PRESSURE FILTRATION TEST-ASSESSMENT BASED ON FILTRATION THEORY

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Abstract: Pressure Filtration Test (PFT) has been used by researchers to evaluate geotextiles for dewatering high water content sediments and sludges. Experiments were conducted to evaluate the effect of applied pressure, sediment slurry water content and geotextile type. Parameters affecting dewatering performance include applied pressure, suspension concentration, and geotextile type. Experimental results obtained from PFT of sediments slurries of three non-cohesive soils (Lake Sediments, Silt and Ottawa Sand) at different pressures will be presented. Discussions will also include conventional evaluation of test results in terms of "Filtration Efficiency" and "Dewatering Time". Considerations of optimization of dewatering using polymers fine sediment slurries will be addressed focusing on polymer dosage and mixing regime.

Keywords: bench-scale testing, dewatering, filtration, geotubes, pressure, suspended solids.

INTRODUCTION

Dewatering in a geotextile tube is accomplished by pumping the sediment slurry to be dewatered through a geotextile tube that is permeable to one or more components of the sediment slurry and is impermeable to the remaining components. Lawson (2006) noted that “Geotextile tubes are part of the system of disposal of slurry like waste and contaminated sediments. Basically, the slurry is introduced into the system where it is first mixed with a dewatering accelerant (if required). The slurry is then pumped into the geotextile tubes where dewatering occurs. Over time, the water passing out of the tubes which can be pumped to a water treatment plant where it is cleaned further, or it may be recirculated to the original slurry ponds, or it may exit directly to the environment (if it is clean enough). At the end of dewatering the contained solids may be left in-place, or they may be transported to an off-site disposal facility, or they may be recycled for other uses. The overall system includes combinations of pumping equipment and pipelines; geotextile, tubes; accelerant additives; water treatment processes; and specific disposal facilities for the final dewatered waste stream.”

The selection of a geotextile for a particular dewatering application requires detailed knowledge of the process in which the geotextile will be used. Upon obtaining this information, several laboratory performance trials are essential to evaluate the changes in the geotextile during and after dewatering. The interaction between geotextile and the sediment slurry governs the success of any dewatering project. The specification of geotextiles for dewatering applications is based on compatibility between geotextile pore-size and sediments to be dewatered determined from performance testing. Efficient dewatering is vital to the cost and efficiency of ancillary operations.

The use of woven geotextiles is widespread within United States based on successful past experiences. Hardman (1994) recognized that the ‘filter fabric’ (geotextile for geotextile tube applications) may not in isolation be the ideal medium for all process conditions; and in some cases separation (dewatering) has to be assisted, for example by using aids or body feeds or by polyelectrolyte treatment (commonly termed polymer conditioning). The selection and performance evaluation of aids, body feeds or polyelectrolytes requires simple and effective evaluation methods. Pressure Filtration Tests are ideal for preliminary screening and performance evaluation of geotextiles and dewatering enhancers for geotextile tube dewatering applications. This paper presents results of laboratory PFT using three non-cohesive soils under different dewatering pressures with five geotextiles. Considerations of polymer flocculation were also evaluated using fine grained sediments and the optimization in dewatering (time and extent) is presented.

PRESSURE FILTRATION TEST

Researchers have adopted PFT as the preferred test method for bench scale evaluation of dewatering performance of geotextile for dewatering different geomaterials. The following section will briefly outline the pressure filtration test methods reported in literature.

Moo Young et al. (2002) first reported the use of a “modified specific resistance to filtration” test apparatus to conduct pressure filtration test aimed at screening geotextile materials for dewatering high water content materials. The apparatus consisted of a rigid wall permeameter having an inside diameter of 128.45 mm with an upper plate equipped with an inlet for applying pressure and a pressure gauge and a lower plate with a fabric holder. The lower plate has an outlet to facilitate collection of filtrate. Test procedure consisted of obtaining representative slurry sample of known solid content and filling the permeameter chamber with the slurry. The initial height of the slurry is recorded, upper plate is fastened and air pressure is applied and adjusted to required pressure. Graduated cylinders were used to collect filtrate with respect to time and at the end of the test the filtration apparatus is disassembled; measurements of final height of dewatered cake and total settlement are recorded. Finally, analyses of dewatered cake and filtrate are conducted.

