TEST REPORT #9

Physical Product Characteristics in Saline Waters

Background and Purpose of Testing

Freshwater compatible (sodium bentonite-based) AquaBlok® typically displays significant primary pore infilling and net vertical expansion when hydrated in fresh water, as described in Test Report No.6. This is because of the dominant clay's (sodium montmorillonite) plate-like structure, highly charged surface area, and great affinity for water - attributes that, in low-salinity environments, result in the clay's dispersed, physically expanded state.

While significant dispersion and expansion of this clay material in low-salinity waters is well recognized and is, in fact, a key principle behind the functioning of environmental barriers like slurry cutoff walls, equally notable is the relative *lack* of sodium bentonite's expansion in saline waters and in some chemically aggressive waters (e.g. Tobin and Wild 1986; Shackelford 1994). Sodium Bentonite's solution-dependent behavior, as illustrated in Photograph 1, is due to montmorillonite's tendency to flocculate rather than disperse in the presence of high ionic-strength solutions.

Sodium bentonite's sensitivity to high ionic-strength waters is also dynamic. The introduction of highly saline or chemically aggressive waters into an initially dispersed slurry wall system, for example, can result in clay flocculation, increased permeability and, in extreme cases, wall failure (Birdwell 2001; D'Appolonia and Ryan 1979; Day 1994).

Other types of clay minerals display a much lower sensitivity to high ionic-strength waters, or to changes in water chemistry over time. One such mineral is attapulgite (a.k.a. palygorskite). Attapulgite has a needle-like structure, a relatively high but minimally charged surface area, and a lower affinity for water – attributes that result in this mineral displaying minimal flocculation or swelling potential, regardless of the chemistry or salinity level of the hydrating water (e.g. Tobin and Wild 1986; Shackelford 1994). Attapulgite's markedly independent behavior with respect to ionic strength or salinity effects is demonstrated in Photograph 2.

Because of its attributes, and the fact that attapulgite can provide for adequately low and stable hydraulic conductivity (see Test Report No. 10), its use in various environmental barriers is increasing (Birdwell 2001; Day 1994; Galan 1996; Murray 2000). Attapulgite's recognized performance in high saline and other chemically aggressive waters form the basis for its inclusion into some saline formulations of the AquaBlok® product.

Published literature also points to advantages associated with using *blends* of clays, like attapulgite plus sodium bentonite, in some environmental barrier systems (Murray 2000; Stern and Shackelford 1998), thus providing justification for including similar blends in other saline formulations of the product.

Calcium bentonite is another type of clay rich material that, similar to attapulgite, tends to show relatively less reactivity (and greater stability) when contacted with high ionic-strength and chemically aggressive waters than does its sodium-rich counterpart (e.g. Alexiew 2000; Koch 2002). As a result of such properties, calcium-rich bentonites are more often being considered for use in environmental barriers (e.g. Dananaj et al., 2005; Koch 2002). Laboratory based experimentation on the relative effectiveness of calcium bentonite-based AquaBlok® products and their potential use in saline environments is ongoing.

Physical compaction or loading of barrier materials placed into terrestrial environments (e.g. landfills, subterranean disposal facilities, etc.) can significantly reduce primary porosity, thereby reducing hydraulic conductivity and increasing barrier effectiveness (Shackelford 1994; Daniel 1994; Komine 2004). The concept of increasing barrier effectiveness through loading should also apply to subaqueous environmental barriers as well, despite the countering influence of buoyancy effects. Empirical laboratory observations indicate that sediment barriers comprised of saline AquaBlok® formulations may benefit from such loading.

Photo 1. Sodium Bentonite-Based Product Hydrated in fresh (left) versus high saline waters (right).

Photo 2. Attapulgite-Based Product Hydrated in fresh (left) versus high saline waters (right).

In this test report, information is presented related to selected, dry and hydrated state characteristics of chosen saline formulations hydrated in either full-strength seawater or in brackish waters. Also presented are data related to the potential effects that loading, either during or after hydration, could ultimately have on the physical characteristics of saline-compatible barriers.

