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Seepage Characteristics and Geotechnical Properties of Flyash Mixed with Bentonite

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Abstract— Flyash is a naturally cementitious coal combustion by-product. It is extracted by the precipitators in the smokestacks of coal-burning power plants to reduce pollution. Flyash is cohesion less material and having very low compressive and shear strength however its strength can be increased by adding low cost cohesive materials such as lime and clayey soil. Among cohesive materials, bentonite is a clay mineral which acts as a stabiliser for flyash. Around 112 million tones of fly ash get accumulated every year at the thermal power stations in India. Some of the problems associated with Fly ash are large area of land required for disposal and toxicity associated with heavy metal leached to groundwater. Even though there are many ways of utilization, geotechnical engineering applications offer scope for its use in large scale. Detailed testing regarding geotechnical utilization was carried out on fly ash from the Harduaganj Thermal Power Station situated near Aligarh in U.P. The chemical composition and physical properties of the fly ash were determined. In the present study seepage and geotechnical properties of flyash mixed with bentonite are studied to enable its use in various engineering applications.

Index Terms— Flyash, Bentonite, Permeability, Optimum moisture content, maximum dry density

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1 Introduction

Coal is the chief source of energy in India. The present generation level of flyash in India is more than 112 million tonnes per year posing serious disposal problems and environmental issues. Indian coal has high ash content (35%-45%) and low calorific value (3500 kcal/kg – 4000 kcal/kg) as a result of which huge quantity of fly ash is generated. It is expected to increase to about 200 MT per year by the year 2012. This would require about 4000 ha of land for the construction of ash ponds. Generally one acre of land is required per megawatt of power generation. Continuous studies have been carried out in India towards management of fly ash (FA), disposal and utilization. Flyash, being treated as waste and is a potential source of air, surface and groundwater pollution. It can be transformed from waste material to resource material by improving its geotechnical properties. The "Flyash Mission" launched by Government of India in 1983 is meant for recognising the potential and gainful utilization of this waste material. Out of total power generated of India, about 70% is produced by thermal power plants (TPPs). The Majority of thermal power plants 84% are run by coal; rest on gas (13%) and oil (3%). Thermal power plants uses 260 million tonnes (MT) of coal which is about 65% of annual coal produced in India The quality of flyash depends on coal, coal particle fineness, percentage of ash in coal, combustion technique used, air/fuel ratio, burners used.

This calls for strategies to use the same effectively and efficiently. Even though there are many ways of utilization, the bulk utilization is possible only in geotechnical engineering applications like construction of embankments, as a back fill material, as a sub base material etc. In most of these applications, fly ash is invariably mixed with soil and compacted. Densification of fly ash improves the engineering properties. In general, the compacted unit weight of the material depends on the amount and method of energy application, grain size distribution, plasticity characteristics as well as the moisture content at compaction. Raymond (1961) investigated the suitability of Agecroft and Bold hopper flyash from U.K. for use as an embankment material. The compaction characteristics were influenced by the pulverization of coal, changes in coal supply and the design of furnace. The lower apparent specific gravities and the particle structure contributed to the lower dry density values of fly ashes. Foster (1963) observed that the compaction curves of fly ash resemble those of cohesionless sands or sandy gravels. Digioia and Nuzzo (1972) reported that the shape of the compaction curves of fly ashes is similar to those for cohesive soils. Joshi et al.,(1975) carried out compaction tests on fly ash samples collected from Grant Avenue power plant of Kansas City Power and Light Company, USA to study their suitability as structur-

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al fill material. The compaction characteristics of fly ashes varied from batch to batch due to variation in the quality of the coal supplied furnace conditions and the collection methods. Toth et al (1988) reported that the variation of dry density with respect to moisture content being relatively small, fly ash can be easily handled with conventional equipments due to the light weight and can be compacted over a wide range of moisture contents. Further, fly ash being a silty non-cohesive material, can be compacted efficiently with rubber tired rollers during construction.

According to Moulton (1978), natural soils have 1 to 5 % air voids at maximum dry density where as the same for flyash is 5 to 15 %. The higher void content tends to limit the build up of pore pressures during compaction and thus allowing flyash to be compacted over a large range of water contents. Yudbhir and Honjo (1991) have reported that fly ashes with high carbon content gave lower dry density values and higher OMC values. Ferguson (1993) studied the feasibility of using class C flyash from Kansas Power and Light Jeffrey Energy Centre for the stabilization of sub grade materials. The addition of flyash altered the compaction characteristics of both granular and cohesive materials. When the compaction tests were carried out immediately after mixing, the compaction characteristics changed due to change in material gradation. When the compaction tests were delayed, hydration products bonded the particles in the loose state and thus disruption of these aggregations was required to densify the material. A portion of the compactive energy is utilized in overcoming the cementation and maximum densities got reduced with increased delays in compaction. Pandian et al. (2001) have reported that the compaction curves of flyashes resemble those of cohesionless soils and the change in water content does not have an appreciable effect on the dry density values.