Filtration Efficiency (FE) was determined comparing the initial total solids (TS_i) and the final total suspended solids (TSS_f) of the sample as:

$$FE (\%) = [TS_i - TSS_f]/TS_i X 100 (\%) \quad [1]$$

Where FE is the Filtration Efficiency in %, TSi is the initial total solids in mg/l and TSSf is the final total suspended solids in mg/l. The degree of dewatering was described in terms of Dewatering Efficiency (DE) determined as:

$$DE (\%) = [PS_i - PS_f]/PS_i X 100 (\%) \quad [2]$$

Where DE is the Dewatering Efficiency in %, PS_i is the initial percent solids (%) and PS_f is the final average percent solids (%).

Moo-Young, et al. (2002) performed ten pressure-filtration tests under 35 and 70kPa of pressure to assess the viability of dewatering lake and harbor sediments by two multifilament polyester and one monofilament polypropylene woven geotextiles. They found that the geotextiles tested had high FE (>95%).

Koerner and Koerner (2005) reported pressure filtration test as an extension of the study by Moo Young et al. (2002). Their device consisted of a one liter graduated cylinder fitted with a flange to receive the geotextile specimen on one end and a pressure cap on the other. A 50mm diameter geotextile specimen is used for test and the sediment slurry was prepared using pulverized soil with reference to American Society for Testing and Materials (ASTM D 422) Particle Size Analysis of Soils – Hydrometer Method. The test procedure consists of mixing 50 gm of pulverized soil added to the cylinder up to the 2000 ml mark and shaking the cylinder to obtain a suspension. Average pressure filtration permeabilities were reported from the pressure filtration tests. Koerner and Koerner (2005) do not report the details of the test or analysis techniques and their main finding was that geotextile dewatering performance was independent of Apparent Opening Size (US Standard Sieve number having opening size closest to that of the geotextile)

Muthukumaran and Ilamparuthi (2006) reported conducting pressure filtration tests cylindrical molds having inside diameter of 90 mm and height of 390 mm. The molds consisted of a top plate, filtration chamber and collection chamber that are all secured during a test. Top plate is provided with two inlets one for applying pressure and another for releasing excess pressure. Sludge in the filtration chamber is dewatered through geotextile placed in between the filtration chamber and collection chamber, supported by a filter screen made of wire mesh to prevent sagging of geotextile. The collection chamber is made conical to prevent deposition of solids from the filtrate. A volume of 2.036 l of slurry can be dewatered under an initial flow head of 320 mm. Test is conducted till flow rate is negligible. This study reported a correlation between geotextile AOS and critical water content at which filtration efficiency is optimum – a conclusion that is contrary to findings from other reported studies (Koerner and Koerner, 2005)

From reported studies it is clear that there is a lack of consensus on test equipment, procedure, and findings that raises a need for a standard test method for PFT. Also, available studies do not address the effect of slurry solids concentration, dewatering pressure and geotextile type on dewatering performance. This study presents test results of dewatering three non-cohesive soils at different dewatering pressures, suspension concentrations using two woven geotextiles. Details of the equipment, sample preparation and test procedure are provided aimed at validating the suitability of PFT as a laboratory test for evaluation of geotextile for dewatering applications. Experimental evaluation using PFT was further extended to evaluate effect of polymer conditioning on dewatering of fine grained sediments to aid in preliminary assessment of geotextile dewatering.

