ASSESSMENT OF THE APPLICABILITY OF AN ANOXIC LIMESTONE DRAIN FOR A SURFACE MINE IN EAST CENTRAL TENNESSEE[1]

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Abstract: Anoxic limestone drains (ALDs) are a cost-effective technique for adding alkalinity to acid mine drainage. However, the applicability of an ALD is limited to a rather narrow range of mine drainage chemical conditions due to concerns about the armoring of limestone with ferric hydroxide, the plugging of flow paths with aluminum hydroxide, and the limited solubility of calcite. While the armoring and plugging potentials can be assessed with careful water quality analyses, the solubility of limestone in a particular mine water cannot, at this time, be predicted from mine water chemistry. Thus, the danger always exists that the ALD will generate insufficient alkalinity to completely neutralize the acidic water, resulting in either insufficiently treated discharge or a need for additional treatment. In order to remove uncertainty from the design of a 4,000-ton ALD, we conducted limestone incubation tests and pilot-scale ALD tests. Incubation tests were done using a modified version of the "cubitainer" procedure developed by the United States Bureau of Mines. The pilot ALD consisted of 65 tons of limestone. Hydrologic loading experiments were conducted that provided an assessment of the ALD performance under design flow conditions and flow rates four times higher than the design flow. Under design flow conditions, the pilot ALD discharged water with alkalinity concentrations similar to that predicted by the cubitainer tests (360 parts per million). With increased flow, concentrations of alkalinity in the pilot ALD effluent decreased, with the water becoming net acidic at a flow rate of 15 gallons per minute. The results of the pilot ALD were used to size a full-scale ALD and model ALD performance under a variety of flow conditions.

Additional Key Words: cubitainer, passive alkaline addition.

Introduction

Anoxic limestone Drains (ALDs) have made the passive treatment of acid mine drainage possible on hundreds of mine sites in the Appalachian coal region. The theory of ALDs is quite simple. Acidic water is directed through a buried bed of limestone gravel (Turner and McCoy, 1990). Limestone dissolution raises pH and adds bicarbonate alkalinity to the water, which promotes metals precipitation in subsequent ponds or wetlands. Anoxic conditions within the limestone bed prevent iron oxidation and limestone armoring. In some cases, it is economically feasible to construct ALDs which

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may last decades due to the low cost and limited solubility of limestone.

However, ALD technology is not without shortcomings. The use of ALDs is not suitable under certain water chemistry conditions. Ferric iron and aluminum both precipitate within an ALD, decreasing performance by armoring limestone and plugging flow paths (Hedin, et.al.). It is also possible that a properly designed and constructed ALD will not generate sufficient alkalinity to completely neutralize acidic water due to limited limestone solubility. Water chemistry which appears similar based on evaluation of standard acid mine drainage analytes may generate dissimilar alkalinity concentrations.

This paper describes the design process of a large ALD system (4,000 tons of limestone). Because of the financial commitment involved in the construction of a 4,000-ton ALD system, it was considered prudent to thoroughly evaluate the ALD concept prior to construction. This paper describes our use of cubitainer tests and a small "test" ALD to provide data.

The research was conducted at Sequatchie Valley Coal Corporation (SVC). SVC operated area surface coal mines located in east central Tennessee. One surface mine, locally referred to as Area 1, was mined from 1978 to 1982. Backfilling, regrading, revegetation, and related reclamation activities were largely completed by 1983. However, acidic seeps began to develop at topographic lows after 1983. In the period that followed, SVC collected acidic water and used standard chemical treatment and precipitation methods. Realizing that chemical treatment may not be in the best interest of SVC or the environment, SVC considered the applicability of constructed wetlands and related passive technologies (Hedin and Massey, 1995). SVC implemented an approach consisting of short term management and development of long term solutions to water quality problems.

