Stabilization of Fine Coal Waste as an Alternative Disposal Technique

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ABSTRACT

The permitting of new fine coal waste impoundments and slurry cell systems has become a nearly improbable venture. When faced with limited or no waste slurry storage areas, the common practice is to dewater the thickener underflow to a solids concentration greater than 55% by weight or greater and co-dispose with coarse reject. However, the combined reject may be difficult to handle and sometimes fails to meet regulatory requirements. A potential solution is stabilization of the reject by the addition of Portland cement. The result is a combined refuse that meets compaction requirements and is impermeable thereby eliminating mine acid formation and leaching of trace elements. Conceptual proof of the technique as a valid option is provided by details of a mining operation utilizing co-disposal with cement addition as well as the findings of a laboratory investigation.

INTRODUCTION

Increased mechanization in the coal mining industry has been accompanied by decreased selectivity and increased proportion of waste materials in the raw coal. As a result, large volumes of waste have been generated from the coal washing process. The simplest approach to dispose fine coal tailing is to impound the tailing slurry by constructing dams by solid mining waste (Snyder et al. 1977). The low cost and convenience have made impoundments the most popular tailings disposal method (Almes 1979; Williams 1991).

Unfortunately, several environmental and safety issues have made the process of obtaining new impoundment permits from the U.S. Environment Protection Agency (EPA) difficult. Moreover, due to the ultrafine particle size of fine coal tailings, the exposed surface area presents potential for the leaching of trace elements associated with the mineral matter contained within the raw coal.

As an alternative to impoundments, industry is choosing to dewater the fine reject and, in most cases, co-dispose with coarse waste material using a stacking method. Belt filter presses have been the most commonly used technology for dewatering fine waste to levels between 55% and 75% solids by weight. Relatively high throughput capacity values, while achieving effective dewatering on clay-rich material, are cited as advantages of belt filter presses. However, chemical consumption is high, with costs in the range of $0.30 to $0.50 per ton of plant feed. Furthermore, the product moisture may not be sufficiently high to

provide enough stability to allow refuse storage using stacking techniques.

Recent commercial applications of plate-and-frame filter presses have provided excellent results when dewatering thickener underflow. Filter cake containing as high as 80% solids by weight is reportedly being produced from plate-and-frame units installed to dewater fine coal waste at preparation plants located in southern West Virginia, U.S. Similar findings have been reported in the literature (Xie et al. 2010; Verma et al. 2010; Forster 1977). Using only the chemicals necessary for the initial solids concentration in a conventional thickener, the plate-and-frame filter provides a cake that is sufficiently stable to meet EPA requirements for compaction. Results reported in this essay support this fact. However, plate-and-frame filters require large capital to install and their semi-continuous operation requires the use of two units. Moreover, the dewatering process does not effectively decrease the exposed particle surface area. When subjected to rain events, the filter cake decomposes back into slurry form. As such, leaching potential of trace elements is not permanently controlled.

The concept of waste solidification could provide a potential solution for the aforementioned issues associated with belt press and plate-and-frame filters. Waste solidification was originally applied to radioactive waste disposal in the 1970s, which involved the deployment of chemical stabilization agents to transform the waste from a liquid phase to solid form with adequate physical strength to allow disposal in a landfill. In fact, waste solidification is commonly employed in the extraction of metallic deposits using the cut-and-fill mining method. The primary factor influencing solidification performance is the type and amount of chemical agents employed. The primary chemical is cement, which is known widely for its hydration reaction with water to generate high strength within a short time. When the solids concentration of the waste is low (i.e., <50% by weight), sodium silicate can be added, which solidifies the water into a 'quick gel' that can be further solidified by the addition of cement. Hydraulic lime is also effective in water adsorption.

Proper selection of the agents and their concentrations is based on the physical strength of the stabilized product, which can be stored in a safe and environmentally friendly manner. The EPA considers a stabilized/solidified material with strength of 0.35 MPa (50 psi) to have a satisfactory unconfined compressive strength to provide a stable foundation for materials placed upon it, including construction equipment and impermeable caps and cover material (Malviya et al. 2006; USEPA). However, according to other researchers, such as Conner (1990), a minimum bearing strength of 0.1 MPa (14 psi) is acceptable for landfill purposes. For wheeled vehicles and other more stringent requirements, 0.24 MPa (35 psi) bearing pressure is sufficient.

