

UTILIZATION OF ELECTRO-OSMOTIC PULSING TECHNOLOGY TO REDUCE RADON GAS DIFFUSION: PRELIMINARY RESULTS

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ABSTRACT

This paper presents the preliminary results of the utilization of *Electro-Osmotic Pulsing Technology* to reduce the diffusion of radon gas through concrete. A laboratory test chamber with state-of-the-art instrumentation was used to measure the diffusion coefficient of radon gas through typical concrete samples 30cm in diameter and 10 cm thick with a water. Within the concrete samples, an electrode was embedded and connected to a patented power supply. Inside the test chamber, the concrete samples were exposed to high concentrations of radon gas and varying levels of electrical field intensity and relative humidity. Preliminary data indicates as much as a 91% reduction in the radon gas diffusion coefficient when the *Electro-Osmotic Pulsing System* is in operation. The effects of system operation, voltage waveform sequence, electrode type and configuration as well as humidity level are discussed. Details of the experimental setup are described.

INTRODUCTION

Radon gas can usually be controlled in residential construction by either preventing its entry or by diluting its concentration once it has entered. The largest contributor to indoor radon levels is from soil gases that enter the building through the foundation. More specifically, indoor radon entry is mainly due to the transport mechanisms of advection (flow by pressure differences) and diffusion (flow by concentration differences) of radon gas under and around a building's envelope.

In general, radon diffusion from the soil through the concrete slab has been ignored in comparison to pressure-driven flow. The importance of diffusion as a significant contributor to indoor radon entry has been highlighted by several recent studies. These include: Holub et al. (1985), Loureiro et al. (1990), Ward et al. (1993), Rogers et al. (1994) and Renken and Rosenberg (1995). These investigations concluded that under certain conditions diffusion of radon gas through intact concrete can be the problematic transport mechanism in residential homes. Therefore, an effective method to reduce the diffusion coefficient of radon in concretes used in residential construction needs to be explored.

This paper presents the experimental results of utilizing an *Electro-Osmotic Pulsing System (EOPS)* to reduce the diffusion coefficient of radon gas through concrete typical of Wisconsin residential foundations. An original experimental system to measure the radon diffusion coefficient is described.

METHODOLOGY

Concrete Samples

Concrete is a porous material which easily allows radon gas to migrate through its pores. These concrete pores are randomly sized, arranged and connected. The movement of water and ions through these tortuous channels is governed by permeation, absorption and diffusion mechanisms. The pore system is related to the water-to-cement ratio, mix proportions and curing. Other potential flow channels may develop in the form of microcracks.

Table 1 describes the concrete composition used in the six samples. These concrete samples were of standard composition (Hool 1918; USBR 1938) with cement:sand:gravel = 1:2:4 and w/c = 0.51. Each cast sample was 30.48 cm in diameter and 10.16 cm in thickness and they were allowed to cure for 30 days in a controlled humidity room. Within the specimen, a rubber or ceramic electrode configuration was embedded 2.54 cm into the concrete during the casting process (Fig. 1). Each electrode was approximately 36 cm in length so that it could be easily connected to the external power supply. Table 2 lists the electrode configuration for each of the six concrete samples while Fig. 2 is a schematic of these electrode configurations. Complete details of the concrete sample preparations are contained in Nam (1999) and are not repeated here, for brevity.

Sample 1 with no embedded electrode was used as the standard example. Samples 2 - 6 were used in conjunction with the EOPS. The single, cross and triple electrode configurations were employed to examine the effect of electrical field coverage area. As indicated in Table 2, two types of electrodes were employed: rubber coated and ceramic coated.

Electro-Osmotic Pulsing Technology

Electrokinetic phenomena in porous materials (e.g., soils and concrete) occurs when there exists a relationship between hydraulic and direct current electric driving forces and flows. The principal mechanisms by which transport takes place under the action of an electrical field are: electromigration, electrophoresis and electro-osmosis (Pengra and Wong 1996).

Electro-osmosis was discovered by Reuss in 1809 and refers to fluid-flow induced by an applied electrical field. More specifically, electro-osmosis occurs when the liquid phase containing ions moves relative to the stationary solid phase of the porous material under the influence of an imposed electrical potential. When a voltage is applied to the positive anode and negative cathode electrodes in a porous media like soil or concrete, an electrical field is created between them. Because the porous medium carries negative charges on their surfaces, they attract positive

ions (atoms missing electrons) from the water in the soil or concrete. Consequently, the positive charges are pulled to the negative electrode as they drag the water with them.