TEST EQUIPMENT AT SYRACUSE UNIVERSITY

Pressure Filtration Test Equipment

The PFT equipment used for this study is shown in Figure 1. The PFT set up consists of a flex-wall permeameter made of acrylic tube permitting observation of the slurry level during dewatering. The permeameter has an inside diameter of 7.2 cm and a height of 17 cm, a larger PFT device having a height of 35 cm is also available at Syracuse University. The permeameter accommodates a circular geotextile sample having a diameter of 7.2 cm and has a wire mesh screen to support the geotextile. The acrylic tube has a provision to fasten it using screws to a base plate using screw fasteners. The top plate has an axial inlet port to apply pressure and the effluent is collected through an axial port on the bottom plate. There is sufficient clearance below the bottom plate to facilitate collection of effluent using small beakers. The effluent characteristics such as total suspended solids, the dewatering time, and characteristics of the final solids after dewatering are determined. The PFT set up can evaluate the dewatering characteristics of 750 ml of given slurry under applied pressure. The dewatering pressures used for this study were 7, 35 and 70 kPa.

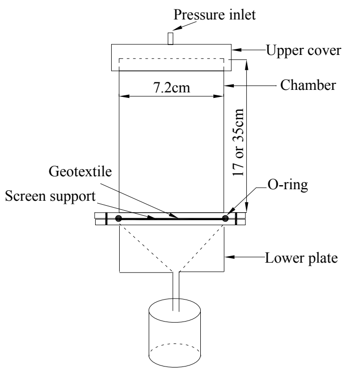

Figure 1. Pressure Filtration Test Apparatus

Materials

Soils

Three types of soils and five types of geotextiles were used for this study. The particle size distribution of Cayuga Lake sediments, Ottawa sand, and Tully silt are shown in Figure 2 and the soil properties are presented in Table 1. Cayuga Lake sediments are classified as ML, Ottawa as SP according to Unified Soil Classification System (USCS). Fine fraction of Tully silt wet sieved trough US Standard Sieve No. 200 was used for the tests.

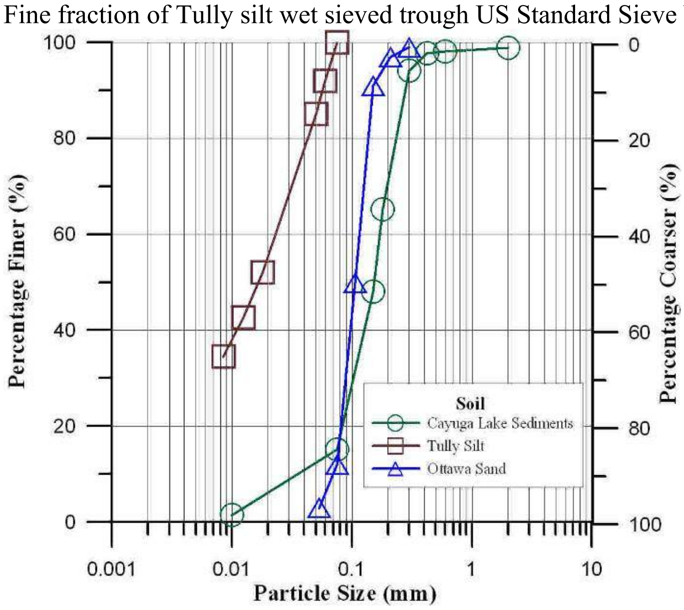

Figure 2. Particle size distribution of sediments

Table 1. Summary of soil properties

Materials	D_{15} (mm)	D_{50} (mm)	D_{85} (mm)	C_u*	C_c†
Ottawa sand	0.076	0.11	0.14	3.47	1.73
Cayuga Lake sediments	0.073	0.16	0.25	3.59	1.83
Silt	0.001‡	0.007	0.05	115‡	10.65‡

* C_u: coefficient of uniformity = D_{60}/D_{10};
† C_c: coefficient of curvature = $(D_{30})^2/(D_{10})(D_{60})$
‡ Estimated

Geotextiles

In this study two woven geotextiles were obtained form their manufacturer's representative of the geotextiles commonly used for geotextile tube dewatering applications. One of the woven geotextiles consisted of a monofilament polypropylene (W1) and other was multifilament polyesters (W2). Properties of the geotextiles tested are presented in Table 2.

