Testing permeability of building materials for radon diffusion

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The diffusion coefficient and length for some building construction materials like limestone powder, sandstone, granite, crasher, soil, sand, cement, fly ash, gypsum, wall putty have been calculated. The diffusion of radon gas through these materials has been carried out under a control study. Uranium ore has been used as radon source and LR-115 solid-state nuclear track detectors are used to record alpha tracks due to diffusion of radon at different heights from the source. The results indicate that the diffusion coefficient and length of radon gas in building materials are the measure of its permeability through that medium.

Keywords: Radon, Permeability, Diffusion, LR-115 detectors

1 Introduction

The transport phenomenon of radon through diffusion is a significant contributor to indoor radon entry[1-2]. The diffusion of radon in dwellings is a process determined by the radon concentration gradient across the building material structure between the radon source and the surrounding air. Radon diffusion and transport through different media is a complex process and is affected by several factors[3-5]. For any material medium the porosity, permeability and the diffusion coefficient are the parameters, which can quantify their capability to hinder the flow of radon soil gas. An increase in porosity will provide more air space within the material for radon to travel, thus reducing resistance to radon transport. The permeability of material describes ability to act as a barrier to gas movement when a pressure gradient exists across it and is closely related to the porosity of material. The radon diffusion coefficient of a material quantifies the ability of radon gas to move through it when a concentration gradient is the driving force. This parameter is proportional to the porosity and permeability of the medium. The diffusion of the radon through the ground is a complex process and is related to the porosity and permeability, which is dependent on grain size distribution, degree of compaction and the water content of the soil[4-7].

Radon diffusion through material media obeys following equation:

\[ N = N_0 \exp \left(-\sqrt{\lambda/D} \right) X \]  \hspace{1cm} (1)

where \( N \) is the concentration of radon at any time \( t \) at a distance \( X \) from source, \( N_0 \) is the concentration of radon at source and \( \lambda \) is the decay constant of radon.

If \( N_1 \) and \( N_2 \) are the radon concentrations at distances \( X_1 \) and \( X_2 \) from source respectively, then using Eq. (1) the diffusion coefficient \( D \) is given by:

\[ D = \lambda \left[ \frac{(X_2 - X_1)}{\ln \left( \frac{N_1}{N_2} \right)} \right]^2 \]  \hspace{1cm} (2)

Eq. (2) can be used to calculate radon diffusion coefficient through material medium.

The diffusion length can be calculated using the equation:

\[ L = \sqrt{D/\lambda} \]  \hspace{1cm} (3)

where \( D \) is radon diffusion coefficient and \( \lambda \) is decay constant of radon.

In the present study, radon diffusion coefficients and diffusion lengths have been calculated using Eqs (2) and (3) for building materials like: limestone powder, sandstone, granite, crasher, soil, sand, cement, fly ash, gypsum and wall putty.

2 Experimental Details

The apparatus designed for the study of radon diffusion through different kinds of building construction materials is shown in Fig. 1. It consists of a hollow plastic cylinder of inner diameter 25 cm and length 50 cm deployed vertically. The uranium ore was used as radon source covered with latex membrane fixed at the bottom of the cylinder in the
cavity. Fourteen open-ended cylindrical diffusion tubes of diameter 1.5 cm and lengths 15 and 25 cm were installed in hollow plastic cylinder fixed with radon source. The top end of each diffusion tube holds LR-115 type-II plastic detector such that its sensitive side always faces the source of radon. LR-115 type-II is frequently used as $\alpha$-particles detector to record alpha tracks. The building construction materials under study in the pulverized form were filled in diffusion tubes and the system was left undisturbed for a period of 30 days. The packing density of each sample was also calculated by taking mass over volume ratio. All the samples were subjected to similar process of exposure as described above.

