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Study Of Fly Ash In Hydraulic Barriers In Landfills – A Review

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ABSTRACT:- Landfilling is the most common method ofsolid waste management in our country. Lining systems for waste containment facilities can be enhanced if they are constructed with reactive materials, that is, materials that retard the movement of solutes, promote biodegradation, or induce chemical conversion. One potential material for constructing reactive liners is Fly ash from coal-fired power plants that contains a modest amount of residual organic carbon, which is a sorbent of VOCs. In this study fly ash is taken into consideration and tested for various parameters associated with the behaviour of hydraulic barriers in landfills to advocate its usability as hydraulic barriers in landfills. Also, the hydraulic conductivity of fly ash decreases with addition of certain additives like lime, cement etc.

Keywords: Landfills, Hydraulic Barriers, Fly Ash, Fly Ash stabilization, Lime cured Fly Ash.

I. INTRODUCTION

A landfill, also called sanitary landfill, is a land disposal site for waste, which is designed to protect from environmental pollution and health risks. It is not the same as an open dump. Landfills are built to concentrate the waste in compacted layers to reduce the volume and monitored for the control of liquid and gaseous effluent in order to protect the environment and human health. Well-constructed and maintained landfills are safer than open dumping sites, but even the best sanitary landfill will fill up and, after many years, probably start to leak[1].

An engineered pit, in which layers of solid waste are filled, compacted and covered for final disposal is called an Engineered Landfill. It is lined at the bottom to prevent groundwater pollution. Engineered landfills consist of a lined bottom; a leachate collection and treatment system; groundwater monitoring; gas extraction (the gas is flared or used for energy production) and a cap system [2].

A landfill liner, or composite liner, is intended to be a low permeable barrier, which is laid down under engineered landfill sites to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities [3], [4].

Compacted soils are widely used for liner systems to isolate waste materials from the environment. The effectiveness of the system is controlled by the permeability and liner thickness. Generally the regulations establish a maximum allowable permeability and a minimum liner thickness [5].

Lining systems for waste containment facilities can be enhanced if they are constructed with reactive materials, that is, materials that retard the movement of solutes, promote biodegradation, or induce chemical conversion. Volatile organic chemicals (VOCs) are the primary contaminants of concern because of their mobility and the low concentrations at which they are toxic. Thus, reactive materials that adsorb VOCs and retard their movement can make liners more effective[6].

One potential material for constructing reactive liners is Fly ash from coal-fired power plants that contains a modest amount of residual organic carbon, which is a sorbent of VOCs [7], [8].

In this study fly ash is taken into consideration and tested for various parameters associated with the behavior of hydraulic barriers in landfills to advocate its usability as hydraulic barriers in landfills.Also, the hydraulic conductivity of fly ash decreases with addition of certain additives like lime, cement etc.

II. HYDRAULIC BARRIERS

2.1 Overview

The Hydraulic Barriers or in simpler terms Landfill Liners play a very crucial role in Engineered Landfills. Due to uncountable biochemical reactions occurring within the waste body, landfills produce biogas and leachates which threaten the pollution of air, water and soil. The environmental impact of landfills depends, to a high extent, on a bottom liner and top capping isolating the landfill from the surrounding. The quality of this isolation is determined by the water permeability as, in fact, no constructions are completely impermeable[9].

The EU Landfill Directive [10] distinguishes three types of landfills i.e. landfills for hazardous waste, landfills for non-hazardous waste, and landfills for inert waste.

2.2 Liner Material Suitability

The EU Directive [10] determines that landfill base and sides should consist of Liner layer with the following requirements:

1. Landfill for hazardous waste – the layer should be characterized by the hydraulic permeability k equal or lower than 10^{-9} m/s and thickness equal at least 5 m,
2. Landfill for non-hazardous waste – the same permeability and thickness equal or higher than 1m,
3. Landfill for inert waste –hydraulic permeability of 10^{-7} m/s or less and thickness of at least 1 m.

