ABSTRACT: This work identifies the main phenomena that control the peptisation and transport of clay particles in a sand core. Clay can be dispersed into small particles in an aqueous solution of low ionic strength. This property is used to generate clay particles with NaCl concentration varying from 0.5 M to 0.015M. For that purpose, a chromatographic column is initially packed with a 5 % clay-sand mixture. The monitored decrease of the NaCl concentration of the feed solution allows the control of transport of the particles without plugging the porous medium. This experimental set-up and this methodology are used to show that, in a column of a given length, the amount of clay particles released into solution, and available to transport depends only on NaCl concentration. Some clay particles are available to migration when the NaCl concentration of the feed concentration is between 0.16 M and 0.05 M (first domain) or between 0.035 M and 0.019 M (second domain). An empirical function, P_d([NaCl]), accounts for this particle generation. Transport is mainly dependent on the hydrodynamic characteristics of the porous medium that vary during the elution, probably due to the particle motion inside the column. A phenomenological modelling is derived from these results, coupling the particle generation term, P_d([NaCl]), with an adapted nonequilibrium transport solute model. A characteristic time of mass transfer between mobile and immobile water zones is attributed to the particles, as for the solute. This is large enough to take into account the kinetic limitations of particles transport. The values of the parameters are determined by independent experiments. Finally, the breakthrough curve of clay particles is predicted when a column of a given length is flushed by a salinity gradient of NaCl in various conditions.

Release of clay particles from an unconsolida

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ted clay-sand core: experiments and modelling

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Generation and Transport Model of clay particles

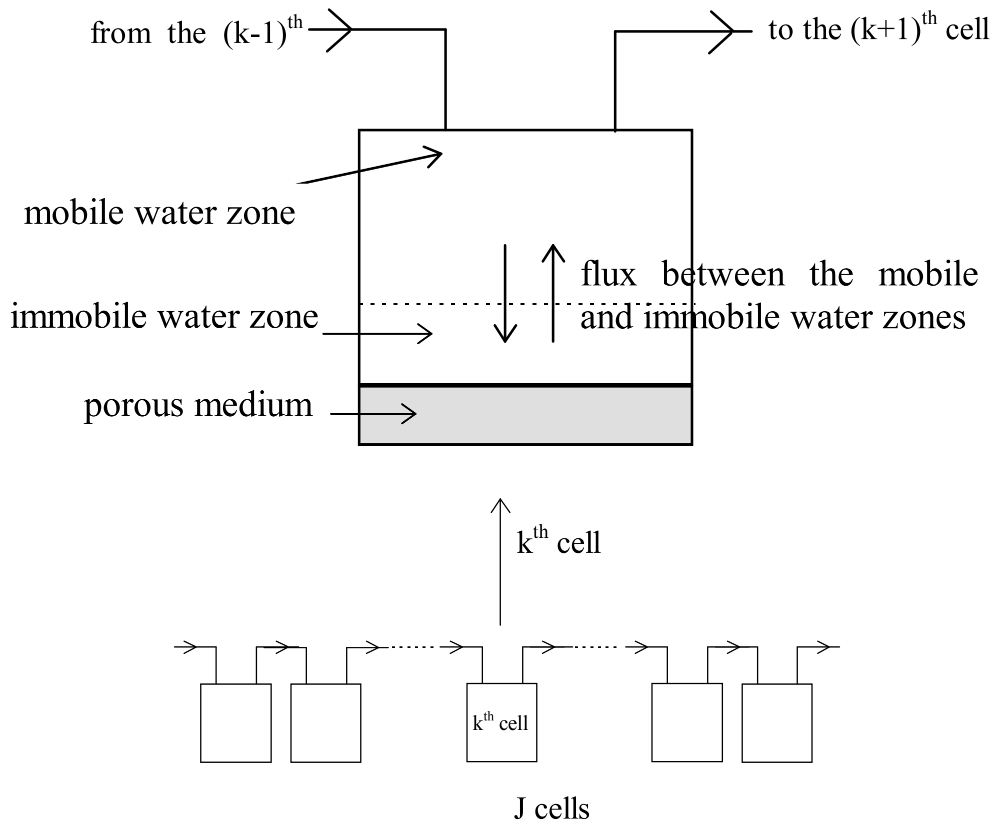
The model includes:

- a model of nonequilibrium solute transport adapted to particles

A mobile water zone, which transport is controlled by convection and dispersion, is assumed to diffuse through the immobile water zone located in dead end pores.