Materials and Methods

Several saline formulations were tested, including two attapulgite-based formulations (4060 SW and 5050 SW) and two blended clay formulations (3070 SW and 5050 SW). Each of the blended formulations included equal dry weight percentages of sodium bentonite and attapulgite clay. The core component for all four formulations comprised crushed limestone aggregate nominally equivalent in size and gradation to AASHTO No. 8 aggregate.

Data presented in this report were developed using the same types of testing equipment and generally following the same methods used to obtain similar data for freshwater formulations (see Test Report No. 1 and No. 6).

For current testing, saline product samples were placed in even, single lifts at dry coverage rates ranging from ~ 20 to ~ 60 pounds per square foot (lbs./SF). For most testing, waters with a salinity level equal to typical full-strength seawater (~ 36 parts per thousand, ppt) were used as the hydrating liquid. A commercially available seawater salt mix was used to prepare the testing solutions and a calibrated specific conductance meter (with temperature correction) was used to verify the target salinity (i.e. electrical conductance) level. The chemical composition of the prepared seawater solutions was verified against the composition of typical seawater.

To demonstrate the effect that physical loading could potentially have on the hydrated thickness of saline product and on the relative abundance of residual primary porosity, sand or aggregate was placed overtop several selected samples at loading rates ranging of from ~ 20 to ~ 50 lbs./SF. Loads were applied either immediately following dry product placement or within two to three days after product had had the opportunity to hydrate and expand un-loaded.

Furthermore, to demonstrate the influence of salinity level on product hydration and expansion as a function of clay type, additional testing was conducted involving the use of variable-strength seawater solutions, at target salinity levels of ~ 9, 18, or 36 ppt, to hydrate two selected saline formulations (5050 SW attapulgite and 5050 SW clay blend). For comparison, one selected freshwater (sodium bentonite-based) product formulation (3070 FW) was also tested. For this testing, all formulations were placed at a dry coverage rate of ~20 lbs./SF.

Results

Dry state characteristics are presented in Figure 1. Mean dry and hydrated thickness values in full-strength seawater as a function of formulation and coverage rate, and with or without immediate or delayed loads applied for selected coverage rates, are included in Figures 2A through 2D. Figures 3A through 3C summarize net vertical expansion, wet bulk density, and percent-moisture, respectively, for all saline formulations combined. Mean dry and hydrated thickness values for SW and FW formulations as a function of salinity and coverage rate are included in Figures 4A through 4C.

Selected photographs are also included for a typical series of column tests conducted for a given saline formulation (Photograph 3) and also to illustrate some formulations' apparent physical responses to the influence of immediate versus delayed loading (Photographs 4 through 7).

Figure 1. Typical Density and Porosity Values for Selected Saline Formulations.

Product Formulation	Aggregate Core	Average Partical Density of Dry Product (g/cm^3)	Approximate Inter-partical Porosity (percent)	Dry Bulk Density, Typical Range (lbs/ft^3) 65 70 75 80 85
3070 SW attapulgite	No. 8	2.24	48	
4060 SW attapulgite	No. 8	-----	-----	
5050 SW attapulgite	No. 8	1.74	36	
3070 SW clay blend	No. 8	2.38	45	
5050 SW clay blend	No. 8	1.75	32	

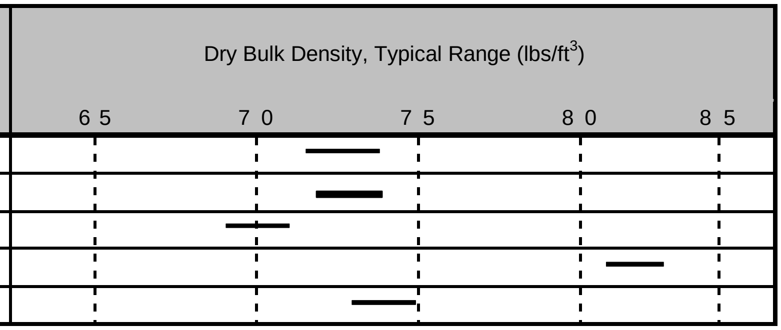


Figure 2. Dry and Hydrated Thickness of Saline Formulations as a Function of Coverage Rate and Loading. Hydrating Water Salinity ~36ppt. (no load applied unless noted)