Evaluation of groundwater quality data at Area 1 revealed good news, but also raised some questions. Positive results included the absence of aluminum and a pH of 5.5 standard units. At a pH of approximately 5.5 standard units, no ferric iron should exist (Stumm and Morgan, 1970). Therefore, armoring of limestone with iron hydroxides and flow path clogging by aluminum precipitates would not be anticipated in an ALD constructed at Area 1. However, acidity concentrations were measured above 300 ppm. ALDs have been properly sized and constructed which generate less than 200 ppm alkalinity (Hedin, et.al., 1994), which would be insufficient to completely neutralize acidity at Area 1. Therefore, as part of the evaluation of ALD applicability at Area 1, SVC desired a knowledge of the amount of alkalinity likely to be produced by an ALD. Cubitainer testing (Watzlaf and Hedin, 1993) was subsequently conducted to estimate alkalinity likely to be generation by an ALD.

Cubitainer Testing

The United States Bureau of Mines (USBM) presented an ALD alkalinity prediction method in April 1993 at the *Thirteenth Annual West Virginia Surface Mine Drainage Task Force Symposium*. The method involves placing limestone and untreated mine water in collapsible containers (cubitainers) and monitoring the alkalinity generation by periodic extraction of water. The method was developed by the USBM during studies of two ALDs with significantly different alkalinity generation characteristics. The USBM studies determined that mine water chemistry, not limestone quality, determined the alkalinity generation characteristics of an ALD. In addition, the researchers noted that the 48 hour alkalinity concentrations predicted by the cubitainer testing method were within six percent of the actual alkalinity generated by the ALDs (Watzlaf and Hedin, 1993). Prior to this research, a method for predicting ALD alkalinity generation did not exist.

In 1993, SVC engaged Skelly and Loy to assist in the evaluation of passive alternatives to chemical water treatment at Area 1. As part of the assignment, the USBM cubitainer procedure was utilized to estimate the alkalinity which may be generated by an ALD at Area 1. Specifics of the cubitainer method follow.

Collapsible, one-cubic foot cubitainers and smaller one-gallon cubitainers were used for the testing procedure. One-cubic foot containers provided adequate water to conduct a series of analytical and biological tests after the cubitainer test was completed. The cubitainers were equipped with two-holed rubber stoppers and lids. Gas impermeable "Nalgene" tubing was then placed through each stopper hole. To form an airtight seal, silicon sealant was placed around the stopper holes and tubing. Two pieces of tubing were used. One was cut to sufficient length to extend to the bottom of the cubitainer while the other was inserted flush with the bottom of the stopper. Clamps were then attached to the tubing. An on/off clamp was attached to the longer tube (used for filling) and an adjustable clamp was attached to the shorter tube (used for expelling oxygen, nitrogen, and liquid samples). By utilizing the adjustable clamp, flow rates into and out of the cubitainers were controlled to avoid introducing oxygen into the container.

Each cubitainer was filled approximately ⅔ full (20 Kg) of 1½"x¾" limestone. The limestone was obtained locally from the Monteagle Formation. Prior to being placed into the cubitainer, the limestone was thoroughly rinsed to remove all fine particles of calcium carbonate. Rinsing was completed in a two-step process. The first rinse was completed using water from the SVC office facility well. Once the limestone was rinsed of fine particles of calcium carbonate on all surfaces, the sample was rinsed with deionized water. This second rinse was employed to completely remove residue (if present) from the well water. Limestone was then placed on a clean tarp and left to dry completely. Once dry, the limestone was introduced into the cubitainers preparing them to be filled with the water sample.

Utilizing the dewatering well field in-place at Area 1, the wells were purged with a minimum of three well volumes prior to the collection of any water samples. Background water quality parameters for pH, dissolved oxygen, and temperature were taken initially before any well purging began. Once wells were purged, readings were again taken to ensure that dissolved oxygen levels remained low, generally less than one part per million (ppm).

The cubitainer filling process then proceeded following the prescribed methods used by the USBM. In addition to using larger cubitainers, one procedural enhancement was employed. Prior to filling each cubitainer with water, each cube was filled with nitrogen. The nitrogen was pumped into each cube to remove oxygen. Through the use of an adjustable clamp, the cube was then collapsed, forcing the nitrogen and remaining oxygen out of the cube. The clamp was fully closed and the cube was refilled with nitrogen. This process was conducted three times, encouraging the replacement of oxygen with nitrogen. Once completed, the cubitainer was filled with sample water.

