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Laboratory Assessment of Geotextile Tube for Dewatering High Water Content Material

고함수비물질의 탈수에 대한 지오텍스타일 튜브의 실험적 평가

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요 지

본 논문에서 고함수비 슬러지나 퇴적물들의 탈수에 지오텍스타일 튜브들의 이용이 연구되었고, 튜브들의 사용에 대한 실용성과 영향을 미치는 요인들도 평가되었다. 개조된 실험기를 사용하여 고함수비물질들과 두종류의 woven지오텍스타일 튜브에 대해서 압력여과시험들이 실험되었다. 실험결과, 1) 지오텍스타일 튜브안쪽에 형성된 필터케익이 튜브안에서 세립자 유지의 주 원인이며, 또한 튜브의 투수율 감수의 원인이고, 2) 필터케익형성을 조정해서 토사유지율과 투수율사이의 균형을 얻는것이 성공적인 지오텍스타일 튜브사용에 가장 중요한것이며, 3) 지오텍스타일, 슬러지 특성, 여과압력등이 탈수효과및 탈수율에 영향을 미침을 알수 있었다

Abstract

The objectives of this paper are to study the use of geotextile tubes for dewatering high water content sludges and sediments and to evaluate their feasibility and affecting factors. To accomplish these objectives, pressure filtration tests were conducted on woven geotextile (Geotex® 46T and 1212T) for high water content materials with a modified experimental apparatus. Test results indicate that 1) the filter cake formed on the inside of the geotextile tube is the major contributor to the retention of fine particles, but also causes a decrease in permeability, 2) controlling the formation of the filter cake and thus achieving a balance between soil retention and permeability is vital to a successful project, and 3) geotextiles, sludge properties, and filtration pressures have some effects on the dewatering efficiency and dewatering rate.

Keywords : Dewatering, Filter cake, Filtration, Geotextile tubes, Sediments, Sludges

1. Introduction

The high water content waste materials are generated annually from a variety of sources such as mining operations, waterway dredging, wastewater treatment facilities, paper mills, agriculture and industrial sites. For example, millions of cubic meters of bottom sediment are dredged and disposed of annually to maintain harbors and navigable waterways. Because of the high water content and low shear strength, these materials are

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very difficult and uneconomical to reuse or dispose of. Dewatering must first be accomplished to reduce the volume of water in the waste. Then the dewatered materials can be transported to a landfill or beneficially used as construction materials in dike enforcement, wetland restoration or creation and other uses (Gaffney, et al., 2001).

Geotextile tubes are used for dewatering high water content materials, because geotextile tube has the advantages of rapid disposal of large volumes of waste, ease of construction, convenient placement, high efficiency, low cost, labor savings and low environmental impacts. Successful applications have been demonstrated in several field projects, including dewatering dredged materials, sewage sludge (Fowler, 1997) and tannery sludge (Hasbach, 1999).

The mechanism of dewatering with geotextile tubes comes from the filtration function of geotextiles. This function involves draining the water through its manufactured plane and at the same time retaining the soil solids on its upstream side. With this function, geotextiles have been extensively used as filters to replace conventional granular filters in all kinds of civil engineering projects. Since 1972, many researchers have investigated geotextile filter design and presented numerous filtration criteria. Generally, three categories of filtration criteria are used in conventional geotextile filter designs: soil retention criteria, permeability criteria and long-term anti-clogging criteria (Koerner 1999, Christopher, 1997, Calhoun, 1972, Giroud, 1982, etc.). Sometimes, other criteria, such as survivability criteria to survive installation and durability criteria to resist adverse chemical and ultraviolet light exposure, are also considered (Luettich et al, 1992). Basically, most of these filter criteria are based on a certain relationship between soil particle size distribution and fabric pore structure characteristics. This relationship generally inherits from granular soil filter design criteria, with certain modifications.

The same concerns, soil retention, permeability and clogging, apply to dewatering using geotextile tubes. However, there are several important differences between geotextiles used in soil retention (filter) applications and geotextiles used as tubes for dewatering. In filter applications, soil retention is the primary concern. Permeability must be sufficient to prevent excess pore water pressure from building up on the upstream side. Maximum soil retention is required to ensure the stability of the soil mass. With tube dewatering applications, permeability is often the primary issue with the condition that sufficient solids are retained. High permeability or flow rate is required to insure that the high water content materials are dewatered as quickly as possible. Filtration efficiency can be used as index for soil retention capacity while dewatering efficiency is a better indicator of the dewatering capacity.

