EVALUATION OF AERATION TECHNIQUES FOR MINE WATER TREATMENT IN PASSIVE SYSTEMS[1]

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Abstract. Removal of metals from mine drainage involves a host of chemical and biological processes including oxidation and hydrolysis reactions. The rate of reactions is dependent on mine water pH, presence of bacterial catalysts, and the availability of oxygen. Oxygen availability becomes particularly important in treatment systems using aerobic processes such as settling ponds and wetlands. Although oxygen is readily available in the atmosphere, encouraging the transfer of oxygen to mine water can be a challenge. Applicability of the various methods to increase oxygen levels in mine water is dependent on mine water chemistry and the availability of treatment area, hydraulic head, and power. Innovative aeration techniques have been developed which use wind, water, and electricity as power. The suitability of techniques must be evaluated on a site-by-site basis. Wind energy has been harnessed using windmill aeration techniques at the Sagamore site in Fayette County, Pennsylvania. Water energy has been utilized through manipulation of available hydraulic head to improve aeration as demonstrated at the Kolb site in Indiana County, Pennsylvania. In cases where adequate aeration cannot be accomplished by passive methods, such as the Kempton site in Garrett County, Maryland, active mechanical aeration using electric power may be a cost-effective alternative.

Additional Key Words: abandoned mine lands, acid mine drainage, best management practices.

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Introduction

Removal of metals from mine drainage involves a host of chemical and biological processes including oxidation and hydrolysis reactions. The rate of reactions is dependent on many factors including pH, presence of bacterial catalysts, and the availability of oxygen. Oxygen availability becomes particularly important in treatment systems using aerobic processes such as settling ponds and wetlands. Oxygen is readily available in the atmosphere with the air we breathe containing about 20% oxygen. However, only about 10 milligrams per liter (mg/L) O_2 can dissolve in water (Skousen et al., 1998) and encouraging the transfer of oxygen to mine water can be a challenge.

Dissolved oxygen (DO) is the amount of gaseous oxygen (tiny, microscopic bubbles) actually present in water. Oxygen enters water through transfer of oxygen across the air-water interface or through photosynthesis of aquatic biota. Likewise, oxygen is consumed during the decomposition process as organic material decays. Natural variation of dissolved oxygen can be due to water temperature, water turbulence, periods of light and dark which control photosynthesis, other biological activity, and salinity.

Iron is the predominant metal of concern in many mine drainage discharges including the Kolb, Sagamore, and Kempton Sites. Iron oxidation can be limited by the availability of DO (Athay et al., 2001). Therefore, sufficient oxygen must be available to effectively remove iron. In well aerated components of passive treatment systems, the rate of iron removal can be increased by a factor of three or more when compared to poorly aerated components (Watzlaf et al., 2001).

Various passive methods are available to increase DO levels in treatment systems for mine water. The method selected is dependent on mine water chemistry and the availability of treatment area, hydraulic head, and electric power. In many cases, simple aeration techniques such as an energy dissipation devise are adequate. More innovative aeration techniques have been developed for sites with higher flows or greater concentrations of metals. These techniques can use the force of water pressure, differential elevation head, wind power, or electricity power.The suitability of aeration techniques must be evaluated on a site-by-site basis. Water energy has been utilized through manipulation of available hydraulic head to improve aeration as demonstrated at the Kolb Site in Indiana County, Pennsylvania. Wind energy has been harnessed using windmill aeration techniques at the Sagamore Site in Fayette County, Pennsylvania. In cases where adequate aeration cannot be accomplished by passive methods, such as the Kempton Site in Garrett County, Maryland, active mechanical aeration using electric power may be a cost-effective alternative.

Kolb Site

The Kolb Site is located in Indiana County, Pennsylvania. The Kolb Site discharge is a high flow (approximately 1,000 gallons per minute), low iron (typically less than 5 mg/L) abandoned underground mine discharge. The DO concentration at the underground mine was typically less than 1 mg/L. An elevation drop of over 40 feet existed from the mine discharge to the available treatment location.

