EXPERIMENTAL INVESTIGATIONS OF GEOTEXTILE TUBE DEWATERING

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Abstract: Geotextile tube dewatering has emerged as the preferred method for dewatering high water content sediments in recent years. Geotextile tubes are flexible tubes constructed using geotextiles and have proven to be rapid, cost effective and environmentally friendly.

Several types of laboratory and field tests have been used by researchers and practitioners to evaluate dewatering characteristics of geotextile tube materials.

The paper will present results from an experimental investigation focused on evaluation of dewatering characteristics of high water content sediments with five different geotextile tube materials (three woven, one non-woven and one composite). Laboratory tests conducted include Jar Sedimentation Test, Falling Head Test, Pressure Filtration Test and Hanging Bag Test. The suitability of laboratory tests for dewatering applications will be discussed. The applicability of existing geotextile filter retention criteria for dewatering applications will be evaluated.

Keywords: geotubes, dredged material, dewatering, efficiency, laboratory test, clogging

INTRODUCTION

Geoenvironmental engineers are often confronted with problems involving potentially contaminated high water content materials which need to be dewatered, contained, and remediated or disposed in accordance with federal or state regulations. Dewatering of high water content materials is essential to decrease the volume of material for further practical and economical considerations. Over the years manufactures have developed several techniques for dewatering dredged sediments and other high water content geomaterials. Geotextile tube dewatering has emerged as the preferred method for dewatering high water content sediments in recent years. Geotextile tubes are also efficient for separating and dewatering contaminated high water content waste (Moo-Young et al. 1999, Mori et al. 2002).Geotextile tubes are flexible tubes constructed using geotextiles and have proven to be rapid, cost effective, customizable, and environmentally friendly. Geotextile tubes are customizable to project specific dimensions and can be stacked vertically on top of each other in situations having space limitations. Generally, a geotextile tube can be fabricated from 1.5 m to 6 m in diameter and between 10 m to 100 m in length (Adel and Pilarczyk, 1996).

Specification of geotextile materials for geotextile tube dewatering application has traditionally been based on compatibility between pore size of geotextile and particle size of the sediments to be dewatered. Dewatering or reduction in suspended solids concentration is accomplished as the sediment slurry passes through the geotextile tube; particles larger than the geotextile pores are retained and the liquid part of the slurry which may contain dissolved solids passes through. In practical applications, the geotextile tube is filled up under pressure, allowed to dewater and re-filled to repeat the cycle 2-6 times till the throughput is insignificant (Lawson 2006). Thus, the geotextile is that critical component which governs the success of any geotextile tube dewatering application. Huang and Lou (2007) note the need for reformulation of filtration criteria (Giroud 1996, Christopher 1997, Liao and Bhatia, 2008) for dewatering systems as conventional soil geotextile retention criteria ignore fundamental aspects of dewatering process. The dewatering is primarily a function of the sediment slurry-geotextile interaction in continuous flow conditions.

The considerations for geotextile selection for dewatering applications include strength, retention of sediment solids, and geotextile-sediment slurry interaction. The lack of an established 'design criteria' for selection of geotextiles requires empirical performance evaluation of geotextile with slurry to determine geotextile suitability and modification slurry characteristics. Common methods used for performance evaluation of geotextile-slurry systems are small scale laboratory tests, pilot-scale tests, and full-scale tests. Laboratory tests commonly conducted include Falling Head Test (FHT) and Pressure Filtration Test (PFT). Pilot-scale tests and full-scale tests include fabrication of a prototype or actual sized geotextile tube to dewater site specific sediments in conditions similar to actual site conditions. Hanging Bag Test (HBT) is an intermediate type of test which can be conducted either in the laboratory or field and is considered as a laboratory test within the scope of this paper. Among the tests available the HBT is the only test that is standardized (GRI GT 14 2004). Laboratory tests are quick, economical, and less reliable whereas pilot-scale and full scale-tests are time consuming, expensive, and more reliable for predicting field performance.

