Project Title: **THE USE OF TAILINGS IN UNDERGROUND COAL MINES IN THE USA**

ICCI Project Number: 08-1/US-6  
Principal Investigator: A.J.S. (Sam) Spearing, Southern Illinois University  
Project Manager: Joseph Hirschi, Illinois Clean Coal Institute

**ABSTRACT**

The mining and use of coal creates a significant amount of waste materials that need to be safely disposed of. It is likely that in the medium term the US Environmental Protection Agency will categorize all such products as toxic, which will complicate the disposal of such products and significantly increase disposal costs. Backfilling or underground disposal is a natural, if not obvious solution, especially if the material placed back in a mine can have low or no permeability so that water table pollution does not present a serious long-term issue after placement. This research using a specific coal waste product proved that the concept of placing backfill at a high density with low permeability is technically viable; however, the methodology requires additional study and it must be made more cost effective. In addition to solving the onerous waste disposal problem, other significant advantages that could be derived from backfilling include reducing or eliminating surface subsidence caused by mining, increasing extraction ratios so that a higher percentage of reserves are recovered, and eliminating the need for explosion proof seals in worked out areas. These potential benefits need to be quantified in terms of technical feasibility and economics in order to present a true comparison with existing technologies for waste disposal.
EXECUTIVE SUMMARY

Most coal mines in the USA use conventional impoundments to dispose of washing plant waste. It is likely that the US Environmental Protection Agency (EPA) will declare such products to be toxic in the near future. This will result in disposal costs increasing significantly. In addition, the environmental lobby is trying to stop the granting of new or modified impoundment permits. The only viable option in the future may be to dispose of these waste products underground. The issue however is the potential contamination of the water table in the long term from water run-off through the placed backfill (Keating et al., 2009). The only solution would be to place the fill with a low (as yet undetermined) permeability coefficient. This can only be achieved by placing the fill at a high density, low porosity, and possibly with a cement addition.

Rheology is the key to the fill design and placement and the project proved that a test material could be produced that met the requirements of a high density placed material with a low permeability. The costs are however higher than current conventional impoundments although impoundment costs are likely to increase as permitting is becoming more time consuming and permits more difficult to obtain. Current surface disposal costs are around $2 to $3/m³ and present backfill total cost is around $12/m³ based on this study. It is anticipated that this could be reduced to about $6 to $7/m³ by dosage optimization and economies of scale. Additional direct and indirect savings would also be gained by backfilling which have not been included in this study, such as:

- Surface subsidence is practically eliminated when backfilling in room and pillar mines and there is about 60% surface subsidence reduction when used with longwall mining.
- The extraction ratio or percentage of reserves recovered in room and pillar production units could be increased because the volume mined would be totally replaced on completion of mining, thus reinforcing pillars and floor substantially, and allowing smaller pillars to be left behind.
- Explosion proof seals needed after a room and pillar production panel has been fully extracted could be eliminated. Six seals can cost as much as $150,000.
- There is no risk of an impoundment failure on the surface and, since the backfill will be placed at a high density and with cement, the material will not liquefy once placed and set underground either.
- Surface impoundment costs are likely to continue to rise whether or not the US EPA classifies coal washing plant waste and coal combustion products as toxic.
- There are no long-term and ongoing costs associated with re-vegetation and water treatment of the impoundment.
- Improved public perception occurs as a mine footprint would be much smaller and easier to manage without a significant impoundment.

These benefits have not been investigated to date as they were beyond the scope of this research project; however, based on this research, it is recommended that a site-specific study be undertaken to fully compare disposal options.
OBJECTIVES

Objectives of this project were to:

- Establish the technical feasibility of using fill effectively in coal mines.
- Compare the cost effectiveness of backfill in coal mines against conventional disposal methods.
- Design and cost an idealized fill system for a coal mine.

INTRODUCTION AND BACKGROUND

Backfilling is the process whereby waste material (generally metallurgical tailings, prepared aggregate, or a combination) is placed back underground into open mine workings. This has many potential advantages for typical underground mining applications, such as:

- Reduced tailings on surface.
- Reduced surface subsidence.
- Increased underground extraction.
- Reduced rockburst (seismic) damage.
- Improved support for mining excavations and/or working surfaces.
- Increased worker safety.
- Improved ventilation.
- Reduced fire risk.

For coal mining, the reduced surface subsidence and the increased underground extraction are important. An additional and significant advantage is that it could replace the need for explosion proof seals. Considering all these advantages, it is likely that backfilling in coal mines would be cost effective. International backfill experience shows un cemented fill typically only costs between $1.50 to $2.50/ton placed underground and cemented fills from $4.00 to $6.00/ton placed underground.

