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About Longitudinal Permeability and Draining Capacity of Non-woven Geotextiles

La perméabilité longitudinale et la capacité de drainage des géotextiles non-tissés

The paper presents a device and a laboratory methodology allowing the simulation of a parallel streamlined flow under a loading perpendicular on the fabrics surface. The results of the experiments reveal the influence of fibre characteristics and consolidation technologies over the studied parameter value. The same conclusions are obtained by a theoretical analysis starting from the idea of an existing laminar flow along a "corridor" limited by two fibres. A comparison between the permeability coefficients experimental values k_p and k_n shows that $k_p = C\ k_p$ $(3 < C < 25)$. The final part of the paper defines the non-woven fabrics drain capacity diminution ratio in relationship both with the loading and the clogging state.

L'article présente un dispositif et une méthodologie de laboratoire, qui permet la simulation d'un écoulement à lignes de courant parallèles en conditions de charge normale sur la surface des géotextiles. Les résultats des expérimentations relevent l'influence des caractéristiques des fibres ainsi que des technologies de fabrication sur la valeur du paramètre étudié. On peut arriver aux mêmes conclusions aussi par un traitement théorique, en partant de l'hypothèse d'un courant laminaire au long d'un couloir bordé par deux fibres. Une comparaison entre les valeurs expérimentales des coefficients de perméabilité k_p et k_n montre que $k_p = C\ k_p$ $(3 < C < 25)$. Dans la partie finale du rapport, on définit théoriquement des indices de réduction de la capacité de drainage des géotextiles non tissés par rapport à la charge et l'état de colmatation.

1. INTRODUCTION

If the fact is accepted that fabrics are porous media having the ability to pass water according to Darcy's Law, the two permeability coefficients can be defined by comparing them to the flow direction as related to the fabrics plane. Thus:

k_n = coefficient of normal permeability (water passing through the fabric perpendicular on its plane);

k_p = coefficient of permeability in the plane (water passing through the fabric parallel with its plane).

Non-woven geotextiles permeability is influenced by many factors reflecting the utilisation conditions of the "soil-geotextile complex". Some of the main influencing factors are:

- fabrics plane normal preasure and loadings dynamics;
- type of fabric, raw material included, fibres caracteristics and dimensions, bonding agents, formation of the fabric, a.s.o.;
- mineralogical composition, shape and dimensions of the neighbouring soil particles;
- physical and chemical water characteristics.

For the study of normal permeability (k_n) the last decade literature offers a large range of methods of determination with devices and methodologies original or adapted after the geotechnical laboratory techniques.

For the longitudinal permeability (k_p) most of the published works notice experimental arrangements for which the flow is radially and symetrically going through the fabric layer. Actually the flow through non-woven fabrics runs symetrically and in the plane taking well established directions, lengthwise or crosswise.

It is of use to remember the fact that one of the non-woven geotextiles feature is the anisotropy of all characteristics especially in comparison with the two directions.

2. DEVICE FOR THE DETERMINATION OF NON WOVEN GEOTEXTILES PERMEABILITY IN THE PLANE

To reunite and simulate all the factors influencing a certain characteristic during the test is known to be almost impossible. Therefore a device has been designed to maintain the equally distributed normal loading as unique factor of influence over the environment.

The operation of the system shown in fig.1 allowes the determination of the discharge passing in the plane of the non-woven fabric for various loadings applied by means of the elastic membrane "2". It is also possible to strictly controle the hydraulic gradient (i) having values that range from $i = 0.01$ up to $i > 1.0$.

The permeability coefficient value obtained with this devices is:

$$k_p = \frac{q}{\pi (D T_\sigma - T_\sigma^2) \cdot i} \qquad (cm/s) \qquad (1)$$

where:
q = rate of discharge (cm^3/s);
D = fabric sample exterior diameter (cm);
T_σ = fabric thickness for σ loading (cm);
i = hydraulic gradient.