The dewatering of non-plastic sediments (uncontaminated) is often observed to be a two stage process consisting of sedimentation and expression. During the sedimentation phase, unflocculated sediment particles settle on the separation medium (geotextile) resulting in growth of a sediment particle deposition commonly termed 'filter cake'; the second phase called 'expression' consists of reduction of the water content of the sediment slurry by percolation through the 'filter cake-geotexile' system. The sedimentation of the filter cake is primarily influenced by the characteristics of the sediments and slurry concentration and the expression is a function of the permeability of the 'filter cake-geotextile' system. The factors that influence dewatering include sediment-slurry characteristics (concentration, pH, temperature, and presence of potential contaminants), geotextile characteristics (pore size, pore size distribution, resistance to clogging, and durability), application of pressure, and test equipment used.

The objective of this study is to investigate the dewatering performance of five different geotextile tube material (three woven, one non-woven, and one composite) with uncontaminated dredged lake sediments. Laboratory tests conducted included Jar Sedimentation Test (JST) to characterize the sediment slurry settling characteristics; FHT, PFT and HBT to determine dewatering performance of the geotextiles.

MATERIALS

Geotextiles

In this study five different geotextiles were selected representative of the types commercially available for geotextile tube dewatering applications. Three woven, one non-woven and one-composite geotextiles were obtained from three different manufactures. The woven geotextiles consisted of one monofilament polypropylene (W1) and two multifilament polyesters (W2 and W3). The non-woven geotextile was a needle punched polypropylene (NW) and the composite (C) consisted of a Polypropylene needle-punched geotextile sandwiched between two layers of a Polyester Multifilament. Properties of the geotextiles tested are presented in Table 1. Pore-size of the geotextiles distributions determined by Capillary Flow Porosimetry are presented in Figure 1.

Table 1. Summary of geotextile properties

Geotextile	Structure-polymer type*	Mass/unit area (g/m^2)	Thickness (mm)	Bubble Point (O_{100})† (mm)	Permittivity‡ (cm/min)	Grab tensile strength§ MD x CD (kN/m)
W1	W, MF-PP	585	1.04	0.40	0.813	96.3 x 70
W2	W, MU-PET	600	1.33	0.24	1.054	175 x 175
W3	W, MU-PET	813	1.73	0.19	0.240	175 x 175
C	COMP-PET,PP	906	3.27	0.10	0.110	184 x 183
NW	NW, NP-PP	550	0.5	0.20	30.000	100 x 100

*W: Woven, NW: Non-woven, C: Composite; MF: Monofilament, MU: Multifilament, NP: Needle punched; PP: Polypropylene, and PET: Polyester.
†Bubble Point (determined as per ASTM D6767-02) and ‡Permittivity values measured using Capillary Flow Test Apparatus

§MD: Machine direction and CD: Cross direction.

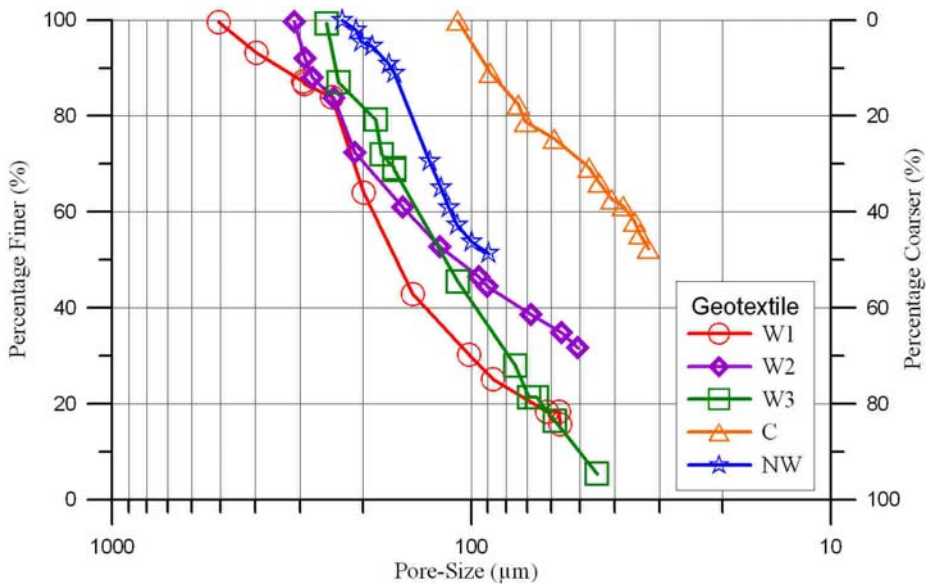

Figure 1. Pore Size Distribution of Geotextiles

Sediment

Uncontaminated dredged lake sediments from a canal lock on Cayuga Lake, NY were used in this study. The in-situ water content of this soil ranged from 30-40%, the in-situ density was 15 kN/m^3 and had a specific gravity of 2.65. The sediments were classified as SM according to Unified Soil Classification System (ASTM D 2487 2004) and had a coefficient of uniformity of 3.60. Particle size analyses indicated that 15% of the sediments were finer than 0.075 mm.