This electro-osmosis technique has been used in field applications since the 1940s for dewatering applications (Yoshida 1993). More recently, the technique has been applied to the removal of contaminants from soils (Probstein and Hicks 1993).

The conventional electro-osmosis method uses a continuous or periodic application of a direct current to maintain the electric field across the porous material. Various problems have been observed with this continuous direct current system and include: corrosion of anode, cracking of concrete and even reversal of water flow. In contrast, the *Electro-Osmotic Pulsing System*, consisting of a patented power supply, a rubber or ceramic coated electrode and a pure copper bar cathode (1.91 cm x 1.91 cm x 27.9 cm), utilizes a pulsating alternating direct current to create an effective electrical potential. As shown in Fig. 3, the EOPS waveform produces a pulse of positive applied voltage, a pulse of negative applied voltage and a period with no applied voltage. Since the positive voltage has a greater duration and amplitude than the negative voltage, a net "upward" movement or pumping action of the water is created. The variable pulsating power supply is distributed by Drytronic Inc. of La Crosse, Wisconsin. The unit provides a steady voltage output of +/- 37 V, a variable current of 0 - 0.20 mA and a voltage waveform sequence of 1 - 97 seconds. The maximum applied positive voltage has a maximum duration of 75% while the neutral and negative applied voltages have maximum durations of 24% of the waveform sequence. The rubber coated electrode consisted of a metal wire 1.5 mm in diameter covered by a rubber coating 2.8 mm in thickness. Considered a more effective electrode, the thin ceramic coated electrode had an outside diameter of 0.87 mm.

Experimental System

Figure 4 is a schematic of the experimental system used to measure the radon gas diffusion coefficients through the concrete samples. Two continuous radon monitors were used to measure the radon concentrations in both the source and collection chambers. These monitors utilized a Lucas scintillation cell and a photomultiplier tube to count the number of alpha emissions given-off by the radon gas present. A diaphragm pump was used in each loop to assure that the air and radon gas was thoroughly mixed. A filter is placed at the entrance of each scintillation cell to remove dust and radon daughter products within the air stream. Two flow meters were used to monitor the flow rates since the calibrated sensitivity of the continuous radon monitors were dependent on the flow rate. The radon source (a commercially available passive radon gas source) was used to build-up the radon gas concentration in the Source Chamber. The Source Chamber and Collection Chamber were attached to each face of the concrete sample to allow the full facial area of each concrete sample to be exposed to the radon-air mixture. Toggle valves and other hardware were employed to create the desired radon gas flow configuration.

Humidity within the Source Chamber was provided by a humidifier. A sensitive pressure transducer monitored the pressure differential across the concrete samples so that pure diffusion transport mechanism could be verified. Environmental conditions (e.g., relative humidity, temperature and barometric pressure) were measured with high-accuracy sensors. A modern PC-

data acquisition system was employed to read the electrical signals of the sensors and radon monitors and to display and record the data.

In this investigation, the radon gas diffusion coefficients through the concrete samples were calculated by using Fick's Law. Fick's Law as applied to a slab of concrete experiencing one-dimensional fixed concentration differences with isobaric and isothermal conditions is expressed as:

$$J = D \frac{\Delta C}{\Delta x} \quad (1)$$

where,

- J = radon flux through the concrete cross-sectional area
- D = diffusion coefficient of radon gas through the concrete sample
- ΔC = radon gas concentration difference across the concrete sample
- Δx = thickness of the concrete sample

The method employed by Renken and Maas (1997) was used to determine the time necessary for steady state to be achieved prior to the initial sampling of the chambers. Details of the experimental procedures and calculations can be found in Nam (1999).

RESULTS

Six different concrete samples were tested. Samples 2 - 6 were tested at three different EOPS voltage waveforms and are referred to as Tests A, B and C. Test A refers to no EOPS operation, Test B refers to a voltage waveform sequence of 65% positive, 25% neutral and 10% negative while Test C had a 75% positive, 22% neutral and 3% negative pulsations. A summary of the experimental steady-state radon gas diffusion coefficient results and EOPS reduction capabilities are contained in Table 3. The experimental uncertainty of the diffusion coefficient was estimated at 10% (Nam 1999).

Effect of EOPS

As shown in Figs. 5 and 6, the radon gas diffusion coefficient through the concrete samples was greatly reduced when the EOPS was in operation. The reduction in D ranged between 42% - 91%. This percent reduction was dependent on the voltage waveform sequence, the electrode type, the electrode configuration, the voltage pulse duration and the relative humidity in the source chamber.

