Chapter

Tracer Transport in a Homogeneous Porous Medium: Experimental Study and Acquisition Data with LabVIEW

Sana Dardouri and Jalila Sghaier

Abstract

This work represent the incorporation of information procurement (DAQ) equipment and programming to acquire information (LabVIEW) as well as real-time transport to show parameter appraises with regard to subsurface stream and transport issues. The main objective is to understand the mechanism of water and solute transfer in a sandy medium and to study the effect of some parameters on the transport of an inert tracer. In order to achieve this objective, a series of experiments were carried out on a soil column equipped with a tensiometer to monitor the state of saturation of the medium and by two four-electrode probes for measuring the electrical conductivity in the porous medium.

Keywords: tracer test experiments, groundwater contaminant, transport in porous media

1. Introduction

The comprehension of contaminant destiny in groundwater conditions is of high enthusiasm for supply and the executives of water assets in urban regions. Contaminant discharges invade through the dirt to cross the vadose zone and achieve the water table where they spread after the specific stream bearings and hydrodynamic states of groundwater bodies. Localization and checking of contaminants is the primary essential advance to remediation systems [1, 2].

In any case, exact data are generally compelled by the absence of thickness of inspecting areas which are illustrative of the region of the boreholes yet do not render of nearby heterogeneities and particular stream headings of the crest [3].

A slug of solutes (tracers) promptly infused into permeable media with a uniform stream field is normally alluded to as the slug-tracer test. The injected tracer will go through permeable media as a pulse with a peak concentration eventually after injection. This sort of test is utilized generally to determinate contaminant transport parameters in permeable media or subsurface conditions [4, 5]. The transport parameters including porosities, pore velocities, and dispersivities are imperative to examine the fate and transport of the contaminants and colloid in permeable media and groundwater [6–9].

Many studies showed that the type of array and the sequence of measurements incredibly affected the shape and intensity of the resistivity contrasts ascribed to tracer temporal spreads [10, 11].

2. Experimental study

2.1 Materials and methods

The experimental setup (**Figure 1**) consists of a cylindrical glass column of 36 cm long and 7.5 cm in diameter. The column is closed below with a plastic cover having a hole at the center of diameter 1 cm and provided with a filter grid preventing the passage of the solid phase beyond the column. The pressure within the column is measured using a tensiometer located 5 cm from the bottom of the column. This blood pressure monitor is of type Soilmoisture model 2100F. There are also two four-electrode probes located 5 and 30 cm from the base of the column. These probes make it possible to follow the transport of a tracer by measuring the electrical conductivity in the ground.

2.1.1 Pressure measurement

The 2100F Soilmoisture Tester (**Figure 2**) is an instrument designed to measure soil pressure potentials. This model is ideal for laboratory measurements such as measurement of soil suction at fixed depth in a soil column. This blood pressure monitor consists mainly of a porous ceramic stem (ceramic is rigid and permeable), a ventilation tube, a plastic body, and a Bourdon manometer. This circulatory strain screen comprises for the most part of a permeable earthenware stem (artistic is unbending and penetrable), a ventilation tube, a plastic body, and a Bourdon manometer.

The operating principle of this blood pressure monitor is simple. Indeed, when the porous ceramic saturated with water is placed in the unsaturated soil, a water potential gradient appears between the interior of the porous ceramic and the soil. These results in a transfer of water to the soil which exerts a depression (suction)

