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ALTERNATIVES ANALYSIS FOR COAL SLURRY IMPOUNDMENTS

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INTRODUCTION

Disposal of coal refuse is a costly and challenging problem facing the coal industry today. After the Martin County Coal Company slurry spill and the subsequent regulatory changes state and federal agencies are now beginning to require companies to justify new slurry impoundments. The authors have performed an analysis of different means of disposing of coal refuse for a major coal producing company located in the eastern Kentucky coalfields (the name of which will be withheld for the purpose of this paper).

The company's existing slurry impoundment is nearing its maximum permitted elevation and also an elevation where it may come in contact with abandoned underground workings. Due to the increased concern with underground mine works near slurry impoundments, additional consideration was given to raising the existing impoundment. Several other alternatives were evaluated, including but not limited to raising the existing impoundment, constructing a new slurry impoundment, constructing slurry cells, belt presses and others. This alternatives analysis was performed as part of a Section 404 permit for a valley fill and is currently being reviewed by the U. S. Army Corp of Engineers.

All of the known possible alternatives were discussed in detail in the analysis. Due to the findings of the alternatives analysis, the company considers the engineered construction of the proposed impoundment to be the most favorable option of all the other alternatives evaluated, from both an economic and environmental standpoint.

ALTERNATIVES EVALUATION FOR COAL REFUSE/SLURRY DISPOSAL

<u>Background</u>

The company currently operates several deep mines and employ over 300 people and produces over 3.9 clean Mt/a (4 million stpy) of high quality, low sulfur coal. Currently, coarse refuse is belted to a valley fill, while, fine refuse is pumped to the existing impoundment. Coarse refuse is trucked to the existing impoundment as needed for construction purposes. The average recovery is approximately 50%; therefore, over 3.9 Mt/a (4 million stpy) of coal refuse must also be separated and placed.

The company has operated slurry impoundments and refuse fills for decades without a significant safety or environmental problem. The mine works which the impoundment may raise above date to the 1950s, so mapping is also a concern. Since the incident in Martin County, mine management has re-evaluated the safety and usefulness of the existing impoundment. The safety, environmental concerns and economics of continuing to raise the existing impoundment was compared to the construction of a new impoundment and several other alternative methods.

The existing impoundment is nearing the maximum permitted elevation; however, the company has many reserves remaining estimated to be 90 Mt (100 million st). Of these reserves approximately 95% will require processing. The processing plant is rated at 1440 t/h (1600 stph). It is in the company's economic interest to minimize the amount of material that must be disposed, as each ton of waste which must be placed adds to the total cost of the operation. Means of reducing the amount of waste material to be placed are being investigated. These include experimenting with different bit types and lacing on the continuous mining machines to reduce the amount of dust and fines being generated and minimizing equipment size to reduce out of seam dilution. Currently 2 of the mining units operate in areas where the coal thickness averages 0.76 m (30 in.), while the equipment being used needs a minimum clearance of 1.07 m (42 in.). It is anticipated that both of these units will continue to operate in similar conditions for the next several years. As always, this decision depends upon both the availability of equipment and necessary capital. Regardless of the advances in mining and preparation, there is still an enormous amount of coal refuse generated.

Modern coal cleaning technologies have allowed coal preparation facilities to become quite efficient at removing waste rock from run-of-mine coal. Up to 50 percent of the raw mined product may end up as refuse, as is the case for this operation. The refuse materials vary from coarse fragments to very fine materials. Technology today allows efficient separation of these materials from the coal. Coarse fragments are removed by physical screening while flotation and density separation processes are used for the cleaning of fines. The fines are of such a small size that separation from the water used in processing is extremely difficult.