Effect of Waveform Sequence

A comparison between the B and C Tests exemplify the effect of waveform sequence on the radon gas diffusion coefficient. The experimental findings showed the longer positive applied voltage pulse produced a greater reduction in the diffusion coefficient. This waveform sequence

effect is highlighted by comparing Tests 6B and 6C. Here, there is a 59% increase in the diffusion coefficient as we increase the positive pulse duration by 10%.

Effect of Electrode Type

A comparison between Tests 2 and 4 illustrates the effect of the electrode type. The data on the single electrode configurations shows employment of the ceramic coated electrode produced as much as a 17% more reduction in the diffusion coefficient than the rubber coated electrode. For the cross electrode configurations of Tests 3 and 5, the results were mixed.

Effect of Electrode Configuration

As indicated by Tests 2 - 6, the radon gas diffusion coefficient was dependent on the electrical field coverage area. By doubling the number of electrode passes through the effective area in Tests 2C and 3C, the value of the diffusion coefficient decreased by 77% for the rubber coated electrode. As the electrode passes were increased threefold in Tests 4C and 6C, the diffusion coefficient decreased by approximately 69% for the ceramic coated electrode.

Effect of Pulse Duration

The experimental results presented in Table 3 utilized a voltage pulse duration of five seconds. The authors are currently testing the effect of the pulse duration on the reduction of the radon gas diffusion coefficient.

Effect of Relative Humidity

Table 4 highlights the effect of relative humidity in the Source Chamber on the EOPS capabilities for Concrete Sample 6C. The data indicates an inverse relationship between the diffusion coefficient and the relative humidity. There is an approximate 24% reduction in D as the relative humidity increases from 86.65% to 96%.

CONCLUSIONS AND RECOMMENDATIONS

This paper presented the preliminary results of an investigation that utilizes an innovative system to reduce the radon gas diffusion coefficient through intact concrete. A 91% reduction in the diffusion coefficient was recognized with the operation of the EOPS for specified conditions. The experimental findings showed the conditions for the most effective EOPS in reducing radon gas migration are: (1) largest electrical field coverage area by employing more electrode passes, (2) longest positive applied voltage pulse duration, (3) highest humidity level exposed to the porous medium (concrete), (4) employment of a ceramic coated electrode as the anode and (5) intact concrete.

The preliminary results of this investigation have indicated that *Electro-Osmotic Pulsing Technology* may be considered as a future effective alternative means of reducing radon gas migration in residential construction.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Conrad V. Weiffenbach, Wisconsin Department of Health and Social Services for his input and the US EPA State Indoor Radon Grants Program for their sponsorship of this study. We would also like to thank Mr. Roger Hayes and Mr. Egil Bjerke, Drytronic, Inc. of LaCrosse, Wisconsin for their consultation and equipment donations. Special thanks to Mr. Gregory Barske, UWM ME Instrument Maker for his ideas and fabrication of the test system.

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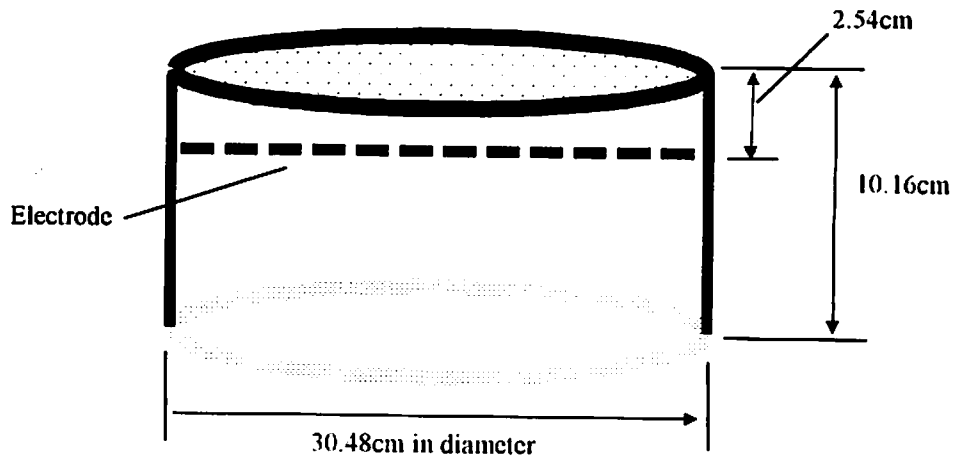
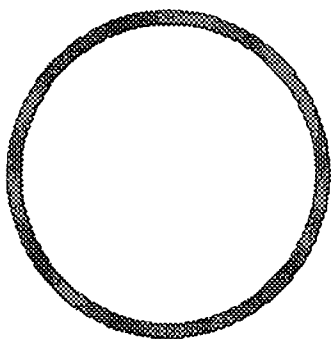
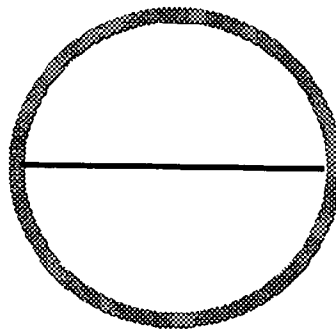