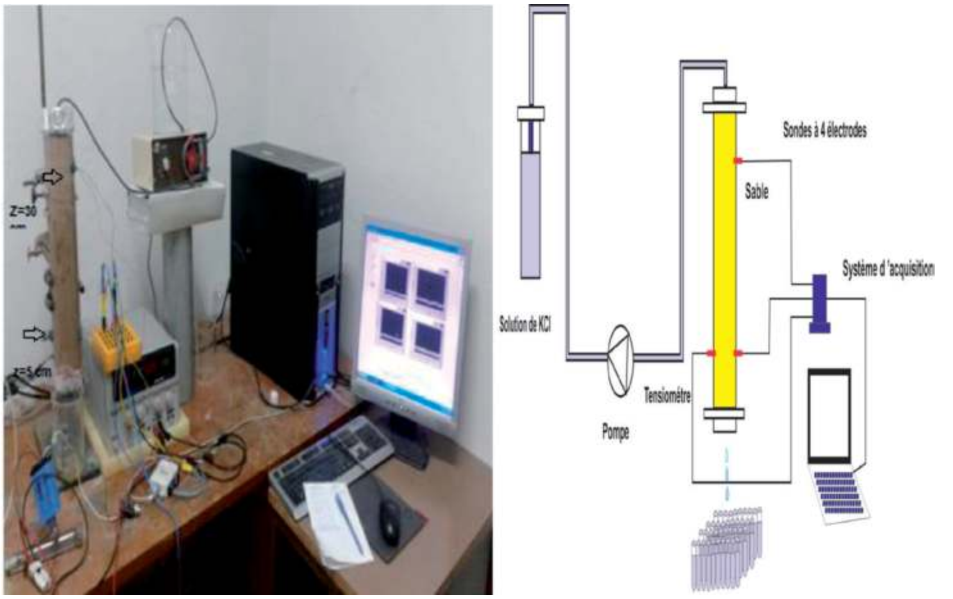

Figure 1.
Experimental device.

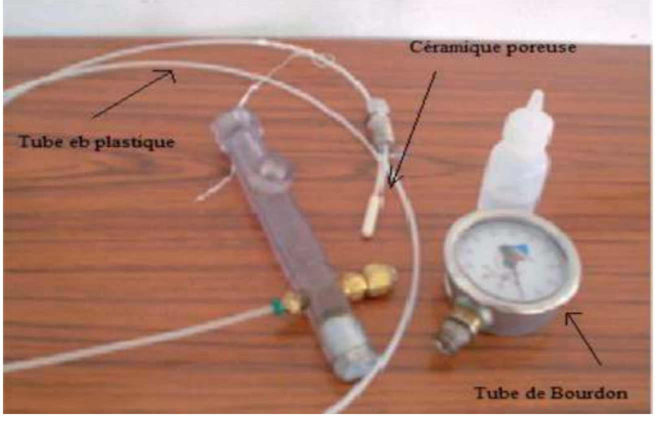

Figure 2.
"Soilmoisture 2001F" blood pressure monitor.

on the water contained in the tensiometer. The transfer of water takes place through the porous wall of the ceramic and can only exist if the liquid phase is continuous from the ground, the wall of the rod, and the inside of the tube. It is necessary to calibrate the monitor before use to ensure proper function. This calibration is performed as follows:

The first step is to immerse the porous ceramic in the water. At the same time, remove the drain screw and fill the plastic tube. It should be noted that filling is done slowly to prevent the occlusion of a large unwanted air volume in the nylon tube. The tube is continued to fill until a flow of water without air bubbles at the aeration tube is obtained. To purge all the air bubbles and make sure that the tube is completely filled with water, the drain screw is tightened, and the moisture present in the porous ceramic is removed.

As the water evaporates on the surface of the porous ceramic, an increase in the Bourdon tube needle is observed due to the increase in vacuum in the tube. After an hour or two, the manometer reading increases to a value equal to or greater than 60 centibar. This is an accumulation of air volume trapped in the nylon tube and the plastic tube. To remove this accumulated air, first tap the plastic tube to remove air bubbles as much as possible, then remove the lid of the plastic tube, and add water as previously done. The inner nylon tube is then trimmed so that it does not exceed 6.35 mm. After balancing, tighten the drain screw and cover.

Acquisition of pressure through a current transducer (**Figure 3**) is accomplished through the NI-DAQ 6009 acquisition card (**Figure 4**). The transducer output

Figure 3.
Current transducer.

