

Appraisal of Suitability of Geosynthetic Clay Liner in Composite Base Lining System of Phosphogypsum Dumping Yard

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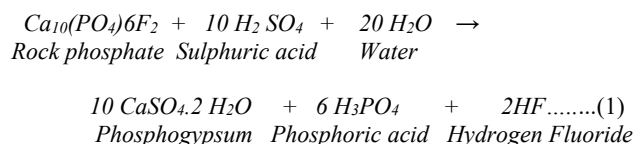
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ABSTRACT: Stockpiling of phosphogypsum without proper measures in the past has led to subsoil and groundwater contamination. With the recent development in regulations in some countries, dumping of phosphogypsum directly on land is prohibited due to its contamination and leaching characteristics. The Central Pollution Control Board (CPCB) of India has recommended a composite base liner system for the disposal of phosphogypsum. The lower part of the composite liner system shall comprise compacted clay or compacted amended soil or any other equivalent soil of permeability, $k \leq 10^{-9}$ m/s, and have a thickness of 60 cm. In the upper part of the composite liner system, a layer of mechanically compacted and neutralized phosphogypsum is placed above the drainage layer. In the present work, the efficacy of geosynthetic clay liner (GCL) is evaluated for use in the lower part of the composite liner system, which can be an option in case suitable clay is not available locally. The study indicated the need of using two layers of GCL to sustain the effect of possible phosphogypsum contamination and satisfy the requirement of permittivity of 60 cm thick compacted clay liner.

KEYWORDS: Phosphogypsum Dumping, Geosynthetic Clay Liner, Permeability, Bentonite, Permittivity, and Base Lining System.

1. INTRODUCTION

Phosphoric acid is one of the main constituents in the production of phosphatic fertilizers. It is manufactured either by the thermal or wet process. However, due to the high production costs associated with the thermal process, its use is limited to small-scale phosphoric acid production. The wet process is widely used for fertilizer-grade production (CPCB, 2014). In the wet process, sulphuric acid is generally used to digest phosphate rock, resulting in both phosphoric acid and by-product phosphogypsum. The chemical reaction involved in the wet process is detailed in Equation 1.



Phosphogypsum is mainly dihydrate calcium sulphate containing the impurities such as residual acid, traces of heavy metals, fluoride, and radionuclides (Arocena et al., 1995; Rutherford et al., 1995; Gennari et al., 2011; Saadaoui et al., 2017). It is a grey-coloured, silt-sized powdered material. Nearly five tonnes of phosphogypsum is generated for every tonne of phosphoric acid produced (Tayibi et al., 2009; Islam et al., 2017; Dvorkin et al., 2018). Most of the generated phosphogypsum ends up in large stockpiles. At present, approximately 6 billion tonnes of phosphogypsum are stockpiled worldwide. Nearly 150 million tonnes are also estimated to be added to these stacks yearly (Xinfeng & Lan, 2022). Of this, 6.5 – 11 million tonnes of phosphogypsum are generated in India (CPCB, 2014; Tulasi & Satyanarayana Reddy, 2022; Palla et al., 2022). If not lined properly, the disposal of phosphogypsum poses serious environmental risks.

In India, phosphogypsum has been excluded from the hazardous waste category. In this regard, the CPCB of India has proposed a few mandatory guidelines for disposing of phosphogypsum on the ground

to control contamination of subsoil and groundwater. The composite baseline system suggested by CPCB (2014) is shown in Figure 1.

In the lower layer of the composite lining system, a 60 cm-thick compacted clay or amended soil with a coefficient of permeability $k \leq 10^{-9}$ m/s is placed. Also, there is an option for using any other equivalent soil with $k \leq 10^{-9}$ m/s in the absence of native clay or amended soil.

Geosynthetic Clay Liners (GCL) are commonly used in waste containment facilities due to their low hydraulic conductivity to water with $k < 10^{-10}$ m/s and ease of installation (Shackelford et al., 2000; Jo et al., 2001; Kolstad, 2004a; Jo et al., 2005; Benson et al., 2010).

