



**HAL**  
open science

## Characterizing water transfer in compacted soils in the context of energy storage, contribution of magnetic resonance imaging (MRI)

Sandrine Rosin-Paumier, Rawan El Youssef, Adel Abdallah, Jean-Christophe Perrin, Sebastien Leclerc

### ► To cite this version:

Sandrine Rosin-Paumier, Rawan El Youssef, Adel Abdallah, Jean-Christophe Perrin, Sebastien Leclerc. Characterizing water transfer in compacted soils in the context of energy storage, contribution of magnetic resonance imaging (MRI). Symposium on Energy Geotechnics Accelerating the energy transition - SEG2023, Oct 2023, Delft, Netherlands. 10.59490/seg23.2023.560 . hal-04311361

**HAL Id: hal-04311361**

<https://hal.univ-lorraine.fr/hal-04311361v1>

Submitted on 28 Nov 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

Peer-reviewed Conference Contribution

# Characterizing water transfer in compacted soils in the context of energy storage, contribution of magnetic resonance imaging (MRI)

Rosin-Paumier Sandrine<sup>1,\*</sup>, El Youssef Rawan<sup>1</sup>, Abdallah Adel<sup>1</sup>, Perrin Jean-Christophe<sup>1</sup> and Leclerc Sébastien<sup>1</sup>

<sup>1</sup> LEMTA, Université de Lorraine, CNRS, Nancy, France.

\* Corresponding author: [sandrine.rosin@univ-lorraine.fr](mailto:sandrine.rosin@univ-lorraine.fr)

The concept of energy geostructures consists in enhancing existing civil engineering structures from an energy point of view thanks to the insertion of heat exchanger tubes. In order to consider the use of compacted soil embankments for heat storage [1], a good knowledge of water movement is required. Indeed, the increase in temperature of the exchangers leads to a migration of liquid/vapour water to the surface layers [2]. A loss of moisture may alter the thermal capacity of the soil [1] and therefore the system energy efficiency. To determine unsaturated hydraulic properties, the Instantaneous Profile Method (IPM) consists in inducing transient flow in a long cylindrical sample of soil and then measuring the resulting water content and/or pore water pressure profiles at various time intervals [3]. The unsaturated hydraulic conductivity ( $k_u$ ) is then computed using Darcy's law. The direct evaporation technique allows the measurement of the suction profile in a soil column submitted to drying [4] using filter papers whose water retention curve is known. This method is quite reliable but requires long equilibrium time. Thus, the tests need several weeks and do not give accurate results at the early stages of drying, as the soil state is close to saturation. The analysis of the results when the soil retention capacity is low is therefore complicated, especially when the flow is coupled with temperature variations.

In this study, this classical method was compared to a faster alternate method using nuclear magnetic resonance imaging (MRI) that allows for non-intrusive, continuous and small-scale monitoring of the effect of thermo-hydraulic solicitations on water transfer within the sample. The use of MRI for monitoring the drying/wetting front progression appeared in 1970 [5]. Simpson et al. [6] presented the successive studies that have made it possible to develop a method for monitoring the movement of water within a sample. These measurements can be 1D, 2D and 3D.

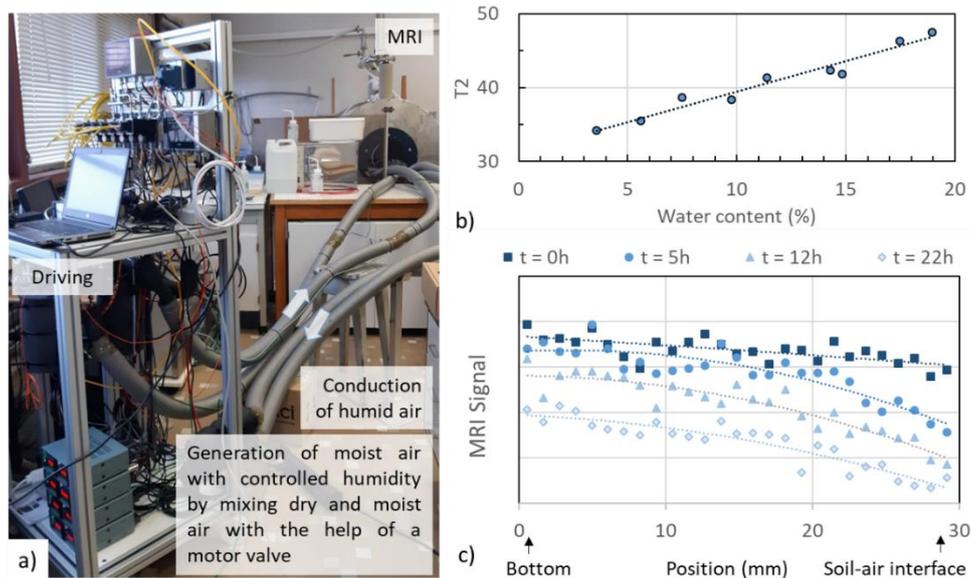
The tests were performed on a sandy lean clay sampled in the Paris region in France. The soil was dried, pulverized, and sieved through a 2 mm sieve before experiments. The compaction state was selected to optimize the heat storage capacity [4] with a water content of 16.3% and a dry density of 1.79 Mg.m<sup>-3</sup>. Ten cylindrical samples of 70 mm in diameter and 20 mm in height were compacted and superimposed with introducing filter paper disks between them. The regular weighting of each sample and each filter paper during three months allowed the derivation of the  $k_u$  curve by the IPM method.

