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FINAL DRAFT

The Use of Filter Press Tests in Soil-Bentonite Slurry Trench Construction

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ABSTRACT

Filter press tests are widely used for field quality control of bentonite slurry in slurry trench excavations and often are incorporated in technical specifications for assessing filtrate properties of initial (freshly mixed) slurry and occasionally for in-trench slurry. In some cases, the results of filter press tests conducted on in-trench slurry are directly or indirectly used to assess the hydraulic performance of the cutoff wall. However, specifications for maximum filtrate loss from filter press testing of in-trench slurry can result in unnecessary construction delays and costs. The authors examine the reasons for specifying filtrate parameters for slurry and present the results of filter press tests conducted on lab and field samples to evaluate the utility of filtrate loss as an appropriate quality control measure for soil-bentonite cutoff walls. These results show no evidence to support that excessive filtrate loss of in-trench slurry (i.e., above the maximum value employed in typical specifications) compromises trench stability or contributes to an overall higher permeability of the completed vertical barrier. Higher in-trench filtrate loss is associated with higher sand content, which results in higher slurry density and improved trench stability. Furthermore, the permeability of all filter cake specimens created in this study from in-trench slurries with sand contents as high as 35 percent were less than 10^{-7} cm/s, which is the lowest target permeability typically specified for soil-bentonite cutoff wall backfill in hydraulic or geoenvironmental containment applications. The authors do not recommend using filtrate loss of in-trench slurry as a quality control parameter for assessing the effectiveness of slurry trench cutoff walls.

BACKGROUND

Soil-bentonite (SB) slurry trench cutoff walls are constructed in two phases: excavation and backfilling. During excavation, the open trench is supported by bentonite-water slurry that forms a filter cake on the trench walls. The slurry is subsequently replaced by soil-bentonite backfill, which consists of a mixture of soil (typically the trench spoils, amended with dry bentonite as needed) and slurry. The low permeability of the barrier system is a result of the low permeability of the backfill, although some would attribute additional benefit from the filter cake (e.g. see Britton et al 2004, Choi and Daniel 2006).

The American Petroleum Institute (API) filter press test, described later in this paper, is used to assess the ability of the bentonite slurry to form an adequate filter cake for maintaining trench stability, i.e., by minimizing slurry loss into the adjacent formation. The API was founded in 1919 primarily to provide an organization through which oil and gas industry stakeholders could work towards standardizing oilfield testing equipment and procedures. The API currently maintains more than 500 standards and recommended practices, including standards pertaining to the measurement of quality control parameters for drilling fluids. The first edition of the standard relevant to this paper was released in 1962 under the title "*API 13B: Recommended Practice Standard Procedure for Field Testing Drilling Fluids*." After the release of the 12th edition of this standard in 1988, the standard was split into two related standards, 13B-1 and 13B-2, where 13B-1 deals with water-based drilling fluids and 13B-2 deals with oil-based drilling fluids. The current edition of the *Recommended Practice for Field Testing Water-based Drilling Fluids, ANSI/API Recommended Practice 13B-1* (2009, 4th edition), is widely referenced in the slurry trench construction industry. The filter press test is addressed in Section 7 (Filtration) of this standard.

FILTER PRESS TESTING IN SLURRY TRENCH APPLICATIONS

The filter press test is used to measure the filtration behavior and cake-building characteristics of the slurry, most commonly a colloidal suspension of bentonite in water. A typical filter press consists of a cylindrical testing cell, a pressure source (compressed air or CO_2), a filtering medium (typically a filter paper placed over a metal screen), and a filtrate receptacle (e.g., graduated cylinder), as shown in Figure 1. Most cells are stainless steel and are mounted in metal frames for ease of use.

