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Tracer Transport Study in Fly Ash being Used as Landfill Material

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Abstract: The suitability of fly ash for its use as landfill material is investigated by examining the fluid transport process through fly ash beds in different compositions with sand. The columns of two different diameters, 3 cms and 4 cms respectively, were designed to carry out the experiments. Glucose solution of known concentration was selected as an ideal tracer to characterize the flow mechanism of tracer through different arrangements of beds. It is suggested that the fly ash use, as a landfill material, may be preferred in appropriate composition with sand or other soil material in comparison to the existing practice of using fly ash only as a fill material. It is observed that a 3:1 mixture of fly ash and sand with 5% lime as binding material shows appreciably faster rate of dispersion of the tracer solution. This design mix, following the relationship between fly ash's pozzolanic ingredient and desired geo-technical properties, also facilitates attaining dual usage, namely, a soil-like consistency for use as a fill material and concrete-like characteristics for use as a final cover.

Key words: Fly ash, soil medium, landfill material, pozzolanic property, uniaxial compressive strength, dispersion of tracer.

Introduction

Fly ash is a major by-product of combustion/incineration processes. It is composed of fine particulates of the carbon and metal oxides (Chugh et al., 1998). It may also include a substantial amount of organic pollutants as well as volatile toxic metals, depending upon the composition of the raw material to be burned (Chugh and Dutta, 1998). The concentration of these compounds and metals in fly ash is evaluated to be almost ten times higher than in the raw material (Palit et al., 1994). So its safe disposal and utilization has become an important area of international concern.

In India, around 75% of the total coal generated is used for power generation with the capacity of 60% of total electricity generation (Govt. of India 2003). Indian coal for power generation is generally medium to low quality with high ash content of 30-50%. As per the available estimate, the production of coal ash in India, including both fly ash and bottom-ash, was 125 million tonnes per annum during the year 2003-04, which is nearly 15% of the total world production (almost 850 million tonnes per annum) of fly ash (Kumar et al., 2004). According to a recent publication from ICCT, Netherlands, only 10% of this large quantity is presently in economic use (for various constructional purposes) and rest is being dumped on open grounds and/or stored in the ponds in view of high cost of disposal, which has led to environmental pollution (Iwaco, 1999). Due to increasing environmental concern and growing magnitude of the problem, it has become imperative to manage this large quantity of fly ash generated. It has been realized over the past decade that fly ash has great potential to be utilized. Its utilization can be broadly grouped into two classes—small-scale utilization and large-scale utilization. Utilization in cement/concrete,

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structural materials etc. give rise to small-scale utilization that leads to *high value applications.* While, utilization in land reclamations, embankment constructions, mine filling etc. give rise to large-scale utilization leading to *low value applications*. The latter seems to be a feasible alternative economically when looking at the large unused quantity of fly ash. Moreover, such application may also increase the soil fertility of reclaimed land, thus transforming the economic cost into benefits. However, the suitability of large-scale utilization will depend on several other factors, which need to be explored before its use. The *strength of the material* and the *fluid flow* through the material are of significant consideration due to *changes in soil bed characteristic.*

The recent studies carried out for testing the strength and deformability behaviour of the different fly ash-soil mixes along with binder material (cement/lime) show that the uniaxial compressive strength increases considerably, when fly ash proportion is increased up to a certain level in the mixture of fly *ash: sand: binder* (Das, 1994; Saxena, 1995; Kate, 1997). However, a choice of the mix would depend on factors individually and in togetherness, such as geometry of mine cavity, process of stowing, environmental considerations, etc.

Pennsylvania Department of Environmental Protection has tested the mix of alkaline fly ash with dredged material for its compatibility to use it for reclamation of mines as well as for the regulatory requirement to control the soil and groundwater pollution and used it as a filler material at Bark camp.[1] Similarly, the fly ash was used to reclaim the acid mine drains in Pike City of Indiana State in USA.[2] After reclamation, the ground was analyzed for various trace metals for many years, and was found to have minimal impact on its quality (Branam et al., 1995). By and large the present practice of utilizing fly ash as a fill material is to pump slurry of fly ash over the sand layer. However, the different arrangements of fly ash with sand could be of interest from the point of view of fluid transport and, therefore, needs to be investigated.

