

FINAL TECHNICAL REPORT
May 1, 2004, through October 31, 2005

Project Title: **DEVELOPMENT AND DEMONSTRATION OF CATTLE
FEEDLOTS ON FARMS USING SULFITE-RICH SCRUBBER
SLUDGE AND FLY ASH (PHASE II)**

ICCI Project Number: DEV03-7
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ABSTRACT

Activities related to the demonstration of a commercial CCBs-based 'Cattle Feeding Pad' are presented in this report. The pad utilized 95% CCBs and 5% binders in its composition. The CCBs used were sulfite-rich scrubber sludge, FBC ash and F-ash obtained from a Southern Illinois power plant burning high-sulfur Illinois coal.

Mix development studies were conducted in Phase I of this project. Phase II studies involved; 1) additional environmental studies evaluating the impact of animal waste on leachate quality, 2) Determination of mix material handling properties, 3) Mix workability evaluation, 4) Development and demonstration of a mixing technology, 5) Pad Design using FEM modeling, 6) Development of QA/QC procedures, 7) Demonstration of a commercial feeding pad, and, 8) Post-construction monitoring.

Results of these studies indicated that the material handling properties of the soil-like mix were suitable for off-site transport. The TCLP leachate of the mix was also found to comply with Class I groundwater standards for all elements except sulfates. Workability evaluation indicated that the mix could be placed up to 48-hours after production without compromising the engineering properties of the constructed pad.

A 6-7 tph mixing circuit was demonstrated to produce approximately 175 tons of mix. This mix was used to demonstrate a commercial 72-ft x 40-ft feeding pad. The pad performance after several months of use was reported to be satisfactory by the farm owner. During post-construction monitoring it was observed that the pad developed a few soft spots after enduring the winter months. Further investigations indicated that the soft spots were a result of low tensile strength of the material in wet conditions. The lack of adequate drainage around the pad led to the pad staying wet for long periods of time. As heavy farm machinery operated on the pad in these conditions, tensile failure may have resulted. To overcome this identified deficiency, FEM modeling was conducted for improved pad design and a suitable mix of superior engineering properties was developed and demonstrated on a small-scale. This pad has performed very well over the past 8-9 months since construction. The project team recommends a large scale demonstration of a pad using the new mix and improved construction practices.

EXECUTIVE SUMMARY

In February 2004, Illinois Clean Coal Institute (ICCI) funded an exploratory grant to evaluate the feasibility of developing construction materials for applications such as a cattle feeding pad using Illinois Coal Combustion By-products (CCBs) with a particular emphasis on sulfite-rich scrubber. As part of this project, detailed laboratory investigations were conducted to develop a suitable mix for implementation. The composition of this mix utilized 42% sulfite-rich scrubber sludge on an as received basis and less than 5% inorganic binders. The samples prepared from this mix possessed high compressive strength (800-1,200 psi over 7 to 14 days), <5% swelling potential, low permeability (8×10^{-7} cm/s), good water sensitivity and durability as measured by the immersion index and the CMRR slake durability tests, very good freeze-thaw resistance, and an environmentally benign leachate with the exception of sulfates. Based on the success of this exploratory work, a demonstration grant was approved by ICCI to develop and demonstrate a mixing system and construct a commercial feeding pad of 1-acre area. Accomplished tasks leading up to the demonstration involved evaluation of impact of animal waste, evaluations on the material handling and workability properties of the mix, design of the pad based on Finite-Element Method (FEM) modeling and development of Quality Assurance/Quality Control (QA/QC) procedures. Some of these tasks were not a part of the original scope of work but were conducted to achieve additional understanding of the mix behavior and hence, improved pad durability. The pad demonstration was followed by post-construction monitoring studies. Issues identified during these studies led to the development of an improved mix design and development of preliminary best-practices construction guidelines.