The column, of porous volume $\mathbf{V_p}$, is represented by **J** identical cells in series. In each cell, the transfer between the mobile ($\boldsymbol{\theta_m} V_p/J$) and the immobile ($\boldsymbol{\theta_m} V_p/J$) water zones is assumed to be controlled by a linear first order kinetic law. $\mathbf{t_M}$ and $\mathbf{t_{MP}}$ are the solute and particle characteristic mass transfer times.

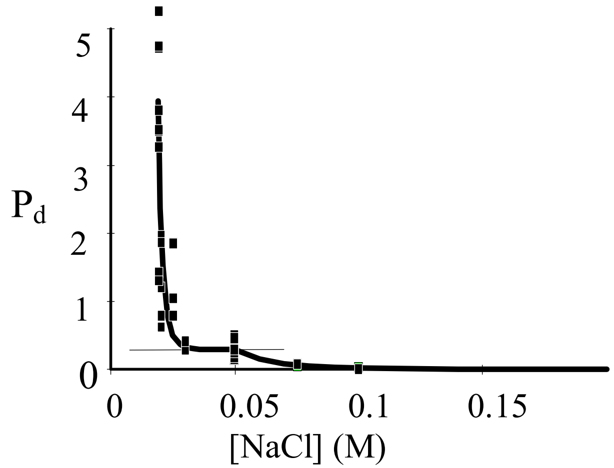
$$Pe = uL/D = 2(J-1)$$



- a particle generation term:

The amount of particles available to migration is only dependant on the NaCl concentration of the solution in equilibrium with the porous medium ==> $\mathbf{P_d([NaCl])}$

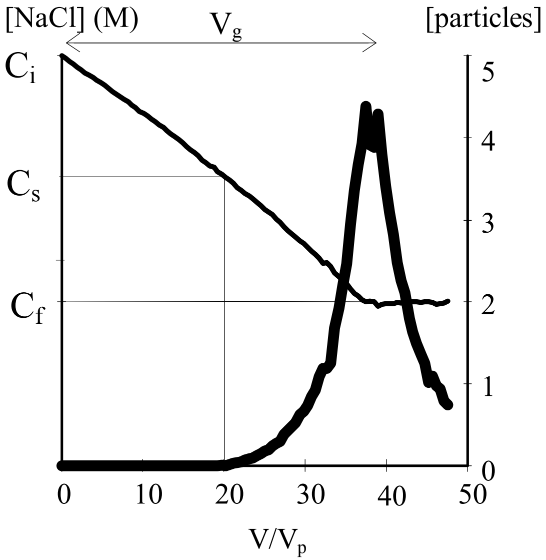
$P_d(C_f)$-$P_d(C_i)$ is the amount of particles which leave the column when the NaCl concentration is decreased from C_i to C_f. This determines the P_d function.



Experimental methodology

The porous medium is a mixture of clay and sand. A liquid chromatographic set-up is used. Clay particles are generated by a smooth decrease of salinity, avoiding clogging the porous medium. An U.V. continuous detector measures the particle concentration in the effluent.

Typical experiment: the NaCl concentration of the feed solution is decreased from C_i to C_f within a V_g volume of solution, then it is maintained constant at C_f as long as particles leave the column.



