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Evaluation of Geotextiles as Liquid Filter

Evaluation de géotextiles en tant que filtres pour liquides

Laboratory filtration tests were conducted on seven filter media (two non-woven and four woven geotextiles and a wire screen). Two commerically available clay products and water of low and high ionic strength were used to prepare suspensions with reproducible properties. The total discharge, the head loss across the filter medium, and the solids removal efficiency were monitored during each test. Values of a filterability index were computed. Although this index was originally developed to rate the performance of granular media, its application to geotextiles yielded values consistent with the performance of each medium as described by observations of discharge velocity, head loss, clogging, and solids removal efficiency. The best overall performance was observed for the non-woven geotextiles. The performance of the 5 µm wire mesh screen appeared to be similar to that of non-woven geotextiles. In general, all four woven geotextiles had the poorest performance, in relation to the other media, under all conditions of suspension, concentration and water chemistry.

Des tests de filtration en laboratoire ont ete entrpris sur sept moyens de filtration (deux non-tisses, quatre tisses et un crible metallique). Ont ete utilises deux produits d'argile disponibles au marche, aussi bien que de l'eau possedant une action ionique basse et elevee, afin de preparer des suspensions avec des qualities reproductibles. La decharge totale, la perte de pression au long du moyen de filtration, aussi bien que l'efficience d'eloignement des solides, ont ete controlles pendant chaque test. Les valeurs d'un indice de filtrabilite ont ete computes. Malgre le fait que cet indice a ete developpe a l'origine pour evaluer la performance du moyen granuleux, son application aux geoxtiles a apportu des valeurs conformes avec la performance de chaque moyen, tel qu'il est decrit par des observations de velocite de decharge baisse de pression, encrassement, et efficience de eloignement des solides. La meilleure performance de tous les moyens a ete observee aux geotextiles non-tisses la performance de la crible de 5 µm est apparue similaire de celle des geotextiles non-tisses. En general, tous les quatre geotextiles tisses ont en la performance le plus faible.

INTRODUCTION

Filtration is one of the main functions of geotextiles. It is the process of allowing the fluid to flow through the fabric while retaining suspended soil particles. Filter cloths have been in use for a long time (1) as components of mechanized filtration systems which may require relatively large pressure gradients. Such systems may be used for dewatering thick slurries (vacuum filters, filter presses, and belt filters) or for clarifying waters with very low concentrations of suspended solids (wedge wire screens, microscreens, and precoat filters). For these cases, very few quantitative design criteria are available for selecting the correct or best filter cloth and designers rely mostly on empiricism, experience, and qualitative charts or criteria (2). For non-mechanized, low maintenance filtration systems, even less information exists on the capabilities of filter cloths to perform as components of the system.

In recent years, the state-of-the-art in designing with geotextiles has substantially advanced (3, 4, 5, 6). In order to evaluate the performance of a geotextile with respect to some of its functions, such as drainage and filtration, it is necessary to obtain its hydraulic properties. The most important hydraulic properties are: permeability, porosity, pore size and distribution, soil retention, level of clogging, and cake formation (7). However, standard methods for testing these properties or even interpreting data from tests are really not available. It has been proposed (7) that the hydraulic properties be determined either relative to the intended use of the geotextile or exclusively on the basis of fabric structure.

Geotextiles are considered herein as shallow or surface filters with a limited capacity for storage of solids. For a single layer woven geotextile the filtration, if effective, results in a cake build-up on the surface. A nonwoven geotextile is a filter with a very shallow depth which is on the order of 10 to 100 times the pore or fiber diameter. Tests on both types of geotextiles are reported herein.

Investigators in the area of filtration have attempted to bridge the gap between theory and empiricism by developing rating techniques and proposing indices for describing the suspension filterability of an arbitrary filter medium. Most of these attempts have been made for application to granular filters. Methodologies proposed for filter cloths (for example, 8, 9) are severely restricted principally because commercially available products come in a wide variety of fabric structures and geometries.

Geotextiles have numerous applications as liquid filters or solid-liquid separators, including settling ponds, groundwater recharge, hydraulic filling, silt fences, silt curtains, and clarifiers for dredging containment area effluents. This work is intended to describe retention and clogging characteristics of several geotextiles challenged with clay-silt suspensions with the results pertinent to one or more of the above applications.

