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A STRUCTURED APPROACH FOR SELECTING MINE EFFLUENT TREATMENT TECHNOLOGIES

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ABSTRACT

As effluent limits become more stringent with each permit renewal, mining companies and their stakeholders are becoming increasingly concerned with the cost, complexity, space required, monitoring issues, and other considerations in order to meet these limits. Coal mining companies are often faced with issues of total dissolved solids (TDS), chlorides, iron, aluminum, manganese, and frequently selenium. Hard rock miners face these as well as the target metals of extraction and processing chemicals. A structured analysis for new and existing treatment facilities can provide a cost effective tactic for selecting the most appropriate solution to a site's effluent concerns.

INTRODUCTION

A number of wastewater treatment technologies exist for managing mine drainage from either coal or hard rock mining. These include passive and active technologies, and often, a combination of technologies may be necessary to achieve the required effluent quality. The technologies should be evaluated using a number of factors, as capital cost is the not the only consideration. These factors include construction and operation costs, reliability, space requirements, speed of implementation, residuals generated, and societal factors such as noise, visual impact, community acceptance, and ability to permit. This process narrows the available candidate technologies and presents a favored technology that can proceed to the next steps of bench scale laboratory tests and pilot scale confirmation tests at the site, prior to permitting, design, and construction. This process produces a streamlined selection process that provides a defendable process selection approach.

FATAL FLAW ANALYSIS

In recommending or selecting a technology, or a combination of technologies to form an mine drainage treatment option, the first objective is to develop a comfort that the technology has a reasonable potential to meet the required effluent limit. Following completion of that task, the range of alternatives that meet the primary requirement should be listed against a list of prerequisites to identify if a critical need cannot be met in a Fatal Flaw Analysis. The alternatives should be researched to compare the ability to meet the range of necessary requirements in an initial Fatal Flaw Analysis. This task looks beyond the ability of a candidate process to treat to the effluent requirements. Then, if a technology does not meet a project critical parameter, that alternative is dropped. Passing technologies can then be evaluated utilizing a cost analysis that considers both life-cycle costs and other non-monetary evaluation criteria (including construction and operation of the proposed facilities). Ratings and sub criteria ratings are then developed to sum a score for each technology to apply an objective analysis to, at times, a subjective process.

EVALUATION CRITERIA

Evaluation using non-monetary criteria is largely subjective. The criteria can be weighted, and each alternative ranked based on this criteria, for a total non-monetary ranking for each alternative. The following presents a list of Non-Monetary Evaluation Criteria:

- Suitable for Climate – Is this technology applicable to the site considering seasonal temperatures and precipitation?;
- Effluent Reliability and Stability – Does the process have demonstrated reliability and stability in similar sites; is the process well commercialized?
- Operability - Ease of operation minimizes operator attention/expertise required to ensure successful process performance;
- Ease of Maintenance - Maintenance requirements not excessive and does not require special expertise; facilities and equipment readily accessible;
- Operator Familiarity - Staff familiarity and ability to use staff experience from existing facilities;
- Reliability – Demonstrated performance; Proven process/technology to meet treatment criteria reliably;
- Hydraulic Sensitivity - Capability to handle variations in hydraulic loads with minimal process impacts;
- Waste Loading Sensitivity - Capability to handle variations in waste loads with minimal process impacts.
- Process Control Stability - Not subject to upset from inadvertent operational changes, toxic slugs;
- Flexibility - Capability for changes in process operations to handle differing waste load conditions and to meet differing treatment objectives for different effluent requirements;
- Environmental Effects - Minimize potential for odors;
- Noise - Minimize potential for noise;
- Visual impacts - Minimizes negative visual impact of facility to nearby viewshed users;
- Hydrological Impact - Minimizes changes to floodplain/runoff (if applicable);
- Footprint - Minimizes footprint and disruption to site, including removal of trees;
- Expandability - Footprint maximizes area available for expansion;

- Flexibility - Easily modified to meet differing future loads, effluent requirements, and/or treatment objectives; and
- Implementation ability – Time to implement facility, including permit, design, construction, commissioning.