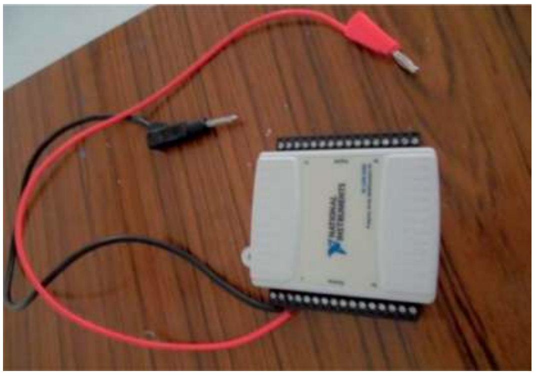

Figure 4.
NI 6009 acquisition board.

is connected to the analog input of the board. The LabVIEW software supplied with the acquisition card allows, thanks to its graphic environment, to obtain the desired measurements. Another solution for the acquisition is the direct use of the NI-DAQmx acquisition card driver with a small code on MATLAB R2012, certainly less developed but which also allows to acquire the pressure data.

Using NI-DAQmx, one must first choose the type of the property to be measured (voltage, current, strain gauge/pressure, temperature, etc.) and then start the acquisition by choosing the number of samples to be measured and the sampling period.

It should be noted that the current transducer used is of the 4–20 mA current loop type. That is, this device measures the pressure by converting it into current such that the minimum value (0cbar) corresponds to 4 mA and the maximum value (100 cbar) corresponds to 20 mA. Measurements can be voltage measurements by connecting the current transducer to a 500 Ω resistor.

2.1.2 Concentration measurement

Two four-electrode probes for the measurement of the electrical conductivity in the soil were carried out within the ENIM, in collaboration with the electrical engineering department. For each probe (**Figure 5**), a printed circuit has been designed which has four equidistant copper surfaces of 6 mm representing the four electrodes. The purpose of manufacturing these probes is to measure the electrical conductivity in the soil as a function of time at a given depth.

The operating principle of these probes consists of sending an alternating electric current into the ground through the two surface electrodes and measuring the potential difference by means of two inner electrodes.

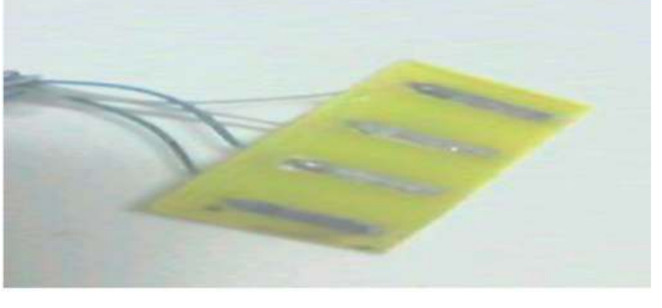

Figure 5.
Four-electrode probe for measuring electrical conductivity.

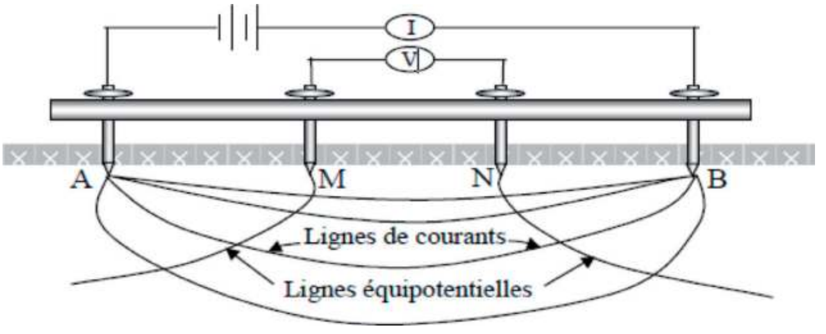

Figure 6.
Schematic diagram of the Wenner model.