EXPERIMENTAL PROGRAM

The experimental program presented herein was conducted as part of an extensive investigation of filtering systems for dredged materials containment area effluents. Accordingly, the selection of test variables and ranges of these variables was influenced by field performance requirements and the expected range of operating conditions. It is believed, however, that the results obtained provide insight into the performance of the geotextiles tested as liquid filters for dilute suspensions and allow their comparison to other solid-liquid separation devices.

The equipment used for conducting the laboratory tests consisted of a suspension storage tank with continuously operating mixers, a variable speed pump, upstream and downstream overflow tanks for constant head operation, a specially designed filter chamber, a manometer board, and a flow meter. The overall arrangement, as well as some of the structural details of the equipment, is shown in Figures 1 and 2.

The suspended solids in the influent suspensions consisted of commercially available clay soils of two different types: kaolinite and illite (Grundite). The kaolinite was a water-processed hydrated aluminum silicate clay known as Hydrite-R marketed by the Georgia Kaolin Company of Elizabeth, New Jersey; the illite was the principal clay mineral in the clay soil marketed under the name Grundite by the Illinois Clay Products of Joliet, Illinois. The grain-size distributions of these two clays, obtained by hydrometer analysis without the use of a dispersing agent, are shown in Figure 3. Both of these clays possess low levels of soluble salts and certainly do not solubilize significantly. The clays may undergo flocculation/deflocculation depending on solution chemistry.

Suspensions were prepared using 1 g/L and 10 g/L dry solids suspended in either fresh or salt water. Fresh water tests were conducted by using Evanston, IL tapwater (ionic strength about 2×10^{-3}). The salt water used for testing (ionic strength about 0.5) had the same ionic composition of the tap water except for the addition of 30 g/L of a commercial-grade granulated sodium chloride (NaCl). Since varying periods of time may be required for the properties of clays to equilibrate with their aquatic environment, the pH and electrophoretic mobility of the clay suspensions were measured as a function of time. Neither mobility nor pH showed much variation in a typical 8 hour test. The mobilities were negative and generally small (1.5 and 1.9 µm/s/volt/cm for kaolinite and Grundite, respectively) in tap water and approached zero in salt water.

The characteristics of the filter media used are summarized in Table 1. The media were selected in order to obtain variation of media material, pore size, and weave pattern. The average pore size given for media "A" and "B" was obtained from available literature (5) and represents the equivalent opening size (EOS) of the media; pore sizes given for media "C" and "F" are the average minimum dimension obtained by a calibrated laboratory microscope; the specifications for material "E" were supplied by the manufacturer.

Reproducible "standard" procedures were used to prepare the artificial suspensions, conduct each test, and analyze the samples taken. Each test was conducted for a specific combination of filter medium, type of water, and type and concentration of suspended solids. All tests were conducted under constant head rather than constant flow rate since this may be more typical of practice. Each test was started with a flow rate of 16.7×10^{-6} m^3/s but the permeability of the specific filter medium dictated the initial head.

After the equipment was prepared and inspected, the suspension was pumped into the upstream constant head tank and allowed to flow by gravity through the filter cell to the downstream constant head tank. Samples of the influent were taken at the beginning, the end, and periodically during each test. Effluent samples were taken at frequent intervals during the first hour of testing and every hour thereafter. The flow rate and water levels in the piezometer tubes were recorded whenever filtrate samples were collected. Each test was terminated either after eight hours of operation or when the flow rate decreased by approximately one order of magnitude from the initial rate.

For each filter medium, influent and effluent were compared to obtain the size and mass removal efficiency. The number of suspended particles of various sizes was obtained by use of a Model A Coulter counter interfaced with a Nuclear Data multichannel analyzer. The mass removal efficiency was evaluated on the basis of gravimetric determinations and turbidity readings; for this purpose, a correlation between turbidity (NTU) and suspended solids concentration was developed for both the suspensions used (10). Both size and mass removal efficiency measurements required substantial dilution of samples. This resulted in added uncertainty in case of very high or very low removal efficiency as noted later.

RESULTS AND DISCUSSION

The results obtained from this experimental investigation are presented in summary in Table 2; this gives the suspension type, concentration of suspended solids, water chemistry, discharge rate, head loss, flow time, and integrated removal efficiency for each test. Basically, three parameters were used to evaluate the clogging and/or blinding tendency of a given filter medium: (a) the run duration, (b) the reduction in discharge velocity, and (c) the rate of head loss increase across the filter medium. The value for mass removal reported in Table 2 is the mean for the duration of each test. Size removal efficiency is the mean number removal for particle sizes between 1.0 µm and 5.5 µm.