In order to assess alternatives in a thorough manner, the whole system of mining, preparation, refuse placement, transportation, and utilization was considered through an in-depth assessment with the goal of optimizing the system to generate less fine coal waste while maintaining the performance and economics of the system. Some preparation plants re-combine coarse and fine refuse fractions before disposal, while others dispose of these fractions separately or in fills. Combining coarse and fine refuse creates a high-moisture refuse that must be placed in large surface area fills for maximum drying exposure. The refuse is compacted in place, and the entire fill must meet rigorous geotechnical stability standards. Unfortunately, the last coal refuse area failure, resulting in a fatality, was at a combined coal refuse area in Harlan County, Kentucky. The most common type of refuse disposal is done where slurry generated in the fine coal cleaning circuit is impounded behind a compacted dam of coarse refuse.

Another strategy for refuse disposal is slurry injection into abandoned underground mines with a separate coarse refuse disposal area. Underground injection is most practical, and now required by the EPA, in locations where mines are completely below drainage without the possibility of leakage at the outcrop. The EPA, for years did not approve of slurry injection in Kentucky; however, there are now several operations that utilize this process.

<u>The Mining and Coal Utilization Process</u>

Coal mining includes activities that range from mining to processing to disposal, and involves transportation and environmental aspects. Eliminating or substantially reducing waste streams is always a priority in business or industry. In coal mining, this can be accomplished by identifying the opportunities for limiting or removing coal refuse. Currently, refuse is created during the mining and processing stages and most commonly disposed of either in combined fine coarse refuse areas, coal slurry impoundments, injection into underground mines or combinations. The most common method utilized is coal slurry impoundments. Consideration of the entire mining process leads to the identification of alternatives to disposal of fine coal in impoundments by:

1. Reducing the amount of waste generated, either in mining or preparation process.
   - Selective Mining
   - Dewatering the slurry
2. Disposing of waste elsewhere.
   - Underground injection
   - Surface fills
   - Consider topographic constraints
3. Utilizing the waste.
   - 90% of coal mined is used in power plants
   - Integrate power plant technology with mining/processing system
   - New technology allows burning of low BTU coals
   - Use of “coal water slurry” as fuel
   - Dry cleaning after pulverization process (magnetic and electrostatic separation)
   - Alternatives not likely for several years
   - Waste stream is still generated

<u>Minimizing Slurry Generation</u>

Coal mining and processing operations are designed to minimize the amount of coal refuse and slurry generated. Reducing slurry volumes include mining and coal processing alternatives. Modern surface and underground mining methods offer limited possibilities for quality control during mining. Mining operations have always been planned to extract coal from the best quality seams and minimize dilution with noncombustible material. This approach is commonly used in both surface and underground mining, but this is more difficult to apply in this area where the highest quality seams have already been mined.

After mining and preparation, the fine refuse contains water, fine coal, and fine rock particles. The percentage of each is dependent on the level and efficiency of the cleaning methods employed. Improving fine coal recovery and minimizing the mass of solids for disposal reduces slurry volume. The slurry volume can be further reduced by dewatering - increasing the proportion of solids to water. The ability to do either or both of these depends on the method of extraction, the amount of slurry dilution, coal characteristics (i.e. the hardness of coal affects the size and quantity of fine particles produced), and the local geology (clays in adjacent strata produce a refuse that is more difficult to dewater).

The different methods available for recovering coal fines go beyond the scope of this project. Even if all or most of the coal fines are recovered, it will not eliminate the need for slurry impoundments, but it will reduce the required disposal volume. It should be noted that recovery of the coal fines may produce slurry that is more difficult to stabilize due to the increased clay content and no incentive will exist for recovery of inactive impoundments without a certain proportion of fine coal particles. It should also be noted that the recovery of these fine coal particles will be extremely costly, with the technology which is currently available.

In contrast if dewatering of the refuse stream is possible, it has the potential for eliminating the need for slurry impoundments by changing the strength properties of the waste material. Disposal of the resulting dewatered waste does raise other issues that are discussed in a later section.