The method of four electrodes was chosen from several generally non-destructive electrical methods because its principle is simple and the application disrupts very little the flow in the ground. The geometry of these probes is based on the Wenner configuration (**Figure 6**).

The electrical resistivity of the ground is written as

$$\rho = \frac{\Delta V}{I}.2\pi a \tag{1}$$

where a is the distance that separates each electrode from the other.

The apparent electrical conductivity is then determined by

$$\sigma_a = \frac{kf}{R_s} \tag{2}$$

where k = a*(1/4) is a constant; f is the temperature correction factor; and Rs is the electrical resistance equal to ΔV/I.

It is essential to know the electrical behavior of the manufactured probe so that we can draw good results and especially choose the appropriate acquisition system. Thus, several tests were carried out with sand and NaCl solution. The probe is pushed into the sand and the solution is injected. At the same time, the response of the probe is visualized on an oscilloscope. It has been concluded that the probe behaves similar to a capacitive impedance since the current and voltage output signals are out of phase (**Figure 7**). In addition, the frequency behavior performed with a GBF also confirms this.

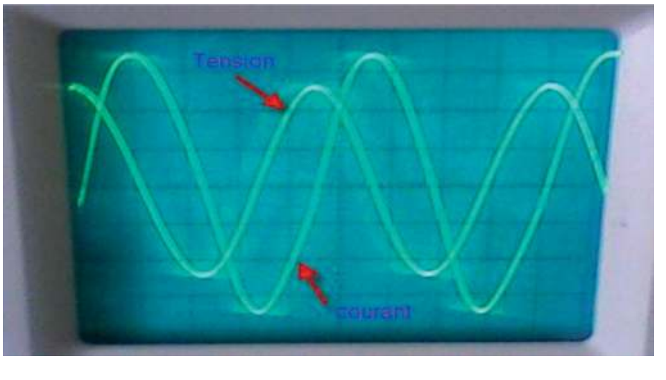

Figure 7.
Electrical behavior of the probe.