Table 2. Properties of geotextiles tested

Geotextile	Structure-polymer type*	Mass/unit area (g/m^2)	Thickness (mm)	Bubble Point (O_{100})† (mm)	Water Flow Rate ‡ (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

*W: Woven,
†Bubble Point (determined as per ASTM D6767-02) and ‡Water flow rate values measured using Capillary Flow Test Apparatus
§MD: Machine direction and CD: Cross direction.

Test Procedure

The test procedure used for PFT is as follows:

- A circular geotextile sample of 7.3 cm diameter was cut, weighed and saturated in deaired water.
- Sediment slurry of the desired solids concentration was prepared by accurately weighing required quantity of oven dry sediments and mixing it with required quantity distilled water in a beaker and mixed by hand using a spatula for at least 2 minutes. Samples of slurry for determination of solids content were taken after an hour and the volume of slurry is noted.
- The geotextile was placed on top of the collection section and the chamber is fastened using screws. The chamber was filled with distilled water and allowed to drain to ensure saturation and water tightness of the set up.
- The slurry volume is noted, stirred and poured into the chamber. The time for pouring of the slurry was about 30 seconds for tests conducted. The filtrate during the pouring is collected using collection beakers of 50 ml volume. The top cover plate is fastened and desired pressure is applied using compressed air.
- The filtrate rate is monitored by collecting the filtrate using collection beakers of 50 ml volume at various time intervals. The time intervals need not be constant but may be increased progressively to account for the drop in filtrate flow.
- The test is continued till no further filtrate is discharged. At this stage the applied pressure is removed and the test set up is dissembled.
- The quantity of filtrate is recorded as the volume and mass of filtrate. The filtrate is oven dried to determine the total solids in the filtrate. Turbidity of the filtrate can also be measured to asses filtrate clarity.
- The water content and thickness of the filter cake were measured and the geotextile sample's weight after the test was recorded, air dried and stored.
- The cumulative volume of filtrate and total mass of solids in the filtrate was recorded.
- Three separate runs of the test were conducted for each geotextile with a given sediment slurry concentration to ensure uniformity and repeatability of the tests.

ASSESMENT OF PRESSURE FILTRATION TEST

Conventional assessment of pressure filtration tests results is by evaluating the FE and the "Dewatering Rate (DR)". In a PFT, filtration is accomplished by deposition of solid particles over a geotextile medium the purpose of which is to retain the solids. This deposition progressively forms a *'filter cake'* upstream of the geotextile, which in turn functions as the filtration medium of remaining suspension which has not yet passed through the *'filter cake-geotextile medium'*. At the beginning of cake filtration, the pressure drop is across the geotextile as no cake formation is present and the flow is governed by Darcy's law and if the suspension was a clean liquid, it would result in a constant flow rate for an imposed pressure gradient resulting in a liner increase in cumulative volume with time as shown in Figure 3. In cake filtration, with the progressive deposition of the cake, a portion of the applied pressure is taken up by the cake leading to a gradual drop in the filtrate volume with time. The most common method of interpretation of constant pressure filtration is based on so-called parabolic law, assuming applied pressure is equivalent to the pressure drop across the cake, wet to dry cake mass is constant, and the particle velocity within cake is small compared to the filtrate velocity, the flow rate (Q) is given by:

$$Q = [P\ A]/[\alpha\ \mu\ w + \mu\ R] \qquad [3]$$

where Q = flow rate, P = applied pressure, R = geotextile resistance, α = specific cake resistance, μ = liquid viscosity, and w = mass of cake deposition per unit area. Resistance is defined as the medium thickness divided by its permeability. Figure 4 shows typical plots of cumulative volume of filtrate as a function of time for pressure filtration tests conducted to dewater Cayuga Lake Sediments, Ottawa Sand, and Tully Silt suspensions at 200% water content (33% Solids) and 400% water content (20% solids) using geotextile W2.