Qualifying a material as landfill liner would depend on its low hydraulic conductivity and high contaminant retention[11].Soil plasticity can also be a reliable indicator of hydraulic conductivity and contaminant retention characteristics of soil. In general, a high plastic soil exhibits low hydraulic conductivity and high contaminant retention [12], [13].

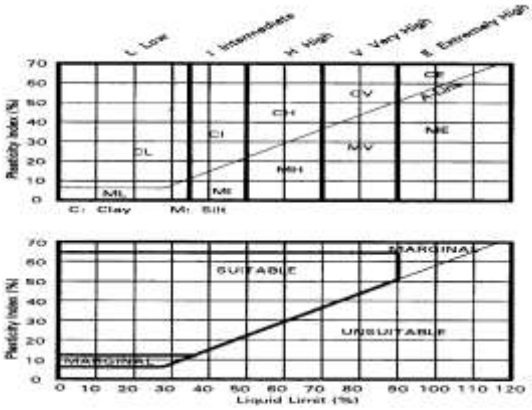

Figure 1: Plasticity and Suitability of materials [14]

Compacted soil used as landfill liners is expected to exhibit hydraulic conductivity (k) less than 10^{-7} cm/s. [15]. Compacted clay liners are normally used as an integral component of the lining system.Osinubi and Nwaiwu [16] worked with Compacted lateritic soil alone, while Osinubi and Eberemu [17] and Osinubi and Eberemu, [18] worked with lateritic soil treated with blast furnace slag and bagasse ash, respectively.

III. FLY ASH

Fly ash is a waste produced from coal-fired power generating stations and is readily available and need to be safely disposed.The pozzolanic and self-hardening properties of fly ash have naturally made it a very attractive material for use in a variety of construction applications such as fills, concrete, pavements, grouts etc. [19].

TABLE 1: Chemical Parameters [20]

	Class		
	N	F	C
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min, %	70.0	70.0	50.0
Sulfur trioxide (SO_3), max, %	4.0	5.0	5.0
Moisture content, max, %	3.0	3.0	3.0
Loss on ignition, max, %	10.0	6.0	6.0

TABLE 2: Physical Parameters [20]

	Class		
	N	F	C
Fineness: Amount retained when wet-sieved on 45 μm (No. 325) sieve, max, %	34	34	34
Strength activity index: With portland cement, at 7 days,	75	75	75

min, percent of control			
Strength activity index: With portland cement, at 28 days, min, percent of control	75	75	75
Water requirement, max, percent of control	115	105	105
Soundness: Autoclave expansion or contraction, max, %	0.8	0.8	0.8
Density, max variation from average, %	5	5	5
Percent retained on 45-μm (No. 325), max variation, percentage points from average	5	5	5

3.1 Use of Fly Ash

Based on ASTM C 618 standards, Table 1. Class C fly ash can be used as stand-alone material, while Class F is commonly blended with chemical additive [20].

Fly ash utilization for soil stabilizationas an additive is attractive because fly ash is an industrial by-product that is relatively inexpensive, compared with cement and lime. Fly ash utilization for soil stabilization, that would be land filled, promotes sustainable construction through reduction of energy use and reduction of greenhouse gases [21].

Pandian, Studied the effect of two types of fly ashes (Class F) and (Class C) on the CBR characteristics of the black cotton soil, the CBR effect depends on the soil cohesion and fly ash type and ratio [22]. Phanikumar and Sharma, study the effect of fly ash on engineering properties of expansive soil. Parameters like plasticity, compaction, strength and hydraulic conductivity of expansive soil were studied. The plasticity was reduced by about 50% by the addition of 20% fly ash [23].

3.2 Soil Stabilization: Depending upon the soil type, the effective fly ash content for improving the engineering properties of the soil varies between 15 to 30% [24]. Ahmed, found out that increasing ash content from zero to 20wt. % decreases liquid limit, increases the plastic limit and decreases the plastic index. Fig.2, Fig. 3 [25].