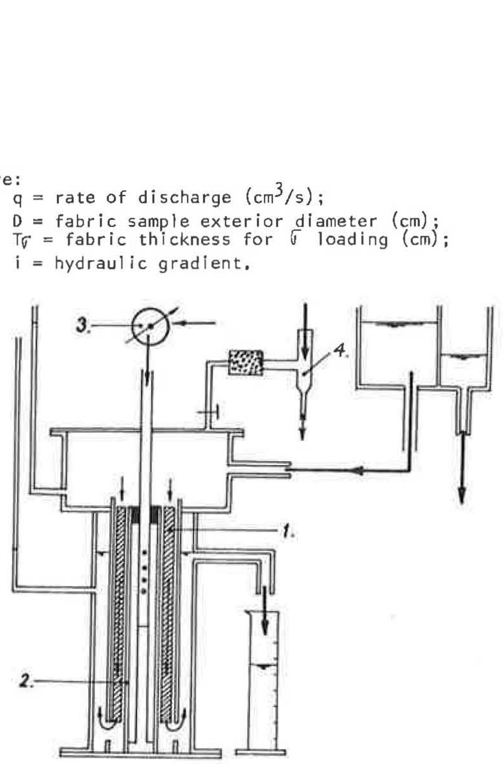

Fig.1. Device for measuring the lengthwise permeability: 1 - cylindrical sample of geotextile; 2 - pressurized elastic membrane; 3 - manometer; 4 - vacuum pump.

3. TESTED MATERIALS. CONDITIONS OF EXPERIMENTS

With the use of the above mentioned device experiments have been made on a large range of non-woven fabrics among which the following are discussed in the present paper:

- MADRIL$^{(R)}$ M - non-woven fabric made of polypropylene fibres having the fineness (linear density of fibres) 0.66 tex (d_f = 31 μm) and with the length 60 mm, mechanically bonded by needlepunching.

The mass for 1 cm^2 of fabric (μ_s) is 2.85×10^{-2} - 5.92×10^{-2} g/cm^2.

- MADRIL$^{(R)}$ V - non-woven fabric made of polypropylene fibres having the fineness 2 tex (d_f = 53 μm) and the length 100 mm, mechanically bonded by needlepunching ($\mu_s = 3.56 \times 10^{-2} - 7.15 \times 10^{-2}$ g/cm^2).

- BIDIM$^{(R)}$ - non-woven fabric made of continuous filament polyester fibres having d_f = 28 μm spun and then mechanically entangled by needlepunching ($\mu_s = 1.49 \times 10^{-2} - 5.41 \times 10^{-2}$ g/cm^2).

- V.P.P. Im.- non-woven fabric made of polypropylene fibres having the fineness 1.7 tex and the length 100 mm bonded mechanically by needlepunching and chemically by Romacryl ($\mu_s = 3.24 \times 10^{-2} - 5.81 \times 10^{-2}$ g/cm^2).

Before being positioned in the device the MADRIL and BIDIM samples have been dipped in water for 24 hours and the V.P.P.Im. sample for 30 days their setting being also performed under water.

Flow rates were measured after one hour from the loading application and the hydraulic gradient stabilization. For each stage three values had been scored up the tests being performed on three samples in three parallel devices.

4. OBTAINED RESULTS

Analysing the diagrame from figure 2 (σ = 0.1-0.22 Pa) one can notice that for any value of σ the $q = \Omega k_p i$ dependence takes place between the limits of domains determined by the intrinsic fabric characteristics (μ_s, T_σ, fibre fineness - λ, non-woven fabric denseness - ∂_σ (3) a.s.o). The observation made for the non-woven fabric BIDIM$^{(R)}$ is valide for all the tested fabrics. In the figure the hatched areas represent experimental values scattering domain.