Following up from the findings of Phase I studies, the Phase II activities were initiated with the evaluation of the impact of animal waste on the environmental properties of the mix. Prior Toxicity Characterization Leachate Procedure (TCLP) leachate data had indicated a moderately alkaline leachate (pH of 11.2) from the designed mix. However, it had been hypothesized that this leachate will be neutralized by the acidic animal waste. Investigations in this project confirmed this hypothesis. When the mix was combined with 50% animal waste, TCLP leachate pH was reduced to levels low enough for discharging the effluent into public waterways. A 50% combination of animal waste with the mix is a conservative consideration as the surface runoff will primarily be governed by the pH of animal waste which is significantly lower. Overall, environmental studies on the designed mix indicated that the mix fixed several trace elements which would have otherwise leached excessively from individual CCBs from the power plant, or, from combinations of CCBs as disposed from the power plant. For example, the fixated scrubber sludge with F-ash was found to be cadmium and sulfates class II non-compliant and lead class I non-compliant. Individually, F-ash and FBC ash were Cd, Cr, Pb, Se, Sulfate and pH non-compliant among other minor trace elements. In comparison, the leachate from the mix was found to be Class I groundwater compliant for everything with the exception of pH and sulfates. The pH issue however was expected to be effectively addressed by animal waste as revealed in this study. For sulfates also, there was a possibility that they may not pose a problem in practice as the TCLP results are only indicative of the maximum possible leaching of elements and compounds from the mix.

Material handling studies were conducted to evaluate the amenability of the mix to stockpiling and transport in trucks from the power plant to the construction site. As part of these studies, the angle of repose for this material was measured at 42°. This angle of repose was just in the right range, being high enough to allow effective stockpiling of the mix yet low enough to allow a clean discharge of material from the truck bed at the construction site. Both these mix properties were verified in the field as the material for the commercial pad was produced and stockpiled before being transported to the construction site. At the site, the material cleanly discharged from the trucks without any residue on the truck bed.

An important goal of this project was to determine the potential market reach for the developed mix. The market reach in this case will be determined by the duration of time the freshly prepared mix remains workable and attains the designed engineering properties upon compaction. To determine this sample workability, samples were made from a freshly prepared mix, and from the same mix as it aged over a period of 72 hours. Strength tests on these samples after curing indicated that there was only a marginal decline in the strength attained by the samples for samples that were prepared using the mix which was aged up to 48 hours. Samples prepared from mixes older than 48 hours however showed a marked reduction in the final strength. Hence, the results indicated that the mix would have to be transported and placed within 48-hours of mixing at the power plant for the constructed pad to achieve its design properties. These results were further confirmed by X-Ray Diffraction (XRD) analysis which analyzed the mineralogical transformations in the aging mix over a period of time. The appearance of ettringite after 12-hours indicated that curing reactions were in progress in the uncompacted mix. Ettringite formation also peaked at about 48-hours indicating a peak in the curing reactions explaining the observed strength behavior in the laboratory samples using aged mixes.

It is well known that sulfite-rich scrubber sludge is extremely difficult to handle due to its thixotropic nature. This issue was observed first hand by the authors as attempts were made in the laboratory and in the field to mix this material with other mix constituents. This problem was overcome in the laboratory after investigations were conducted and it was found that the sludge starts to behave as a fluid when it attains greater than 50% moisture content on a wet basis. At this consistency, the sludge can be dispersed finely into the mix with other constituents. Also, it was expected that the higher water content of the sludge will reduce the costs associated with dewatering the sludge at the power plant. In Phase II studies, the mixing circuit was designed and demonstrated in two incremental steps. First, a larger scale 6-7 tph mixing circuit was successfully demonstrated to process approximately 175 tons of CCBs. Material produced by this circuit was used to construct a commercial -size pad. To further increase the capacity of the mixing circuit to about 120 tph, modifications to the power plant byproducts handling circuit were designed. A paddle mixer with the required capacity was already available and installed above a truck load-out at the power plant. Preliminary tests successfully mixed FBC ash and scrubber sludge using this system and loaded several truckloads of this mix over a few hours. However, additional modifications in the plant were required to bring the F-ash to this mixer. Delays in incorporating these modifications in the power

plant delayed and finally prevented the construction of the 1-acre pad which required mix production of 2,300 tons. However a smaller but commercial-size 72-ft x 40-ft pad was successfully demonstrated as part of this project. This task yielded important data and experience to improve the technology for a future construction of the 1-acre pad.

Prior to the construction of the commercial-size pad, FEM modeling studies were conducted for pad design. These studies indicated a small possibility of pad failure under tensile stresses encountered as farm machinery (typically skid-steers) turned on the pad surface. Hence, reinforcement was introduced in the pad design. The FEM model also indicated a requirement of at least 6-inches of pad thickness. Based on these results, a pad with an average thickness of 8-inches with 10-inches at one corner and tapering down to a low of 6-inches at the diagonally opposite corner to allow for water drainage was designed. Also prior to pad construction demonstration, QA/QC procedures were developed which utilized on-site penetrometer measurements which related to similar measurements on lab samples with known compaction density.