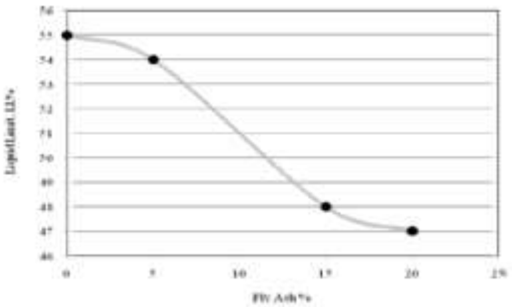

Figure 2: Liquid Limit of Soil with Fly Ash [25]

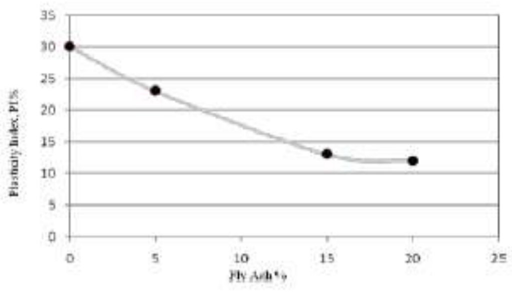

Figure 3: Soil Plastic Index with Fly Ash [25]

The dry density increases as the fly ash raise up to 15 %, then reduced to 1.53 at 20% ash.Fig.4 [25].

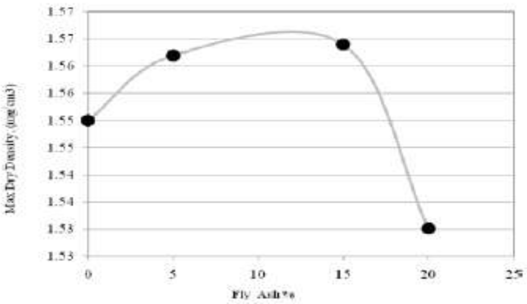

Figure 4: Soil Maximum Dry Density with Fly Ash [25]

The optimum moisture content decreases until 15 %, then after that it starts to increase. Fig.5 [25].

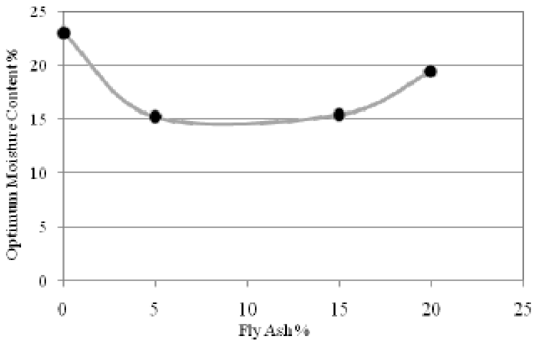

Figure 5: Soil – Fly Ash Optimum Moisture Content [25]

Yilmaz, established that 20% bentonite-fly ash mixture meets the permeability criterion ($k<1.00x10^{-7}$ cm/s) to be used as a liner material in waste disposal areas [26]. Palmer, showed that mixtures of Class F and C ashes combined with a coarse aggregate (bottom ash) can be compacted to achieve hydraulic conductivity near or below 10^{-7} cm/s at compaction water contents above optimum water content [6].

Adamska, found out that in compacted fly ash–HDPE geomembrane interfaces, the addition of 10% cement reduced the interface contact strength. In general, a lower interface strength was associated with modified compaction, for both fly ash and fly ash with cement. A dependence of contact strength parameters δ (interface friction angle) and c_a (adhesion) on the amount of cement addition was observed [27]. Kalinski, achieved Hydraulic conductivities of compacted portland cement–fly ash mixtures on the order of 10^{-5}–10^{-6} cm/s which is not adequate with respect to the criterion of 10^{-7} cm/s often used for waste containment layers, but this material may be suitable for other geotechnical applications such as earth dams and highway base courses [28].

