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Investigation of Radon Gas Diffusion through Thermocol Sheet: Effect of Thickness

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Exposure to indoor radioactive gases for long spells increases the risk of health-related issues. The primary mechanism contributing to indoor radon levels is radon transportation, subsequently exhalation from the soil matrix/ building material matrix to the enclosed indoor air of dwellings. Long-term exposure to elevated indoor radon levels may lead to the possibility of health-related problems. The use of Radon Transportation Resistive (RTR) material in the building construction may reduce the indoor radon concentration. The purposes of present study is to investigate the radon diffusion process through the thermocol sheet. This experimental study examined the Thermocol sheet for Radon Diffusion Coefficients (RDC) and Radon Diffusion Length (RDL). The mean RDC and RDL values for the investigated sample were to be (2.56 ± 0.72) x10^{-8} (m^2. s^{-1}) and 0.10 ± 0.01 (m).

Keywords: Radon Transportation Resistive (RTR); Thermocol sheet; Passive Measurement Technique; Radon Diffusion Coefficients (RDC); Radon Diffusion Length (RDL)

1 Introduction

Radon (^{222}Rn) is a radioactive gas. Exposure to radiation produces by Radon gas and its decay products is harmful to the living body. A definite concentration level of indoor radon (^{222}Rn) gas is always present in the living zone of dwellings[1-5]. Several studies have confirmed that the inhalation of radon and its progeny is a well-known risk factor for lung cancer[6-9]. Radon exhalation from building materials and soil depends upon factors like the radon diffusion process, thickness, and dimension of the building material[10-11]. IAQ (Indoor Air Quality) is one of the critical parameters for developing a healthy workplace and residence environment, as a considerable amount of time is spent indoors in the present working set-up. The diffusion process of radon gas through the building material is essential to extrapolate the radon exhalation rate to the indoor radon environment by an organized investigation through measurements and model prediction.

The study of the radioactive gas diffusion process is important to investigate and propose the best Radon Transportation Resistive (RTR) building material. The diffusion coefficient and diffusion length are needed for quantifying indoor radon accumulation after applying an impermeable radon barrier. By covering the radon-emitting surface with RTR materials, indoor radon levels are expected to be decreased. Radon diffusion studies were performed for foil, rubber, paper, and coating material to check the radon tightness of the material[12,13]. Thermocol sheet also has applications to prepare architectural decorative mouldings and thermocol sandwich concrete brick[14,15]. However, no information is available in the literature about the radon tightness of thermocol sheets. The present research paper includes the measurement of the radon gas diffusion coefficient and diffusion length through a thermocol sheet. The effect of varying thicknesses of thermocol sheets on the radon diffusion process is considered, and experimental results are reported. The manuscript's organization includes the material and method used in this study in Section 2. Section 3 describes the results and discussion part of the study, followed by concluding remarks, applications, and the future scope of experimental work.

2 Material and Methods

Solid State Nuclear Track Detection (SSNTD) using LR-115 is one of the reliable technique for time integrated measurements of alpha track density[16-20]. In this work, alpha track density was measured using cellulose nitrate film (LR-115), Type-II SSNTDs (Solid State Nuclear Track Detector) of a 12 mm

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thickness coated on a 100 mm plastic base. LR-115, Type-II SSNTDs, is extremely sensitive to alpha particles of 4 MeV energy but is insensitive to light and X-ray photons. Radon source-Pylon of activity 110 k.Bq was utilized in dry powder form in this diffusion study. Thermocol sheet samples of thicknesses 0.01, 0.03, 0.05, 0.07, and 0.09 m were used to study the radon diffusion processes.

2.1 Theory of Radon Diffusion Coefficient and Radon Diffusion Length

To investigate the dependability of Alpha Track Density (Tracks.cm^{-2}), radon concentration (Bq.m^{-3}), radon diffusion coefficient, and radon diffusion length on thermocol sheet thickness, five samples of thickness 0.01, 0.03, 0.05, 0.07, and 0.09 m were studied. The radon concentration at the bottom of the samples was very height due to the presence of a radon source of high activity. Due to the molecular diffusion of radon gas atoms from high radon concentration (Radon source side) towards low radon concentration (LR-115 detector side), transportation of radon gas starts through the thermocol. Detailed theory and mathematical modeling are described elsewhere to calculate RDC and RDL[21-23]. If the thickness of two sheets are X1 (m) and X2 (m) and at the detector side N1 (Bq.m^{-3}) and N2 (Bq.m^{-3}) are the radon concentration, then equation (1) and equation (2) gives the value of Radon Diffusion Coefficients (RDC), and Radon Diffusion Length (RDL). Where, λ is the decay constant of radon gas.