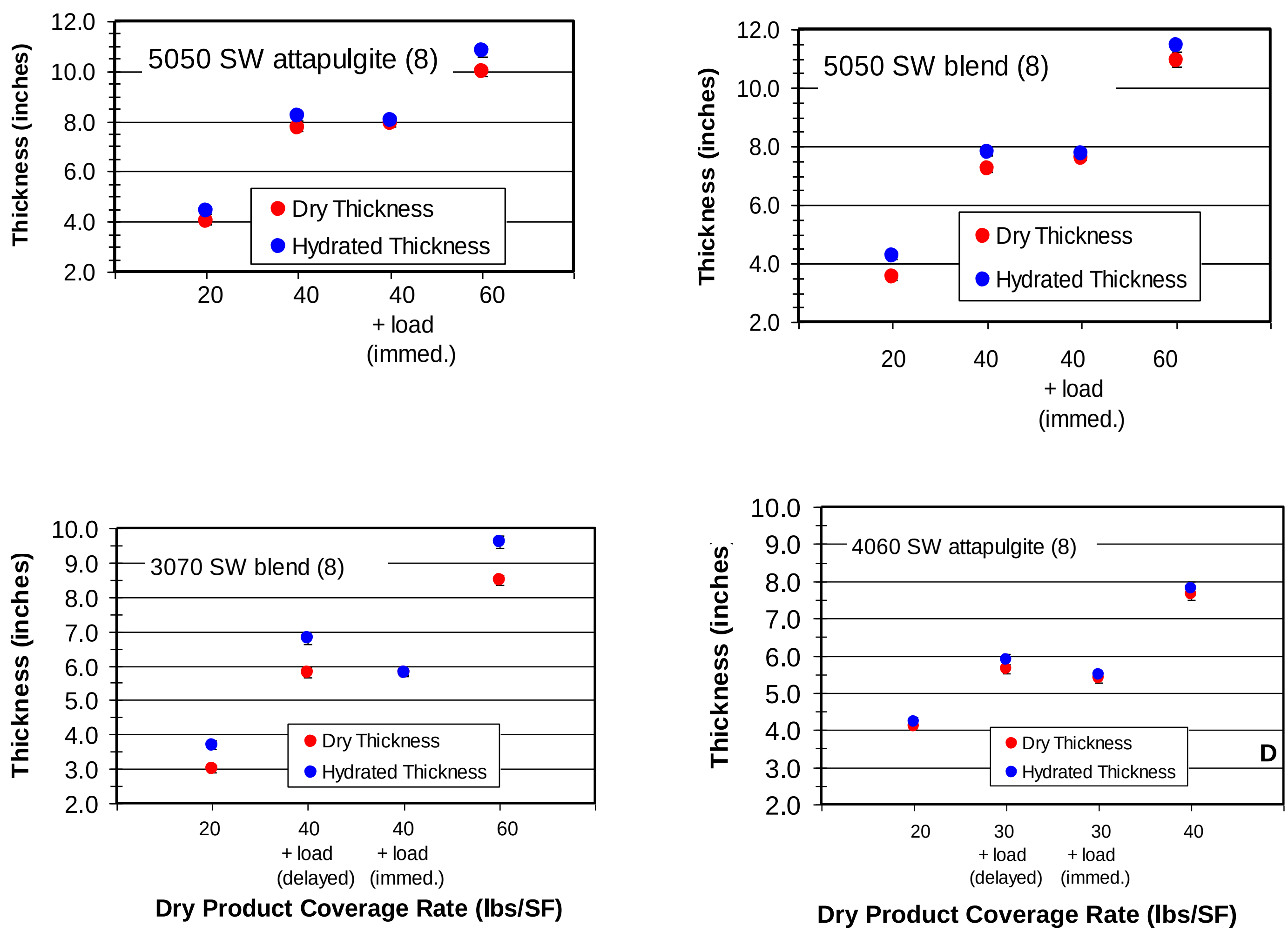


Photo 3. Typical Series of Column Tests.

