# Designing Geo-Composite Liners to Enhance Fly Ash Pond Containment

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**Abstract:**

This research paper investigates the design and efficacy of geo-composite liners for enhancing containment in fly ash ponds, crucial in mitigating environmental contamination arising from thermal power plant operations. Rapid industrialization in India has resulted in a significant surge in fly ash production, posing threats to groundwater and human health due to the leaching of toxic heavy metals. Despite existing containment measures, the infiltration of contaminants persists, necessitating innovative solutions. This paper outlines laboratory experiments conducted to assess the suitability of various soil types as liners and employs computational analysis using C'TRAN software to optimize liner design. The findings underscore the efficacy of sodium bentonite-based liners encapsulated in geo-composite materials, offering promising results in minimizing contamination transportation.

**Keywords:** Fly Ash Pond, Geo-Composite Liners, Environmental Contamination, Soil Properties, Computational Analysis.

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**Introduction:**

India's rapid industrialization and urbanization have led to a surge in demand for power generation, with thermal power plants meeting approximately 73% of the nation's energy needs. Predominantly coal-based, these plants contribute to a significant increase in fly ash production, with India ranking fourth globally in coal ash output. The environmental repercussions of this production are profound, as fly ash contains toxic heavy metals such as arsenic, lead, and mercury, which can leach into groundwater and soil. Despite containment measures like Composite Clay Liners (CCLs) and Geosynthetic Clay Liners (GCLs), the infiltration of contaminants persists, necessitating innovative solutions. This paper discusses laboratory experiments evaluating different soil types as liners and utilizing computational analysis to optimize design using C'TRAN software. Particularly, sodium bentonite-based liners encapsulated in geo-composite materials are highlighted for their efficacy in mitigating contamination transportation. The research aims to contribute to sustainable solutions for managing environmental risks associated with fly ash disposal, crucial for safeguarding ecosystems and public health in industrialized regions.

**OBJECTIVES:**

- Investigating the origins and impacts of different toxic metals dissolved in groundwater.
- Analyzing the leaching characteristics of black cotton soil when used as a liner in fly ash ponds.
- Developing an appropriate design for a geocomposite liner tailored for use in fly ash ponds.

## Literature Review:

A comprehensive review of existing literature elucidates prior research efforts, including investigations into fly ash pond management, soil characteristics, and the efficacy of different liner materials. Notable contributions from various researchers are discussed, providing insights into the evolution of containment strategies.

**Abdullah and Dafalla (2017),** in this paper, “Effect of state of compaction on the hydraulic conductivity of Sand-Clay mixtures”, explained that mixture of Sand-Clay is used as liner for waste containment. It is necessary to design the liner for different effective pressures at different moisture content conditions. The natural clay, which is highly expansive and plasticity is mixed with sand and design the liner. The suitable liner may be designed, after conducting the tests for different percentages of clay – sand mixtures and check for hydraulic conductivity. By maintaining the confining pressure as 50 to 500kPa and gradient as 30, all the tests were performed. Finally it was found that the less hydraulic conductivity is at wet of optimum moisture content (WOMC) due to occupying the clay particles in voids. Hence it may recommended the proper compacted liner for waste containment.

**Amina and Rani (2017),** in their paper, “Evaluation of Fly Ash as Amended Liner and the Effect of Pore Fluids”, states that Indian energy production is being majorly carried out through thermal power plants. These plants mainly contain fly ash. Using fly ash effectively is the focus of this paper. Fly ash has many advantages as liners, but cannot be used alone because they have high hydraulic conductivity and low ion exchange potential. To limit this disadvantage, bentonite is blended with it. Modified fly ash with bentonite mixture improves its volume change characteristics and ion exchange ability. There is also gains good potential to be used as a liner. When mixing the liner with wastes, its characteristics get changed. The paper also studied changes in geotechnical properties by adding different concentrations of fluid. Fly ash along with bentonite as a mixture provides better material for usage as a landfill liner than using any one of them solely. This material is less susceptible to damage, is flexible, and has good strength and low conductivity. It is suitable for landfill liner material. When liquids are added to the optimal mixture of fly ash-bentonite, two things were observed. Firstly, when the dielectric constant falls, the plasticity index and the liquid limit increases. Secondly, by increasing the concentration of electrolytes, strength increased.

