Indian Geotechnical Journal, 27 (2), 1997

Technical Note

Permeability of Amended Soil Liners for Landfills

Manoj Datta*, Ashish Juneja† and D.K. Vats‡

Introduction

Low Permeability compacted clays are used as seepage barriers in liner systems of engineered landfills. When low permeability clay is not available locally, in-situ soils may be mixed with medium to high plasticity imported clays or commercially available clays such as bentonite to achieve the required low value of permeability. A component liner made of amended soil is normally expected to have a coefficient of permeability of 10^{-7} cm/sec or less and a thickness of 100 cm or more.

The soils found in or around Delhi comprise of alluvial sands and silts. The parmeability of such soils is high and one has to provide low permeability liners at landfill sites where municipal wastes are disposed. As low permeability clays are not encountered in Delhi, one of the options for constructing the liners is to use amended soils. This paper describes the results of a laboratory study conducted in two types of compacted materials, namely, Delhi silt (a locally available soil) and pond ash (a byproduct of coal combustion available in abundance at Delhi's thermal power stations) to identify the feasibility of achieving a permeability of 10^{-7} cm/sec or less by amending these materials with different types and proportions of clay additives.

The following were the objectives of the laboratory study :

(a) To identify the influence of mixing different types and quantities of clay additives on the compaction characteristics of Delhi silt and pond ash;

---

* Assoc. Professor, Civil Engineering Department, I. I. T. Delhi, New Delhi – 110016, India.

† Geotest Consultants (India), B-2/10, Rajouri Garden, New Delhi – 110027, India.

‡ College of Military Engineering, Pune, India.

(b) To identify the influence of mixing different types and quantities of clay additives on the permeability of Delhi silt and pond ash; and

(c) To arrive at the minimum additive content required for achieving permeability of 10^{-7} cm/sec for Delhi silt and pond ash.

Literature Review

The influence of addition of different quantities of bentonite (0 to 15 percent) on the coefficient of permeability of soils has been reported by D'Appolonia (1980), Lundgren (1981) and Daniel (1993). All investigators have shown that the permeability decreases very rapidly when the percentage of bentonite increases from 0 to 6 percent. Thereafter, the rate of decrease of permeability slows down gradually.

The minimum bentonite content required to achieve a permeability of 10^{-7} cm/sec has been reported as :

(a) 4% for fine sand and 3% for graded sand by Lundgren (1981);

(b) 10 to 15% for uniformly graded sand and 5 to 10% for well graded sand by Sharma and Lewis (1994);

(c) 7 to 10% for sands having porosity of 30 to 35% by American Colloid Company (1975);

(d) 11% for Ottawa sand by Edil and Erickson (1985);

(e) 6% for mixture of gravel and sand consisting of 27% fines by Sharma and Kozicki (1988);

(f) 5% for silty sand by Sharma and Hullings (1993); and

(g) 5% for loess by Knitter et al. (1993).

Literature pertaining to the influence of additives on coefficient of permeability of pond ash could not be identified.

Methodology

Disturbed samples of Delhi silt were collected from I.I.T. Delhi campus. Disturbed samples of pond ash were collected from Indraprastha Power Station of Delhi Electric Supply Undertaking. Standard compaction tests were performed on these samples in the laboratory and the maximum dry density (MDD) and optimum moisture content (OMC) obtained. Three types of clay additives were used – clay available from nearby area (Dhanauri clay) and two commercially available clays (kaolinite and bentonite). Each additive was added to the base material in different quantities (ranging from 5 to 20%) and the influence of the additive on MDD and OMC identified. As compacted samples prepared at MDD and OMC were first saturated in permeameters and then the permeability evaluated. The influence of the amount of additive on the coefficient of permeability was studied to arrive at the minimum additive content required for achieving a permeability of 10^{-7} cm/sec or less.

Experimental Investigations

The test variables in the laboratory study were :

(a) type of base material – Delhi silt and pond ash;

(b) type of clay additives – Dhanauri clay, kaolinite and bentonite; and

(c) quantity of additives.

Additives were mixed to the base materials in the proportion of 5, 10, and 15% (for the base material pond ash, the quantity of additive was extended upto 20% in some tests). Laboratory tests were conducted in three phases.

In the first phase, the grain size distribution and Atterberg limits of the base material as well as of the additives were determined as per standard I.S. code procedures.