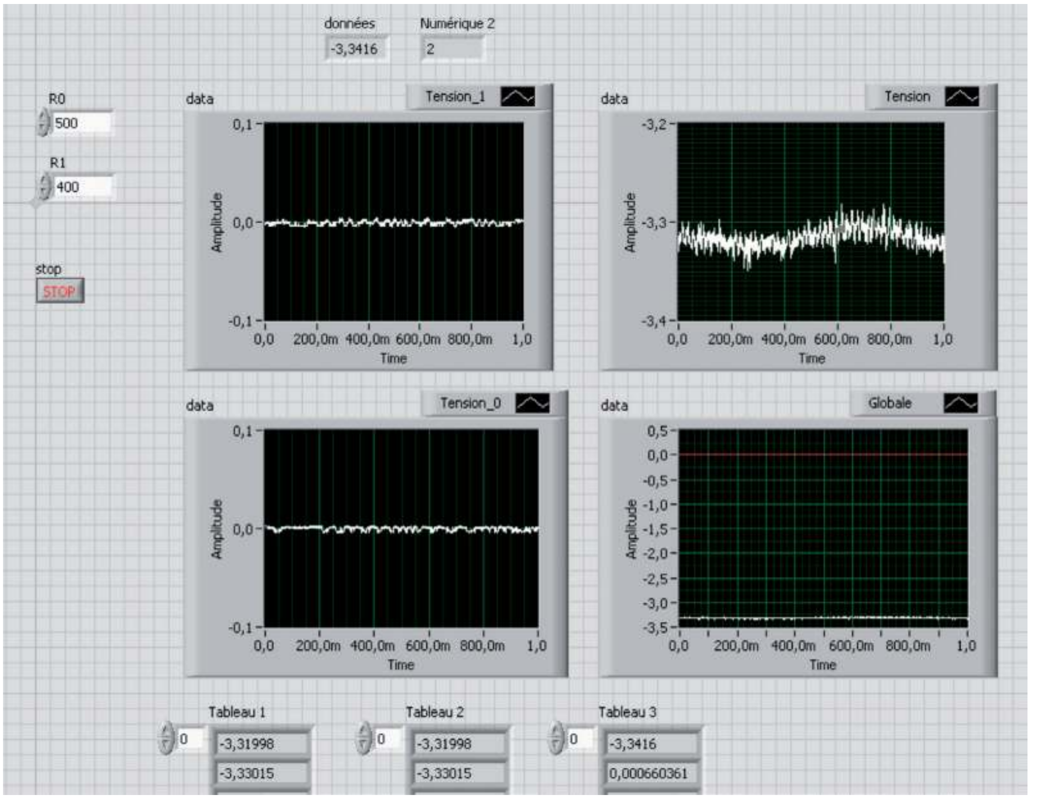

Figure 8.
Front side of the program under LabVIEW.

2.2 Data acquisitions

Regarding the acquisition of the data signals, the LabVIEW software was manipulated to record the results acquired by the three current sensors (pressure sensor and two electrical conductivity sensors). We chose an average acquisition frequency corresponding to 1800 points for the tracer injection phase and 720 points for the leaching phase. The acquisition principle diagram under LabVIEW (program front panel (**Figure 8**)) is as follows:

2.2.1 Synthesis of the experiments carried out on the soil column

A total of four experiments was performed on homogeneous porous media under saturated conditions with a slot injection of a tracer. The tests carried out are summarized in **Table 1**. The main tasks performed are mentioned and dissolved for each experiment.

- The column is filled with initially dry soil, and the sand is well sanded to prevent maximum entrapment of air bubbles in the porous medium.
- During filling, two four-electrode probes are introduced at two levels of the column, z = 5 and z = 30 cm, to measure the electrical conductivity in the soil. The tensiometer is also introduced at a height of 5 cm from the bottom of the column.
- A well-defined volume of water is fed at the top of the column for saturation of the medium.

	Experiences			
	A	**B**	**C**	**D**
Type of injection	Slot	Slot	Slot	Slot
Average injection rate ($l.min^{-1}$)	0.044	0.053	0.053	0.07
Tracer used	NaCl	KCl	KCl	KCl
Tracer concentration ($g.l^{-1}$)	2.8	0.74	0.74	0.74
Medium studied	Sousse sand	Monastir sand	Sousse sand	Sousse sand
Water status of the saturated medium	Distilled water	Distilled water	Distilled water	Distilled water
Medium saturation condition	Saturated	Saturated	Saturated	Saturated

Table 1.
Summary of all experiments carried out in the soil column.

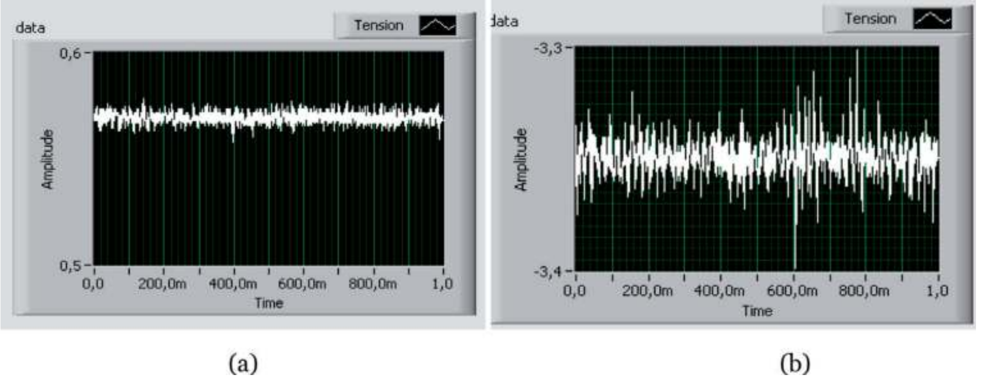

Figure 9.
Recording tensions acquired by the tensiometer for (a) a saturated medium and (b) an unsaturated medium.

