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SIMULATION DIFFUSIVE AND ADVECTIVE TRANSPORT OF RADON GAS THROUGH CONCRETE SAMPLES

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ABSTRACT

The model based on Method of Finite Elements (MFE) which simulates the radon diffusion through the concrete sample in the form of cylinder, is defined in the present work. The diffusion process with concurrent radioactive decay of radon is considered in the model. Differential equations which describes the diffusion and other involved processes were replaced by a system of linear equations of finite elements method Such system was solved using a software package, called PAK As a solution, software gives space-time distribution of radon in the sample of concrete, as well as, total radon flux on non exposed surfaces of cylinder.

The method described and applied here could be used to determine the diffusion coefficient for each type of concrete. Knowledge of diffusion coefficient could enables estimation of radon flux density into the building.

Keywords : radon gas, finite element method, diffusion coefficient, concrete

1. INTRODUCTION

In recent decades, there has been a worldwide concern about the health risk from exposure to radon and its progeny. For public exposure to radon and its progeny more than 80 % of them are from the exhalation of indoor air.

Radon concentration in soil can easily be larger than 10 kBq/m^3. It can be transported by various processes through the concrete slabs below buildings. This is one of the main routes of radon entry into homes and offices. Concrete is the basic material for building construction in developed countries. Knowledge of diffusion characteristics of concrete enables the estimation of the contribution of radon diffusion from the soil to the total indoor radon concentration.

Concrete is a complex and heterogeneous material, which, under some conditions can be treated as a porous and homogeneous material for radon diffusion. Radon transport through the concrete is governed by two main processes: diffusion, caused by gradient of concentration; radon concentration in soil below concrete slab is significantly larger than in air above it, and advection, caused by difference in pressure of a gas below and above concrete slab.

It has been shown [1] that about 80 % of radon beneath the concrete slabs penetrates the rooms above them by diffusion, and relatively small amount of radon comes into rooms by advection 20 %.

The model based on Method of Finite Elements (MFE) which simulates the radon diffusion through the concrete sample in the form of cylinder, is defined in the present work. The diffusion process with concurrent radioactive decay of radon is considered in the model. Differential equations which describes the diffusion and other involved processes were replaced by a system of linear equations of finite elements method [3,4]. Such system was solved using a computer software [5]. As a solution, software gives space-time distribution of radon in the sample of concrete, as well as, total radon flux on non exposed surfaces of cylinder.

2. THEORETICAL BASIS FOR SIMULATION

Radon flux density, J through the concrete slab in the direction, x, is determined by Fick's law of diffusion where, D is diffusion coefficient (in m^2s^{-1}), $\partial C/\partial x$ is gradient of concentration, C, in $(Bq/m^3)/m$. Radon flux density is radon activity transported throughout unit surface in unit time (in $Bq\ m^{-2}\ s^{-1}$). The diffusion coefficient is characteristic of a medium for radon transport, and determines a space-time distribution of radon inside the sample. Experimental measurement of the

$$J = -D\frac{\partial C}{\partial x} \qquad (1)$$

diffusion coefficient is possible if the amount of radon transported through the sample is determined in some way.

The differential equation which describes the radon transport through a concrete sample in three dimensions is

$$-\lambda C + \frac{\partial}{\partial x}(D_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(D_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(D_z \frac{\partial C}{\partial z}) = \frac{\partial C}{\partial t} \qquad (2)$$

where, $\lambda = 2.1 \cdot 10^{-6}\ s^{-1}$ is the decay constant of radon, and D_x, D_y and D_z are diffusion coefficients along x,y and z, axes.

The geometry studied theoretically is a cylindrical concrete sample isolated on the lateral side, so that there is no lateral radon leakage. The bases of the cylinder are free, one is exposed to the radon concentration C_0, while the other is free for radon flux. In such arrangement, diffusion is dominant along X direction, and the terms containing ∂y and ∂z in equation (2) can be neglected. So, the equation that describes the radon diffusion in this case is given as

$$-\lambda C + D_x \frac{\partial^2 C}{\partial x^2} = \frac{\partial C}{\partial t} \qquad (3)$$

Radioactive decay of radon is described by the first term ($-\lambda C$) in equation (3). To solve the equation (3) one needs the initial condition defined as

$$For \quad t < 0 \qquad and \qquad 0 < x < L \qquad C = 0. \qquad (4a)$$

and boundary conditions, which are given as follows:

$$for \qquad x = 0 \qquad and \qquad t > 0 \qquad C = C_0(t) \qquad (4b)$$

$$for \qquad x = L \qquad and \qquad t > 0 \qquad C = 0. \qquad (4c)$$

where, L is the thickness of the concrete sample (the height of the cylinder), t=0 is the starting moment of irradiation to the radon, $C_0(t)$ is radon concentration at one end of the cylinder (varying with the time t). The initial condition (4a) means that the sample was radon free before irradiation.