$$\text{RDC}\ (\text{m}^2\text{s}^{-1}) = \lambda[(X_2 - X_1)/\ln(N_1/N_2)]^2 \qquad ...(1)$$

$$\text{RDL}(m) = \sqrt{D/\lambda} \qquad ...(2)$$

2.2 Experimental set-up for detectors deployment

The exponential setup for the passive measurement of radon gas consists of a hollow cylinder container made-up of plastic material. The diameter and length of the container are 25 cm and 50 cm, respectively. The 150 gm. uranium ore in powder form was used as a radon source at the bottom of the container. Two pieces of 2 cm x 2 cm dimensions of Solid State Nuclear Track Detector (SSNTD) LR-115, Type-II were fixed at the top of each theromocol sample, and samples were deployed vertically in the container as shown in Fig. 1. The deployment period of 30 days was taken in undisturbed condition. After the radon exposure time from the source, the LR-115, type-II detectors were removed from thermocol sheets for chemical etching and counting.

2.3 Chemically Etching Unit

After the measurement period, irradiated detectors (SSNTDs) were etched in an aqueous solution of 2.5 N NaOH using an etching unit. Operation parameters of the etching unit were set accordingly to get the desirable etching rate. The temperature of the etching solution was maintained at 60 °C, and etching period was kept for 90 minutes without stirring to remove a bulk thickness of 4 mm from the detector. The developed tracks were counted with a spark counter. The picture of the constant temperature bath unit is shown in Fig. 2.

2.4 Spark Counting Unit

Follow-up the etching process of the detector, the LR-115, Type II SSNTD film was peeled off from the base. The counting of etched tracks registered in LR-115, Type II SSNTD film, was performed using a spark counter. The operating voltage of the counter for pre-sparked counting was set at 900 V and then counted at the operating voltage of 500 V obtained from the plateau graph of

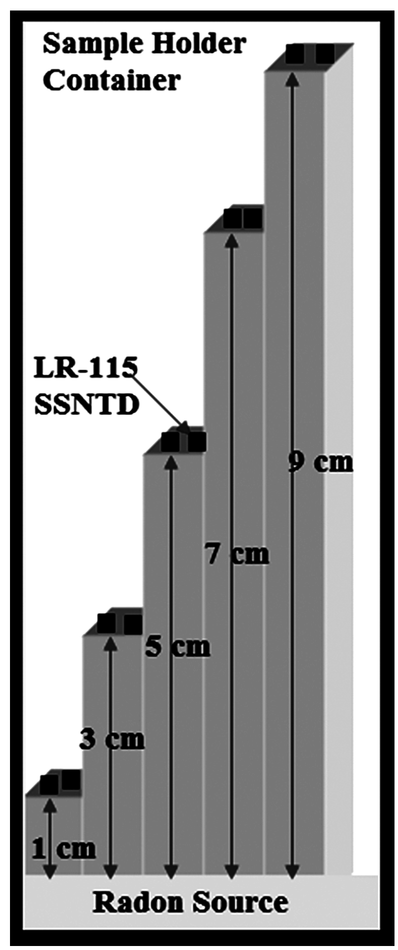

Fig. 1 — Experimental set-up for detectors deployment.

the spark counter unit. Spark counting head and counting unit are shown in Fig. 3. The radon concentration was calculated for each sample in different cases using a calibration factor for LR-115. This calibration factor was attained by inter-laboratory comparison exercises at the Environmental Assessment Division of BARC, Mumbai, and used by many researchers[24-28].

Fig. 2 — Chemically Etching Unit .

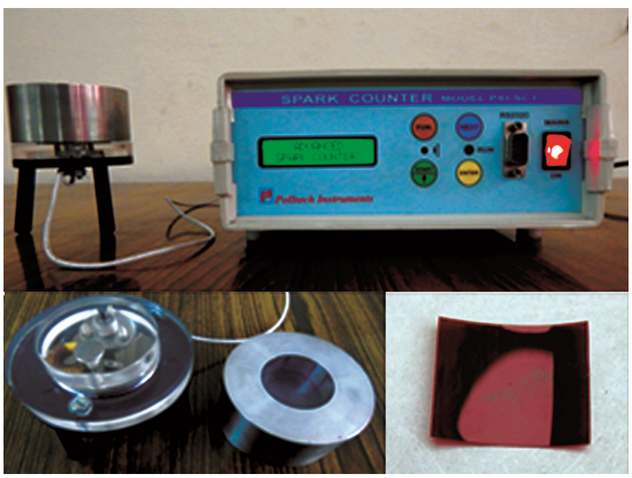

Fig. 3 — Spark Counting Unit.