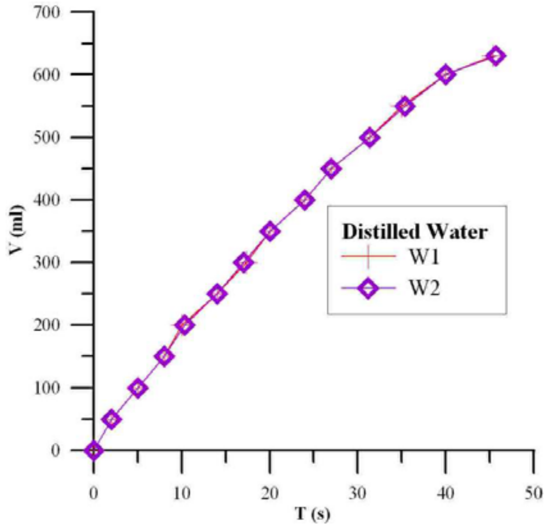

Figure 3. Cumulative volume of filtrate as a function of time

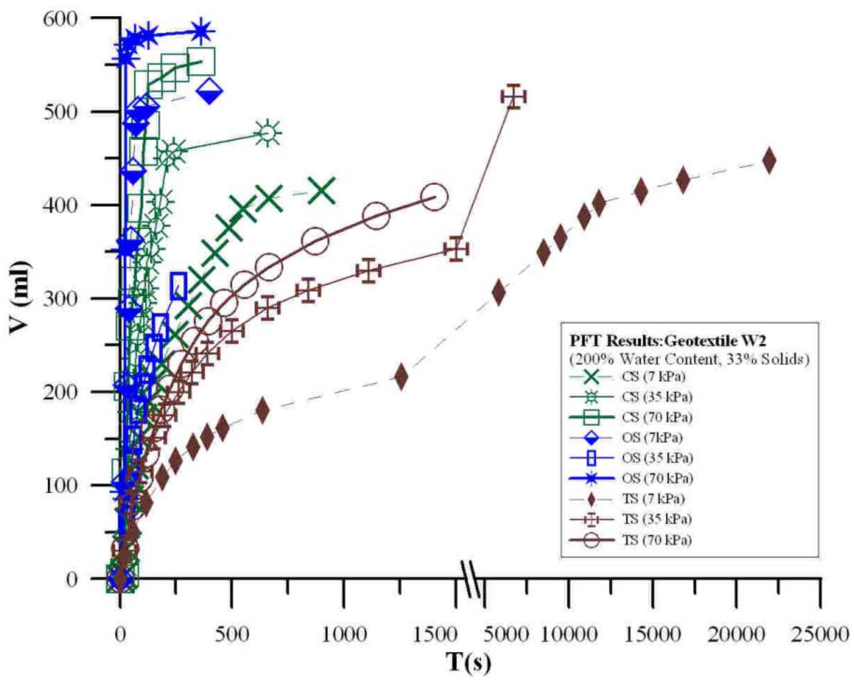

Figure 4. Cumulative volume of filtrate as a function of time for dewatering Cayuga Lake Sediments (CS), Ottawa Sand (OS), and Tully Silt(TS) using PFT with geotextile W2 at 200 % water content .

TEST RESULTS AND DISCUSSION

The results of pressure filtration test using geotextile W2 for dewatering Cayuga Lake Sediments, Ottawa Sand and Tully Silt are shown in Figure 4, which is a plot of cumulative volume of filtrate as a function of time. The results of FE are presented in Table 3. W1 has O_{100} of 0.4mm, succeeded in retaining Cayuga Lake sediment and had a FE in excess of 95 %. Dewatering rate of Ottawa sand with W1 was rapid (as can be observed in Figure 4). However, FE was also greater than 95%. Almost all of Tully silt passed through W1 as the sediment slurry was introduced into the equipment, which indicated that W1 was not successful in dewatering Tully silt thus the FE was found to be zero at all applied pressures. Similar FE was observed for W2 in dewatering Cayuga Lake Sediments and Ottawa Sand. Geotextile W1 was found to be efficient in dewatering Ottawa sand and Cayuga Lake sediments with FE greater than 95. FE for W1 to retain Tully silt was near 0. Greater flow rates are observed at higher applied pressures due to greater pressure drop across the filter cake thereby increasing the quantity of filtrate.