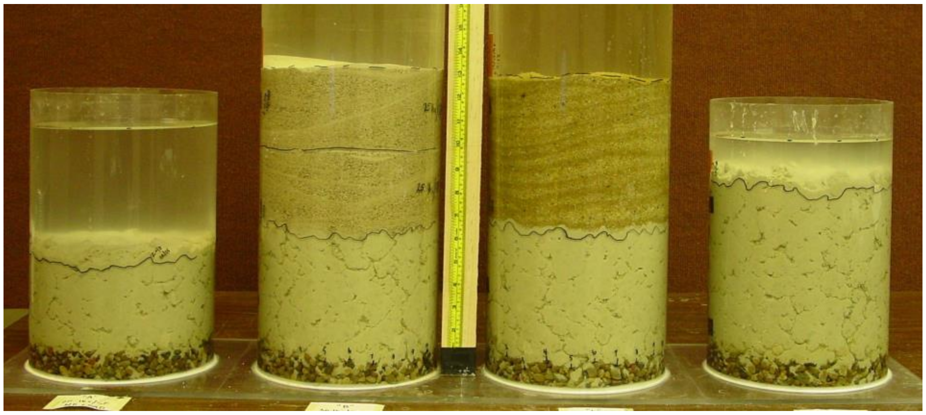


Figure 3. Mean Net Vertical Expansion, Wet Bulk Density, and Percent Moisture of Hydrated Product.

