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# A Comparative study of indoor radon contributed by diffusive and advective transport through intact concrete

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**Abstract**

The present work is aimed that out of diffusive and advective transport which is dominant process for indoor radon entry under normal room conditions. For this purpose the radon diffusion coefficient and permeability of concrete were measured by specially designed experimental set up. The radon diffusion coefficient of concrete was measured by continuous radon monitor. The measured value was $(3.78 \pm 0.39)\times10^{-8}$ $m^2/s$ and found independent of the radon gas concentration in source chamber. The radon permeability of concrete varied between $1.85\times10^{-17}$ to $1.36\times10^{-15}$ $m^2$ for the bulk pressure difference fewer than 20 Pa to 73.3 kPa. From the measured diffusion coefficient and absolute permeability, the radon flux from the concrete surface having concentrations gradient 12-40 $kBq/m^3$ and typical floor thickness 0.1 m was calculated by the application of Fick and Darcy laws. Using the measured flux attributable to diffusive and advective transport, the indoor radon concentration for a typical Indian model room having dimension $(5\times6\times7)$ $m^3$ was calculated under average room ventilation (0.63 $h^{-1}$). The results showed that the contribution of diffusive transport through intact concrete is dominant over the advective transport, as expected from the low values of concrete permeability.

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## 1. Introduction

During the last three decades, extensive work had been carried out by many researchers to understand the exact mechanism of indoor radon entry into the house (Minkin and Shapovalov, 2008; Lively and Goldberg, 1999). Two important transport processes

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through which the radon soil gas enters into the residential buildings are advection and diffusion. The advective transport of radon can be described by Darcy's law in terms of permeability of concrete (Savovic et al., 2011) which strongly depends upon the pressure differential across it, while the diffusive transport of radon can be expressed by Fick's law of diffusion in terms of diffusion coefficient. Initially radon diffusion through soil and building materials are believed to be dominant process for indoor radon entry. But in many houses, the measured indoor radon concentrations were found higher than predicted by the diffusion theory (Minkin, 2002). Advective transport through cracks, holes and other penetrations are believed to explain high radon entry rates into structures (Font and Baixeras, 2003). Diffusion and advection transport through the intact concretes are much related to the micro-structure and the matrix of the intervening medium. Kendrick and Langner (1991) from their experimental study concluded that the radon diffusion is prevalent to the indoor radon entry, while the advective transport shared only 20%. Ventilation and stack effect insides the building create a pressure gradient of the order of 5-10 Pa, which increases to 15 Pa during heating season. The radon diffusion coefficient, porosity and permeability of concrete are important parameters that play important role in the transport of radon through the concrete floor (Renken and Rosenberg, 1993). This work is aimed to find the answer of the question that which, out of diffusive and advective transport is dominant under normal room conditions (< 20 Pa) using a specially designed experimental diffusion chamber.

## 2. Theory

### *2.1. Measurement of radon diffusion coefficient through concrete*

Consider concrete slab of thickness (d) and cross sectional area (A) exposed to a high radon concentration $C_\infty$ on one side and ventilated at the other side under a pressure gradient $\nabla P$. The transport of radon through concrete is given in terms of diffusive flow and advective flow. The non-steady-state transport of radon in a sample of concrete is given by (Chauhan and Kumar, 2013a)

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} - \frac{k}{\mu}\nabla P.\frac{\partial C}{\partial z} - \lambda C \tag{1}$$

Where D is a radon diffusion coefficient, k and μ are permeability and kinematic viscosity of gas. Where the first term represents the diffusion of radon through concrete due to differences in the radon concentration on both sides of slab, second term represent the rate of radon transport due to advective flow caused by the pressure gradient $\nabla P$, third term represents the natural decay of radon in source chamber. Under steady state the solution of Eq. 1 with boundary condition z = 0, C = $C_m$ and z = d, C = 0 is given by

$$C = -\frac{C_m \exp\left(\frac{k\nabla P z}{2\mu D}\right).\mathrm{Sinh}\left(\frac{z-d}{2}\sqrt{\frac{k^2(\nabla P)^2}{4\mu^2 D^2}+\frac{\lambda^2}{D^2}}\right)}{\sinh\left(\sqrt{\frac{k^2(\nabla P)^2}{4\mu^2 D^2}+\frac{\lambda^2}{D^2}}\right)d} \tag{2}$$

Using $l_d = \sqrt{\frac{\lambda}{D}}$ and $l_a = \frac{-k\nabla P}{\eta\mu\lambda}$ terms as radon diffusion length (Font, 1997) and radon advection length and η is the porosity of concrete, Eq.2 becomes

$$C = -\frac{C_m \exp\left(\frac{\eta\lambda z l_a}{2D_e}\right).\mathrm{Sinh}\left(\frac{z-d}{2}\sqrt{\frac{\eta^2\lambda^2 l_a^2}{4D^2}+\frac{1}{l_d^2}}\right)}{\sinh\left(\sqrt{\frac{\eta^2\lambda^2 l_a^2}{4D^2}+\frac{1}{l_d^2}}\right)d} \tag{3}$$

For pure diffusive flow, $l_a = 0$, Eq. 3 becomes $C = -\frac{C_m \mathrm{Sinh}\left(\frac{z-d}{2l_d}\right)}{\sinh\left(\frac{d}{l_d}\right)}$ (4)

Eq. 4 is the same equation described by the Jiranek and Hulka (2000) for pure diffusive flow. The radon flux in the receiver chamber due to diffusion through the concrete is given by Fick's law

$$J_d = -D\left|\frac{\partial C}{\partial z}\right|_{z=d} \tag{5}$$

$$J_d = \frac{DC_m}{l_d.\sinh\left(\frac{d}{l_d}\right)} = \frac{C_m l_d \lambda}{\sinh\left(\frac{d}{l_d}\right)} \tag{6}$$

Under the pressure gradient $\nabla P$ the net radon flux through concrete is due to diffusion and advection through concrete is given by

$$J = J_d + J_a \tag{7}$$

$$J_a = \frac{k.\nabla P}{\mu}C_m \tag{8}$$

Using Eq. 6, 7 and 8 the permeability (k) of the concrete can be calculated. The measurement of radon diffusion coefficient through concrete was measured by protocol suggested by Jiranek and Rovenska (2012).