Selection of cementitious mixes as a barrier for landfill leachate containment

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SELECTION OF CEMENTITIOUS MIXES FOR LANDFILL BARRIERS.

ABSTRACT

Concrete has not traditionally been an economic material for most landfill barriers. Most barriers have been made with clay and many materials that have the potential for use as constituent materials concrete have been disposed of within the landfills. Recent increases in disposal costs including the introduction of the landfill tax have, however, made low cost low strength concrete a financially attractive option. In this paper the required properties of concrete mixes for this purpose are discussed. The results of an extensive investigation into potential mixes are presented and the measured properties are compared with those, which are required. All of the mixes which have been investigated have large amounts of secondary materials in them. If these secondary materials were treated as wastes their disposal costs would be high so the mixes may be defined as "negative cost concretes". The results indicate that some of these mixes are well suited to the application.

1. INTRODUCTION

Despite major initiatives for waste minimisation, disposal of large volumes of waste to landfill will continue for the foreseeable future. The landfill industry is now based on facilities, which are engineered to minimise pollution of the local environment. The containment is normally achieved with clay-based systems supplemented with high-density polyethylene (HDPE) membranes.

The cementitious chemical barrier is one of the main engineering features of the current plans for a UK repository for medium and low level nuclear waste. The concept has been developed in response to a requirement for a barrier, which will have a predictable performance in a deep saturated geological environment over a timescale of up to a million years. The barrier is built out of conventional engineering materials but its method of operation is far from conventional for an engineering structure because it is essentially sacrificial. The main function of the barrier is to condition the chemistry of the repository to high pH by dissolving alkalis in the groundwater. The alkalis are free sodium, potassium and lime and subsequently the calcium silicate hydrate which forms the structure of the hardened cement.

Physical containment with concrete is well understood and documented (1). The degree of containment will depend on the permeability of the barrier. The permeability of concrete is relatively easy to measure and this has been achieved in a wide variety of different ways. One of the better methods is the use of a Hoek cell (2).

Chemical containment has been studied in detail for nuclear waste (3). In the type of repository for which a chemical barrier would be used the main mechanism of loss of radionuclides is caused by flowing groundwater. This flow may be present in the area before the repository is built or it may be caused by the heat generated in the repository. In order to operate for a long time a chemical barrier depends on other barriers to limit the flow of groundwater through it. This is normally achieved by positioning the repository in a geology with a very low permeability. In this situation the permeability of the repository itself can be shown not to have a significant effect on the flow of water through it.

Thus water will enter the repository very slowly and the chemical barrier works by conditioning it before it reaches the waste and also after it leaves the waste but before it leaves the repository. Before it reaches the waste the barrier will raise the pH of the water, reduce the Eh, and remove many dissolved ions such as sulphates. In this way the barrier will ensure that the solubility of the radionuclides in the waste is as low as possible. For example raising the pH from 8 to 12.5 will reduce the solubility of Uranium by an order of magnitude, Plutonium and Protactinium by one and a half and Americium by three and a half. After the water leaves the waste the barrier will provide a high capacity for sorption to remove radionuclides from it.

It may be seen that, unlike a conventional engineering structure, the method of operation of a chemical barrier is sacrificial. As it operates the cement matrix carbonates and reacts with sulphates and other materials to an extent, which would indicate failure in a conventional structure.

2. OBJECTIVES FOR WASTE CONTAINMENT

In order to select concrete mixes for non-nuclear waste containment it is important to establish the exact objectives for the system. These may be divided into short and long term objectives.

SHORT TERM

In this discussion the short term is considered to be the working life of the landfill and the early post closure phase until the first deposited waste has been in place for about 50 years. This is the time when the "landfill reactor" is working most effectively on the organic component of the waste. The objective for landfills with a substantial organic loading will therefore be to provide complete containment and a leachate balance, which provides sufficient moisture to promote the reactions but controls the leachate head on the liner.

LONG TERM

In the very long term the contents of a landfill will disperse into the environment from which they came. For nuclear waste the objective is to contain the waste until the activity has substantially decayed but, once the organic degradation is complete, there is no further reduction in toxicity for non-nuclear waste. The long-term objective for non-nuclear waste containment may therefore be to provide an environmentally acceptable transition between the aim of absolute containment in the short term and the certainty of dispersion in the very long term. The absolute physical certainty that all landfills will eventually have to dilute and disperse their inventory of heavy metals and other stable toxins does not appear to be recognised by current legislation. It is of note that some waste materials (e.g. Pulverised Fuel Ash) have a sufficiently low permeability that in normal deposition they do not generate leachate for about 30 years so short term containment is irrelevant.

REQUIREMENTS OF THE BARRIER CONCRETE

The following requirements for the barrier concrete arise from the above considerations:

1. Cube strength of 5 N/mm^2 is adequate.

2. The strength requirement is only for emplacement. After 2 years little strength is required.

3. Expansion of the barrier is harmless. In operation it will be subject to triaxial compression. Thus sulphate attack or unsound cements should be harmless.

4. The permeability must remain low.

5. Cracking is inevitable. What must be avoided is large cracks with large "boulders" between them. Small cracks will close due to the compression and will seal from mineral deposition (autogenous healing) or clay intrusion from the middle layer.

6. Alkaline buffering is essential but this must only be available to the leachate permeating through the barrier. There can never be sufficient buffering for the entire waste load.

3. LITERATURE REVIEW

The following observations have been reported in an initial study by the author (4). Samples of cementitious materials approximately 20mm thick were exposed to water pressures up to 10MPa in a 100mm diameter modified Hoek cell. To measure the physical containment the flow rate was measured and this was used to calculate a coefficient of permeability. To measure the ability of the barrier to buffer the leachate the buffering capacity of the water flowing from the cell was measured by titration. The theoretical buffering capacity of the sample was calculated and the proportion of this that was remaining was plotted against the number of sample volumes that had flowed through the cell. The results from the initial observations are summarised in Table 1; these show the effect of permeating a volume of water equal to 30 times the sample volumes.