EXPERIMENTATION

The overall goal was to determine the "Filtration Efficiency" (FE) and the "Dewatering Rate" (DR) of the five different geotextiles considered using available laboratory test procedures (FHT, PFT and HBT). JST were conducted to determine sedimentation characteristics of Cayuga Lake Sediments at different slurry concentrations. Sediment slurry was prepared by mixing oven dried sediments with distilled de-ionized water for JST, FHT and PFT and with municipal tap water for HBT. Homogenization of the slurry was achieved by manual mixing for JST, FHT and PFT and for HBT mechanical mixing using a hand drill fitted with a paddle stirrer. The pH of the slurries was determined to range from 7-8 from electrometric measurements (Bigham et al.1996) using an Oaktron® pH 11 meter.

Jar Sedimentation Test

The objective of a Jar Sedimentation Test (JST) is to determine the initial constant rate of settling, clarity of supernatant liquid and the final proportion of settled sediments. The test consists of sedimentation of a slurry of known concentration in a standard graduated cylinder and recording height of the sediment-slurry interface at suitable time intervals to obtain at least 10 sets of time vs. height readings. The initial settling rate is determined as the slope of the initial linear portion of the interface height vs. time plot. If the supernatant liquid is found to have poor clarity or settling rate is excessively low (e.g. < 0.1 cm/sec) consideration should be given for modifying slurry characteristics by chemical treatment (Tarleton and Wakeman 2007). The use of chemical conditioning is often necessary to achieve timely clarification and settling of dredged sediments.

Falling Head Test

The FHT setup consists of a permeameter having an inside diameter of 7.2 cm and a height of 17 cm, a larger FHT device having a height of 35 cm is also available at Syracuse University. A schematic of the apparatus is shown in Figure 2. The permeameter consists of a chamber with a top cover plate and a bottom collection section which accommodates a circular geotextile sample having a diameter of 7.2 cm. The geotextile is supported by a wire mesh screen to prevent sagging. The acrylic chamber can be fixed to the bottom collection section using screw fasteners to obtain an air-tight permeameter. The cover plate has an axial inlet port to apply pressure and the effluent is collected using beakers through an axial port on the bottom section. No additional pressure is applied during a FHT and the dewatering is accomplished under gravity.

Huang and Luo (2007) have reported a study on dewatering reservoir sediments using a falling head test and recommend dewatering performance evaluation using only FHT on a case-by-case basis. The FHT is easy to perform and is a preferred test for screening candidate geotextiles and evaluation of role of chemical conditioning. The test is not representative of the geotextile tube dewatering, utilizes a small sized sample and cannot be used to determine effect of pressure on dewatering.

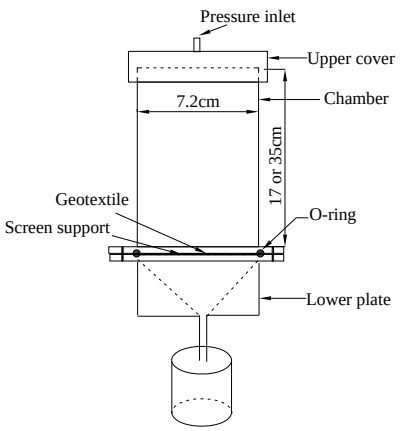

Figure 2. Pressure Filtration Test Apparatus

Pressure Filtration Test

The PFT is an improvisation over the FHT in that it allows application of pressure to accelerate the dewatering rate. The PFT has been favoured by researchers as a bench-scale test (Moo Young et al. 2002; Koerner and Koerner 2005; Liao and Bhatia, 2005, 2008; Muthukumaran and Ilamparuthi 2006) for determination of dewatering performance of geotextiles although variations exist in the experimental setups reported in literature. The PFT at Syracuse University utilizes the same setup used for FHT with the only difference being the application of external pressure through the axial port on the top plate. The PFT also is not representative of the geotextile tube dewatering process, lacks a standard, tests a small sized sample, and the scaling up or correlation of test results to predict actual geotextile tube performance has not been reported in literature. In spite of the limitations, PFT is convenient, economical, rapid and flexible for preliminary evaluation of geotextile alternatives and the role of chemical conditioning.

