BARRIERS, BEYOND PERMEABILITY

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Abstract: Vertical barriers impeding horizontal ground water transport have been installed by various techniques for decades. In the case of permanent enclosures, the chemical contaminant stock is the containment's objective. To consider hydraulic conductivity as the sole confining criterion could be misguided when analyzing long-term performance. Molecular diffusion resulting from chemical molecules moving through an aqueous phase from a highly concentrated level to a lesser concentrated level under a so called chemical gradient can be, over the long term, a cause of major contaminant transport. In other words, the barrier could be a chemical sieve. This is especially true when the boundary conditions are unaffected as is the case of a barrier supposed to protect an active waterway. Since barrier materials have different chemical components and structures, they can exhibit very distinct molecular diffusion characteristics while showing hydraulic conductivities in the same order of magnitude. A low permeability self-hardening slurry barrier material - made of a mixture of attapulgite clay and blast furnace slag cement at a water/solids ratio of 5 - has been tested for molecular diffusion with saline solutions and compared with known data given for clay liners and soil bentonite trenches. Despite the material's extremely high water content, the apparent porosity and the coefficient of molecular diffusion are significantly lower. Tortuosity or the pore space physical complexity is advanced as an explanation for these results.

<u>Purpose of the research</u>: prompted by an encounter with the Michigan D.E.P. asking for molecular diffusion characteristics of a proprietary self-hardening slurry mix (referred below as GRT/SHS) and offered as a superior alternate to a soil bentonite slurry wall.

<u>Researchers</u>: on diffusion, Prof. R. Kerry Rowe of Western Ontario University assisted by Mr. Craig Lake, and Dr. Frank S. Barone of Golder Associates, Mississauga, Ont. And for hydraulic conductivity testing, Mr. Graig Thomas P.E., of the URS Group Totowa, NJ geotechnical laboratory. Research was privately funded by Liquid Earth Support, Inc.

<u>About the author</u>: a civil/geotechnical engineer associated with the practical end of ground modification techniques for 35 years, with in depth knowledge of geofluids and a specific interest in ground blast furnace slag cement properties at high w/c ratios.

We will refer to GRT/SHS as a stable suspension of slag cement in a paligoskite (attapulgite or sepiolite) clay slurry where the total solids may represent only 13 to 22% of the total mass. Such fluid suspensions are used as trenching or drilling muds or as slurry grout in the process of ground modification techniques such as jet grouting or deep soil mixing. Once set and cured, these compounds form solids of very low permeability, with remarkable chemical resilience and surprising strength (see, by same author, in FSU1997 conference proceedings p. 62: "Very low conductivity S-H-S for permanent enclosure").

Although most contaminants are generally either organic compounds or heavy metals (molecular diffusion coefficient do vary with each type of solute), a saline solution (NaCl) is first used as a means of comparing materials from a molecular diffusion coefficient standpoint. Typically, in clay based materials, sorbtion of chloride is limited and a diffusion test can be carried out at zero hydraulic gradient with negligible sorbtion, thus at steady state. Different apparatus can be used, but in both laboratories, a half cell apparatus was used, with the chemical gradient being created through a fairly thin sample (20 mm) with the solute in one half cell and distilled water in the second half cell. Daily sampling in each cell is compensated by distilled water additions in each half cell, causing dilution in both chambers. Tests typically run a few weeks until a finite trend towards equilibrium is established and enough data is collected to adjust a diffusion computer model (POLLUTE was used both by Rowe and Barone).

In the case of a soil bentonite wall, the soil fraction that is the bulk of the mass, can vary from a well graded sand and gravel with fines, to a silty clay with little sand. The porosity, density, and sorbtion can vary widely even on the same site should the geology vary. This variability may cause the molecular diffusion properties to change and require statistical analysis to evaluate the potential flux across the entire barrier. Although from a permeability standpoint, research has demonstrated that addition of dry bentonite to soil mixes could always satisfy hydraulic conductivity requirements, diffusion testing on the same mixes has shown that the diffusion coefficient was independent of the amount of bentonite in the pore matrix. Working with a GRT/SHS has the merit of dealing with a known formulation whose properties will be very close over the entirety of the barrier. From a contaminant standpoint, SHS is not subject to dielectric constants or cation exchange capability that affect swelling clays such as is the case of bentonite gel filled matrix of soil bentonite barriers. It is also worthy to note that the effective diffusion coefficient ($D_{e)}$ for saturated clays is generally less than one order of magnitude than the free liquid diffusion coefficient (D_l) with either organics or inorganics. This is alarming in view of the amount of barriers that were designed and installed with only hydraulic conductivity in mind. As a point of reference, bentonite sand mixes or compacted clay till will have a diffusion coefficient in the range of 5 to 10 x10^{-6} cm^2/s.

Physical properties of GRT/SHS:

	Solids content	Weight pcf	w_o	dry weight pcf	porosity	ditto w. Poresizer	Hydr. Cond. K
UoW.Ont.	18%	69.5	438%	12	.92	.70 to .80	3.6 E^{-9} cm/s
Golder	*22%	73.5	308%	22	.85	n.a.	4.6 E^{-10} cm/s
	18%	70	476%	12.9	.90	n.a.	1.1 E^{-9} cm/s
	11.1%	69.5	508%	12.0	.93	n.a.	n.a.
	17.1%	72.9	314%	18.4	.88	n.a.	n.a.
	20.4%	76.2	244%	24.8	.86	n.a.	n.a.

* with 10% carbon black and 1% caustic

Diffusion tests results: (all NaCl solutions, 3.3 g/l for U.W. Ont. and 2.45 g/l for Golder)

	Mix	duration Days	K_d mg/l	n_e	Best fit POLLUTE D_e	Tortuosity
UoW.Ont.	18%	17	0	.5-.7	1×10^{-6} cm^2/s	n.a.
	18%	42	4.1	.7	1×10^{-6} cm^2/s	n.a.
Golder	22%	60	1	.11	1.2×10^{-6} cm^2/s	.08
	18%	60	1	.26	$.3 \times 10^{-6}$ cm^2/s	.02
	11.1%	60	1	.69	$.6 \times 10^{-6}$ cm^2/s	.08
	17.1%	60	1	.32	$.12 \times 10^{-6}$ cm^2/s	.08
	20.4%	60	1	.34	$.15 \times 10^{-6}$ cm^2/s	.01

Discussion: Despite the very high water content of these mixes, a very tight network is created to provide a matrix with an exceptional tortuosity factor. This represents a possible reduction of the diffusive flux by a factor of 50 by comparison to sand bentonite mixes. The possibility of optimizing the formulation of these materials towards greater sorbtion and lower effective porosity offers distinct options to a permanent enclosure designer.

Applications of GRT/SHS as horizontal blankets, either as layers created at the bottom of ponds or as jet grouted horizons are in the realm of practical applications as a means of creating complete man-made enclosures.