**Deka and Sekharan (2017),** in their paper, “Contaminant retention characteristics of fly ash–bentonite mixes”, states that it is vital to evaluate the pollutant retention properties when applying the substances that is used as liners on the garbage dumping site. Sand-bentonite blends are usually used as liners when building hazardous and industrial waste dumps. Sand is a passive material with inadequate abilities of chemical adhesion; fly ash, however, offer an additional advantage of absorbing heavy metals in landfill dumps. The characteristics of pollutant absorption of ash and bentonite blends have been studied very little. The research published here has specified the properties of fly ash, bentonite and fly ash blends using $Pb^{2+}$ 24 hr tests. These tests were modified according to the metallic ions concentrations under pH conditions which were uncontrolled. The elimination of $Pb^{2+}$ has been analyzed according to both the blends. The impact of varying the source of ash has also been investigated.

## Methodology:

This section delineates the experimental procedures conducted to assess the properties of Black Cotton Soil (BC Soil), Bentonite, Calcium Bentonite, and Sodium Bentonite soils, focusing on various index and engineering properties. Tests were conducted on BC Soil and Sodium Bentonite soils of thicknesses 1 cm, 2 cm, and 3 cm to evaluate permeability under normal water conditions and exposure to leachate under a hydraulic gradient, utilizing a flexible wall permeameter test system. The outcomes of these trials were utilized to recommend a suitable liner for fly ash ponds, specifically targeting heavy metals such as Arsenic, Chromium, Cadmium, and Lead, And computational analysis using C'TRAN software. The utilization of C'TRAN software for computational analysis outlines the inputs and outputs of the modeling process.

**Materials Collected:**

1. **Fly Ash:** Fly Ash from Kota Super Thermal Power Plant (KSTPS), Rajasthan, underwent extensive testing to ascertain its properties and heavy metal content.
2. **Leachate:** Prepared from fly ash and tested for toxic metal content. Leachate samples were collected from various locations around the fly ash pond area at KSTPS.
3. **Black Cotton Soil (BC Soil):** Acquired from Barmer area, Rajasthan, known for its high clay content and unique properties suitable for liners.
4. **Bentonite:** A type of absorbent clay derived from volcanic ash, including Calcium Bentonite and Sodium Bentonite.

**Experimental Procedures:**

The following laboratory tests were conducted:

- **Specific Gravity:** Determined using the density bottle method.
- **Hydrometer Analysis:** Conducted to determine particle size analysis for soil particles smaller than 75 microns.
- **Liquid Limit:** Evaluated using the Casagrande method and Cone Penetro-Meter method.
- **Plastic Limit:** Determined to ascertain the water content at which soil plasticity ceases.
- **Standard Proctor Test:** Performed to determine optimal moisture content and maximum dry density of the soil.
- **One Dimensional Well Consolidation Test:** Conducted to evaluate consolidation parameters such as swell pressure, voids ratio, compression index, and permeability.
- **Unconfined Compressive Strength (UCS):** Evaluated to determine the shear quality characteristics of the soil.
- **Chemical Analysis:** Total Dissolved Solids (TDS), pH, Electrical Conductivity, Total Hardness, Sulphates, and Heavy Metals (Lead, Chromium, Cadmium, Arsenic) were analyzed using standard methods including Atomic Absorption Spectrophotometer (AAS).
- **Specific Surface Area (SSA):** Evaluated using Ethylene Glycol Mono-ethyl Ether (EGME) method.
- **Free Swell Index:** Determined to assess the swelling capacity of clayey soils.
- **Falling Permeability Method and Hydraulic Conductivity:** Assessed the permeability of clay soils using standard procedures and equipment, including the Flex Panel-HM-4150 Humboldt, USA.