The proposers are currently working on a major industry-based project on a new composite barrier system, which uses the concretes described in this paper and is shown in figure 1 (5). This work includes carrying out large-scale site trials to demonstrate the construction of the system. The trials consist of cells approximately 8m wide which are designed to contain leachate to a depth of 1m maximum allowable leachate level in current landfill practice and are made with the candidate barriers.

The vast majority of commercial applications of and hence research efforts into landfill liners focuses on HDPE based systems, yet interest in mineral barriers continues to grow, especially overseas (1). Current research is concentrated in three subject areas: geotechnical investigations into the composite sand-clay-geotextile system, leak detection studies undertaken on behalf of both the regulators and operators (6) and research into waste leaching (7,8,9). The latter has resulted in the formation of an EC thematic network on leach testing procedures (10), which has direct relevance to this project. Similar work in construction materials has generated a wealth of knowledge in the leaching of cements and concretes, which has also resulted in an EC thematic network being established (11). The CEN have drawn on these initiatives along with those of the national standards authorities in Europe and North America (12) to produce draft standard procedures for waste characterisation testing of wastes and construction materials.

4. EXPERIMENTAL METHODS

4.1 Materials used
The various waste or by-product materials used in the laboratory investigation, are listed below:

a) Sodium sulphate
b) Spent borax
c) Ferrosilicate slag (lumps and sand size)
d) Ferrosilicate copper slag
e) Soda slag
f) Chrome Alumina slag
g) Cement Kiln Dust ,CKD
h) Run of station ash
i) Lagoon ash
j) PFA
k) Granulated Blast Furnace Slag, GBS
l) Steel slag
m) Burnt Oil Shale
n) By-product Gypsum
o) GGBS
p) Shell foundry sand
q) Green foundry sand
r) Sodium sulphate solution

These waste materials which were used can be divided in the three following categories:

- Those materials, which may be used as aggregates in the concrete or mortar layers, such as Spent foundry sands Residues from the castings industry. These materials are principally quartz sands with residues of thermally degraded binders such as clay minerals (green sand) and phenolic resins combined with carbon char (shell sand) and Semi-crystalline slags from the metals refining industry i.e. alkaline sulphates, ferrosilicates and heavy metal–bearing "soda" slags.
- Waste alkalis, which may be suitable activators for cementitious ground, granulated blast furnace slag (GGBS) or Pulverised fuel ash (PFA) i.e. Liquid raffinates such as alkaline sodium sulphate solution produced during acid neutralisation of processing waste.
- Those waste materials which have inherent cementitious properties, like Spent borax, GGBS and Gypsum 'filter cake' recovered from acid neutralisation arising from pigment manufacture.

The bulk of the materials is wastes from the castings and metals refining industries such as metalliferous slags and spent foundry sands. Subsequent laboratory work has focussed on examining these materials as cementitious binders in their own right and as cement replacement materials or as chemical activators for other cementitious materials. This has allowed the solids to be grouped into those materials which have cementitious

properties, those which are relative chemically inert and would be suitable for use as aggregates and to identify any materials which are not suitable for use as liner materials.

One entirely new cementitious material was developed exclusively, the spent borax. It is a zinc-oxide containing sodium tetraborate slag, finely ground to produce a cementitious matrix. The chemical composition of this material indicates it to have a high resistance to attack by organic acid mixtures, suggesting it to be very suitable for use as a landfill liner material (13).
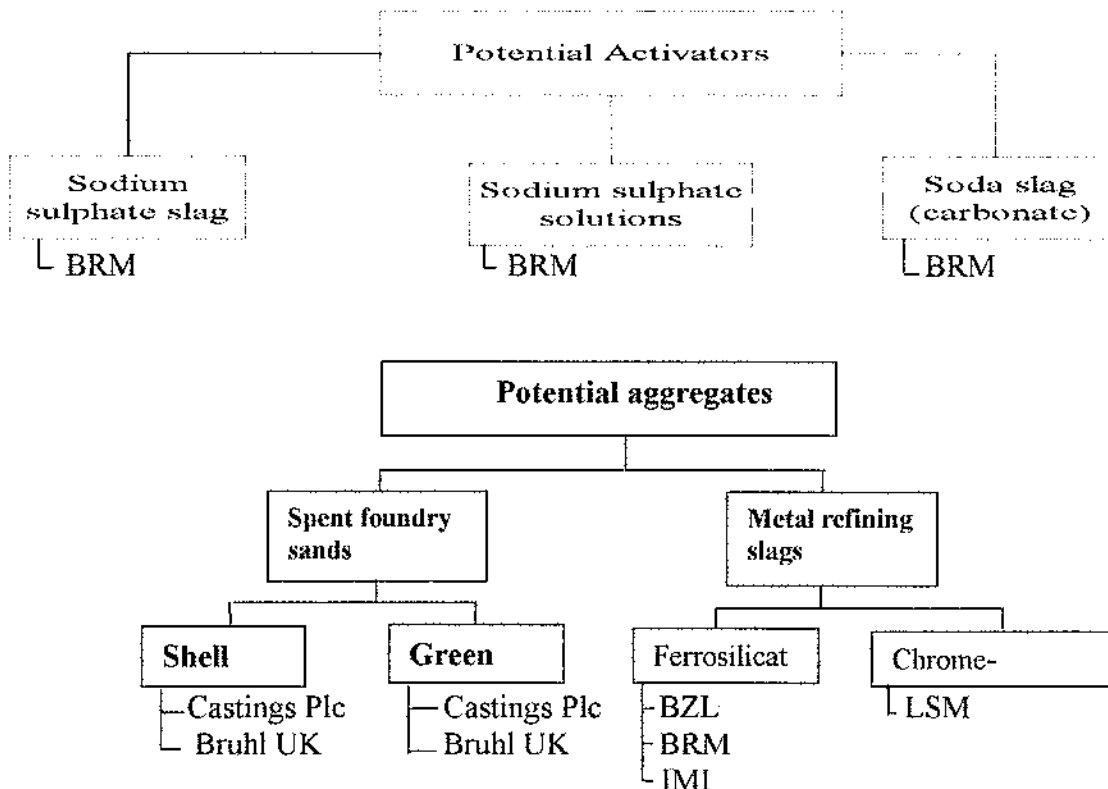
Figure 2: Waste types supplied in the liners project.

