A Drainage Geocomposite for Coal Combustion Residual Landfills and Surface Impoundments

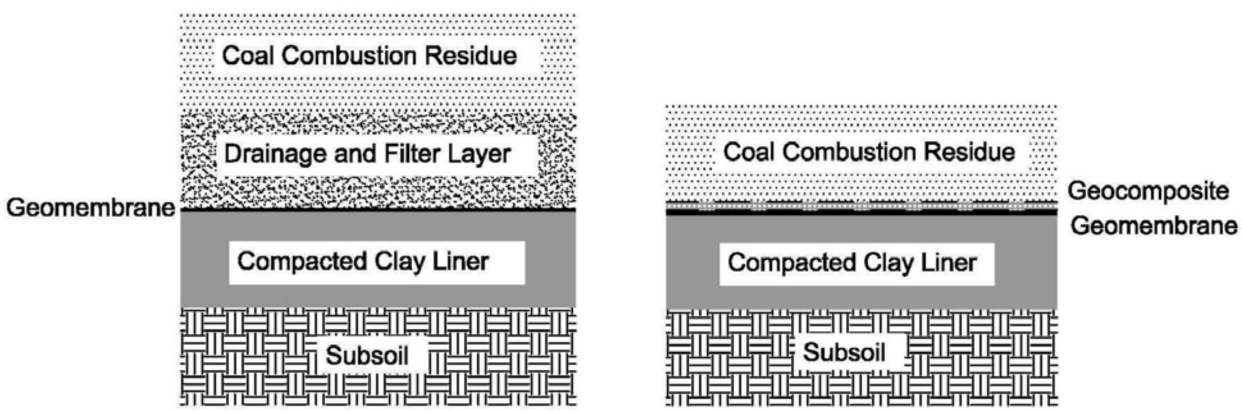
Dhani Narejo[1], Mengjia Li[2], Ed Zimmel[3] and Yin Wu[4]

[1,3,4]GSE Lining Technology LLC, 19103 Gundle Road, Houston, TX

[2]BGE China, 5th Floor, Zhonghang Keji Dasha, Zhichun Road, Beijing, China

Introduction

Drainage geocomposites have been used successfully in landfills for more than two decades with few or no known or documented issues. Standard drainage geocomposites come with a 130 grams/m^2 to 270 grams/m^2 nonwoven needlepunched geotextile filter. With an apparent opening size (AOS) close to 0.2 mm, these geotextiles do not satisfy filter criteria against most high volume CCRs such as fly ash and gypsum sludge. This, combined with some anecdotal evidence of clogging of a drainage geocomposite core due to the piping through the geotextile filter, has hindered the use of geocomposites on several recent projects. It is imperative for the filter geotextile not only to satisfy the filter criteria against CCRs, but also to show an acceptable level of performance in multiple index and performance tests. Figure 1 illustrates this problem by comparing the mineral and geosynthetic composite liner systems. Figure 1(a) shows a composite liner system where sand or select CCRs are used as filter and drainage media. An equivalent system is shown in Figure 1(b) with a drainage geocomposite where the top geotextile is of interest regarding the filtration properties.



(a) Mineral Drainage Layer (b) Geosynthetic Drainage Layer

Figure 1 - Single Composite Liner Systems.

This paper describes a geotextile that has been developed specifically to work with fine particulates including silt, clay, fly ash and gypsum. When bonded to a geonet, the resulting geocomposite can be used with CCRs - hence the topic of this paper. The paper does not explore the structure of the geotextile or the geonet but rather focuses on their performance properties based on a number of test methods. Traditional filter criteria are used to determine the required opening size of the geotextile against such CCRs as fly ash and gypsum. The properties of the geotextile are then compared to the requirements of the design procedures. Then the performance of the geotextile is presented based on the laboratory and field tests.

Filter Design Requirements

The retention is a critical requirement when selecting a geotextile filter for soils and CCRs with gradations finer than 0.075 mm. Figure 2 presents gradation curves for two CCR materials. Important characteristics of the gradation curves are summarized in Table 1. Sample A is a fly ash from a coal generation plant and Sample B is a FGD gypsum material from the same plant. More than 90% of the samples pass are finer than 0.075 mm (#200 US sieve).