As another means to minimize oxygen introduction to the cubitainers, water obtained from the sample well was collected using an ISCO Model No. 3710 portable sampler equipped with a peristaltic type pump. Multiple water samples were collected from the well at a ten-foot depth. Continuous dissolved oxygen readings were monitored at this depth. Water flow rates and nitrogen release from the cubitainer were then controlled using the clamps. Each of the cubitainers was filled through the tubing which extended to the bottom of the cube. Water was introduced while forcing the nitrogen from the cubitainer. The filling procedure continued until no visible air space remained within the cubitainer.

Once each cubitainer was filled, the tubes were clamped shut. The cubitainers were then placed into a trough filled with continuously circulating water originating from the well field. The purpose of the filled trough water bath was to keep the filled cubitainers at a constant temperature (approximately equivalent to the groundwater temperature). This procedure also served to keep the cubitainers in an anoxic state. Water was pumped from the dewatering wells into the trough for the duration of the 48-hour test period.

Cubitainers remained in the water bath for a period of 48 hours. After a period of 48 hours, the one-cubic foot cubitainers were taken out of the water bath and retained for subsequent aeration and settling, analytical testing, and biological testing. The one-gallon cubitainers were kept in temperature controlled coolers for a period of one week. Samples of cubitainer water were collected after 4, 8, 24, 48, 72, 96, and 120 hours. Alkalinity and pH readings were made on each of these samples.

Cubitainer Results

Evaluation of the alkalinity results revealed that the alkalinity increased from approximately 140 mg/l to 340 mg/l in the first 48 hours of the cubitainer test performed on the larger containers. Figure 1 depicts time versus alkalinity for the first five days of the smaller scale, longer duration, one-gallon cubitainer test which confirmed results from the larger cubitainers. This figure indicates that near maximum alkalinity was achieved in the first 48 hours of the test period. Therefore, if past research conducted by the USBM is validated by this cubitainer testing, it would be expected that a properly sized and constructed ALD at Area 1 would generate alkalinity of a similar magnitude. These results indicated favorable conditions existed for utilization of an ALD at Area 1.

Pilot-Scale ALD Testing

The cubitainer test provided confidence on the applicability of an ALD solution for Area 1. As plans for the full scale ALD evolved, questions regarding ALD performance under variable flow conditions were raised. To address this concern, a small ALD was designed that would allow testing of alkalinity generated under variable flow regimes.

The 65-ton test ALD was constructed in January 1995. A rectangular pit 60 feet long, six feet wide, and four feet deep was developed to contain the gravel sized limestone. The ALD limestone was wrapped in filter fabric and plastic and buried under two feet of spoil. The plastic may inhibit water losses or gains while the spoil is intended to ensure anoxic conditions existed within the ALD. The source water was obtained from a nearby groundwater pumping system. In order to test the ALD under a variety of flow conditions, a control valve was placed in the test ALD influent line to allow for flow rate adjustment. The exit pipe was placed above the top elevation of the ALD to ensure that the limestone would remain completely under water.