4.2 Initial screening of mixes:

The classification of materials (See figure 2) has involved particle size analysis of the solids, optical and electron microscopy, physical testing and both classical and instrumental chemical analysis.

Over one hundred different mixtures with different proportions and materials were prepared and tested for stability in water from the waste samples. Cup mixed specimens were cured for 4-5 days in 95% relative humidity and 20°C ± 2°C condition and then submerged under 150 ml of water. The pH of the water and disintegration of the specimens were monitored. The ones, which did not disintegrate, were judged satisfactory for use as paste or aggregates phase in the liner mixture when the mix satisfied other chemical and engineering requirements. It was noted that Spent Borax (passing 300μm) could be used as a cementitious material.

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4.3 Mix designs:

The mix designs of all the mixes (i.e. paste, mortar and concrete) are given in Table 3. The grading used for mortar and concrete mixes made in laboratory was according to B.S. 882 .

Table 3 :

Table 3: continued

2000-2001

	PASTE:								
18/04/00	CKD : 100 : : : :	0.38		4.8	6	4.28E-11		12.7	
18/04/00	CKD : 100 : : : : : Sodium Sulphate	0.38		5.1	5.5	5.56E-13		13	
19/04/00	CKD : 60 PFA : 40 : : :	0.3		4.1	14.2	4.20E-11	8.49E-12	12.1	9
19/04/00	CKD : 60 PFA : 40 : : : Sodium Sulphate	0.3		2.2	12.1	1.96E-11	3.48E-12	12.4	8.6
10//05/00	GBS : 60 PFA : 30 OPC : 10 : :	0.21		6.6	7.5	2.49E-09		13.4	
10//05/00	GBS : 50 CKD : 40 OPC : 10 : :	0.26		6.5	8.1	1.46E-13			
11//05/00	GBS : 60 CKD : 30 OPC : 10 : :	0.24		6	7.6	9.16E-11		12.2	
11//05/00	CKD : 70 PFA : 25 OPC : 5 : : Sodium Sulphate	0.34		10.6	12.9	0.00E+00			
12//05/00	GBS : 40 Lagoon Ash : 30 GGBS : 30 : : Sodium Sulphate	0.21			14.8	3.12E-10		10.4	
	GBS : 40 Lagoon Ash : 30 GGBS : 30 : : Sodium Sulphate	0.21				4.09E-10		10.5	
12//05/00	Lagoon Ash : 70 CKD : 30 : : : Sodium Sulphate	0.34			2.9				
22//05/00	Lagoon Ash : 40 GBS : 40 GGBS : 20 : : Sodium Sulphate	0.22		7.4	24.3	1.38E-09		12.5	
05/06/00	GBS : 40 GGBS : 30 Lagoon Ash : 30 : : Sodium Sulphate	0.22		0.8	7.9				
07/06/00	GBS : 55 CKD : 35 OPC : 10 : : Sodium Sulphate	0.28		8.8	14.7	2.19E-12		9.5	
07/06/00	CKD : 60 Lagoon Ash : 40 : : : Sodium Sulphate	0.35		4.9	12.9	1.53E-12	5.74E-12	10.4	8.5
08/06/00	CKD : 60 Lagoon Ash : 40 : : :	0.35		6	16.7	1.67E-10	8.72E-12	12.4	8.9
08/06/00	GBS : 55 CKD : 35 OPC : 10 : :	0.28		7.6	13.5	4.37E-11		13	
10/06/00	CKD : 70 Lagoon Ash : 25 OPC : 5 : :	0.41		4.8	16.3	1.16E-10	8.78E-12	13	6.5
10/06/00	CKD : 70 Lagoon Ash : 25 OPC : 5 : : Sodium Sulphate	0.41		4.2	15.5				
	MORTAR:								
22/06/00	GBS : 15.7 CKD : 10 OPC : 2.9 Ferrosilicate slag : 71.4 : : Sodium Sulphate	0.38		1.7	6.7	1.44E-08	1.11E-08	9.6	9.1
04/07/00	GBS : 13.8 CKD : 8.7 OPC : 2.5 Ferrosilicate slag : 75 : : Sodium Sulphate	0.38		1.1	5.9				
11/07/00	CKD : 17.2 Lagoon Ash : 11.4 : Ferrosilicate slag : 71.4 : :	0.36		0.6	4.4	2.99E-09	6.29E-09	11.8	10
	CKD : 17.2 Lagoon Ash : 11.4 : Ferrosilicate slag : 71.4 : :	0.36				1.06E-09	1.50E-09	9.2	9.7
24/07/00	CKD : 24 Lagoon Ash : 16 : Ferrosilicate slag : 60 : :	0.33		1.1	8	3.19E-10	8.00E-12	13.4	12.8
24/07/00	CKD : 20 Lagoon Ash : 11.7 OPC : 1.6 Ferrosilicate slag : 66.7 : :	0.32		2	8.4	4.80E-10	6.00E-10	13.5	13
24/10/00	CKD : 20.5 Lagoon Ash : 13.6 : : Fine chrome alumina :65.9 :			1.1	1.7	4.49E-09	5.01E-09	11.8	12.3
	CONCRETE:								
22/06/00	Lagoon Ash : 6.8 GBS : 7.7 GGBS : 4.8 Fine chrome alumina : 33.4 Coarse chrome alumina :47.3 : Sodium Sulphate	0.37	2913	1.5	11.3				
22/06/00	GBS : 7.3 GGBS : 4.6 Lagoon Ash : 6.4 Shell sand : 4.7 Fine chrome alumina :31.9 Coarse chrome alumina : 45.1 Sodiu	0.46	2865	0.6	8.7				
22/06/00	CKD : 13.5 PFA : 4.8 OPC : 1 Shell sand : 4.5 Fine chrome alumina :28.9 Coarse chrome alumina : 47.3 Sodium Sulpha	0.3	2940	3	6.5	3.63E-09	1.30E-09	9.6	6.6
03/07/00	CKD : 13.4 Lagoon Ash : 4.8 OPC : 1 Shell sand : 4.4 Fine chrome alumina :29 Coarse chrome alumina : 47.4	0.52	2750	3.2	8.2	1.51E-10	8.12E-11	9.2	9.4
03/07/00	CKD : 11.5 PFA : 7.7 : Shell sand : 4.4 Fine chrome alumina :29 Coarse chrome alumina : 47.4 Sodium Sulphate	0.42	2820	2	9.1	2.21E-10	1.86E-10	11.1	9.2
03/07/00	CKD : 11.5 PFA : 7.7 : Green sand : 4.4 Fine chrome alumina :29 Coarse chrome alumina : 47.4 Sodium Sulphate	0.45	2855	2.1	7.6	3.97E-10	3.90E-10	9.9	9.3
03/07/00	GBS : 10.5 CKD : 6.7 OPC : 1.9 Shell sand : 4.5 Fine chrome alumina :29 Coarse chrome alumina : 47.4 Sodium Sulpha	0.42	2965	5.3	3.1				
11/07/00	CKD : 13.1 Lagoon Ash : 8.7 : Fine ferrosilicate : 32.7 Ferrosilicate lumps :45.5 :	0.3	2170	1.2	4.6				
18/09/00	CKD : 7 PFA : 8.6 : Shell sand : 4.2 Fine chrome alumina :30.4 Coarse chrome alumina : 49.6			4.4	6.9	2.30E-09	4.51E-09	10.1	9.9
26/09/00	CKD : 7.9 Lagoon Ash : 5.2 OPC : 1.1 Shell sand : 4.7 Fine chrome alumina :30.8 Coarse chrome alumina : 50.3			2.8	6	1.25E-08		8.5	
	CKD : 7.9 Lagoon Ash : 5.2 OPC : 1.1 Shell sand : 4.7 Fine chrome alumina :30.8 Coarse chrome alumina : 50.3				6		4.33E-09		8.5
	CKD : 7.9 Lagoon Ash : 5.2 OPC : 1.1 Shell sand : 4.7 Fine chrome alumina :30.8 Coarse chrome alumina : 50.3				6		8.24E-09		6.8
5 month old	CKD : 7.9 Lagoon Ash : 5.2 OPC : 1.1 Shell sand : 4.7 Fine chrome alumina :30.8 Coarse chrome alumina : 50.3				6	3.20E-09	3.44E-09	11.1	9.1
24/10/00	CKD : 14.2 Lagoon Ash : 10 : : Fine chrome alumina :46 Coarse Lime stone : 29.8			0.9	1.3	1.20E-08	7.42E-09	12.2	12.1