The above are a sample of the evaluation criteria, and that may be added to or subtracted from based on the importance to the project. As most of these criteria are subjective and there are a large number of candidate technologies, a simplification of the analysis is critical. This simplification presents the technologies in a numerical rating considering the relative evaluation score, and often pairwise comparison. For the Pair-wise Comparison method, each candidate alternative is matched head-to-head with each other candidate alternative. Each alternative gets one point for a one-on-one win on the criterion and no points for a loss. Candidates with the most points become the preferred alternative.

CASE STUDY

An example of a structured analysis selection approach is presented below for a coal mine experiencing acid mine drainage (AMD).

An Eastern US underground coal mine experienced numerous seeps that flowed into a medium sized river. A regulatory directive required the owner to implement a remedial action, and several treatment options were considered. The seeps were physically separated by over a mile, and contained significantly varying constituent levels, but the major contaminants included aluminum, iron, and manganese. The flows, when summed from each of the sources, totaled a maximum of 75 gpm, however a design maximum of 150 gpm was requested. The constituent concentrations and regulatory limits are shown below:

Table 1 – AMD Concentrations and Required Effluent Limit

Parameter	Influent Concentration	NPDES Monthly Avg Effluent Limit
Flow Avg, gpm	42	
Flow Max, gpm	75	
Flow, Design, gpm	150	
pH, S.U.	3.3	6-9
Fe, mg/l	50 - 67	1.5
Al, mg/l	7.5 – 11.4	0.75
Mn, mg/l	7.6 – 9.0	1

TDS, mg/l	3,000	
Acidity, mg/l	126 - 155	
SO4-, mg/l	1412- 1900	
Cl-, mg/l	350-290	

A number of options were considered.

Aerobic wetlands were considered as a possible alternative, but considerations of the required footprint plus cold weather operation were negatives to this approach. Anoxic limestone drains (ALD) were evaluated to treat each seep, however concerns with physical location of the seeps immediately adjacent to the river, iron concentrations coating the limestone rendering it insoluble, and the high sulfate concentration forming gypsum could clog the ALD. Other options included aerobic wetlands, limestone ponds, limestone sand treatment, successive alkalinity producing systems (SAPS), and physical chemical treatment systems were considered. Anaerobic wetlands would not easily remove manganese, as that constituent must be oxidized before removal by precipitation or greensand filters. Reverse osmosis was considered, but managing the reject was considered a strong negative.

Physical chemical mechanical systems were considered as well. A single stage precipitation process was evaluated as possible, but was considered difficult to operate, as the aluminum and iron can be removed by precipitation at a neutral pH, but manganese, once oxidized, required a much higher pH for removal, at perhaps a pH of 10.5 to 11. With the addition of sodium hydroxide to elevate the pH, hydroxides of aluminum are formed. These aluminum hydroxide precipitants exhibit an amphoteric characteristic and will dissolve forming the complex ions $Al(OH)_4$. When the pH would be adjusted from near neutral to the high pH for the manganese precipitation, complexed aluminum will redissolve back into solution, elevating the aluminum in the discharge. Critical pH control may solve this approach, but the drawback of consistent critical pH control within an operational deadband was deemed a negative factor.

The first step in evaluating the potential treatment options for this AMD problem was to develop a list of criteria that would constitute project success. In general, evaluations of alternatives were performed to determine the treatment configuration and processes that will most cost effectively meet the requirements identified in the design basis. The analysis to determine cost effectiveness is integrated with consideration of subjective parameters in this section, along with an evaluation of the treatment alternatives to meet effluent limits and considers solids treatment processes for handling and disposing of residuals. Residuals handling can account for as much as 50% of capital and operational costs. The tank based options may have significant residuals handling costs. In addition, recycle flows from solids handling and treatment processes can significantly affect liquid treatment processes and should be further evaluated.

In general, alternatives should be evaluated using a cost analysis that considers both life-cycle costs and other non-monetary evaluation criteria (including construction and operation of the proposed facilities).

Evaluation using non-monetary evaluation criteria is largely subjective, and non-monetary criteria can be weighted, thus giving each alternative a score for a total non-monetary ranking for each alternative as discussed above.