In general, mass and size removal efficiencies were quite low and run times long. The apparent contradictory observation of low size removal yet eventual filter clogging suggests that the coarsest sizes in the suspension are responsible for clogging of the filter.

Increasing influent concentrations from 1 g/L to 10 g/L had varied effects on filter performance. In every test conducted with a high concentration of Grundite, immediate clogging of the filter due to sedimentation and blocking of the face was observed. Similarly, high concentrations of kaolinite caused rapid clogging (run lengths less than 1000 s) in all but the two non-woven fabrics. The run times, in many cases, became so short that it was impossible to obtain samples for determining mass removal efficiencies. In other tests, the mass removal was such that the measured removal efficiency was beyond the accuracy of the experimental method. As expected, high salt concentration suspensions, in general, had increased removal efficiencies compared to tap water suspensions as a result of flocculation of the clays in the salt water.

Comparison of results obtained during this investigation with known data using similar suspensions was possible only for the non-woven media A and B and is presented in Figure 4. According to the information provided (11), a suspension of loess with a concentration of 7 g/L was used to challenge the filter cloths. It can be observed that the results of this

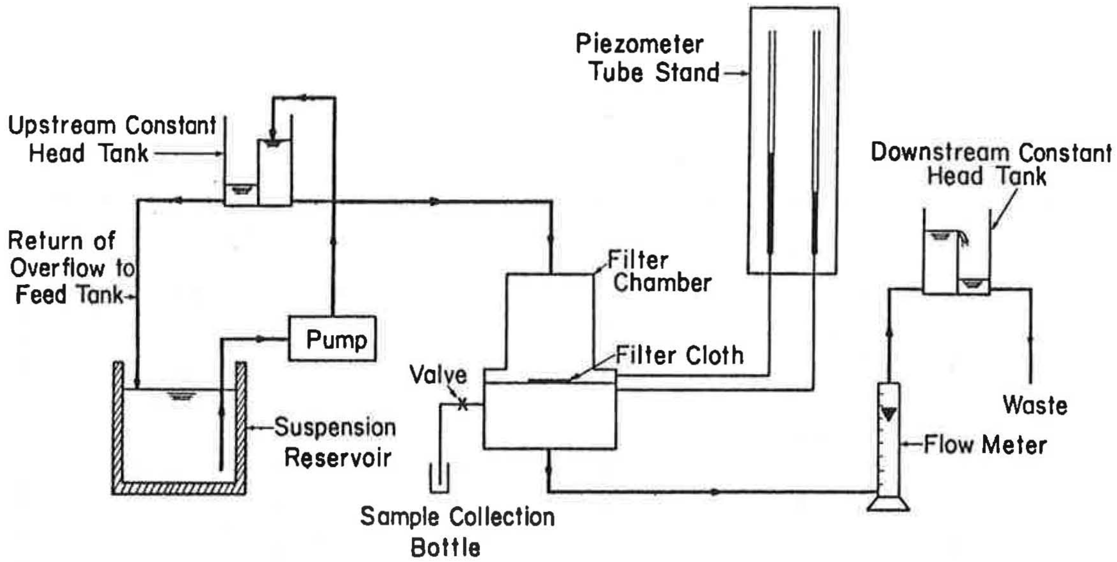

Figure 1. Arrangment of Equipment for Laboratory Testing.

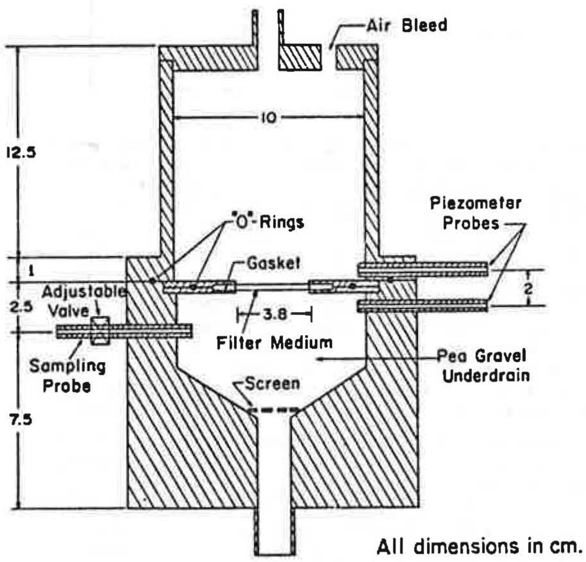

Figure 2. Structural Details of Testing Apparatus.