FIG. 1. Photograph of standard filter press apparatus with carbon dioxide pressure source assembly

Filter press tests are conducted by first pouring the slurry into the cell to within 1.0-1.5 cm (0.4-0.6 in) of the top and placing a graduated cylinder under the drain tube to collect the filtrate. Next, pressure is applied to the slurry, and the liquid pushed out of the slurry through the filtering medium (the filtrate) is collected in the graduated cylinder over a period of 30 minutes. The collected volume is referred to as the *filtrate volume* or *filtrate loss*. The remaining slurry is then decanted from the cell, and the thickness of the filter cake is measured. Tests typically are performed at room temperature using an applied pressure of 690±35 kPa (100±5 psi). For a detailed procedure, the reader is referred to API standard 13B-1 (API 2009).

Most technical specifications for slurry trench construction require the maximum filtrate loss for freshly prepared slurry to be 15-30 mL. In addition to the fresh slurry requirement, some specifications also include a maximum filtrate loss for in-trench slurry. For example, in-trench slurry requirements for 20 selected SB cutoff walls in the US from 2007 to 2014 are summarized in Table 1. Maximum filtrate loss was specified in eight (40 %) of these 20 projects. In these cases, the requirement varied from 20-30 mL. Each project also specified an acceptable range of in-trench slurry density, primarily to ensure that the in-trench slurry is light enough to allow effective backfill placement. In a few cases, a maximum sand content of 10-25 % was also specified for the in-trench slurry.

TABLE 1. In-trench slurry requirements for selected projects.

Year	State	Public / Private	Max. Filtrate Loss (mL)	Density Range (Mg/m^3)	Max. Sand Content (%)
2014	California	Public	N/A	1.03 to 1.36	N/A
2014	North Dakota	Public	N/A	1.03 to 1.36	N/A
2014	Illinois	Public	20	1.20 to 1.36	N/A
2013	Colorado	Private	30	1.03 to 1.39	25%
2013	Massachusetts	Private	N/A	1.15 to 1.52	25%
2013	Missouri	Private	N/A	1.03 to 0.24 less than backfill	N/A
2013	Louisiana	Private	N/A	greater than 1.03	N/A
2012	North Dakota	Private	N/A	1.03 to 0.24 less than backfill	N/A
2012	Iowa	Private	N/A	1.03 to 1.28	N/A
2012	Louisiana	Private	30	1.03 to 1.36	N/A
2011	North Dakota	Public	N/A	1.03 to 1.36	15%
2011	Kentucky	Private	N/A	1.03 to 0.24 less than backfill	N/A
2011	Mississippi	Public	N/A	1.03 to 0.24 less than backfill	20%
2010	Kentucky	Private	N/A	1.12 to 0.24 less than backfill	N/A
2010	Texas	Public	N/A	>0.24 less than backfill	10%
2010	California	Public	20.5	1.28 to 1.44	N/A
2008	Florida	Private	30	1.03 to 1.36	20%
2007	California	Public	20	1.03 to 1.36	15%
2007	Michigan	Private	30	1.03 to 1.36	20%
2007	Illinois	Public	20	1.15 to 1.36	N/A

N/A = not applicable

Ultimately, the purpose of the slurry in slurry trench excavations is to prevent collapse of the trench during excavation and backfilling. To do so, the slurry must be capable of forming and maintaining an effective seal. The two primary mechanisms contributing to the formation of a filter seal along the walls of a slurry trench, as described in Xanthankos 1979, are (1) surficial filtration in which the slurry is filtered through the exposed trench face under pressure, resulting in deposition of a layer of bentonite and other fine soil particles along the trench face (i.e., the filter cake), and (2) deeper filtration in which the bentonite and other fine soil particles in the slurry are driven into the surrounding soil formation at locations where the pores are too large to filter the particles at the trench face, resulting in deeper penetration of the seal.

Filter cake formation in the filter press test is achieved primarily through surficial filtration, with filter cake development being controlled through the filtering of solids as the slurry is driven through the filter paper. In the field, the ability of slurry to form an adequate filter cake is dependent on a number of factors, including bentonite quality, the extent of bentonite hydration prior to introduction into the trench, and the chemical properties of the slurry mix water and groundwater. These factors can be evaluated, to some extent, during design by conducting filter press tests on slurry samples prepared in the laboratory. In this regard, filter press testing is an important component of cutoff wall design. In addition, filtrate loss for freshly mixed slurry is appropriate as a quality control (QC) parameter to demonstrate the bentonite quality and the adequacy of the field slurry preparation methods. However, filtrate loss of in-trench slurry is less useful as a QC parameter, as discussed below.