In order to capture the underground mine discharge, a mine seal was installed with an 18-inch discharge pipe. The 18-inch pipe was fitted with a gate valve to re-route the water during operation and maintenance and allow for emergency discharge if the pipe became clogged. The 18-inch pipe was fused together with watertight connections. The pipe crossed a stream, shared a trench with a gas line, crossed a driveway, and crossed a railroad prior to entering the treatment site.

The energy available to aerate the water was provided by the elevation head from the discharge to the treatment site. At the treatment basin site, an elbow was installed which raised the discharge to approximately eight feet above the water level. Old metal screens and collars were salvaged from a coal yard dump and fabricated for use as an aeration fountain. The average DO concentrations measured near the fountain were greater than 10 mg/L. The fountain aeration created such a turbulent water flow that baffles were subsequently installed to provide a stilling area to promote iron settling. The Kolb Site has demonstrated that utilization of water power through effective manipulation of differential elevation head can provide impressive DO enhancement.

Sagamore Site

The Sagamore Site is located in Fayette County, Pennsylvania, and was the first use of a windmill aerator installed to enhance DO concentrations and improve the efficiency of a passive treatment system. The Sagamore Site treats two discharges with a combined flow rate of approximately 100 gallons per minute. The water can be characterized as net-alkaline with influent iron concentrations of 15 to 20 mg/L. The Sagamore Site was constructed in an area with little elevation drop from the collection point to the ultimate discharge elevation into Indian Creek. As a demonstration project, windmill aerators were installed to evaluate their applicability and use in passive treatment systems.

The treatment system consists of two settling basins approximately six feet in depth. A sampling program was established to measure temperature and DO concentrations with and without windmill aerator operation. The sampling plan included measurements taken at perimeter locations around the basins including the influent and effluent as well as at depths of one, three, and five feet on a grid pattern at ten locations in each basin.

The sample results revealed some interesting trends. The collection point near the larger of the two underground mine discharges typically had a DO concentration of 1 to 2 mg/L. After traveling through 800 feet of pipe, the DO increased by an average of 3 mg/L. An energy dissipater placed at the pipe discharge increased the DO by an average of an additional 1 mg/L. The initial sampling point for the smaller of the two discharges had an average DO concentration of 6 mg/L after passing through an anoxic limestone drain and flushing network. During conveyance through 600 feet of pipe, a DO increase of approximately 2 mg/L was measured. An additional ½ mg/L was added in the short elevation drop into the pond. Therefore, through passive methods, the DO was increased by approximately 3 to 4 mg/L from the discharge location to the basin entrance. In addition, the DO levels in the second basin were approximately 2 mg/L higher than the first basin which may be attributed to the elevation drop enhancement between the basins. Four of the sample sets were collected in the time frame November 21, 2002, through July 31, 2003, when the windmill aerator diffusers were inactive. Two windmills were installed with diffusers placed near the discharge end of the first basin. One sample was collected in October 2003 while the diffusers were in operation. Based on the average of all DO measurements in the basins, preliminary data results indicate that DO concentrations were 1.5 mg/L higher in the sample collected during windmill aerator operation. Additional monitoring is planned in 2004 including a sampling during a warmer water temperature period to confirm these findings. However, based on initial data collected, windmill aeration can provide positive benefits to a passive treatment system.

Kempton Site

The Kempton Site is located in Garrett County, Maryland, and includes discharges which average over 2,000 gallons per minute. The typical source water quality has a pH of 3.5, iron of 32 mg/L, aluminum of 15 mg/L, and an acidity of 400 mg/L. This translates into nearly 2,000 tons of acidity per year. Alkalinity is added using an Aquafix water wheel feeding system. Water emanating from the underground mine pool typically has a DO content of less than 1 mg/L. To complicate the treatment system design, limited space is available. Without impacting more than one acre of existing wetland, only two acres of surface area are available for the treatment system footprint. From the elevation of the existing chemical addition point to the discharge into the wetland system, less than five feet of elevation head are available for natural aeration. These constraints led to an evaluation of aeration methods using electric power.