Current coal waste surface disposal is reported to be up to $6.00/ton (Mohanty et al., 2007) and if the advantages of reduced subsidence, increased extraction (room and pillar only), and eliminating explosion proof seals are factored in, backfilling should be less costly, improve safety, and be more environmentally friendly. The best case scenario is that savings could be potentially large with significant safety and environmental advantages.

Backfilling is not a new technology in North American mines but it has been seldom used on coal mines and has not been fully studied and optimized when used. For coal mines, pipeline transportation would be the most cost effective backfilling technology using as much of the available hydraulic head as possible (i.e., via vertical boreholes or shafts).

Admixtures can improve the flow of backfill pastes but foam technology may be more effective. Foams are commonly used with cementitious mixes in underground
construction projects such as to pump grouts behind concrete segments in tunnels excavated by tunnel boring machines (TBMs). These mixes are routinely pumped in small diameter pipes over 10,000ft.

Foam technology could be a solution as it combines the benefits of both a paste and a hydraulic fill because:

- For transportation, the foam produces a “pseudo” low density slurry making pipeline pressures low and reducing pipe wear rates.
- After placement, the foam is destroyed producing a paste like material with desirable physical properties.

Foam technology however may not be viable as foams are adversely affected by free carbon.

Aspects that need specific coal related research include:

- Establishing the rheology of coal waste when used as a fill material, and optimizing it. With this information the technical and financial viability can be determined.
- A new conceptual transportation and discharge design with foam, if it proves viable.
- The performance of backfill material after placement/deposition.

Backfilling has been successfully implemented on numerous mines and benefits derived from the judicious use of admixtures has been well documented (Spearing, 2000). In addition, limited testing at BASF (Spearing et al, 2010) has enabled the following potential advantages of foamed fill to be identified:

- Foam enables/improves the transport properties of relatively dry, coarse materials.
- Foam reduces and in most cases eliminates segregation of solids and water in high density backfills during transport.
- Foam lubricates plug flow by forming an air annulus between the plug and the pipe wall.
- Foamed material will compress under pressure and expand upon release of pressure, but remains unproven in a full-scale pipeline of significant length.
- There is a significant decrease in the compressive strength of backfill material that has not been subjected to de-foaming.
- The amount of foam generated during mixing increases with the degree of gap grading or void ratio of the material being foamed.
- The addition of foam to material that is being pumped, regardless of particle size gradation, significantly decreases pumping pressure.
EXPERIMENTAL PROCEDURES

This research focused on the rheology of the coal waste candidate material from a mine in Illinois. Rheology is the key as it governs the distribution infrastructure (pipe and pump sizes) needed, the preparation method, the method of placement and containment, in addition to performance once placed underground. It is therefore the key to the total in-place cost and technical viability. Characteristics of the specific coal waste material used in this research was not important, as the rheology test methodology using pipe loops can be used on any potential backfill material.

Two pipe test loops, one 2-inch and the other 3-inch in nominal diameter, were used in order to be able to establish a scaling methodology for extrapolation to larger pipe diameters. The relationship is not linear. Figure 1 is a schematic of the test loop system as designed by the subcontractor on this project, Paterson & Cooke. Figure 2 is a view of the apparatus being assembly at the Illinois Coal Development Park (ICDP). These loops were used to investigate the effect of tailings mix design, admixtures, tailings concentration, and pipeline pressures on rheology. The objective of the work was to identify optimum mix designs in terms of minimizing pipeline friction losses and the amount of water in the fill. Minimizing the amount of water in the fill reduces water handling after placement underground and optimizes fill performance after placement.

Figure 1: Isometric view of the 2-inch and 3-inch combined pipe loop system.
Figure 2 shows the actual pipeloop test apparatus.

![Figure 2: Pipe loops being assembled.](image)

RESULTS AND DISCUSSION

**Task 1** - Build and commission the 2 pipeline test loops.

Paterson and Cooke, the consultant subcontracted for this task, designed the test loop system chosen for this project. The rig was ordered, assembled, and commissioned after some modifications to improve accessibility and operational safety. Modifications and retrofits included the following, some of which are shown in Figure 3:

- A ladder up the vertical pipe sections to access pressure gauges safely.
- A stairway and handrail to the tank and mixer.
- Additional valves to help clean loops after testing or to clear the system in case of a blockage.
- A valve bank to help flush any build-up from pressure transducers.
- A removable canopy to protect the PC data logger from the elements and to shade it from sun glare, which made it difficult to read.
- Pipes were welded to a frame to stop them from vibrating and moving during high
pressure tests. This would also however pose a problem if there was a serious blockage as it would be difficult to remove and clean pipe sections.

