Geotextiles Permeability as a Function of Temperature

A. Bezuijen
Delft Geotechnics, The Netherlands
H. -J. Kohler & H. -U. Abromeit
Federal Waterway Engineering and Research Institute BAW, Germany

ABSTRACT: The correction factors used in various standards to compare permeabilities, measured at different water temperatures, assume laminar flow through the geotextile. In such a situation the permeability is inversely proportional to the viscosity of the pore fluid. In reality the flow through a geotextile in a permeability test will have a laminar and a turbulent component. Therefore the temperature correction generally overestimates the real influence of temperature. For a temperature change from 10 to 20 °C this overestimation can be as much as 30% for a highly permeable geotextile.

In the paper results of constant and falling head permeability tests are presented and compared with a theoretical description of the flow through the geotextile based on the Forchheimer relation.

1 Introduction

The water permeability of a geotextile is an important parameter in filter applications. In a number of cases a sufficient permeability perpendicular to the plane of the geotextile is necessary in combination with a limited opening size. Index tests have been developed in various countries to be able to compare the permeability of various geotextiles. Permeability tests are standardized e.g. in the ASTM in the USA, the German DIN and the Dutch NEN. Further a European standard is being developed and a draft version is available (CEN 1993). Although results of these tests have only a limited relevance for practical applications (e.g. Köhler et all., 1994) , yet the decision to use a certain geotextile is often based on the result of such a test, which makes the outcome of the test important.

It was found that the result of the test depends on the water temperature. Therefore a temperature correction table or graph is included in the standards mentioned above. This correction is based on the temperature dependency of the water viscosity. During the preparation of the Dutch NEN on permeability there were some doubts as to whether the correction factor was correct and a number of permeability tests were performed on different geotextiles at different temperatures to measure the temperature dependency. These "constant head" tests, performed at Delft Geotechnics showed, that the generally applied correction does not describe the real temperature dependency. "Falling head" tests were performed at the BAW to obtain results over a larger range of gradients. In the falling head tests also a sample of granular material was included for comparison.

2 Theory

The flow through granular material with both a laminar and turbulent component is generally described with the Forchheimer equation:

$$i = aq + bq^2 \tag{1}$$

Where i is the hydraulic gradient $(-)$, q the specific discharge (m/s) and a and b are coefficients with dimensions s/m and $(\mathrm{s/m})^2$ respectively. In this equation the first term on the right hand side represents the laminar flow conditions and the second term the turbulent flow conditions. From fluid mechanics it is known that viscosity is important only in case of laminar flow. For example the force on a sphere F_l with diameter D_u propagating with a velocity v through a liquid can, in case of laminar flow, be described with Stokes law:

$$F_l = 3\pi\nu D_u v \tag{2}$$

With ν the kinematic viscosity. In case of turbulent flow, the force is independent of the viscosity of the fluid and can be written as:

$$F_l = C_w \frac{\pi}{4} D_u^2 .0.5 \rho v^2 \tag{3}$$

where ρ is the volumetric weight of the fluid and C_w a factor that only depends on the shape of the sphere. Using equation (1) for granular material, it is also found that only the 'laminar' a coefficient depends on the viscosity (den Adel, 1989). This is the reason why the correction factor used to correct permeability measurements performed at different temperatures overestimates the temperature dependency. It is assumed that the flow is purely laminar. In case of purely turbulent flow no correction factor is needed.

3 Permeability - Permittivity

For granular material the permeability (dimension m/s) is used to describe the water flow capacity, relating the discharge of pore water to the hydraulic gradient. For geotextiles the permittivity (dimension 1/s) is often used. This parameter relates the discharge through the geotextile with the head loss over the geotextile. The advantage of this latter parameter is, that it is not necessary to measure the thickness of the geotextile, which is difficult to measure accurately. Using laminar flow theory the relation between permittivity (ψ) and permeability (k) is:

$$\psi = k/t_g \tag{4}$$

where t_g is the thickness of the geotextile. Using the Forchheimer relation, the relation between head loss and specific discharge can be written as:

$$dh = a_h q + b_h q^2 \tag{5}$$

With a_h and b_h coefficients with dimensions s and s^2/m respectively[1]. The relation between the permittivity and this formula reads:

$$1/\psi = a_h + b_h q \tag{6}$$

From this equation it is clear that the permittivity will be constant in case of laminar flow when the second term on the right hand side can be neglected and depends on q when turbulence is of importance. The relation between a, b and a_h and b_h is comparable to the relation between laminar permeability and permittivity (equation (4)):