In the second phase, Proctor compaction tests (IS light compactive effort) were conducted on the base materials as well as on mixtures of base materials with different proportions of additives. A total of 20 tests were performed and OMC and MDD determined for all the cases. For each test on a mixture of base material and additive, special care was taken to thoroughly mix the two materials in dry state prior to the addition of water. This was essential to ensure uniform distribution of the additive in the matrix of the base material.

In the third phase, as-compacted samples were prepared at MDD and OMC in the compaction mould and then transferred to the permeameter by the process of extrusion and trimming. Each sample was subject to saturation prior to performing permeability tests.

Permeability tests were conducted on as-compacted-then-saturated samples using a flexible wall permeameter (modified triaxial type) for Delhi silt and silt-clay mixtures and a rigid wall permeameter (consolidation cell) for pond ash and ash-clay mixtures. In both the cases, test procedures specified by Olson and Daniel (1981) were followed.

For tests performed in the flexible wall permeameter, the samples were of 3.8 cm diameter and 3.0 cm height. Saturation was achieved by initially allowing water to flow through the sample (bottom upwards) by applying a vacuum at the top of the sample for one hour. Thereafter, back pressure was applied, and raised gradually to 4.0 kg/cm^2 to dissolve the remaining air into the water in the pore space of the sample. The back pressure of 4.0 kg/cm^2 was sustained for a variable period to time (Table 1). Saturation was confirmed at the end of application of sustained back pressure by measuring the B-factor (Skempton's pore water pressure parameter). B-factor of 0.90 or more (degree of saturation greater than 97 percent) was taken as acceptable. Permeability was then measured under a hydraulic gradient of 167, after the passage of 6 pore volumes of water.

For tests performed in the rigid wall permeameter, the samples were of 6.0 cm diameter and 2.0 cm height. The procedure for achieving saturation was as follows. Each sample was placed in the consolidometer and surrounded by water, keeping the top surface open to the atmosphere. Water was allowed to rise in the sample under capillary action, as well through as upward flow induced by a hydraulic head of 40 cm. To check that full saturation was achieved by the above procedure, an initial series of tests were performed to ascertain the degree of saturation with varying time of immersion and upward flow of water. Table 1 shows that 100% saturation was achieved after 4 hours for pond ash – Dhanauri clay mixture, after 8 hours for pond ash-kaolinite mixture and 24 hours for pond ash-bentonite mixture. A vertical stress of 1.0 kg/cm^2 was applied on all samples in the

TABLE 1 : Saturation of Samples in Permeameters

Base Material	Additive	Permeameter	Saturation Technique	Total Time	Degree of Saturation or B-factor
Delhi Silt	15% Dhanuari	Flexible Wall	Vacuum in initial stage followed by back pressure of 4 kg/cm^2	48 hrs.	B = 0.964
	15% Kaolinite			92 hrs.	B = 0.928
	15% Bentonite			93 hrs.	B = 0.964
Pond Ash	15% Dhanuari	Consolidometer	Immersion and upward flow under hydraulic gradient of 20	4 hours	Saturation = 100%
	15% Kaolinite			8 hrs.	Saturation = 100%
	15% Bentonite			24 hrs.	Saturation = 100%

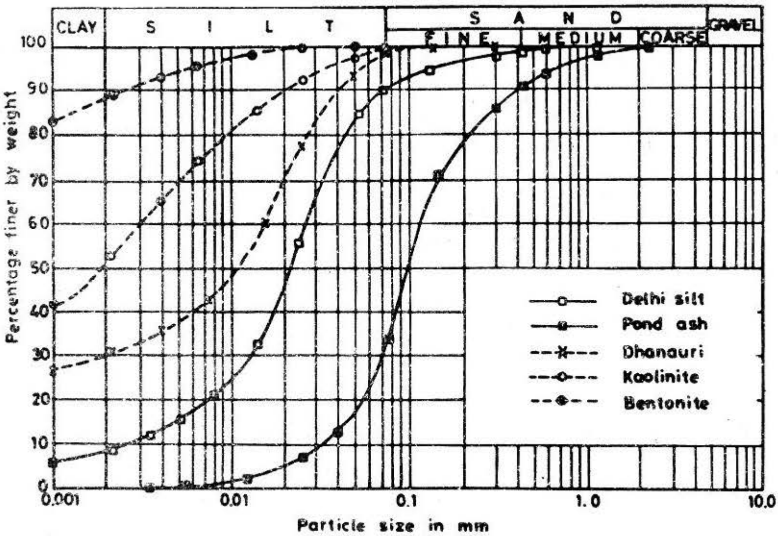

FIGURE 1 : Grain Size Distribution

fixed wall permeameter prior to permeation of water, to preclude the possibility of side wall leakage. Permeability was measured under a hydraulic gradient of 60 to 80, after the passage of 6 pore volumes of water.

