LESSONS LEARNED FROM FULL-SCALE, NON-TRADITIONAL PLACEMENT OF FLY ASH

Caroline Loop
The Pennsylvania State University
University Park, Pennsylvania

Abstract

Reclaiming a surface mine pit or lake can have significant long-term benefits including the reduction of AMD, elimination of hazardous physical conditions, and the return of land to productive use. Fluidized bed combustion (FBC) ash from waste coal burning plants in the anthracite region contains dehydroxylated clays, calcium oxide, and gypsum which influence the chemistry of the water they come in contact with. If ash is distributed properly, the same minerals will act to strengthen and shrink pore spaces within the FBC ash monofill by encouraging the growth of minerals such as 14Å tobermorite, calcite, and ettringite. With proper placement and monitoring, alkaline FBC ash can be an important resource for eliminating abandoned mines, as shown in the cases of the Big Gorilla and Knickerbocker pits.

Introduction

In Pennsylvania, coal combustion by-product (CCB) ash is conventionally placed at least eight feet above the regional water table and four feet above any perched water table, so that it is not in contact with groundwater. This article is based on two full-scale demonstration projects in the anthracite region of Pennsylvania in which this was not the case. In the first project, dry fluidized bed combustion (FBC) ash was placed in standing mine water, and in the second project, FBC ash was slurried into a dry mine pit. A third demonstration, where FBC ash was to be slurried into standing mine water, has not yet taken place. The structural stability of the final ash monofill, basin to pore scale water chemistry, and long-term predictions are all key to a successful project and will be considered in this paper.

The need exists for a way to reclaim abandoned pit lakes that are common throughout the anthracite region of Pennsylvania. These lakes have been the location of drownings, cause further degradation of the regional water quality, and are an eyesore. Little clean fill exists near these sites in the anthracite region, as they were often deep-mined with minimal overburden removed. The cost of reclaiming the Shen Penn pit alone was estimated at \$20 to \$28 million, if a by-product material was not available (Dalberto et al., 2004). The goal of the reclamation projects discussed in this paper was to use FBC ash to create an inert, if not alkaline, plug of fly and bottom ash that fills the former surface mine. Once ash fills a pit lake, conventional reclamation using ash and clean fill can take place, finishing with a seeded area that conforms to the land's pre-mining contour.

At the site of the Big Gorilla project, where dry fly and bottom ash were being placed into standing mine water, the lake surface was not connected to a regional water table. The approximately 130 million gallon lake, called the "Big Gorilla," was a remnant of the mining of the Mammoth coal seam and is bordered to the south by the Centralia thrust fault. Over 3 million tons of ash was used to fill the pit lake over a period of approximately 6 years. The Northeastern Power Company (NEPCO) generates fly and bottom ash as it burns waste anthracite coal in a fluidized bed in which limestone is used to control sulfur emissions. The amount of limestone is adjusted to the sulfur content of the material, and the resulting fly ash is approximately 6.5 % wt. portlandite, 0.4% wt. calcite, and 0.5 % wt. gypsum. The four other major components of the FBC fly ash are dehydroxylated clays (63.6% wt.), quartz (20% wt.), mullite (7% wt.), and hematite (2% wt.). The mineralogy of FBC ashes resulting from the burning of waste culm piles in the anthracite region differs significantly from both class C and class F ash from pulverized coal plants. The mineralogy and placement technique have contributed to the structural integrity of the ash monofill.

Structural Stability

Ash leaves NEPCO through two silos, at which point it is transported by trucks in 35 ton loads to two platforms at the eastern end of the Big Gorilla pit. The upper and lower platforms were originally built of clean fill, until the practice became cost-prohibitive. Once the demonstration permit was issued, in 1997, ash was placed close to the edge of the platforms by a dumping truck and a bulldozer was used to push it into the water. The routine use of trucks and bulldozers was the only compaction that took place on the ash platforms. Initially, ash was only placed from the upper platform during the winter, due to the fear of slippery conditions closer to the water, but this concern proved unnecessary with time, and platforms were used without regard to the season.

Quantification and close control of the structural stability of the ash platforms should be a component of any plan for ash placement in water. The Proctor density test is a measure of the density of cohesive materials as a function of moisture content and serves as a baseline for field measurements of compaction. The recommended amount of moisture is added to the ash in the trucks at the plant; this process is called conditioning. Once the fly and bottom ash was placed on the platforms, a ^{137}Cs densitometer was used by the PA DEP to ensure the DEP requirements of 90% or greater of the laboratory measured Proctor density value. At times, the field density was over 100% of the theoretical value, but it was never below 90%. At the Big Gorilla site, both a field penetrometer and bearing capacity tests were used to determine the weight bearing capacity of the platforms. The soil penetrometer tests routinely met or exceeded a value of 3.0 tons per square foot (tsf) and the drilling tests determined that the bearing capacity was greater than 2 tsf.