This paper studies experimentally the fluid mechanism through the different arrangements of fly ash-soil beds as a function of time and space. An apparatus has been designed and installed and a tracer flow study is carried out. The scope of the present study was limited to understand the transport behaviour of pollutants from different arrangements of fly ash in soil bed, once it is used for filling up the undergrounds or open cast mines. Conclusions were drawn on the basis of data obtained by the experiments.

Experimental Set up

i. Characterization of Fly Ash and Sand

The fly ash used in the study was procured from the Badarpur Thermal Power Plant at Delhi. On the other side, the sand was collected from the river Yamuna, which flows in the vicinity of Badarpur power station. The various properties of fly ash and sand are listed in Table 1.

Table 1: Physical Properties of Indian Fly Ash and Sand

Sl. No.	*Property*	*Sand*	*Fly ash*
1.	Particle size (mm)	0.04-0.52	0.002-0.02
2.	Coefficient of uniformity	1.76	2.8
3.	Coefficient of curvature	1.09	2.47
4.	Dry density	13.1-16.3 K-N/m^3	12.8 K-N/m^3
5.	Void ratio	0.64-1.04	-
6.	Specific gravity	2.67	2.14
7.	Aterburg Limit	Non-plastic	Non-plastic
8.	Permeability (cm/sec)	10^{-2} to 10^{+1}	10^{-6} to 5×10^{-4}
9.	Optimum moisture content (%)	-	32.0

ii. Design of the Columns

Two cylindrical glass columns were designed. Each column was of 1.0 m length and diameter of 3.0 cm and 4.0 cm respectively. The outlet was provided at the bottom of the columns (Figure 1). The top of the column was left open to input the tracer.

iii. Preparation of the Filter

A slow sand filter (SSF) was introduced over the wire gauge at the bottom of the columns to avoid the escape of smaller particles of the fly ash and sand from the column.

iv. Preparation of the Beds

Four different types of beds of fly ash-sand mix were prepared. The arrangements of the layers in the beds are mentioned as:

a. Only fly ash
b. Fly ash with sand layer at bottom of the bed

1. *http://www.dep.state.pa.us/dep/deputate/minres/bamr/bark_camp/barkhomepage.htm*
2. *http//www.dep.state.pa.us/dep/deputate/minres/bamr/bark_camp/Alternative/dredgedc.htm*

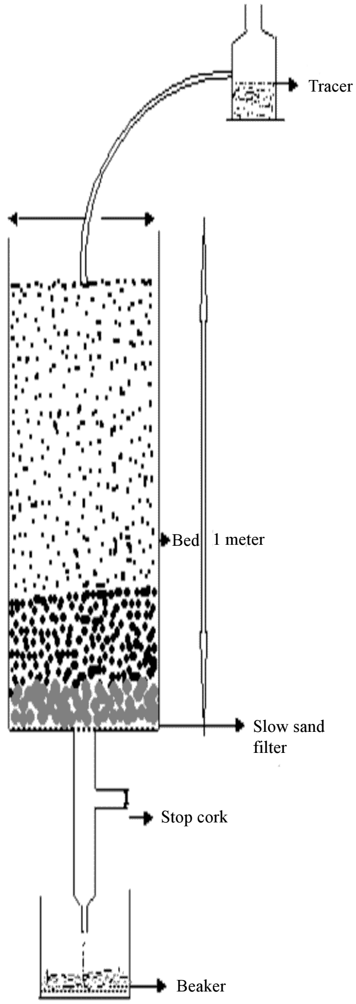

Figure 1: Experimental set up to study the hydrodynamic dispersion of tracer through filter bed.

