

HYDRODYNAMIC DISPERSION OF SOLUTE IN POROUS MEDIA

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ABSTRACT

A measure for the mixing process by hydrodynamic dispersion in porous media is the dispersion coefficient described by a longitudinal and a transversal component. The dispersion coefficient is dependant on the flow rate of the groundwater and the dispersivity factor which can be determined by the structure (sedimentological properties) and the texture (inhomogeneity, stratifications) of the porous medium. For some natural granulometric mixtures, the dispersion coefficients as determined in laboratory testing are specified and compared with bibliographic data.

INTRODUCTION

Media dissolved in the groundwater are subjected to a modification of their concentration while they are carried along with the current. This modification is caused by reciprocal action between the solute and the porous medium as well as by the chemico-biological degradation and by physical phenomena. To this effect, the most relevant physical action is the hydrodynamical dispersion. It is a mechanical mixing process within the porous medium. The dispersion coefficient is a measure for the degree of dispersion. It is to be determined via the longitudinal (D_L) and the transverse (D_T) component (refs. 1, 3, 4, 5, 9). The purpose of this research work is to undertake tracer explorations in artificial porous media, the results of which may be used to determine dependences of the dispersion on parameters of the groundwater flow and the porous aquifer. For some natural loose rock, the coefficients of the longitudinal dispersion as determined by laboratory tests were to be compared with bibliographic values determined in field testing. The relative investigations are carried out in columns and flow receptacles.

RESULTS

Longitudinal Dispersion

Dependence of the Longitudinal Dispersion on the Parameters of the Groundwater and of the Porous Medium. A great number of tests carried out on artificial

granular mixtures (refs. 6-8) yielded the following results which are being reproduced in an abridged form:

1) The coefficient D_L of the longitudinal dispersion and the distance velocity v_a are linked to each other via the relation

$$D_L = B_L \cdot v_a^{A_L} \quad (1)$$

The constant parameter A_L lies within the range of $1.0 \leq A_L \leq 1.2$. The magnitude B_L presents the dimension of a length parameter ("dispersion length"), as long as $A_L = 1$. The ratio $B_L = D_L / v_a^{A_L}$ (longitudinal dispersivity) depends on the parameters of the groundwater flow and of the porous aquifer.

2) D_L increases, on account of the viscosity of the liquid, as a function of the decreasing temperature of the groundwater.

3) D_L increases in line with the increasing densification and, particularly, in line with the increasing medium granulometry for $d_{50} \geq 0.5$ mm and, finally, in line with the increasing degree of disparity of the porous medium. On the other hand, the influence of the granular form and of the coarseness and splinteriness of the grain on the D_L -factor is only slight.

4) D_L increases with constant stratum density in line with the decreasing water content.

5) There is no direct relation between the permeability of the porous medium and D_L .

Longitudinal Dispersion of Natural Materials. As far as the natural materials investigated, we base our research work on loess rock samples originating from one and the same deposit area. From the sedimentological point of view, they therefore differ only in quite a few parameters. TABLE 1 shows a summary of the natural grain mixtures tested in our laboratory, with their characteristic parameters derived from screening curves and from the factor A_L and B_L calculated according to the equation (1).

The results shown in figure 1a come to confirm the experience gained with respect to the longitudinal dispersion on the basis of the artificial grain mixtures. Thus, the results of the measurements carried out on drift and valley sands in Northern Germany (Fig. 1a, I and II) show small dispersivity values (B_L in the millimeter and centimeter range), which is due to their small granular sizes and disparity degrees. In analogy to this, the measurements carried out on tertiary gravel sands in Bavaria (Fig. 1a, III) with their larger grain sizes and disparity degrees result, consequently, in higher dispersivity values (B_L in the centimeter and decimeter range). The largest dispersivity values originate from the fluvio-glacial gravels in Bavaria, with grain sizes of up to 13 mm and uniformity coefficients of up to 45 (Fig. 1a, IV and V; B_L being in the centimeter to meter range).