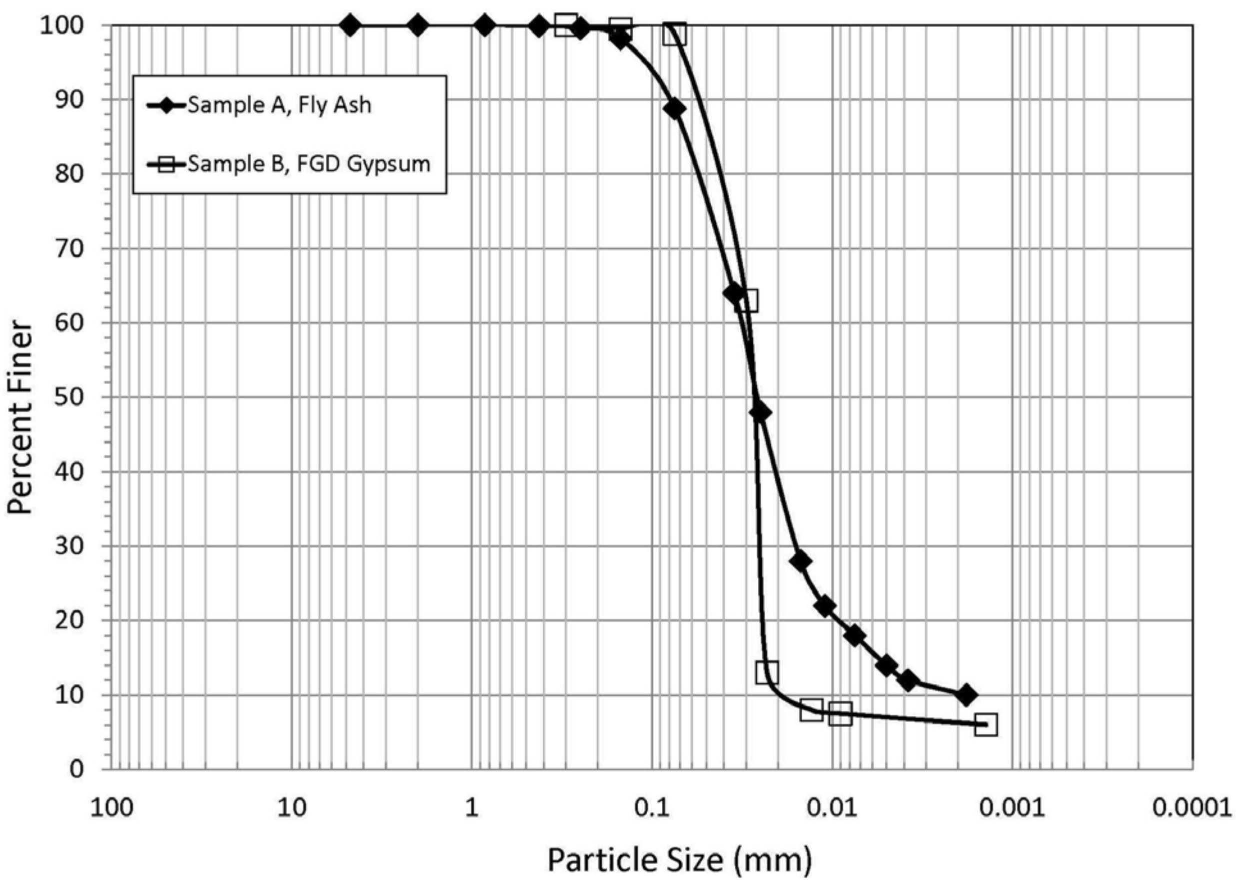


Figure 2 – Gradation of Two Samples used in Calculations, A = Fly Ash, B = FGD Gypsum.

Table 1 – Gradation Values for Two CCR Materials.

Property	Sample A: Fly Ash	Sample B: FGD Gypsum
D_{85}	0.065	0.048
D_{60}	0.032	0.029
D_{50}	0.026	0.028
D_{30}	0.017	0.027
D_{10}	0.002	0.022
C_c	4.5	1.2
C_u	16	1.3
C_u'	3.2	1.4

C_c is known as coefficient of curvature of a soil and is defined as:

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \tag{1}$$

C_u is known as a uniformity coefficient and is defined as:

$$C_u = \frac{D_{60}}{D_{10}} \tag{2}$$

C_u' is known as a modified coefficient of uniformity and has been defined as:

$$C_u' = \sqrt{\frac{D'_{100}}{D'_0}} \tag{3}$$

Where D'_{100} and D'_0 are extremities of a line passing through the gradation curve (Luettich et al., 1992).