Apparent Opening Size (AOS) of the fabric is often used in filtration criteria. AOS is defined as the 95% opening size and is specifically measured using ASTM standard test D 4751. This test is conducted dry. Experience has shown that the common criteria used in filter design are not applicable to geotextile tube dewatering. Additional filtration research carried out at Lehigh University (Tucker, 2000) found that the fines which pass through the fabric are significantly smaller than the smallest characteristic opening size of the fabric. This supports the assertion that within the AOS range of most geotextiles, soil grain size and geotextile AOS have very little to do with successful retention of material within a geotextile tube (Gaffney, et al., 1999).

The purpose of this paper is to study the filtration compatibility (soil retention and permeability) between different geotextiles and high water content materials using pressure filtration tests described in this paper, and to evaluate the feasibility and efficiency of using geotextile tubes for dewatering various high water content materials. Pressure filtration tests were conducted to obtain information about the dewatering efficiency, the reduction in permeability caused by the formation of filter cakes, and factors that may affect these processes.

2. Pressure Filtration Experiments

2.1 Equipment

The pressure filtration tests were conducted with a

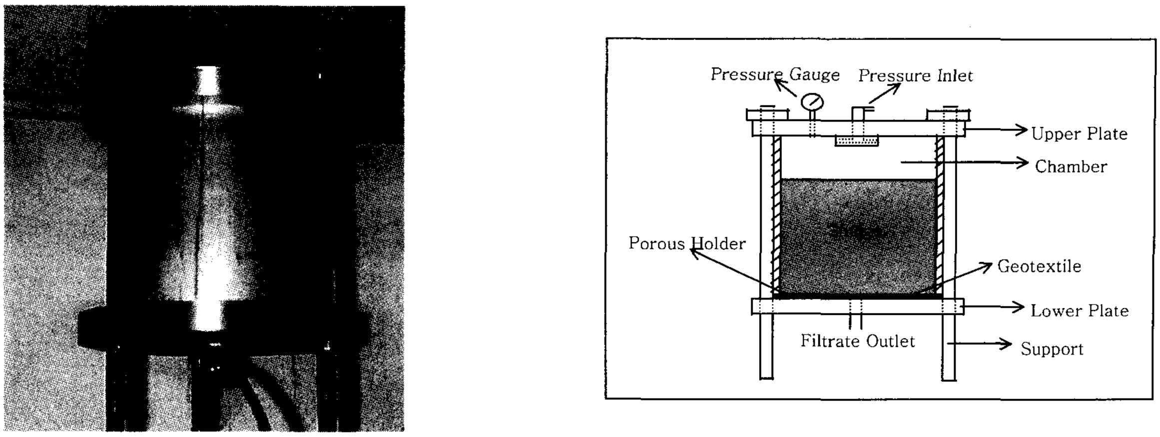

Fig. 1. Filtration test apparatus

modified "Specific Resistance to Filtration" test apparatus (Fig. 1). This apparatus is made of stainless steel and consists of three parts, a chamber with an inner diameter of about 128.45 mm, an upper plate with a pressure inlet and a pressure gauge, and a lower plate with a fabric filter holder, an outlet to collect filtrate and the support. The air pressure is applied to the inlet on the upper plate.

The sample is mixed sufficiently (to represent dredging), and the initial water content is measured, before it is placed into the chamber. After the sample is placed into the chamber, its initial height is marked. Then the screws on the upper plate are tightened, the air pressure applied and promptly adjusted to the required pressure. Graduated cylinders are used to collect and measure the volume of filtrate with respect to time. After the test is finished, the filtration device is disassembled. The final height of the dewatered cake is measured, and the total settlement is calculated. Finally, the analyses of the dewatered cake and the filtrate are conducted.