As previously mentioned, waste stabilization provides another very significant environmental benefit. The stabilized product has reduced leaching rates due to fixation of the heavy metals within the solidified matrix or by chemical reaction between stabilization agents and waste elements (Chen et al. 2009; Paria et al. 2006; Pinarli et al. 2005; Dermatas et al. 2003; Mulligan et al. 2001; Johnston et al. 1997; Conner et al. 1990, 1998; Myers 1986).

Due to compaction issues with the co-disposal of coarse and fine reject, a coal producer located in western Kentucky utilizes a waste stabilization process that employs the use of Portland cement. This publication provides a detailed description of the process along with the results of a detailed laboratory investigation that focused on process optimization.

COAL PREPARATION AND WASTE STABILIZATION PLANT

The Armstrong Dock and Preparation Facility located in Centertown, Kentucky, is operated by Armstrong Coal Company. The plant has a throughput capacity of 1,200 tons/hr and cleans coal from a blend of the Kentucky No. 12, No. 13 and No. 14 seams with a mass yield to the product of around 70%. Coal from the Kentucky

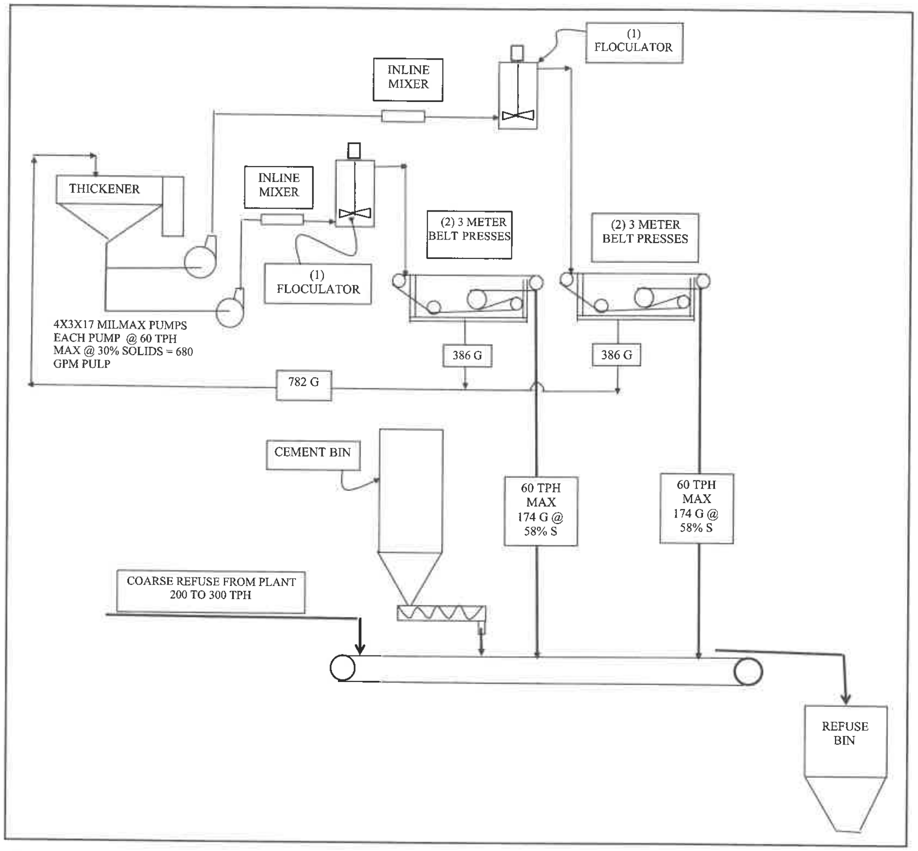

Figure 1. Flow sheet of the Armstrong refuse treatment process

No. 9 and No. 11 seams are treated separately with typical mass yield values of 60% and 68%, respectively. The plant utilizes dense medium cyclones and spiral concentrators to clean the particle size fractions coarser than 0.15 mm.

The amount of coarse refuse varies with the plant feed source but typically ranges between 200 and 300 tons/hr. The mass flow rate of fine refuse is relatively constant at 120 ton/hr due to the capacity constraints of the belt filter presses. As a result of this constraint, the plant feed rate must be reduced below the 1,200 tons/hr rated capacity if the amount of clays or fines become unmanageably high. There are times when the plant feed rate is reduced to 900 tons/hr to handle an elevated amount of fines.

The coarse and fine waste materials are co-disposed using a series of lifts. The fine waste is dewatered in four Phoenix Model WX-3.OG6 belt filters. The chemical cost to run the belt presses averages $0.55 per ton of plant feed, whereas the other chemical costs at the plant are around $0.045 per ton.