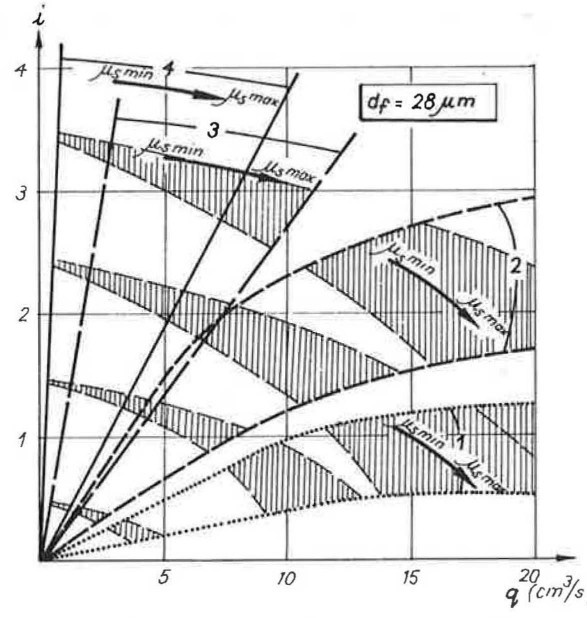

Fig.2. 1 - σ = 10 k Pa; 2 - σ = 14 k Pa; 3 - σ = 18 k Pa 4 - σ = 22 k Pa; $\mu_{s\,min} = 1.49 \times 10^{-2}$ g/cm^2; $\mu_{s\,max} = 5.41 \times 10^{-2}$ g/cm^2

Such a behaviour is to be explained by the re-setting of fibres due to the σ loading as well as to the appearance of several by-phenomena generated by the water movement (i.e. fibres vibrations) and depending of the polymer specific weight (γ_p), λ, ∂_σ and μ_s. Thus, in the expression of q discharge the term influenced by this fibres re-setting is the product between Ω (flow cross section) and k_p. For emphasizing the variation law $\Omega k_p = f(\sigma)$ the diagram shown in figure 3 had been drawn (for BIDIM$^{(R)}$).

In the representation $\Omega k_p = f(\sigma)$ the hatched area corresponds to the areas from figure 2 in which the discharge velocities v are directly proportional to the hydraulic gradient i and the domain limited by the dotted lines correspond to the areas in which $v = f(i)$ has an exponential form.

From the point of view of permeability as a function of non-woven fabric fibres fineness (fig.4) for any value of σ the diferences are obvious and they diminish when $\sigma_{n+1} > \sigma_n$.

The diagrams from figure 5 comparatively present the variation $k_p = f(\sigma)$ and $k_n = f(\sigma)$ for the four tested materials. One can notice differences of behaviour in comparison with the fabric layer bonding technology. Thus for the same value of σ the mechanically bonded fabrics have permeabilities almost one order of magnitude higher than those both mechanically and chemically bonded.

The marked permeability diminution tendency for V.P.P. Im. fabrics can be due to the bonding film in time capacity to swell when being in contact with water.

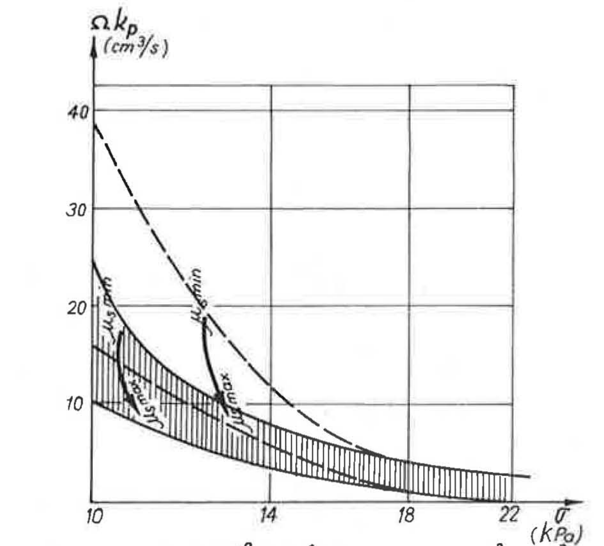

Fig.3. $\mu_{s\ min}=1.49\times10^{-2}$ g/cm^2; $\mu_{s\ max}=5.41\times10^{-2}$ g/cm^2.