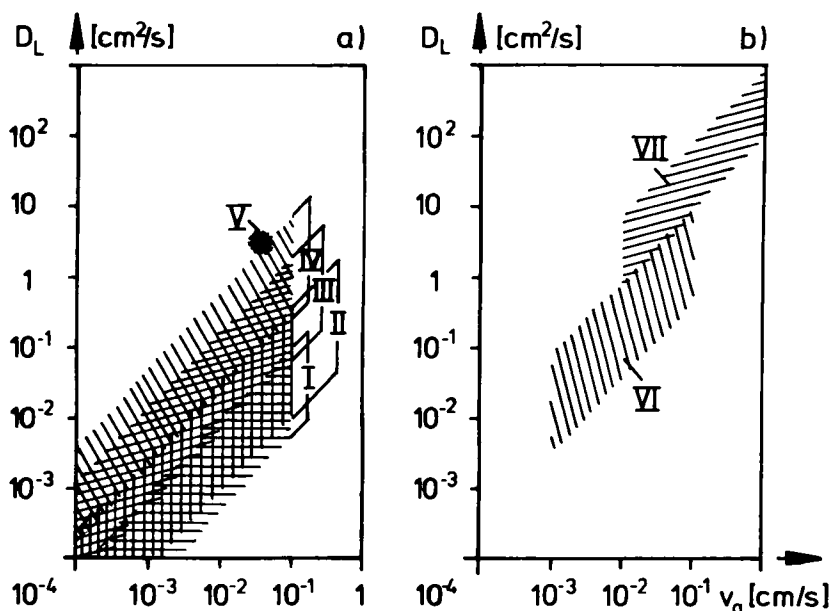


Fig. 1. Coefficient D_L of the longitudinal dispersion as a function of the distance velocity v_a .

- a) Laboratory tests carried out with aeolian sands (I) and valley sands (II) in Northern Germany, as well as with tertiary gravel-sands (III) and fluvio-glacial gravels (IV = column tests, V = receptacle tests) from Bavaria.
- b) Field tests covering sands and gravels (VI) according to BEYER (ref.2) and fluvio-glacial gravels (VII) according to KLOTZ et al. (ref.9).

Comparison of the Longitudinal Dispersion of Laboratory and Field tests. The evaluation of the colouring tests carried out by BEYER (ref.2) in seven different aquifers in Eastern and Northern Germany (characteristic parameters: see TABLE 1), may be summarized as follows (Fig. 1b, VI): While the lab-measurements carried out on comparable sands resulted in longitudinal dispersivities of up to 20 cm, the B_L -value as determined by BEYER range between 5 cm and 125 cm, and thus, within the upper range, superior by approx. the factor 6.

If we compare the dispersion values of the fluvio-glacial gravels of Bavaria (characteristic values: see TABLE 1) based on the results of the laboratory and field tests (Fig. 1, IV, V and VII), we will recognize that the dispersion values as determined in field testing, exceed the maximum laboratory test values by abt. the factor 8. On the other hand, the longitudinal dispersivity is, theoretically, no function of the flow length. It is true, however, that both within the flow receptacle (flow length 1 to 4 m) and on the test field (1 to 20 m), the incorporation and/or the natural deposits of the sediments, as well as extrinsic interventions may entail inhomogeneities which might increase the

dispersion volume.

TABLE 1

Characteristic values from screening curves and parameters A_L ($= 1.07$) and B_L of the longitudinal dispersion in natural granular mixtures. d_{10} = grain diameter with 10 % undersize, $U = d_{60}/d_{10}$ = uniformity coefficient.

Type of Sediments	Origin	d_{10} (mm)	U	see Fig.1	B_L ("cm")
19 aeolian sands	North Germany	0.06-0.2	1.5-3.2	I	0.06-1.1
24 valley sands	North Germany	0.1 -0.28	1.5-8.0	II	0.1 -4.0
20 tertiary grave sands	Upper Bavaria	0.14-0.29	1.7-42.5	III	0.7 - 20
10 fluvio-glacial gravels	Upper Bavaria	0.18-2.4	5.8-45	IV	3 - 70
Fluvio-glacial gravels	Murnau/Bavaria	0.31 ± 0.09	16.5-8.5	V	50 - 120
Sands and gravels	North and East Germany	0.1 -0.6	3 - 25	VI	5 - 125
Fluvio-glacial gravels	samples from the test field	0.032 - 0.63	10 -150	VII	100 - 960

Influence of Stratifications and Inhomogeneities on the Longitudinal Dispersion.