c. Fly ash with sand layer at the middle of the bed
d. A design mix of fly ash-sand-lime

The ratio of fly ash:sand in the beds is 3:1. The third bed was designed in order to examine the impact on fluid flow by shifting the sand layer in contrast to the second bed. The fourth bed (design mix) was designed by keeping in mind the stability of reclaimed land for its future use. For this purpose, sets of experiments were performed to measure the strength of various compositions of fly ash-sand mix with varying percentage of lime (1% to 7%). The compositions of fly ash-sand taken were 1:1, 2:1, 3:1 and 4:1. The fly ash-sand in ratio of 3:1 with 5% lime was found to have the maximum strength (23 kg/sq. cm in 28 days). In contrast, the strength measured in case of only fly ash and only sand, were respectively 9.5 and 14 kg/sq. cm for 28 days. Thus the fourth bed was prepared with a mix of fly ash-sand in ratio of 3:1 with 5% lime as a binding material.

v. Selection of Tracer

The selection of appropriate tracer for the present study was done by keeping in mind its non-reactivity with soil and its availability at affordable cost. Glucose was selected as an ideal tracer. Glucose solution of N/10 concentration was prepared for the present study.

Methodology

The column beds were made fully saturated initially with distilled water. Glucose solution of known concentration (N/10) as tracer was introduced at the top of the saturated column beds and the supply of tracer was kept continuous. Samples were collected at the outlet of the column, at regular intervals of one hour to record the concentration of the tracer in the effluent coming out from the column bed. The supply of tracer was discontinued on observing the steady state (i.e. the state of complete saturation with tracer). At this instance, distilled water was supplied continuously to push the tracer out and clean the column. However, the collection of samples continued as long as it kept giving any amount of tracer concentration from the outlet. The concentration of tracer at the outlet was worked out by titrating the solution with Fehling's solution (Sambhalwal, 1994; Vogal, 1984) by using the following relationship:

$$N_1 V_1 = N_2 V_2$$

where, N_1 = the input concentration of glucose solution (Co); V_1 = volume of glucose solution entering into column of bed; N_2 = the output concentration of glucose solution (C); and V_2 = volume of glucose solution coming out from the column.

Two different diameter columns (3 cm and 4 cm) were used to investigate the effect of area/space on the fluid transport process, when other parameters were kept constant.

Results and Discussion

The results of the tracer transport experiments through different arrangements of fly ash-sand beds show that the concentration of tracer at the column outlet varies gradually with time till it reaches the steady state (fully saturated with tracer). (This phenomenon of transport of liquid is called mechanical dispersion, where points at different concentration move at different velocities.) At this point of maximum limit of saturation of filter bed, distilled water was introduced and was continued until the output concentration becomes almost zero, which indicates the complete washing of the filter bed. The results are shown in Figures 2 and 3 for small and large diameter columns respectively. The shaded lined zone in figures is an indicative of the period of steady state (when the output continues to be the maximum) and would be dependent on choosing the time of discontinuing the supply of tracer.

