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Processing the spike- like radon anomaly exhalation from the soil surface by electrical model

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ABSTRACT

A model based on electric circuit theory has been developed to simulate the radon concentration in an accumulator chamber from the soil surface. This model simulates the radon generation on earth as a voltage source, diffusion to the earth's surface as an electrical conductor, the convection flux of radon as an electrical current source and radon concentration in a chamber as a voltage across a capacitor. We use this model for processing the spike like an anomaly of radon. This paper offers a radon anomaly spike like has a duration time less than several hours. It is shown that the time constant of a general setup is very large with compare the duration time of a spike like anomaly. In this condition the actual shape of radon flux in earth is different from radon measuring concentration in the chamber.

With regard to this model it is shown that the rise time of measured radon concentration must be equal the duration time of a spike like anomaly and the fall time must have a constant time equal the five times of constant time of our setup and it is independent of the shape of the anomaly.

1. Introduction

In all natural soils and rocks radon atoms are continuously produced in α decay chain of Uranium and Thorium. A fraction of them emanates into air-filled pore volume of soil and eventually escapes to the atmosphere. The migration of radon in the earth and exhalation from the earth's surface has been studied extensively in the last decades (Nazaroff, 1992; Kohel et al., 1994; Negarestani et al., 2002; Yakovleva, 2003; Lehmann, 2004). The understanding of radon migration into the earth and exhalation of the earth's surface is important in many applications, such as radiation protection in residential building, uranium ore prospecting, or earthquake prediction. The pre-earthquake stress gradients move underground fluids, carrying some dissolved gases such as radon, helium, methane … to the subsurface region which are permeable for soil gas. So subsoil radon anomaly is observed in the soil-gas measurement at or near a fault before and after an earthquake (Laskar et al., 2011).

In a previous publication (Musavi Nasab, 2011) we have modeled the radon exhalation from water to air. To better understand the mechanism of Radon migration into the earth and exhalation from the earth's surface a new model based on an electrical circuit theory has been introduced. The most common method of measurements of radon exhalation rate from soil surface in the countries of Europe and America is based on the principle of radon accumulation in a closed container which is mounted on the surface of the soil. In the next section, a static accumulation chamber has been considered that is located on the surface of the soil. Then the differential equation of temporal evolution of the volume average radon concentration in the static chamber has been compared to the differential equation of temporal change in voltage across a capacitor in the RC electric circuits and the equivalent electric circuit for radon exhalation from earth to an accumulation chamber has been obtained. This model considers the migration of radon through the earth by diffusion–convection mechanism and in one dimension geometry. The subsurface has been considered as a parallel-media model. In the parallel-media model, radon is assumed to be transported from the earth to a closed area via two parallel connected media. The measured data at our site in the Kerman have been used to model the behavior of radon in the atmosphere of the closed chamber. It is shown that this electrical model introduces clearly technique for solving the problems related time variation of radon concentration that can be used for earthquake prediction. For example, by using this model we analysis the shape of measured radon concentration (Bqm^{-3}) in a closed area that caused by a spike like an anomaly of radon flux ($Bqm^{-2}\,s^{-1}$) in the earth. Similar spikes-like anomaly patterns, a flux of radon anomaly that has a duration time less than several hours, were suggested by several Authors (Chyi et al., 2005; Ramola et al., 2008;

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Yang et al., 2005).

2. Materials and methods

2.1. Accumulation chamber

In this subsection we describe the temporal evolution of the radon activities in the static chamber from a mathematical point of view. We use the conclusion of this for modeling the radon concentration in the accumulation static chamber from the soil surface by an electric circuit. Let C(t) denote the average of volume radon concentration (Bqm^{-3}) in the static chamber at time t (s), J(t) the radon flux from soil surface to the accumulation chamber at time t ($Bqm^{-2}\,s^{-1}$) and λ the decay constant of radon isotopes (s^{-1}). Then the temporal evolution of the radon concentration in a static chamber with the volume V_L (m^3) and the area of base S (m^2) is given by (Wilkening and Watkins, 1976):

$$V_L \frac{dC(t)}{dt} = S\,J(t) - \lambda\,V_L\,C(t) - V_L\,\lambda_V\,[C(t) - C_{ext}] \tag{1}$$

where C_{ext} is the outdoor atmospheric of radon concentration and λ_v (s^{-1}) is the total rate of leakage in the measurement chamber. The flux out of the earth, J(t) is driven by diffusion, $J_d(t)$, and convection, $J_a(t)$,

$$J(t) = J_d(t) + J_a(t) \tag{2}$$

In this paper, the earth has been considered as a parallel-media model. In the parallel-media model, radon is assumed to be transported from the earth to a closed area via two parallel connected media. A schematic representation of this model is given in Fig. 1 each medium has its own permeability, diffusion coefficient and volume. Furthermore, it is assumed that there is no exchange of radon between media. Then we have:

$$V_L \frac{dC(t)}{dt} = [S_A\,J_d(t) + S_B\,J_a(t)] - \lambda V_L\,C(t) - V_L \lambda_V\,[C(t) - C_{ext}] \tag{3}$$

It is assumed that in the medium A the diffusion current is majority current and in the medium B convection current is majority current and $S_A >> S_B$.