- The pressure load within the column is monitored until it reaches a positive and stable value indicating saturation of the medium (**Figure 9a**).

- Once assured that our medium is saturated, we begin the tracer injection with a peristaltic pump (Roth Cyclo I) at a constant average flow rate.

3. Results and discussions

3.1 Evolution of electrical conductivity

The four experiments are described well, through the evolution of the electrical conductivity in the soil and the phenomena of convection and dispersion. Indeed, moving away from the upper base of the column (tracer injection point), that is, to say down the height of the column, the electrical conductivity decreases. It is clear, by comparing two curves of the same sample at z = 5 cm and z = 30 cm, that there is a significant delay (**Figure 10**).

This delay and this small peak are the reasons for the quasi-total dispersion of the tracer in the soil water and, subsequently, the decrease of the electrical conductivity. The high value of the electrical conductivity in the Sousse sand in experiment A (**Figure 10a**) is justified by the high concentration of the NaCl tracer injected into the column.

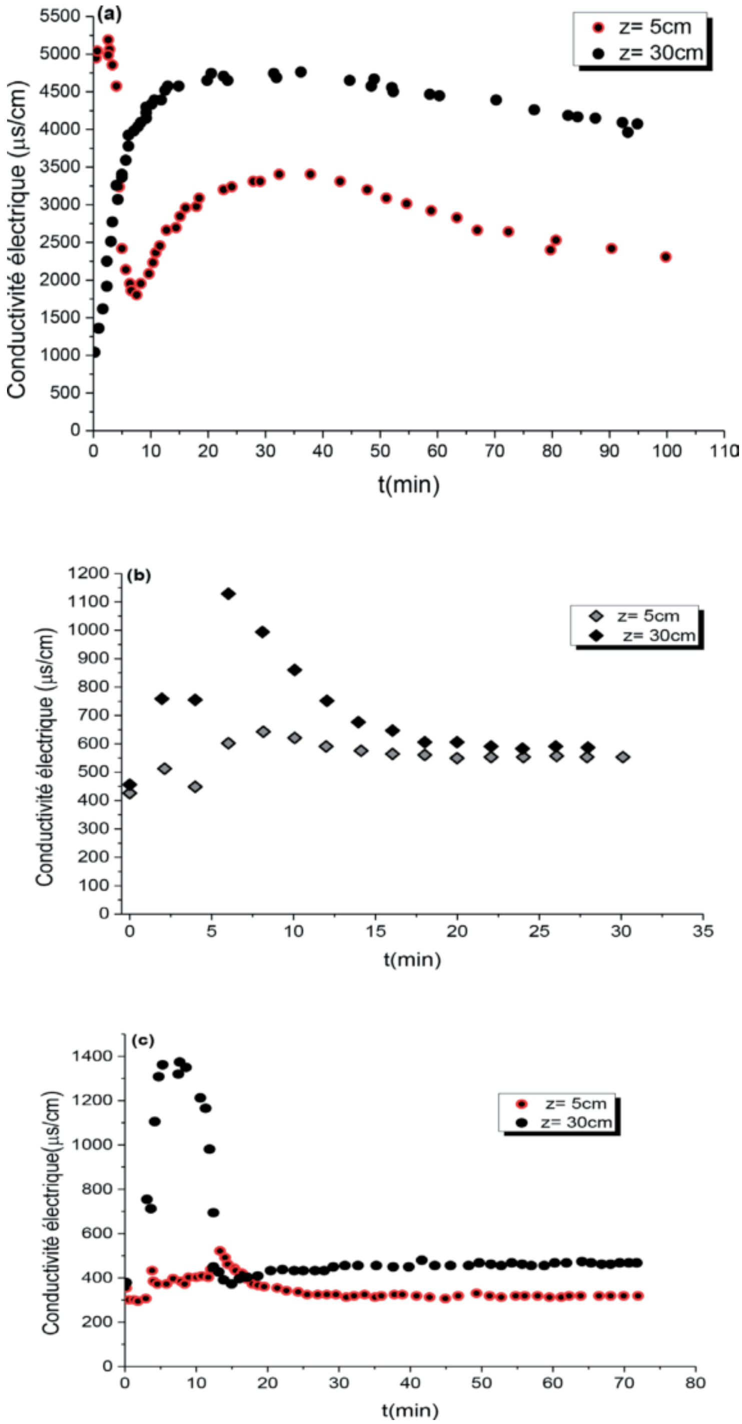

Figure 10.