[NaCl] variation are performed between 0.5 M and 0.015 M

Flow rate 1ml/mn

Porous volume ≈ 3ml

Porous medium: 5 % clay weight, sand

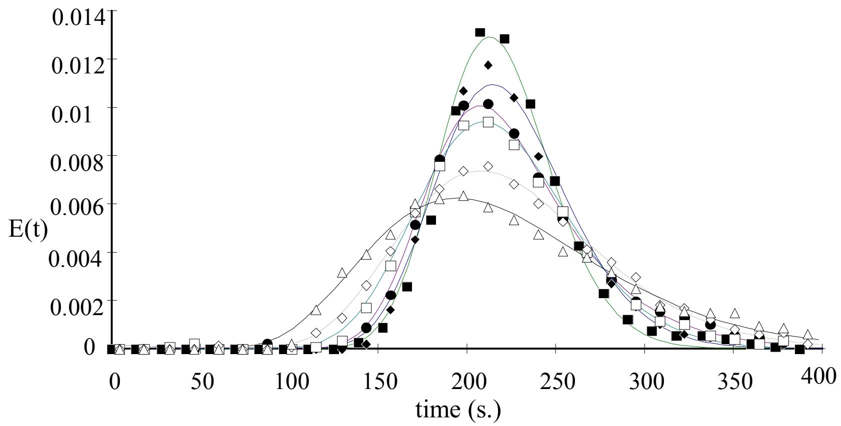
The parameters used to control the experiments are C_i, C_f, V_g

Experimental observations and interpretation

1° Kinetic limitations

Particles continue to leave the column while the NaCl concentration of the feed solution is kept constant ==> the system is not at the equilibrium.

The hydrodynamic characteristics of the porous medium are measured experimentally.
Initially, the water flow is near that of a piston flow. But immediately prior to the detection of the first eluted particles from the output of the column, preferential pathways and dead zones are created; their size increases as the NaCl concentration is decreased.



Residence Time Distribution of a tracer for water.

The measurements are performed on the same column, after each step of [NaCl] down to C_g (0.5 M, 0.2 M, 0.15 M, 0.075 M, 0.05M)

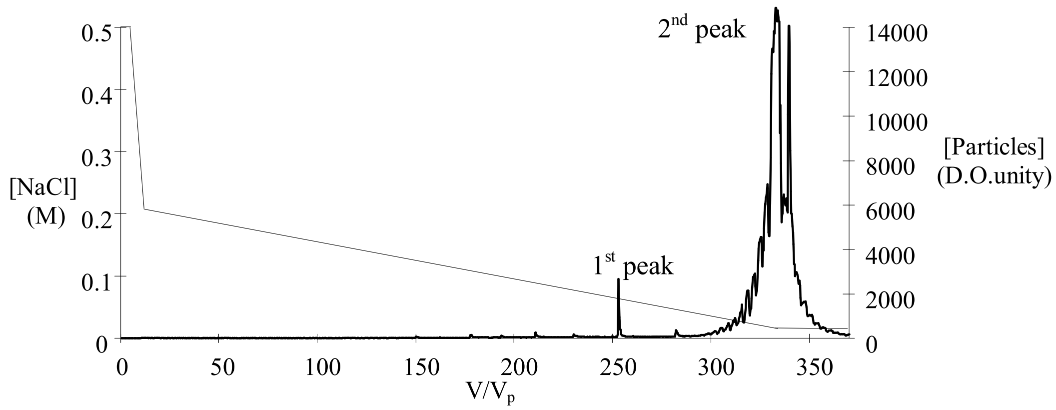
The peak of the breakthrough curve is shifted towards shorter time.

2° Threshold Concentration

Particles begin to leave the column when the NaCl concentration drops below threshold concentration.

In the NaCl domain from 0.5 M to 0.015 M, two threshold concentrations occur. C_{s1} = 0.16 M and C_{s2} = 0.035 M.

Choosing a sensible V_g, it is possible to see the two domains of particle output. (==> figure)

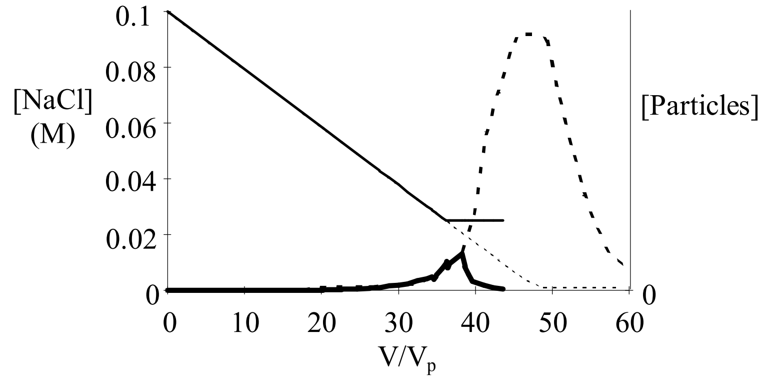


3° Amount of particles

The amount of particles that leave the column is only dependant on C_i and C_f, not on V_g.