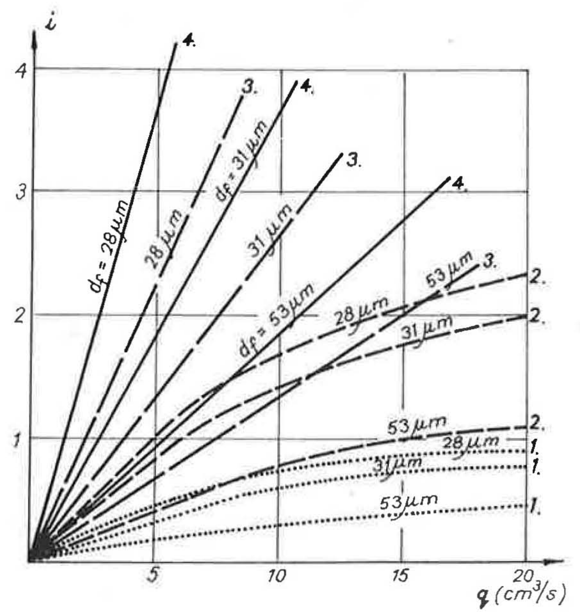

Fig.4. Fibres fineness influence over the drained discharges; d_f = fibre diameter.

For the determination of k_n a modified oedometer box had been used (1). Comparing the results obtained for k_n and k_p one can notice an existing relation of the type $k_p = C\,k_n$ in which C is varying as a function of λ and σ. In table 1 the ratio k_p/k_n values obtained by experiment are presented.

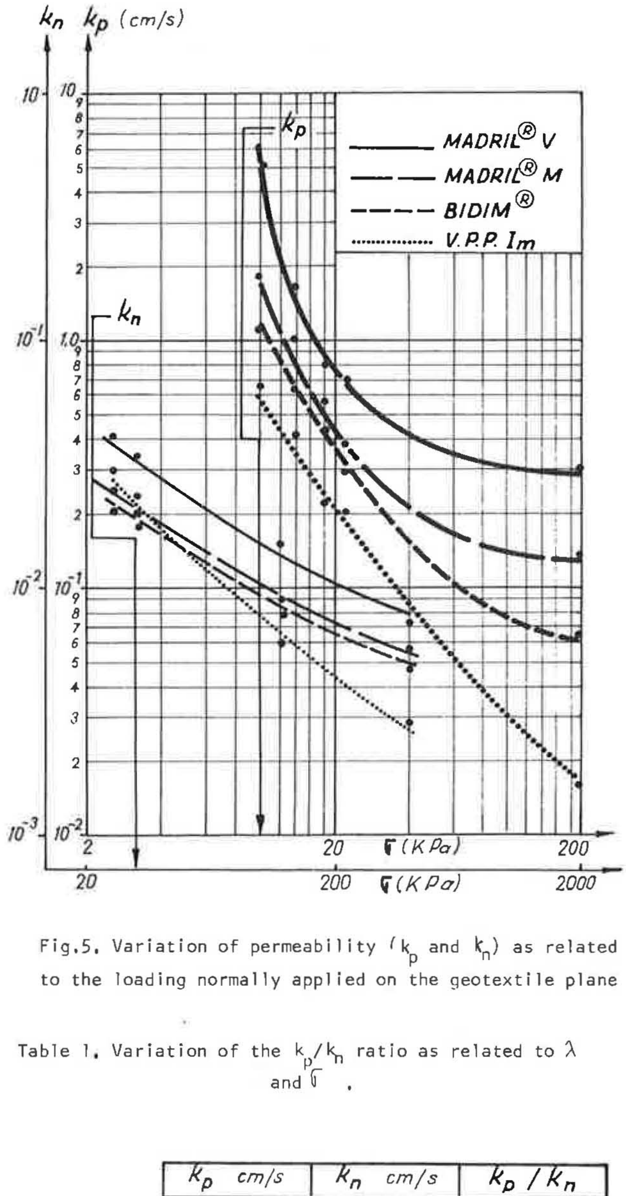

Fig.5. Variation of permeability (k_p and k_n) as related to the loading normally applied on the geotextile plane