When the co-disposal practice was initiated, the material did not reach the required compaction levels. Hydrated lime was added in an effort to enhance the stability of the fine waste, which worked to a degree but did not provide the

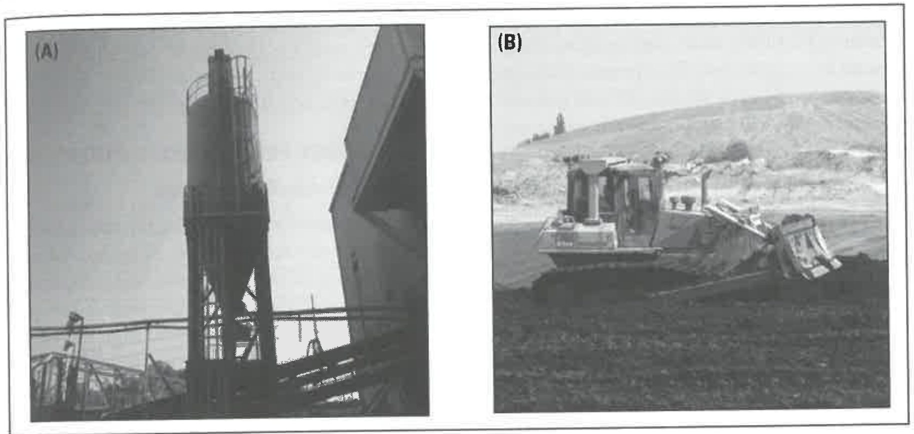

Figure 2. Components of the refuse treatment process (a) cement bin and conveyor and (b) dozer handling of the combined refuse

desired impact on compaction. Portland cement was tried and found to provide the desired effect. By adding cement at a rate of three tons/hr, which is around 2.5% of the fine refuse, the co-disposed reject material can be handled in a matter of days and compacted to the required level in as little as two weeks. The cement cost is $0.27 per ton of plant feed.

The waste treatment process involves splitting the thickener underflow using two variable speed pumps with the output of each pump having volumetric and mass solids flow rates of 680 gallons/min and 60 tons/hr, respectively. As shown in Figure 1, the output of each pump is fed through an in-line mixer and flocculator prior to entering to belt filter presses. The plant coarse refuse is placed on a conveyor belt in the plant and run under a bin where the Portland cement is added (Figure 2a). The belt containing the coarse refuse and cement then enters the belt filter facility where the belt filter product is placed on the belt. The combined coarse and fine refuse with the cement is dumped through a pug mill and the final mixture subsequently placed on another conveyor that transports the material to the waste disposal area. Dozers are used to spread the material (Figure 2b).

A sample of the combined refuse was collected from the placement area and tested to determine the unconfined compressive strength (UCS). The measurement was conducted according to ASTM standard D1633-84: Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders (USEPA). The sample was molded into a 25.4 mm (2-inch) diameter by 50.8 mm (4-inch) cylinders and cured for 1, 2, 4, 5 and 7 days. The samples were sealed in molds for one day and subsequently cured outside the mold in open air.

As shown in Figure 3, unconfined compressive strength of the combined refuse is around 20 psi after seven days of curing using one percent cement concentration, which is substantially lower than the EPA requirement of 50 psi. Nonetheless, the strength is sufficient for grading and compaction using dozers and for trucks to travel across after setting for a few days.

Proposed Plate-and-Frame Filter Installation

The recent commercial application of plate-and-frame press filters for dewatering fine waste has shown the ability to achieve 80% solid concentrations in the filter cake and excellent stability when placed with coarse refuse, which is a fact supported by the laboratory test data presented in this publication. The performances have been achieved with no additional chemical costs beyond those associated with conventional thickening of the plant fine waste. As a result, a technical and financial costs analysis was performed to compare belt filter presses and cement addition system with plate-and-frame presses. As shown in Tables 1 and 2, the amount of capital needed to purchase plate-and-frame units to treat the 120 tons/hr of fines is slightly greater than $7.5 million as compared to nearly $2 million for the belt filter presses. Despite the high capital

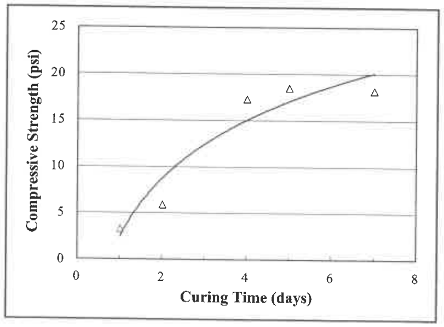

Figure 3. Unconfined compressive strength of the co-disposed reject material with cement

cost, the plate-and-frame filters are a significantly better economic option due to the reduced annually operating costs, which are largely associated with cationic flocculation and cement additions.