Hanging Bag Test

The HBT is an intermediate test between laboratory and pilot scale (prototype test) which has been used in the field before a full scale test. The current standard test method for the HBT is Geosynthetic Research Institute GRI-GT 14 (2004), an extension of a test originally proposed by Fowler et al. (1994) for the US Army Corps of Engineers which is further amplified in Koerner and Koerner (2003, 2006). A schematic of the test set up is shown in Figure 3. The test uses a standard geotextile bag (40 cm diameter and 150 cm length) suspended from a test frame or scaffold. The bag is filled with about 150 L of slurry to be dewatered and the effluent is collected during the filling stage and subsequently for every 7.6 cm drop in the level of the slurry within the bag. The effluent quality (total suspended solids) and time for dewatering are measured. Completion of test is indicated by no further discharge of effluent from the bag, upon which the standard recommends assessment of the characteristics of the cake formed within the bag although no qualitative or quantitative measures or methods are provided for this purpose.

The HBT has several inherent limitations including non-representative test method, labour intensive, deceptive measure of slurry level within the bag, and lack of information regarding suitability of test results for correlation to actual geotextile tube performance. Koerner and Koerner (2006) emphasize the need for development of a standard test method that can be used by engineers to select or approve fabrics for optimal geotextile tube field performance.

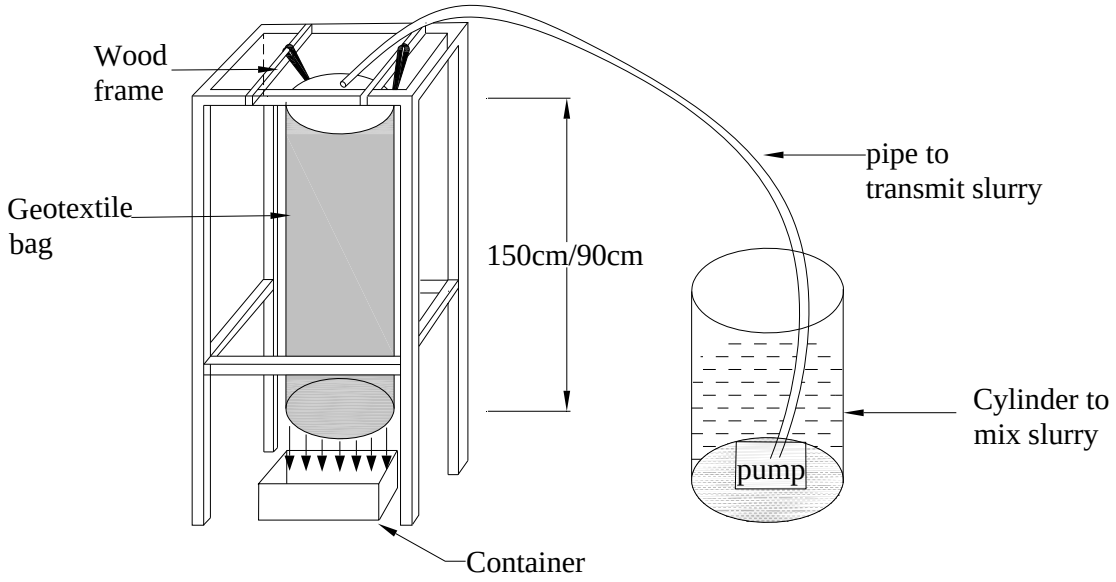

Figure 3. Hanging Bag Test Set-up

Geotextile Tube Demonstration Test

Ten Cate Mirafi® has recently developed a demonstration of Geotube Dewatering Technology (GDT). The test consists of filling a scale model of geotextile tube with conditioned slurry to be dewatered. The slurry is filled into the model tube manually through a stand pipe to a predetermined height representative of 6.89 kPa pressure. The GDT demonstrates dewatering and can be used for assessment of quality and quantity of effluent, role of chemical conditioning, reduction in percent solids. The findings may be extrapolated to estimate the results of a full scale project (Ten Cate Mirafi 2007). The suitability of this recently developed proprietary test has not yet been reported in literature.

