Demonstration of Cattle Feeding Pads using Coal Combustion Byproducts including Sulfite-rich Scrubber Sludge

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ABSTRACT

Based upon development of an optimized mix of coal combustion byproducts in the laboratory, a commercial scale cattle feeding pad was demonstrated at a livestock farm. The pad was designed using finite element analysis which considered the impact of heavy machinery movements on the pad surface in addition to livestock movements. Mix production was accomplished in an auger mixer circuit to meter the six mix constituents in desired proportions while achieving homogeneous mixing. The material was transported to the construction site over 16 km away in end-dump trucks without any issues. The mix was compacted using a skid-steer mounted vibratory smooth roller using a developed set of construction practices and quality control and assurance protocols. Since construction, the pad has performed satisfactorily till to date. Post-construction studies involved environmental monitoring which indicated benign leachates.

INTRODUCTION AND BACKGROUND

As consumption of coal for power generation increases each year, disposal of Coal Combustion Byproducts (CCBs) has been a major concern for power plants from economic and environmental points of view. Most power plants dispose their waste products at on-site ponds or off-site landfills incurring significant disposal related costs and environmental monitoring costs in the process. Hence, effective utilization of CCBs has been a focus of research. The most common byproducts produced by power plants burning mid-western coals are fluidized bed combustor (FBC) ash, F-class fly ash and sulfite-rich scrubber sludge. FBC fly ash is produced by burning high sulfur coals in fluidized bed combustors in the presence of limestone for capturing the generated sulfur-dioxide. This ash is characterized by presence of a large amount of Calcium Sulfate (anhydrite) and free lime. FBC ash possesses cementitious properties and can gain very high strength over a short-time. The problems with the use of FBC fly ash alone are alkaline leachates, high swelling potential and brittle materials. F-ash is produced by combustion of bituminous coals in pulverized and cyclone boilers. F-ash
possesses pozzolonic properties and the material gains strength over a longer time period. Over the past few years, researchers have found beneficial uses of FBC and F-fly ashes for structural fills, road sub-base and in concrete applications. Sulfite-rich scrubber sludge is the by-product of wet-scrubbing sulfur dioxide produced from the combustion of high sulfur coals with limestone slurry. Beneficial uses of sulfite-rich scrubber sludge are very few resulting in the requirement to dispose this material at a high cost.

Cattle Feeding Pad Application

The authors have identified and investigated a large volume utilization application for sulfite-rich scrubber sludge in cattle feeding pads. Laboratory studies conducted have established the technical and economic feasibility of this application. High strength materials have been produced with 7 d cure strengths of 5.5-6.9 MPa and 28 d cure strengths of 6.9-8.3 MPa. The higher strength mixes have been developed while reducing the consumption of inorganic binders, as compared to the current practice. The developed mixes have shown excellent and durability properties. ASTM leachate and Toxicity Characterization Leachate Procedure (TCLP) tests (SW 846) have indicated that the leachate from the developed mixes will meet Class I ground water quality standards with the exception of sulfate, which, may not be an issue in practice since the tests represent the worst possible scenarios which are rarely encountered. The properties of the developed mixes are summarized as:

- Compressive strength - 7 d - 5.8-6.9 MPa
- Compressive strength – 28 d - 6.9-8.3 MPa
- Elastic modulus - 800 - 1200 MPa
- Bulk density- 1 350-1 525 kg/m³
- Moisture content - less than 1%
- Water absorption - 16-25%
- Durability - Two cycle wetting durability - 3-7% sample deterioration
- Immersion index: 0 (best possible)
- Swelling - less than 3%
- Modified freeze-thaw - No deterioration after 20 cycles

Engineering economic evaluations for this application indicates that feeding pad construction using the developed mixes 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. Additional details of this research are presented elsewhere (Chugh et. al., 2006, Chugh et. al., 2005a).