Semra, investigated the properties of fly ash, phosphogypsum and red mud for their use as liner material and the results demonstrate that addition of the these materials to the zinc leach residue drastically reduces the heavy metal content in the leachate. Fly ash and red mud performs better than phosphogypsum [29].Herrmann et al, established a relation between compaction and hydraulic conductivity and the hydraulic conductivity of fly ash–sewage sludge mixes could be kept between 1.7 x 10^{-11} m/s and 8.9 x 10^{-10} m/s if the compaction energy was 2.4 J/cm^3 [30].

One more study advocates the suitability of Fly ash as it states that its hydraulic conductivity decreases as the moisture at compaction increases, which is particularly visible at smaller compaction energy. A considerable reduction in the influence of moisture at compaction is noted at higher values of effective stresses (120-200 kPa). Obtaining the required permeability coefficient $k \leq 10^{-9}$ m/s is possible at high values of effective stresses and high moistures [31].

3.3 Stabilization of Fly Ash: A study on effect of bentonite on fly ash reported that addition of bentonite increasesthe Cation Exchange Capacity and the specific surface area of fly ash. The liquid limit of fly ash, which is low, also increases. The shrinkage limit of fly ash increases on addition of highly shrinking bentonite, which helps to prevent cracking of the material due to desiccation [32].

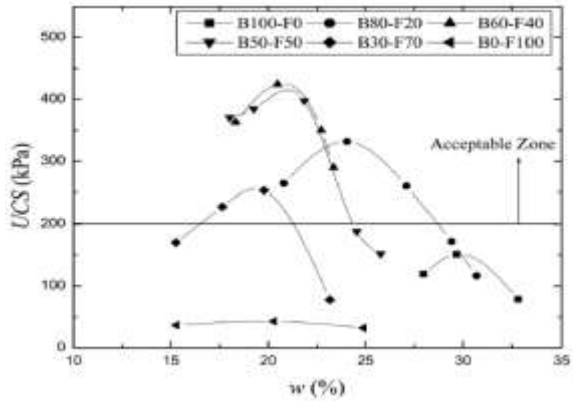

Figure 6: Unconfined compressive strength with different compaction states in Fly Ash-Bentonite mixes [33]

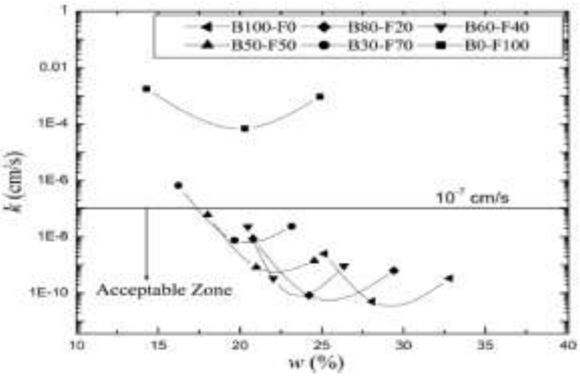

Figure 7: Hydraulic conductivity with different compaction states in Fly Ash-Bentonite mixes [33]

In efforts of stabilizing Fly ash, a study used various concentrations of lime and gypsum to obtain required hydraulic conductivity of the mix.A hydraulic conductivity of 2.27×10^{-9} m/s was determined for an admixture of fly ash mixed with 3% lime and 3% gypsum.The strength of the fly ash material is increased but once lime was introduced in excess a decrease was observed. Furthermore, the addition of lime and gypsum reduced the optimum water content at which the maximum dry density is obtained for the fly ash. This would indicate that the addition of additives has a lubrication effect on fly ash therefore improving its durability in the liner system [34].