Results and Discussion

(a) Grain Size Distribution and Atterberg Limits

The grain size distribution curves of the base materials and the additives have been plotted in Fig. 1. The percentage sand, silt and clay size fractions are listed in Table 2 along with the Atterberg limits. From the figure and the table, one observes that pond ash is predominantly sand sized and non-plastic, whereas Delhi silt is predominantly silt sized and exhibits low plasticity.

From among the three additives, one notes that bentonite contains the maximum clay sized particles and exhibits the highest plasticity, whereas Dhanauri clay contains the least clay sized particles and exhibits the lowest plasticity.

(b) Influence of Additives on Compaction Characteristics

The effect of additives on the compaction behaviour of Delhi silt and pond ash is shown in Figs. 2(a) to 2(c) and Figs. 3(a) to 3(c) respectively. The MDD and OMC have been tabulated in Table 3.

Table 2 : Grain Size Distribution and Atterberg Limits

Material	Grain Size Distribution			Liquid Limit	Plastic Limit	Plasticity Index	IS Classification
	Sand (%)	Silt (%)	Clay (%)	(%)	(%)	(%)	
Delhi silt	10	81	9	20.0	17.0	3.0	ML
Pond Ash	67	33	—	34.1	NP	NP	SP-SM
Dhanauri clay	01	69	30	37.5	19.0	18.5	CI
Kaolinite	—	49	51	49.0	21.0	28.0	CI
Bentonite	—	12	88	265.0	46.0	219.0	CH

One notes from the figures, as well as from the table, that the addition of additives causes a significant change in the compaction characteristics of Delhi silt. For the base material pond ash, an increase in the quantity of each additive causes an increase in the MDD and a decrease in the OMC, for all types of additives. No such consistent pattern is discernible in the case of Delhi silt, where one observes a relatively small change in the values of MDD and OMC with the increase in quantity of each additive.

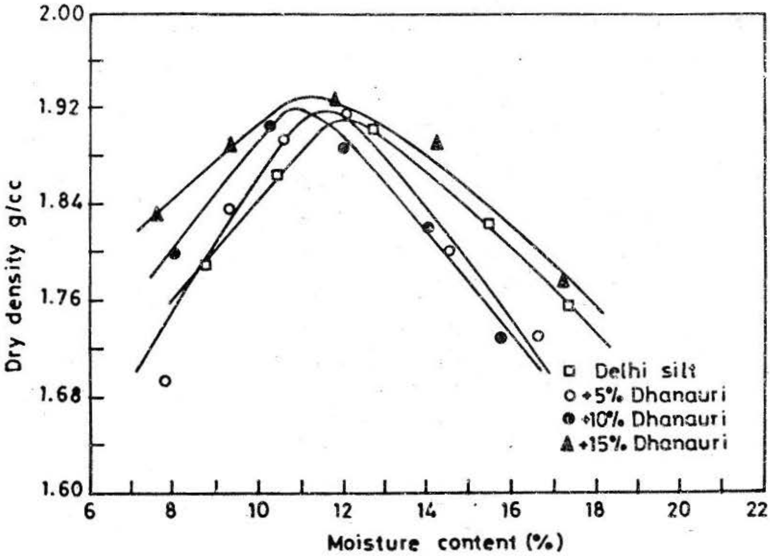

FIGURE 2(a) : Compaction Test Results for Delhi Silt and Delhi Silt + Dhanauri Clay