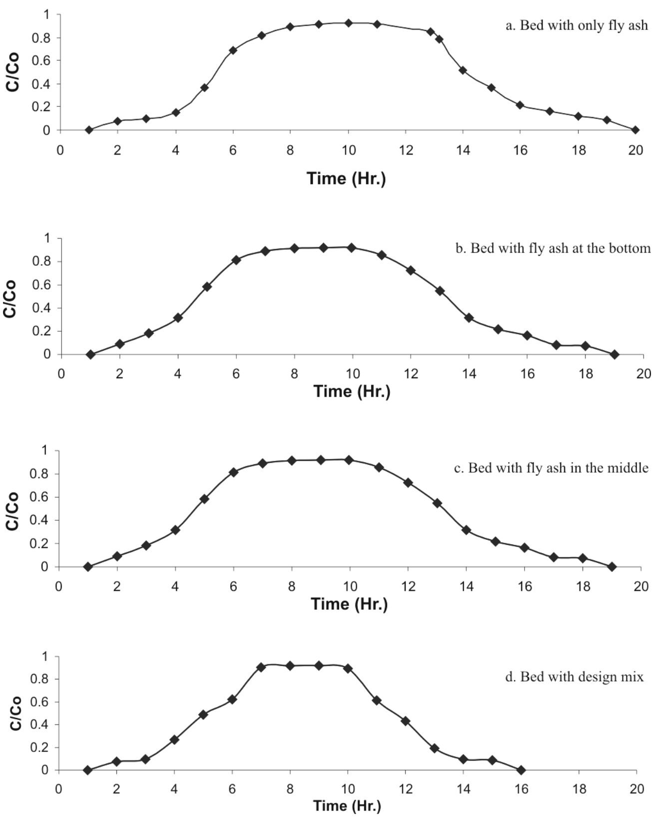

Figure 2: Concentration profile of N/10 glucose solution through the different arrangements of fly ash-sand beds in the small diameter (3 cm) columns.

The column beds containing only fly ash as filter medium takes more time in reaching the steady state as compared to the beds containing fly ash-sand mix. This can be attributed partially to lesser permeability of fly ash medium, which retain the liquid for a longer time. Another reason could be the particle size of fly ash. Fly ash particles are predominantly of silt-size due to which fly ash tend to wick water into itself (i.e. water migrate vertically through fly ash in upward direction) and may therefore cause capillary rise and hence slows down the flow of tracer.

Further, the rate of transport of liquid in fly ash-sand mix depends upon the arrangement of fly ash and sand

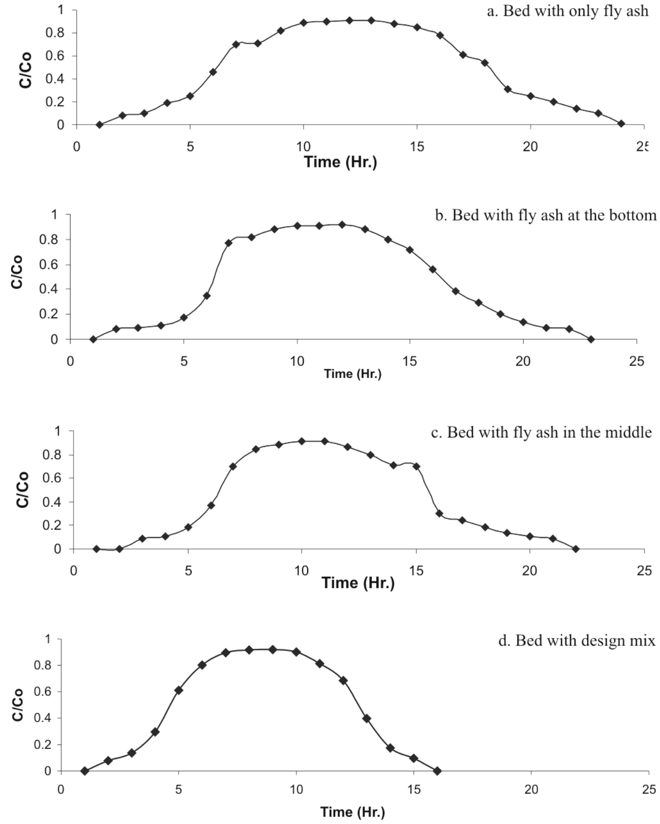

Figure 3: Concentration profile of N/10 glucose solution through the different arrangements of fly ash-sand beds in the large diameter (4 cm) columns.

layers in the bed. The bed of fly ash, with sand layer at the bottom (Figures 2b and 3b), reaches steady state for output concentration in longer time, than the bed with sand layer in the middle (Figures 2c and 3c). Here the sand layer is acting as a forcing agent to control the phenomenon of capillary rise, which may affect in improving the flow and hence faster spread of tracer due to advection as well as mechanical dispersion.