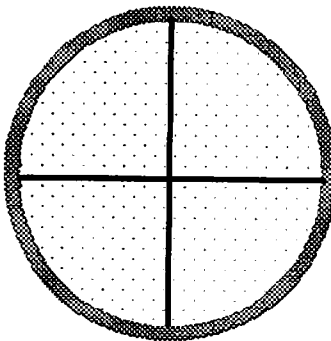
Fig.1. Cross-section of concrete sample with embedded electrode.



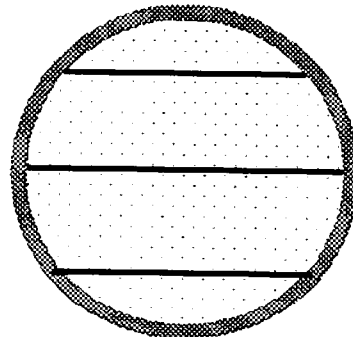
(1) No electrode



(2) Single



(3) Cross



(4) Triple

Fig.2. Schematic of electrode configurations.

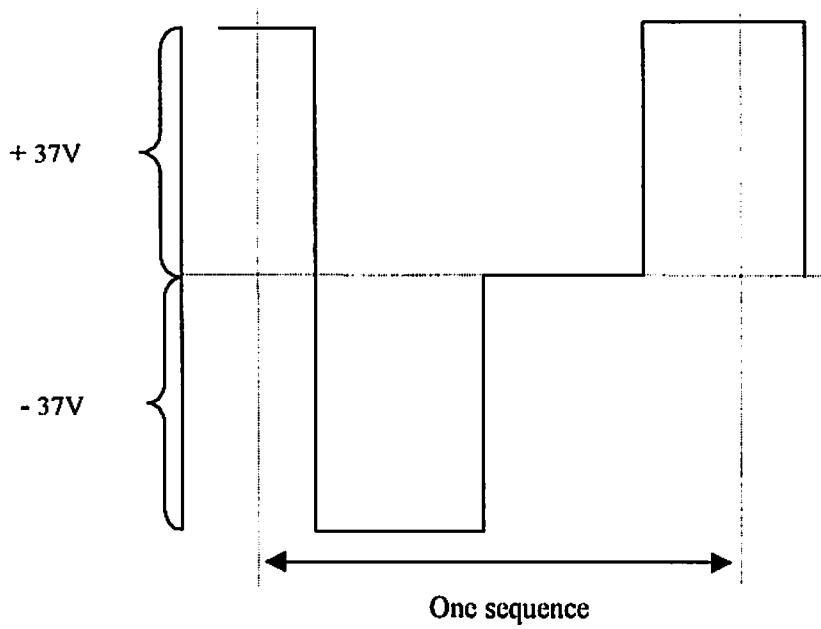


Fig. 3. EOPS voltage waveform.