These considerations were evaluated for each of the criteria to identify if a fatal flaw existed that would render an alternative not feasible for this application. If a technology exhibits a Fatal Flaw, then that technology will be eliminated from further consideration. The result of a Fatal Flaw Analysis is presented in Table 2 below:

Table 2 – Fatal Flaw Analysis

	Effluent Reliability/ Consistency	Operability	Construction Cost	Maintenance Cost	Operator Friendliness	Hydraulic Sensitivity	Waste Load/Residual Sensitivity	Flexibility	Odor/ Offsite Enviro. Impacts	Noise	Visual Impacts	Hydrological Impact	Footprint	Expandability	Construction Timing
Aerobic wetlands	H	L	L	L	L	L	H	L	H	L	L	L	F	L	L
Anaerobic wetlands	**F**	L	M	M	M	M	H	L	L	L	M	M	F	H	M
Anoxic Limestone Drains	**F**	M	H	H	M	M	H	L	H	M	H	M	M	H	M
Successive Alkalinity Producing Systems	M	M	M	L	L	L	M	H	H	L	M	H	**L**	M	M
Limestone Ponds	F	H	H	M	H	M	H	M	M	M	M	M	M	H	M
Open Limestone Channels	**F**	H	M	M	M	M	H	H	M	L	M	M	M	H	M
Limestone Sand Treatment	**F**	H	M	L	M	M	H	L	M	L	H	M	M	M	M
Reverse Osmosis	H	L	H	M	M	L	**F**	L	L	L	L	L	L	L	H
Sulfate Reducing Bioreactors (SRBR)	**F**	H	H	H	M	**F**	M	L	L	M	M	L	L	H	M
SRBR/Aerobic Wetlands	H	H	H	H	M	H	M	L	L	M	M	L	L	H	M
Single Stage	M	M	**H**	L	H	M	H	M	H	L	M	L	H	M	M

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Physical Chemical ppt															
Dual Stage Physical Chemical ppt	H	M	**H**	L	H	M	H	M	H	L	M	L	H	M	M

Legend
F = Fatal Flaw; H= High Cost, Complexity, or Effectiveness; M= Medium; L= Low Cost, Complexity, or Effectiveness

Table 3 lists a multiplier as the first step in the ranking of the alternatives. Each parameter is given a relative number for the importance of that parameter. In the Table 4, a subjective rating of that ranking is applied to provide a weight of that ranking. Then finally, the numerical weights of the rankings are compared one against another to provide a priority of the options to consider for meeting effluent criteria. These criteria and the weightings are specific to this project and will vary at other sites based on site conditions and owner desires.

Table 3. Project Specific Multiplier Weightings for Ranking Evaluation

	Multiplier	Comment
Commercially Proven	8	Proven Technology Elsewhere
Construction Time	7	Equipment Delivery and Construction
Operability (ease of)	5	Can the Operator easily operate process?
Hydraulic Variability (ability to manage)	5	EQ tank should buffer this.
Waste Loading Variability (ability to manage)	5	EQ tank should buffer this.
Chemical Storage & Delivery (extent, hazard, DG compliance requirements, complexity)	5	Impacts footprint and distances to premises boundaries; System security.
Secondary Waste	4	Was secondary waste created? If so, what is the difficulty and cost to manage?
Footprint (small)	4	Critical for this site.

Power Requirement (low)	4	Small flows - all relatively low.
Capital Cost (low)	4	Initial Capital including site acquisition and engineering
O&M Cost (low)	4	Can override capital over a long period of operation.
Start-up Period (low)	2	This is intended to be "initial commissioning".

Based on the Fatal Flaw Analysis, several treatment technologies were eliminated because of treatment deficiencies, space requirements, or other factors. The technologies passing the Fatal Flaw Analysis include Dual Stage Physical Chemical Precipitation; SRBR/Aerobic Wetlands; Single Stage Physical Chemical Precipitation; and SAPS.