Table 3: Mix designs and results of compressive strenght and hydraulic conductivity of mixes:

| Date cast 1998-1999	Materials and percentage by mass for each mix (with the liquid type if other the water used)	Water /Cem	Density Kg/m3	7days Str. MPa	28 days Str. MPa	Water Perm m/s	Leachate Perm m/s	Through pH (water)	Through pH (leachate)
	PASTE:								
26/02/99	GGBS : 70 Soda slag : 30	0.33		5.1	0.3				
08/03/99	PFA : 70 Soda slag : 30	0.29		0.3	34	2.69E-10	7.30E-10	10	6
	PFA : 70 Soda slag : 30	0.29				3.56E-11		10	
16/03/99	Spent Borax : 70 Soda slag : 30	0.3		2.2	0.7				
19/03/99	Spent Borax : 100	0.25		38	46	8.40E-09	3.22E-08	10	6.6
	Spent Borax : 100	0.25				2.43E-09		10	
24/03/99	OPC : 100	0.3		50	69	6.03E-10	5.62E-11	13.5	10
26/03/99	PFA : 67 Soda slag : 30 OPC : 3	0.35		10	30	1.08E-10	4.37E-10	13.5	7
15/04/99	Spent Borax : 75 Run of Station Ash : 12.5 Soda Slag : 12.5	0.22		12	10.6				
20/04/99	Gypsum waste : 57 GGBS : 43	0.29		0.6	7.5	8.03E-09		7.5	
22/04/99	Gypsum waste : 61.5 GGBS : 23 Soda Slag : 15.5	0.31		0.2	1.6	4.89E-09	5.67E-09	10	9
26/04/99	Spent Borax : 87.5 PFA : 12.5	0.17		48	35	9.67E-10	3.71E-09	10	10
	Spent Borax : 87.5 GGBS : 12.5	0.17		33.5	24	2.07E-09	1.03E-08	10	10
28/04/99	Spent Borax : 87.5 GGBS : 12.5	0.17				1.29E-09		10	
19/05/99	GGBS : 90 OPC : 10 Sodium Sulphate	0.32		36	41	2.13E-11	7.83E-12	14	
02/07/99	Spent Borax : 100	0.17			47.7	6.64E-11		10	
3 month old	Spent Borax : 100	0.17				3.40E-10	3.21E-08	10	8
3 month old	Spent Borax : 100	0.17				2.20E-09			6.5
dry curing	Spent Borax : 100	0.17				7.71E-08	5.33E-09	8	6
0707/99	GGBS : 90 OPC : 10	0.32		26	33.5	0.00E+00	1.58E-10		9
14/07/99	Spent Borax : 87.5 Soda Slag : 12.5 Sodium Sulphate	0.18		9.1	15.3				
19/07/99	Spent Borax : 87.5 Soda slag : 12.5	0.23		15.4	16.1				
15/07/99	Soda slag : 50 PFA : 50 Sodium Sulphate	0.21		0.35	0.11				
8/10/99	Run of Station Ash : 90 OPC : 10	0.28		0.15	10	1.60E-09			
12/10/99	GBS : 60 Run of Station Ash : 30 OPC : 10	0.23		0.1	13	3.57E-10		10	
14/10/99	Steel slag : 90 OPC : 10	0.15		0.7	5	1.03E-09			
14/10/99	Steel slag : 60 Run of Station Ash : 30 OPC : 10	0.19		0.1	17	6.53E-10			
	MORTAR:								
12/11/98	PFA : 24 OPC : 12 Ferrosilicate slag : 64	0.5		1.8	9.3	too expensive			
13/11/98	GGBS : 20 OPC : 10 Ferrosilicate slag : 70	0.61		3.4	14.2	too expensive			
16/11/98	Spent Borax : 70 PFA : 30	0.48		2.2	17.2	too expensive			
16/11/98	Spent Borax : 70 GGBS : 30	0.64		2.2	16.1	too expensive			
17/11/98	Spent Borax : 70 PFA : 20 OPC : 10	0.56		0.1	4.4	too expensive			
17/11/98	Spent Borax : 70 GGBS : 20 OPC : 10	0.59		0.8	3	too expensive			
25/05/99	GGBS : 16 OPC : 1.8 Chrome Alumina : 82	0.5		17	22	1.45E-10	6.73E-10	14	6.5
27/05/99	GGBS : 8.5 OPC : 0.9 Chrome Alumina : 90.6 Sodium Sulphate	0.98		7.5	11.5	3.36E-09	3.41E-09	8	7.5
26/05/99	GGBS : 7.5 OPC : 0.8 Green sand : 27.5 Chrome Alumina :64.2 Sodium Sulphate	1.5		12.5	17.5	2.03E-12	1.77E-12	8	7
	GGBS : 7.5 OPC : 0.8 Green sand : 27.5 Chrome Alumina :64.2 Sodium Sulphate	1.5				2.41E-12		8	
30/09/99	GBS : 90 OPC : 10	0.32		0.5	0.35	very porous	very porous		
5/10/99	OPC : 10 Burnt oil shale : 90	0.32		2.1	0.45	6.32E-10			
	OPC : 10 Burnt oil shale : 90	0.32				7.87E-10		9.5	
	CONCRETE:								
15/01/99	PFA : 15 OPC : 10 Ferrosilicate slag : 75	0.36	2760		32.9				
30/04/99	Spent Borax : 25 Chrome Alumina : 25 Coarse Ferrosilicate :50	0.33	3100	19.9	32.5	8.83E-09	3.48E-08	8.5	6.5
30/04/99	Spent Borax : 25 Shell sand : 25 Ferrosilicate slag :50	0.38	2800	9	18	9.13E-09	4.61E-08		6.5
30/04/99	PFA : 12.5 Soda slag : 10 OPC : 2.5 Ferrosilicate slag : 50 Chrome Alumina :25	0.31	2900	6	15	4.82E-09	4.96E-09	6.5	10
30/04/99	PFA : 12.5 Soda slag : 10 OPC : 2.5 Shell sand : 25 Ferrosilicate slag :50	0.35	2700	7	6	5.10E-09	5.68E-09	8.5	13
29/10/99	GGBS : 7.6 OPC : 0.9 Green sand : 27.3 Coarse chrome Alumina :64.2 Sodium Sulphate	1.48	2685	11	13	0.00E+00	1.95E-12		8.5
	GGBS : 7.6 OPC : 0.9 Green sand : 27.3 Coarse chrome Alumina :64.2 Sodium Sulphate	1.48	2685			0.00E+00			
07/12/99	Spent Borax : 18.5 Ferrosilicate sand : 36.8 Coarse limestone :44.7	0.47	2660	5	4.5	1.51E-08	4.12E-08	10	
	Spent Borax : 18.5 Ferrosilicate sand : 36.8 Coarse limestone :44.7	0.47	2660			1.80E-08		10	