The bed with design mix of fly ash and sand with 5% lime (Figures 2d and 3d) shows the fastest transport of the tracer solution. However, increased density and long term pozzolanic action of fly ash, which ties up free lime, results in lowering its permeability. In fact, the presence of sand improves permeability in totality and provides an effective way to prevent capillary rise and establishes a good correlation between porosity, permeability and compressive strength.

The results from the column bed of 4 cm diameter, when compared with those from the column bed of 3 cm diameter (Figure 4), demonstrate that with an increase in area of the bed, the process of transport of tracer is delayed considerably. This delay may be attributed to the dominating effect of molecular diffusion. The spread of tracer could be occurring in the horizontal directions to occupy maximum available pores.

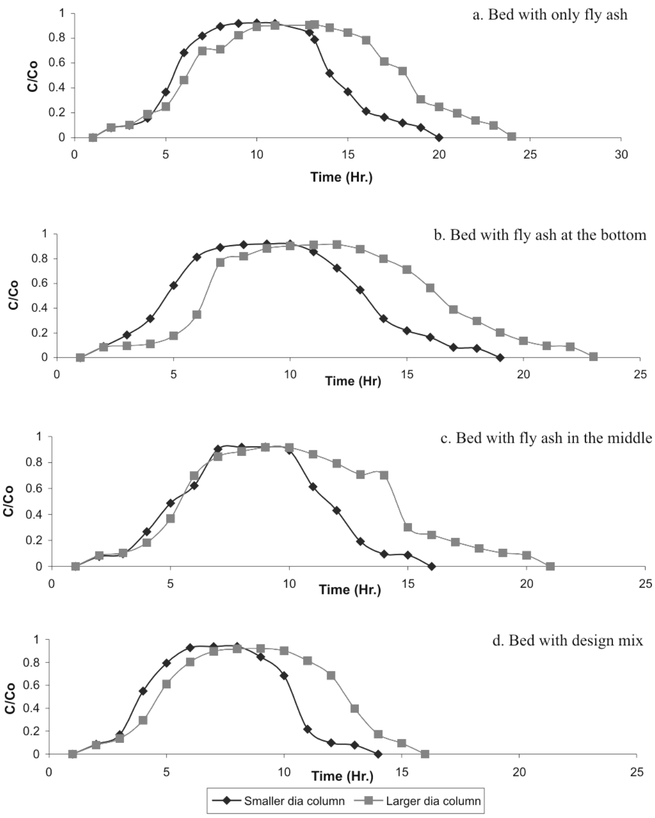

Figure 4: Comparison of the rate of the output glucose concentration through large and small diameter columns

Conclusions

Fly ash may be a good alternative as a fill material. However, fly ash alone cannot be a suitable filling material as it results in the loss of shear strength, when mixed with water. It is always suggested that it should be used along with sand or similar material. Further, the results demonstrate that the mix of fly ash-sand in ratio of 3:1 with 5% lime has faster dispersion property. It also gives an effective way to prevent capillary rise in saturated fly ash beds. The strength test on such mix also shows appreciably high uniaxial comprehensive strength, which can easily tolerate the overburden when used as a fill material for the open cast mine areas. As a result, it facilitates attaining dual usage, namely, a soil-like consistency for use as a fill material and concrete-like characteristics for use as a final cover. In case when appropriate composition of fly ash with sand or other soil mediums, as suggested, is not feasible for large scale filling, a sand layer should be placed in the middle of the bed. It will also solve the problem of fly ash disposal up to a greater extent.

Types of mixes may need to be explored for using fly ash as a fill material on commercial scale. It would be site specific as well as subject to the use of soil amendment indented for the kind of use. Experiments may include the studies of transport phenomena through multiple sand layers in between fly ash. More rigorous experiments may be taken up to examine binder lime (or any such material) in various proportions to consider strength of the beds, particularly when the site demands the use of material other than sand.

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