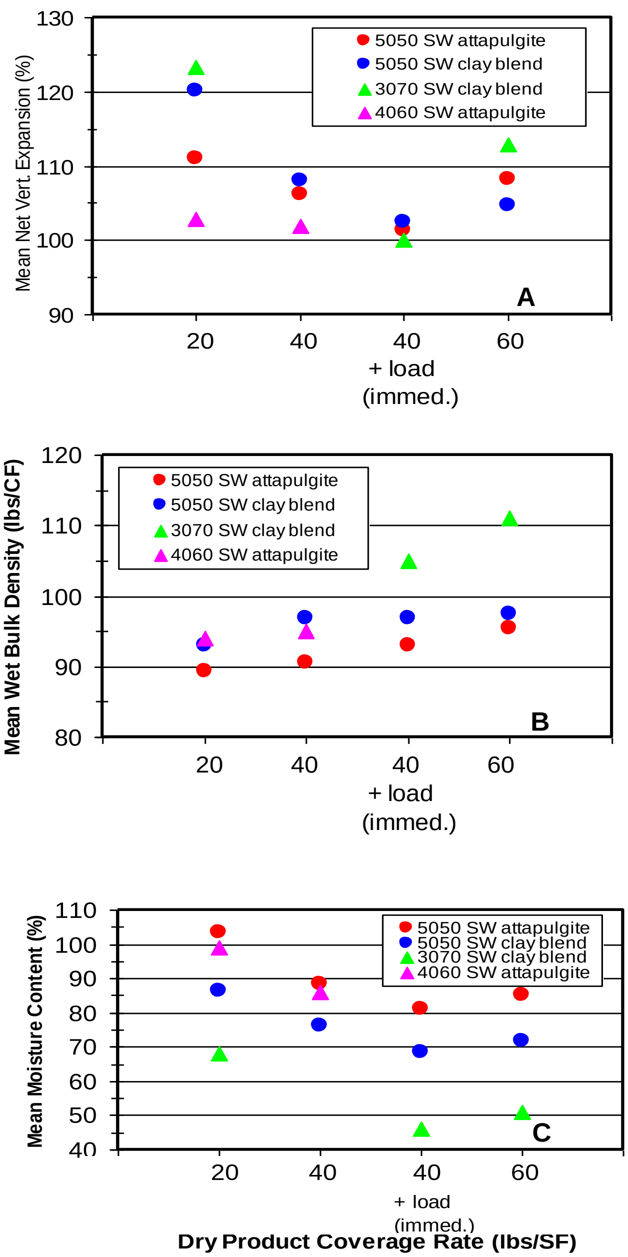
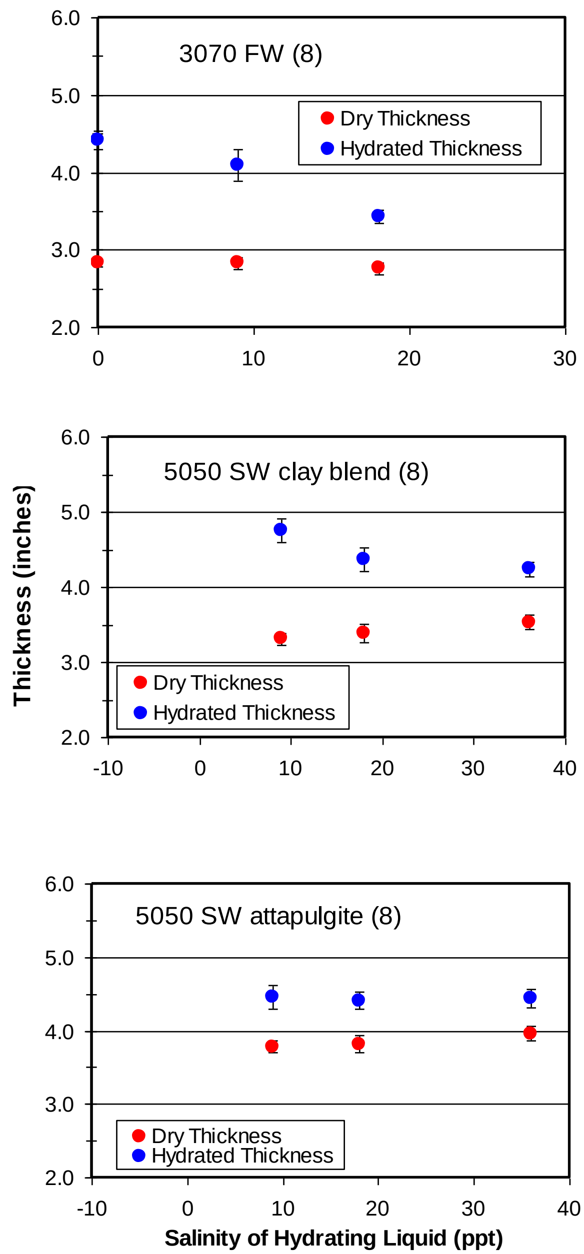


Figure 4. Dry and Hydrated Product Thickness as a Function of Formulation and Salinity of Hydrating Water (dry coverage rate ~20 lbs/SF).



Observations and Conclusions

Dry particle density and especially dry bulk density values for attapulgite-based materials tend to be somewhat lower than for comparable blended clay formulations (Figure 1), which are, in turn, typically lower than freshwater formulations (see Test Report No. 6). This is probably due to the lower specific gravity of attapulgite, 2.58 g/cc, relative to that for bentonite, 2.82 g/cc (Shackelford 1994).

Once hydrated, saline formulations, particularly attapulgite-based material, display relatively little net vertical expansion in full-strength seawater, as illustrated in Figures 2A through 2D. The low-expansion character of saline formulations in high-saline waters, as summarized in Figure 3A, is especially noteworthy when compared to the significant expansion displayed by freshwater formulations in fresh water (see Figure 3A of Test Report No. 6).