Fly Ash has become an important raw material for various industrial and construction applications. It's widely used in manufacturing of bricks, cement, asbestos-cement products and roads/embankments. The studied are carried out for improvement of agricultural crops, wastelands, and zeolites. This waste has found application in domestic and wastewater treatment, purification, paint and enamel manufacturing. In future, large-scale application of this waste product may be possible for recovery of heavy metals, reclamation of wasteland, and floriculture. The detailed investigations carried out on fly ash elsewhere as well as at the Indian Institute of Science show that fly ash has good potential for use in highway applications. Its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties, etc. can be gainfully exploited in the construction of embankments, roads, reclamation of low-lying areas, fill behind retaining structures, etc. It can be also used in reinforced concrete construction since the alkaline nature will not corrode steel. This not only solves the problems associated with the disposal of fly ash (like requirement of precious land, environmental pollution, etc.) but also helps in conserving the precious top soil required for growing food. The future poses challenges to the scientists, technologists, engineers towards sound management of fly ash disposal & deposition technologies. The problem is not due to lack to technical competence but more of adoption, implementation and better management of improved & appropriate technologies. On the basis of studies carried out on fly ash utilization, it is sighted that use of fly ash in building construction posses great gains. Either fly ash used in brick manufacturing or in concrete mixes, it gives very good results in almost every aspect including good strength, economically feasible and environment friendly. The guideline for all thermal power stations as regards disposal techniques/ strategies should ensure minimum adverse impact on the flora & fauna of a particular place. The attempt should be to consciously reduce environmental damage to ensure more effective management of fly ash which India needs.

2 MATERIALS USED IN THE STUDY

2.1 Flyash

For the laboratory test flyash collected from Harduaganj Thermal Power Station, which is located 14 km north of Aligarh by the side of upper Ganga Canal generates 440 MW of electricity. The chemical and physical properties of flyash are shown in Tables 1 and

2.2 Bentonite

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Bentonite is type of clay mineral (Montmorillonite) which cheap and easily available whose properties are determined in soil mechanics laboratory. The chemical and physical properties of bentonite are given in Tables 2 and 3.

2.3 Methods

All the tests were carried out as per the relevant Indian Standards. Their physical properties are listed in table1 whereas table 2 reports their chemical analysis. Different percentages of bentonite were added to flyash. Their specific gravity was determined by density bottle. Standard Proctor Compaction Tests were carried out on the so obtained flyash and bentonite mixes to obtain maximum dry density (MDD) and optimum moisture content (OMC). The permeability of pure flyash and bentonite as well as of their mixes was measured by Falling Head Test method.

3 Particle Size Distribution

The particle size analysis is meant to understand the textural behaviour of the flyash and bentonite. The size analysis was done by two following methods:

(a) Grain size analysis- Mechanical method (Sieve Analysis) **(IS -1498-1970)**
(b) Grain size analysis- Hydrometer method (Sedimentation Analysis)

Permeability By Falling Head Test (IS: 2720- Part 17, 1986)

The permeability of pure flyash and bentonite as well as of their mixes was measured by Falling Head Test method, after their compaction at optimum moisture content, maximum dry density and by saturating it for three days.

Formula used: The coefficient of permeability has been determined by the relation.

$$K_T = \frac{2.303}{At} aL \log_{10} \frac{h_1}{h_2}, where$$

K_T = Coefficient of permeability in cm/sec. at test temperature
a = Inside cross sectional area of stand pipe in cm^2
A = Cross sectional area of soil sample
L = Length of soil sample in cm
h_1 =Initial head in cm
h_2= Final head in cm
t = Time interval in seconds in which the head drop from h1 to h2

Temperature Correction

$$K_{27} = (\mu_T / \mu_{27}) \times K_T$$

μ_T = Dynamic viscosity of water at test temperature.
μ_{27} = Dynamic viscosity of water at 27^oC.
K_{27} = Coefficient of permeability at 27^oC (Standard temperature)

Proctor Compaction Test (IS- 2720- Part 7, 1974)

This test was used for determining the variation of moisture content with the dry density and then to find out optimum moisture content (OMC) corresponding to maximum dry densities of the material used in this study. The relation between the moisture content and dry density is not linear. The determination of optimum moisture content (OMC) and maximum dry density of the materials under study is essential because they are adopted for preparing the test specimen for determining their permeability.