Rankilor (1981) presents the following retention criterion for soils with $0.02 \le D_{85} \le 0.2$:

$$\frac{O_{50}}{D_{85}} \le 1 \tag{4}$$

Where O_{50} is the geotextile opening corresponding to 50% finer openings. Equation 4 states that O_{50} of the geotextile should be less than D_{85} of the CCR being retained. D_{85} of sample A (fly ash) and sample B (FGD gypsum) is 0.065 mm and 0.048 mm, respectively. Therefore, the O_{50} of the geotextile should be less than 0.065 mm for the fly ash sample and 0.048 mm for the FGD gypsum sample.

However, Sweetland (1977) suggests the following criterion for uniform soils with C_u of less than 4:

$$\frac{O_{15}}{D_{85}} \leq 1 \qquad (5)$$

The above equation states that O_{15} of the geotextile should be less than D_{85} of the CCR being retained. Based on Table 1, this requirements translates into the O_{15} of 0.065 mm and 0.048 mm for the fly ash and the FGD materials, respectively.

Christopher and Holtz (1985) suggest the following retention criterion for soils with greater than 50% finer than 75 μm sieve.

$$O_{95} \leq 1.8*D_{85} \qquad (6)$$

The above equation results in an O_{95} requirement of 0.11 mm based on the fly ash sample and 0.086 mm based on the gypsum sample.

Chen and Chen (1986) suggest the following retention requirement:

$$\frac{O_{90}}{D_{85}} \leq 1.2 \; to \; 1.8 \qquad (7)$$

$$\frac{O_{50}}{D_{50}} \leq 10 \; to \; 12 \qquad (8)$$

Equation 7 requires that the O_{90} of the geotextile be less than 0.078 mm for the fly ash sample and 0.057 mm for the FGD gypsum sample. Equation 8 states that O_{50} of the geotextile should be less than 0.26 mm and 0.28 mm for ash and FGD samples, respectively.

Based on a large number of experiments on soils with fine particles, Bhatia and Huang (1995) suggest the following retention criterion for soils with C_c of less than 7 which is the case with the CCRs in Figure 2:

$$\frac{O_{95}}{D_{85}} < 2.71 - 0.36 \times C_c \qquad (9)$$

The above equation indicates a value of O_{95}/D_{85} of less than 1.1 for the fly ash sample and 2.3 for the FGD gypsum sample. Applying this requirement to the fly ash and FGD gypsum materials in Table 1 translates into the O_{95} requirement of 0.072 mm and 0.11 mm, respectively.

Luettich et al. (1992) present a detailed chart that includes recommendations for fine grained soils. For soils with D_{20}>0.002 mm and D_{10}<0.075 mm, they suggest calculating C_c and C_u' and then using the corresponding equations based on these values. Following their flow chart and assuming both materials to be uniformly graded and placed with a medium density, the applicable equation is as follows:

$$O_{95} < 1.5 \times C_u' \times D_{50} \quad (10)$$

An O_{95} of less than 0.12 for the fly ash sample and 0.06 for the FGD gypsum sample is suggested by Equation 10. The required value of O_{95} increases to 0.16 mm and 0.078 mm for the ash and FGD gypsum, respectively, if these materials are placed at a higher density as the coefficient on the right side of the equation changes to 2.

Many experts have published criteria for retention based on their own laboratory testing and idealized materials, such as sand and glass beads. Some of these criteria are described above with respect to two samples, one of fly ash and the other of FGD gypsum. The O_{95} suggested for a suitable geotextile varies from 0.05 mm to 0.1 mm depending on the specific retention criteria author and the gradation of the CCR. A geotextile with an O_{95} higher than 0.1 mm may result in piping. On the other hand, a geotextile with an O_{95} of much lower than 0.05 while acceptable based on the retention requirements, may result in clogging. As these are all empirical methods, and since CCRs are a new application for drainage geocomposites, accelerated and performance testing should be performed.