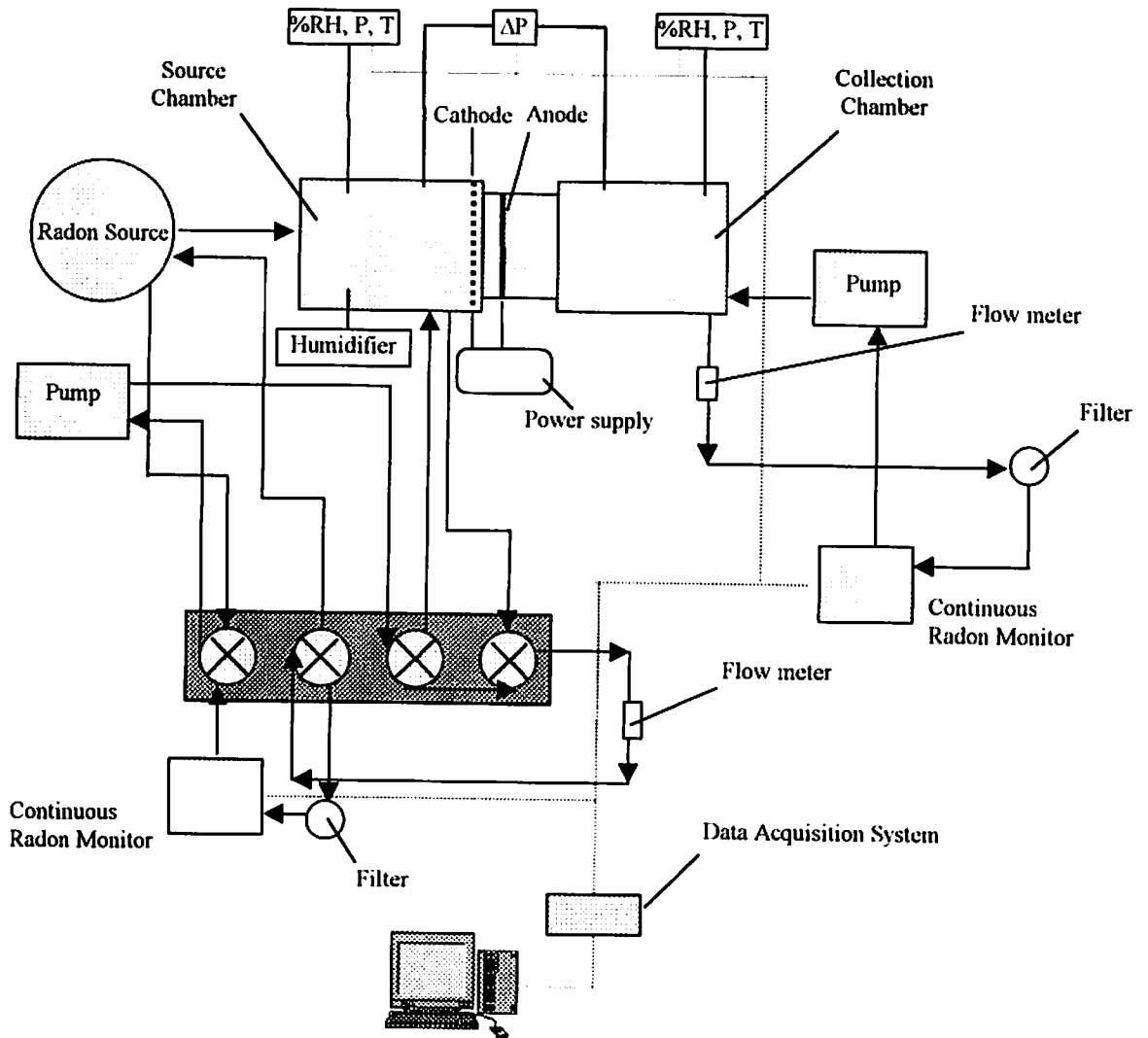


Fig. 4. Schematic of experimental system.

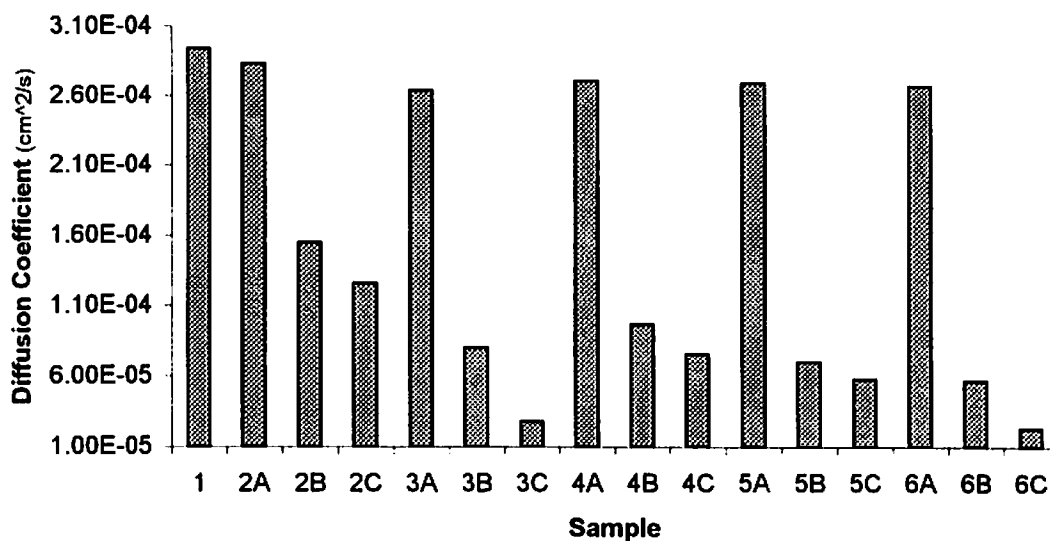


Fig.5. Effect of EOPS on the radon gas diffusion coefficient.