In medium A, the steady state of the radon activity A(z) in the pore air of a soil at depth z determined by an equilibrium between diffusive transport, radioactive decay and radioactive production can be described by the differential equation (Chyi et al., 2005):

$$\varepsilon_a D_e \frac{d^2C(z)}{dz^2} - \lambda(\varepsilon_a + \kappa\varepsilon_w + \rho k)C(z) + \lambda f C_{Ra}\rho = 0 \tag{4}$$

where ε_a and ε_w represent the air-and-water-filled porosity of the rock, D_e the effective diffusion coefficient ($m^2\,s^{-1}$), κ the dimensionless aqueous-gas partition coefficient, k the sorbed-gas partition coefficient ($m^3\,kg^{-1}$), ρ the dry bulk density (kgm^{-3}), C_{Ra} the radium activity ($Bqkg^{-1}$) and finally f is the dimensionless emanation coefficient. Providing a homogeneous subsurface soil (so that soil parameters, ε_a, ε_w, D_e, κ, K, ρ, C_{Ra} and f are constant) the solution of (4) satisfying the boundary condition $C(z=0)=C_0$ at the soil surface(z=0) and the boundary condition dC/dz = C_∞ at infinitely great depth ($z\rightarrow\infty$) is:

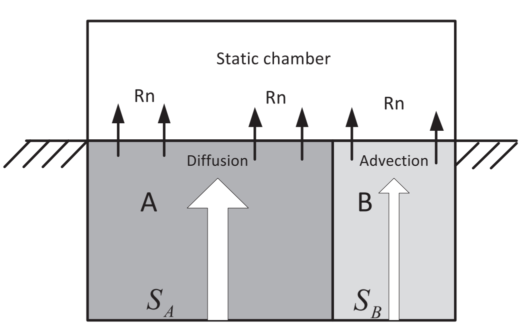

Fig. 1. Parallel media for radon transport from rock to earth's surface.

$$C(z) = C_\infty - (C_\infty - C_0)e^{\frac{z}{z^*}} \tag{5}$$

(Note that $z<0$ below the surface), where $C_\infty = fA_{Ra}\rho/(\varepsilon_a + \kappa\varepsilon_w + \rho k)$ is the activity in the pore air given at very great depths and $z^* = \sqrt{\frac{\varepsilon_a D_e}{\lambda(\varepsilon_a + \kappa\varepsilon_w + \rho k)}}$ is the diffusion length. From this we get the diffusive flux through the soil surface z=0,

$$J = \varepsilon_a D_e \frac{dC(z)}{dz}\Big|_{z=0} = \frac{\varepsilon_a D_e (C_\infty - C_0)}{z^*} \tag{6}$$

We assume that the radon activity at the soil surface is always equal to the activity in the static chamber, letting $C_0 = C(t)$ so that

$$J(t) = \frac{\varepsilon_a D_e [C_\infty - C(t)]}{z^*} \tag{7}$$

In the medium B, radon can be transported via bulk (rock) movement of a carrier gas (CH_4, CO_2) (Etiope and Martinelli, 2002). Radon transport due to movement of gas (e.g. Soil gas) is called advective transport. The flux of radon in the gas-phase due to convection is given by:

$$J_a = C_\infty u \tag{8}$$

where J_a is the flux of radon in the gas-phase as a result of convection ($Bqm^{-2}\,s^{-1}$), C_∞ is radon concentration in the gas-phase (Bq/m^3) and u flow rate of gas (ms^{-1}). Darcy's law describes the advective transport of a fluid through a porous medium when the flow is laminar and the resistance to flow is dominated by the viscosity of the fluid. In differential form, Darcy's law may be written as

$$u = \frac{-k}{\mu \nabla p} \tag{9}$$

where k is the intrinsic permeability of the soil (m^2), μ is the dynamic viscosity of the fluid (Pa s), and ∇P is a pressure gradient ($Pa\,m^{-1}$). Then from Eqs. (6) and (7), we have:

$$J_a = C_\infty\left(\frac{-k}{\mu\nabla p}\right) \tag{10}$$

By inserting j from Eq. (10) into Eq. (1), we have:

$$V_L \frac{dC(t)}{dt} = [C_\infty - C(t)]/[z^*/S(\varepsilon_a D_e)] + S_B\,J_a - \lambda V_L\,C(t) - V_L\,\lambda_V\,[C(t) - C_{ext}] \tag{11}$$

2.2. Electrical model

The temporal variation of radon concentration in the accumulation chamber simulates with electrical model. Eq. (11) is similar to the differential equation of the temporal voltage change across the capacitor of the electric circuit that is shown in Fig. 2 the temporal change in the capacitor voltage of this electric circuit can be described by the differential equation

$$C_p \frac{dV_C(t)}{dt} = \frac{V_i - V_C(t)}{R_i} + I - \frac{V_C(t)}{R_0} - \frac{V_C(t) - V_G}{R_1} \tag{12}$$

where C_P is the capacitance of the capacitor (F), V_i is the input voltage source (V), $V_c(t)$ is the capacitor voltage (V), R_i is the resistance of the input voltage source (in ohms) and R_o is a resistance that depend on the capacitance of the capacitor (Ω) and I is a depended current source (A) to V_i. A complete comparison between the parameters of Eq. (11) and Eq. (12) can be seen in Fig. 2 and Table 1. The Pspiese software that is a famous software in the analysis of electrical circuit, has been used to obtain the response of the circuit.

2.3. Measurement setup

To examine the model the continuous radon monitoring in soil gas is carried out on the campus of the Kerman graduate university of