OBJECTIVES

Following the successful mix design and feasibility demonstration in the laboratory (Chugh et. al., 2006), the goal of this study was to demonstrate the technology for construction of full-scale commercial cattle feeding pads with the following specific objectives:
• Develop a technology for mixing and preparation of a soil-like mix using CCBs at the power plant site.
• Evaluate material handling and workability properties of the mix which are important for commercialization.
• Further evaluate environmental properties of the mix in the presence of animal waste.
• Develop engineering design of the pad based on finite element modeling (FEM).
• Develop ‘best construction practices’ and QA/QC protocols, and,
• Demonstrate a full-scale commercial size (22 m x 12 m) CCBs-based cattle feeding pad.

EXPERIMENTAL PROCEDURES AND MODEL DEVELOPMENT

The following experimental procedures were utilized in this study. Description of the FEM model development also follows the discussion of the experimental procedures in this section.

Experimental Procedures

The mix constituents were mixed in a standard laboratory dough mixer (Blakeslee Model B-207). The standard test procedure of determination of moisture content (ASTM D3302) was followed for measuring the moisture content of the mix. Compaction of samples was performed using standard compactive effort (ASTM D698, Procedure B). The compacted samples were cured under indoor laboratory conditions. Bulk density of the samples was measured using the weight-volume relationships and porosity of the samples was obtained from the water absorption measurements. The compressive strength of the samples was measured using ASTM D1633 standard test procedure to determine the uniaxial compressive strength. Tensile strength of the samples was measured using ASTM D3967-05 splitting tensile strength test.

The relationship between the moisture content of the mix and the density of the compacted samples was determined using the ASTM D558-04 standard test procedure. The samples of this experiment were cured to determine their strengths for the relationship between the bulk density and compressive strength of the samples.

The workability of the samples was studied by preparation of samples after 12, 24, 36 and 72 h after the mix preparation. X-Ray Diffraction (XRD) analysis was used to study the changes in mix at the mineralogical level. Angle of repose measurements were conducted for determining the material handling properties such as handling, loading and dumping of the mix. The measurements were made by studying the sliding characteristics of the soils. The laboratory results were verified with the measurements in the field.

AASHTO T 215-70 (constant head) test procedure was utilized to measure the coefficient of permeability of the samples.
The environmental properties determination involved the ASTM shake test (ASTM D - 3987) conducted at SIU and the EPA method SW-846 TCLP extraction conducted at a commercial laboratory.

Finite Element Model Development

For the design of the commercial feeding pad, a FEM model was developed to determine the minimum required pad thickness and the pad stability. There were separate models developed to analyze the static pressures exerted by cattle hooves and the dynamic pressures exerted by movement of farm machinery on the feeding pad. The static analysis was conducted on a two dimensional plane strain model and three dimensional models were used for the dynamic analysis. Details of these studies are part of a separate article submitted for publication (Chugh, et. al., 2007, submitted to Fuel).

Field Demonstration Procedures and Post – Construction Monitoring

As part of the field demonstration activities a best-practices construction manual was developed (Chugh et. al., 2005b). QA/QC procedures were also developed based on penetrometer measurements in the lab and in the field. Details are included in the subsequent section. The monitoring of pad performance continued even after the cattle traffic was allowed on the pad. Environmental testing of surface run-off and lysimeter collected samples was also conducted.

RESULTS AND DISCUSSION

CCBs Characterization

The three CCBs used in this demonstration, namely, F-fly ash, FBC fly ash and Scrubber sludge were characterized for particle size distribution and oxides compositions. The particle size characteristics and oxides compositions are presented in Tables 1 and 2.

Table 1. Particle size characteristics of the CCBs utilized in this demonstration.

<table>
<thead>
<tr>
<th>CCB</th>
<th>$D_{50}$ (μm)</th>
<th>Coefficient of Uniformity ($C_u$)</th>
<th>Coefficient of Gradation ($C_c$)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-fly ash</td>
<td>60</td>
<td>14.3</td>
<td>0.463</td>
<td>non-uniform, gap graded</td>
</tr>
<tr>
<td>FBC-fly ash</td>
<td>22</td>
<td>6.2</td>
<td>1.02</td>
<td>medium uniform, well graded</td>
</tr>
<tr>
<td>Scrubber Sludge</td>
<td>15</td>
<td>2.86</td>
<td>0.865</td>
<td>uniform, well graded</td>
</tr>
</tbody>
</table>
Table 2. Oxide composition of CCBs utilized in this demonstration.