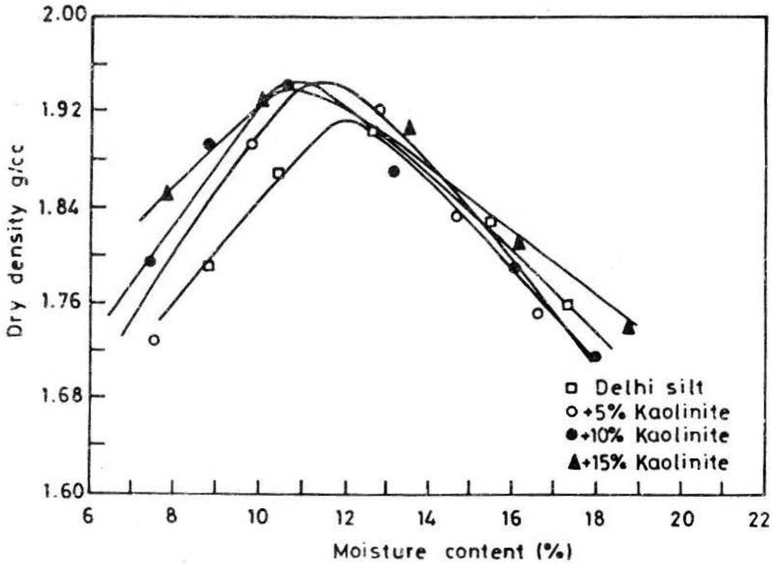

FIGURE 2(b) : Compaction Test Results for Delhi Silt and Delhi Silt + Kaolinite

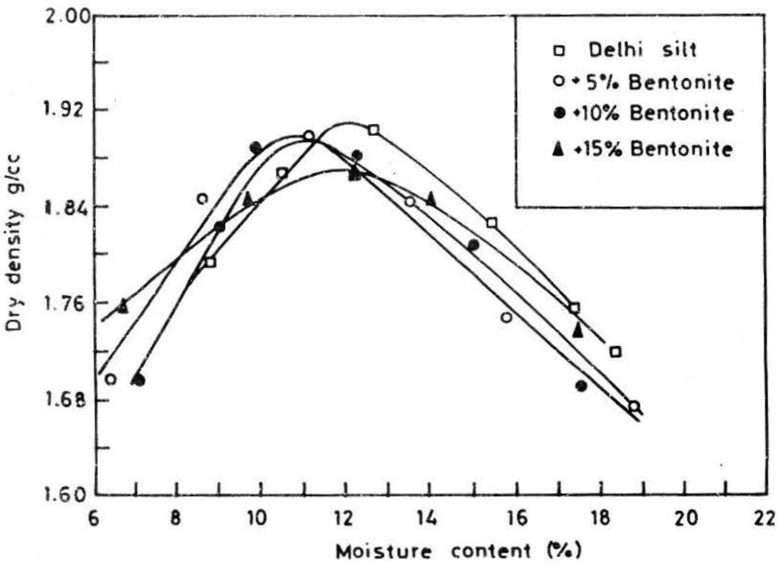

FIGURE 2(c) : Compaction Test Results for Delhi Silt and Delhi Silt + Bentonite

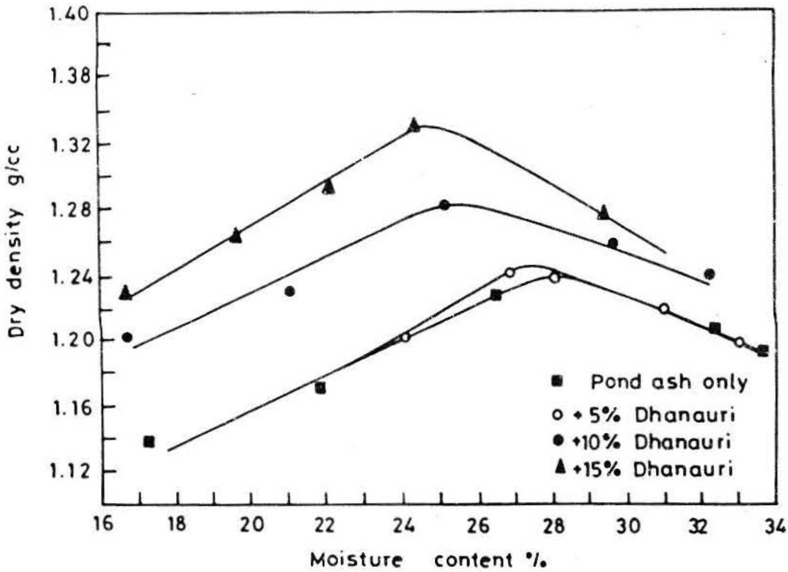

FIGURE 3(a) : Compaction Test Results for Pond Ash and Pond Ash + Dhanauri Clay

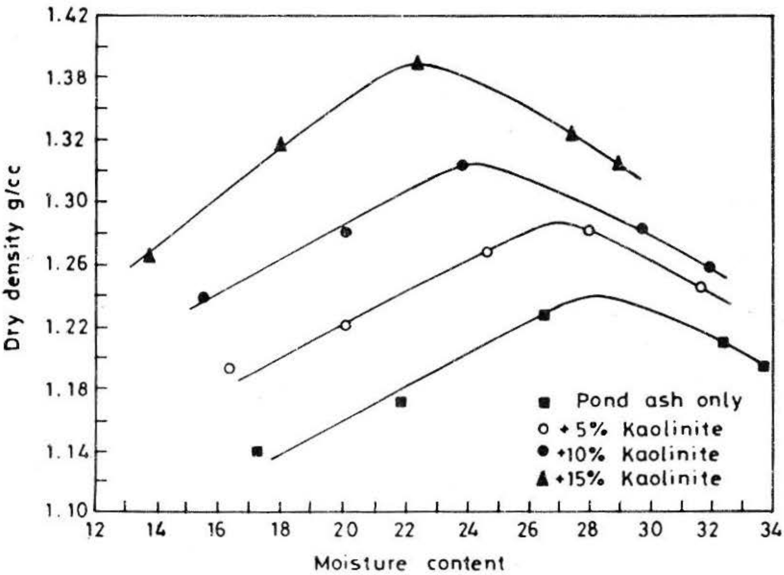

FIGURE 3(b) : Compaction Test Results for Pond Ash and Pond Ash + Kaolinite

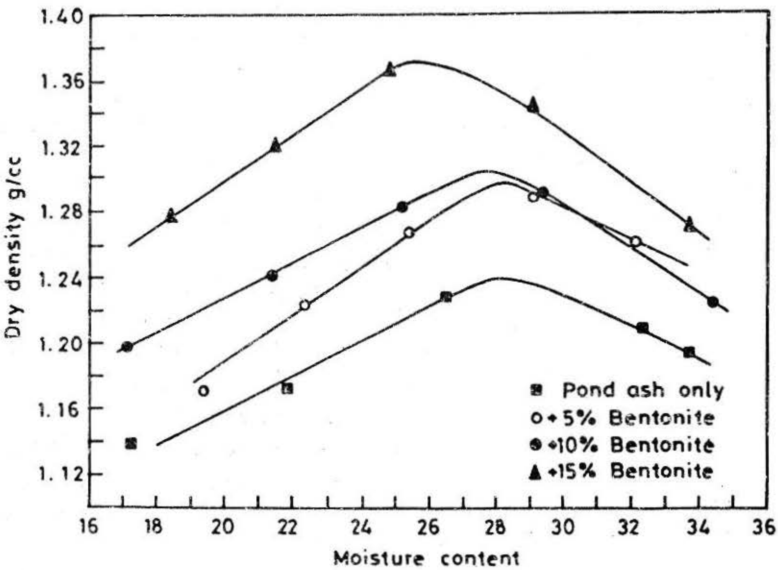

FIGURE 3(a) : Compaction Test Results for Pond Ash and Pond Ash + Bentonite

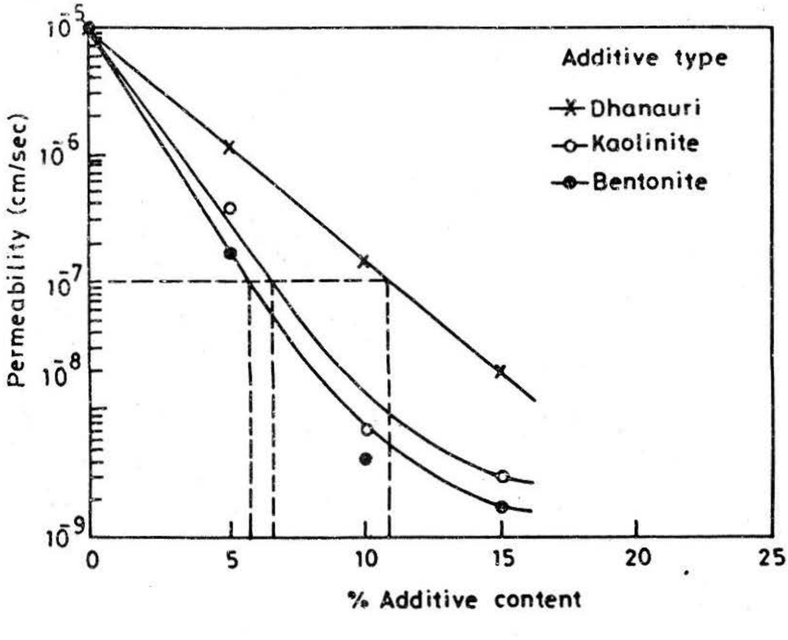

FIGURE 4 : Effect of Additives on Permeability of Delhi Silt

Table 3 : Compaction Test Results

(a) Delhi Silt + Clay Additive

Additive Type	Proportion	Maximum Dry Density (g/cc)	Optimum Moisture Content (%)
No Additive	—	1.910	11.8