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4 Results and Discussion

Finally, a graph of Moisture Content vs. Dry Density is plotted. Optimum moisture content and maximum dry density values are obtained from the graph. From the graph OMC of pure flyash is found to be 38% and dry density 10.35 kN/m^3. The OMC of pure bentonite comes to be 21.5% and dry density 16.85 kN/m^3. The variation of dry densities with moisture contents of flyash and bentonite mixes in different proportions are shown in Fig.4.

The specific gravity of fly ash is generally low compared to bentonite because of the presence of cenospheres (Pandian et.al., 1998). It depends upon the type of coal, degree of pulverization, burning conditions etc. The flyash contain mostly silt size fractions whereas for bentonite, the clay size fraction dominates making the flyash relatively coarse grained.

The chemical analysis shows flyash to contain 0.6% CaO, it is to be remembered that the presence of calcium plays a very important role in the engineering behaviour of flyash. The values of maximum dry density and optimum water content for flyash-bentonite mixes are reported in Table 4. It can be seen that fly ash has higher optimum moisture content due to the particles being cenospheres which can hold a considerable quantity of water internally. A relatively lower value for the optimum dry density for flyash is also due to the above reason, a low specific gravity and a relatively uniform grain size distribution. However, it should be kept in mind that in spite of the low values for dry density, the flyash exhibit high frictional characteristics making them suitable for geotechnical applications (Pandian et.al, 2001).

Plain flyash is cohesionless material which remains in non plastic state up to 20% bentonite-flyash mixes. Hence the bentonite up to 20% can be used as admixture to improve the geotechnical properties of flyash. At the same time this proportion of bentonite addition also wards off the problem posed by swelling of bentonite if used in higher proportions that is more than 30% as worked out in this study. This admixture can be very well used as subgrade material for pavements.

The maximum dry density up to 20% bentonite-flyash mix did not show any remarkable increase (10.35–12.45 kN/m^3). But, from 30% to 75% bentonite-flyash mixes, maximum dry density increases rapidly (13.15–14.65 kN/m^3), although the optimum moisture content has very little variation (25% - 21.5%).

As the bentonite content in the mixture increases, the permeability reduces. The decrease in permeability at 20% bentonite-flyash mix is 95.6% and at 75% bentonite-flyash mix, the permeability reduces up to 98%. This shows that 20% bentonite-flyash mix can be used as cover or liner at waste material disposal sites.

A perusal of Fig. 6 reveals that up to 8% bentonite, the permeability reduces at a constant rate of about 9 %, thereafter up to 20% bentonite, the reduction in the value of permeability was observed to be about 7%. At 20% bentonite the permeability of bentonite flyash mixture was reported to be 5.13×10^{-5} i.e. in the initial range of clay. So a mixture of flyash mixed with 20% bentonite may be used as a low permeable mass.

6 **CONCLUSIONS**

The conclusion drawn from the present study is that 20% bentonite-flyash mix is an optimum mix that can be safely used as a subgrade material of pavements and as cover or liner at waste disposal sites.

The study shows the compacted density of flyash-bentonite mix is low compared to bentonite alone which will be beneficial since a lower density will result in lower earth pressures leading to savings. The earlier studies have shown that flyash has a high frictional value which will be beneficial in its use in geotechnical applications. Further, since it is a freely draining material, it can be used in the construction of embankments etc. leading to its bulk utilization. When flyash mixed with bentonite, it becomes cohesive therefore the dust problems are solved and at the same time the engineering properties of flyash get improved. Thus bentonite proves to be an effective admixture for improving the flyash quality and at the same time affords a means of utilizing the same without adversely affecting the environment.

The optimized 20% bentonite-flyash mixture can also be used as backfill material in low lying urban lands for the purpose of laying foundations of low to middle order structures.

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Table 1 Chemical Properties of Flyash

S. NO.	Properties	Value
1	Silicon Dioxide	45 to 60 percent
2	Aluminum Oxide	21 to 29 percent
3	Iron Oxide	5 to 18 percent
4	Calcium Oxide	0.5 to 6 percent
5	Magnesium Oxide	0.2 to 3 percent
6	Sulphur trioxide	From traces to 0.4 percent.

