MODELING RADON TRANSPORT IN CONCRETE

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As the amount of time people spend indoors has increased over the past two decades, indoor-air pollution has become an issue of great interest. The indoor-air pollutants exhibit elevated concentrations caused by their emission into a smaller and less ventilated volume and, most probably, interact in a synergistic manner to generate a health disorder. Radon is the major pollutant in indoor air in most European countries and is estimated to induce in the Netherlands (where radon concentrations are relatively low) about 800 (200-1400) fatal lung cancers per year among the 16 million inhabitants. With the main goal to reduce the risk imposed by radon, research is focus primarily on the understanding of the nature of radon transport. The interest in modeling radon transport in concrete is based on the fact that in the Netherlands 75% of the indoor-radon originates from building materials of which concrete is the most widely used.

A transport model similar to that employed for sand [4] will be used also for concrete. The underlying transport equation is a steady-state radon-diffusion equation written in terms of radon-concentration in the air filled pores of the material, C_a:

$$\nabla(D\nabla C_a) - \beta\lambda C_a + S = 0 \quad with \quad \beta = \varepsilon(1 - m + Lm) \quad and \quad S = \eta\rho_b\lambda C_{Ra} \quad (1)$$

with D the radon bulk diffusion coefficient, L the Ostwald coefficient ($0.26K^{-1}$) and λ the decay constant of radon ($2.1\ 10^{-6}\ s^{-1}$). β is the partition corrected porosity, i.e. the porosity, ε, corrected for the partition between the air and the water phase, with the moisture content of the pores denoted by m. The radon production, S, is defined as the product between the emanation coefficient of radon, η, the bulk-dry density, ρ_b, and the radium concentration, C_{Ra}, characterizing the material. For modeling purposes the material parameters are divided into moisture dependent and independent. As the total connected porosity is independent on the moisture content, a value of 0.115±0.005 was determined for dry concrete samples[5]. A value of 2260±30 kgm^{-3} was determined for the bulk dry density and a radium concentration of 21.7±0.4 Bq kg^{-1} is characteristic for this type of concrete [1].

For concrete, the dependence of the diffusion coefficient on the moisture content:

$$D = D_0 e^{-a(m+m^5)} \quad (2)$$

is shown in Fig. 1 together with the profile determined for sand [3]. The measurement methodology is described in [2]. The emanation coefficient was determined on crushed concrete parts at various moisture contents. Results are shown in Fig. 2.

To obtain information on the moisture content and its distribution, a numerical model (DuCOM) that couples the hydration process of cement in concrete directly to the evolution of its microstructure and moisture transport was used [3]. Additionally, information on the evolution of various porosities (capillary and gel) and pore-size distribution in concrete can be obtained from this program and are shown in Fig. 3 and Fig. 4, respectively. The initial network of capillary pores is in time and with proceeding hydration replaced with a more refined network consisting of gel pores. Saturation profiles for gel and capillary pores are presented in Fig. 5. Saturation levels are maintained relatively high especially for the gel pores and in general for all the pores located but on the surface layer. Thus, in first instance a homogeneous distribution of the moisture content could be tested.

Radon release rates as function of the moisture content of concrete are modeled employing the parameters described above and compared (Fig. 6) with experimental data[1]. A very good agreement exists between the two profiles.

Radon transport in concrete is essentially different than in sand. Not only the radon diffusion coefficient in concrete is about two orders of magnitude smaller than in sand but also the emanation process exhibits a linear increase and there seems to be no ‘optimum’ moisture content of the pores like in sand. Most probably this difference is supported by the fact that a very fine network of pores is characteristic for concrete. If in sand Fick’s law best describes diffusion, in concrete corrections for a Knudsen regime (related to the gel pores) have to be performed. Gel pores are responsible for the extremely dense microstructure and for the highly branched porous network. Moisture ingression and loss is affected in the sense that first gel pores will be saturated with water and only then water will also fill the capillaries. In concrete the highest radium activity concentration was measured for the cement powder/paste, about two orders of magnitude compared to sand being the main cause for the higher radon release rates than for sand.

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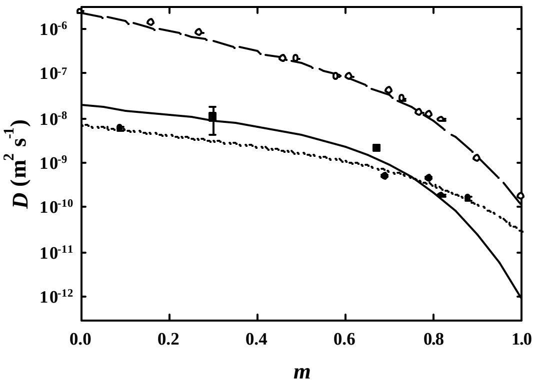


Fig. 1 Bulk radon diffusion coefficient as function of moisture content, m. The dotted line is a least squares fit to the data points determined for two different samples (circles and squares). The dashed line is a least squares fit to experimental data for sand (open circles). The solid line is a fit that keeps the ratio of the diffusion coefficient at m=0 and m=1 at the values found for sand.