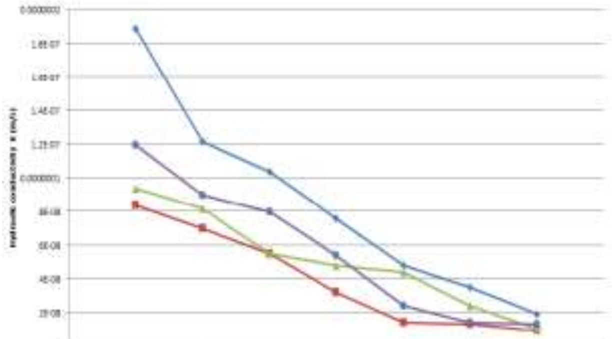

Figure 8:Hydraulic conductivity (m/s) with time for Fly ash admixtures with 3% gypsum [34]

Hilmi, carried out a study on micro structural, chemical, mineralogical, and thermal analysis on fly ash stabilized with lime as well as with the cement separately. The results obtained from both cement and lime stabilized samples showed that the hydration products that account for gain in strength were almost same for both the stabilizing agents [35].

Ghosh, studied the SEM of modified fly ash specimen and it was shown that a compact matrix was produced by the addition of lime to fly ash. Due to the reduction in interconnectivity of the pore channels of the hydration products the permeability had been reduced to 10^{-7} cm/s. In 3 months' curing the strength of fly ash, stabilized with 10% lime and 1% gypsum, reached a value of 6307 kPa, i.e., 36.7 times the strength of fly ash with zero percent additive [36]. Ghosh and Subbarao, studied the stabilization of low lime fly ash with lime and gypsum. The values of hydraulic conductivity on the order of 10^{-7} cm/s were achieved with the help of proper proportioning of the mix, and adequate curing [37].

Maitra et al, studied the effect of gypsum on the strength development of two Class F fly asheswith different lime contents after curing them for different periods and soaking the cured specimens in water and with different leachates containing heavy-metal ions. It was seen that the strength of both the fly ash was improved up to a particular amount of the lime content, which could be considered as optimum lime content, and thereafter the improvement was gradual [38].

Reddy and Gourav, studied the lime-pozzolana reaction required very long curing period to achieve appreciable strength under ambient temperature conditions. The test results reveal thatoptimum lime–fly ash ratio yielding maximum strength is about 0.75 in the normal curing conditions, and 24 h of steam curing (at 80^oC) is sufficient to achieve nearly possible maximum strength [39].

IV. CONCLUSIONS

Proper disposal of Solid waste is a must in today's scenario. Solid waste management is a major issue which has to be handled properly.Landfill is by far the most commonly practiced waste disposal method in the majority of countries. Leachate arising from most of the landfills is heavily polluted and thus detrimental to surface and subsurface sources.Although compacted, fine grained soils have been used as a hydraulic barrier to cover waste in the landfills and prevent the leachate to percolate down the sites for many years, their life cycle hydraulic performance has long been questioned. Due to high shrinkage potential of clay liners, they are subjected to Cracking, Fracturing and Aging which results in an increased Hydraulic Conductivity that poses a big threat to the environment.

There is a need to introduce new materials for use as Hydraulic Barriers to overcome the problems being encountered by the clay liners. Fly Ash has proved to be a suitable material for its use as landfill liners. Fly ash is an abundantly available waste product of the generation of power by burning of coal. Primarily fly ash has two classes namely Class F and C. Class C Fly ash has self-cementitious properties and thus it doesn't need to be stabilized, whereas Class F fly ash lacks in free lime availability that results in absence of the self-cementitious properties and can be cured using additives like lime, bentonite etc.The studies have shown that with proper compaction at optimum moisture content, fly ash achieves hydraulic conductivities of the order of 10^{-7}cm/s. The studies show that the high alkaline conditions which prevail in fly ash do not allow most of the toxic elements that are present in leachate. Furthermore fly ashes undergo little shrinkage but not a higher volume change. Fly ash can be engineered with the addition of lime to obtain good strength and the acceptable hydraulic conductivity. Hence fly ash makes a suitable material for its use as a landfill liner.

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