As with dry state characteristics, wet bulk density values for saline formulations also tend to vary as a function of clay type, with attapulgite-based product displaying slightly lower values than comparable blended formulations (Figure 3B). These trends in wet bulk density are accentuated by the lower moisture content of blended product (Figure 3C).

Figure 4 confirms what was conceptually demonstrated in Photographs 1 and 2: that a progressively lower degree of vertical expansion occurs as freshwater product is hydrated with increasingly saline waters (Figure 4A), whereas variable salinity levels have less effect on the expansion of saline formulations, particularly attapulgite-based product (Figures 4B and 4C). The salinity dependent behavior of freshwater formulations is also reflected in greater hydraulic conductivity values when freshwater product is permeated with increasingly saline permeants (see Table 1 of Test Report No. 10).

As expected, hydrating saline product under an immediately placed load greatly minimizes its net vertical expansion, whereas a limited degree of net expansion is observed when saline product is allowed to hydrate two or three days prior to load placement (Figure 2; Photographs 4 through 7).

Previously cited literature implies that loading of capping material may be an appropriate step towards construction of effective saline-product barriers in saline environments. Nevertheless, the optimal *timing* for load placement as well as the extent of loading may depend on a number of factors. For example, in some cases, product compaction encouraged by immediate loading may effectively restrict the flow of hydrating waters into macropore spaces, resulting in a greater abundance of residual porosity, at least over the short term (Photographs 4 and 6). This is in contrast to the significant primary pore infilling which may occur for the same types of saline formulations upon allowing them to first hydrate a few days before loading (Photographs 5 and 7).

The technical and economic advantages of applying sand and/or aggregate loads over saline product, including the most appropriate timing for load placement, are aspects of cap design and construction that should be evaluated on a case-by case basis.

Photo 4. 3070 SW Clay Blend, 40lbs./SF (immediate load).

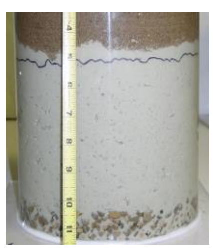


Photo 5. 3070 SW Clay Blend, 40lbs./SF (delayed load).

Photo 6. 4060 SW Attapulgite, 30lbs./SF (immediate load).

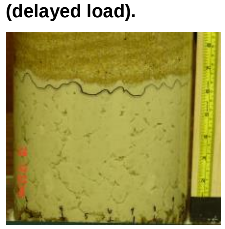


Photo 7. 4060 SW Attapulgite, 30lbs./SF (delayed load).

Material Selection and Placement

The results presented herein highlight important questions to consider when contemplating design and construction of clay based sediment barriers in impacted brackish or saline sediment environments, including: Which attapulgite-based or blended product formulation should be used at a given site? At what coverage rate should the chosen dry product formulation be placed to achieve a particular target hydrated thickness? Or, should a load be placed overtop the product and, if so, what should the load be (composition and rate) and when should it be applied?

Adequate answers to these and related questions will typically involve a consideration of various factors such as site-specific conditions (e.g. salinity levels, sediment characteristics, ecological attributes, etc.), construction timeframe and sequencing, relative costs for capping materials and placement, etc. The primary consideration, though, is often a clarification of the performance-related results that are sought through sediment capping. For example, if achieving a low-permeability barrier (equal to or less than 10^{-7} cm/s) is the primary performance goal for a particular capping project, then issues such as those discussed in Test Report No. 10 should be considered.

On the other hand, if physical isolation of contaminated sediments from bioturbating benthic organisms is the target performance goal, then hydrated cap thickness may be a principle design consideration (Clarke et al. 2001). This will also require the recognition that, for most saline applications, the target hydrated cap thickness is more-or-less the placed (dry) thickness.

Or, if minimizing cap permeability and benthic isolation are both project goals, then consideration could be given to surcharging hydrating (or hydrated) capping product with an appropriate thickness of granular material, e.g. sand, that is particularly attractive habitat for local benthic communities.

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