4.4 Evaluation of mixes:

4.4.1 Physical strength;

The compressive strength of pastes and mortars were determined by casting 50 mm cubes and the compressive strength of concrete by 100 mm cubes. All the specimens were cured at 95 per cent relative humidity at $20\pm 2°C$ and tested according to B.S. 1881,part 116. The results of the compressive strength of the mixes are shown in Table 3.

4.4.2 Measurement of Transport Properties;

The hydraulic conductivities (permeabilities) of the specimens were determined using a continuous high-pressure flow experiment in which solution is eluted through the materials at pressures up to 10 MPa depending on the compressive strength of the particular specimen. The apparatus is a modified Hoek Cell (2,4) and is adapted to measure both the flow and pressure drop across the sample (Figure 2). To maintain the structural integrity of the sample, and prevent flow past its sides, a confining pressure is applied (as in a triaxial cell) around an impermeable sleeve surrounding the sample. By maintaining the pore solution pressure below that of the confining pressure, the internal structure of the barrier material is maintained. In addition to providing a reaction vessel, the cell is used as a constant head permeameter, allowing dynamic measurement of permeability changes over the duration of each experiment.

Both deionised water and a synthetic (acetogenic) leachate have been eluted through the materials to examine their effects on permeability evolution and buffering capacity of the concrete. The results of the permeability tests are given in Table 3. The composition of artificial leachate used is given in Table 2.
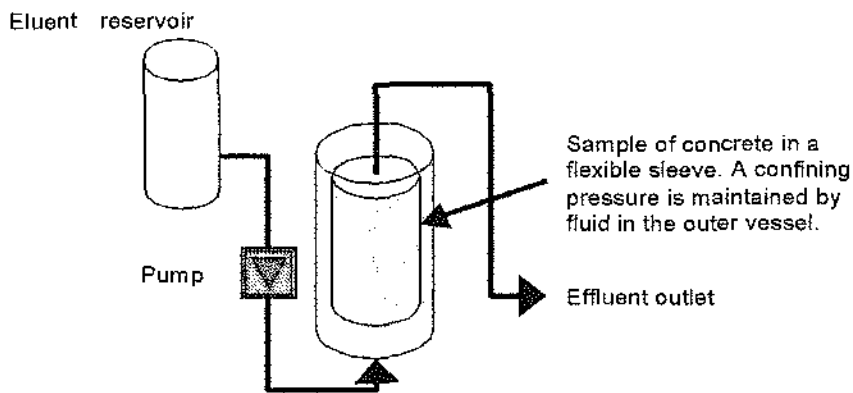
Figure 3: Schematic view of high-pressure permeability apparatus.

4.4.3 Physical observation:

Physical observations of samples after water or leachate was passed through the specimens were carried out. The specimens, which disintegrated, are not included in table 3.

5. DISCUSSIONS

Figures 4 and 5 respectively show the water permeability and leachate permeability against 28-day compressive strength of the mixes studied in respect of the highest percentage by weight used cementitious material. As expected it can be observed from these figures that the coefficient of permeability and strength do not hold a certain relation for a particular cementitious material. For example in the OPC mixes (Fig. 4) the OPC paste with 69 MPa strength gives same coefficient of permeability as the OPC mortar made with 90 percent Burnt oil shale and 10 percent OPC with compressive strength of only 0.5 MPa. In general mixes made with CKD, OPC, GBS and GGBS gives lower permeability compare to the rest of the materials used.