At the Knickerbocker site, which was receiving a slurry of fly and bottom ash from the Schuylkill Energy Resources co-generation plant, Proctor density and bearing capacity tests were routinely conducted by the PA DEP, and the results deemed positive. One important goal of the slurry configuration was to minimize turbulence of the water as it flowed from the pipe and over the ash. In this regard, the pipe outlet was placed close to the ground, and only a very shallow slope was allowed for the slurry to flow over. Shortly after the slurry left the pipe, the fly and bottom ash mixture was stable enough to walk and drive a vehicle on. At one point, a smaller test was conducted to evaluate the effects of adding cement kiln dust (CKD) on the ash strength. In this test, the slurry line, containing additional CKD, was discharged into standing mine water. The ash behaved in the water in a manner similar to a delta formation, where ash settled out as it left the pipe and the water flowed to the far end of the cell. The additional CKD was found to contribute to the increased packing density of the ash fill.

The structural success of the ash plugs is not independent of the chemistry, as will be further discussed in the next section. It can be attributed to the chemical interaction of the components of the FBC ash, specifically, calcium hydroxide (CaO), the dehydroxylated clays, and gypsum. When CaO is exposed to moisture it becomes the mineral portlandite $(CaOH)_2$. The addition of CaO to water can raise the pH of the water to a theoretical value 12.45. This increase in pH, and concurrent increase in alkalinity, is required for the development of pozzolanic reactions in the ash. In the presence of CO_2, the Ca will contribute to the precipitation of calcite. The heating process (to approximately 800ºC at NEPCO) causes clays that were initially present in the waste coal to lose hydroxyl ions, in turn making them more reactive, especially in the presence of the high pH values that were found in the ash platform (11-12). C-S-H can be formed, and is thought of as the “glue” in Portland cement. The gypsum in the ash was also found to serve an important purpose in contributing to the formation of ettringite, a calcium, and aluminum sulfate mineral. Ettringite is a mineral present in Portland cement that can form in the pore spaces of the ash.

The mechanical compaction of the ash platform by the trucks and bulldozers, which minimizes density and the size of pore space is the first step to structural stability. The second step is the continued filling of existing spaces by the growth of minerals such as calcite, C-S-H, and ettringite. These processes are likely occurring on very different time scales.

Water Chemistry

Three water sources are especially important in the Silverbrook Basin. The first is the Big Gorilla water, which shows a significant change in chemical composition as ash is first placed in the pit lake. The two more long-term indicators of change in the basin are the pore water within the ash platform, which must be monitored by wells, and the basin outflow point. The pit lake water should be studied as the first field measured indication of the long-term ash/water interaction. This is especially true for the first months of ash placement, as the water can change significantly in chemical composition with relatively small inputs of ash, especially in the case of highly alkaline FBC ash. The water in the surface mine pool should ideally be largely contained within the surface mine pool, unless beneficial aspects may be provided by mixing it with acidic water in the surrounding area. Since the goal of the ash placement is to fill the entire mine pool, the water in the pit lake is transient. Therefore, high pH and alkalinity values will not be of as great a concern for wildlife as if the altered lake water were to be a permanent feature.

Within the first 3 months of ash placement in the Big Gorilla, the pH value of the water rose from 3.6 to approximately 10. After the first winter hiatus in ash placement, the pH value was most commonly between 11 and 12. The alkalinity increased and decreased significantly in response to ash placement, with concentrations between 50 and 200 mg/L when no ash was added to the water. In addition to being controlled by carbonate reactions, the alkalinity in the mine pit lake was also governed by the silica and hydroxide content of the water, which fluctuated with ash input. When placing ash after a break in ash placement, the silica concentration initially increases, but with further ash placement, the silica concentration decreases and alkalinity increases, until the alkalinity is controlled primarily by the hydroxide content of the water. Carbonate reactions control the alkalinity when the ash is not actively contributed to the water. The substantial carbonate fraction of the ash also represents a long-term reservoir of alkalinity. A white rim was present on the banks of the Big Gorilla mine pool, demonstrating that in the zone that mixes with CO_2, calcite will precipitate. It is expected that in the high pH porewater, the pores that are open to CO_2 diffusion will eventually have calcite precipitated within them.