LIMITATIONS OF IN-TRENCH SLURRY FILTER PRESS TESTING

There are three main reasons why the use of filtrate loss as a criterion for in-trench slurry is unnecessary and potentially problematic. First, filter press testing does not provide complete information to make a determination regarding whether or not an effective seal has formed in the trench. Whereas the filter press test may provide useful information about filter cake formation (mechanism 1 above), the test provides no information about seal development from deeper filtration within the adjacent soil formation (mechanism 2 above). Thus, specifications for in-trench filtrate loss based on filter press testing are inherently conservative in that the seal is assumed to be created solely by the surficial filter cake rather than by the combination of a filter cake and deeper clogging of the pores within the native formation.

Second, use of a maximum filtrate loss criterion for in-trench slurry can increase the potential for trench instability. The density of in-trench slurry will naturally increase relative to freshly mixed slurry due to suspension of soil particles in the slurry during excavation. To illustrate this point, consider the results in Figure 2a that show the relationship between slurry density and sand content for field (in-trench) slurry samples (18-35 % sand by volume) collected from a site in California, along with

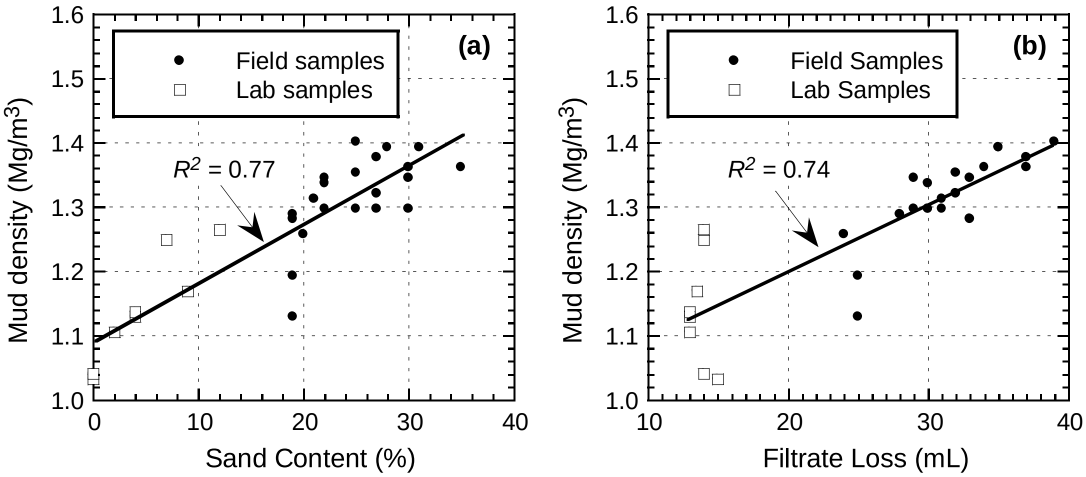

FIG. 2. Relationship between mud density and (a) sand content and (b) filtrate loss of field (in-trench) and laboratory mixed bentonite slurries

laboratory samples of slurry (6 % bentonite) containing no sand (simulating freshly prepared slurry in the field) or amended with masonry sand to simulate in-trench slurry with lower sand contents than encountered at the California site (5-12 % by volume). These results show that mud density can be expected to range from 1.1 to 1.4 Mg/m^3 (or approximately 70-90 pcf) due to the presence of suspended soil. By comparison, the mud density of the freshly prepared slurry (sand content = 0 % in Figure 2a) is 1.03-1.04 Mg/m^3 (64-65 pcf). Despite the higher filtrate loss values for the in-trench samples containing 18-35 % sand (25-40 mL; see Figure 2b), the higher density results in greater fluid pressure against the trench walls and, therefore, a higher factor of safety against trench collapse relative to freshly mixed slurry. Substantial money and time can be spent de-sanding slurry to improve the in-trench filtrate loss if needed to comply with project specifications, all the while lowering the slurry density and making the trench more susceptible to collapse. Furthermore, de-sanding does not always solve in-trench filtrate loss issues, as filtrate loss is affected by other factors, such as groundwater or mix water chemistry.