The pipe loop test system was commissioned mainly by SIUC personnel, the Paterson and Cooke representative, Malcolm Keevey, and technicians from Heartland Pumps of Carterville, IL.

![Figure 3: Two views showing some of the test loop modifications.](image)

**Task 2** - Work in the short term with a local mine to establish a slurry backfilling system that can be converted into a higher density/paste system at a later stage. Establish baseline rheology for a typical coal waste at different densities.

The flow behavior of any candidate material needs to be tested individually as it changes mainly depending on particle size distribution (PSD) and mineralogy. To establish whether high density backfilling was viable, a random spiral waste product material was selected for testing. Unfortunately, the mine operator who had committed to cooperate with this project when the proposal was submitted was unwilling and unable to participate in the research for various non-technical reasons. Fortunately, a different southern Illinois coal mine provide enough spiral waste product from their preparation plant to complete the work.

The spiral waste sample was sieved through various standard screens up to 150 microns (U.S. sieve No. 100). Only 17.1% of the sample passed the 150 micron sieve. The size distribution of the portion of the sample that passed the 150 micron sieve was determined using a Fritsch Particle Laser Sizer. A composite graph of this size analysis is given in Figure 4.

The mineralogy of both the material retained on the 150 micron screen and the material that passed the screen was determined by XRD. The material retained on the screen contained mainly calcite and quartz with less illite, kaolinite, and pyrite, and with only a trace of marcasite. The material passing the screen contained quartz and illite with less kaolinite, pyrite, and calcite and a trace of marcasite. Pyrite and calcite are more
abundant in the coarser portions of the tailings.

![GARSON CONTROL: MECHANICAL + LASER PARTICLE SIZE ANALYSIS](image)

**Figure 4:** Particle size distribution of the spiral waste.

In the 2-inch diameter pipe loop, the maximum density that could be transported without an admixture to reduce the pressure was less than 1.63. At a relative density of 1.63, the material became unstable and the pressure increased uncontrollably as the material started to plug the pipe loop.

Figures 5 through 10 show readings from pressure transducers located in the 2-inch pipe loop at different material relative densities. Figures 11 through 16 show the same information for the 3-inch pipe loop. Six pressure transducers were used and a density meter was also fitted to the system. These results are summarized in Tables 1 and 2. For reference purposes, pressure readings when just water is pumped through the 3-inch test loop are provided in the Appendix.

The pressure drop information provided in this data can then be used to design a backfill system with a predetermined maximum flow rate and a fixed delivery path.
Table 1: Results in the 2-inch pipe loop.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Flow rate (m³/hr)</th>
<th>Relative density</th>
<th>Maximum pressure (kPa)</th>
<th>Maximum pressure differential (kPa)</th>
<th>Flow rate (m/s) and Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>7.3</td>
<td>1.2</td>
<td>26</td>
<td>3.0</td>
<td>0.93</td>
</tr>
<tr>
<td>60</td>
<td>29.5</td>
<td>1.2</td>
<td>138</td>
<td>101.2</td>
<td>3.77</td>
</tr>
<tr>
<td>15</td>
<td>7.2</td>
<td>1.3</td>
<td>29</td>
<td>5.2</td>
<td>0.92</td>
</tr>
<tr>
<td>60</td>
<td>29.2</td>
<td>1.3</td>
<td>144</td>
<td>106.5</td>
<td>3.73</td>
</tr>
<tr>
<td>15</td>
<td>7.0</td>
<td>1.4</td>
<td>46</td>
<td>16.4</td>
<td>0.90</td>
</tr>
<tr>
<td>60</td>
<td>29.1</td>
<td>1.4</td>
<td>163</td>
<td>123.8</td>
<td>3.72</td>
</tr>
<tr>
<td>15</td>
<td>6.8</td>
<td>1.5</td>
<td>70</td>
<td>35.4</td>
<td>0.87</td>
</tr>
<tr>
<td>60</td>
<td>29.1</td>
<td>1.5</td>
<td>206</td>
<td>161.7</td>
<td>3.72</td>
</tr>
<tr>
<td>15</td>
<td>7.1</td>
<td>1.6</td>
<td>211</td>
<td>157.2</td>
<td>0.91</td>
</tr>
<tr>
<td>60</td>
<td>29.0</td>
<td>1.6</td>
<td>388</td>
<td>318.1</td>
<td>3.71</td>
</tr>
<tr>
<td>15</td>
<td>6.9</td>
<td>1.63</td>
<td>939</td>
<td>781.7</td>
<td>0.88 Unstable</td>
</tr>
<tr>
<td>60</td>
<td>28.5</td>
<td>1.63</td>
<td>1003</td>
<td>851.8</td>
<td>3.65 Unstable</td>
</tr>
</tbody>
</table>

Note: The internal diameter of a 2-inch Schedule 40 pipe is 2.07 inches.