Description of the New Geotextile:

Figure 3 shows a new drainage geocomposite with a filter that has been developed to work with CCRs. The top geotextile consists of a NW-NP layer and a woven layer. Two layers are mechanically bonded together in a needlepunching process. Each of the components has been selected to optimize the filtration and drainage functions of a drainage geocomposite when placed under such materials as fly ash, gypsum, silt and clay. Table 2 presents data based on several samples of the final product resulting from the product development work. The material is installed in the field with the layered geotextile facing upwards. Although developed specifically for a drainage geocomposite, the geotextile can be used by itself to act as a filter under CCRs.

Figure 3 - A Picture of the Double-sided Drainage Geocomposite with the New Filter Geotextile.

Table 2 – Specifications of Layered Geotextile.

Property	Test Method	Average Value
Mass	ASTM D 5261	540 grams/m^2
AOS, O_{95}	ASTM D 4751	0.088 mm
FOS	CAN/CGSB 148.1	0.05 mm
O_{50}	*	0.068 mm
O_{15}	*	0.046 mm
Permittivity	ASTM D 4491	0.3 sec^{-1}
Grab Strength	ASTM D 5034	1196 N
Grab Elongation	ASTM D 5034	13%
Puncture Strength	ASTM D 4833	978 N
Mullen Burst Strength	ASTM D 3786	4743 Kpa

*Texas Research International, Austin, TX

Laboratory and Field Performance

Several filter press tests were performed on the geotextile samples from different rolls. The test equipment and procedure used were similar to the American Petroleum Institute (API) RP 131, EPA method 9096 and ASTM D5891. Fly ash sample A in Figure 2 was used in the filter press tests. The ash sample was placed in an oven and dried for 24 hours at 105°C. The dry sample was mixed with tap water to prepare a 500% slurry. The geotextile test specimen was placed within the test device and a known volume of slurry was poured over the geotextile. The test cell was closed and a pressure of 27 kPa (3.9 psi) applied over the slurry. The flow rate was monitored with time and the effluent was collected for the entire test duration. The effluent was dried in an oven and piping was calculated as the total mass of ash passing through the geotextile divided by the total mass of the ash in the slurry multiplied by 100. The retention efficiency was calculated as 100 - piping.

Figure 4 shows flow rate vs. time from seven different samples that were considered as candidate materials for the purpose of this stage of the evaluation. At the end of four minutes, flow rates ranged from 0 to 60 ml/sec/m^2. Only one of the samples had a flow rate of 95 ml/sec/m^2. A value of 0 generally meant that no liquid is left within the slurry for the pressure being applied. An average retention efficiency of 99.6% was obtained for samples developed further in this program. This average does not include one sample that had a piping rate of 7.7% and was therefore not considered suitable material for further evaluation. Several researchers and experts have reported retention efficiencies of 95 to 99% for acceptable geotextile performance in similar accelerated tests. The retention efficiency of 99% obtained in the tests reported in this paper is a conservative value.