Table 1. Variation of the k_p/k_n ratio as related to λ and σ.

	k_p cm/s		k_n cm/s		k_p/k_n	
	σ (KPa)		σ (KPa)		σ (KPa)	
	22	200	22	200	22	200
MADRIL® V	$7\cdot10^{-1}$	$3\cdot10^{-1}$	$4\cdot10^{-2}$	$1{,}2\cdot10^{-2}$	17,5	25
MADRIL® M	$3{,}6\cdot10^{-1}$	$1{,}4\cdot10^{-1}$	$2{,}6\cdot10^{-2}$	$7{,}3\cdot10^{-3}$	13,8	19,2
BIDIM®	$2{,}8\cdot10^{-1}$	$6\cdot10^{-2}$	$2{,}2\cdot10^{-2}$	$6{,}5\cdot10^{-3}$	12,7	9,2
VPP Im	$2\cdot10^{-1}$	$1{,}7\cdot10^{-2}$	$2{,}8\cdot10^{-2}$	$4{,}5\cdot10^{-3}$	6,4	3,8

5. THEORETICAL CONSIDERATIONS CONCERNING THE PERMEABILITY IN THE PLANE OF GEOTEXTILE

The relation (2) given by Poiseuille (2) is supposed for the average laminar flow velocity through a capillary tube

$$v = \frac{\gamma_w}{8\eta_w} R^2 i \qquad (cm/s) \qquad (2)$$

in which:

γ_w = unit weight of water;

η_w = dynamic viscosity of water;

R = radius of the capillary tube

is also true in the case of non-woven fabrics considering a flow along a capillary "corridor" limited by 2 fibres having a d_f diameter (fig.6).

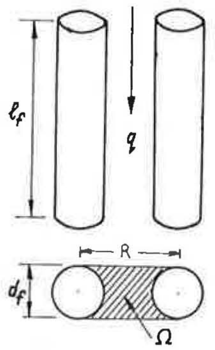

Fig.6. Model of laminar flow: R = distance between fibres; Ω = flow cross-section.

If the hydraulic radius R_H is to be defined as the ratio between the amount of water passing through the capillary "corridor" with Ω section and the wetted surface

$$R_H = \frac{4R - \pi d_f}{4\pi} \qquad (3)$$

the following expression is obtained for R

$$R = \frac{\pi(4R_H + d_f)}{4} \qquad (4)$$

Replacing the value of R given by (4) in the relation (2) one obtaines

$$v = \frac{\pi^2}{128}\frac{\gamma_w}{\eta_w}(4R_H + d_f)^2 x i \quad (cm/s) \qquad (5)$$

If refference is to be made now to the ensemble of fabric the hydraulic radius R_H can be defined as the ratio between the water amount passing through the fabric pores and fibres wetted side surface. Thus if it is supposed that the fibres have an absolute value volume (for a normal loading σ) they make a void equal to e_σ (e_σ = = void ratio) and their side surface is equal to A_l (A_l= = fibres side surface corresponding to μ_s mass).

$$R_H = \frac{e_\sigma}{A_l} \qquad (6)$$

Replacing the R_H value given by (6) in the relation (5) one obtaines:

$$v = \frac{\pi^2}{128}\frac{\gamma_w}{\eta_w}\left(\frac{4e_\sigma + A_l \cdot d_f}{A_l}\right)^2 i \quad (cm/s) \qquad (7)$$

The relation (7) represents the expression of the flow velocity through a section entirely full of water. In order to meet the real flow conditions through porous media the multiplication of (7) by porosity n_σ or by the ratio($(e_\sigma/1+e_\sigma)$) is necessary. Thus:

$$v = \frac{\pi^2}{128}\frac{\gamma_w}{\eta_w}\left(\frac{4e_\sigma + A_l \cdot d_f}{A_l}\right)^2 \cdot \frac{e_\sigma}{1+e_\sigma} \cdot i, \qquad (8)$$