Table 2: Results in the 3-inch pipe loop.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Flow rate (m³/hr)</th>
<th>Relative density</th>
<th>Maximum pressure (kPa)</th>
<th>Maximum pressure differential (kPa)</th>
<th>Flow rate (m/s) and Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>7.4</td>
<td>1.2</td>
<td>19</td>
<td>0.6</td>
<td>0.43</td>
</tr>
<tr>
<td>60</td>
<td>29.6</td>
<td>1.2</td>
<td>64</td>
<td>35.5</td>
<td>1.72</td>
</tr>
<tr>
<td>15</td>
<td>7.4</td>
<td>1.3</td>
<td>23</td>
<td>1.7</td>
<td>0.43</td>
</tr>
<tr>
<td>60</td>
<td>29.5</td>
<td>1.3</td>
<td>71</td>
<td>39.8</td>
<td>1.72</td>
</tr>
<tr>
<td>15</td>
<td>7.1</td>
<td>1.4</td>
<td>30</td>
<td>5.5</td>
<td>0.41</td>
</tr>
<tr>
<td>60</td>
<td>29.5</td>
<td>1.4</td>
<td>76</td>
<td>42.2</td>
<td>1.72</td>
</tr>
<tr>
<td>15</td>
<td>6.9</td>
<td>1.5</td>
<td>46</td>
<td>16.7</td>
<td>0.40</td>
</tr>
<tr>
<td>60</td>
<td>29.4</td>
<td>1.5</td>
<td>90</td>
<td>51.5</td>
<td>1.71</td>
</tr>
<tr>
<td>15</td>
<td>6.7</td>
<td>1.6</td>
<td>100</td>
<td>61.6</td>
<td>0.39</td>
</tr>
<tr>
<td>60</td>
<td>28.8</td>
<td>1.6</td>
<td>151</td>
<td>101.0</td>
<td>1.68</td>
</tr>
<tr>
<td>15</td>
<td>7.0</td>
<td>1.67</td>
<td>185</td>
<td>129.1</td>
<td>0.41</td>
</tr>
<tr>
<td>60</td>
<td>27.8</td>
<td>1.67</td>
<td>287</td>
<td>214.6</td>
<td>1.62</td>
</tr>
</tbody>
</table>

Note: The internal diameter of a 3-inch Schedule 40 pipe is 3.07 inches.
Figure 5: 2-inch diameter pipe loop at relative density of 1.2.

Figure 6: 2-inch diameter pipe loop at relative density of 1.3.

Figure 7: 2-inch diameter pipe loop at relative density of 1.4.
Figure 8: 2-inch diameter pipe loop at relative density of 1.5.

Figure 9: 2-inch diameter pipe loop at relative density of 1.6.

Figure 10: 2-inch diameter pipe loop at relative density of 1.63 (pressures still climbing)
Figure 11: 3-inch diameter pipe loop at relative density of 1.2.

Figure 12: 3-inch diameter pipe loop at relative density of 1.3.

Figure 13: 3-inch diameter pipe loop at relative density of 1.4.
Figure 14: 3-inch diameter pipe loop at relative density of 1.5.

Figure 15: 3-inch diameter pipe loop at relative density of 1.6.

Figure 16: 3-inch diameter pipe loop at relative density of 1.66.
Task 3 - Improve on the optimum density using admixtures.

In the 2 inch diameter pipe loop, the spiral waste at a relative density (RD) of 1.63 became unstable and very difficult to pump with pressure continuing to increase and not stabilize. Instantaneous measurements were however still taken as shown in Figure 17.

In an effort to control the spiral waste paste slurry, admixtures were added. The first two admixtures had no effect, but the third admixture (a proprietary development dispersant from BASF) had a very dramatic effect on reducing the pressure (before the pump seized due to the strain it had been under) as shown in Figure 18.