Figure 5, is a plot of variation of filtrate solids with time since start of the PFT for sediment slurries at 200% water content (33% solids) at various dewatering pressures using geotextile W2. Piping refers to the total amount of solids that pass through the filter (in this study the geotextile-cake interface) and is expressed as weight per unit area of filter common unit being g/m^2. Lafleur et al. (1989) suggests that a piping rate of 2500 g/m^2 of soil mass through a granular filter does not affect its stability. Aidylek and Edil (2002) suggest allowable piping rate must be 1900 g/m^2. During the initial stages of the test, relatively greater amounts of filtrate solids are observed which later stabilizes to a negligible amount. Similar trends have been observed by Huang and Luo (2007) in dewatering reservoir sediments using Falling Head Test. This behavior limits the applicability of existing geotextile filter retention criteria. Liao

(2008) had identified the selection and evaluation of polymer conditioning as a thrust area for further research. The investigation also found that no unique filter criteria could predict the filtration performance of the tested geotextiles with fine sediments. Preliminary findings from a study directed at optimizing dewatering (maximization of FE and dewatering rate along with minimization of piping) is presented in the following.

Table 3. Results of FE from PFT

	Cayuga Lake			Ottawa sand			Tully Silt		
Geotextile	7 kPa	35 kPa	70 kPa	7 kPa	35 kPa	70 kPa	7 kPa	35 kPa	70 kPa
W1	97.96	98.08	97.57	/	/	/	0	0	0
W2	99.56	W2	99.55	99.57	99.86	99.85	99.83	90.57	92.70