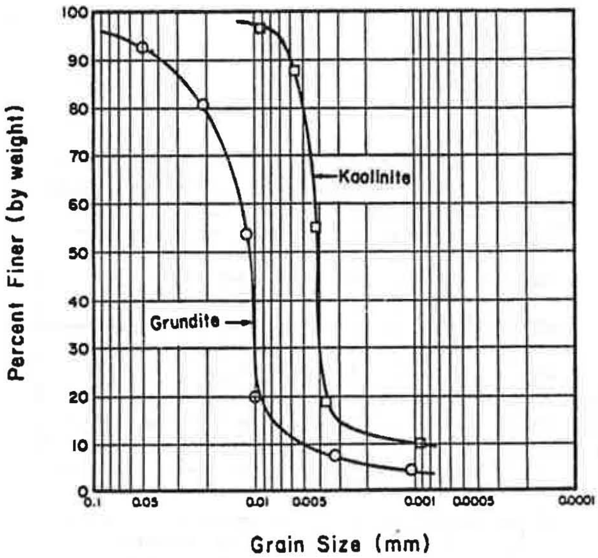

Figure 3. Grain Size Distributions of Suspended Solids

investigation would suggest higher removal efficiencies in the 15-20 μm size range than observed by Monsanto (11); however, results presented herein are not inconsistent.

Based on the results summarized in Table 2, the following observations can be made with respect to the different types of filter media tested:

Non-woven--These materials generally showed the best overall behavior; for run durations ranging from two hours to seven hours, the mass removal efficiency was found to range from 2% to 29% and the size removal efficiency for 1.0 μm to 5.5 μm diameter particles ranged from nil to 56%. Medium A had longer runs before clogging, smaller head loss build-up, and slightly lower removal efficiencies than medium B. Neither medium performed well with suspensions having high influent solids concentrations; immediate clogging was experienced for Grundite suspensions and the performance was even poorer for kaolinite suspensions. For low concentration suspensions the performance of both media was better for either suspension type of water chemistry.

Wire Screen--The performance of the wire screen tested (5 μm opening size) appears to be similar to that of the non-woven media tested under similar conditions.

Table 1

Characteristics of Filter Media

Medium Identification	Average Pore Size (microns)	Weave Pattern	Basic Material	Manufacturer
A	180	Random Fiber	Polyester Homofilament	Monsanto Company
B	150	Random Fiber	Polypropylene Homofilament and Nylon Heterofilament	Celanese Corporation
C	5		Stainless Steel	Cambridge Wire Cloth Company
D	-	2-2 Twill	Multifilament	Lamports Company
E	29	1-1 Plain	Monofilament	Tetko Inc.
F	50	2-2 Twill	Monofilament Polypropylene	National Filter Media Company
G	-	2-2 Twill	Multifilament Polypropylene	National Filter Media Company

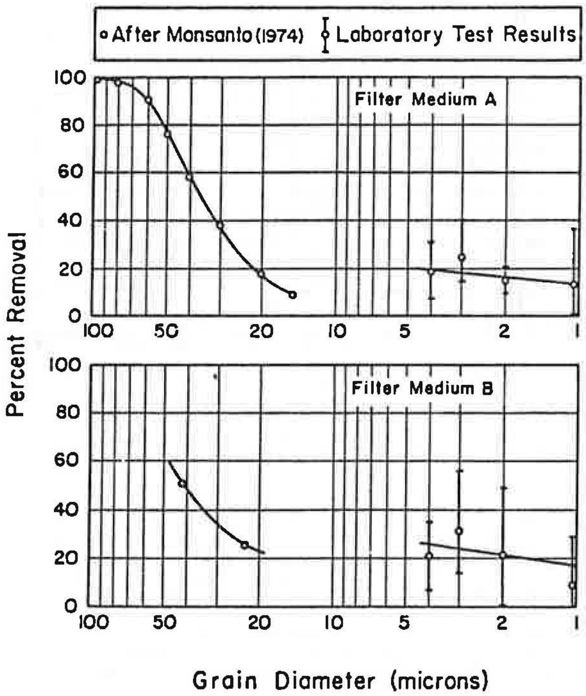

Figure 4. Comparison of Results with Known Data for Media A and B.