3 Results and discussion

The objective of this experimental study was to measure the RDC and RDL for thermocol sheet. The effect of Thermocol Sheet Thickness (m) on Alpha Track Density (Tracks.cm^{-2}) and Radon Concentration (Bq.m^{-3}) was also taken into consideration. The measurement are listed in Table 1 and 2, respectively. Alpha track density for 0.01 m, 0.03 m, 0.05 m, 0.07 m, and 0.09 m thickness of thermocol sheet was measured to be 25 ± 5, 20 ± 1, 18 ± 4, 12 ± 2 and 12 ± 2 (Tracks.cm^{-2}), respectively. Measurement results of radon concentration near the surface (Detector side) of thermocol sheet (m) for 0.01 m, 0.03 m, 0.05 m, 0.07 m, and 0.09 m thickness of thermocol sheet were found to be 40 ± 8, 32 ± 1, 29 ± 6, 19 ± 3 and 19 ± 2 (Bq.m^{-3}), respectively. Fig. 4(a) shows the variation of alpha track density and radon concentration with an increase in sheet thickness. Results show that the alpha track density and radon concentration quantity becomes constant after 0.07 m of sheet thickness. The optimal thickness of the thermocal sheet as a radon-resistive material is 0.07 m. Fig. 4(b) shows Alpha track density decrease as the thermocol sheet thickness (m) increases with R^2 = 0.91. The RDC and RDL for thermocol sheet were calculated by using equations (1) and (2). Table 3 shows the results of RDC and RDL i.e. (3.61 ± 2.55) × 10^{-8} (m^2. s^{-1}) and 0.11 ± 0.05 (m) respectively, through the thermocol sheet when the difference in the thickness of sheet for calculation purposes was kept at 0.02 m. Table 4, Table 5, and Table 6 shows the results of RDC and RDL for difference in the thickness of sheet 0.04 m, 0.06 m, and 0.08 m respectively. The mean RDC and

Table 1 — Measurement results of Alpha Track Density for different thicknesses of Thermocol Sheet

S. N.	Thickness of Thermocol Sheet (m)	Track Density (Tracks.cm^{-2}) Count 1	Track Density (Tracks.cm^{-2}) Count 2	Track Density (Tracks.cm^{-2}) Count 3	Track Density (Tracks.cm^{-2}) Count 4	Track Density (Tracks.cm^{-2}) Mean ± STD
1.	0.01	21	23	33	23	25 ± 5
2.	0.03	19	20	21	20	20 ± 1
3.	0.05	15	20	14	21	18 ± 4
4.	0.07	13	11	14	10	12 ± 2
5.	0.09	10	12	12	13	12 ± 2

Table 2 — Measurement results of Radon Concentration near to the surface (Detector side) of Thermocol Sheet

S. N.	Thickness of Thermocol Sheet (m)	Rn-222 (Bq.m^{-3})	Rn-222 (Bq.m^{-3})	Rn-222 (Bq.m^{-3})	Rn-222 (Bq.m^{-3})	Rn-222 (Bq.m^{-3}) Mean ± STD
1.	0.01	33 ± 3	37 ± 3	52 ± 5	37 ± 3	40 ± 8
2.	0.03	30 ± 3	32 ± 3	33 ± 3	32 ± 3	32 ± 1
3.	0.05	24 ± 2	32 ± 3	22 ± 2	33 ± 3	29 ± 6
4.	0.07	21 ± 2	17 ± 2	22 ± 2	16 ± 1	19 ± 3
5.	0.09	16 ± 2	19 ± 2	19 ± 2	21 ± 2	19 ± 2

