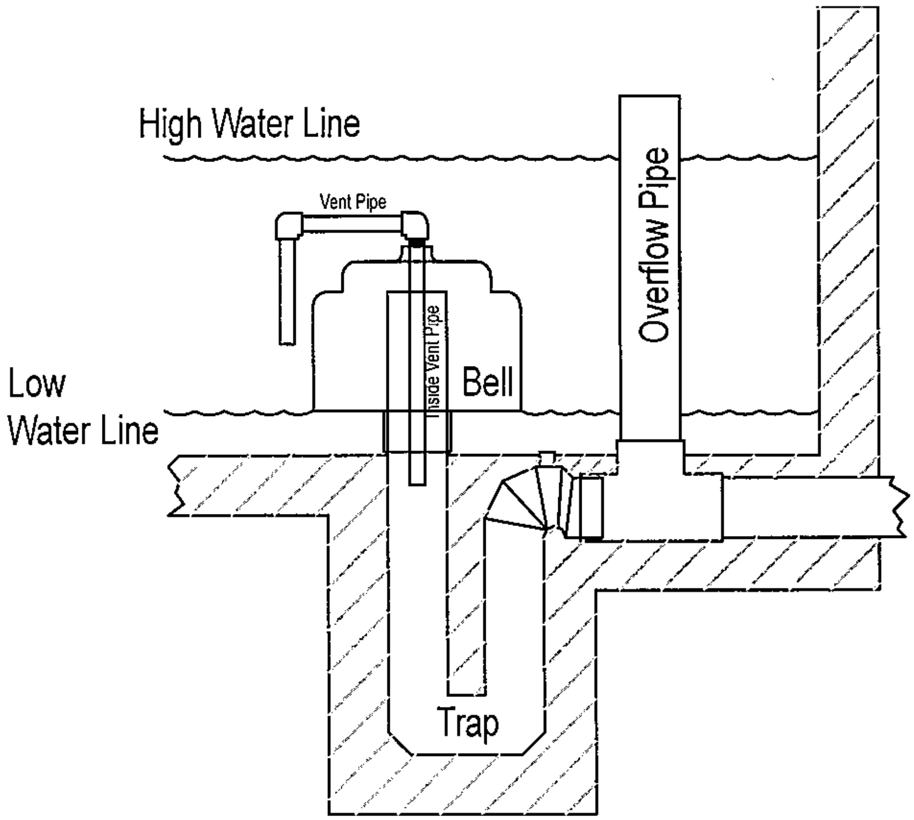


Figure 3. Dosing siphon operation (Courtesy of Fluid Dynamic Siphons, Inc., Steamboat Springs, CO USA)