RESULTS AND DISCUSSION

The current test series included JST, FHT, PFT and HBT tests. JST were used to evaluate the sedimentation characteristics at different sediment solids concentration followed by dewatering performance evaluation using FHT, PFT and HBT. The test results and discussions follow.

Sedimentation Characteristics

Twelve jar sedimentation tests were conducted at four different sediment solid concentrations (20%, 25%, 33%, and 50%) to determine the settling characteristics, supernatant clarity, and the final proportion of solids due to gravity sedimentation. Figure 4 (a) shows interface height as a function of time for different sediment solid concentrations and 4(b) shows the mass rate of sedimentation per unit area as a function of percent solids. The plot for each concentration is the average of three separate runs and the sedimentation parameters are shown in Table 2.

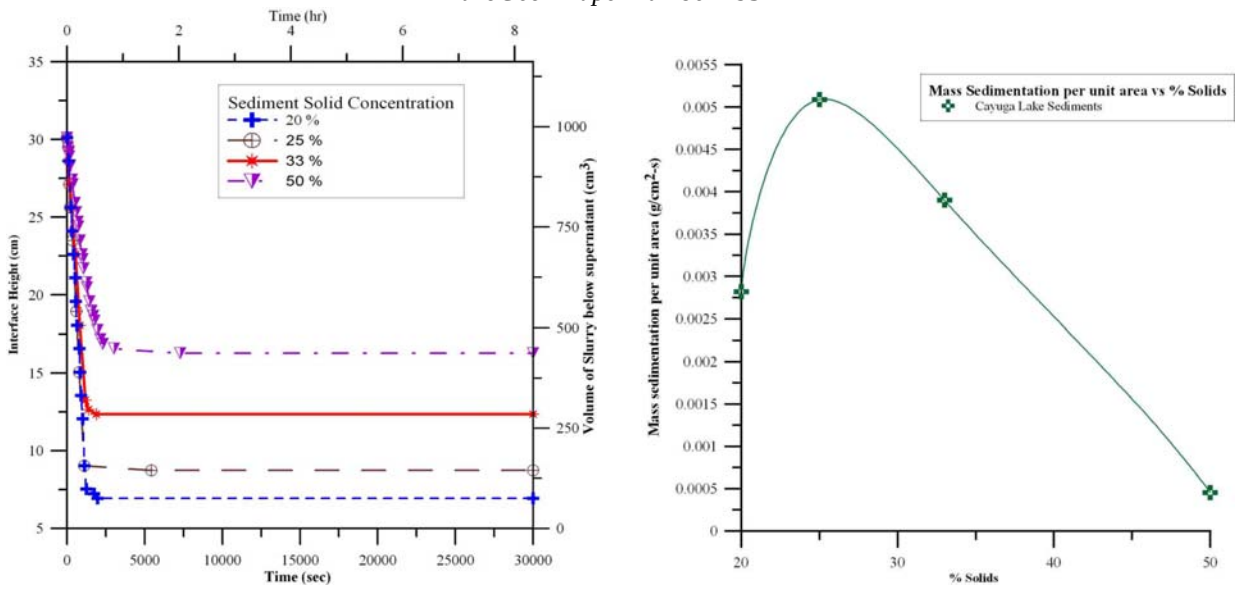

Figure 4. (a) Interface height as a function of time and **(b)** Mass sedimentation rate per unit area as a function of percent solids for Cayuga Lake Sediments

Table 2. Summary of JST results

Parameter	Sediment Solids Concentration			
	20 %	**25 %**	**33 %**	**50 %**
Initial constant rate of settling (cm/s)	1.32E-2	1.91E-2	1.04E-2	8.49E-4
Final proportion of settled sediments (%)	25.03	28.90	43.28	54.72

From Table 2, the initial constant rate of settling was least for 50% and highest for 25% solids. However, the initial constant rate of settling was less than 0.1 cm/s for all sediment solids concentration indicating need for modifying slurry characteristics by chemical treatment (Tarleton and Wakeman 2007). Thus, dewatering or thickening the considered sediment slurries using settling tanks or gravity thickeners will require chemical conditioning and the size of thickener can be designed using the results presented in Figure 4 (Tarleton and Wakeman 2007). From the JST results, 33% solids was selected for further study as it had sedimentation velocity and the mass rate of sedimentation values within the range of values for other sediment concentrations.