Third, filtrate loss of in-trench slurry is not a reliable indicator of the potential for trench instability. For example, the slurry wall in California from which the in-trench samples in Figure 2 were collected was installed without trench stability issues, despite filtrate loss values approaching 40 mL. This lack of correlation between high filtrate loss and trench instability for the California site is consistent with the experiences of the authors on numerous other projects. Also, cement-bentonite (CB) slurry walls have been installed successfully in a wide range of soil conditions, despite the fact that CB slurries typically exhibit filtrate loss values on the order of 100-300 mL (Evans 1993), approximately an order of magnitude greater than those for typical SB slurry. The filter press test was originally developed for the drilling industry to assess the filtration characteristics of drilling fluids, which are important for borehole stability at great depth and pressure and for borehole development at the end of drilling. Although filter press testing has been logically extended to slurry trenching, the filtration characteristics of the slurry are less critical in a slurry trenching application. Other QC parameters, including viscosity (Marsh funnel), density (mud balance), pH, and sand content, are readily performed in the field and provide the slurry specialist with adequate information regarding the slurry in the context of trench stability (of these tests, viscosity and mud density are the most important). These parameters, along with other observations related to sidewall instability, e.g. tension cracks, cave-ins, and inconsistencies in backfill slope profile readings, are sufficient to determine whether or not the slurry is functioning as intended.

For these reasons, filtrate loss of in-trench slurry should not be used as a performance criterion. The recommended specifications outlined in *Section 02 35 27* of the U.S. Army Corp of Engineers Guide Specification for Construction of Soil-Bentonite (SB) Slurry Trenches (USACE 2010) for in-trench slurry properties, summarized in Table 2, include measurement of in-trench slurry filtrate loss for informational purposes only.

TABLE 2. Recommended in-trench slurry performance specifications.

Property	Performance Objective
Marsh Funnel Viscosity (sec)	>40
Density (Mg/m^3)	1.025 to 0.24 less than backfill density
Filtrate loss (mL)	N/A – measured for informational purposes only
Sand Content (%)	N/A – measured for informational purposes only

These recommended specifications are considered by the authors as appropriate for most applications. A slurry trench specialist can use the test results generated in accordance with Table 2 and proper backfill slope profiling to execute a successful slurry trench installation in a wide variety of soils and groundwater conditions. Especially difficult soil or groundwater conditions may necessitate stricter requirements or alternate requirements, but these instances are rare.

FILTRATE LOSS AND FILTER CAKE PERMEABILITY

Some owners and engineers may consider the filter cake to be a contributing part of the hydraulic barrier rather than a sacrificial layer that provides temporary excavation support. Specifications that include a maximum filtrate loss for in-trench slurry may be based on the assumption that a low filtrate loss is required to achieve a filter cake permeability that is similar to or lower than the permeability of the backfill.

To investigate this assumption, the same field (in-trench) and laboratory mixed slurry samples described previously (see Figure 2) were tested for filter cake permeability to determine the relationship between filter cake permeability and filtrate loss. After the filtrate loss tests were completed, the remaining slurry was decanted, and the filter cakes were subjected to permeability testing within the filter press by replacing the decanted slurry with water and permeating the cake specimens for 8 hours at 690 kPa pressure. The results, shown in Figure 3, indicate that while the permeability of the