Table 2 Chemical Properties of Bentonite

S. NO.	Properties	Value
1	SiO_2	40 to 50%
2	Fe_2O_3	2 to 4%
3	Al_2O_3	18 to 25%
4	CO_3 + HCO_3 as CO3	Max. 5%
5	Moisture	Max. 7%
6	MgO	2 to 4%

Table 3 Physical Properties of Bentonite and Flyash

S.NO.	Properties	Flyash	Bentonite
1	Specific Gravity	2.11	2.74
2	Optimum Moisture Content	38%	21.5%
3	Maximum Dry Density	10.35KN/m^3	16.85 kN/m^3

Table 4 The OMC and Max. Dry Density of Bentonite - Flyash Mixes

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Sample	**Max. Dry Density** $(\gamma_d)_{max}$ **(kN/m³)**	**Optimum Moisture Content OMC, (%)**
Pure Flyash	10.35	38.0
1% Bentonite - Flyash Mixture	10.70	39.5
2.5% Bentonite - Flyash Mixture	10.75	39.0
5% Bentonite - Flyash Mixture	11.05	38.5
7.5% Bentonite - Flyash Mixture	11.25	38.0
10% Bentonite - Flyash Mixture	11.55	33.5
12.5% Bentonite - Flyash Mixture	11.45	35.0
15% Bentonite - Flyash Mixture	11.75	32.0
17.5% Bentonite - Flyash Mixture	12.15	29.5
20% Bentonite - Flyash Mixture	12.45	29.0
30% Bentonite - Flyash Mixture	13.15	25.0
40% Bentonite - Flyash Mixture	13.80	24.0
50% Bentonite - Flyash Mixture	14.05	23.5
75% Bentonite - Flyash Mixture	14.65	22.0
Pure Bentonite	16.85	21.5