<table>
<thead>
<tr>
<th>Composition</th>
<th>FBC-fly ash</th>
<th>F-fly ash</th>
<th>Scrubber Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>43.86</td>
<td>40.99</td>
<td>1.40</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.51</td>
<td>15.73</td>
<td>1.20</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.71</td>
<td>1.08</td>
<td>0.03</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>8.54</td>
<td>22.15</td>
<td>0.35</td>
</tr>
<tr>
<td>CaO</td>
<td>17.58</td>
<td>4.31</td>
<td>41.23</td>
</tr>
<tr>
<td>MgO</td>
<td>1.22</td>
<td>0.57</td>
<td>0.80</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.39</td>
<td>3.43</td>
<td>0.03</td>
</tr>
<tr>
<td>NaO₂</td>
<td>0.39</td>
<td>0.7</td>
<td>0.28</td>
</tr>
<tr>
<td>SO₃</td>
<td>9.31</td>
<td>2.57</td>
<td>54.32</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.30</td>
<td>1.21</td>
<td>0.24</td>
</tr>
<tr>
<td>SrO</td>
<td>0.05</td>
<td>-</td>
<td>0.05</td>
</tr>
<tr>
<td>BaO</td>
<td>0.09</td>
<td>-</td>
<td>0.05</td>
</tr>
<tr>
<td>Mn₂O₃</td>
<td>0.05</td>
<td>0.15</td>
<td>0.02</td>
</tr>
<tr>
<td>LOI</td>
<td>1.48</td>
<td>7.11</td>
<td>-</td>
</tr>
</tbody>
</table>

The oxide compositions indicate the self cementitious behavior of FBC fly ash (due to high CaO content) and pozzolonic nature of F-fly ash (due to high CaO+Al₂O₃+SiO₂ content). Even though the calcium oxide content in scrubber sludge is high (due to unused calcium carbonate), the reactivity of the sludge is generally low due to low free lime content in it. The scrubber sludge is rich in SO₃ content due to inhibited oxygen cycle used in the scrubbing process. The SO₃ content in the FBC-fly ash being 9.31% is not a major concern. The SO₃ content in different CCBs ranges about 5-10% and its presence in FBC-ash delays the hydration reactions but has no effect on the ultimate strength (Chugh et. al., 2000). However, at higher sulfate contents the sample durability is significantly reduced. The concern with high sulfate content would be formation of ettringite during the initial hydration reactions and the swelling effects could reduce the strength and performance of the mix.

Develop and demonstrate CCBs mixing technology to prepare soil-like mixes

Sulfite-rich scrubber sludge is highly viscous and exhibits thixotropic rheology making handling and mixing extremely difficult. Hence, it was necessary to develop and demonstrate a reliable mixing technology that will handle this material along with other mix constituents while providing intimate mixing. Such a technology capable of producing 6-7 t h⁻¹ of mix was developed and demonstrated. The mixing circuit was operated over a period of 21 d to generate approximately 160 t of mix. A schematic of the mixing circuit is presented in Figure 1. Picture of the mixing circuit taken during the time of demonstration and a stockpile of the mix output is presented as Figure 2.

Initial trials with the mixing scheme revealed problems related to dispersion of the dewatered scrubber sludge in the mix. To address this concern, the scrubber sludge was diluted to about 50-55% solids and kept in suspension in a slurry form. This solids content level was chosen as such so that the slurry contained the required water
content to generate a final mix with about 25-27% moisture content. The scrubber sludge slurry was pumped into a mixing auger where other solid constituents, F-ash, FBC ash, lime and cement were metered in the appropriate proportions using two sets of metering augers. When the sludge was added in a slurry form, it readily mixed intimately with other mix constituents. This was evident when cross-sections of samples prepared from the mix were observed and not found to contain a discrete phase of scrubber sludge. An added advantage of using sludge in a slurry form was that the dewatering costs of the power plant would be reduced as the sludge would not be dewatered to levels required earlier for its transport to disposal sites.