LABORATORY EXPERIMENTAL STUDY

Thickener Underflow Samples

A representative sample of the thickener underflow was collected in three 55-gallon drums. Upon arrival at the laboratory, the sample was split into representative sample lots of five gallons each. A sample was collected from one of the five gallon buckets and analyzed for the particle size distribution, ash and sulfur contents. The total solids content of the slurry was 35.09% by weight. A proximate analysis showed the sample contained 51.17% ash and 4.95% total sulfur on a dry basis. The particle size distribution is provided in Table 3.

Stabilization Tests

In each test, around 900 grams of thickener underflow slurry with the desired solids content was mixed thoroughly with the Portland cement for about five minutes, and then injected into three 50-mm diameter by 100-mm plastic cylindrical molds to cure. Typical curing times were 1, 7, 14, and 28 days (EPA/625/6-89/022). Treated tailings were sealed in molds for one day and then removed to finish curing in open air. Specimens were cured in a storage chamber with around 50% relative humidity and 18 °C temperature. After the desired curing time, the specimens were subjected to an unconfined compressive strength (UCS) test. The measurement was conducted according to ASTM standard D1633-84: Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders (USEPA). Results of the unconfined compressive strength of three cured specimens were obtained and averaged.

Tests were conducted over a range of cement and solid concentrations to determine the parameter effects on the compressive strength. The solid concentration values of 50%, 60% and 75% by weight were evaluated by filtering the thickener underflow slurry by pressure filtration and then adding water if necessary to achieve the desired solids concentration. It is noted that the fine tailings slurry with solid content of 50% and 60% by weight was in liquid form and fluid enough to be mixed with an overhead propeller mixer at 2,000 rpm.

In addition, since co-disposal with coarse reject was utilized at the Armstrong plant, the fine-to-coarse reject ratio was varied. The evaluation was achieved by adding limestone having a size of about about 6mm (0.25-inch) as a pseudo-coarse refuse to the thickener underflow at fine-to-coarse mass ratio of 8:2, 7:3 and 6:4, respectively. For the tests involving a solids concentration of 75% solids by weight, the waste is no longer in slurry form. As such, a ball mill was applied to mix the simulated coarse waste into the fine waste of 75% solids.

Table 1. Capital and operating costs of plate-and-frame filters for fine coal waste dewatering and placement

	Plate-and-Frame Filter			
Year	Capital Cost	Operating Cost	Total	Cumulative
2012	$7,586,400	$215,600	$7,802,000	$7,802,000
2013		$215,600	$215,600	$8,017,600
2014		$215,600	$215,600	$8,233,200
2015		$215,600	$215,600	$8,448,800
2016		$215,600	$215,600	$8,664,400
2017		$215,600	$215,600	$8,880,000
		NPV @ 10%	$7,714,021	

Table 2. Capital and operating costs belt press and 1% cement application installation for fine coal waste dewatering and placement

	Belt Press Filter & Cement Addition			
Year	Capital Cost	Operating Cost	Total	Cumulative
2012	$1,925,000	$4,724,268	$6,649,268	$6,649,268
2013		$4,724,268	$4,724,268	$11,373,536
2014		$4,724,268	$4,724,268	$16,097,804
2015		$4,724,268	$4,724,268	$20,822,072
2016		$4,724,268	$4,724,268	$25,546,340
2017		$4,724,268	$4,724,268	$30,270,608
		NPV @ 10%	$19,658,693	

Table 3. Particle size distribution of the thickener underflow

Particle Size Fraction (mm)	Weight (%)
+0.425	2.23
0.425 x 0.212	14.13
0.212 x 0.150	4.94
0.150 x 0.075	11.49
0.075 x 0.045	9.70
−0.045	57.21
Total	100.00

LABORATORY RESULTS AND DISCUSSION

The Armstrong plant currently adds cement at a concentration of around one percent of the total dry weight of the combined coarse and fine coal refuse. The same cement dosage was maintained in the initial tests while evaluating the effect of solids concentration and the fine-to-coarse coal ratio. The coarse reject acts as a bulking agent and reduces the volume of waste that needs to be treated with cement. The thickener underflow is filtered to achieve samples of 50%, 60% and 75% solid contents. Coarse material was added to achieve fine-to-coarse ratios of 8:2, 7:3 and 6:4 by weight. The mixed waste compounds were cured in molds for 24 hours and then the molds were removed and cured in open air for one more day.

