A Methodology for Evaluating the Costs of Alternative AMD Treatment Systems [1]

by

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Costs of treating acid mine drainage (AMD) have become an increasingly large component of the total costs of mining in many Appalachian coal regions. moreover, mine operators may remain legally responsible for the costs of treating AMD long after actual mining operations have ceased. It is therefore important for mine operators and policy makers to know the technical and economic feasibility of alternative systems for treating AMD. This paper presents a methodology for calculating and comparing the economic costs of alternative AMD treatment systems. The method is illustrated with a cost analysis of two alternatives, ammonia anq hydrated lime, for a variety of technical and economic scenarios.

Background

The combination of relatively high annual precipitation rates and the chemical composition of the rock formations which are associated with coal deposits in much of the eastern U.S. make surface coal mining operations particularly susceptible to acid mine drainage (AMD) problems. Drainage water from areas subject to AMD problems are characterized by low pH levels and excess quantities of metal ions, primarily iron, manganese, and aluminum. With current technologies, such drainage water requires treatment by chemicals before being discharged into streams to meet water quality standards. Since the early 1970's, West Virginia surface mining regulations have advocated mining and reclamation techniques designed to reduce acid formation during and after mining operations.

Even with the application of carefully developed mining and reclamation practices, amendments, and other technologies, AMD problems persist. While laboratory analysis of some techniques indicate the potential for excellent control, success on actual mine sites has been limited. As a result, AMD is a continuing problem and the coal industry pays a high price for treatment of the water draining from mine sites.

EVALUATION OF THE AMD PROBLEM

If, as is often the case in problem areas, AMD problems develop during or after mining operations, a plan to treat the discharge must be developed. Treatment of AMD includes neutralization of the acidity and precipitation of excess metal ions to meet the relevant effluent limitations in discharge water established in the NPDES/Article 5A Permit for the specific site.

[2] See Fletcher, Phipps and Skousen for a comparative cost analysis of caustic soda, soda ash, ammonia and hydrated lime.

At a minimum, an operator must achieve EPA's "technology based" effluent limitations established in (Federal Register) 40 CFR, Part 434. These requirements include effluent limitations for pH, iron, manganese, suspended solids, and settleable solids. However, in situations where EPA's technology based 3 effluent limitations will violate the water quality standards , a more stringent effluent limitation will be established in the NPDES permit. These stringent limitations are known as "water quality based" effluent limitations.

A water quality based effluent limitation considers the stream's use and quality and the discharge's quality and quantity. Also, a water quality based effluent limitation may be assigned when the receiving stream does not have sufficient dilution capacity (i.e., the discharge quantity is equal to or greater than the receiving stream flow). Therefore, determination of the receiving stream's use and flow rate (seasonal variation included) is of paramount importance.

Depending on the stream use, other parameters and/or effluent limitations may also be assigned in the NPDES permit which will require monitoring and meeting a performance standard. For instance, the location of the treatment facility may dictate the type of effluent limitation that may be established in the permit. In most cases, the location of the treatment facility cannot be changed since it must be located near the source or collection pond. However, if the location can be varied, the treatment facility should be located so it discharges into a larger flow stream, and/or into a less sensitive stream. These factors will determine the effluent limitations assigned in the NPDES permit.

Once the effluent limitations (either "technology based" or "water quality based") are established, a treatment facility can be designed to treat the water to achieve these limits. In most cases, a variety of alternative treatment methods could be employed to meet the limits specified. Four chemicals are widely used to treat AMD: limestone (calcium carbonate), hydrated lime (calcium hydroxide), soda ash briquettes (sodium carbonate), and caustic soda (sodium hydroxide). A fifth, ammonia (anhydrous ammonia), is now being used in some locations. Each chemical has advantages and disadvantages which make it more appropriate for a specific condition. In a particular situation, the best choice among the available alternatives will depend on both technical and economic factors. The technical factors include acidity levels, rate of water f low, and the types and levels of heavy metals in the effluent. The economic factors include prices of reagents, labor, machinery and equipment; the number of years that treatment will be needed; and the interest rate.