Dhanauri Clay	5	1.915	11.3
	10	1.920	10.8
	15	1.925	10.8
Kaolinite	5	1.945	11.0
	10	1.940	10.6
	15	1.935	10.2
Bentonite	5	1.905	10.9
	10	1.900	11.0
	15	1.866	12.4

(b) Pond Ash + Clay Additives

Additive Type	Proportion	Maximum Dry Density (g/cc)	Optimum Moisture Content (%)
No Additives	—	1.240	28.0
Dhanauri Clay	5	1.245	27.4
	10	1.283	25.3
	15	1.330	24.6
Kaolinite	5	1.287	26.7
	10	1.325	23.8
	15	1.389	22.2
Bentonite	5	1.297	28.3
	10	1.303	27.8
	15	1.370	25.7

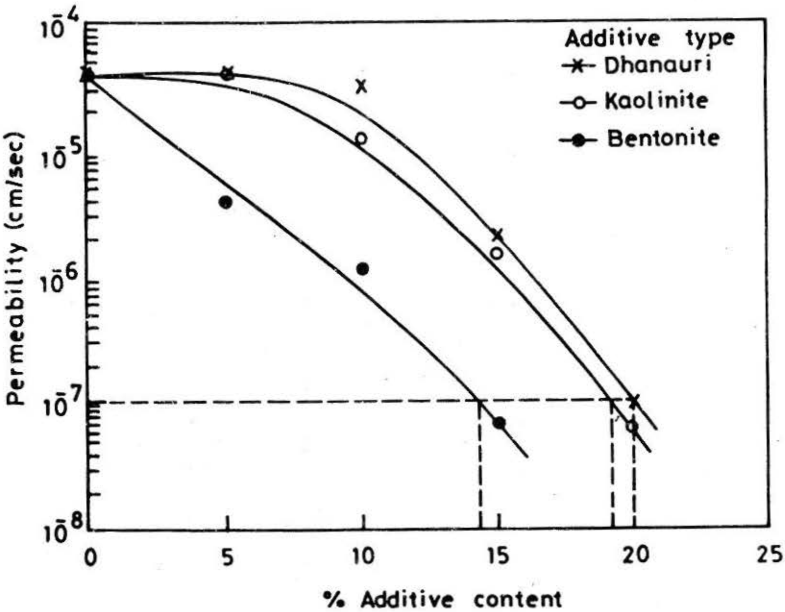

FIGURE 5 : Effect of Additives on Permeability of Pond Ash

Table 4 : Additive Content Required to Achieve Coefficient of Permeability on 1×10^{-7} cm/sec

Base Material	Additive Type	Additive Required (%)
Delhi Silt	Dhanauri Clay	10
	Kaolinite	6
	Bentonite	4
Pond Ash	Dhanauri Clay	20
	Kaolinite	19
	Bentonite	14

(c) Influence of Additives on Permeability

The results of permeability tests on the base material as well as on the mixtures of base material with different quantities of additives are presented in Fig. 4 for Delhi silt and in Fig. 5 for pond ash. One observes from these figures that compacted Delhi silt exhibits a permeability of 8.0×10^{-6} cm/sec and compacted pond ash exhibits a permeability of

3.9×10^{-5} cm/sec. Addition of additives causes the permeability to decrease with increasing quantity of additives. The rate of decrease of permeability is observed to be more rapid in the case of Delhi silt than in the case of pond ash. For pond ash, an addition of 5 to 10% Dhanauri clay and kaolinite is observed to have minimum impact on permeability, but a large drop is observed thereafter (Fig. 5). Amongst the different types of additives, bentonite is observed to cause the maximum decrease in permeability for a fixed quantity of additive.