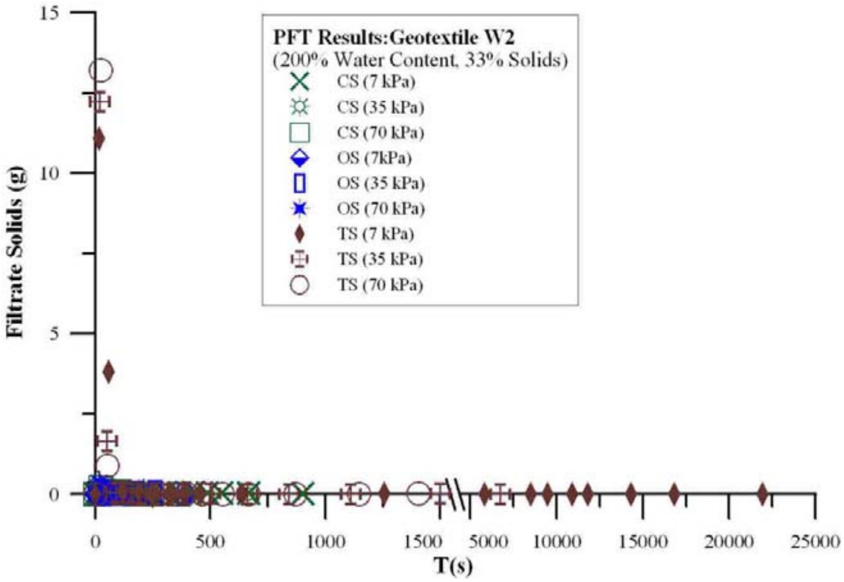

Figure 5. Variation of filtrate solids with time

Considerations of polymer conditioning

From equation [3] it is evident that rate of dewatering can be improved by controlling applied pressure (P), permeability (effectively inverse of resistance), and viscosity of the filtrate. Particle size distribution has a significant effect on the filter cake formation and permeability. In geotextile tube dewatering there are limitations in applying pressure; thus, desirable changes to the particle size and viscosity of the filtrate can be enforced by polymer conditioning. It has been well recognized that the key to almost all dewatering operations lies in the use of either chemical additives such as high molecular weight polymer flocculants, or surface chemical conditions to control interparticular interaction in the suspension thereby controlling the rate and extent of dewatering (de Krester et al. 2001). Flocculation using polymers aggregates (flocs) fine particles in suspension thereby enhancing solid liquid separation irrespective of the dewatering method employed. Traditionally, the evaluation of polymers has been done by experimental observations of settling behaviour, supernatant clarity and floc characteristics. The growing demands for expedited dewatering using geotextile tubes necessitates development of test methods to rapidly screen available polymer-geotextile alternatives and proceed to prototype performance trials. Among available test methods, the PFT is most conducive toward bench scale dewatering performance evaluation of geotextile-conditioned slurries. It is well known that choosing correct mixing regime and application technique is important as ensuring optimum polymer choice (Gregory, 1981). Most geotextile tube dewatering applications utilize inline dosing of polymers into dredged slurry that is further introduced into geotextile tube for dewatering. Thus, mixing energy and mixing time are critical factors to be considered in evaluation of polymers.

Potential enhancement of dewatering performance of Tully silt was investigated as a part of this study. Qualitative screening tests to determine preliminary type and dosage of polymer was conducted by WaterSovle, LLC in Grand Rapids, MI who recommended sequential application of polymers A and B for optimizing dewatering. Polymer A was a Water-in-Oil Emulsion Anionic Flocculant Polyacrylamide Copolymer and polymer B was a Liquid Cationic Coagulant. The use of anionic, non-ionic and cationic polymers in various combinations and sequences to improve dewatering characteristics of fine sediments is well known (Mishra, 1988).

An innovative evaluation methodology was developed to determine optimum polymer dosage for dewatering Tully silt using conventional Jar Test Apparatus (AWAA, 2007) from water treatment industry along with PFT. Experimentation included use of Jar Test to initially mix the sediment slurry and to flocculate it upon polymer addition. The conditioned slurry was then dewatered using a modified PFT procedure. The presented PFT procedure was modified to collect the filtrate in a graduated cylinder facilitating visual observation of filtrate quantity instead of collection beakers as the filtrate flow rate was greater than unconditioned slurries. The cumulative amount of solids passing was measured by oven drying the filtrate in a standard laboratory oven at 110^o C. Considerations of polymer conditioning of Tully silt sediments at 200% water content (33% Solids) were addressed using geotextile W1 which was had earlier failed to dewater the unconditioned sediments. Dewatering pressure was maintained at of 35 kPa for tests involving polymers to limit the test variables.

Results of polymer conditioning

The influence of polymer dosage and mixing considerations on dewatering characteristics of Tully silt sediment slurry at 200% water content dewatered under 35 kPa using geotextile W1, which was earlier found to be most inefficient in dewatering (FE = 0) is shown in Figure 5. The optimum polymer dosage was determined for a root mean square velocity gradient (G) of 50 s^{-1} (50 rpm) for 300 s mixing period and the role of mixing energy was further evaluated using the 'optimum polymer dosage' for the same mixing period. The values of RPM for the jar-test unit were obtained from standard G calibration curves (USACE, 1987). From Figure 6, it is evident that polymer dosage can expedite dewatering of Tully silt sediments relative to the unconditioned sediment slurry (Control).