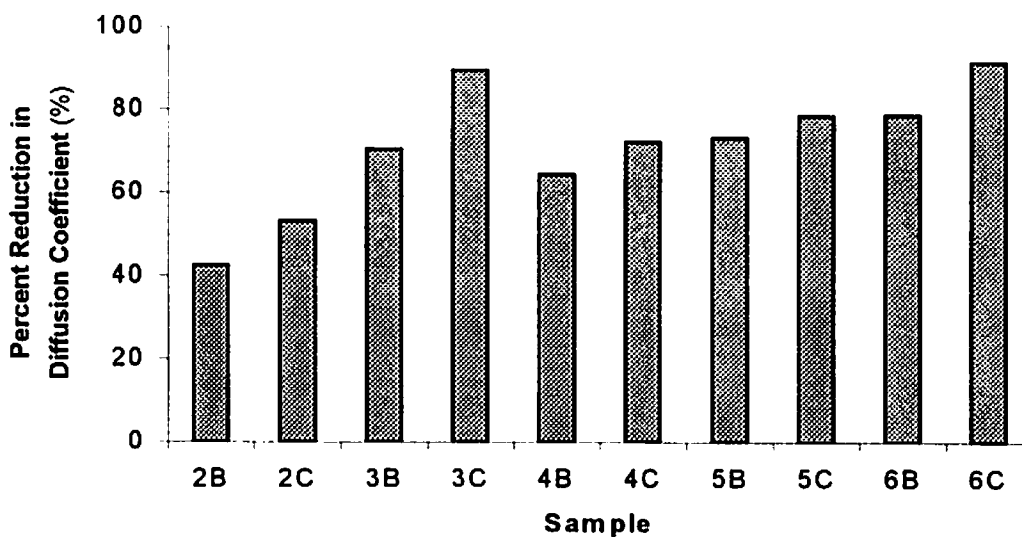


Fig.6. Reduction of radon gas diffusion coefficient with the application of EOPS.

Table 1. Concrete sample composition.

	Sample (standard)
Portland Cement I (lbs.)	5.15
Sand (lbs.)	10.4
Pea Gravel (lbs.)	20.8
Water (lbs.)	2.63
Water/Cement Ratio (w/c)	0.51
Porosity (%)	20.9

Table 2. Concrete sample electrode configurations.

Sample	Electrode Configuration
1	None
2	Single (rubber coating)
3	Cross (rubber coating)
4	Single (ceramic coating)
5	Cross (ceramic coating)
6	Triple (ceramic coating)

Table 3. Experimental results of steady-state radon gas diffusion coefficient.

Test	EOPS waveform (%+/%N/%-)	D (cm^2 / s)	RH in Source Chamber (%)	% Reduced
1	-	2.94×10^{-4}	83.3	-
2A	-	2.83×10^{-4}	81.3	-
2B	65/25/10	1.55×10^{-4}	74.6	42.5
2C	75/22/3	1.26×10^{-4}	94.6	53.2
3A	-	2.64×10^{-4}	84.6	-
3B	65/25/10	7.98×10^{-5}	71.4	70.4
3C	75/22/3	2.84×10^{-5}	94.1	89.5
4A	-	2.71×10^{-4}	88.6	-
4B	65/25/10	9.68×10^{-5}	92.4	64.3
4C	75/22/3	7.54×10^{-5}	94.6	72.2
5A	-	2.69×10^{-4}	90.0	-
5B	65/25/10	7.01×10^{-5}	89.6	73.2
5C	75/22/3	5.79×10^{-5}	89.2	78.5
6A	-	2.67×10^{-4}	89.6	-
6B	65/25/10	5.67×10^{-5}	90.6	78.7
6C	75/22/3	2.31×10^{-5}	94.3	91.4

Table 4. Effect of relative humidity on the diffusion coefficient for Concrete Sample 6C.

%RH	D (cm^2 / s)
86.65	3.04E-05
93.18	2.51E-05
94.37	2.42E-05
96.00	2.31E-05
96.25	2.36E-05