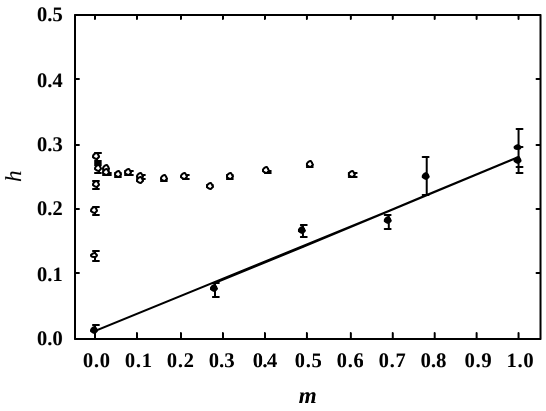


Fig. 2 Radon emanation coefficient as function of moisture content, m. The open circles are the experimental data points determined for sand. The solid line is a linear fit through the experimental data points (filled circles) for concrete.

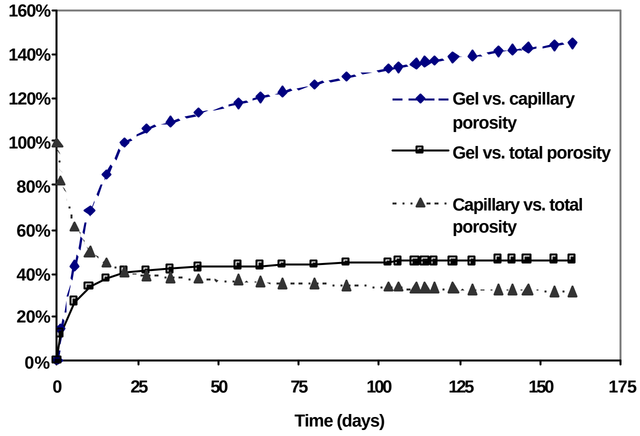


Fig. 3 Time evolution of the gel (squares) and capillary (triangles) porosities versus total porosity for concrete. The ration of gel versus capillary porosity is also shown(circles).

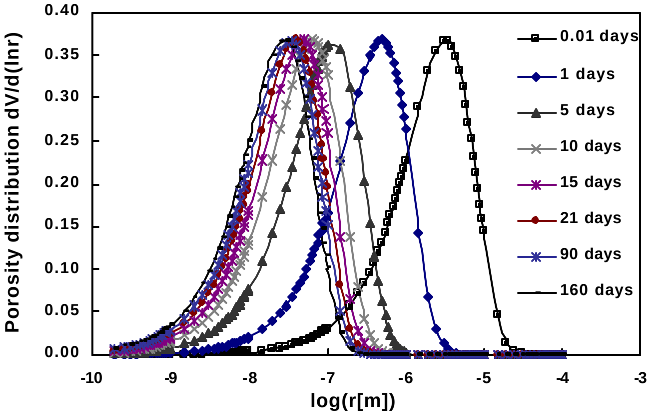
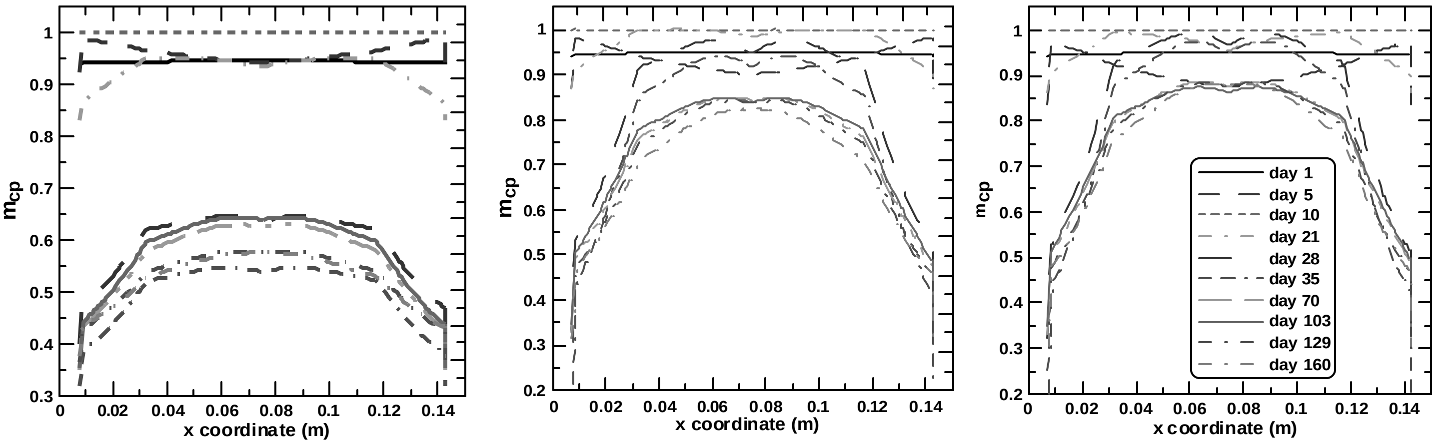
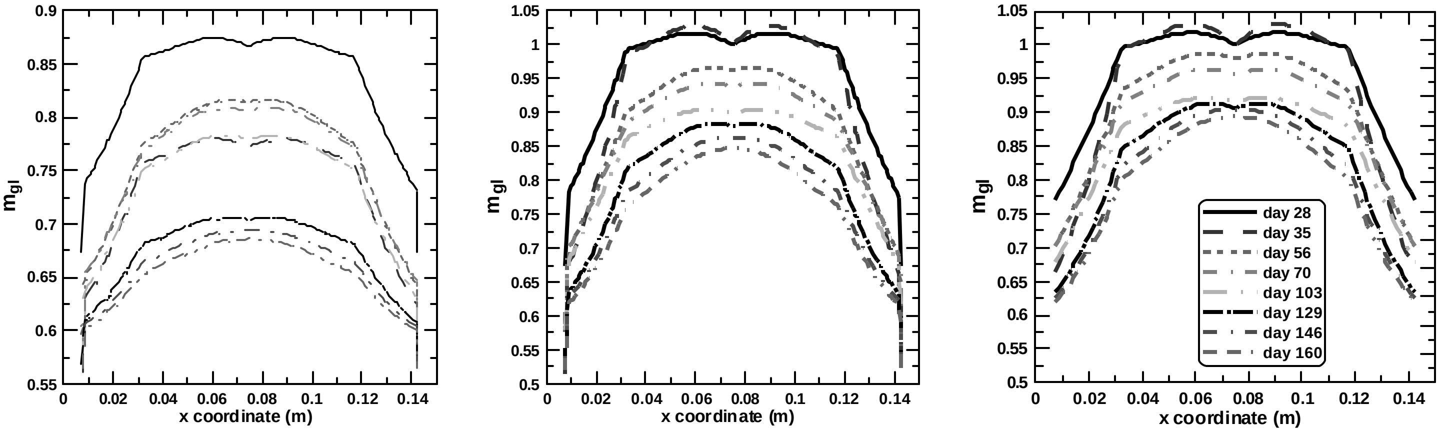