Figure 6 compares the water and leachate permeability coefficients. Leachate always shows higher permeability. The strength development is shown in figure 7 and as expected 28 day strength is increased for each group of materials with different rates.

In general the higher the through pH value the lower the permeability of mixes. (see figures 8 and 9).

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Table 1. Initial Experimental Results (Claisse and Unsworth 1995).

Mix Type	% buffering remaining after 30 volumes	Initial Intrinsic permeability m^2	Permeability after 30 volumes m^2
OPC 35 MPa	94	2E-16	9E-17
OPC 20 MPa	70	9E-16	4E-16
60/40 OPC/PFA	90	9E-18	4E-18
55/45 OPC/PFA	98	8E-17	1E-17
45/55 OPC/GGBS	98	7E-19	5E-17

OPC: Ordinary Portland Cement
PFA: Pulverised Fuel Ash
GGBS: Ground Granulated Blastfurnace Slag

Table 2 Composition of artificial leachate

1 litre of synthetic leachate contains: -
       -500 ml DI water
       -2.043g concentrated sulphuric acid
       -4.48g Acetic acid
       -1.897g Potassium chloride
       -7.755g Calcium acetate
       -1.186g Ammonium chloride
       -0.91g Sodium chloride
       -2.588g Sodium hydroxide
       pH = 5.1

| Composition		Main Physical Function
Alkali activated slag concrete containing spent foundry sand and metallurgical slag aggregate	Hard-wearing layer	Mechanical support of vehicles during operational phase
Non-swelling clay	Softer sealing layer	Physical containment of leachate and crack sealing.
Portland cement concrete containing aggregate of crushed demolition waste and spent foundry sand.	Base layer	Base for sealing layer
	Sub-soil	
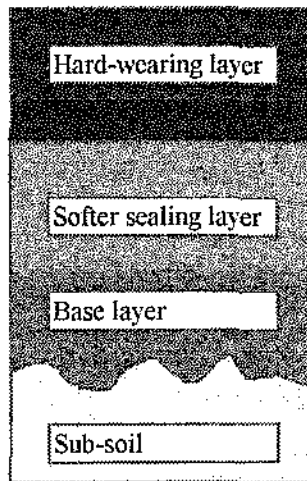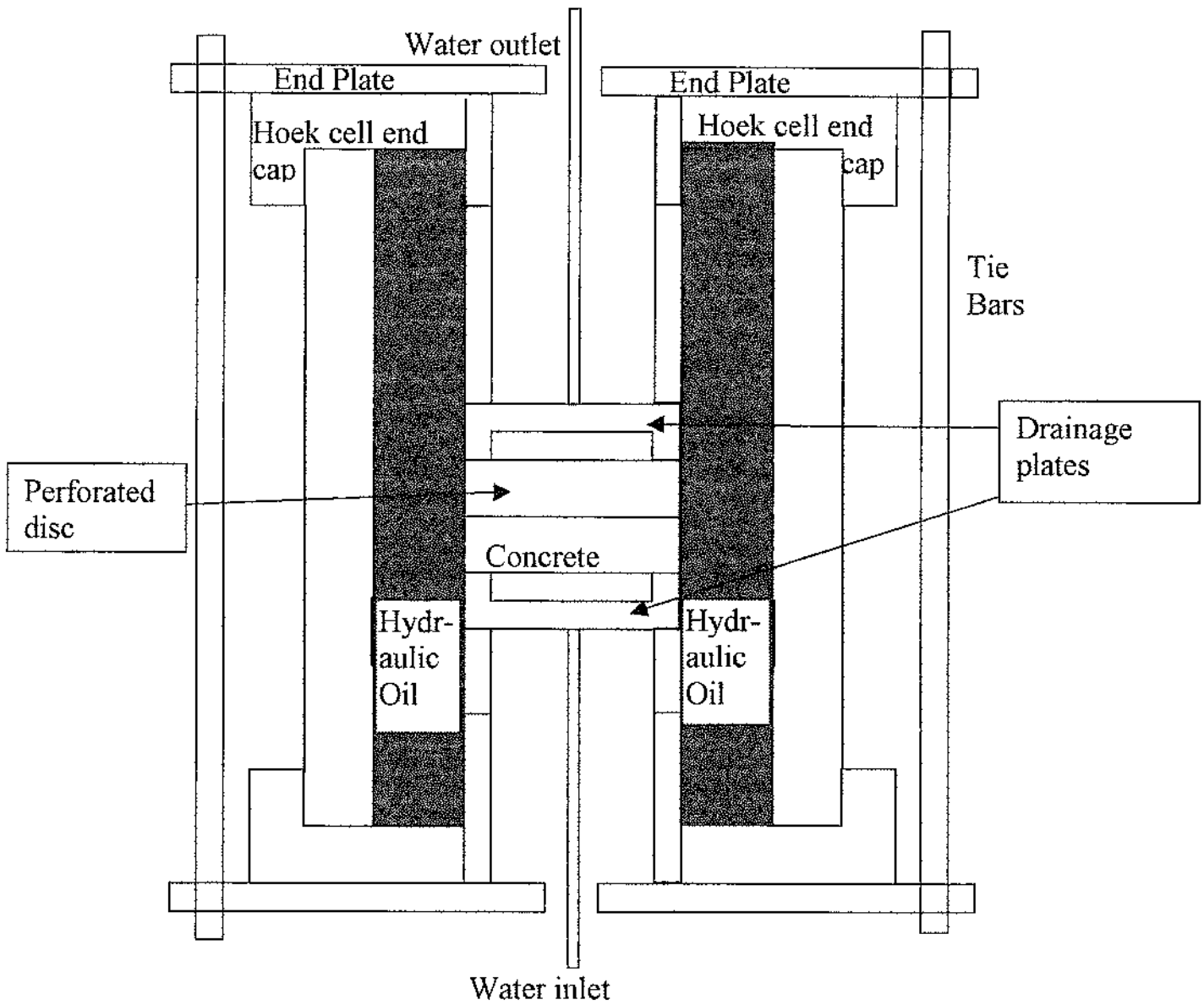
Figure 1