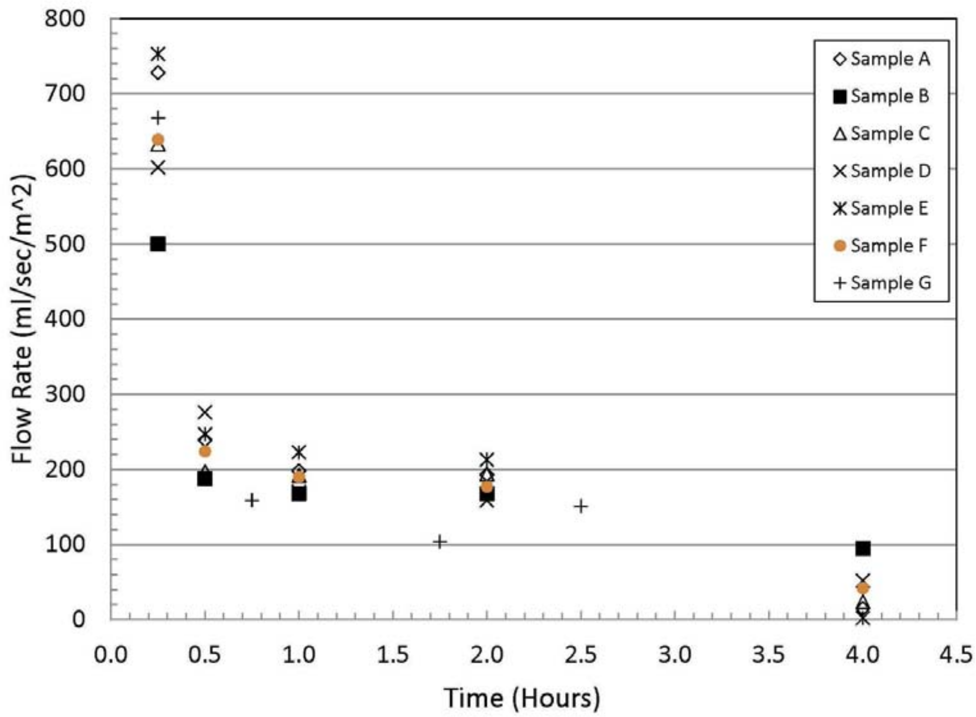


Figure 4 - Filter Press Test Results on the Geotextile Sample.

A review of the published literature shows that the gradient ratio test (ASTM D5101), or one of its variants, is the most popular performance test for geotextile filters. One of the samples showing the highest commercial potential was selected for further evaluation against Sample A of fly ash in Figure 2. The ASTM test method D5101 was followed as the procedure. Three different samples of the same geotextile were evaluated in the test. An average density of 1222 kg/m^3 was obtained for the ash. An air-dried and pulverized sample of fly ash was used. The standard sample placement method as described in Section 9.4.1 of the test method was used. The sample was saturated by backfilling the permeameter from the bottom up. Tests were performed at system gradients of 1, 3 and 6.

Figure 5 shows the relationship between time and gradient ratio for a system gradient of 1. Similar results were obtained at system gradients of 3 and 6. The figure shows that the gradient ratio value stabilizes between 1.0 and 1.5 at the end of the tests. The US Army Corps of Engineers who originally developed the gradient ratio test in 1977, proposed a gradient ratio value of 3 or more as an indication of the clogging of the geotextile. This criteria has been used by many experts as the basis of qualifying the geotextile filters. A gradient ratio value of less than 0.5 is considered indicative of piping but there is less consensus on this value. The trends in Figure 5 show that the geotextile does not experience clogging or piping for the fly ash sample used in the evaluation.