At the end of the exposure time, the detectors were removed, chemically etched in 2.5N NaOH solution at 60°C for 90 min and thoroughly washed and dried. The alpha tracks were counted using an optical Olympus microscope with CCTV camera and a monitor, at 600 X. Large number of graticular fields of the detectors were scanned to reduce statistical errors. The background correction was also applied in each case under study. The radon concentration was calculated for each sample in different cases. The values of diffusion coefficients for different kinds of building construction materials were calculated using Eq. (2) and the diffusion lengths using Eq. (3).

### 3 Results and Discussion

For building materials under study, the average values of diffusion coefficient are found to vary from $0.06 \times 10^{-6}$ m$^2$ s$^{-1}$ for granite to $6.44 \times 10^{-6}$ m$^2$ s$^{-1}$ for crasher and the corresponding diffusion length varies from 0.17 m for granite to 1.74 m for crasher (Table 1). On the basis of radon diffusion lengths through these materials, they are divided into three categories; tight, less permeable and permeable for radon flow. In the tight category the materials are granite and limestone powder having radon diffusion length less than 0.5 m. The less permeable materials like soil, cement, fly ash and wall putty have diffusion lengths between 0.5 to 1.0 m while the permeable materials, crasher, sand and gypsum have radon

<table>
<thead>
<tr>
<th>Building construction material</th>
<th>Packing density $\times 10^3$ Kg m$^{-3}$</th>
<th>Diffusion coefficient $\times 10^{-6}$ (m$^2$ s$^{-1}$) AMISE*</th>
<th>Diffusion length (m) AMISE*</th>
<th>Comparative permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone powder</td>
<td>1.52</td>
<td>0.44 ± 0.09</td>
<td>0.45 ± 0.12</td>
<td>tight</td>
</tr>
<tr>
<td>Sand stone</td>
<td>2.34</td>
<td>2.54 ± 0.27</td>
<td>1.09 ± 0.05</td>
<td>permeable</td>
</tr>
<tr>
<td>Granite</td>
<td>2.71</td>
<td>0.06 ± 0.01</td>
<td>0.17 ± 0.01</td>
<td>tight</td>
</tr>
<tr>
<td>Crasher</td>
<td>1.03</td>
<td>6.44 ± 0.35</td>
<td>1.74 ± 0.24</td>
<td>permeable</td>
</tr>
<tr>
<td>Soil</td>
<td>1.36</td>
<td>1.65 ± 0.21</td>
<td>0.88 ± 0.05</td>
<td>Less permeable</td>
</tr>
<tr>
<td>Sand</td>
<td>1.53</td>
<td>4.29 ± 0.34</td>
<td>1.42 ± 0.46</td>
<td>permeable</td>
</tr>
<tr>
<td>Cement</td>
<td>1.43</td>
<td>1.21 ± 0.05</td>
<td>0.76 ± 0.02</td>
<td>Less permeable</td>
</tr>
<tr>
<td>Fly ash</td>
<td>1.22</td>
<td>2.06 ± 0.04</td>
<td>0.98 ± 0.01</td>
<td>Less permeable</td>
</tr>
<tr>
<td>Gypsum</td>
<td>2.22</td>
<td>2.64 ± 0.11</td>
<td>1.11 ± 0.37</td>
<td>permeable</td>
</tr>
<tr>
<td>Wall Putty</td>
<td>1.42</td>
<td>1.03 ± 0.04</td>
<td>0.69 ± 0.02</td>
<td>Less permeable</td>
</tr>
</tbody>
</table>

*SE (standard error) = $\sigma/\sqrt{N}$, where $\sigma$ is SD (standard deviation) and N is the no of observations.
diffusion lengths more than 1.0 m through them. The comparative variation in radon diffusion lengths for different building materials is shown in Fig. 2. Similar results have been reported\textsuperscript{4,8,9} for cement, soil, sand and marble chips. The minor differences may be due to the difference in the nature, grain size and porosity of the materials. The results of our investigations also provide better insight into the selection of building construction materials capable of controlling the indoor radon levels.

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**References**