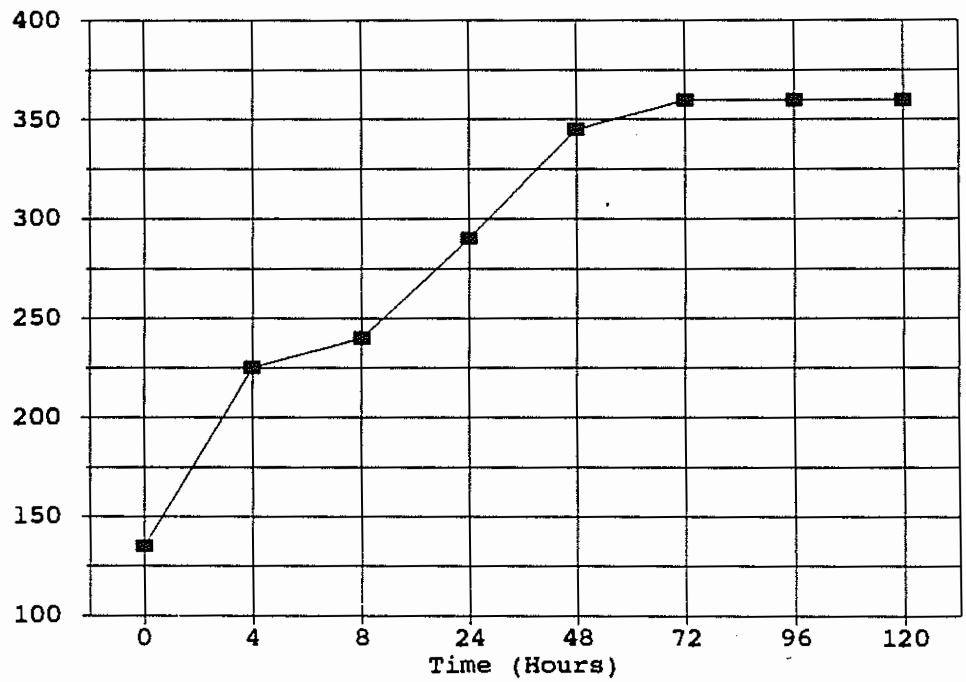

Figure 1. Cubitainer Test Contact Time Versus Alkalinity

The ALD was operated between February and May 1995. The test ALD was used to determine alkalinity generation over a range of flow conditions. In order to obtain the maximum alkalinity concentration, an ALD should contain at least 12 tons of limestone for each gallon per minute (gpm) of flow (Hedin et. al., 1994). Thus, the base flow rate used for the test ALD was approximately five gpm.

Figure 2 graphically depicts flow rate versus alkalinity concentrations for flow rates which approximate the base flow rate (three to eight gpm). These data exclude flow rate adjustment tests described later in this paper. After initial system flushing, water exiting the test ALD contained alkalinity concentrations of approximately 360 ppm. After a few months of operation, the alkalinity stabilized at approximately 320 ppm.

Figure 3 depicts flow rate versus alkalinity concentrations during flow rate adjustment tests in the ALD. As expected, alkalinity generation decreased as flow increased. The flow was increased up to 20 gpm (approximately 3 tons of limestone per gpm of flow). This flow is equivalent in tons of limestone per gpm to a flow much greater than the maximum expected flow to the ALD. Therefore, the pilot-scale test covered the full range of conditions anticipated in the proposed full scale ALD. At a flow rate of 15 gpm, alkalinity concentrations had been reduced to approximately 265 ppm and the water exiting the test ALD became net acidic.