![Figure 17: Unstable flow in the 2-inch pipe loop at RD of 1.63.](image1)

![Figure 18: Pressure reduction in the 2-inch pipe loop using BASF dispersant.](image2)

Similar results were obtained with the 3-inch pipe loop as shown in Figures 19 and 20. Initially, at a small dosage level of 100 ml of dispersant, the pressure remained the same; but at 1,000 ml, the pressure reduction was significant.
These results showed the potential benefits of admixtures in pumping high density coal waste materials. These benefits of reduced pressures have been well established internationally on rock backfill applications, but coal waste mineralogy is clearly very different and additional product development is still needed.

**Task 4** - Experiment with foam technology to see if it can be practically applied.

Reduced water content in backfill material would have obvious advantages such as increased strength, reduced negative effect on a weak floor (e.g. fireclay) from run-off water during placement, reduced shrinkage, and improved stability. It was hoped that foam would reduce water content and also make the material flow more easily having a lower pressure gradient. Preliminary testing in the laboratory using mainly a slump cone (see Figure 21) revealed good potential for incorporating foam with the objective of further reducing total water content in a pumpable coal waste paste/slurry. The photograph on the left of Figure 22 shows spiral waste with limited water in a state that would be impossible to pump. The photograph on the right of Figure 22 shows the same material with a foam addition that made it at least readily flowable in the lab.
Tests were undertaken with the pipe loop using a powdered foaming agent from BASF. The spiral waste material was mixed at a reduced water content with the foaming agent in a conventional concrete mixer and introduced via buckets into the tank above the pump. The foamed material was readily flowable as shown in Figure 23.

Figure 21: Slump tests with and without foam (same water content).

Figure 22: Spiral waste with (right) and without (left) a foam addition.

Figure 23: Mixing spiral waste and the foam effectively.
Foamed material was introduced four different times into the pipe loop and each time a serious blockage was created. Flushing was very difficult and the pump stalled multiple times during each test. Using luck and by-pass valves with pressurized water, the blockages were cleared each time and the material discharging from the loop was found to “plug” (i.e., exhibit no signs of any foam). It is believed that under pressure, clays in the spiral waste became active and absorb the water that helped to create the foam, thus causing it to collapse and form high solid plugs.

BASF believes that the solution will be to create a new admixture that has the ability to act as a clay dispersant (as was the successful admixture used) and also offer limited foaming. They are working on development of this new product.

**Task 5** - Prepare a conceptual backfill design for optimum rheologies (this task was subcontracted to Paterson and Cooke).

The hydraulic design of the backfill system was determined using mainly the 2-inch pipe loop flow data at a relative density of 1.63. It was possible to determine the Bingham yield stress and plastic viscosity model by fitting the Buckingham model to the laminar flow data and the Wilson-Thomas model to the turbulent flow data (Wilson and Thomas, 1985). The Bingham equation is given below:

\[
8V/D = \left( \frac{\tau_y}{K_{BP}} \right) \left[ 1 - \left( \frac{4\tau_y/3\tau_o}{\tau_o} \right) + \left( \frac{1}{3} \right) \left( \frac{\tau_y}{\tau_o} \right)^4 \right]
\]

where:
- \( V \) is the pipe velocity
- \( D \) is the internal pipe diameter
- \( \tau_y \) is the Bingham yield stress
- \( \tau_o \) is the wall shear stress
- \( K_{BP} \) is the Bingham plastic viscosity

The result is a plot of the coal waste rheology as shown in Figure 24. It should be noted that the laminar to turbulent transition is later than the model predicts.

Pipeline friction losses for a larger 5-inch internal diameter pipe were then predicted using the Buckingham equation and the estimated Buckingham yield and viscosity values. Figure 25 represents the hydraulic grade line for a theoretical layout to deliver a spiral waste for placement underground at 50m³/hr with an admixture and 3% cement by weight. This layout was assumed to be:

- 1,000m (0.6 miles) from the plant horizontally to a surface borehole.
- 150m (0.1 miles) of vertical depth in the borehole.
- 3,000m (1.9 miles) of underground transport distance.
Figure 24: Coal waste rheology.

Figure 25: The hydraulic grade line.

**Conceptual Plant Layout**

Next, the scope was extended to develop the conceptual plant layout shown in Figure 26. Various components of the proposed system will now be described in detail.
Figure 26: Conceptual backfill plant design.
**Equipment**

- A 26m³ cement silo provides 48 hours of storage. A screw conveyor feeds cement to the continuous mixer.
- Process water is stored in a 25m³ unlined storage tank and pumped into the continuous mixer using a centrifugal pump. About 10 m³/hr should be available and used to adjust the waste product slump coming off (in the theoretical case) the spiral circuit via a belt filter.
- A 1,200m³ rubber-lined buffer tank provides 24 hours of storage for spiral waste. The tank is equipped with an agitator to stop settlement. The agitator is powered by a 100kW motor. A centrifugal pump delivers the spiral waste product to the continuous mixer.
- A high-rate continuous mixer equipped with a 75kW motor produces the backfill material. Power draw is adjustable for quality control of the mix (consistency). The mixer feeds directly into the pump throat.
- A hydraulic piston pump with a minimum rating of 6.1 MPa pumps the backfill mix underground for placement. A Putzmeister HSP2180 with a 8.8 MPa rating and a 200kW power pack would be suitable.