The influence of stratifications and inhomogeneities of the porous media on the longitudinal dispersion was investigated only in a small number of tests:

1) The longitudinal dispersivities of porous media which in a faulted configuration were built-in in test patterns are smaller than those dispersivities which were determined on porous media taken from an unfaulted environment (Fig. 2).

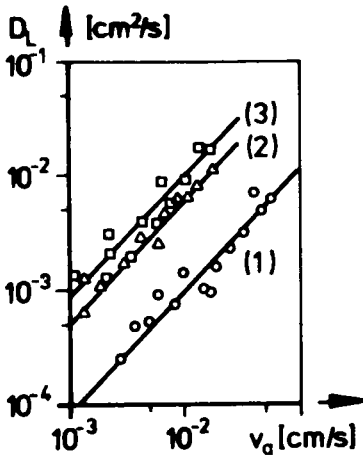


Fig. 2. Coefficient D_L of the longitudinal dispersion as a function of the distance velocity v_a for valley sands with faulted incorporation (1) and with unfaulted incorporation (2) and (3) into a column.

2) The longitudinal dispersivities of a mixed sample composed of various granular fractions do not differ from those which are determined on the basis of an arrangement where the different fractions of one and the same thickness are traversed in series (Fig. 3).

3) The longitudinally stratified porous media with substantial permeability differences show several tracer transmission curves. When

the strata show only slightly varying permeability parameters, we obtain stronger longitudinal dispersivities with respect to the homogeneous porous medium (Fig.4).

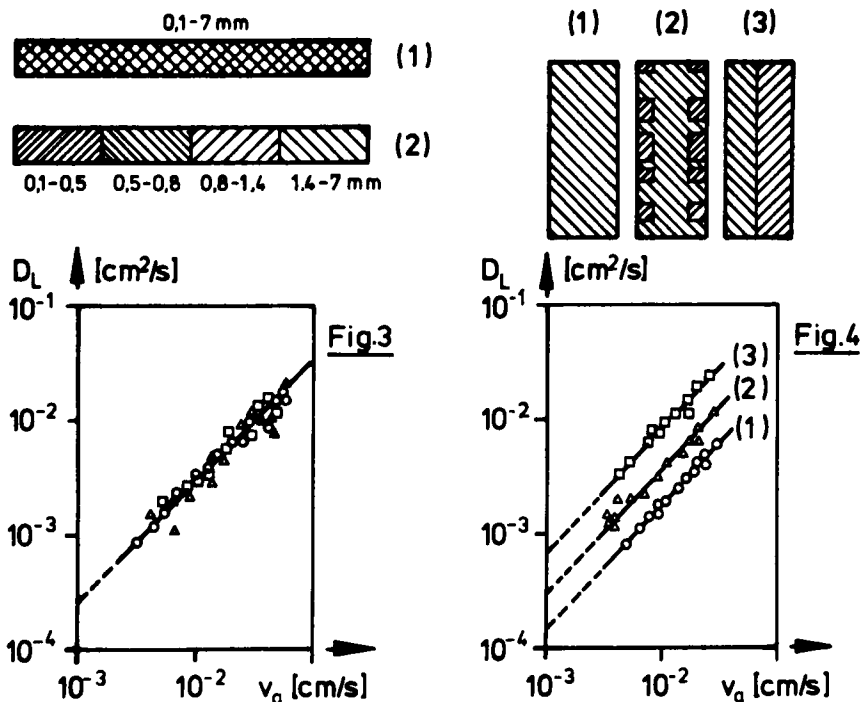


Fig. 3. Coefficient D_L of the longitudinal dispersion as a function of the distance velocity v_a for sands of the grain size 0.1 - 7 mm (measuring points \circ , measuring arrangement see (1)) and for granular fractions arranged one after the other of 0.1 - 0.5 mm, 0.5 - 0.8 mm, 0.8 - 1.4 mm and 1.4 - 7 mm (measuring points Δ \square , measuring arrangement see (2)).