[3] A water quality standard is based on water or stream use and provides a numerical criteria to protect that use. For example, a stream may have a cold water (trout) fishery and an iron limitation of 0.5 mg/l may be required to protect and maintain that use.

Treatment of AMD

Ammonia

Anhydrous ammonia is being used in some areas to neutralize acidity and to precipitate metals in AMD. Ammonia is usually injected into ponds or into inlet water as a vapor and, due to its high solubility, reacts very rapidly and can raise the pH to 9.0 or higher. Ammonia consumes acid (H+) and also generates hydroxyl ions (OH-) which can react with metals for precipitation. it should be injected near the bottom of the pond or water inlet because ammonia is lighter than water and rises to the surface. Ammonia can be effective for manganese removal which occurs around a pH of 9.5. The most promising aspect of using ammonia for AMD treatment is its cost when compared with caustic soda. A cost reduction figure of 50 to 70% is usually realized when ammonia is substituted for caustic (Skousen et al., 1990).

Major disadvantages of using ammonia are (1) the hazards associated with handling the chemical and (2) uncertainty concerning potential biological reactions. Specialized training and experience are important for the safe dispensing of this chemical. Companies using ammonia must also conduct additional analyses of their discharge water as it is released into the stream. The extra analyses include temperature, total ammonia-N, and total hot acidity. In addition, operators must monitor downstream to assess biological conditions.

Operators must be careful to inject the appropriate amount of ammonia or to install a pH-driven monitoring system due to the potential hazardous consequences of excess ammonia application. If a pH monitoring system is used, care must be exercised if the pH level exceeds 9. For a pH range of 6 to 10.5, titration tests of AMD samples from West Virginia treated with caustic soda have shown a nearly linear relationship between pH and incremental additions of caustic soda. Such tests using ammonia show a logarithmic relationship over a similar range. only a small pH change occurs in the AMD with the addition of ammonia once a pH of 9.2 is reached indicating that pH is not particularly sensitive to changes in ammonia concentrations at level of 9.2 or higher. Therefore, at these relatively high pH levels, caution should be exercised in using pH monitoring systems. The addition of large amounts of ammonia would result in only a small increase in pH and could lead to other water quality problems related to excess concentrations of dissolved nitrates. Therefore, in situations where manganese is the ion of primary concern, caustic soda may be preferred.

Hydrated Lime

Hydrated lime is a very common chemical used for neutralizing AMD. It is particularly useful and cost effective in large flow, high acidity situations where a lime treatment plant with an aerator are constructed to help dispense and mix the chemical with the water. The powdery hydrated lime is hydrophobic, so extensive mixing is required to make hydrated lime soluble in water. The length of time that the system will be in operation is also a critical factor in determining the annual cost and total value of a lime treatment system due to the large initial capital expenditure. Hydrated lime has limited effectiveness in some places where a very high pH is required to remove certain ions such as manganese.

Cost Analysis [4]

In general, the costs can be divided into four categories: (1) initial investment or capital cost and the anticipated life of the investment including salvage value, if any, (2) annual chemical cost, (3) annual repair and maintenance cost, and (4) annual management and labor cost. Once the amount and timing of the cost components are determined, the alternative technologies can be compared on two primary factors: net present value or annualized cost. other considerations, both economic (e.g., cash flow and perceived risk), and non-economic (e.g., familiarity with a particular technology) , may affect the ranking in a particular situation.

The ammonia and hydrated lime treatment systems were selected for analysis in this paper because they demonstrate the need for a consistent economic framework for evaluating and comparing costs. The ammonia system has a relatively low installation cost and a relatively high annual cost. The hydrated lime system has high installation costs but has relatively low annual operation costs. In order to compare the costs of alternatives that have different cash flows in different time periods, economists use two related concepts: net present value (NPV) and annualized cost. Both of these concepts recognize that a dollar paid today does not have the same value as a dollar paid ten years from now, since in the latter case the dollar could have earned ten years of interest before payment was due.

The net present value technique converts all cash f lows in all years to their present value using a discount rate. For example, at a discount rate of 10 percent, a dollar paid in five years has a present value of $0.62 while a dollar paid in 20 years has a present value of $0.15. By converting all cash flows to the current period, it is possible to compare the economic costs of alternatives that have different cash flow patterns.