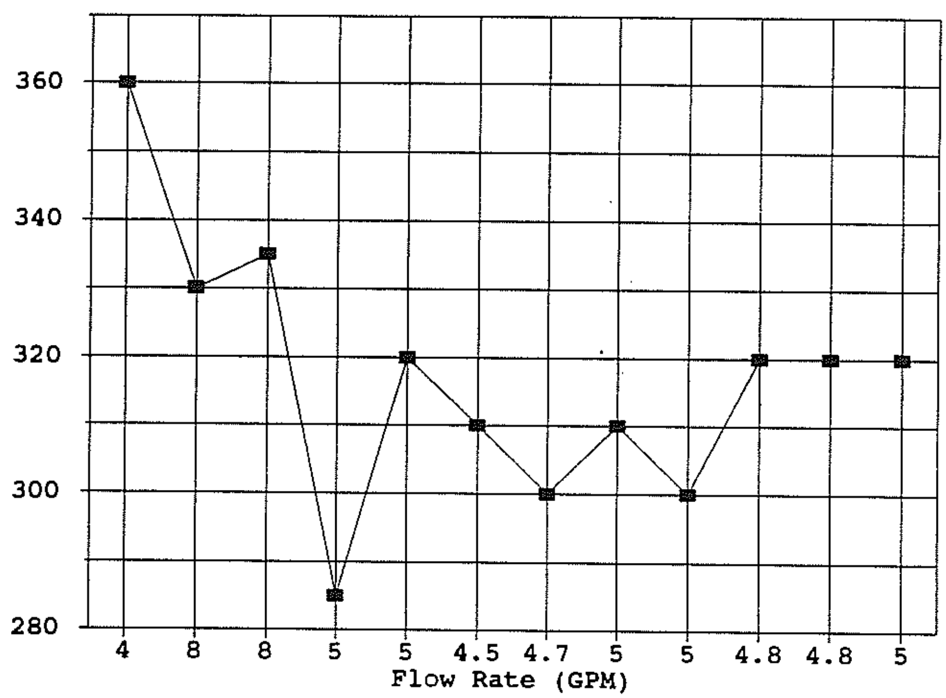

Figure 2. Pilot ALD Flow Rate Versus Alkalinity

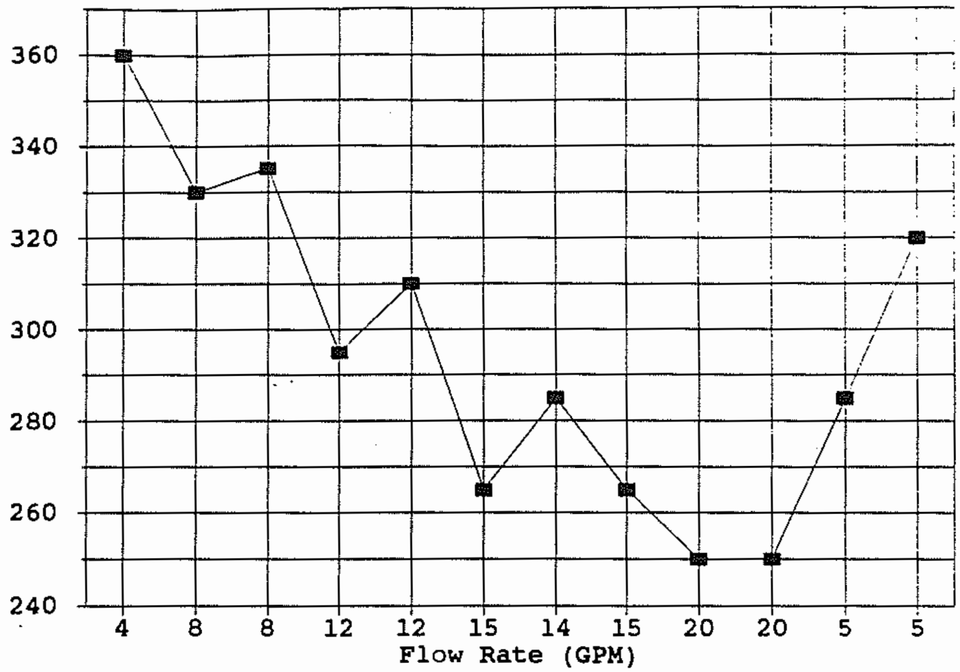

Figure 3. Pilot ALD Flow Rate Versus Alkalinity Flow Rate Adjustment Test

During maximum flow conditions expected in the full scale system, the limestone to flow ratio is anticipated to be eight. At a comparable flow rate in the test ALD (eight gpm), alkalinity concentrations exceeded 300 ppm. Using this result as a prediction tool, net alkalinity would be expected even during maximum flow conditions.

The last two months of test ALD data collection was evaluated to determine potential variation of alkalinity generation when flow remained relatively constant. The alkalinity generation was remarkably constant in the range of 310 to 320 ppm. These data are depicted by the last eight readings of Figure 2.

Conclusions

Due to the inability to determine alkalinity generation in an ALD based on water chemistry alone, other techniques must be employed. Two available methods are cubitainer testing and pilot-scale ALD testing. As documented here, both methods provided similar results under recommended ALD sizing criteria. In addition, a pilot-scale system can be used to simulate extreme flow conditions which may be anticipated. The pilot-scale test can also be used to estimate the flow rate at which the ALD effluent would become net acidic. At that point, the ALD alone would generate insufficient alkalinity to completely neutralize the acidic water.

The methods presented in this paper formed the design basis for a 4,000-ton full scale ALD which has been installed at SVC's Area 1 near the end of 1995. Initial results from the full scale ALD are remarkably similar to both the cubitainer test and pilot-scale ALD test. The first discharges from the full-scale ALD to the receiving streams have alkalinity concentrations of approximately 340 ppm. This result validates the usefulness of the techniques described in this paper.

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