Fig. 4. Coefficient D_L of the longitudinal dispersion as a function of the distance velocity v_a for valley sands with little different screening curves and different incorporation modes within a square column: (1) homogeneous incorporation, (2) and (3) stratified incorporation.

Transverse Dispersion

From the investigations carried out on monogranular materials and summarized by BERTSCH (ref. 1), it can be deduced that the coefficient D_T of the transverse dispersion is linked to the distance velocity v_a by the relation

$$D_T = B_T \cdot v_a^{A_T} \quad (2)$$

The magnitude A_T in equation (2) lies between the range of $0.4 < A_T < 1.3$, while the transverse dispersivity B_T depends, as does B_L , on the parameters of the

porous medium.

The first step towards the determination of the transverse dispersion consisted in using columns to carry out measurements of the concentration-time-distribution ratios transversely to the direction of flow, followed by an estimation of the width of the tracer cloud b (parameters: flow velocity, porous medium): b increases in line with the granular size of the porous medium. The point-wise addition of the tracer to the sands covering a flow length of 115 cm, resulted in a lateral propagation of the tracer under an angle of aperture of 3 to 7° (5.5 cm b 14.5 cm). The assessed D_T -values of the sands fit well into the D_T -value ranges indicated by BERTSCH (ref.1) (Fig. 5). The ratio D_L/D_T of the sands investigated are to be found within the range of 2 D_L/D_T 10 and is comparable with the values given in literature (refs. 3, 5, 10).

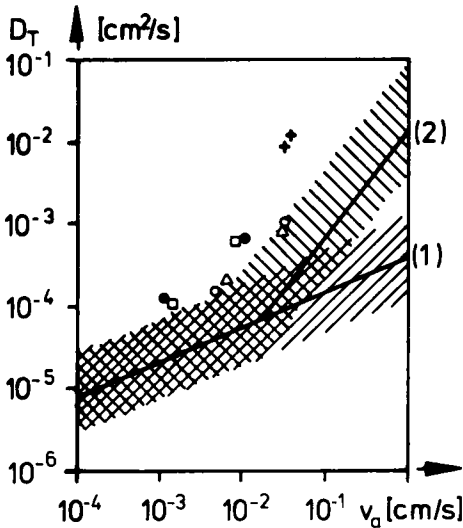


Fig. 5. Coefficient D_T of the transverse dispersion as a function of the distance velocity v_a according to BERTSCH (ref. 1), for spherical shapes (1) (variation range // // // //) and monogranular materials (2) (variation range \ \ \ \ \ \). D_T -values determined by approximation for quartz sands showing a grain size of 0.1-0.4 mm (measuring points o), 0.2-0.7 mm (Δ), 0.5-1.5 mm (\square) and 1-2 mm (\bullet) as well as D_T -values computed for fluvio-glacial gravels originating from the vicinity of Murnau/Bavaria (measuring points +).

The tests carried out in a fluvio-glacial gravel deposit (at Murnau/Bavaria) produced for v_a the following result: $(3.5 \pm 0.3) \cdot 10^{-2}$ cm/s and flow lengths of 400 cm, a 70 cm wide tracer cloud (corresponding to the angle of aperture of 8°) and, finally, the following coefficients on the transverse dispersion: $D_T = (1.1 \pm 0.3) \cdot 10^{-2}$ cm²/s. These D_T -values are superior to the values given by BERTSCH (ref. 1) (Fig. 5), the relative factors being approx. 100 above the BERTSCH-values. As far as the fluvio-glacial gravels are concerned, the relative D_L/D_T -values amount to several hundred points ($170 \leq D_L/D_T \leq 405$), and thus by the factor 20 to 30 superior to the values given for the monogranular materials.

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