The results shown in Figure 4 indicate a very significant impact by solid concentration. After only two days of curing, the samples containing 75% solids by weight obtained an unconfined compressive strength of nearly 55 psi with fine reject by itself, whereas a value of almost 90 psi were obtained with fine-to-coarse ratios of 7:3 and 6:4. For the samples with 50% and 60% solids contents, compressive strengths of 20 psi and less were obtained. The results indicate that there is a critical solids concentration between 60% and 75%, below which a stabilized refuse will require significantly greater amounts of cement. It should be noted that the results agree with industrial reports indicating plate-and-frame filter presses are providing filter cake with solid concentrations of around 80% and excellent stability when placed in a waste disposal area where the material is stacked.

The addition of coarse reject to the fine reject improves the overall strength of the combined refuse at all solid concentrations. The unconfined compressive strength nearly doubles under all

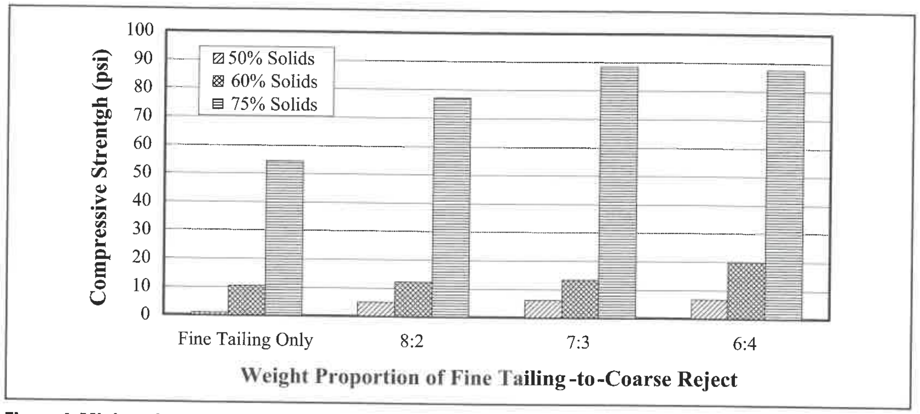

Figure 4. Mixing of fine tailings and coarse reject with multiple mixing ratios; 2-day curing and 1% cement

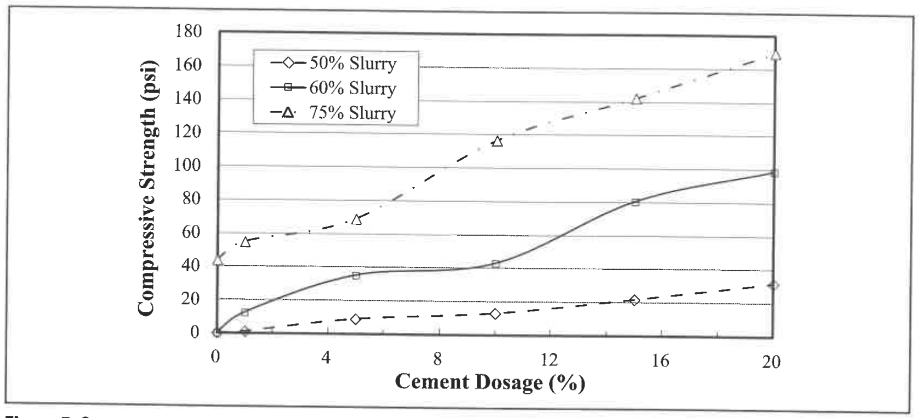

Figure 5. Cement dosage impact on compressive strength after two curing days over a range of solid concentrations

three solid concentrations as the coarse-to-fine ratio was adjusted from no coarse reject addition to a ratio of six parts fines to four parts coarse.

An evaluation performed with the thickener underflow material without the coarse material found that the material having a 75% solids concentration provided natural unconfined strength without the need for cement addition. Figure 4 shows that material formed into cylinders and cured with no cement had an unconfined compressive strength of around 40 psi. The dewatered thickener underflow containing 50% and 60% solids by weight with no cement had no compressive strength. Adding cement at a one percent concentration provided a two-day strength of 12 psi for 60% solids content material, whereas high cement additions were required for the 50% solids material (Figure 5).