Several types of aeration systems were evaluated for the Kempton Site. Because iron is the predominant metal in the discharge water (average concentration of 32 mg/L), the goal for the selected aeration system is to provide adequate DO to oxidize ferrous iron (Fe^{2+}) to the ferric state (Fe^{3+}) and precipitate the ferric iron as ferric hydroxide [$Fe(OH)_3$].

Aeration systems were evaluated based on power cost, equipment cost, oxygen transfer rate, air flow, suitability, and operation and maintenance. The aeration system evaluation was limited to floating (surface) aerators, fine bubble diffusers, aspiration strippers, sparging rings, and Maelstrom Oxidizer based on time and cost constraints.

Floating aeration systems consist of a series of floating, buoyant rings which support a submerged impeller driven by an electric motor. The impeller forces water upward across a circular baffle, causing the water to spray into the air. These aerators have a relatively low equipment and installation cost per unit. However, due to the number of aerators required, high maintenance costs, and high power requirements, this aeration method was not selected for the Kempton Site.

Fine bubble diffusers force air through a diffuser plate placed in the bottom of the pond with very fine holes, introducing fine bubbles into the water. The fine bubble diffuser does provide high oxygen transfer at a low power cost. However, fine bubble diffusers used in waste water applications are subject to chemical and biological fouling. Due to the potential fouling of ceramic and membrane diffusers with metal precipitates, fine bubble diffusers were not recommended for use at the Kempton Site.

An aspiration stripper pumps water at high pressure through elongated slots in pipes to aspirate air into the water. The process has a relatively low oxygen transfer rate as compared to other aeration techniques. In order to achieve a similar DO concentration, the water may require recycling through the system creating a high energy demand. The piping system is also subject to clogging. Due to the high energy demand and operation and maintenance concerns, an aspiration stripper was not recommended for use at the Kempton Site.

A sparging ring has holes in the upper side and is placed at a depth below the surface of the pond. Air is forced through the holes thereby creating a stream of air bubbles rising to the surface of the pond. The oxygen transfer zone is limited to a narrow area of the pond, making this system somewhat inefficient. The blowers must overcome water pressures over 800 pounds per square foot resulting in a high energy cost. Maintenance requirements may be high due to clogging of the holes in the rings with metal precipitates and the requirement of raising them from the placement depth for maintenance. For these reasons, a sparging ring was not recommended for the Kempton Site.

The Maelstrom Oxidizer system is comprised of individual modules sequentially aligned, allowing continuous gravity flow through the system. Air is injected in the modules distributing high-volume, low-pressure air through the apertures causing a swirling motion, or maelstrom, in the water. As the maelstrom created by the individual oxidizers rotate clockwise, adjoining oxidizers create a maelstrom in a counterclockwise direction. This turbulent action strips carbon dioxide and raises DO levels. This action is repeated as the discharge passes through a series of modules providing an opportunity for oxidation, then replenishment of used DO. Due to the low-pressure requirements of the injected air, power requirements are relatively low. After evaluating the various methods of oxidization available for use at the Kempton Site, the Maelstrom Oxidizer was recommended and is being fabricated.

Conclusions

Various techniques are available to aerate mine water that supplement the natural processes of oxygen transfer across the air-water interface and photosynthesis. All techniques require manipulation of available energy sources, which vary from site to site. The sources of energy may include water pressure, differential elevation head, wind power, electric power, or even solar power. The method selected should be based on mine water chemistry, treatment system objectives, and the availability of treatment area, hydraulic head, and electric power. In many cases, simple aeration techniques such as the use of an energy dissipation devise or a section of rock lining are adequate. Additional aeration techniques are available and may be applicable for situations with high flow rates and greater concentrations of metals. Differential elevation head provided the energy used to create a fountain aeration for a flow rate of over 1,000 gallons per minute as demonstrated at the Kolb Site in Indiana County, Pennsylvania. Wind energy has been harnessed using windmill aeration techniques at the Sagamore Site in Fayette County, Pennsylvania. In cases where adequate aeration cannot be accomplished by passive methods, such as the Kempton Site in Garrett County, Maryland, active mechanical aeration may be necessary to meet treatment objectives.

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