

## STUDY OF WATER MIGRATION BY MICRO MR IMAGING

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**Abstract:** Magnetic Resonance (MR) microscopy is a noninvasive tool that enables high resolution imaging of water concentration in non-magnetic materials. In this study, water migration in a dense porous material (dental cement) was monitored by 1D MR microscopy. The measured concentration profiles were later analyzed via three different migration models: an imbibition model, a diffusion model and a combined model. From the best fit to the experimental data, model parameters were obtained.

**Key Words:** Magnetic Resonance Microscopy, Porous Materials, Water Migration

## INTRODUCTION

Water dynamics plays an important role in many biological, chemical and physical processes. The absence of water may retard processes such as cement hardening [1] or cell growth. However, its presence is often unwanted. This is especially true in porous materials which are exposed to harsh atmospheric conditions in winter. Water in the pores of these materials freezes and expands, causing mechanical damage to the materials.

Water migration in 1D can be modelled via an imbibition model [2] in which the progress of a water concentration front  $C$  is proportional to the square root of time

$$C(x,t) = \begin{cases} C_0 & ; \quad x < \sqrt{D_1 t} \\ 0 & ; \quad elsewhere \end{cases} \quad (1)$$

In a diffusion model [3], the diffusion process governs water migration ( $D$  is the diffusion constant and  $l$  is the sample length)

$$C(x,t) = C_0 \left( 1 - \frac{4}{p} \sum_{n=0}^{\infty} \frac{1}{2n+1} \sin\left(\frac{(2n+1)px}{2l}\right) \exp\left(\frac{-(2n+1)^2 p^2 Dt}{4l^2}\right) \right) \quad (2)$$

The imbibition model (Eq. (1)) and the diffusion model (Eq. (2)) can be combined. The combined model assumes that imbibition is the driving force for water migration, and that the water simultaneously diffuses

$$C(x,t) = \frac{C_0}{2} \left( 1 - \operatorname{erf}\left(\frac{x - \sqrt{D_1 t}}{2\sqrt{Dt}}\right) \right) \quad (3)$$

## MATERIALS AND METHODS

Water migration can be accurately monitored via high-resolution magnetic resonance imaging in non-magnetic and non-conductive materials. We were particularly interested in situations where at the beginning of migration the material was completely dry and at the end was saturated with water. For the experiment, cylindrically-shaped samples of dental cement with a diameter of 3 mm and a length of 5 mm were used. The long surface of the samples was coated with a varnish to prevent water migration into the cement, while the ends of the samples were left uncoated. One end of the cylinder was exposed to a constant water concentration, and the other end was in contact with the air around the sample. Water migration was monitored by 1D profiles of water concentration along the sample axis. Experiments were performed on a 100 MHz Bruker Biospec system equipped with micro-imaging accessories. To improve the signal to noise ratio of the water profiles, each profile was obtained from 20 MR signal averages.

## RESULTS AND DISCUSSION

Figure 1 depicts water concentration profiles in dental cement measured via 1D MR microscopy at 12 hour intervals from 0 to 790 hours after the onset of water intrusion. The experimental data in Fig. 1a were analyzed by the imbibition model (Fig. 1b), the diffusion model (Fig. 1c) and their combination (Fig. 1d).

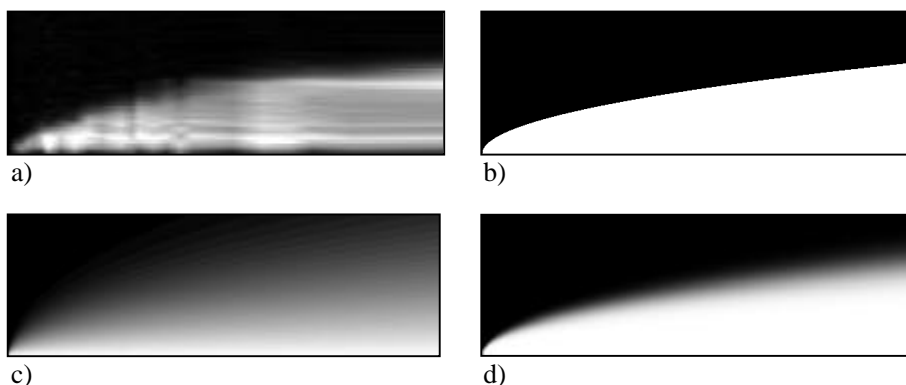


Fig. 1. Water concentration (image intensity) as a function of depth (0-4 mm, vertical axis) and time (0-790 hours, horizontal axis) for: a) experimental data, b) imbibition model, c) diffusion model and d) combined model.

The least squares method [4] was used to find the best fit of the experimental data to the models in Eqs. (1-3). The corresponding model parameters are as follows: imbibition -  $D_i$  [ $\text{m}^2/\text{s}$ ]  $2.317 \cdot 10^{-12}$  ( $1 \pm 0.003$ ), diffusion -  $D$  [ $\text{m}^2/\text{s}$ ]

$1.456 \cdot 10^{-12}$  ( $1 \pm 0.019$ ), combination -  $D_i$  [ $\text{m}^2/\text{s}$ ]  $2.333 \cdot 10^{-12}$  ( $1 \pm 0.015$ ) and  $D$  [ $\text{m}^2/\text{s}$ ]  $3.226 \cdot 10^{-14}$  ( $1 \pm 0.25$ ).

In conclusion, we showed that MR microscopy is a powerful tool for non-invasive monitoring of the water migration process in porous materials.

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