Evolution of electrical conductivity: (a) experiment A, (b) experiment B, and (c) experiment C.

3.2 Effect of the hydraulic conductivity of the medium

It can be seen from **Figure 11** that the electrical conductivity curve for slot tracer injection in the Sousse sand has the same behavior as the Monastir sand. The peaks of the ascending part of two curves are at very close moments. This indicates that the hydrodynamic characteristics of two media are close and that there is no interaction between the tracer and the medium [12]. The peak shape of the curve of the Monastir sand sample proves that during the flow, there is no preferential

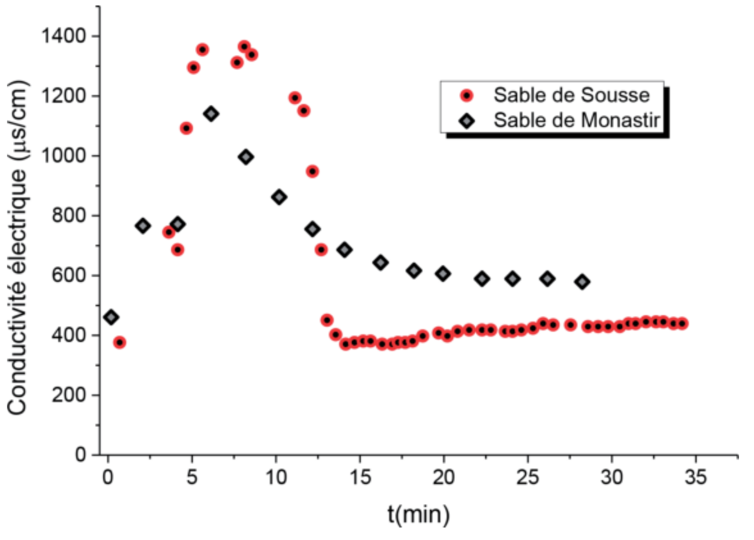

Figure 11.
Effect of medium permeability: comparison between experiments B and C.

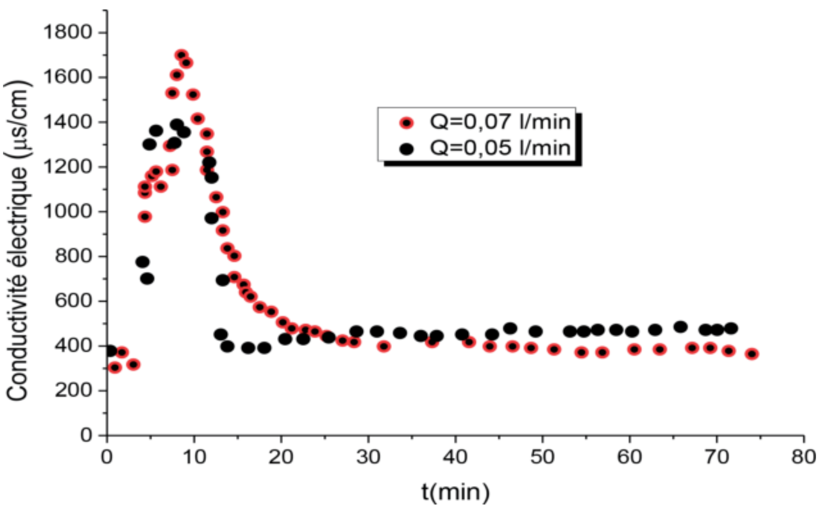

Figure 12.
Effect of average tracer injection rate: comparison between experiments C and D.

path creation. The small offset in ordinates for the two curves can be justified by the nature of sandy environment. The sand of Sousse is thinner and has a lower saturation hydraulic conductivity than the sand of Monastir. The low hydraulic conductivity of the Sousse sand results in greater retention of the tracer and an increase in the measured electrical conductivity.