The next step was to assign the rankings and relative weighting to those alternatives that passed the Fatal Flaw Analysis. In working with a client – consultant team-based approach, the ranking criteria and the relative weighting of the alternatives was assigned to each of these remaining alternatives.

Table 4: Consideration Ranking Definitions and Weighting Used for Technology Review

Considerations	Rankings	Multiplier	Definition
Commercially Proven	5	8	Frequently Used
	3		Often, but not Frequently Used
	1		Infrequent, but commercially available
Construction	5	7	Delivery in 2 months
	3		Delivery in 4 months
	1		Delivery 6 months or beyond
Operability	5	5	Requires minimal operator attention and expertise
	3		Requires moderate operator attention and expertise
	1		Requires full operator attention and expertise
Hydraulic Variability	5	5	Capable of handling wide flow variations
	3		Moderate upset due to flow variations
	1		Process unable to perform with flow variation
Waste Loading Variability	5	5	Capable of handling large water quality variations
	3		Moderate upset due to water quality variations
	1		Process upset occur easily
Chemical Storage & Delivery	5	5	Chemical storage and delivery not required
	3		Chemical storage and delivery required
	1		Hazardous chemical storage and delivery required
Secondary Waste	5	4	Produces no waste for treatment/disposal
	3		Produces waste that needs disposal
	1		Waste needs further treatment prior to disposal
Footprint	5	4	Requires small footprint
	3		Require moderate footprint
	1		Require large footprint
Power Requirement	5	4	Requires little energy
	3		Requires moderate energy
	1		Requires high energy
Capital Cost	5	4	Low capital cost
	3		Moderate capital cost
	1		High capital cost
O&M Cost	5	4	Low O&M cost
	3		Moderate O&M cost
	1		High O&M cost
Start-up Period	5	2	No start-up period required
	3		Moderate start-up period required
	1		Long start-up period required

Initial capital cost and operational costs were given a lower ranking compared to the probability of alternative consistently meeting effluent requirements with varying hydraulic and constituent load. Other factors were assigned in a similar consultative approach. The results of the rankings and weighting are presented in Table 5 for the aluminum, iron, and manganese reductions that were critical to this design approach.

Table 5. Comparative Selection Ranking and Weighting Scores

	Commercially Available	Construction Time	Operability	Hydraulic Variability	Waste Load Variability	Chemical Storage & Delivery	Secondary Waste	Footprint	Power	Capital Cost	O&M Cost	Startup Period	Summation Scores
Multiplier	8	7	5	5	5	5	4	4	4	4	4	2	
SAPS	8	7	10	5	5	25	15	4	20	12	20	2	133
SRBR/Aerobic Wetlands	8	7	15	15	15	25	15	12	20	20	20	2	174
Single Stage Physical Chemical Precipitation	40	35	15	15	15	15	9	20	12	12	12	10	210
Dual Stage Physical Chemical Precipitation	40	35	25	25	25	15	9	20	12	4	12	10	244

Based on the above rankings weighting, and summation score of the four alternatives showed, from highest to lowest ranking, are Dual Stage Physical Chemical Precipitation; SRBR/Aerobic Wetlands; Single Stage Physical Chemical Precipitation; and SAPS

CONCLUSIONS

Mining waste that contain complex constituents can be managed through a number of treatment alternatives, but selecting a defendable alternative involves more than just selecting the lowest capital cost approach. Often, the most appropriate solution may involve a number of successive treatment technologies to form an alternative. Treatment to achieve applicable effluent limits is required prior to discharge to a POTW, direct discharge, or other disposal alternatives. Obtaining quality data on flow and concentrations is critical and should be obtained over a theater of seasons. Selection of potential technologies can be narrowed by a structured evaluation process described in this paper. Additionally, there are a number of technologies that should be verified by treatability testing. Bench scale tests as well as field pilot tests are an integral component of a successful project. This structured evaluation technique is only a tool and should not supplant actual lab and field tests and process experience.

As treatment alternatives may be comprised of a number of individual technologies, comparative treatability should include the various highest ranking technologies to confirm a robust and cost effective approach to treating mining wastes. This holistic approach can achieve a defendable solution, as presented by the approach in this paper.

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