$$a_h = a t_g \quad b_h = b t_g \tag{7}$$

4 Measurements

Measurements were performed between 5 and 30 °C. The constant head tests have been performed according to the Dutch NEN 5167 (NEN 1990). The filter velocity varied between 0 and 60 mm/s. The falling head tests were performed in accordance with a method developed by BAW (Köhler, 1993). This method is used as a base for the CEN standard for a falling head test (CEN 1993). De-aired water was used in all the tests. Table 1 presents the results of tests for temperatures between 9 and 27 °C. The traditional correction factor R_t to correct the permeability to a temperature of 20 °C is:

$$R_T = \frac{1.762}{1 + 0.0337T + 0.00022T^2} \tag{8}$$

with T the temperature in degrees Celsius. This relation is used to calculate the ratio between the permeability measured at the higher and lower temperature in table 1 in the column $R_{T,calc}$. The measured ratio is also presented in table 1 in column R_T. This is the ratio in the head loss measured at a velocity of $20 \cdot 10^{-3}$m/s. (the "head loss index" in the draft CEN standard). The last column in the table presents the ratio of the head loss due to the laminar term in equation (5) (the first term on the right hand side) and the total head loss. From the results it is clear that the temperature dependency is not very well described with equation (8). In some cases it is too low in others too high.

5 Discussion

According to the theory described in section 2 temperature correction is only necessary for the laminar term a_h of equation (5). However, the measurements give no straightforward conformation of this theory. Yet the principle seems right. Looking more in detail to the last two measurements, it is found that the permittivity of the high permeable gravel disc, with only a small contribution of the laminar term in equation (5) (8%) to the total head loss, is nearly independent of the temperature and the permeability of the 5 layers of geotextile with a high contribution of the laminar term (87%) follows quite closely the traditional temperature correction, see figure 1.

It is further shown that for the geotextile the temperature dependency of the permittivity decreases for increasing gradients and thus increasing discharges, see figure 2. The reason for this decrease can be derived from equation (6). At a higher gradient the permittivity ψ decreases because q increases and the

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[1] This formula is also used in the draft CEN-standard on permittivity (CEN1993).

sample	10 °C		20 °C		R_T	$R_{T,calc}$	R_l
	a_h (s)	b_h (s^2/m)	a_h (s)	b_h (s_2/m)	(-)	(-)	(%)
constant head							
Typar 3407 (11-19°C)	0.68	17.9	0.64	13.2	1.16	1.25	68
Bidim B2 (10-21°C)	0.32	-1.59	0.27	0.91	1.00	1.34	97
UCO Hi-flow x.44.317 (10-21°C)	0.26	19.7	0.22	19.4	1.07	1.34	38
Lotrak 16/15 (10-20°C)	5.44	342	3.47	173	1.77	1.31	47
falling head							
Terrafix 600							
1 layer (11-23°C)	2.63	20.8	0.97	18.33	2.3	1.37	79
3 layers (11-22°C)	7.84	47.7	4.66	34.7	1.64	1.34	88
5 layers (9-20°)C	10.07	66.0	7.99	62.7	1.23	1.34	87
gravel disc 6-8mm (11- 27°C)	0.0351	21.6	0.0378	20.9	1.03	1.5	8

R_T is the measured ratio in permeability. $R_{T,calc}$ is the calculated ratio in permeability (eq. 8)
R_l is the ratio of the "laminar head loss" to the total head loss

Table 1: Results of permeability measurements measured at water temperatures between 9 and 27°C. The examined temperature range is mentioned for each product.

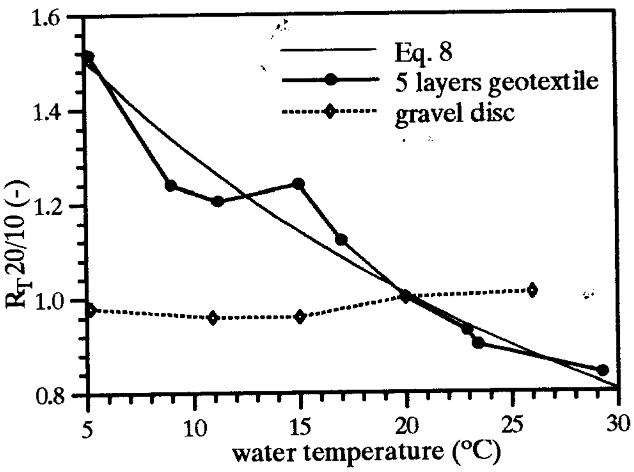

Figure 1: Calculated temperature correction factor (R_T) compared with measurements.