FHT Results

Three FHT were conducted with each of the five geotextiles with Cayuga Lake sediment slurry containing 33 % solids. The results of the FHT are shown in Figure 5 ,the plot of dewatering rate vs. time has two distinct phases; the initial phase corresponds to the reduction in flow rate from a relatively higher value at the start of the test to almost a constant rate indicating sedimentation of the 'filter cake'. The constant flow rates observed upon formation of the 'filter cake' indicates second phase of percolation thought the cake. From the results it is clear that all geotextiles had similar dewatering behaviour. The dewatering of sediment slurries is a complex phenomenon involving dynamic interactions including sediment settling, cake formation and growth, filtration and solids passing through. FHT conducted under gravity dewatering pressure normally indicated similar dewatering behaviour for the geotextiles tested. FE from FHTs was greater than 99%.

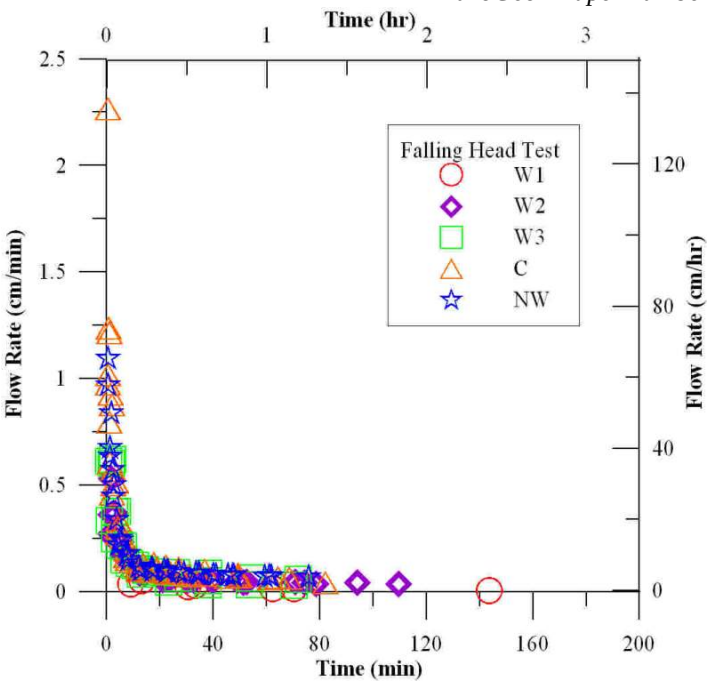

Figure 5. Falling Head Test Results

PFT Results

Fifteen PFT were conducted on Cayuga Lake sediment with 33% of solids concentration under the dewatering pressure of 35kPa. The results are given in Figure. Dewatering rates still had two phases: sedimentation of filter cake and subsequent permeation through the cake. Due to extra dewatering pressure, dewatering rates significantly increased relative to those in FHT. Determined FEs from PFT was larger than 95%. Under an applied pressure of 35kPa, the permeability of 'filter cake-geotextile system' was higher for woven geotextiles than for NW and C which may be due to attributed to compressibility effects.