3.3 Injection flow effect

The influence of injection rate of a tracer KCl on the curves of the electrical conductivity in a sandy medium (sand of Sousse region) at a height z = 30 cm from the bottom of the column is studied. The two selected flow rates are high and correspond to flow rates in the column of 0.327 and 0.458 cm/s. By increasing the flow, the tracer appears faster and disappears more slowly. Indeed, the higher the flow rate, the greater the dispersion phase of the breakthrough curve [13]. In our case, the two flow values are close, which explains why the variation has no significant effect on the shape of the tracer restitution curve (**Figure 12**).

4. Conclusion

In this chapter, we studied the transport of two inert tracers in a homogeneous porous medium (sand). The effects of injection rate and permeability of the medium on the evolution of the tracer elution curve were examined.

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References

[1] Herrera GS, Pinder GF. Space-time optimization of groundwater quality sampling networks. Water Resources Research. 2005;**41**:W12407

[2] Meyer PD, Valocchi AJ, Eheart JW. Monitoring network design to provide initial detection of groundwater contamination. Water Resources Research. 1994;**30**(9):2647-2659

[3] Kim KH, Lee KK. Optimization of groundwater-monitoring networks for identification of the distribution of a contaminant plume. Stochastic Environmental Research and Risk Assessment. 2007;**21**(6):785-794

[4] Bear J. Some experiments in dispersion. Journal of Geophysical Research. 1961;**66**(8):2455-2467

[5] Mackay DM, Freyberg DL, Roberts PV. A natural gradient experiment on solute transport in a sand aquifer. 1. Approach and overview of plume movement. Water Resources Research. 1986;**22**(13):2017-2029

[6] Boy-Roura M et al. Towards the understanding of antibiotic occurrence and transport in groundwater: Findings from the Baix Fluvia alluvial aquifer (NE Catalonia, Spain). Science of the Total Environment. 2018;**612**:1387-1406

[7] Han B, Liu W, Zhao X, Cai Z, Zhao D. Transport of multi-walled carbon nanotubes stabilized by carboxymethyl cellulose and starch in saturated porousmedia: Influences of electrolyte, clay and humic acid. Science of the Total Environment. 2017;**599**:188-197

[8] Liang X, Zhan H, Liu J, Dong G, Zhang YK. A simple method of transport parameter estimation for slug injecting tracer tests in porous media. Science of the Total Environment. 2018;**644**:1536-1546

[9] Ma J et al. Enhanced transport of ferrihydrite colloid by chain-shaped humic acid colloid in saturated porous media. Science of the Total Environment. 2018;**621**:1581-1590

[10] Bellmunt F, Marcuello A, Ledo J, Queralt P. Capability of cross-hole electrical configurations for monitoring rapid plume migration experiments. Journal of Applied Geophysics. 2016;**124**:73-82

[11] Lekmine G, Auradou H, Pessel M, Rayner JL. Quantification of tracer plume transport parameters in 2D saturated porous media by cross-borehole ERT imaging. Journal of Applied Geophysics. 2017;**139**:291-305

[12] Bayard R. Etude de l'adsorption/désorption de polluants organiques dans les sols: Approche méthodologique et application au pentachlorophénol et aux hydrocarbures aromatiques polycycliques. Diss. Lyon, INSA; 1997

[13] Dalla Costa C. Transferts de traceur en milieu poreux consolidé et milieu poreux fissuré: Expérimentations et Modélisations [Doctoral dissertation]. Université Joseph-Fourier-Grenoble I; 2007