Fig. 4 Pore-size distribution for the capillary porosity in concrete for a time period of 160 days. The distribution parameter for the gel porosity being constant, no change in time occur; gel of the same properties being constantly produced.



Capillary pores Z_1=0.75 cm Z_2=3.25 cm Z_3=7.5 cm



Gel pores Z_1=0.75 cm Z_2=3.25 cm Z_3=7.5 cm

Fig. 5 Saturation profiles and their time evolution for capillary (upper plots) and gel (lower plots) pores in a concrete sample. Profiles are obtained as diagonal cross sections over a symmetrical 3-dimensional profile at three different heights (Z_1, Z_2, Z_3).

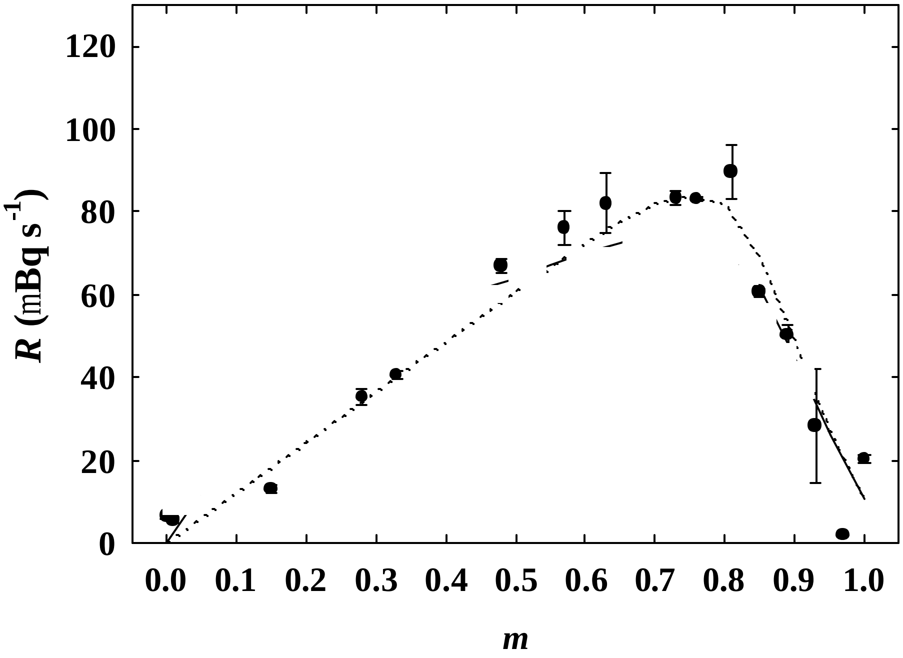


Fig. 6 Results of 3-dimensional model calculations using a homogeneous moisture distribution.