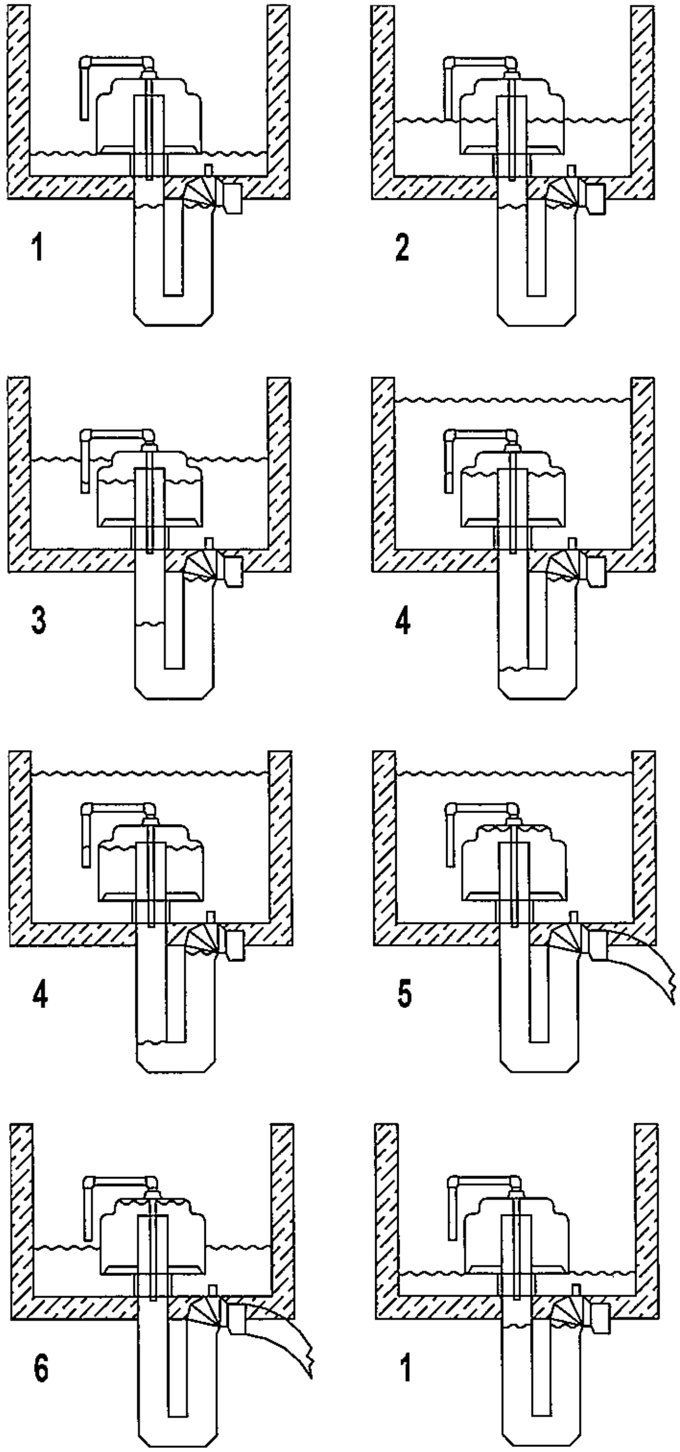


Figure 4. Modified VFR or SAPS incorporating an automatic dosing siphon (not to scale)

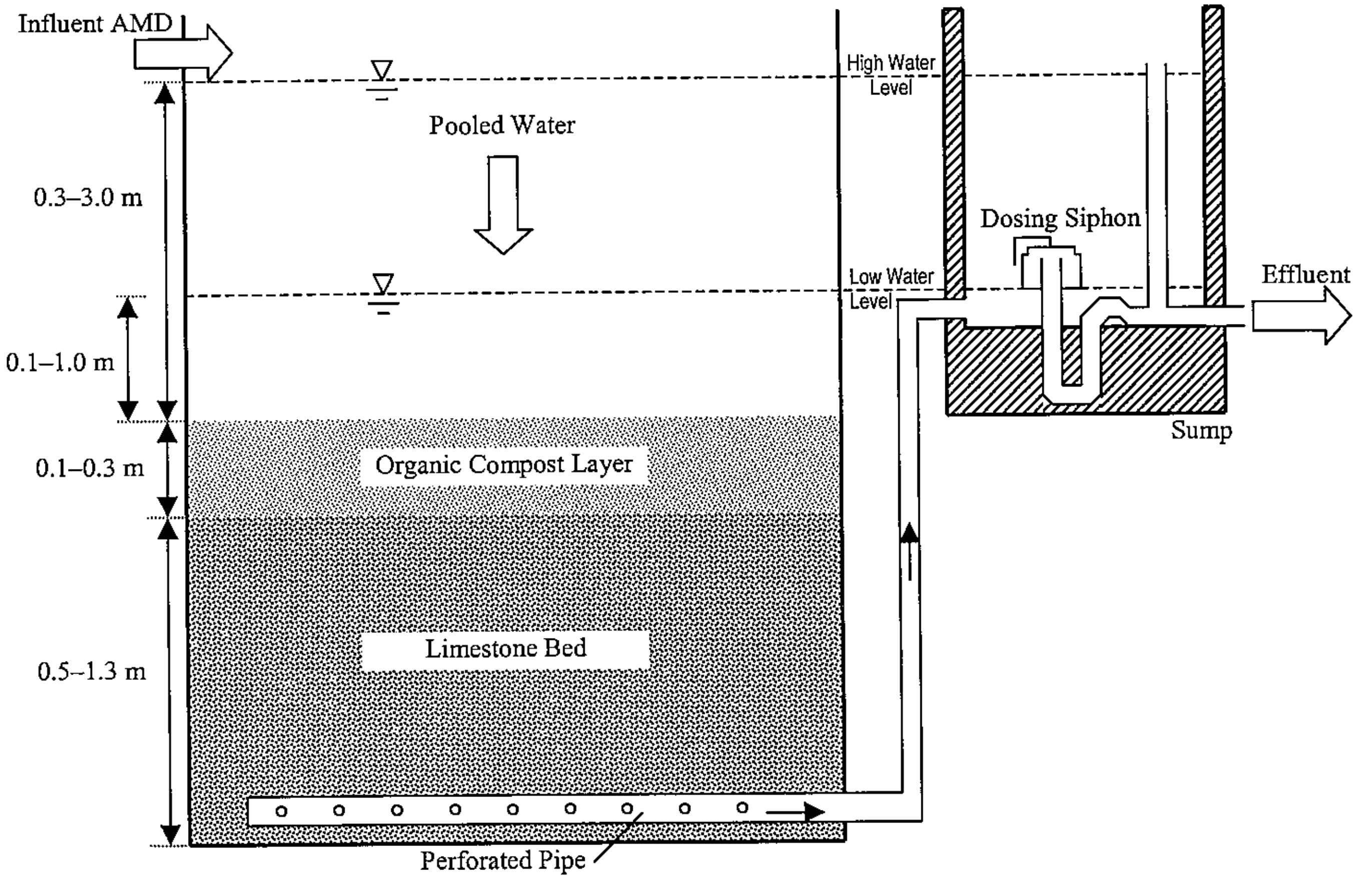
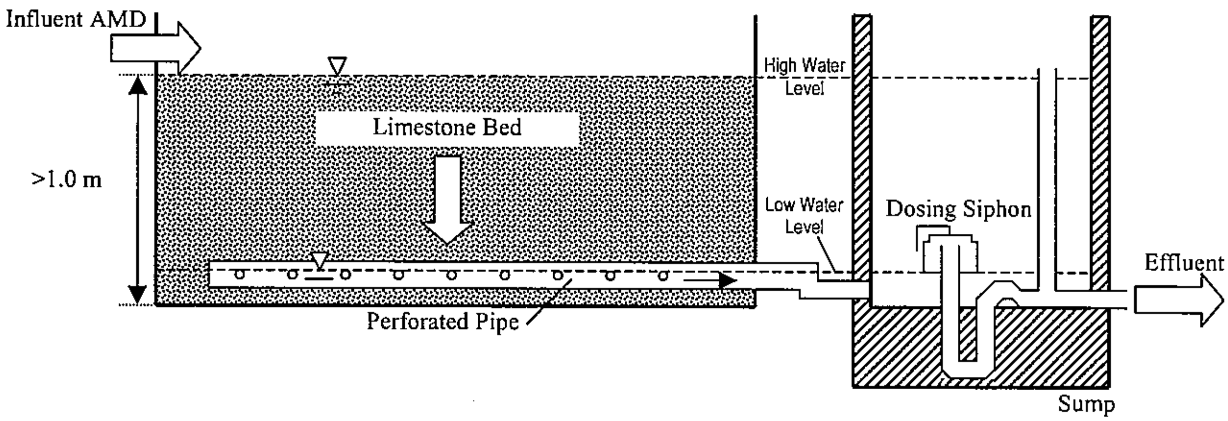