One side of the cylinder is exposed to radon. It diffuses through the cylinder and radon flux appears on another side of the cylinder. The radon flux increases and after certain time it becomes constant (if the radon concentration is constant on the end). Such situation is called steady state. We considered that steady state was achieved at the moment t_s, when radon concentration on the free side is more than 90 % of concentration on the exposed side of the sample.

By applying Fick's law it is possible to establish a relationship between radon flux through the free base of the cylinder and the gradient of concentration. The total amount of radon, Q, which passed through the free base of the sample for exposure time t, is given as

$$Q = -\varepsilon A \int_0^t D \left(\frac{\partial C(t,x)}{\partial x} \right)_{x=L} dt \qquad (5)$$

where, ε is porosity; A is the surface area of the cylinder base.
Equation (3) with conditions (4) was solved numerically by the FME. Briefly, this method consists of discretization of the space and forming the "network" of elements with the finite dimension. All elements are connected with each other on contours with finite numbers of nodes. Radon concentration is calculated in each node by using "so called" interpolation functions. A more general description of FME can be found in [3] and [4]. A software package, called "PAK" [5] has been applied for analysis of radon diffusion through concrete. The software was rearranged and modified for the simulation of radon diffusion in cylindrical concrete sample.

3. DATA OBTAINED BY SIMULATION AND COMPARISION WITH EXPERIMENTAL DATA

We have simulated radon diffusion through the cylinder when one of it's basis is exposed to the high radon concentration Co = $(36.7 \pm 2.9)\cdot 10^3$ $Bq\cdot m^{-3}$. The geometry used in calculation was the same as it was in our experimental setup. Space and time distributions of the radon concentration in concrete sample were obtained by simulation.
With the simulation it is possible to determine t_s for each type of concrete (known diffusion coefficient) and geometry of the sample. The opposite is also possible, when it is known t_s one can determine diffusion coefficient. It was shown by [2] that diffusion coefficient is in the range from $4.96\cdot 10^{-8}$ m^2/s to $14.9\cdot 10^{-8}$ m^2/s. In the simulation we varied the diffusion coefficient in this range with the step $1\cdot 10^{-8}$ m^2/s and calculated t_s. The results of these simulations are given in Fig. 3. By increasing the diffusion constant, the time t_s decreases, i.e. the equilibrium state is achieved for shorter time.
The results obtained by the simulation in combination with the experimental data can be applied in determination of diffusion constant of different types of concrete. It is possible to determine the time t_s experimentally, while the diffusion curve was determined by the simulation for a given type of concrete. Then, from the diffusion curve one can determine the value of diffusion constant of that concrete.
In the experiments we used, the concrete samples typical for the construction of buildings in Serbia. The equilibrium state is achieved after t_s= 12 h of exposure. From the diffusion curve one was determined the diffusion coefficient of 4.3×10^{-8} (m^2s^{-1}).
In order to check the value of the diffusion coefficient we performed new simulations, where the input parameter was 4.3×10^{-8} (m^2s^{-1}) for diffusion coefficient. We simulated the situation in which the concrete samples of different thickness were exposed for 12 hours. One side of the sample was exposed to a radon concentration of 36.7 $kBq\cdot m^{-3}$..
The data obtained by the simulation are consistent with experimental values. Some discrepancy for the thicker samples can be explained by experimental errors.

4. CONCLUSION

Concrete is complex heterogeneous material, but in the case of radon diffusion it can be considered as a homogeneous and porous material where dominant processes are diffusion and advection.
Knowledge of the diffusion characteristics of concrete is important for the estimation of radon flux from the soil in buildings. Also, the concrete slabs are a barrier for radon transport. The parameter describing the diffusion characteristics of the concrete is diffusion constant.
The results presented here can be used for improving the existing technology for preventing of radon entry from soil into buildings and homes.

The obtained results can be used for improvement of the existing practice regarding the manufacturing of concrete elements in order to lower of radon penetration from soil into homes and buildings offices.

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