Figure 1. Schematic of a 6-7 t h\(^{-1}\) mixing circuit for producing the designed feeding pad mix.

Figure 2. Commercial implementation of feeding pad (a) mixing (b) mix stockpile.
Conceptual design and preliminary testing of a full-scale mixing technology

Options were evaluated for production of the soil-like mix on a larger scale. A paddle mixer capable of mixing about 110 t h\(^{-1}\) of the mix was already available and installed above a truck load-out at the power plant. These mixers are common place for wetting the byproduct ashes to minimize dust prior to transport. Successful tests were conducted using this mixer for mixing FBC ash and scrubber sludge and loading it into trucks. To introduce other mix components (lime/cement/sand and F-ash) into the paddle mixer, SIU designed a conceptual circuit. The overall schematic for the mixing circuit is shown in Figure 3. This circuit provided the power plant flexibility to manage all their by-products at a single location for either beneficial uses or for hauling to dump sites.

![Figure 3. Schematic of full-scale mixing circuit planned for implementation at the Power Plant. SBA-Spent Bed Ash. (1 tph = 0.909 t h\(^{-1}\), 120 gpm = 455 l m\(^{-1}\))](image)

Evaluate material handling and dumping characteristics of soil-like mixes

Evaluation of the handling properties of the soil-like mix and its amenability to loading, unloading and transportation in trucks was evaluated. Laboratory studies on material handling properties were followed by full-scale demonstration which included transportation in trucks and delivery at the construction site.

The material handling and dumping characteristics of the feeding pad mix were evaluated in the laboratory through angle of repose measurements. The measured angle of repose in the laboratory was 42\(^\circ\) with the horizontal. This level of angle of repose is very beneficial as it is low enough to allow clean dumping of material from trucks while being high enough to allow stockpiling of the material. Both these properties were validated during the demonstration of the commercial pad as the material was stockpiled and then loaded and transported in tandem trucks and discharged at the construction site. The discharge of the material from the trucks was entirely trouble free with absolutely no material adhering to the truck bed.
Evaluate workability characteristics of soil-like mixes over time

The time for which the mixed CCBs remain workable and amenable to material handling and compaction determines the reach of the material from the power plant to the deployment site. A mix that stays workable for a longer duration is highly desirable as the market reach will be proportional to the squared time. Hence, studies on mix workability were conducted. Mineralogical changes in the mix and the cured strength of the compacted mix were evaluated as a function of time. Samples were prepared and XRD scans run to identify mineralogical changes at 0, 12, 24, 36, 48 and 72 h after mix preparation. The mineralogical changes observed in the mix indicated that the mix had a shelf-life of 48-72 hours. Close to designed strength values were obtained from a 48 h aged mix indicating that the freshly prepared mix must be transported and placed within 48 h to achieve the desired engineering properties of the pad. Details of this investigation are submitted for publication elsewhere (Chugh, et. al., 2007, submitted to Fuel).

Determine effect of cattle waste on performance of feeding pad materials and on surface water quality

To determine the impact of animal waste on the environmental properties of the feeding pad, samples were made incorporating 0, 30, 50, 70 and 100% animal waste (solid manure + urine) into the feeding pad mix. The samples were prepared in this fashion to identify the maximum possible impact of animal waste on leachate as the animal waste is intimately mixed in the matrix of the pad. The samples were cured for 14 d and tested using TCLP procedure to determine leachate characteristics. The leachate from the 50% animal waste mix indicated Class I groundwater quality compliance for all elements with the exception of Arsenic which was still Class II compliant and sulfates which exceeded Class II standards as with all other mixes involving scrubber sludge and FBC ash. It is noted here that Arsenic does not appear as a problem element in any other mix not involving animal waste. Hence, further evaluation is necessary to investigate if the presence of animal waste in fact induces arsenic leaching.