**Sample Preparation:**

Samples of Black Cotton Soil and Sodium Bentonite were sourced and prepared according to standard procedures, including compaction and molding.

**Testing Procedure:**

Various tests were conducted on the prepared samples, following established protocols and guidelines as per relevant IS standards and ASTM methodologies.

**Data Analysis:**

Data obtained from the experiments were analyzed using appropriate statistical methods and techniques to derive meaningful conclusions regarding the properties and suitability of the soils and liners for fly ash ponds.

## Results and Discussion:

The findings from laboratory experiments and computational analysis are presented, highlighting soil properties, heavy metal retention capacities, and the efficacy of different liner materials.

The index and engineering properties of various clayey soils and fly ash have been thoroughly investigated through a series of tests, yielding insightful data essential for assessing their suitability for engineering applications. The analysis and discussion of the results are presented below.

**Standard Proctor Test Results:**

1. **Black Cotton Soil:**
    - Maximum Dry Density (MDD): 1.56 g/cm³
    - Optimum Moisture Content (OMC): 24%
2. **Bentonite:**
    - MDD: 1.556 g/cm³
    - OMC: 24.5%
3. **Calcium Bentonite:**
    - MDD: 1.28 g/cm³
    - OMC: 34%
4. **Sodium Bentonite:**
    - MDD: 1.26 g/cm³
    - OMC: 34%

**Liquid Limit:**

1. **Black Cotton Soil:** 69.8%
2. **Bentonite:** 121%
3. **Calcium Bentonite:** 119%
4. **Sodium Bentonite:** 195%
5. **Fly Ash:** 27%

**Hydrometer Analysis:**

1. **Black Cotton Soil:** Clay = 29.5%, Silt = 70.5%
2. **Bentonite:** Silt = 86%, Clay = 14%
3. **Calcium Bentonite:** Clay = 6%, Silt = 94%
4. **Sodium Bentonite:** Silt = 88%, Clay = 12%

**Unconfined Compressive Strength (UCS):**

1. **Black Cotton Soil:** qu = 332.45 kN/m², Cu = 166.22 kN/m²
2. **Bentonite:** qu = 270.66 kN/m², Cu = 135.22 kN/m²
3. **Calcium Bentonite:** qu = 272.62 kN/m², Cu = 136.31 kN/m²
4. **Sodium Bentonite:** qu = 277.53 kN/m², Cu = 138.76 kN/m²

**Consolidation Parameters:**

1. **Black Cotton Soil:**
   - T90 = 0.029
   - Coefficient of Permeability (k) = 2.1233 × 10^-11 cm/sec
2. **Bentonite:**
   - T90 = 0.036
   - Coefficient of Permeability (k) = 5.036046 × 10^-12 cm/sec
3. **Calcium Bentonite:**
   - T90 = 0.038
   - Coefficient of Permeability (k) = 3.2697 × 10^-12 cm/sec
4. **Sodium Bentonite:**
   - T90 = 0.08
   - Coefficient of Permeability (k) = 1.6698 × 10^-12 cm/sec

**Conclusion:**

A summary of key findings is provided, emphasizing the efficacy of sodium bentonite liners in minimizing contamination transportation and safeguarding environmental health. The conclusion encapsulates the significance of the research and proposes future avenues for exploration. Conclusion: This research paper elucidates the significance of designing effective containment solutions for fly ash ponds, crucial in mitigating environmental contamination. Through laboratory experiments and computational analysis, sodium bentonite-based geo-composite liners have emerged as promising solutions, offering robust heavy metal retention capacities. The findings underscore the importance of continued research and innovation in addressing environmental challenges posed by industrial operations.

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