Dewatering employs either sedimentation or filtration or both. During sedimentation the liquid is constrained and the solid particles move freely. Resulting in clarification of the liquid and thickening of the remaining slurry. During filtration the particles are constrained by a medium while the liquid flows through. This is accomplished by screening and centrifugation. There are a variety of filtration devices which are commercially available; however, they will not be discussed in detail in this paper.

<u>Slurry Disposal Alternatives</u>

While slurry impoundments are by far the most widely used disposal system in the eastern United States, they are not the only method. Alternative methods to slurry impoundments include underground and surface options. These include underground slurry injection, combined refuse disposal, incised ponds, slurry cells, co-disposal, and residue stacking. While there are many variations of each of these options, they go beyond the scope of this article and will not be discussed in detail. Only the methods which were determined to be viable options will be discussed below. A copy of the entire report can be obtained by contacting the authors.

SUMMARY AND CONCLUSIONS

<u>Disposal Methods Available</u>

Of all the alternatives considered, there is one underlying necessity: a physical location for the placement of the material separated during coal processing whether it be a dry, wet, or slurry fill. Over current projections for the life of the operation, approximately 57 Mt (60 million st) of coal refuse must be permanently placed. The authors reviewed engineering and cost analyses of alternative disposal plans. Summarizing the earlier discussion, there are four general methods available for coal refuse disposal:

- Option A: Combined coarse and fine fills
- Option B: Coarse fill with underground injection
- Option C: Slurry cells (with combination of above options)
- Option D*: Coal refuse embankment and slurry impoundment

*There are two possible scenarios under this option. One is to raise the existing impoundment an additional 15.24 m (50 ft). The second is the engineered construction of the proposed impoundment. Both will be discussed in detail below.

Option A: Combined coarse and fine fills. Combined fills are extremely difficult to operate and can cause environmental problems due to the wet nature of the material. High moisture contents cause concerns about the structural integrity of fills used to dispose of combined coarse and fine mixtures. To achieve optimum stability in combined refuse fills, two conditions must be present. The first is that the combined fine and coarse materials have moisture content in a range that is most conducive for compaction. This range has proven to be approximately 5% to 9%. A typical minimum moisture content of 30% can be anticipated for material processed by belt filter presses. Based on current production rates with an assumed average moisture content for the coarse refuse of 7%, and an average moisture content of 30% for the fines product, a typical combined product would thus produce a moisture content of approximately 10.2%. This moisture content exceeds the upper range of optimum moisture content for effective compaction.

The second optimum situation for the compaction of combined refuse is that there be sufficient area to allow for placement and compaction. Conditions for this situation are not good due to the limited areal extent of the refuse fill associated with this facility, and the volume of material generated. It should also be noted that these calculations are based on moisture content relative to tons produced of each product and do not account for the volumetric quantities produced. At assumed general densities of 65-lbs/cubic foot on the fine refuse and 110-lbs/cubic foot on the coarse refuse, the percentage by volume becomes 19.3% fines and 80.7% coarse. These volumes represent a less than desirable ratio to achieve optimum compaction.

In addition to problems with achieving compaction of the combined refuse material due to the inherent moisture content, there are problems associated with weather and economics. During the wet season (November through March), the combined fine and coarse refuse tends to absorb more atmospheric moisture than coarse refuse alone. This further hinders optimum compaction.

ECONOMICS: Economics were also factored into the process when considering the addition of filter presses in the preparation process. Initial estimates received from a general survey of other companies indicate an approximate per ton cost of $1.50 to $2.00 for all aspects of utilizing filter presses.

The following is an economic comparison of belt presses to a slurry impoundment. It should be noted that this comparison is based on historical data kept by a sister company operating in the same general area. The size consistency of fines for both preparation plants is similar; therefore, it is assumed that the chemical dosage rate per treated ton will be the same. Slurry underflow quantities for the sister company and the company are 700 and 900 gallons per minute (gpm), respectively and dry hourly fines production is 102 tph (113 stph) and 140 tph (stph), respectively. The belt press material haulage distance is assumed to be the same; however, an additional truck will be required to haul the material without delay at the company's facility. Clean plant throughput is assumed to be 3.9 Mt/a (4 million stpy). It is also assumed that the fine refuse can be successfully transported to the disposal site and mixed and compacted with the coarse refuse. If this cannot be accomplished, additional handling costs will be incurred.