Table 1. Geotextile properties

Geotextile properties	46T	1212T
Fiber type	Polypropylene	Polyester
Wide width tensile strength, (kN/m)	70105	210210
Wide width elongation, (max)	20%	15%
Puncture strength, (N)	1155	1555
Apparent opening size (AOS), (mm)	0.425	0.425
Water Flow Rate, (l/min/m^2)	810	200
Permittivity, (sec^{-1})	0.3	0.1

2.2 Materials

Two woven geotextiles (Geotex® 46T and 1212T) are used in this study. The first product is composed of monofilament and fibrillated polypropylene fibers and the second one is multifilament polyester fibers. Strength and hydraulic properties of the geotextiles including AOS were obtained from the manufacturer (Table 1). These values are minimum average roll values (MARV) shown

Table 2. Materials properties

Properties	Values		
	GBB	PS	TWM
Water content (%)	588	122	269
Percent solids (%)	14.5	45.1	25.2
Density (g/cm^3)	1.09	1.37	1.16
Initial void ratio, e	13.5	3.3	6.3
Degree of saturation, S (%)	100	100	100
Viscosity value (mPa·s) (25°C)	2100	13000	5600
Organic content (%)	24.1	8.4	25.2
Specific gravity of solid, G_s	2.29	2.66	2.28
Plastic limit, PL (%)	68.8	39.5	48.5
Liquid limit, LL (%)	92.5	55.0	64.0
Plasticity index PI (%)	23.7	15.5	15.5
Shrinkage limit SL (%)	58.9	38.2	N/A
Shrinkage ratio SR	1.01	1.27	N/A
Percent passing No.200 sieve (%)	99	100	100
D_{85} (mm)	0.05*	0.031*	0.021
D_{50} (mm)	0.023	0.014	0.005
D_{15} (mm)	0.005	0.002	0.0006
C_u	10	30	13
C_c	1.34	4.50	1.68

* Estimated by extrapolation.

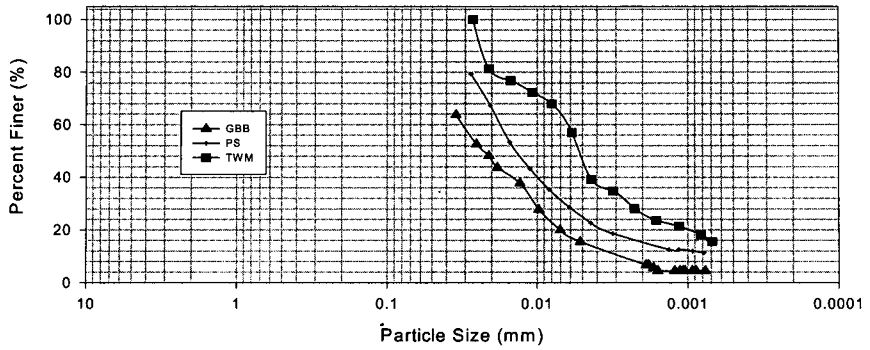

Fig. 2. Particle size distributions

in the machine (warp) and cross-machine (fill) directions. MARVs are calculated as the typical minus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any samples taken from quality assurance testing will exceed the value reported.

Three high water content materials (GGB, PS, TWM) were tested. GGB is a contaminated, fine-grained lake sediment. PS and TWM are two dissimilar sludges from pulp and paper mills. ASTM methods are used to determine the physical and geotechnical properties (Table 2) and solid particle size distributions (Fig. 2).

2.3 Results

Pressure filtration tests were conducted on two filtration pressures, 5 psi (34.5 kPa) and 10 psi (69.0 kPa). Filter cake formation was reported to occur at 5 psi (34.5 kPa), similar to actual field conditions when filling a tube. The higher pressure test, 10 psi (69.0 kPa) replicated the dewatering in a tube over an extended time period.

Data derived from the pressure filtration tests were studied to identify possible factors affecting filtration and dewatering behaviors. Table 3 summarizes the test results, including the initial water content, filtration efficiency, dewatering efficiency, dewatering rate, Total Suspended Solids (TSS) in filtrate, and consolidation coefficient.

The filtration efficiency is determined by comparing the final TSS of the filtrate to the initial Total Solids (TS) of the sample as shown in the following equation.