Immediate clogging was experienced for high concentration suspensions. At low concentrations the mass removal efficiency was about 15% and size removal efficiency ranged from 1% to 26%; the rate of change of flow rate with time was much smaller than for non-woven media and there was no appreciable increase in head loss with time.

Woven--In general, all four media tested had poor performance (immediate clogging or very short run time) under all conditions of suspension concentration and water chemistry. Medium F (pore size of 50 μm) can be considered an exception for the case of kaolinite suspensions; it had a mass removal efficiency of 8% to 15% and sustained a run time of two hours to three hours.

Over the last 50 years a number of efforts to develop filter indices have focused primarily on application to deep bed rather than surface filters. Sought is an index to facilitate prediction of the behavior of an arbitrary fibrous filter medium. Early attempts to develop such an index resulted in the formulation of expressions which incorporated only one or two of the many variables encountered in cloth filtration. In most cases the dominant variable used was the head loss across the filter. Efforts to incorporate certain cloth characteristics such as pore size and pore geometry in the index (8, 9), were unsuccessful because they required standard pore configurations and could not account for multifilament fabrics or randomly oriented fibers (non-woven media). Furthermore, it was recently concluded (7) that the hydraulic properties of a geotextile are mainly affected by the method of construction and not by the type of material (polymer) used.

Filterability indices have been proposed for a long time (12) to describe granular filter performance; none have found wide applicability or acceptance. However, an index originally proposed by Hudson (13) was developed to the point where a commercial device mar-

Table 2

Results of Laboratory Filtration Tests

Filter Medium	Suspension	Type of Water	Concentration (g/ℓ)	Duration of Test (hours)	Discharge Velocity (cm/sec) Initial	Discharge Velocity (cm/sec) % Change	Head Loss (cm) Initial	Head Loss (cm) Final	Removal Efficiency (%) Mass	Removal Efficiency (%) Size	Filterability Index (10^4)
A	Kaolinite	Fresh	1	4.5	1.46	40	3.56	--	2	ND	7
			10	6.0	1.46	80	3.30	4.83	ND	17-40	14
		Salt	1	4.0	1.46	45	1.02	2.54	4	10-17	5
			10	3.0	1.46	93	1.52	4.06	ND	11-20	32
	Grundite	Fresh	1	7.0	1.46	59	2.03	8.89	9	0-8	8
			10	IC	—	—	—	—	—	—	—
		Salt	1	5.5	1.46	88	2.54	5.84	14	21-31	21
			10	IC	—	—	—	—	—	—	—
B	Kaolinite	Fresh	1	2.0	1.46	95	3.05	7.87	20	29-51	82
			10	2.0	1.46	93	2.29	10.16	ND	0-56	150
		Salt	1	6.5	1.46	87	4.57	8.38	ND	0-16	27
			10	5.0	1.46	90	4.83	7.87	19	9-28	37
	Grundite	Fresh	1	6.0	1.46	87	7.87	11.43	5	12-35	44
			10	IC	—	—	—	—	—	—	—
		Salt	1	3.0	1.46	91	12.45	16.00	29	0-14	161
			10	IC	—	—	—	—	—	—	—
C	Kaolinite	Fresh	1	3.0	2.05	37	23.88	26.67	16	2-20	64
			10	4.0	1.46	32	14.48	14.48	2	1-26	32
		Salt	1	NT							
			10	IC	—	—	—	—	—	—	—
	Grundite	Fresh	1	4.0	1.46	42	13.72	—	10	1-8	27
			10	NT							
		Salt	1	4.0	1.46	46	11.18	—	15	ND	22
			10	IC	—	—	—	—	—	—	—
D	Kaolinite	Fresh	1	0.5	1.46	92	16.76	24.64	6	0-9	1926
			10	IC	—	—	—	—	—	—	—
		Salt	1	NT							
			10	IC	—	—	—	—	—	—	—
	Grundite	Fresh	1	IC	—	—	—	—	—	—	—
			10	IC	—	—	—	—	—	—	—
		Salt	1	NT							
			10	IC	—	—	—	—	—	—	—
E	Kaolinite	Fresh	1	IC	—	—	—	—	—	—	—
			10	IC	—	—	—	—	—	—	—
		Salt	1	NT							
			10	IC	—	—	—	—	—	—	—
	Grundite	Fresh	1	IC	—	—	—	—	—	—	—
			10	IC	—	—	—	—	—	—	—
		Salt	1	NT							
			10	IC	—	—	—	—	—	—	—
F	Kaolinite	Fresh	1	NT							
			10	3.0	1.46	90	1.52	2.79	8	7-30	14
		Salt	1	NT							
			10	2.0	1.46	91	4.57	6.10	15	10-27	62
	Grundite	Fresh	1	2.0	1.46	92	4.57	7.37	12	8-16	107
			10	IC	—	—	—	—	—	—	—
		Salt	1	NT							
			10	IC	—	—	—	—	—	—	—
G	Kaolinite	Fresh	1	2.0	1.46	91	4.57	8.38	4	0-25	95
			10	NT							
		Salt	1	NT							
			10	0.67	1.46	90	42.16	43.69	25	4-37	1674
	Grundite	Fresh	1	NT							
			10	IC	—	—	—	—	—	—	—
		Salt	1	NT							
			10	IC	—	—	—	—	—	—	—