The amount of particles that leave the column is plotted as a function of the NaCl concentration. From this, P_d curve is determined (see model)

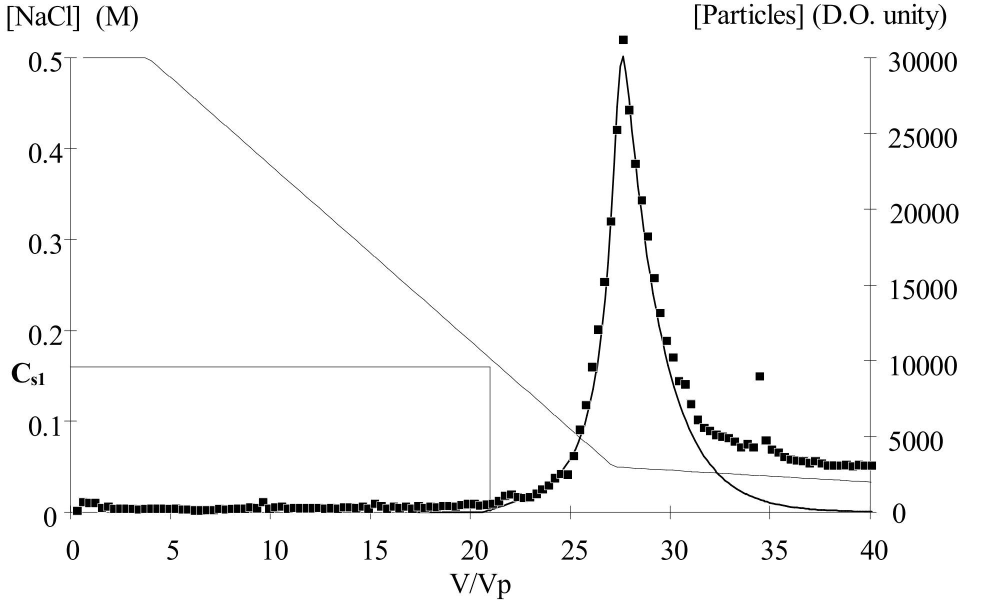
In two different columns equilibrated with the same NaCl solution, the total amount of particles that leave the column depends on the final [NaCl] concentration. (=> figure)



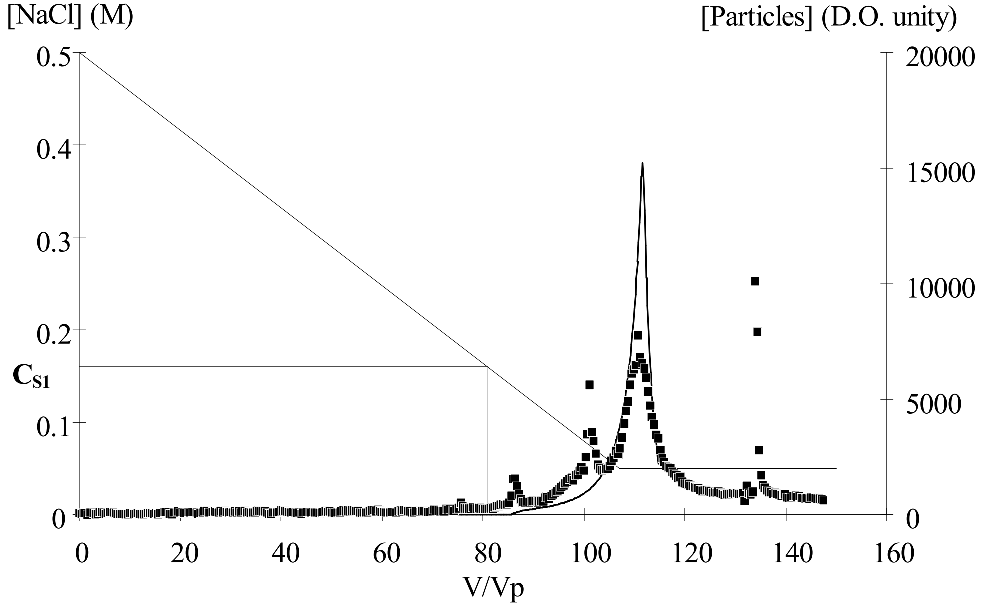
Breakthrough curves of particles of column 1(- - -) and column 2 (—)