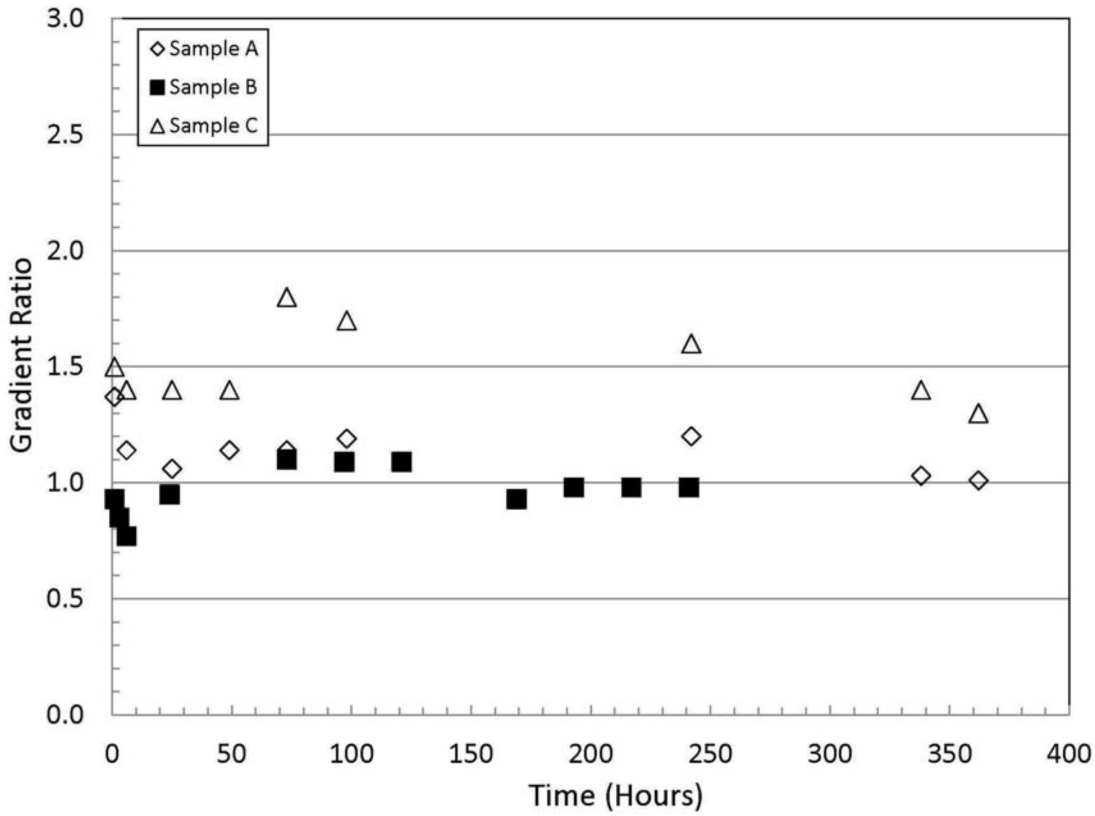


Figure 5 - Gradient Ratio Test Values for the Geotextile against Fly Ash.

Many additional tests were performed according to the hydraulic conductivity ratio method (ASTM D5567) and flexible wall permeameter method (ASTM D5084). None of the tests showed piping or clogging of the geotextile. All tests were performed by either third party laboratories or a university. The piping or soil loss in the laboratory tests stabilized around 2 gram/Liter which is three orders of magnitude less than what is considered acceptable for soil filters. The tests showed that a stable filter was achieved with the geotextile within about two pore volumes of the liquid flow.

Field tests were conducted at the Olentangy River Wetland Research Park at Ohio State University. Four existing test basins of intermediate size were utilized for the tests. Each test basin measured approximately 4.9 meters by 1.5 meters and had a side slope of 2H:1V. A collection trough 0.6 meters in width was placed at one end of each basin. The test basins were then lined with a geomembrane to ensure that water could exit only through the geocomposite via. the collection trough. The geocomposite with the layered woven-NW geotextile facing upwards was installed in the test basins above the geomembrane. The test basins were filled with about 0.3 meter (1 ft) of fly ash and gypsum CCRs. A 2100 liter (550 gallon) tank was installed at one end of each of the basins to provide the water for the testing. The tanks were plumbed sequentially so that about 4,200 liters of water was available for each of the test basins. The berm on the downstream side was isolated from the geocomposite with a geomembrane under it.

The field hydraulic conductivity tests were performed according to ASTM test method D2434. To ensure consistency with the laboratory test program, six pore volumes of water were released into each of the test basins at controlled rates to maintain a constant head of water during the testing process. Staff gauge measurements within the test basin and the collection trough were taken at timed intervals. A metropolitan water source was used for all test basins. In situ temperature, conductivity and pH measurements were taken within the basins. One liter leachate samples were collected periodically from the open end of the geocomposite at the collection trough. These samples were sent to an offsite testing laboratory to determine turbidity, total suspended solids (TSS) and total dissolved solids (TDS).

Total suspended solids with pore volume is presented in Figure 6. Similar trends were seen for total dissolved solids and turbidity. Total suspended solids decreased exponentially with pore volume in all four test basins. Concentrations within first pore volume ranged from 20 to 300 mg/L. The final pore volume had concentrations of Below Detection Limit (conservatively represented as 4 mg/L) to 18 mg/L. Generally water with a TSS of less than 20 mg/L is considered to be clear while water with a concentration over 150 mg/L appears dirty. Municipal wastewater treatment plants must provide treatment to meet the TSS limit of 30 mg/L. The trend is consistent with the filter press and HCR tests. The geotextile forms a stable filter cake within less than two pore volumes for the CCR materials utilized in the test program.

Summary and Conclusions

The layered geotextile presented in this paper was developed for lamination with a geonet to form an acceptable drainage geocomposite for CCRs. Having a fuzzy surface with a woven filter makes it possible to laminate the geotextile to a geonet while minimizing intrusion into the drainage core. The woven geotextile further improves long-term transmissivity of the geocomposite by forming a higher strength bridge over the ribs of the core than is the case with NW-NP geotextile. This layered geotextile offers a better opportunity of satisfying retention requirements against CCRs due to a lower opening size than is the case with standard NW-NP geotextiles. At the same time, this geotextile does not suffocate a geonet which is a concern with bulky NW-NP geotextiles. Performance, accelerated and field tests show that the geotextile forms an acceptable filter against CCRs including fly ash and gypsum. The drainage geocomposite, referred to as CoalDrain by GSE Lining Technology, has shown potential to replace sand and gravel filter and drainage layers in CCR containment projects.