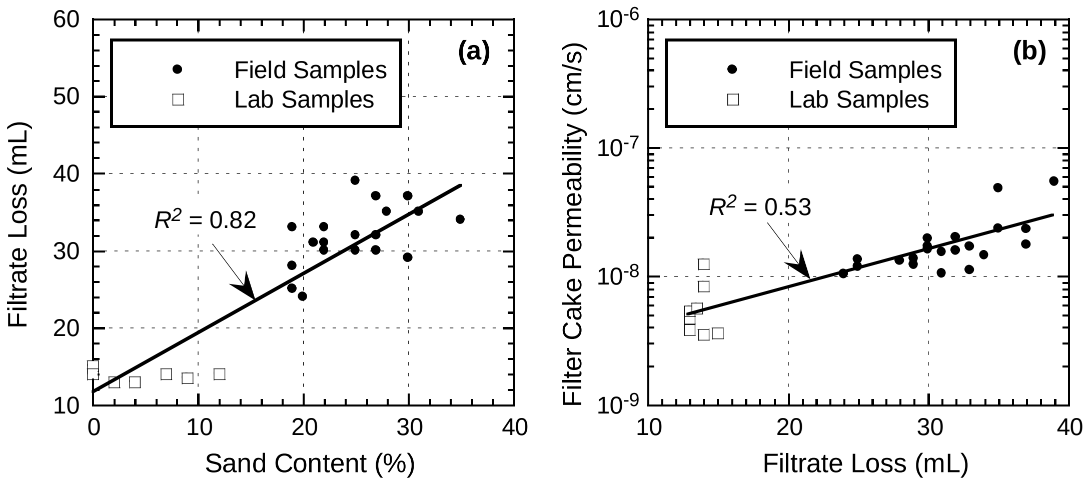

FIG. 3. Relationship between (a) filtrate loss and sand content and (b) filter cake permeability and filtrate loss for field (in-trench) and laboratory mixed bentonite slurries.

filter cakes increased with increasing filtrate loss from 12 to 40 mL, the permeabilities of all specimens were less than 10^{-7} cm/s, which is the lowest target permeability typically specified for SB backfill in hydraulic or geoenvironmental containment applications. Thus, the filter cake can be expected to provide a similar or lower permeability relative to the backfill, assuming the cake remains intact after backfilling. However, since neither the integrity nor the thickness of the filter cake can be verified in the field, the actual contribution of the filter cake to the overall permeability of an SB barrier cannot be determined.

CONCLUSIONS

Filter press tests are commonly performed on bentonite slurry as a QC tool for slurry trench cutoff wall installations. Although filter press testing of freshly mixed slurry is useful for demonstrating the adequacy of the field slurry materials and preparation methods, filter press testing of in-trench slurry offers limited value for assessing the adequacy of the trench seal in the field. The filter press test does not necessarily represent filter cake formation against the native soil along the trench face and does not account for the contribution of deeper filtration of solids into the native formation to the overall trench seal. Also, filtrate loss is not a reliable indicator of the potential for trench instability, as evidenced by the successful installation of cement-bentonite (CB) slurry walls in a wide range of soil conditions despite the higher filtrate loss typically exhibited by CB slurry relative to bentonite slurry. Finally, filtrate loss of in-trench slurry is directly related to the sand content of the slurry. Higher sand contents yield higher filtrate loss values, but also yield higher mud densities that produce higher safety factors for trench stability. Thus, filter press testing of in-trench slurry to meet a particular maximum filtrate loss criterion is not recommended. Industry guide specifications no longer include a maximum in-trench filtrate loss criterion, but the use of such a criterion persists in technical specifications for public and private projects.

Specifications that include a maximum filtrate loss for in-trench slurry may be based on the assumption that a low filtrate loss (e.g., < 30 mL) is required to achieve a filter cake permeability that is similar to or lower than the permeability of the backfill. The results of a series of permeability tests on filter cake specimens prepared from slurries containing suspended sand contents of 5-35 % by volume show that filter cake specimens created from slurries with filtrate loss values up to 40 mL exhibited permeabilities of 10^{-7} cm/s or less in all cases. Thus, high filtrate loss of in-trench slurry is not expected to diminish the overall hydraulic performance of an SB barrier. Furthermore, given that the integrity of the filter cake after backfilling cannot be verified and the cake thickness cannot be measured, the contribution of the filter cake to the overall hydraulic performance is unknown. For this reason, the overall barrier permeability should be considered equivalent to the backfill permeability.

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