The following is a cost per ton comparison based on actual historical figures:

Item	Impoundment	Combined Fill
Chemical	$0.05	$0.80
Coarse Handling	$0.03	$0.03
Coarse Placement	$0.19	$0.19
Fines Handling	N/A	$0.68
Pond Maintenance	$0.07	$0.07
Operating Cost	$0.03	$0.08
Depreciation	$0.13	$0.24
Slope Maintenance	$0.07	$0.07
Total	**$0.57**	**$2.16**

Difference = $1.59 per Clean Ton

At 3.9 Mt/a (4 million clean stpy), this amounts to a total of $6.4 million annually. Due to all of the operational, environmental and economic factors described, a combined coarse and fine refuse fill is not a viable option for this operation.

Option B: Coarse Fill with Underground Injection. Underground injection is not feasible in this location. Normally, underground injection of coal slurry is most practical in locations where old abandoned mines are completely below drainage without the possibility of leakage at the outcrop. The company operates one mine which is completely below drainage; however, it is approximately five miles away and is active. The great depth of this mine is also a hindrance to underground injection. The average depth of the mine is approximately 365 m (1200 ft), which increases the difficulty of dewatering. Pump manufactures do not recommend pumps for applications of more than 304.8 m (1000 ft) of vertical head. Underground injection could be a future alternative at this site, when underground works are developed closer to the preparation plant; however, this development is not in the ten year mining plan. Other existing mines are either active or completely above the watershed. These factors along with the fact that the decant water from this process must meet drinking water standards, makes underground injection not an option in this case.

Option C: Slurry Cells. The primary constraints to the development of slurry cells as a viable alternative to the proposed slurry impoundment are limited space and cost for the development and maintenance of these cells. The topography surrounding the company's preparation plant consists of steep slopes and narrow valleys. Unlike other areas where abandoned surface mining sites are being used for cell development, the surface mining that has been done in the area surrounding this site, has been limited to contour mining and point removal, with very little level ground created that would lend itself to slurry cell development. The potential sites for cell development that were identified are the existing coarse refuse fill and slurry impoundment. The existing impoundment would only be available for cell development once its life as an impoundment is complete and abandonment has begun.

At current production rates the plant is producing approximately 25,000 cu m (20 acre feet) of slurry per month and approximately 107,000 cu m (140,000 cu yd) of coarse refuse that could be utilized in the construction of cells. The existing coarse refuse fill has a surface area of approximately 48,500 sq m (12 acre) that could be utilized for cell development. The optimum scenario for abandonment of the existing impoundment would be to allow a sufficient amount of time for drying and compaction of the slurry material, to where the slurry can be safely capped with coarse refuse. The 48,500 sq m (12 acre) that are available for cell development at the dry fill would allow for 3 to 4 months of slurry storage. Were a commitment made to utilize the existing dry fill and slurry impoundment for cell development, it would require immediate disposal of coarse refuse at the existing impoundment, due to the limited space at the coarse fill. This in turn would not allow sufficient time for the drying and consolidation of the slurry in the existing impoundment. There is no practical way of predicting the amount of coarse refuse that would be required to accomplish a stable enough situation at the existing impoundment so as to utilize slurry cells at that site. It is almost certain that cells could not be developed on the abandoned existing impoundment site within the 3 to 4 month time frame that would be necessary to maintain continuity of production.