Significantly greater compressive strengths were realized after seven days of curing as shown in Figure 6. With no cement, the strength of the material formed from a 75% solid content sample obtained a value greater than 150 psi. Cement addition over the range tested doubled the overall

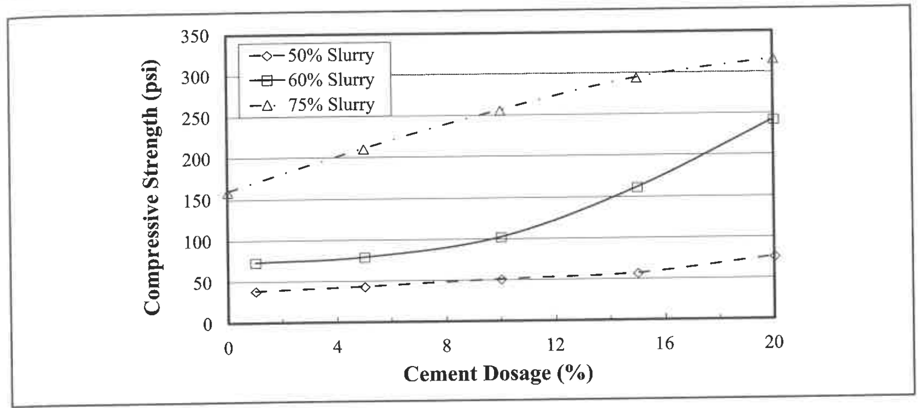

Figure 6. Cement dosage impact on compressive strength after seven curing days over a range of solid concentrations.

strength. However, the natural strength of the material explains the successes being reported by industrial applications of the plate-and-frame filter press.

However, if dewatering of the fine reject results in solid concentrations of 60% or lower or weather conditions decreases the solids content of the reject to 60% or lower, the addition of cement can provide a viable solution, as shown in Figure 6. Cement additions of one percent by weight provided compressive strengths above the EPA requirements of 50 psi for the 60% solids material and just below the level for fine waste with 50% solids.

Tests have been conducted with fine reject samples treated with cement and submersed in water for a number of days. Samples that were not treated with cement immediately returned to slurry form. However, samples treated with five percent or more cement retained their shape during submersion. The fine reject treated with one percent concrete became soft and broke up into smaller particle agglomerates. In addition, the pH of the water in which the cement treated specimens were submersed was around 9.0, whereas the pH was slightly acidic for samples not treated with cement. The results indicate potentially favorable environmental impacts from treating the waste with cement.

CONCLUSIONS

The preferred method for disposing of fine coal refuse is placement in slurry impoundments. However, the practice may be discontinued in the future due to regulatory issues. Operations that have been unable to obtain permits for slurry impoundments have already adopted alternative methods, which typically involve dewatering the fine refuse using belt filter presses and, more recently, plate-and-frame filters.

The Armstrong Dock and Preparation Facility employs belt filter presses to dewater the fine reject. The belt press product is combined with the coarse reject and disposed by stacking the combined reject. However, compaction issues required stabilization of the waste using Portland cement, which has proven to be very effective. Hydrated lime was tested and found to be ineffective and more costly on a per ton basis than Portland cement. The amount of cement added is approximately 2.7% by weight of the fine reject material. The total chemical cost of operating the belt presses and cement addition system is $0.55 per ton of plant feed.

Laboratory tests revealed that the addition of cement at a level of one percent by weight is sufficient for the fine coal waste at the Armstrong operation after filtration to a solids concentration of 60% by weight. The one percent cement-treated material produced unconfined compressive strengths exceeding the EPA requirements of 50 psi needed for stable foundations that can support construction equipment, impermeable caps and cover material. The stabilized material also limits the exposure of particle surface area, which should provide positive environmental impacts.

An economical comparison between a plate-and-frame application and the current belt press and cement treatment process at the Armstrong Facility indicates significant financial gains for the plate-and-frame system. The technical benefits of the plate-and-frame is the production of filter cake containing 80% solids without the need of chemicals beyond those typically applied in the conventional thickening process. Laboratory tests conducted on 75% percent solid material showed significant natural compressive strength without the need for cement. After seven curing days, the unconfined compressive strength of fine reject containing 75% solids was slightly greater than 150 psi. As such, the plate-and-frame filter provides a product that is stackable and able to support construction equipment.

Lab results showed that solid concentrations of 60% or lower required the use of cement to obtain the required compressive strength. If the plate-and-frame material is subjected to high rainfall, the material may return to slurry form and thus require the cement addition to meet the desired stability.

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