**Piping, Fittings, and Valves**

For the hypothetical backfill distribution system, an unlined 125 mm (5 inch) NB pipe will adequately transport the volume required at a velocity of about 1.1m/s. To safely handle system pressures, Schedule 40 API Grade X42 pipe is needed.

Victaulic-type couplings are ideal for underground piping where the distribution system needs to be moved once a mining section had been totally filled. These coupling are relatively simple, quick, and easy to attach and remove.

Low-pressure knife valves are used at the plant, but ball valves are used after the pump because of higher pressures.

**Instrumentation**

Instrumentation is used to maintain quality and consistency for the following operations:

- Flow meters for waste material feed, mixing water, admixture dosing, and cement addition.
- Level controllers for maintaining the level in the hopper feeding the pump.
- Strategically placed pressure transducer after the pump and at the top and bottom of boreholes to control the feed and limit pipe wear.

**Flushing**

Backfill systems should always be flushed clean after use. A total of 10 m³ of water mixed with compressed air should be adequate to achieve this.

**Power Requirements**

The peak installed power is estimated in Table 3.
Table 3: Backfill power requirements.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Number of units</th>
<th>Installed power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admixture dosing system</td>
<td>1</td>
<td>2 kW</td>
</tr>
<tr>
<td>Coal waste pumps</td>
<td>2</td>
<td>100 kW</td>
</tr>
<tr>
<td>Water pump</td>
<td>1</td>
<td>10 kW</td>
</tr>
<tr>
<td>Hydraulic pump power pack</td>
<td>2</td>
<td>400 kW</td>
</tr>
<tr>
<td>Cement conveyor</td>
<td>1</td>
<td>10 kW</td>
</tr>
<tr>
<td>Waste buffer tank agitator</td>
<td>1</td>
<td>100 kW</td>
</tr>
<tr>
<td>Other equipment</td>
<td></td>
<td>13 kW</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>710 kW (952 hp)</strong></td>
</tr>
</tbody>
</table>

**Task 6** - Cost the backfill system and compare it with costs for a conventional waste disposal system. Design an idealized layout.

**Backfill Costs**

Based on Paterson and Cooke’s previous experience with backfill plants, the capital cost to build the plant and infrastructure as outlined in Task 5 are shown in Table 4.

Table 4: Backfill plant and infrastructure capital cost.

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Cost estimate ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil construction</td>
<td>340,000</td>
</tr>
<tr>
<td>Tanks and plate work</td>
<td>460,000</td>
</tr>
<tr>
<td>Mechanical equipment</td>
<td>1,750,000</td>
</tr>
<tr>
<td>Piping</td>
<td>670,000</td>
</tr>
<tr>
<td>Electrical</td>
<td>440,000</td>
</tr>
<tr>
<td>Controls</td>
<td>180,000</td>
</tr>
<tr>
<td><strong>Total direct costs</strong></td>
<td><strong>3,800,000</strong></td>
</tr>
<tr>
<td>Spares</td>
<td>170,000</td>
</tr>
<tr>
<td>Contractors costs</td>
<td>950,000</td>
</tr>
<tr>
<td><strong>Construction costs</strong></td>
<td><strong>4,900,000</strong></td>
</tr>
<tr>
<td>Engineering (10%)</td>
<td>490,000</td>
</tr>
<tr>
<td>Administration/management (5%)</td>
<td>245,000</td>
</tr>
<tr>
<td><strong>SUB-TOTAL</strong></td>
<td><strong>5,600,000</strong></td>
</tr>
<tr>
<td>Contingencies (25%)</td>
<td>1,400,000</td>
</tr>
<tr>
<td><strong>TOTAL CAPITAL COSTS</strong></td>
<td><strong>7,000,000</strong></td>
</tr>
</tbody>
</table>

Operating costs are estimated in Table 5. Assuming no interest and a 10-year plant life, the capital cost contribution to the backfill operating cost is $1.74/m³ of placed fill. These capital and operating cost estimates are thought to be -0%, +25%, so tend to be on the high side.
Table 5: Backfill plant and infrastructure operating cost.