The efficiency of a GCL depends on the hydraulic conductivity of sodium bentonite (sealing material in GCL), which is mainly composed of montmorillonite (Shackelford et al., 2000; Jo et al., 2001; Kolstad, 2004a; Jo et al., 2005; Shan & Daniel, 1991; Lee & Shackelford, 2005; Bradshaw & Benson, 2014; Tian & Benson, 2014).

GCL has several advantages over Compacted Clay liner (CCL) in terms of low hydraulic conductivity. Studies have proved that the hydraulic conductivity of GCLs is 10-100 times lower compared to CCL (Shackelford et al., 2000; Uma Shankar et al., 2017). It requires less skilled labour for installation and is less expensive. It occupies less space compared to CCL. Further, the Bentonite in GCL imparts self-healing ability through its swelling capacity, facilitating the sealing or reduction of leakages resulting from accidental punctures (Uma Shankar et al., 2017).

The use of GCL in the base lining system of phosphogypsum dumping yards has not been explored due to the concern that hydraulic conductivity increases through cation exchange. Hence, in the present work, the suitability of using GCL in the lower layer of the composite base lining system is assessed by studying the hydraulic conductivity of GCL when exposed to neutralized phosphogypsum. The present study intends to help the phosphate-based fertilizer industrial sector to ease the process of providing base lining systems with GCL as an alternative to CCL where suitable clay is not available.

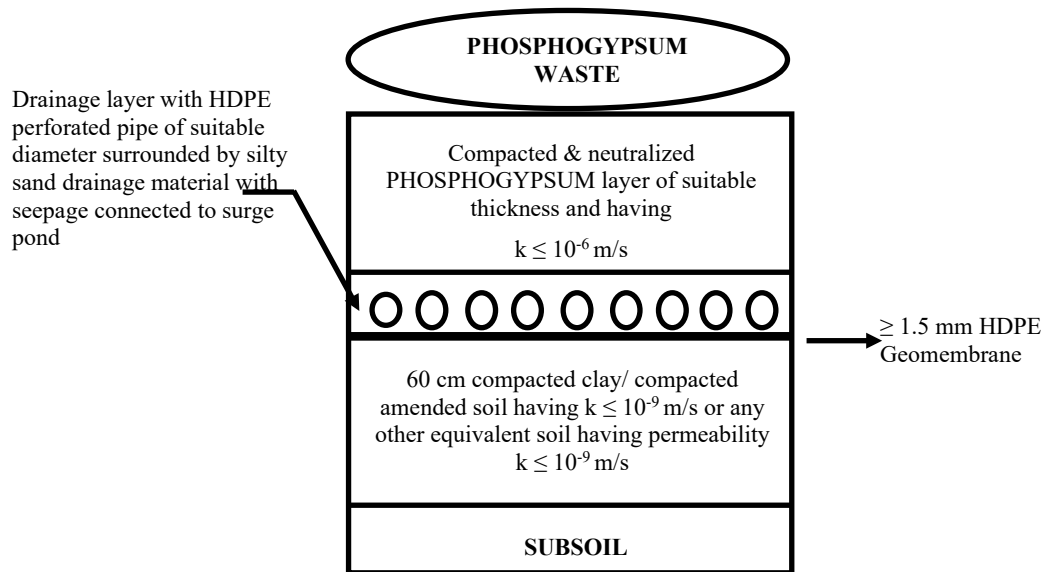


Figure 1 Base lining system for phosphogypsum stack suggested by CPCB (2014)

2. MATERIALS

2.1 Phosphogypsum

Phosphogypsum used in the present study was procured from Coromandel International Pvt Ltd, Visakhapatnam, Andhra Pradesh, India. The index and engineering properties are determined in the laboratory to evaluate the properties of phosphogypsum. The specific gravity of the phosphogypsum is determined by using a density bottle by utilizing kerosene as pore fluid. The permeability of the phosphogypsum is evaluated from the variable head permeability test. The California Bearing Ratio of phosphogypsum is determined by testing the specimen prepared in an OMC – MDD compacted state after 96 hours of soaking. The properties of phosphogypsum determined from the laboratory tests are presented in Table 1.