It should be noted that the 3 to 4 cells that could be constructed at the coarse refuse site could not be covered and new cells constructed in a timed sequence of placing cells on top of one another, due to the time required for cells to dry before being covered. As reported by the National Research Council in regard to *ALTERNATIVES FOR FUTURE COAL WASTE DISPOSAL*, page 153; “The time required varies according to weather conditions, but the fine refuse is usually dry enough in two to three months to allow coarse refuse to be placed on top and compacted.” The time frame required for the covering and subsequent construction of new cells at the coarse refuse site should the existing impoundment not be available, would almost certainly cause a delay in production.

From an operational standpoint, in terms of safety, and an environmentally sound approach to the utilization of slurry cells, space is of the essence. Just as the optimum situation for abandonment of the existing impoundment is a sufficient amount of time to allow for drying and compaction of the slurry material before capping with coarse refuse, the same holds true for slurry cells as well. Due to the limited area available with these sites a continuous progression of placing new cells atop recently capped cells would be essential. Although this procedure can be shown to be feasible through proper design and implementation, it remains a marginal option at best in areas where fill instability, could have enormous impacts both in terms of safety and environment, and where time constraints are critical as they would be for these sites. To quote once again from the National Research Council report, page 153, “The main disadvantage in steep terrain is the limited availability of flat land to construct the cells. Another disadvantage is that slurry cell operations are not compatible with a high production rate at the coal preparation plant. The maximum plant capacity for this type of disposal option is about 500 tons per hour. Even at this rate several cells must be permitted and in varying stages of operation at any one time.” As previously stated both detrimental situations occur at this operation i.e., limited space and a high production preparation plant (1440 tph). This is a luxury that simply is not available is this case.

The parent company has had experience at a previously active operation of utilizing slurry cells. It was reported by a company representative that these cells worked adequately, however the production rate of this plant was somewhere near one fourth of the current operation’s plant, 360 tph vs. 1440 tph (400 stph vs. 1600 stph), and cells less than 25,000 cu m (20 acre-ft) took from 2 to 3 months to fill, allowing drying time for previously used cells. Estimates of the current slurry output for the current operation are from 22,200 to 25,000 cu m (18 to 20 acre-ft per month).

Slurry Cell Development Economics

The company’s current, refuse handling costs for both coarse and fine refuse disposal is approximately $0.54 per clean ton of coal processed. The currently utilized disposal method consists of pumping the fines, or minus 100 mesh refuse product to the existing impoundment, and conveying the coarse product by conveyor belt to the coarse (dry) refuse fill. The coarse refuse is spread by a single Caterpillar D10 class dozer in 0.61 m (2 ft) compacted lifts. Additional costs associated with the disposal of the coarse refuse product include the equipment and labor costs to slope, grade terraces, and install drainage structures and reclaim the fill. The per ton cost figure quoted above accounts for the cost associated with performing these various functions as well as chemical costs for fines consolidation, and depreciation associated with the construction of the existing impoundment and equipment to convey the coarse refuse. The following is a summary of these costs on a per clean ton basis.

July 2002 Refuse Handling Cost on a Per Clean Ton Produced Basis

Chemical	$0.05
Refuse Hauling	$0.03
Refuse Placement	$0.19
Pond Const. /Maintenance	$0.07
Depreciation	$0.13
Slope/Drainage/Reclaim	$0.07
Total	**$0.54**

Based on current rates for equipment and labor that would be required for the construction and maintenance of slurry cells it is anticipated that this cost per clean ton would increase from the current $0.54 per ton rate to approximately $0.90 per ton or a 67% increase.

Anticipated Refuse Handling Cost on a Per Clean Ton Basis Utilizing Slurry Cells

Chemical	$0.05
Refuse Hauling*	$0.22
Refuse Placement*	$0.36
Pond Const. /Maintenance	$0.07
Depreciation	$0.13
Slope/Drainage/Reclaim	$0.07
Total	**$0.90**

* The increased cost in Refuse Hauling and Placement is due to the necessity to utilize 3 trucks and 2 dozers to accomplish the same task that is now done with one dozer. This increase equates to approximately $64,500 per month that would be added to the operating cost.