Table 3. Summary of pressure filtration test results

	Initial Water Content(%)	Filtration Efficiency(%)	Dewatering Efficiency(%)	Dewatering Rate(min^{-1})	Max. TSS in Filtrate(mg/L)	Consolidation Coefficient(cm^2/sec)
Material: GGB						
46T-5	526.1	99.3	44.73	0.0089	1248	3.3×10^{-4}
46T-10	581.1	99.9	67.92	0.0064	374	1.8×10^{-4}
1212T-5	527.1	99.4	64.69	0.0072	1243	2.1×10^{-4}
1212T-10	578.5	99.8	47.34	0.0098	415	2.4×10^{-4}
Material: PS						
46T-5	121.5	99.9	21.45	0.0396	1250	9.66×10^{-5}
46T-10	115.8	99.9	20.41	0.1357	1000	1.33×10^{-4}
1212T-5	121.2	99.8	20.92	0.0528	2000	1.39×10^{-4}
1212T-10	114.7	99.9	14.78	0.1787	970	1.46×10^{-4}
Material: TWM						
46T-5	269.1	99.3	38.23	0.0039	2697	2.79×10^{-5}
46T-10	269.1	99.7	36.57	0.0824	8743	5.99×10^{-5}
1212T-5	269.1	99.5	32.12	0.0207	1723	5.19×10^{-5}
1212T-10	269.1	99.5	36.19	0.0791	1767	9.80×10^{-5}

$$FE = \frac{TS_{initial} - TSS_{final}}{TS_{initial}} \times 100\% \qquad (1)$$

where,

FE = Filtration efficiency, %

$TS_{initial}$ = Initial total solids, mg/L

TSS_{final} = Final total suspended solids in the filtrate, mg/L

A similar concept of dewatering efficiency is used here to describe the dewatering degree in each test. It is determined by comparing the final percent solids to the initial percent solids:

$$DE = \frac{PS_{final} - PS_{initial}}{PS_{initial}} \times 100\% \qquad (2)$$

where,

DE = Dewatering efficiency, %

$PS_{initial}$ = Initial percent solids, %

PS_{final} = Final average percent solids, %

The success or failure of a dewatering project often hinges on how quickly a particular sludge will be dewatered to an acceptable dryness (usually defined in terms of percent solids). To measure this concept, the dewatering rate was defined as the slope of a curve of percent solids and time (Figs. 6~8).

The coefficient of consolidation, C_v, is estimated according to the Early Stage Log t Method (Das, 1997), using the following equation.

$$C_v = \frac{0.0385 H_{dr}^2}{t_{22.14}} \qquad (3)$$

where,

C_v = Coefficient of consolidation (cm^2/sec)

$t_{22.14}$ = Time at an average consolidation degree of 22.14% (seconds),

H_{dr} = Average longest drainage path during consolidation. (The average value of the initial and final height of the dredged material layers in the chamber were used.)

3. Discussions of Results

3.1 Filter Cake

Table 3 shows that for almost all the tests, the filtration efficiencies are quite high. The high filtration efficiencies indicate that although most of the solid particles of the samples have a grain size much smaller than the AOS of the geotextiles, the geotextiles still retain a very high percentage of the solids. Only a very small portion of the solids actually pass through the geotextiles with the filtrate under the filtration pressure. The TSS in the filtrate is high at the beginning of the tests, but then will drop dramatically very soon as the filter cake forms. Comparing the results of tests for each sludge/geotextile under two filtration pressures reveals that higher filtration pressure has very little effect on filtration efficiency, indicating that pressure is not a controlling factor for fine particle retention.