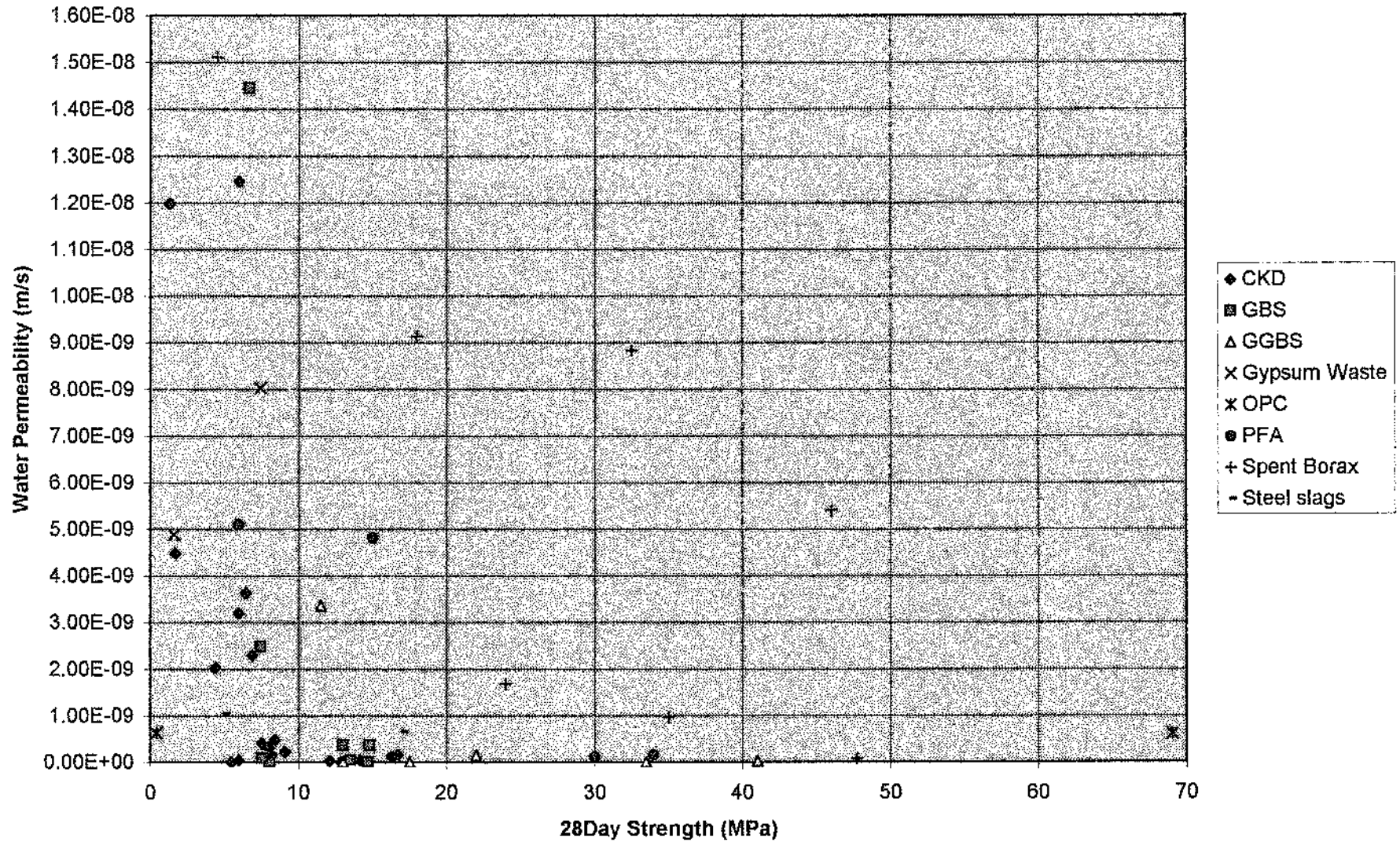Figure 2

Fig. 4: Water permeability versus Compressive strength for all mixes.

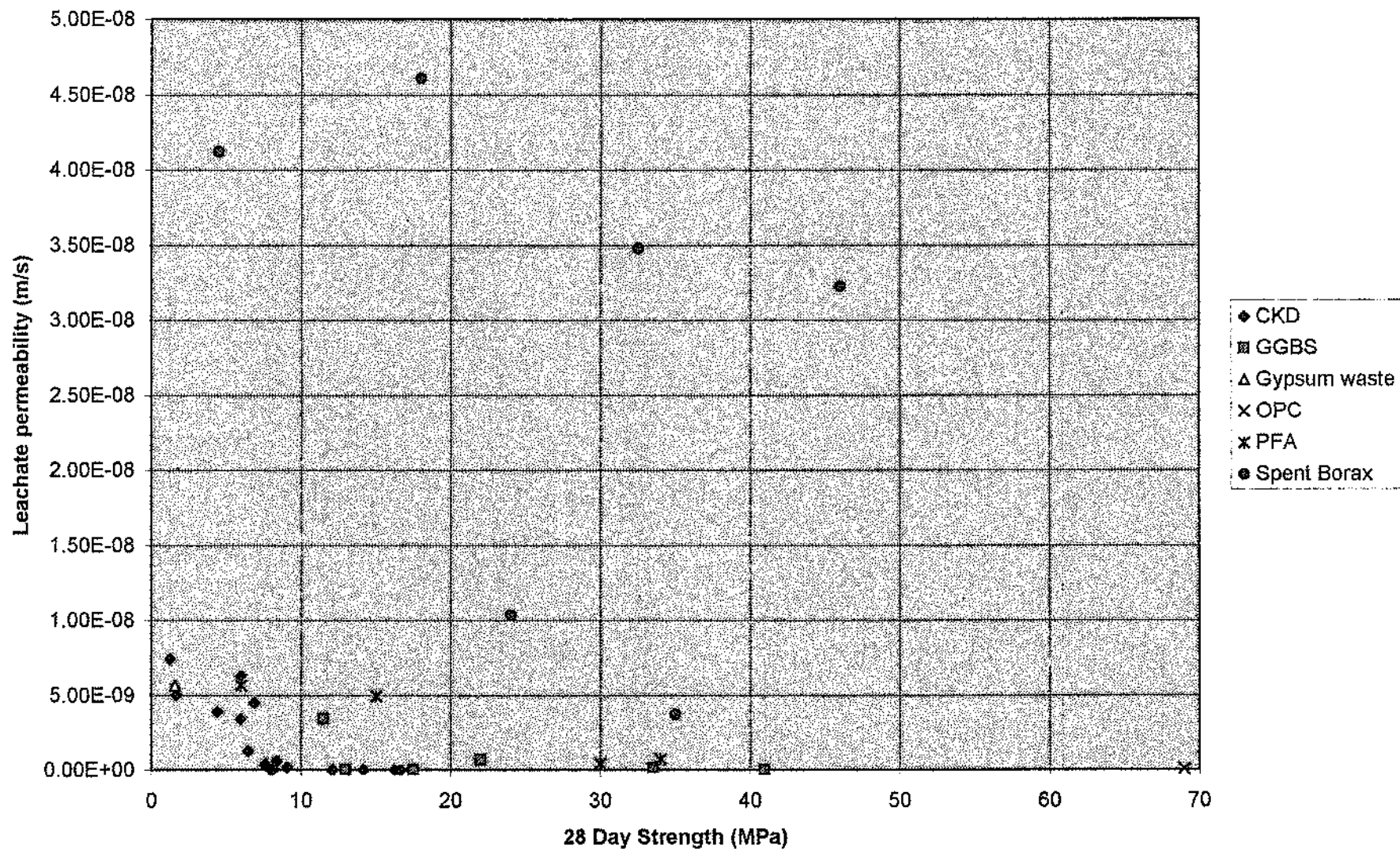Fig. 5: Leachate permeability versus compressive strength .