Notes: IC = Immediate Clogging ND = Not Determinable NT = Not Tested keted in the United Kingdom was designed for its determination. This filterability index (12), FI, is computed as

$$FI = \frac{hC}{vtC_o} \qquad (1)$$

where h is the head loss across a granular filter layer, v is the discharge velocity, C and C_o are the effluent and influent suspended solids concentrations, respectively, and t is a certain time period over which the measurements are made. It can be seen that FI is dimensionless and independent of filter depth. High (poor) values are obtained for high head loss or poor filtrate, and low (good) values result for high flow rates, long run times, or low effluent concentrations.

Equation (1) is employed to the results of this study and numerical values of FI are given in Table 2. Note that each variable needed in the determination of the index is time dependent; thus, a weighted averaging was used for each test to develop a single representative value for each parameter over the duration of the test. The averaging technique is expressed mathematically as

$$B_{avg} = \frac{\Sigma\ B(t)\ \Delta t}{\Sigma\ \ \Delta t} \qquad (2)$$

where B(t) is any one of the time dependent variables at the end of a time increment Δt.

Most recent efforts to utilize indices for depth filters require analysis for behavior in a time element and thus the application of Equation (1) to surface or fibrous filters (geotextiles) is not farfetched. In fact, the index (a) was developed on the basis of "single pass" tests, and (b) incorporates the effects of head loss, flow quantity, and mass removal efficiency. Relatively shallow sand layers (30mm thick) were recommended for evaluation of the index. All in all, the index when applied to fibrous media (Table 2) yielded values that were consistent with the performance of each medium, as described by any of the other parameters listed in Table 2. However, these latter values should be considered only as a guide to the performance of a given filter medium; they do not yield information on the time variation of efficiency, blinding versus cake build-up on the medium, or the nature of the breakthrough (if it occurs). Nevertheless, the filterability index can constitute an effective basis for rapidly comparing various filter media or operating conditions.

The results obtained from a filtration test and the performance of a fibrous filter medium are a very sensitive function of the geometric characteristics of the medium. These characteristics include pore size, pore size distribution, porosity, weave pattern, and individual fiber geometry. Obtaining accurate measurements of the effects of these parameters is not possible at this time since standard methods for fibrous filter media rating have not been advanced yet. However, it can be observed that the effects of some, if not all, of these parameters are incorporated into the filterability index presented above, even if only implicitly. For example, a very tightly woven fabric may have small pore sizes and low porosity; neither of these parameters appear in the filterability index but they should be expected to have a significant effect on the removal efficiency, head loss, and/or run time of a test; all of these effects are apparent and incorporated in the filterabilty index. It can be seen that tightly woven fabrics have higher FI than the non-woven varieties on Table 2 independent of suspension and water type.

CONCLUSIONS

Based on the limited experimental investigations reported herein, the following is concluded:

1. In general, geotextiles appear to be poor candidates for use as components of non-mechanized, low maintenance filter systems.
2. Non-woven geotextiles appear to have a better overall performance than woven geotextiles.
3. An indexing technique based on measurements of head loss, flow rate, and mass removal efficiency shows promise of at least effectively screening or rating different geotextiles as liquid filters.
4. Because of the high degree of complexity which exists in the behavior of geotextiles as liquid filters, it is suggested that any new rating technique be employed with caution and that additional tests to those described herein be conducted before sizing a system using geotextile filters as one component.

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