Figure 5. Modified limestone pond designs incorporating an automatic dosing siphon: A. Fully draining and B. Partially draining (not to scale).

A. Fully Draining



B. Partially Draining

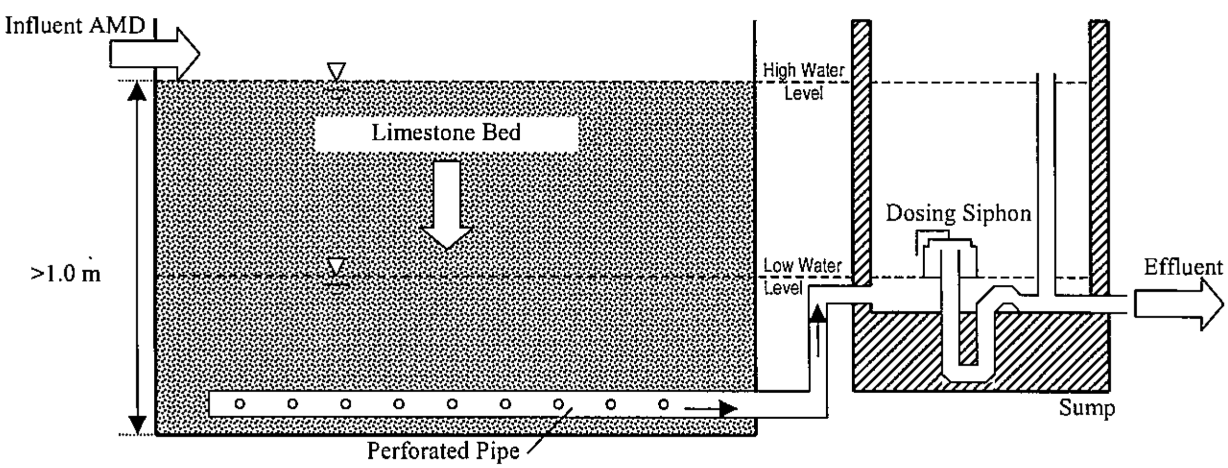


Figure 6. Modified ALD incorporating an automatic dosing siphon (not to scale)