Fig. 6: Leachate versus water coefficient of permeability.

Legend:
- ◆ CKD
- ▩ GGBS
- × OPC
- ✳ PFA
- ● Spent Borax
- + Gypsum waste
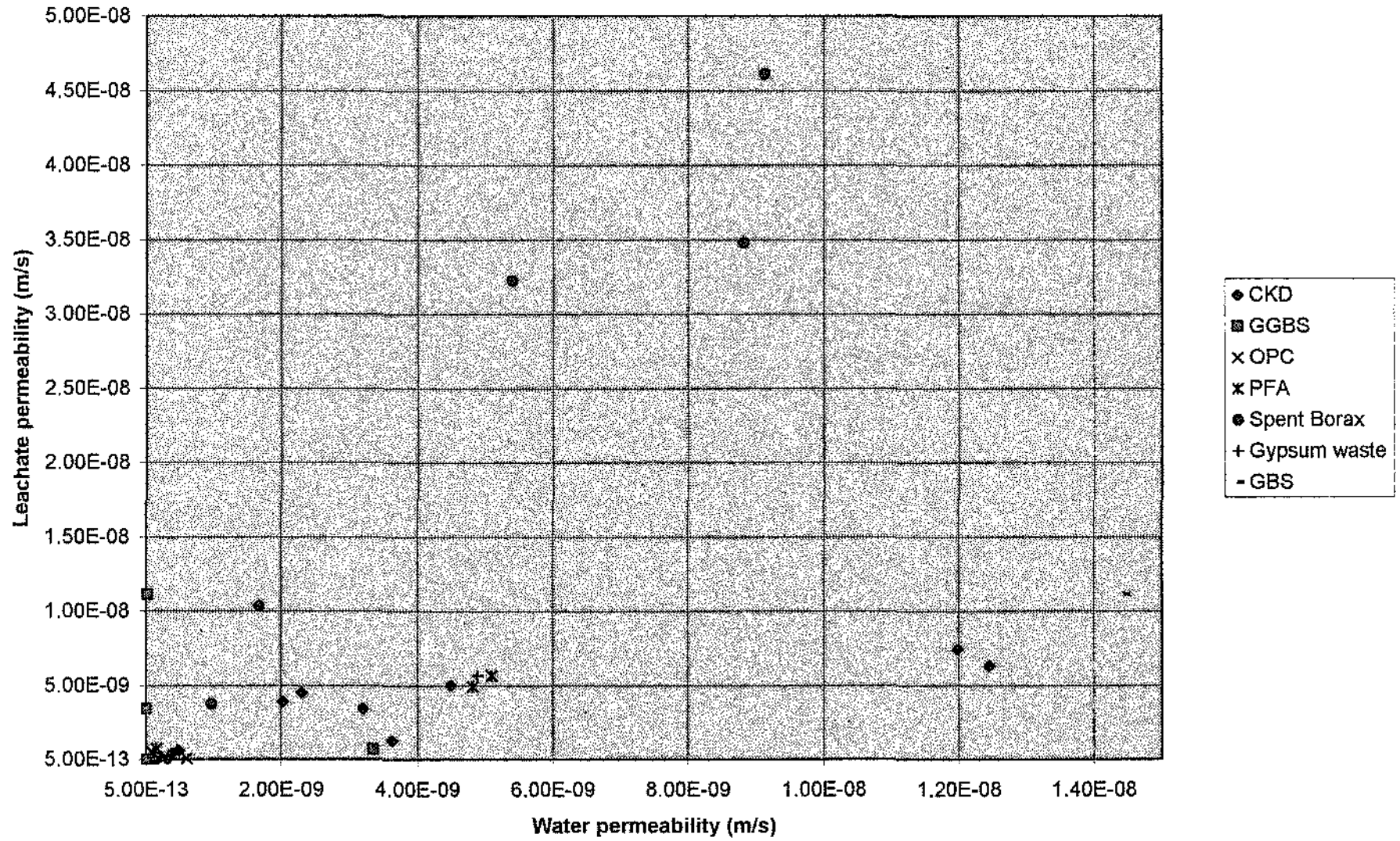- − GBS

Y-axis: Leachate permeability (m/s)
X-axis: Water permeability (m/s)

Fig. 8: Through pH versus permeability .