When using AOS as the characteristic pore size of geotextiles, almost all commonly used soil retention criteria in filter design were not satisfied in the filtration tests. It is the filtration capability provided by the combination of geotextile and filter cake that allows the geotextiles tube to retain the solid particles while letting the water flow out. The mechanism of the filtration depends on the porous structure of the geotextiles and the formation of the filter cake during the tests. The porous structure of polypropylene fabrics is quite different from polyester fabrics due to inherent characteristics of the yarns. The formation of the filter cake can be monitored by tracking the flow rate as it changes during the test. Fig. 3 to Fig. 5 show the change in flow rate during the tests. It can be seen that the flow rates drop rapidly after the filtration tests begin. The trend indicates the formation of a filter cake, which is caused by the interactions between the test samples and the geotextiles. At the very beginning of the filtration, the water and some fine particles flow out through the geotextile under the filtration pressure. At this time the flow rate is high because of the high permeability of the geotextile. And during this process, some solid particles begin to bridge

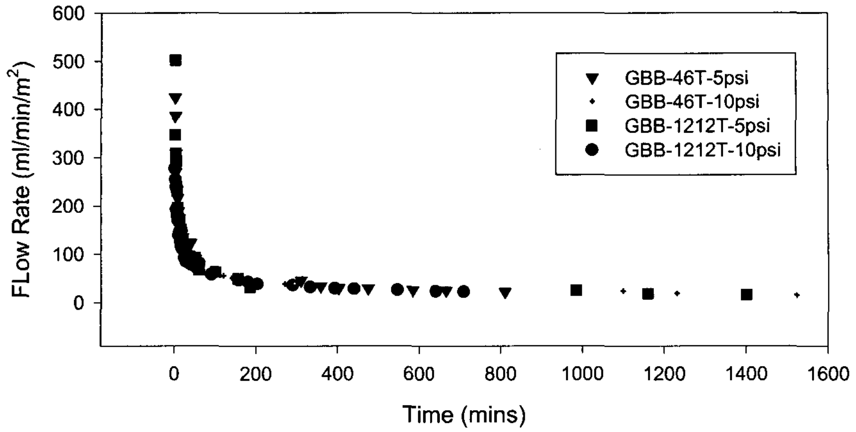

Fig. 3. Flow rate of tests on GBB

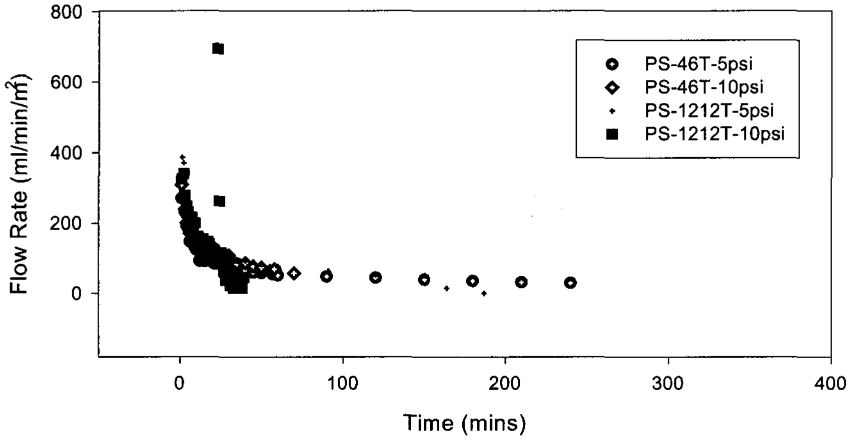

Fig. 4. Flow rate of tests on PS

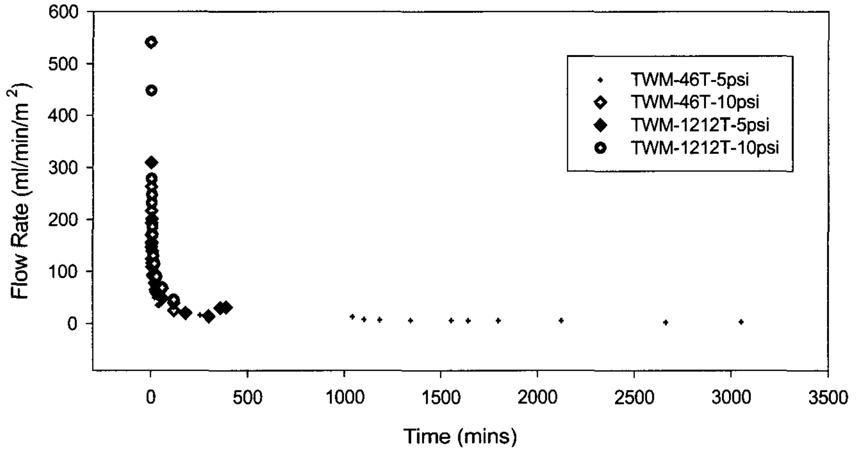

Fig. 5. Flow rate of tests on TWM

the openings and occupy void spaces in the geotextile. The permeability of the filter layer decreases until a new equilibrium is reached.