2.2 Lime

Commercially available lime is used in the study. The lime has a pH of 12.1. The chemical constituents of lime given by the manufacturer are presented in Table 2.

2.3 Fly Ash

Fly ash used in the study is procured from the National Thermal Power Corporation (NTPC), Visakhapatnam, Andhra Pradesh. The pH of the fly ash is found to be 7.9. The fly ash is categorized as a class – F. The chemical composition of fly ash obtained from NTPC is presented in Table 3 and the engineering properties of Fly Ash are presented in Table 4.

2.4 Geosynthetic Clay Liner (GCL)

The GCL used in the study is procured from Garware Wall Ropes Ltd., Pune, India. It consists of granular sodium bentonite sandwiched between a woven (carrier) geotextile and a non-woven (cover) geotextile bonded by needle punching. Various tests are performed in the laboratory to assess the physical properties of GCL. The thickness of the GCL is measured using a thickness measuring gauge under a normal pressure of 2 kPa. The tensile strength of the geotextile in the GCL is determined from a wide-width tensile strip test. The permeability test on GCL is conducted in an oedometer after saturation under a pressure of 515 kPa. The properties of the GCL used in the study and determined in the laboratory are listed in Table 5. Wet sieve analysis is performed to calculate the percentage fines in

the Bentonite of GCL. The properties of Bentonite in the GCL are presented in Table 6.

Table 1 Properties of phosphogypsum

Property	Value	Relevant Testing standard
pH	2.47	IS 2720 Part 26-1987
Specific Gravity	2.59	IS 2720 Part 3 - 1980
Grain size distribution		IS 2720
Gravel size (%)	0	Part 4-1985
Sand size (%)	5	
Fines (%)	95	
Clay size fraction (%)	8	
Compaction Characteristics		IS 2720
(i) Optimum moisture content (%)	22.8	Part 8-1983
(ii) Maximum dry unit weight (kN/m ³)	14.1	
Shear Parameters		IS 2720
i) OMC&MDD condition		Part 13-1986
(a) Cohesion (kN/m ²)	0	
(b) Angle of internal friction	34°	
ii) Saturated condition		
(a) Cohesion (kN/m ²)	0	
(b) Angle of internal friction	26°	
Coefficient of permeability (m/s)	1.36×10 ⁻⁶	IS 2720 Part 17-1986
Soaked CBR (%)	2.2	IS 2720 Part 16-1987

Table 2 Chemical composition of lime

Constituent	(%)
CaO	83.4
MgO	0.4
Fe ₂ O ₃	1.4
Al ₂ O ₃	1.2
SiO ₂	1.9
SO ₃	0.4
Na ₂ O	2.8
CO ₂	3.2
CaCO ₃	7

Table 3 Chemical Composition of fly ash

Constituent	(%)
SiO ₂ +Al ₂ O ₃ +Fe ₂ O ₃	93.78
SiO ₃	60.16
Reactive silica	34.46
MgO	0.79
Na ₂ O	0.90
SO ₃	0.16
CaO	3.95
Cl	0.006
Loss of ignition	0.47

Table 4 Engineering properties of fly ash

Property	Value	Relevant Testing standard
Specific gravity	2.1	IS 2720 Part 3 - 1980
Grain Size Analysis		IS 2720
Gravel (%)	0	Part 4 -
Sand (%)	18	1985
Fines (%)	82	
Plasticity Characteristics		IS 2720
(i) Liquid Limit (%)	NP	Part 5 -
(ii) Plastic Limit (%)	NP	1985
Compaction Characteristics		IS 2720
(i) Optimum moisture content (%)	18.5	Part 8-
(ii) Maximum dry unit weight (kN/m ³)	13.6	1983
Shear Parameters		IS 2720
(i) OMC&MDD condition)		Part 13-
(a) Cohesion (kN/m ²)	0	1986
(b) Angle of internal friction	29	
(ii) Saturated condition		
(a) Cohesion (kN/m ²)	0	
(b) Angle of internal friction	26	
Permeability (m/s)	2.72×10^{-7}	IS 2720 Part 17- 1986