Paste pH measurements were also conducted on the animal waste mixes to verify the expectation that the presence of acidic animal waste will help neutralize the slightly alkaline leachate reported from the feeding pad mix to bring it below 9 to allow its discharge into public waterways. The measured paste pH's for the animal waste mixes are presented in Table 3. It appears that the surface runoff and leachate on the pads will be exposed to animal waste contents in the higher end of this range and will thus be effectively neutralized.

Overall, environmental studies on the designed mix indicated that the mix composition fixed several trace elements which would have otherwise leached excessively from individual CCBs from the power plant, or, 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 Sulfates and pH. 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 indicate the maximum possible leaching of elements and compounds from the mix. Summary results of TCLP leachate studies conducted are presented in Table 4.

Table 3. Paste pH of feeding pad mix combined with animal waste.

<table>
<thead>
<tr>
<th>Feeding Pad Mix (%)</th>
<th>Animal Waste (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>7.49</td>
</tr>
<tr>
<td>30</td>
<td>70</td>
<td>7.79</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>8.71</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>9.22</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>9.99</td>
</tr>
</tbody>
</table>

Table 4. TCLP leachates from the developed mixes as compared to the individual CCBs disposed from the power plant. All values reported in parts per million.

<table>
<thead>
<tr>
<th>Element</th>
<th>SS-CFP</th>
<th>Mod. CFP</th>
<th>AW 50</th>
<th>70x40 RUNO</th>
<th>FA</th>
<th>FBC</th>
<th>SS Fixed</th>
<th>Class I</th>
<th>Class II</th>
</tr>
</thead>
<tbody>
<tr>
<td>As 0.009</td>
<td>0.025</td>
<td>0.175</td>
<td>0</td>
<td>0</td>
<td>0.04</td>
<td>0.04</td>
<td>0.007</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>Ba 0.135</td>
<td>0.187</td>
<td>1.35</td>
<td>0.109</td>
<td>0.18</td>
<td>0.43</td>
<td>0.17</td>
<td>0.35</td>
<td>0.005</td>
<td>0.05</td>
</tr>
<tr>
<td>Cd 0</td>
<td>0</td>
<td>0.005</td>
<td>0</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.005</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Cr 0.06</td>
<td>0.075</td>
<td>0</td>
<td>0.03</td>
<td>0.13</td>
<td>0.05</td>
<td>0.08</td>
<td>0.1</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Pb 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
<td>0.04</td>
<td>0.0075</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Hg 0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.002</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Se 0.01</td>
<td>0</td>
<td>0.01</td>
<td>0</td>
<td>0.09</td>
<td>0.04</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Ag 0.005</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>SO4 2320</td>
<td>934</td>
<td>1493</td>
<td>2064</td>
<td>263</td>
<td>866</td>
<td>2820</td>
<td>400</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>pH 11.2</td>
<td>11.2</td>
<td>7.13</td>
<td>7.97</td>
<td>3.22</td>
<td>12.52</td>
<td>-</td>
<td>6.5-9</td>
<td>6.5-9</td>
<td></td>
</tr>
</tbody>
</table>

SS-CFP Cattle Feeding Pad Mix with 25% Scrubber Sludge
Mod-CFP Cattle Feeding Pad Mix with 25% Sand and 5% Cement
SS-Fixed Scrubber Sludge and F-ash mix produced at SIPC
AW-50 SS-CFP Mix 50% + Animal Waste 50%
FA F-ash
FBC FBC Ash
Class I Groundwater Quality Standard
Class II Groundwater Quality Standard

Style Coding
Normal Class I Compliant
Italics Class II Compliant
Bold Class II Non-compliant
Full scale demonstration of a commercial feeding pad.