The commercial-size 72-ft x 40-ft pad was demonstrated at Beasley Farms. The entire pad was constructed in four quadrants. In each of the quadrants, small modifications in the construction design were incorporated to improve the performance of the pad. A plastic and steel grid fencing was used as reinforcement in Quadrants I and III respectively and placed at the interface of the two lifts. A 6-mil thick vapor barrier was placed at the base soil – pad interface in Quadrant I which acted as a sealant. Asphalt coating was applied to Quadrants II and III to ascertain its effect on surface performance. Aggregate waste from a limestone quarry was spread on the surface of Quadrant I. Vertical and horizontal lysimeters were installed in three quadrants to collect samples for water quality monitoring. Quadrant IV was not subjected to any modifications as it was a measure of the baseline performance of the pad.

The CCBs mix for pad construction was prepared at the power plant and transported to the site in 10-ton Tandem trucks. A skid-steer was then used to spread the delivered mix on the leveled base soil layer. A vibratory roller attachment on the skid-steer was used to compact the material in two lifts of about 4-5 inches and as per the QA/QC protocols developed in this study. The pad was watered during the compaction process to supplement the moisture lost during stockpiling and transportation of the material. After compaction, the pad was covered with plastic sheeting for 7 days to prevent surface moisture loss. Cattle were allowed on the pad 7 days after the installation of the last pad section. Initial pad performance was reported to be satisfactory by farm owner.

Post-construction monitoring involved regular inspections of the pad surface and collection of surface run-off and lysimeter leachate samples for environmental analysis. The environmental samples did not indicate any issue with the pad. However, it was observed that after a period of sustained wet weather, the pad developed soft spots. After further analysis and investigation, it was concluded that the construction practice which did not allow proper drainage facilities was the main cause that led to the observed pad behavior. Poor pad drainage resulted in portions of the pad staying constantly saturated with water. Under these conditions, the reduction in the tensile strength of the material

caused local failures as skid-steers operated on the pad surface in these conditions. Despite this shortcoming, Jeff Beasley and other local area farmers who inspected the pad were satisfied with the pad performance with respect to (a) conditions on other soil-only feeding pens on the farm, (b) performance of other commercialized and popular out-of-state pads installed using a different technology developed by other researchers, and (c) the high cost of poured concrete as an alternative.

To overcome the observed shortcoming of the pad, additional laboratory studies were conducted to improve the surface abrasion characteristics, increase the strength and improve water sensitivity of the pad material. A new mix was successfully formulated with these improved characteristics. The measured tensile strength under water saturated condition of materials prepared from this modified mix exceeded the maximum tensile stress values predicted by the FEM model that may be encountered in the pad as a skid-steer turned on the pad surface. Hence, it was expected that this material would perform better than the earlier mix used in pad construction and would not fail even under constantly water-logged conditions. A small 4-ft x 4-ft pad was constructed using this modified mix. This pad has been performing very well and has shown little signs of degradation even as 8-9 months have elapsed since construction at the time of this writing. To address the drainage issue and to incorporate other construction practice improvements which evolved from the commercial pad demonstration experience, a best-practices CCBs-based feeding pad construction manual was developed. This manual will serve as a very useful tool in the construction of future feedlots using this technology.

Engineering economic evaluations were also conducted to compare the cost of implementing the developed technology in comparison with the alternative of constructing a conventional concrete pad. The cost of constructing a 1-acre concrete pad was estimated at \$168,000 based on USDA/NRCS estimates. Adjusting this estimate with construction cost data from handbooks and after corrections for local area factors yields a cost of \$136,000 for constructing the 1-acre pad. In comparison, the cost of a 1-acre CCBs based pad was estimated at \$38,000. These estimates imply that feeding pad construction using the mixes developed in this research will cost only 25-30% of the cost of conventional concrete feeding pads. In addition, disposal and dewatering cost savings will accrue to the power plant which will be substantial depending on the market for the material. Even otherwise, the power plant has indicated that the mixing circuit could be used on a regular basis to dispose scrubber-sludge and other less desirable byproducts by sending them to off-site landfills by mixing them with the fly ashes which are sent to these landfills. The mixing circuit developed in this project will enable the power plant to accomplish this resulting in large disposal cost savings.

Overall, the findings indicate that there is a significant potential for this technology which will result in cost savings to farmers and the power plant while improving the utilization of CCBs. The developed technology has the flexibility to be adapted to develop other appropriate mixes for other applications. The authors also recommend that as the changes to the byproducts handling system are completed at the power plant, the 1-acre pad demonstration should be conducted.