One also observes from the figures that it is possible to achieve a permeability of 10^{-7} cm/sec or less, both in the case of Delhi silt and pond ash. The quantity of additives required for this purpose are listed in Table 4; from which one notes that one needs additives in the range of 4 to 10% for Delhi silt and 14 to 20% for pond ash mixes. The quantities of additives required are observed to be dependent both on the composition of the base material, as well as the composition of the additive.

Conclusions

The present study leads to the following conclusions :

(a) It is possible to significantly reduce the permeability of Delhi silt as well as of pond ash by adding Dhanauri clay, kaolinite and bentonite as additives and compacting the mixed materials at their optimum moisture content to their maximum dry density.

(b) To serve as liners for landfills, Delhi silt requires small quantity of additives (in the range of 4 to 10%) whereas pond ash requires larger quantity of additives (in the range of 14 to 20%).

(c) Though bentonite is the most effective additive for reducing permeability, one can also use clay available locally (or nearby) for this purpose. Larger quantities of local clay would be required in comparison to bentonite. The final choice would be governed by economic considerations keeping in view the fact that commercially available bentonite would usually be substantially more expensive than locally available clay.

It may be noted that before adopting amended Delhi silt and amended pond ash as liners for any landfill, one would have to conduct leachate compatibility tests (Datta and Juneja, 1997) to confirm that the permeability of these materials would not increase under the ingress of leachate generated from the landfills.

References

AMERICAN COLLOID COMPANY (1975) : "Use of Bentonite as a Soil Sealant for Leachate Control in Sanitary Landfill", *Volclay Soil Laboratory Engineering Report, Data 280-E*, Skokie, IL, p.36.

D'APPOLONIA, D.J. (1980) : "Soil-Bentonite Slurry Trench Cutoffs", *Journal of Geotechnical Engg.* Div., ASCE, Vol.106, No.GT4, pp.399-417.

DANIEL, D.E. (1983) : *Geotechnical Practice for Waste Disposal*, Chapman & Hall, Great Britain, 682p.

DATTA, M. and JUNEJA, A. (1997) : "Landfill Liners : Compacted Clay and Amended Soils", *Waste Disposal in Engineered Landfill*, M. Datta (Ed.), Narosa Publishing house, New Delhi, pp.108-129.

EDIL, T.B. and ERICKSON, A.E. (1985) : "Procedure and Equipment Factors Affecting Permeability Testing of a Bentonite Sand Liner Material", *Hydraulic Barriers in Soil and Rock*, ASTM STP 874, Philadelphia, pp.155-170.

KNITTER, C.C., HASKELL, K.G. and PETERSON, M.L. (1993) : "Use of Low Plasticity Silt for Soil Liners and Covers", *Proc. of 3rd Int. Conf. on Case Histories in Geotechnical Engineering*, St. Louis, Mo., S. Prakash Ed., pp.1255-1259.

LUNDGREN, T.A. (1981) : "Some Bentonite Sealents in Soil Mixed Blankets", *Proc. of 10th Int. Conf. on Soil Mechanics and Foundation Engineering*, Stockholm, Vol.2, pp.349-354.

OLSON, R.E. and DANIEL, D.E. (1981) : "Measurement of the Hydraulic Conductivity of Fine-Grained Soils", *Permeability and Ground Water Contaminant Transport*, ASTM STP 746, pp.18-64.

SHARMA, H.D. and HULLINGS, D.E. (1993) : "Direct Shear Testing for HDPE/ Amended Soil Composites", *Geotechnics '93 Conf. Proc.*, Vancouver, British Columbia, Canada, pp.1469-1481.

SHARMA, H.D. and KOZICKI, P. (1988) : "The Use of Synthetic and/or Soil-Bentonite Liner for Groundwater Protection", *Proc. of 2nd Int. Conf. on Case Histories in Geotechnical Engineering*, St. Louis, Mo., S. Prakash Ed., pp.1149-1156.

SHARMA, H.D. and LEWIS, S.P. (1994) : *Waste Containment System, Waste Stabilization and Landfills : Design and Evaluation*, John Wiley & Sons Inc., New York, 588 p.