Table 5 Properties of Geosynthetic clay liner

Property	Value	Relevant testing standards
Mass per unit area (g/m ²)		IS 14716 (1999)
a) GCL	5031	
b) Non-woven geotextile	309	
c) Woven geotextile	148	
Thickness (mm)		IS 13162, Part 3-1992
a) GCL	6.812	
b) Non-woven geotextile	3.726	
c) Woven geotextile	1.508	
Tensile strength (kN/m)	158.75	IS 13162, Part 5-1991
Permeability (m/s)	3.8×10^{-12}	ASTM D6766 - 20a

Table 6 Properties of Bentonite in the GCL

Property	Value	Relevant testing standards
Specific Gravity	2.75	IS 2720, Part-3, 1980
Fines (%)	92.4	IS 2720, Part 4, 1985
Liquid limit (%)	236.84	IS 2720, Part 5, 1985
Free Swell Index (%)	836.8	IS 2720, Part 40, 1977

3. NEUTRALIZATION OF PHOSPHOGYPSUM USING FLY ASH AND LIME

In the composite base lining system suggested by CPCB, a neutralized layer of phosphogypsum shall be placed in the upper part, and 0.6 m thick CCL shall be provided in the lower part. After several trials, it was found that the addition of fly ash even up to 50% did not neutralize the phosphogypsum; hence, lime is added to make up the pH to 7. It is observed that the addition of 1.6% lime and 50% fly ash to phosphogypsum has reached a pH of 7 (Satyanarayana Reddy & Tulasi, 2023).

The permeability of neutralized phosphogypsum with 1.6% lime and 50% fly ash in a compacted state is then determined to assess its suitability for use in the upper part of the composite liner system. The Compaction and Permeability characteristics of phosphogypsum neutralized with fly ash and lime are presented in Table 7.

Table 7 Compaction and Permeability characteristics of phosphogypsum neutralized with 50% Fly ash and 1.6% lime

Property	Value
Compaction characteristics	
(i) Optimum moisture content (%)	23
(ii) Maximum dry unit weight (kN/m ³)	12.6
Permeability(m/s)	3.99×10^{-7}

Phosphogypsum neutralized with 1.6% lime and 50% fly ash satisfies the permeability requirement specified by CPCB ($k \leq 10^{-6}$ m/s) for use in the upper part of the lining system.

4. EFFECT OF NEUTRALIZED PHOSPHOGYPSUM ON THE PERMEABILITY OF GCL

The GCL specimens are saturated in a large cell triaxial test apparatus under a cell pressure of 550 kPa by applying a back pressure of 515 kPa for 48 hours, as per ASTM D 6766 - 20a. The saturated GCL specimens are placed in permeameters and exposed to a compacted layer of neutralized phosphogypsum for periods of 4, 7, 14, and 28 days. The permeability of the GCLs with different exposure periods to neutralized phosphogypsum is determined by transferring the

GCLs to oedometers and performing variable head permeability tests. The values of the coefficient of permeability of GCLs exposed to neutralized phosphogypsum are presented in Table 8.

Table 8 Permeability of GCL exposed to neutralized phosphogypsum

No. of Days of exposure	Coefficient of Permeability (m/s)
0	3.8×10^{-12}
4	8.0×10^{-9}
7	8.25×10^{-9}
14	8.3×10^{-9}
28	8.31×10^{-9}

The values of the coefficient of permeability in Table 8 indicate that there is an increase in permeability after 96 hours, which is attributed to the replacement of native sodium cations bound to the bentonite with calcium in the phosphogypsum. Due to increased permeability, GCL did not satisfy the permeability requirement of the CPCB ($k \leq 10^{-9}$ m/s). Hence, use of another layer of GCL is proposed and the permeability of two GCLs is studied by exposing them to neutralized phosphogypsum and then testing in an oedometer. Table 9 presents the coefficient of permeability of two GCLs exposed to neutralized phosphogypsum.

Table 9 Permeability of two GCLs exposed to neutralized phosphogypsum

No. of Days of exposure	Coefficient of Permeability (m/s)
0	3.8×10^{-12}
4	1.42×10^{-11}
7	1.48×10^{-11}
14	1.48×10^{-11}
28	1.48×10^{-11}

From Table 9, it can be observed that there is no significant increase in effective permeability when two layers of GCLs are laid. The system of two GCLs meets the permeability requirement of the lower layer of the composite lining system.