4 The price of soda ash was $0.13 per pound, ammonia was $0.15 per pound, caustic soda was $0.25 per pound and hydrated lime $0.03 per pound. All labor was evaluated at the current union wage rate of $27 per hour.

The annualized cost technique, which is also called amortization, converts the net present value into a series of equivalent annual cash flows over the life of the investment. It is the same technique that is used to calculate the monthly payments on a loan to purchase a house. Since, by construction, the present value of the annualized costs is the original net present value, both measures contain exactly the same economic information. Therefore, either criterion will give the same ranking of alternatives.

In addition to the NPV or annualized cost criteria, the timing of actual annual cash flows may also be of interest, since a treatment system with large initial investment costs may require use of borrowed capital.

The ammonia treatment system used in the cost analysis is based on an electrically-controlled, continuous vapor system. The electric controller is a closed loop feedback system that monitors the pH in the collecting pond and adjusts the rate flow of ammonia accordingly. The controller adds about $4500 to the installation costs and increases annual maintenance approximately $400. It is also possible to run the ammonia system using needle valves instead of the electric controller in locations that do not have electricity, though the pH in the pond would have to be monitored more frequently. It was assumed that the ammonia tank was rented from the ammonia supplier, a 1000 gallon tank was used for the low flow/low acidity situation, and a 10,000 gallon tank was used for all higher flow and acidity conditions.

Hydrated lime treatment systems have higher installation costs than ammonia treatment systems because of the need to construct a lime treatment plant and install a pond aerator. However, the cost of hydrated lime is extremely low. The combination of high installation costs and low reagent cost make hydrated lime systems particularly appropriate for long term treatment of high flow/high acidity situations. ,

As shown in table 1, for a five year planning horizon ammonia has the lowest annualized costs for the low flow/low acidity situation, even though it has higher reagent costs than hydrated lime. This occurs because ammonia has lower installation and labor costs. As we move into the higher flow and acidity cases, hydrated lime and ammonia have very similar annualized costs. In the highest flow/acidity category, hydrated lime is clearly the least costly treatment system, costing around $250,000 less in annualized cost than ammonia.

Moving to a 20 year planning horizon (table 2) makes hydrated lime treatment systems look even more cost effective relative to ammonia since the costs of the lime plant may be amortized over a longer time frame. Ammonia is still the least expensive choice for the low flow/low acidity situation, but hydrated lime is clearly the least expensive alternative for all of the higher flow higher acidity conditions.

Table 1. Costs of Alternative Technologies to Treat Acid Mine Drainage in West Virginia.

(Five Year Planning Horizon, Six Percent Discount Rate)

Flow and Acidity Conditions				
Flow (gpm)	50	1000	250	1000
Acidity (mg/l)	100	100	500	2500
Chemical				
Ammonia				
reagent costs	$1,116	$22,323	$27,904	$558,071
repair costs	495	495	495	495
tank rental	480	1,200	1,200	1,200
annual labor	9,855	9,855	9,855	9,855
electricity	600	600	600	600
installation costs	5,936	6,357	6,357	6,357
salvage value	0	0	0	0
NPV	58,785	151,569	175,077	2,408,334
Annualized cost	**$13,955**	**$35,382**	**$41,563**	**$571,730**
Hydrated Lime				
reagent costs	$526	$10,527	$13,158	$263,169
repair costs	3,300	3,500	3,500	4,000
annual labor	11,232	11,232	11,232	11,232
electricity	3,500	11,000	11,000	11,000
installation costs	25,000	50,000	50,000	80,000
salvage value	6,250	15,000	15,000	20,000
NPV	103,174	202,735	213,821	1,299,061
Annualized cost	**$24,493**	**$48,129**	**$50,760**	**$308,392**

Sensitivity Analysis

It is possible to analyze the sensitivity of the cost estimates to variation in the model parameters. For example, tables 1 and 2 show the variation in NPV and annualized cost for different water flow/acidity combinations. It is also possible to analyze the sensitivity of the results for different economic situations. For example, in tables 1 and 2 it was assumed that the interest (or discount) rate was 6 percent. [5] Table 3 presents the NPV and annualized costs for the twenty year horizon when the discount rate is 10 percent. The main effect of increasing the discount rate is to lower the NPV for each alternative. The annualized cost is much less sensitive to changes in the discount rate. The relative rankings of the alternative systems do not change, that is, ammonia is still the cheapest alternative for the low flow/low acidity situation, and hydrated lime is the cheapest for all other situations.