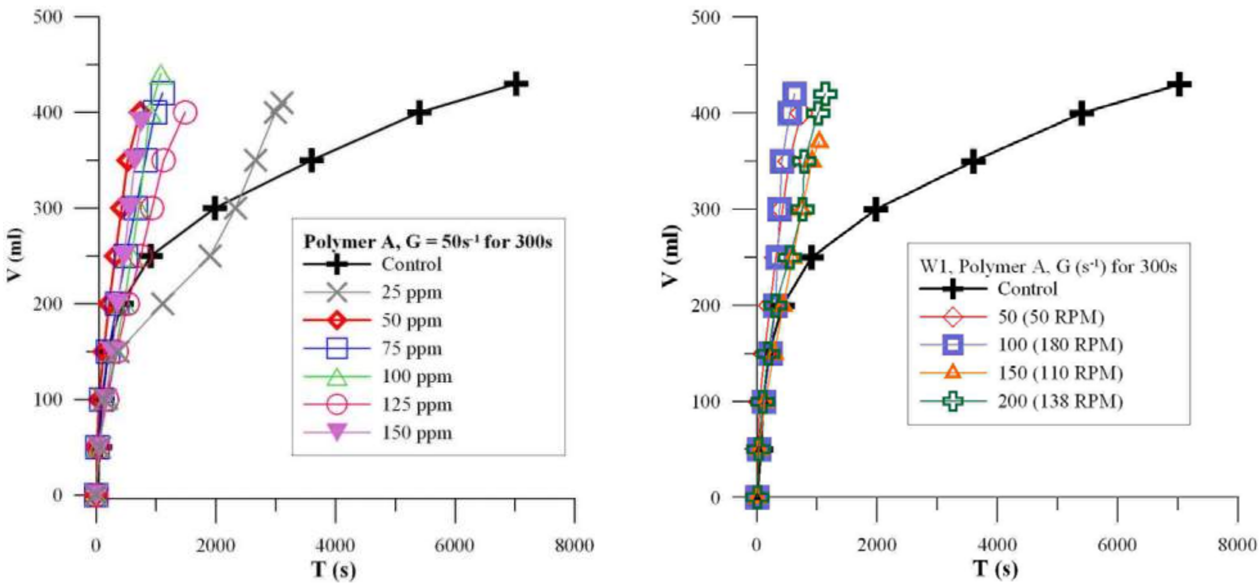

Figure 6. Considerations of polymer dosage and mixing energy for dewatering Tully silt sediments at 200% water content (33% solids) under applied pressure of 35 kPa

Table 4 presents the results of dewatering polymer conditioned Tully Silt sediment slurry at 200 % water content (33% solids). It is clear that there is improvement in FE with addition of polymer A. Optimum polymer dosage is defined as that dose corresponding to 'lowest dewatering time and amount of piping'. From the experimental study on polymer dosage, 50 ppm dosage was deemed to be optimum at G= 50 s^{-1} for 300 s mixing time as it had the lowest dewatering time and amount of piping among the dosing and mixing regimes considered. Further research is currently underway at Syracuse University to understand the role of polymers in enhancing dewaterability of natural sediments.

Table 4. Results of dewatering polymer treated Tully Silt sediments slurry at 200% water content (33% solids) under applied pressure of 35 kPa using geotextile W1

Dosage (ppm)	FE (%)	Piping (g/m^2)
0	0	> 2500
25	99.16	180-260
50	99.75	88-143
75	99.55	137-147
100	99.04	315-427
125	99.79	70-334
150	99.85	203-270

G (s^{-1})	FE (%)	Piping (g/m^2)
50	99.75	88-143
100	97.87%	732-904
150	99.79%	700-870
200	99.48%	150-196

CONCLUSIONS

Geotextile tube dewatering of sediments slurries is accomplished by cake filtration in which the principal medium is the "filter cake" built up from the sedimentation of the soil particles. Characterization and optimization of sediment slurry dewatering using geotextiles can be effectively achieved with bench-scale evaluations using the PFT. The optimization of dewatering can be achieved by changing sediment slurry characteristics using polymer conditioners thereby enhancing throughput quantity and quality. Considerations of polymer flocculation must be evaluated by simulating site specific mixing regime and environmental conditions. There is a need for establishing a standard for the PFT to facilitate empirical characterization of dewatering performance of geotextile tube materials.

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