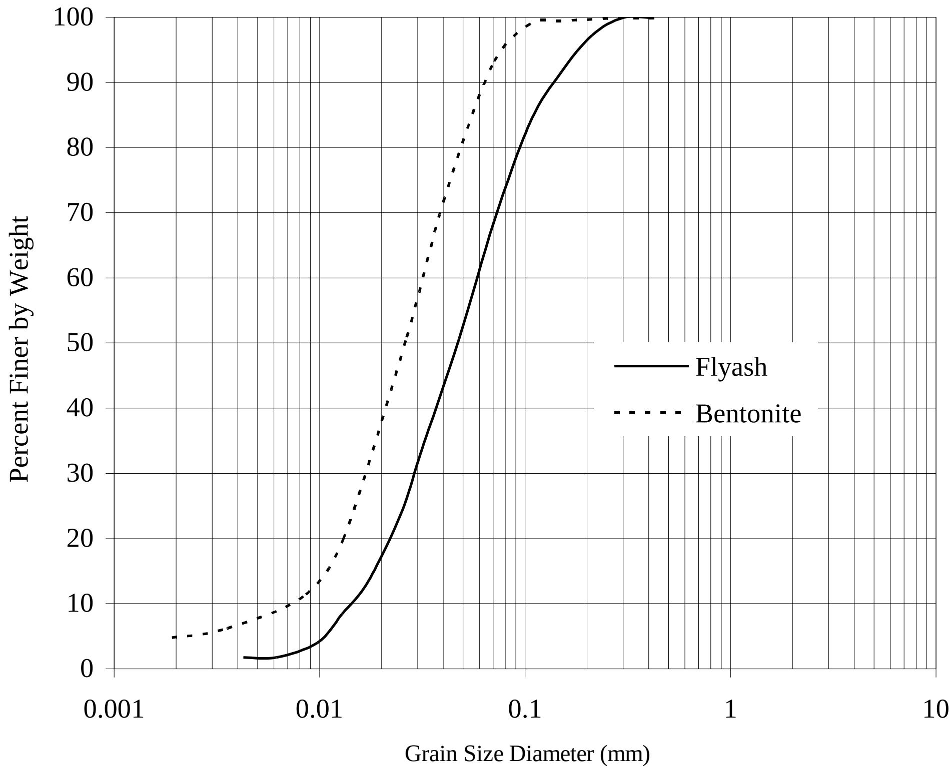

Fig. 1 Grain Size Distribution of the Plain Soil and Fly Ash

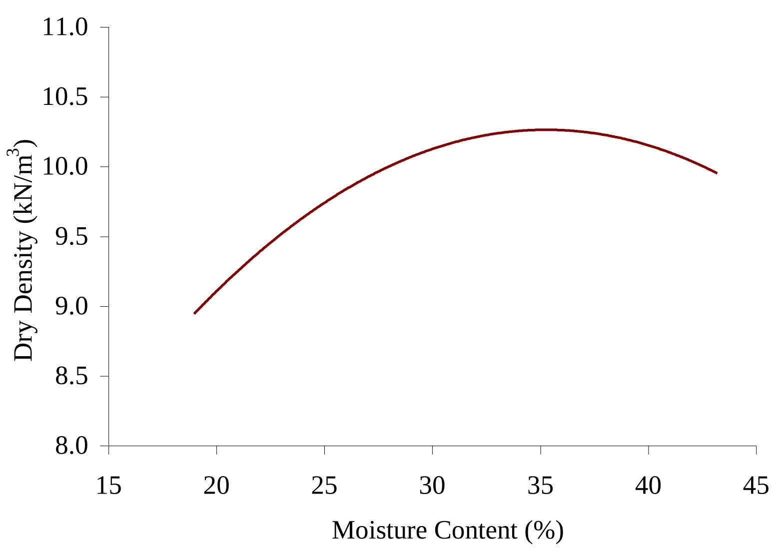

Fig. 2 Dry density-moisture content

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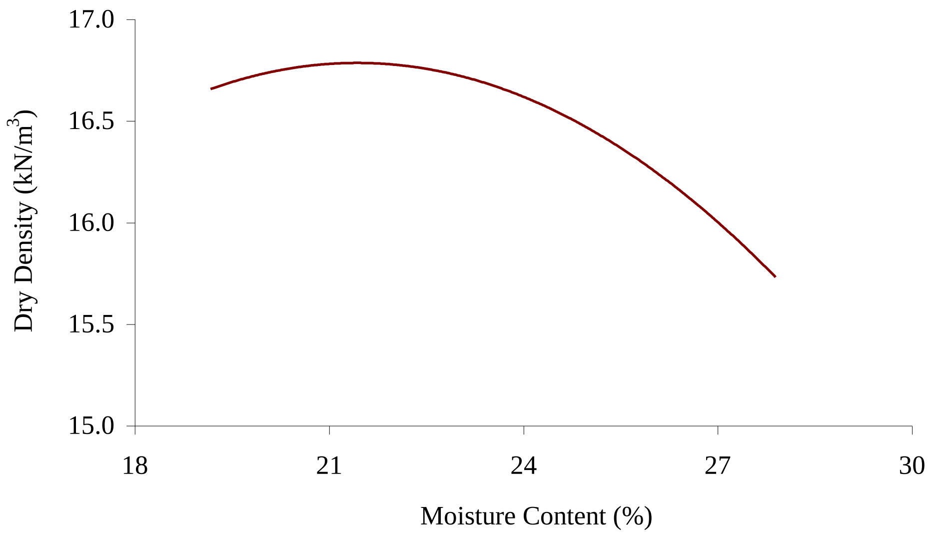