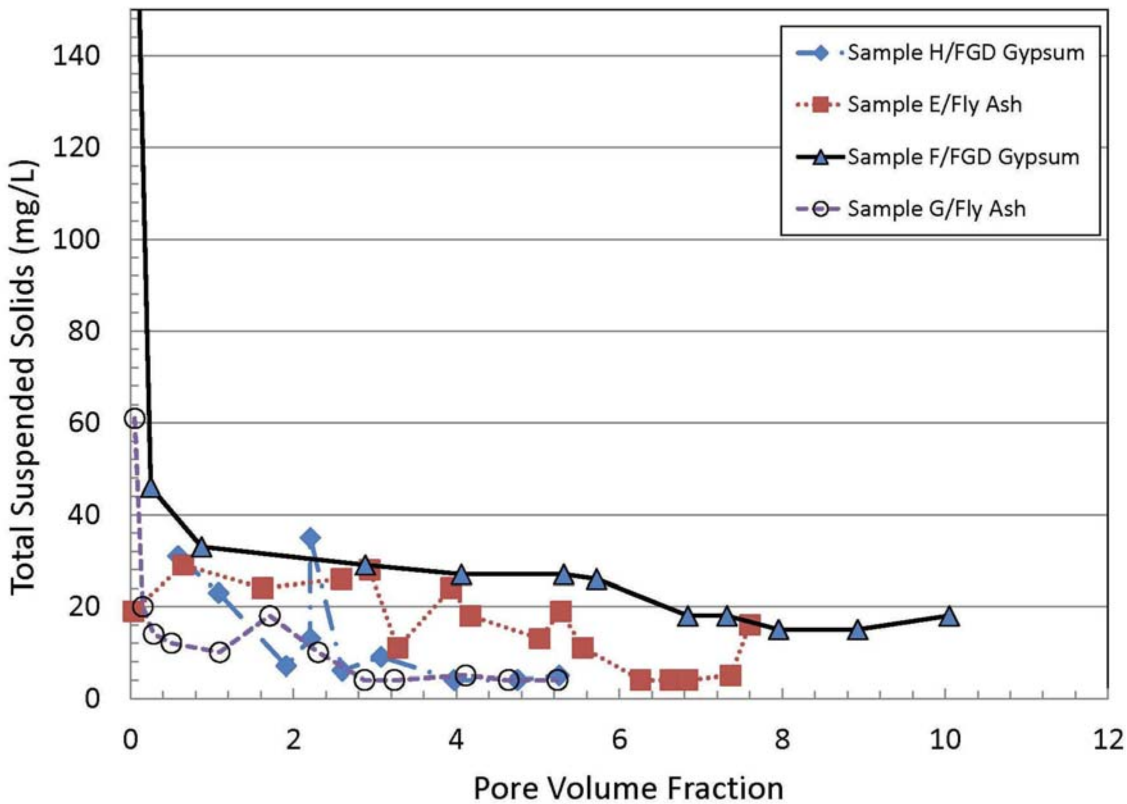


Figure 6 - Total Suspended Solids from Field Tests.

References

Chen R. and Chen C. (1986) Permeability Characteristics of Prefabricated Vertical Drains. *Proceedings of the Third International Conference on Geotextile*s. Vol. 1, Vienna, Austria, April 1988, pp. 46-53.

Christopher, B. and Holtz, R. (1985) *Geotextile Engineering Manual.* US Department of Transportation, Federal Highway Administration, Washington DC, USA, Report No. FHWA-TS-86/203, March 1985, p. 1044.

Rankilor, P. (1981) *Membranes in Ground Engineering*, John Wiley & Sons, Chichester, United Kingdom, pp. 377.

Sweetland, D. (1977) The Performance of Non-woven Fabrics as Drainage Screens in Subdrains. M.Sc. Thesis, University of Strathclyde, Glasgow, United Kingdom, p. 207.