The formation of filter cakes also can be verified by water content distribution after dewatering. A basic trend for water content distributions is that the water content decreases from the top to the bottom (sludge/geotextile interface). In other words, the water content of the dewatered cake will decrease with its proximity to the geotextile layer. A much drier thin layer of soil attached to the upstream side of geotextiles can be separated from the upper materials. This thin layer with the geotextiles functions as a filter to retain fine particles and cause the permeability to drop. This finding also coincides with field test results. When a geotextile tube is used to dewater the sludge or sediment, a dry outer "shell" can form near the geotextile/soil interface and the water content will increase as a function of the distance away from the geotextile (Gaffney, et al, 1999).

Whether a filter cake can be formed or how fast it will form depends on the sludge properties such as porosity, viscosity, and specific gravity, geotextile hydraulic properties, flow conditions and filtration pressure. In the case where a filter cake can not be formed or forms quite slowly, piping of solids may occur causing much greater loss of fine particles loss.

3.2 Dewatering Capacity

When geotextiles tubes are used for dewatering high water content materials, the dewatering capacity will be the major concern. It includes two aspects: dewatering efficiency (how high a final percent solids can be obtained) and dewatering rate (how long the dewatering will take). Obviously dewatering efficiency and dewatering rate will be controlled by the interaction between the sludge and the geotextile, affected by the sludge properties, geotextile properties and filtration pressures.

Table 3 also lists the dewatering efficiency values for all the tests conducted. For the same material under the same filtration pressure, the dewatering efficiency will vary with geotextile, depending on the hydraulic properties of geotxtile. Other factors such as specific gravity, and filtration pressure also have some effects on the dewatering efficiency.

As expected, percent solids increase with time during the dewatering processes, as shown in Fig. 6 to Fig. 8. The increases appear to be linear for the sediments and