In column 1, [NaCl] is decreased from 0.1 M to 0.001 M (- - - -), whereas in column 2, [NaCl] is only decreased from 0.1 M to 0.025 M (—).

Comparison between experiments and simulations

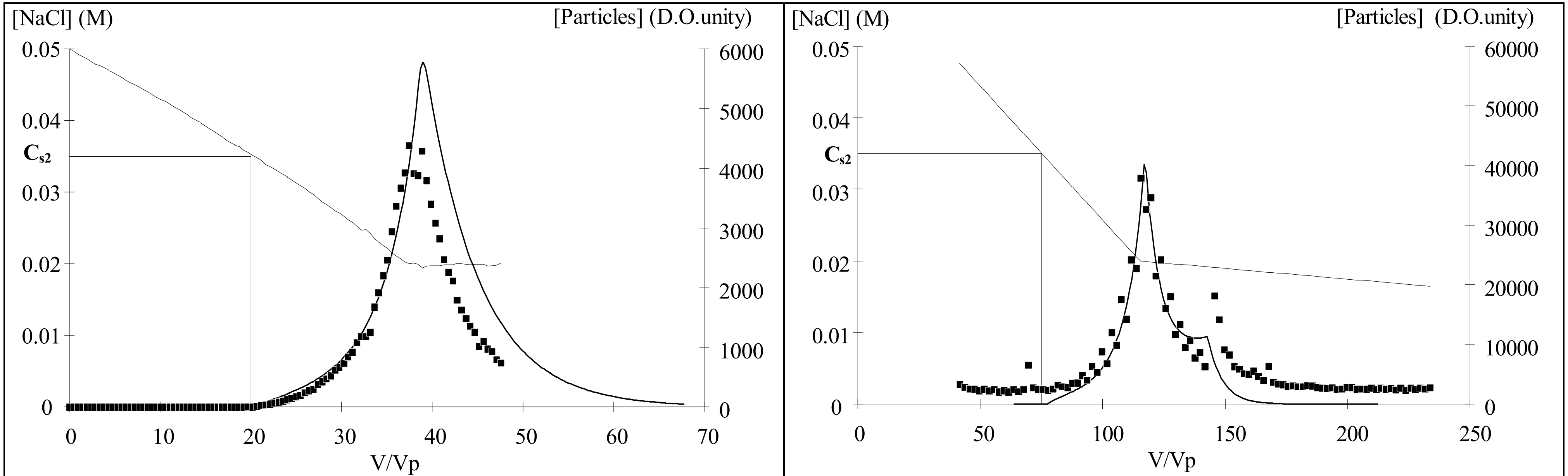


Small $V_g = 23.3\ V_p$, $C_i = 0.5$ M, $C_f = 0.05$ M



Large $V_g = 107\ V_p$, $C_i = 0.5$ M, $C_f = 0.05$ M

simulation parameters: $J = 51$, $\theta_{im} = 0.125$, $t_M = 0.05\ V_p/Q$, $t_{MP} = 12\ V_p/Q$



Small $V_g = 37.5\ V_p$, $C_i = 0.05$ M, $C_f = 0.015$ M

Large V_g, $V_g = 80\ V_p$, $C_i = 0.05$ M, $C_f = 0.02$ M then

$V_g = 254\ V_p$, $C_i = 0.02$ M, $C_f = 0.01$ M

Simulation parameters: $J = 15$, $\theta_{im} = 0.285$, $t_M = 0.09\ V_p/Q$, $t_{MP} = 20\ V_p/Q$