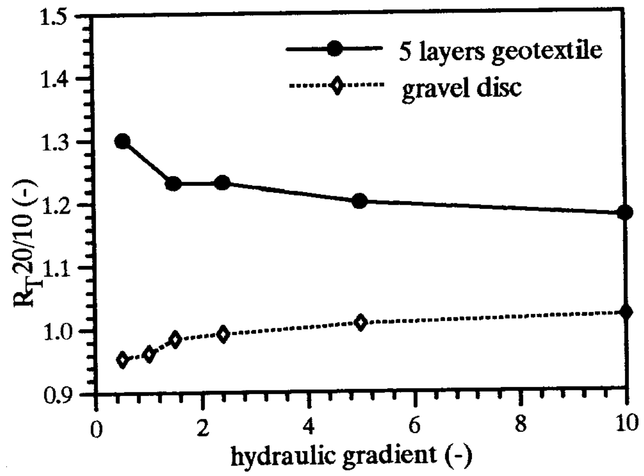

Figure 2: Measured temperature correction factor (R_T) as a function of the gradient.

contribution of the turbulent term $b_h q$ increases. The assumption that only correction for the laminar term is needed results in a decrease of the total measured correction factor when the contribution of the not corrected turbulent term increases.

It is assumed that the discrepancy between measurements and theory is caused by the following reasons: The parameters a_h and b_h cannot be determined with great accuracy. It appeared that different combinations of a_h and b_h lead to practically the same results. This is demonstrated in figure 3. This figure shows the head as a function of time as measured in a falling head test for 5 layers of Terrafix 600 at 20°C. The measurement points are simulated with a formula simulating the hydraulic head as a function of the hydraulic head and the parameters a_h and b_h. The best fit is obtained using a non-linear regression technique to determine a_h and b_h. This fit shows that the result of the test can be described very accurately with equation 5. The other fits are obtained by putting a_h to a value of 8 and 12 respectively and determining the best fit for b_h. The figure shows that although the values for a_h and b_h differ quite considerably, the simulated curves are still close to the measured curve. This means, that small measurement errors can lead to considerable variation in a_h and b_h. With this result it can be concluded, that these parameters can be used to describe the permittivity of the geotextile, but only if the permittivity is calculated in the range the geotextile is tested on. Outside this range large errors are liable to occur.

Another reason is the material to be tested itself. Theory assumes a rigid material which is not influ-

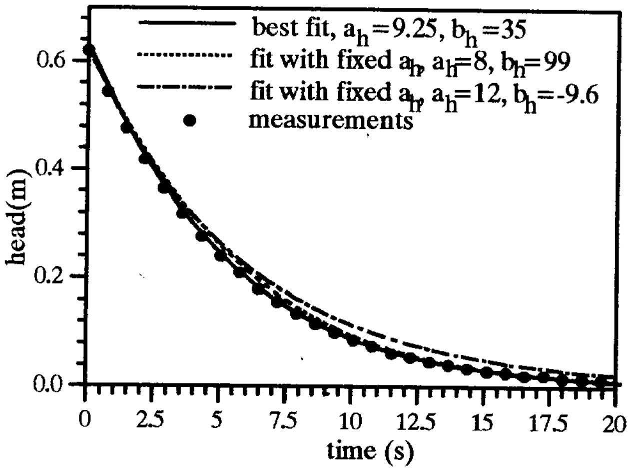

Figure 3: Result of a falling head test on 5 layers terrafix 600 simulated with different parameters for a_h and b_h.

enced by temperature changes. This is correct for the gravel disc in which the gravel was bonded. It is not correct for a flexible material as a geotextile. Different hydraulic heads result in different loads on the geotextile and changes in the pores of the geotextile, leading to changes in the permittivity. Such an effect will influence the permittivity parameters. Furthermore the mechanical properties of the polymer in geotextiles change considerably with temperature. Due to the reasons mentioned above, a temperature correction coefficient will always introduce inaccuracies. When a large permittivity is needed Bidim B2 should be tested with a high temperature and Lotrak 16/15 with a low temperature, according to table 1. In the temperature between 10 and 20°C 30% can be 'gained' in permittivity when the right temperature is chosen. To prevent this inaccuracy is was decided for the European CEN standard to allow only a narrow temperature range (18 - 22 °C) in which a permittivity test can be performed.

6 Conclusions

Simulation of the results of falling head tests with a formula based on equation (5) showed that the Forchheimer equation can describe the permittivity of a geotextile over the range tested on.

The results of the permittivity tests show that a correction factor for the temperature as prescribed in various standards on permittivity is not correct.

From a theoretical point of view it must be possible to use a temperature correction for the laminar term in the permittivity relation only. However, due to the difficulty in determining the parameters a_h and b_h accurately and deviations that may occur due to the flexibility of the material tested on (geotextiles), the best way of obtaining comparable results from different tests is to allow a temperature range as small as practically possible, as suggested in the CEN standard.

7 References

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