**Trial Demonstration**

Prior to the demonstration of the commercial pad, a test pad was constructed at the power plant site to shake-down the mixing circuit and determine optimum construction practices. This 6 m x 6 m test pad was demonstrated and used approximately 20 t of CCBs. Figure 4 presents pictures of the test pad at the power plant. Based on experience gained during construction of this pad, a detailed Construction Practice Manual was compiled. This is available elsewhere (Chugh et. al., 2005b). After the pad cured for 10 d, it was used for stockpiling the mix to be used in the development of the commercial pad. The pad performed very well even as a full-size front-end loader operated on it to scoop material from the stockpile and load it in trucks for transport to the commercial demonstration construction site.

Before the full-scale demonstration of the feeding pad was initiated, additional laboratory studies and FEM studies were conducted to determine the engineering design of the pad. Quality assurance and control protocols were also developed through these laboratory and field studies. The results of these are presented below.

![Figure 4. Pictures of trial pads placed at the power plant.](image)

**Laboratory Studies**

Moisture content of the mix is an important parameter during construction. Higher moisture content increases the final cured density of the mix up to a certain level beyond which it starts to decreases. Higher cured density is also related to increasing compressive strength. Hence, ideally, the moisture content of the mix needs to be at a point which yields the highest cured density at the targeted compaction effort. To determine this optimum moisture level, tests were conducted in the laboratory at standard proctor compactive effort to yield the optimum moisture content of 36% on a dry basis (26.5% on a wet basis) as indicated in Figure 5 (a). The relationship between cured density and compressive strength is shown in Figure 5 (b) which indicates that at
the optimum moisture content, a material with strength of about 8.6 MPa should be produced. However, mix workability is another consideration that goes into determination of the optimum moisture content. During the lab experiments, it was observed that the mix becomes unworkable rapidly beyond about 27% moisture content on a wet basis. Hence, the targeted moisture content for the mix preparation for demonstration was set at 25% to allow for a safety factor so that the mix does not exceed 27% moisture. However, interestingly it was discovered that the workability considerations are significantly different during field compaction. The mix in this case remained workable even beyond 27% moisture content. Hence, supplementary water was added to the mix during the compaction process to increase the moisture content up to the 26-27% level and also replenish any evaporative losses during mix stockpiling and transport.

Figure 5. Moisture-density-strength relationship for the feeding pad CCBs mix.

**Pad Design - FEM Modeling**

Finite element modeling was used to study the development of stresses in the pad during routine conditions of use and for basing the pad design on that data. The maximum stresses encountered during dynamic and static loading were determined and compared to the strengths of the developed material. The modeling results indicated a need for a 20-30 cm thick pad with reinforcement in between the lifts. This pad design was used in the demonstration with certain modifications as described below. Details of pad design and FEM modeling are submitted for publication elsewhere (Chugh, et. al., 2007, submitted to Fuel).

**Implementation of the Commercial Feeding Pad (22 m x 12 m)**

The preparation of the construction site for the commercial pad at the demonstration site involved cleaning and grading of the surface of the base soil layer. The entire pad was constructed in four quadrants. In each of the quadrants, small modifications in the construction process were made to improve the performance of the pad. The FEM
analysis had provided the requirement for reinforcement to avoid tensile failure of the surface of the pad. Hence a plastic and a steel grid fencing were used as a reinforcement in Quadrants I and III, respectively and placed at the interface of the two lifts. A 150 μm thick vapor barrier was also 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. In the overall pad layout presented in Figure 6, the pad thickness at the south-west corner was 25 cm and tapered down to 7.5 cm at the north-east corner. The thicknesses at the north-west and south-east corners were 20 cm. Quadrant I was expected to perform the best while Quadrant IV would be the worst.

Figure 6. Construction layout of the 22 m x 12 m commercial feeding pad.