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Cost estimate ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor (4)</td>
<td>200,000</td>
</tr>
<tr>
<td>Maintenance</td>
<td>100,000</td>
</tr>
<tr>
<td>Admixture</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Cement (3%)</td>
<td>1,400,000</td>
</tr>
<tr>
<td>Power</td>
<td>200,000</td>
</tr>
<tr>
<td><strong>TOTAL ANNUAL OPERATING COST</strong></td>
<td><strong>4,900,000</strong></td>
</tr>
<tr>
<td><strong>COST/M³ OF BACKFILL</strong></td>
<td><strong>$12.16/m³ placed</strong></td>
</tr>
<tr>
<td><strong>COST/T (SOLIDS)</strong></td>
<td><strong>$10.67/t solids placed</strong></td>
</tr>
</tbody>
</table>

Notes:
1. The cost for the proprietary development dispersant (admixture) from BASF uses the estimated bulk cost, not the present “development” cost of $22/gallon.
2. It is assumed that fill is placed 24 hours per day (1200m³/day) for 48 weeks per year.
3. The solids content in the fill is 1.14 tons/m³.

**Conventional Impoundment Disposal Costs**
The following are real costs from an Illinois Basin mine producing about 1.68 million m³ of total refuse per year (Pilcher, 2010). They are well below the cost of up to $6/ton quoted by Mohanty et al. (2007).

Approximate capital cost breakdown for preparing a new impoundment
- Land purchase 33%
- Site preparation 8%
- Under-drain 4%
- Slurry line 10%
- Pumps and motors 8%
- Initial permitting 21%
- Refuse bin 8%
- Other 8%
**TOTAL CAPITAL COST $900,000**

Operating cost breakdown for waste handling and disposal
- Haulage transport 87%
- Chemicals 9%
- Other 4%
**TOTAL OPERATING COST $2.29/m³**
**TOTAL COST $2.34/m³**
Comparing Backfill Costs and Conventional Impoundment Disposal Costs

Based on the above cost values, cemented high density backfilling in coal mines is significantly more costly than traditional impoundment disposal; however, the development of a dispersant with some foaming ability could drastically reduce the admixture cost by two-thirds thus reducing the backfill placement cost to around $7.20/m³. The admixture dosage could also be optimized but it is unlikely that the cost could be reduced much below $6.00/m³.

Evaluating the effect on costs stemming from additional benefits associated with backfilling that are unrelated to waste disposal were outside the scope of this project. These additional benefits are tangible and intangible and include:

- No surface subsidence when used with room and pillar mining and about a 60% surface subsidence reduction when used with longwall mining.
- The percentage extraction could be increased in room and pillar mining production units because the volume mined would be totally filled on completion, thus substantially reinforcing pillars and allowing for smaller pillar design.
- Explosion proof seals needed after a production panel has been fully extracted could be eliminated in room and pillar workings. A set of six such seals can cost upwards of $150,000 in total.
- No risk of an impoundment failure on the surface. Furthermore, since the backfill will be placed at a high density and with cement, the material will not liquefy once placed and set underground either.
- Surface impoundment costs will likely rise significantly in the future if the US EPA classifies coal washing plant waste and coal combustion products as toxic, which is expected soon.
- No long–term, on-going costs associated with re-vegetation and water treatment of the impoundment.
- Improved public perception as a mine footprint will be much smaller and easier to manage without a significant impoundment.

Additional Task – Evaluate placed backfill permeability.

The permeability of the backfill after placement is a key to stopping toxic materials leaching over time from the fill. To show how this could be achieved, the permeability coefficient was measured for a spiral waste product at a high relative density of 1.63, with no modification, and then with various materials to reduce the permeability. Any candidate material can be used for backfilling as long as the necessary investigative work is done, including PSD, mineralogy, permeability, flow studies etc.

Overall mineralogy was established, as described in Task 2, for both coarse and fine spiral waste product. Permeability was measured using a fixed head permeameter as shown in Figure 27.
Clearly, the objective is to make the placed material have as low a permeability as possible. This can be achieved in two ways: minimizing porosity and adding a cementing agent. Results are shown in Table 6, at a constant head of 76.2 cm.