The expression (8) has the same form as the Darcy's Law ($v = k_p i$). For d_f, A_l and e_σ relations can be written as a function of laboratory measured elements, namely

$$d_f = 2\sqrt{\frac{\lambda}{10^5 \pi \gamma_p}} \qquad (cm) \qquad (9)$$

$$A_l = 2\mu_s\sqrt{\frac{10^5\pi}{\lambda\gamma_p}} \qquad (cm^2) \qquad (10)$$

$$e_\sigma = \frac{T_\sigma \cdot \gamma_p}{\mu_s} - 1 \qquad (11)$$

Replacing in (8) the values given by (9),(10),(11) one obtains for k_p from the velocity expression the value

$$k_p = \frac{\pi}{32} 10^{-5} \frac{\gamma_w}{\eta_w} \lambda \left(\frac{T_\sigma \gamma_p^2 - \gamma_p \mu_s + \mu_s^2}{\gamma_p \mu_s^2}\right)^2 \frac{T_\sigma \gamma_p - \mu_s}{T_\sigma} \quad (cm/s) \qquad (12)$$

Analysing the expression (12) one can notice the non-woven fabrics physical characteristics influence over the permeability value, fact also revealed by the results of the above described experiments. The values of k_p obtained by using the relation (12) are quite resemblant to those obtained by experiments. Between the calculated value of k_p and its experimental one (k_{p_c} and $k_{p_{ex}}$) there is a relation of the type

$$k_{p_{ex}} = C \cdot k_{p_c} \qquad (13)$$

where C is a coefficient varying as a function of the fabric compaction. For C values had been experimentally obtained ranging between 1.4 and 0.25 inversely proportional to the σ value increment. Thus, the expression (12) can be formulated:

$$k_p = C \frac{\pi}{32} 10^{-5} \frac{\gamma_w}{\eta_w} \left(\frac{T_\sigma \gamma_p^2 - \gamma_p \mu_s + \mu_s^2}{\gamma_p \mu_s^2}\right)^2 \lambda \frac{T_\sigma \gamma_p - \mu_s}{T_\sigma} \quad (cm/s) \qquad (14)$$

6. ASPECTS CONCERNING THE NON-WOVEN FABRICS DRAIN CAPACITY

If one considers a non-woven fabric having T thickness and B width the following expression can be written (4)

$$k_p = \frac{q}{T \cdot B \cdot i} \qquad (cm/s) \qquad (15)$$

If it is noted: k_{pi} = initial permeability; $k_{p\sigma}$ = permeability under loading; permeability diminution ration "r" can be thus defined

$$r = \left(1 - \frac{k_{p\sigma}}{k_{pi}}\right)100 \qquad (\%) \qquad (16)$$

when i = ct the relation (16) becomes

$$r = \left(1 - R\frac{q_\sigma}{q_i}\right)100 \qquad (\%) \qquad (17)$$

where

$$R = \frac{T_i}{T_\sigma} \quad or \quad R = \frac{1}{1-\varepsilon} \qquad (18)$$

in which ε = fabric strain under loading.

The index "r" thus expressed can be considered as fabric drain capacity efficiency ratio. The coefficient R is a typical element for each fabric depending on the fabric type and the σ loading. Fabrics drain capacity is liable to be influenced in time by the clogging with solid flow or by a biological clogging.

Thus in the case of solid flow clogging, the water containing fine particles passes through the fibred material lengthwise reaching the collector in a time interval $\Delta t_m = t_2 - t_1$. Obviously the length of the material favours the particles retention to a greater extent than in the case of a normal flow on the fabric plane. Consequently a corresponding transport capacity of solid flow will be imposed to the fabric. This requirement can be satisfied if the fabric is correctly selected taking into consideration the fibres characteristics and bonding technology influence over its permeability in the plane.