The CCBs mix for pad construction was prepared at the power plant and transported to the site in 10 t Tandem trucks which end- discharged the material without any trouble whatsoever. A skid-steer was then used to spread the delivered mix on the leveled base soil layer. A vibratory roller attachment on skid-steer was used to compact the material in two lifts of about 10-13 cm. The pad was sprayed with water 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 d to prevent surface moisture loss. Cattle were allowed on the pad 7 d after the installation of the last quadrant. Images taken during the different steps involved in the implementation are presented in Figure 7. A total of 136 t of CCB’s were placed in this pad.
Figure 7. Demonstration of Feeding pad (a) site preparation (b) installation of Lysimeters (c) mix delivery (d) mix compaction and (e) finished pad (Quadrant - I).
Quality Control/Quality Assurance Protocols

In addition to the optimized mix design, compaction is the most important parameter having an impact on the final pad performance. To ensure that a standard compactive effort was used during field construction, a Quality Assurance/Quality Control (QA/QC) protocol was developed and used during construction. The samples prepared in the laboratory using standard compactive effort were tested immediately after preparation and after 1, 3 and 7 d using a penetrometer. Load measurements were recorded for penetrations of 6.35 mm, 12.7 mm and 19.05 mm. During field implementation, a skid steer mounted vibratory smooth roller was used to make 4 passes on the pad. Penetrometer readings were recorded on this pad and compared with the laboratory data to ensure that the load required to penetrate the corresponding depths was higher in the field than in the lab. This technique allowed an indirect measurement of the field compaction effort which was found to be higher than the standard effort used in the preparation of the laboratory samples. Readings were taken immediately after implementation and after 1, 3 and 7 d to arrive at the same conclusion. To ensure uniform compaction of the pad, penetrometer measurements were taken in a 1.5 m centers grid on the entire pad. The results were plotted as shown in Figure 8. The plots indicate that a uniform compaction was achieved except at the extremities which could not be accessed properly with the roller.

![Figure 8. Compaction QA/QC penetrometer observations.](image)

Post-Construction Monitoring

Following construction of the commercial pad, monitoring was continued through the following winter months. Over this period, the pad was observed to develop soft spots in areas that were subjected to constant influx of water or in areas prone to standing water. Laboratory investigation revealed that this pad behavior was primarily due to poor drainage at the site and secondarily due to the presence of scrubber sludge which swelled and softened when subjected to water for extended periods of time. Despite this shortcoming, the pad owner and other farmers in the local area who inspected the pad were satisfied with its 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 large increase in the cost of poured concrete.

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 formulated with these improved characteristics. This mix substantially reduced or eliminated the use of scrubber sludge while replacing it with river sand in the mix and replacing the combination of two inorganic binders with only one binder. This mix was found to perform satisfactorily in laboratory abrasion tests and water sensitivity tests. The modified mix properties and development is discussed in a separate article submitted elsewhere for publication (Chugh, et. al., 2007, submitted to Fuel).

CONCLUSIONS

This research demonstrated a commercial-size application of a cattle feeding pad using CCBs. Mixes were developed and further refined to improve the abrasion and water-sensitivity of the material based on post-construction monitoring of the constructed pad. Prior to pad demonstration, FEM modeling was used to develop a pad design. Additional evaluations of the mix properties with respect to its workability over length of time elapsed since mix preparation and its material handling characteristics were also conducted. A 42° angle of repose was measured for the fresh mix which was found to be optimum for enabling stockpiling of material while still allowing a clean discharge of the material from truck beds after transportation. From a workability standpoint, tests indicated that construction needs to be conducted within 48-72 h from mix preparation to achieve the designed engineering properties. Environmental properties of the leachate and surface run-off from the developed mixes and from the constructed pad with and without the presence of animal waste were studied and found to comply with Class I ground water quality standards with the exception of sulfates. It is to be noted that the current byproducts from the power plant, alone, or, in combinations as disposed, do not comply with Class I or II ground water limits for several elements.

The demonstration activities led to the development of pad Construction Practice Manual and QA/QC procedures for use in the construction of future pads. Engineering economic evaluations referenced earlier indicate 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.

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REFERENCES