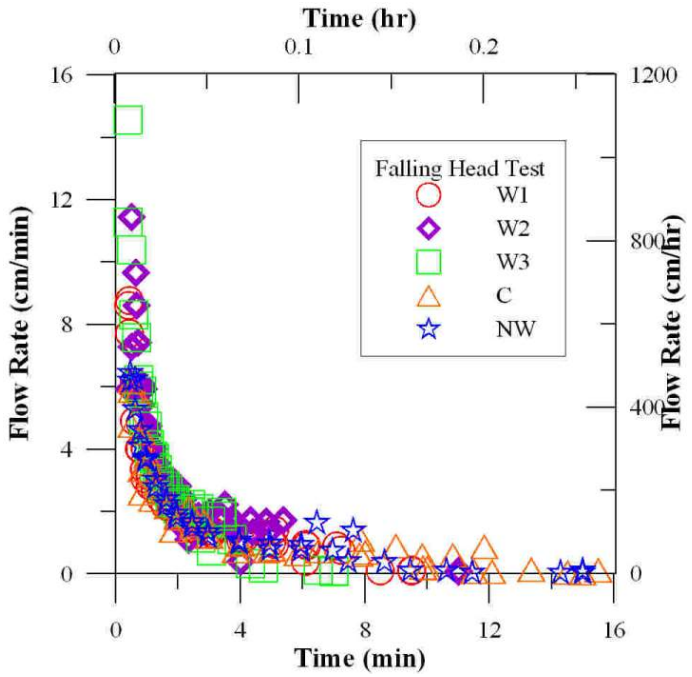

Figure 6. Pressure Filtration Test Results

HBT Results

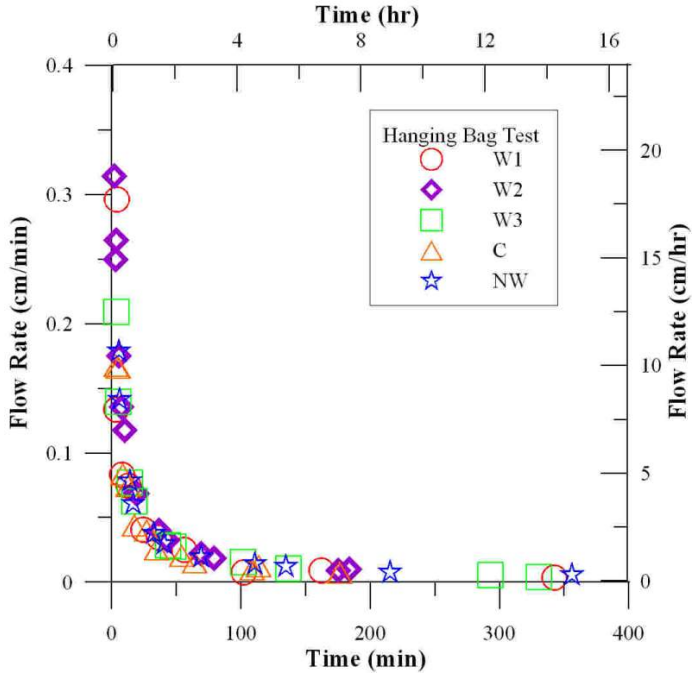

Figure 7. Hanging Bag Test Results

Two HBT were performed using each of the five geotextiles and Cayuga Lake sediment slurry containing 33 % solids. The curves representing the behaviour of dewatering rate have the same trend as that in PFT. The woven geotextiles had larger initial dewatering rates than NW and C geotextiles. However, the initial dewatering rates in HBT were much smaller than those in PFT because of a larger filter cake and lower dewatering pressure. Since the filling time was longer in HBT, more particles could settle down and more fines were captured in the finer leading to a more tortuous pores, the permeability of filter cake-geotextile system in the reduction phase was lower for NW and C geotextiles. After the dewatering rate was stable, the permeability of the filter cake-geotextile system for these five geotextiles was observed to be similar. FE from HBTs was greater than 99%. However, in some geotextiles (NW and C) water was observed at the top of filter cake contained in the bag made after a 24 hour period indicating potential clogging occurred in the geotextiles.

CONCULSION

Geotextile tube dewatering is a complex process and is highly dependent on geotextile properties such as pore size distribution and permeability, sediment characteristics such as solids concentration, particle size distribution, permeability, and the applied pressure.

- Solids concentration and particle size distribution influences the settling velocity of the particles and the rate of the formation and permeability of the filter cake. Further research is necessary to understand the role of particle settling on slurry dewaterability.
- From the experiments conducted the dewatering time was found to decrease with increase in applied pressure and increase in 'filter cake thickness'
- Optimizing dewatering of sediments requires maximization of FE and minimization of the dewatering time. Small scale tests (FHT and PFT) were found to predict dewatering performance similar to relatively larger HBT. There is a need for a standard PFT to facilitate evaluation of geotextile dewatering characteristics with project specific materials.

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Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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