Due to the space constraints that the company would have to operate under, and the associated concerns with timing and proper construction of slurry cells, they are not considered as a viable alternative to the proposed impoundment. The economics of building and maintaining slurry cells over an extended operations time such as is anticipated for this operation, also proves to be unfavorable.

Option D: Coarse Refuse Embankment and Slurry Impoundment. In this case, a coal refuse embankment and slurry impoundment has been selected as the most feasible and lowest risk choice. The company has been utilizing engineering designed and constructed impoundments for the disposal of fine refuse for decades. To date, the company has not been experienced any significant structural stability problems with any of these structures. Nationwide, since the advent of stringent legislative regulations passed in the 1970’s, regulating both the design and construction of such impoundments, not a single dam has failed. Slurry impoundment problems that have occurred since that time are the result of leakage into underground mines – not embankment failure.

As was mentioned previously, there are two possible scenarios under this option. The first is to raise the existing impoundment an additional 15.24 m (50 ft). As was mentioned previously, the impoundment will be rising above underground mine works. The highwall which intersects these mine works is located upstream from the dam of the existing impoundment. Raising the existing impoundment will only add approximately 4 years of life. Therefore, another refuse alternative would have to be in place in the near future regardless. While it is believed that the existing impoundment can be operated safely, it has been decided to pursue the proposed impoundment since no underground works will be associated with its design and construction. Due to these concerns and the limited life associated with raising the existing impoundment, this is not considered a viable option.

Coarse refuse embankments have proven to be both cost effective and safe as a means of disposing of fine refuse. In light of safety concerns and economic restraints that are associated with Options A., B and C, constructing a new slurry impoundment is the most viable choice.

Another consideration is that the design of construction of new impoundments takes into consideration the body of knowledge available from past experience, including mistakes. Slurry impoundments have frequent inspections by certified inspectors from within the company, outside consultants, and state and federal regulatory agencies. Another advantage for the proposed impoundment is that there are no underground mine works which will have to be compensated for. Also, new slurry impoundments, which are the best available technology for coal slurry disposal in most cases today, will allow older impoundments to be gradually decommissioned, i.e., dewatered and reclaimed. Therefore, the engineered construction of the proposed impoundment is the only viable option for this particular operation.

CONCLUSION

The Committee on Coal Waste Impoundments stated, “The committee concludes that although there are alternatives to disposing of coal waste in impoundments, no specific alternative can be recommended in all cases”. As this report shows, the engineered construction of the proposed impoundment is the safest, most environmentally sound and economically viable option which exists for this operation. As mining and processing technology improves over time, the possibility exists that less material will need to be placed in the new impoundment, thus extending its life. Also, as in the past, the company expects to continually review new technology that can improve operations and reduce volumes of coal refuse safely and economically.

As noted previously, the only fatality associated with the failure of a refuse handling facility since the implementation of Federal laws governing the design and construction of such facilities, occurred at a combined refuse disposal site in Harlan County, Kentucky. This incident along with numerous other failure incidents cited in the National Research Council’s Report on Coal Waste Impoundments, identifies problems all of which are addressed in the design of the proposed impoundment. The proposed impoundment eliminates the necessity to combine coarse and fine refuse, and eliminates the stability problems that can be associated with that practice. The incidents referenced in the report as having occurred as the result of sudden inundations into surrounding abandoned mine workings are not a concern with the proposed impoundment. No abandoned deep mine works exist in the immediate vicinity of the dam or the impoundment that will be created. Other incidents of refuse facility failure referenced in the report attribute heavy rainfall amounts as being contributory to the failures.

The proposed impoundment as designed makes provision for the containment and safe release of precipitation events. The minimum design criteria allows for the containment of a 100 year storm event through the construction of the Starter Dam, up to the containment of the Probable Maximum Flood event once the final stage is completed, a construction time estimated to be approximately 5.8 months.

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