For the MRI method, 9 samples of 36 mm in diameter and 10 mm in height were compacted at the initial state then brought to different degrees of saturation. The measurement of the water proton relaxation time using a Bruker Biospec 24/40 superconducting magnet (100 MHz), allowed the definition of a calibration curve which connects MRI signal to the water content of the samples (Figure 1b). A Single Point Imaging pulse sequence [7] was used to obtain the signal intensity (encoding time 75  $\mu$ s <  $\tau$  < 200  $\mu$ s). In an image acquired with the SPI method, the intensity of each voxel ( $S$ ) is :

$$S = M_0 \exp\left(\frac{-\tau}{T_2^*}\right) \quad (1) \quad \text{Where } M_0 \text{ is the magnetization in a pixel and } T_2^* \text{ is the transverse relaxation time.}$$

The calibration curve is shown in Figure 1b. Then, a larger sample of 30mm in height was compacted and exposed to an air flow at 20°C and 30% relative humidity through using a remote humid air generation system. 27 measurements points were monitored

with an interval of 1.1 mm along the sample. Four examples of the recorded profiles are shown in Figure 1c. The evolution of the water content inside the sample is then calculated using the calibration curve to interpret the water migration in the samples submitted to humidity- and temperature-controlled air (Figure 1a). The pre-established retention curve of the soil will be used to calculate its matric suction. At each depth, the flow velocity and the hydraulic gradient will be calculated from the water content profiles and suction profiles respectively in order to determine the unsaturated hydraulic conductivity.



**Figure 1:** a) photograph of the MRI experimental setup; b) calibration curve ; c) drying example at T=20°C and HR=30%

These experimental developments allow the non-intrusive and continuous quantification of water movement in unsaturated soils during the application of coupled thermo-hydraulic solicitations. The understanding of these fundamental parameters is a key step for studying thermo-hydrromechanical behavior of compacted soils considered for heat storage. The results provide insight into the feasibility of these structures in terms of their long-term energy efficiency and stability.

**Data Availability Statement:** data will be published in Dorel, the University of Lorraine open data repository, at the end of the study

**Contributor statement:** Editing, article writing, presentation: Rosin-Paumier with contribution of all authors; Laboratory tests: El Youssef; Result analysis: El Youssef, Abdallah, Leclerc, Rosin-Paumier; MRI expertise, technical development: Perrin and Leclerc.

## References

- [1] Boukelia, A., Rosin-Paumier, S., Eslami, H. & Masroui, F. (2019). Effect of temperature and initial state of fine grained soils on variation of thermal parameters. *European Journal of Environmental and Civil Engineering*, 23(9), pp. 1125-1138
- [2] McCartney, J.S., Coccia, C.J.R., Alsharif, N.A., Stewart, M.A., Baser, T., Traore, T. & Goode, J.C. (2014). Unsaturated Soil Mechanics in Geothermal Energy Applications. *6<sup>th</sup> Int. Conf. on Unsaturated Soils*, UNSAT Taylor and Francis-Balkema, pp. 835-841
- [3] Hamilton, J., Daniel, D.E. & Olson, R.E. (1981). Measurement of hydraulic conductivity of partially saturated soils ; permeability and groundwater contaminant transport. *American Soc. for Testing and Material*, STP 746, Zimmie & Riggs Eds., pp. 183-196
- [4] Wind, G.P. (1968). Capillary conductivity data estimated by a simple method. *Water in the unsaturated zone*, proc. of the Wageningen Symposium, ed. Rijtema & Wassink, 1, pp.181-191
- [5] Prebble RE. & Currie JA. (1970). Soil water measurement by a low-resolution nuclear magnetic resonance technique. *Soil Sci.* 21: 273–288.
- [6] Simpson, A.J., McNally, D.J. & Simpson M.J. (2011). NMR spectroscopy in environmental research: From molecular interactions to global processes. *Progress in Nuclear Magnetic Resonance Spectroscopy*, 58, pp. 97–175
- [7] Young, J.J., Bremner, T.W., Thomas, M.D.A., Balcom B.J. 2006. Pure Phase Encode Magnetic Resonance Imaging of Concrete Building Materials. In Stapf, S.S. & Han, S.I. (eds), *NMR Imaging in chemical engineering*, Wiley-VCH, Germany, pp. 285-303
- [8] Amin, M.H.G, Hall, L.D., Chorley, R.J., Richards, K.S., Carpenter, T.A. & Bache, B.W. (1996). In V.P. Singh, B. Kumar (Eds.), *Subsurface water Hydrology*, Kluwer Academic, Dordrecht, pp. 3–16
- [9] Van Genuchten, M.T. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal*, 44, pp.1892-1898