Fig. 3 Dry density-moisture content

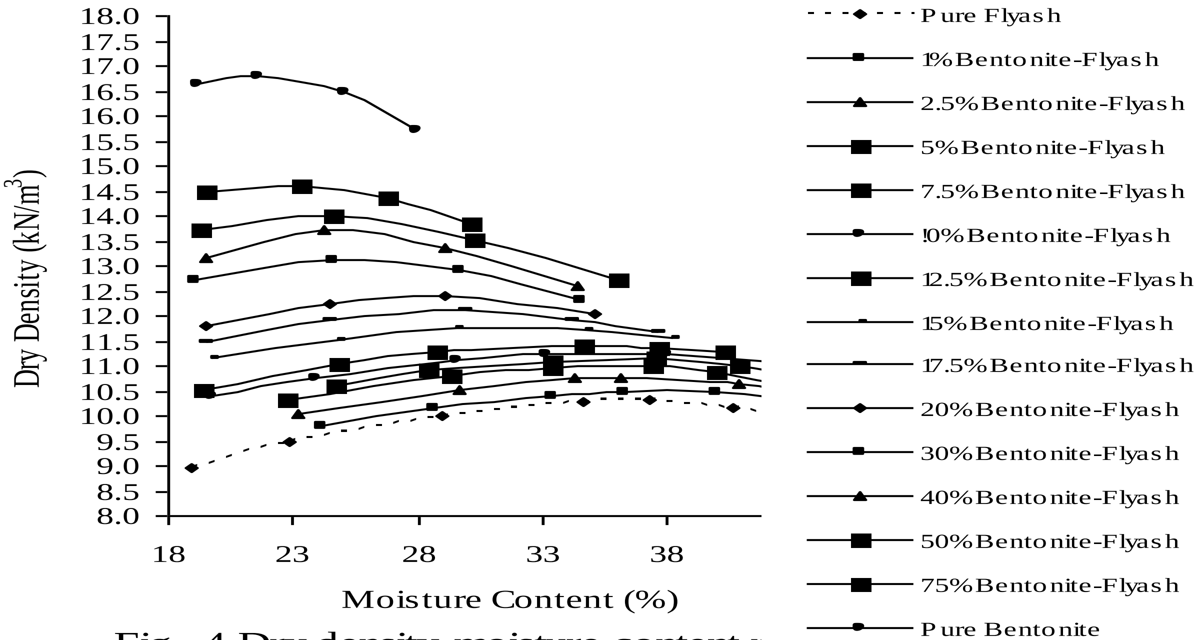

Fig . 4 Dry density-moisture content r[illegible]
of bentonite-flyash mixture(%)

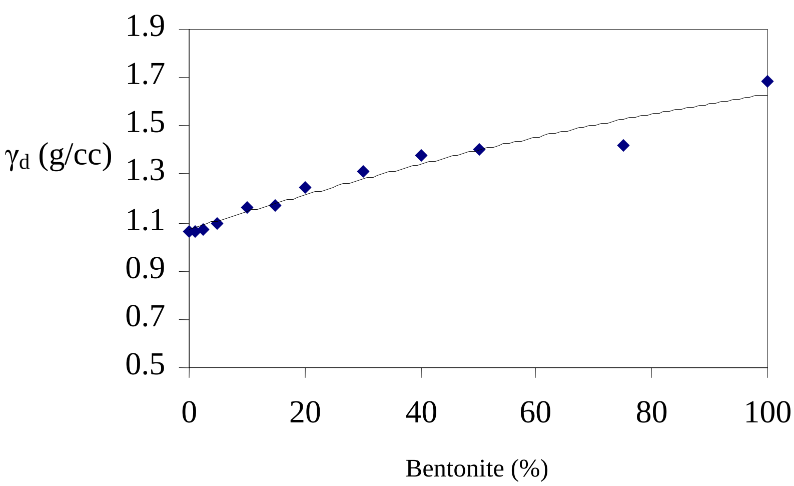

Fig. 5 Variation of γ_d with % bentonite

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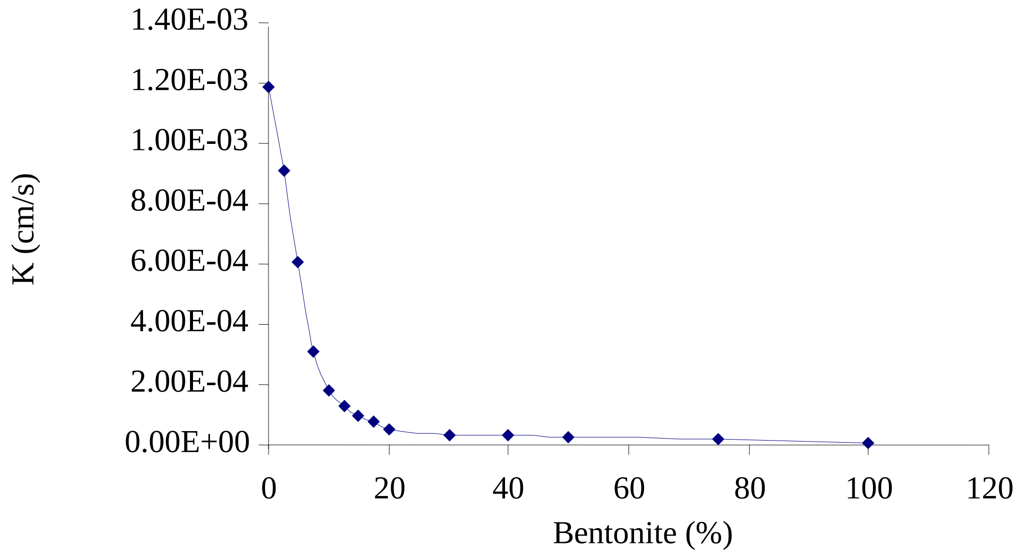

Fig. 6 Variation of permeability in flyash with bentonite