Because aluminum (Al) is amphoteric, it can be present in toxic concentrations at high or low pH values. When the ash was initially added to the water and the pH became neutral, most of the aluminum in the water precipitated as a hydroxide and was covered by successive layers of ash. This same process alters iron and manganese aqueous concentrations. However, the dissolution of dehydroxylated clays and mullite at high pH values would also contribute to the aluminum concentration in water within the mine lake and the pore spaces. Geochemical modeling of the Big Gorilla ash pore waters and scanning electron microscope (SEM) analysis of the ash from the Knickerbocker site indicate the presence of ettringite. When enough sulfate and calcium are available, the aluminum content of the water at higher pH values (above 11.5) can be controlled by ettringite (Loop, 2003). An additional benefit of the presence of ettringite is that it can bind within its structure more toxic elements such as Cr, As, and Cd (Gougar et al., 1996).

Geochemical modeling of the waters sampled from a borehole in the ash platform indicated that the water was supersaturated with respect to 14Å tobermorite. Assuming thermodynamic equilibrium, PHREEQC (Parkhurst, 1995) was used to speciate the water. The concentrations of Ca and Si in the water encourage cementitious reactions to take place, a primary indication of which is the presence of tobermorite. 14Å tobermorite is very similar in composition to C-S-H, an important binding component of Portland cement.

Thus, the FBC ash has CaO and $CaSO_4$ from the addition of limestone to capture sulfate, as well as reactive clays containing more easily dissolved Si and some Al. In non-FBC ash, amendments with alkaline material, for example cement kiln dust or lime kiln dust, may be necessary to achieve these results.

The changes throughout the basin can be measured by monitoring wells, if they intersect major flowpaths. In the case of the Silverbrook basin, where the Big Gorilla is located, only one well showed altered chemistry as a result of ash placement in the Big Gorilla. The well was within 100 feet of the pit lake and registered a change in chemistry approximately 2 years after the first ash was put into the pit. The chemical change only lasted for about a year, at which time the connection between the lake water and the well was sealed.

More useful than monitoring wells, in areas where preferential flow occurs, can be a mine outflow point, analogous to a spring in limestone bedrock. The Silverbrook outflow drains the entire basin, including the deep mines, and is a large-scale monitor for processes occurring throughout the basin. No chemical signatures in the outflow could be isolated as impacts from the Big Gorilla, however there were indications of change in the basin. Calcium, iron, and sulfate concentrations have all increased, but began prior to ash placement in the surface mine pool. The increase in calcium concentration began in 1992, and can be traced to land reclamation in the basin near areas that may have contained preferential pathways to the deeper, Buck Mountain coal seams, such as cropfalls. The calcium concentration is a reflection of the dissolution of CaO from the ash, which contributes to the alkalinity in the basin, but has yet to affect the alkalinity measured at the outfall. Iron and sulfate concentrations in the Silverbrook outfall have been increasing as culm has been collected and stored onsite. This unfortunate change is a consequence of the moving of the culm from onsite and beyond, which exposes fresh surfaces of the pyrite to weathering, and in turn generates more acid mine drainage. However, because the waste coal is being burned, after this process, the pyrite is being removed permanently, as opposed to waste coal piles that remain sources for acidic drainage for decades. Seasonal signatures of sodium and chloride can also be detected in the water. Thus, no direct effects of ash placement in the Big Gorilla mine pool can be distinguished in the Silverbrook outflow, after seven years of ash placement.

Long-Term Predictions

Current indications of the long-term effect of ash placement in the Big Gorilla mine pool and the Knickerbocker pit point to an inert material with very low values of hydraulic conductivity. It had been initially hoped that alkalinity from the FBC ash placed in the Big Gorilla would enter the deep mines below and have a beneficial effect on the basin's water. In fact, this has not occurred. Only very limited amounts of water have left the Big Gorilla, and the water that has must have become acidic during interaction with pyritic material and mixing with acidic water in the subsurface. This does, however, leave a large reservoir of alkaline material in the pore spaces of the ash monofill, which will contribute to high pH values of the pore water, and will in turn increase the stability of the ash and decrease the permeability of the ash fill. Permanent monitoring wells will be located in the ash placed at these locations and will continue to be monitored for changes in chemistry of the waters. The permit for ash placement on the NEPCO site will soon revert to a conventional land reclamation permit, as the ash will be above the water table. At both NEPCO and at the Knickerbocker site, ash will be used to return the land to the estimated pre-mining contour, which will eliminate the highwalls. Clean fill will be placed on the ash, and vegetated. Water flow into the deep mines through the Big Gorilla and Knickerbocker areas will be largely eliminated due to the low permeability of the ash in the subsurface.

References

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Dr. Caroline Loop is a postdoctoral researcher at the Materials Research Institute at Penn State. Her primary interests are subsurface contaminant transport, low temperature geochemistry, the molecular-scale investigation of environmental samples, and the use of by-product materials for environmental reclamation. She holds a B.A. in both geology and economics from Smith College, as well as a M.S. degree in environmental pollution control and Ph.D. in geosciences from Penn State.