The equivalence of the GCL system to a conventional compacted clay liner is further verified in terms of Permittivity (Permeability across the layer, $P = k/z$, where k is the coefficient of the layer and z is the thickness of the layer). From the calculations, it is found that the permittivity of two GCL systems is $1.086 \times 10^{-9} \text{ s}^{-1}$ which is less than the required permittivity of compacted clay liner recommended by CPCB (less than $1.67 \times 10^{-9} \text{ s}^{-1}$). Hence, two GCLs can be used as an alternative to CCL in the lower part of the composite base lining system of phosphogypsum ponds. The suggested composite base lining system for phosphogypsum stacking areas/ponds in the present study is shown in Figure 2.

The material cost of a 0.6 m thick CCL per square meter area is about Rs 540/-, whereas the cost of two GCLs (each of 6.8 mm thick) is about Rs 400/- based on prevailing market rates. Thus, the cost of two GCLs is less by 25% in comparison to equivalent CCL. However, transportation costs and layer-wise compaction charges shall be taken into account while arriving at actual cost economics.

5. CONCLUSIONS

The use of a single layer of GCL of thickness 6.8 mm in a base lining system with phosphogypsum does not ensure control of leachate entry, as the permeability of GCL increases ($k = 8.31 \times 10^{-9}$ m/s) due to the cation exchange phenomenon resulting from exposure to neutralized phosphogypsum.

The placement of two layers of GCL of thickness 13.6 mm in base lining system guarantees the required level of imperviousness ($k = 1.48 \times 10^{-11}$ m/s) as specified by CPCB. Hence, a system of two GCLs can be used in the lower layer of the composite base lining system as an alternative to CCL.

Based on material cost, using two GCLs in the lower layer of a composite base lining system is about 25% more economical than using CCL.

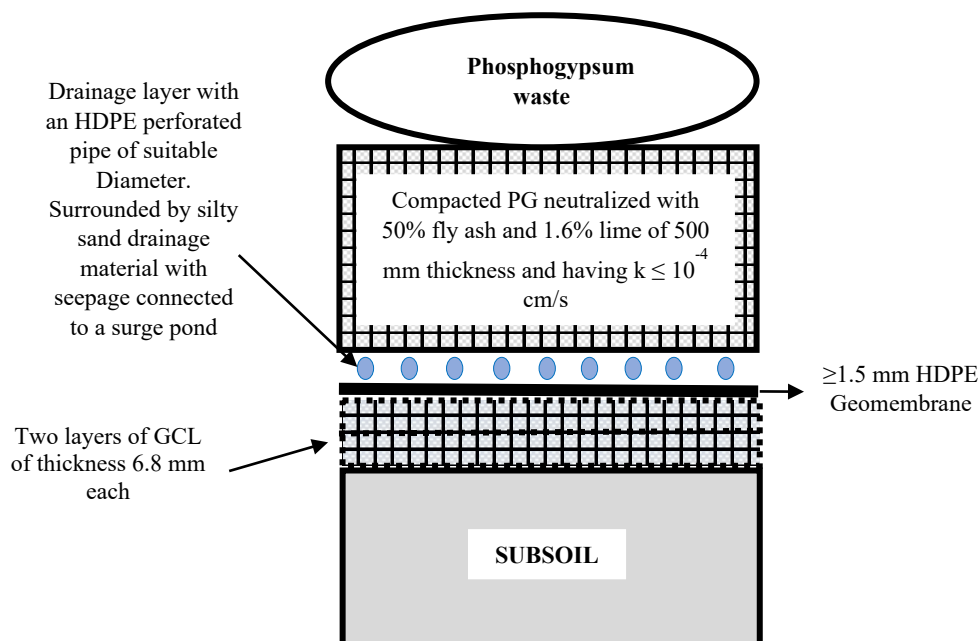


Figure 2 Suggested Baseline System for Phosphogypsum Dumping Yard

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