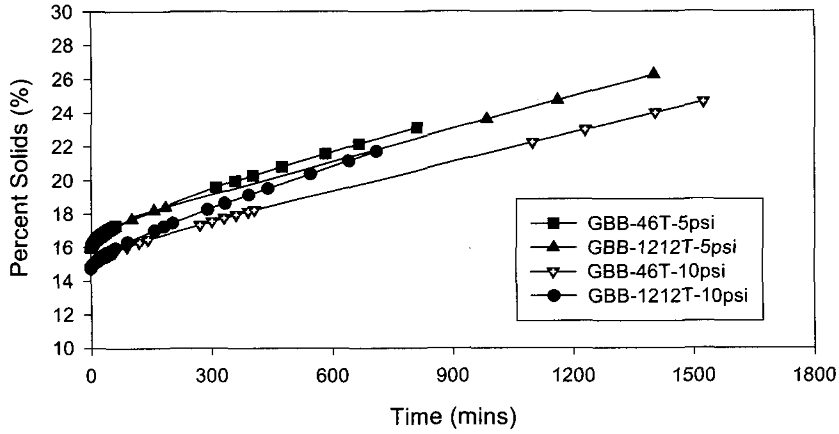

Fig. 6. Percent solids changing in tests on GBB

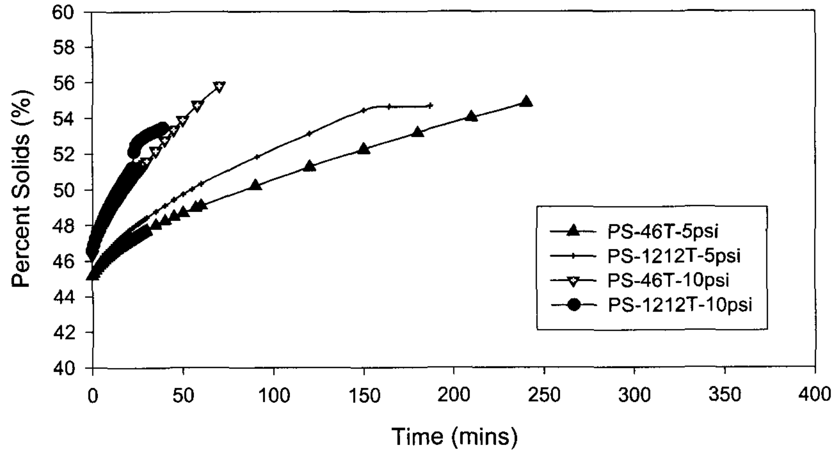

Fig. 7. Percent solids changing in tests on PS

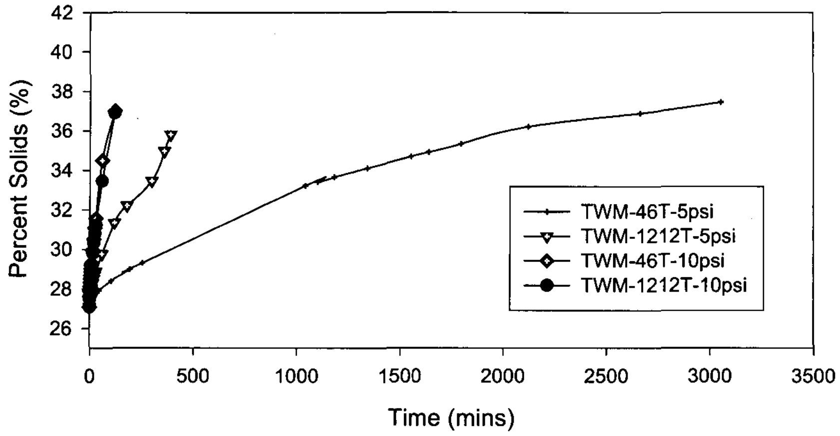

Fig. 8. Percent solids changing in tests on TWM

curvilinear for the biological (waste activated) sludges. The slope (dewatering rate) varies with geotextiles, pressures as well as material properties. However, for different materials, the significance of each factor is different. For GGB, two geotextiles (46T and 1212T) have little influence on the dewatering rates. Meanwhile, for sludges PS and TWM, the dewatering rates change obviously with different geotextiles used. The influence of filtration pressure can be seen in Fig. 7 and Fig. 8. Higher filtration pressure tends to increase dewatering rate but also has the higher potential to cause clogging thus reduce permeability. Sludge properties appear to be the dominant control factors. For this reason, testing of the sludge is often recommended prior to full-scale use in the field. One cannot predict dewatering success based largely on geotextiles AOS or grain size.

The relationship between specific gravity and percent organics is understandable. As the percent organics increase, the overall density (unit weight) of a sludge will decrease. From the tests, it appears that the final water content is higher in the sludges that have higher percent organics. This relationship may be predictable, and further testing may show to be a useful predictor of the final dryness that can be achieved using geotextiles tubes.

4. Conclusions

This study was conducted to explore the use of geotextile tubes for dewatering high water content sludges and sediments, evaluate their feasibility and possible affecting factors. Pressure filtration tests were conducted and analyzed based on this study.

(1) Woven geotextile tubes are far better filtration containers for dewatering high water content materials.

(2) When using woven geotextile tubes for dewatering, soil retention is not a problem. Even when the common soil retention criteria are not satisfied, great portions of fines are retained inside the tubes because of the formation of a filter cake on the upstream of the geotextile. Permeability is the major concern in dewatering applications. The actual permeability of the geotextiles will be much lower than the manufacture's index which is determined using water, not sludge. After the filter cake forms, the permeability drops sharply.

(3) Dewatering efficiency and dewatering rate can be used to measure the dewatering capacity of geotextile tubes. These parameters are affected by several factors related to primarily the sludge, but also to the geotextile. Sludge properties appear to be the dominant control factors for dewatering efficiency. For this reason, testing of the sludge is often recommended prior to full-scale use in the field. One cannot predict dewatering success based largely on geotextiles AOS or grain size. Higher filtration pressure tends to increase dewatering rate but has very little effect on filtration efficiency. In other words, it causes faster dewatering but does not help much to reach a higher final percent solid.

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