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient of permeability (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral waste only</td>
<td>2.21 * 10^{-4}</td>
</tr>
<tr>
<td>Spiral waste and 2.5% fly ash by weight</td>
<td>1.58 * 10^{-4}</td>
</tr>
<tr>
<td>Spiral waste and 3.0% fly ash by weight</td>
<td>1.37 * 10^{-4}</td>
</tr>
<tr>
<td>Spiral waste and 1.0% Portland cement by weight</td>
<td>8.58 * 10^{-7}</td>
</tr>
<tr>
<td>Spiral waste and 3.0% Portland cement by weight</td>
<td>2.15 * 10^{-7}</td>
</tr>
</tbody>
</table>

It is important to note that the permeability can be reduced by three orders of magnitude with the addition of relatively low amounts of Portland cement. These results are not optimized and could be improved further by a combination of porosity (void ratio) reduction and cement addition. These tests would have to be done in the lab with any
specific fill material, as the most cost effective permeability coefficient reduction system will differ depending mainly on the chemistry and size distribution of the material.

It is currently unknown, and beyond the scope of this preliminary research project, how low the permeability coefficient must be to protect the water table in the long term, but results are considered to be very encouraging. The required permeability coefficient needed to stop unacceptable water table pollution is needed.

**Additional Task** – Backfilling without the use of admixtures.

To evaluate the cost benefit of an admixture, a plant design without admixtures was prepared by Paterson and Cooke. Rheologies with and without admixtures are shown in Figure 28.

![Figure 28: Fill rheology with and without admixture.](image)

For the backfill system developed and costed in Tasks 5 and 6, backfilling without the use of admixtures would increase the maximum pressure to a massive 41 MPa compared to the equivalent 8.8 MPa with the dispersant admixture. This is well beyond the capacity of conventional positive displacement pumps. It is therefore considered impractical to not use admixtures. The backfill density could be reduced (i.e., the water content increased), but this would be self-defeating as extra water would reduce strength and increase permeability.
Conclusions

- It is technically feasible to pump high density coal waste underground as opposed to the current practice of pumping low density slurry underground or to an impoundment. The inherent disadvantages associated with the low density slurry are mainly with all of the free water present.
- Based on assumptions made concerning costs, the high density fill option would be significantly more costly than traditional impoundment disposal. There is however considerable potential to reduce high density backfill costs significantly.
- Any candidate fill material needs to be tested in pipe loops to obtain its rheology. Slump tests can be used as an initial test, but relying only on this test can create errors.

Recommendations

Based on the work accomplished in this project, it is recommended that additional research be conducted to fully investigate the option of cost effectively and safely disposing of coal washing plant waste and/or coal combustion product waste underground as a high density fill for a specific potential site. This research should include investigating:

- The safe and technically feasible increased extraction that may be possible with backfilling. This can be determined using numerical computer modeling.
- Whether backfilling would indeed replace the need for explosion proof seals.
- The permeability coefficient needed to safeguard the water table in the long term.
- Modeling to prove that backfilling would eliminate long-term subsidence in room and pillar mines.
- The feasibility of backfilling behind longwall panels (as is common in German and Polish coal mines). The main benefit would be surface subsidence reduction from the current level of approximately 60% of seam thickness to less than 30% of seam thickness based on the European experience.
- A full site-specific cost comparison between traditional surface impoundment disposal and backfilling.
- More cost effective admixtures.

ACKNOWLEDGEMENTS

The investigator greatly appreciates the effort of graduate students, Mark Theisinger, Jon Reisterer, and Gopi Bylapudi, in completing this project. ICCI/DCEO research funds and the cooperation of the Coal Research Center at SIUC are sincerely appreciated. The laboratory, pipe loop assistance, and direct financial contribution of BASF Construction Chemicals is also gratefully acknowledged. Heartland Pumps’ expertise and assistance in commissioning the pipe loop system was invaluable.
REFERENCES


DISCLAIMER STATEMENT

This report was prepared by Dr. A.J.S. (Sam) Spearing of Southern Illinois University Carbondale, with support, in part, by grants made possible by the Illinois Department of Commerce and Economic Opportunity through the Illinois Clean Coal Institute. Neither Dr. Spearing of Southern Illinois University Carbondale nor any of its subcontractors nor the Illinois Department of Commerce and Economic Opportunity, Illinois Clean Coal Institute, nor any person acting on behalf of either:

(A) Makes any warranty of representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or

(B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring; nor do the views and opinions of authors expressed herein necessarily state or reflect those of the Illinois Department of Commerce and Economic Opportunity or the Illinois Clean Coal Institute.

Notice to Journalists and Publishers: If you borrow information from any part of this report; you must include a statement about State of Illinois’ support of the project.
APPENDIX

Figure A-1 showing pressures in the 3-inch pipe test loop with only water being pumped is provided just as a reference check.

![Pressure for Different Flowrates](image)

Figure A-1: Water pressures in the 3-inch pipe loop.