5 It should be noted that the "interest" rate used is actually a discount rate, which is the opportunity cost of capital for the firm adjusted for the expected rate of increase in annual treatment costs. For example, if the firm can borrow capital at 10 percent, and the expected rate of inflation in treatment costs is 4 percent, the discount rate would be 6 percent.

Table 2. Costs of Alternative Technologies to Treat Acid Mine Drainage in West Virginia.

(Twenty Year Planning Horizon, Six Percent Discount Rate)

Flow and Acidity Conditions				
Flow (gpm)	50	1000	250	1000
Acidity (mg/l)	100	100	500	2500
Chemical				
Ammonia				
reagent costs	$1,116	$22,323	$27,904	$558,071
repair costs	495	495	495	495
tank rental	480	1,200	1,200	1,200
annual labor	9,855	9,855	9,855	9,855
electricity	600	600	600	600
installation costs	5,936	6,357	6,357	6,357
salvage value	0	0	0	0
NPV	151,915	403,833	467,843	6,548,819
Annualized cost	**$13,245**	**$35,208**	**$40,789**	**$570,956**
Hydrated Lime				
reagent costs	$526	$10,527	$13,158	$263,169
repair costs	3,300	3,500	3,500	4,000
annual labor	11,232	11,232	11,232	11,232
electricity	3,500	11,000	11,000	11,000
installation costs	25,000	50,000	50,000	80,000
salvage value	0	0	0	0
NPV	237,863	465,885	469,070	3,399,402
Annualized cost	**$20,738**	**$40,618**	**$43,250**	**$296,375**

Finally, it is possible to use the model to calculate the break even point between two alternatives by varying a price or dollar amount until the net present values are equivalent for the two alternatives. For example, in table 2, for the low f low/acidity situation, ammonia would be cheaper than hydrated lime until the price of ammonia became greater than $.77 per lb. As another example, in the high flow/high acidity case, hydrated lime would be cheaper than the ammonia treatment unless the installation costs for hydrated lime increased from $80,000 to $1,248,000.

Table 3. Costs of Alternative Technologies to Treat Acid Mine Drainage in West Virginia.

(Twenty Year Planning Horizon, Ten Percent Discount Rate)

Flow and Acidity Conditions				
Flow (gpm)	50	1000	250	1000
Acidity (mg/l)	100	100	500	2500
Chemical				
Ammonia				
reagent costs	$1,116	$22,323	$27,904	$558,071
repair costs	495	495	495	495
tank rental	480	1,200	1,200	1,200
annual labor	9,855	9,855	9,855	9,855
electricity	600	600	600	600
installation costs	5,936	6,357	6,357	6,357
salvage value	0	0	0	0
NPV	113,945	301,040	348,552	4,862,164
Annualized cost	**$13,384**	**$35,360**	**$40,941**	**$571,108**
Hydrated Lime				
reagent costs	$526	$10,527	$13,158	$263,169
repair costs	3,300	3,500	3,500	4,000
annual labor	11,232	11,232	11,232	11,232
electricity	3,500	11,000	11,000	11,000
installation costs	25,000	50,000	50,000	80,000
salvage value	0	0	0	0
NPV	182,998	385,691	381,096	2,543,831
Annualized cost	**$21,495**	**$42,132**	**$44,763**	**$296,797**

Conclusions

The main point of this paper was to present and illustrate a methodology for comparing the economic costs of alternative AMD treatment systems. The actual costs used in the analysis are based on a survey of mine operators in West Virginia in late 1990. Actual costs will vary by region and by operation. The value of the methodology presented is that it can be tailored to individual physical and economic situations by varying the parameters of the model.

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