As far as the biological clogging is concerned the phenomenon although depending on less measurable environmental factors can be simply expressed as $q_{to} > q_t$ in the time interval $\Delta t_b = t - t_o$. In comparison with environmental conditions Δt_b is much greater then Δt_m.

If it is considered that in Δt_m interval σ, T and i are constant one can write

$$r_c = \left(1 - \frac{\Omega_{t_2}\, k_{pt_2}}{\Omega_{t_1}\, k_{pt_1}}\right) \cdot 100 \qquad (\%) \qquad (19)$$

where Ω represents the effective surface of flow through the drainant fabric before (Ω_{t_1}) and after (Ω_{t_2}) clogging. Thus (19) acts as a ratio expressing the drain capacity diminution by clogging.

If it is admitted that by clogging with solid flow μ_s increases by a weight corresponding to n soil particles (considered as being spherical) having the unit weight γ_s and the diameter d

$$\Delta\mu_s = \mu_{st_2} - \mu_{st_1}$$

$$\Delta\mu_s = \frac{n\pi d^3 \gamma_s}{6} \quad , \qquad (g) \qquad (20)$$

the surface Ω_s, by which the n particles obturate the initial effective surface of flow Ω_{t_1} will be:

$$\Omega_s = \frac{3}{2}\,\frac{\Delta\mu_s}{d \cdot \gamma_s} \qquad (cm^2) \qquad (21)$$

Thus if for B = 1, Ω_{t_1} has the value

$$\Omega_{t_1} = T - d_f \cdot l_f \qquad (22)$$

in which l_f = nominal length of fibres (3)

$$\Omega_{t_1} = T - 2\mu_s \sqrt{\frac{10^5}{\lambda\pi\gamma_p}} \qquad (cm^2) \qquad (23)$$

then

$$\Omega_{t_2} = \Omega_{t_1} - \Omega_s \qquad (24)$$

or

$$\Omega_{t_2} = T - 2\mu_s \sqrt{\frac{10^5}{\lambda\pi\gamma_p}} - \frac{3}{2}\,\frac{\Delta\mu_s}{d\gamma_s} \qquad (24')$$

Thus (19) can be written:

$$r_c = \left\{1 - \frac{k_{pt_2}}{k_{pt_1}}\left[1 - 1{,}5\,\frac{\Delta\mu_s}{d\gamma_s}\,\frac{\sqrt{\lambda\pi\gamma_p}}{\left(T\sqrt{\lambda\pi\gamma_p} - 2\mu_s 10^{2,5}\right)}\right]\right\} 100\ (\%) \quad (25)$$

Analysing the expression (25) one can notice that the reduction by clogging of the drain capacity is influenced by the dimensions of the retained particles and their amount as well as by the fabric intrinsic characteristics.

As far as the ratio between the permeability before and after the clogging is concerned the problem is more difficult as after clogging the flow passes through a grain-fibre-structured porous medium.

7. CONCLUSIONS

- The present paper submits to the attention of the specialists a device and a laboratory methodology for the determination of lengthwise permeability (k_p) for non-woven fabrics that simulates the hydraulic and loading real conditions.

- The study deals with the geotextile intrinsic permeability aiming at emphasizing its characteristics influence over the viewed parameter. The results of the experiments over a large range of non-woven fabrics (from which four are presented) demonstrate the lengthwise permeability dependence on the fibres fineness, the fabrics strain under loading as compared to the applied loading, the materials production technology a.s.o. The theoretically obtained expression of k_p on the basis of a laminar flow through a "corridor" limited by two fibres confirm the results of the experiments.

- Comparing the experimental values obtained for k_p and k_n it is noticed that $k_p/k_n > 1$ (3 ... 25).

- Analysing the intrinsic drain capacity of the fabric as well as that existing in clogging conditions diminution and efficiency indices are defined for the studied parameter. In this case too the necessity to take into consideration the geotextile fibres characteristics is emphasized. Furthermore the drain capacity under the circumstances of the existing clogging phenomenon is influenced also by the retained solid particles dimensions and amount.

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