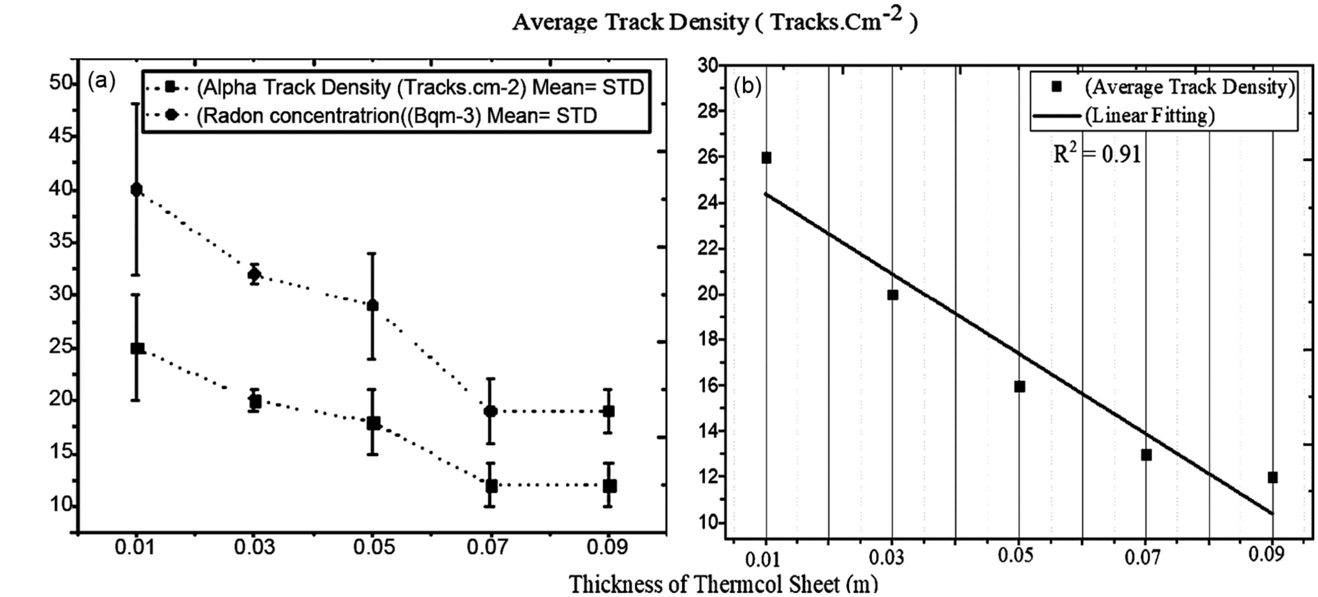

Fig. 4 — (a) Alpha Track Density and Radon Concentration & (b) Linear Fitting of Alpha Track Density with thickness of Thermocol sheet.

Table 3 — Radon Diffusion Coefficient and Radon Diffusion Length with Thermocol Sheet Thickness difference of 0.02 m

S. N.	X1 (m)	X2 (m)	(X2-X1) (m)	N1 ($Bq.m^{-3}$)	N2 ($Bq.m^{-3}$)	Diffusion coefficient ($m^2. s^{-1}$)	Diffusion length (m)
1.	0.03	0.01	0.02	40	32	1.69×10^{-8}	0.09
2.	0.05	0.03	0.02	32	29	8.67×10^{-8}	0.20
3.	0.07	0.05	0.02	29	19	4.70×10^{-9}	0.05
				Average ± SE		$(3.61 \pm 2.55) \times 10^{-8}$	0.11 ± 0.05

Table 4 — Radon Diffusion Coefficient and Radon Diffusion Length with Thermocol Sheet Thickness difference of 0.04 m

S. N.	X1 (m)	X2 (m)	(X2-X1) (m)	N1 ($Bq.m^{-3}$)	N2 ($Bq.m^{-3}$)	Diffusion coefficient ($m^2. s^{-1}$)	Diffusion length (m)
1.	0.05	0.01	0.04	40	29	3.25×10^{-8}	0.12
2.	0.07	0.03	0.04	32	19	1.24×10^{-8}	0.08
3.	0.09	0.05	0.04	29	19	1.88×10^{-8}	0.09
				Average ± SE		$(2.12 \pm 0.59) \times 10^{-8}$	0.10 ± 0.01

Table 5 — Radon Diffusion Coefficient and Radon Diffusion Length with Thermocol Sheet Thickness differenceof 0.06 m

S. N.	X1 (m)	X2 (m)	(X2-X1) (m)	N1 ($Bq.m^{-3}$)	N2 ($Bq.m^{-3}$)	Diffusion coefficient ($m^2. s^{-1}$)	Diffusion length (m)
1.	0.07	0.01	0.06	40	19	1.36×10^{-8}	0.08
2.	0.09	0.03	0.06	32	19	2.78×10^{-8}	0.12
				Average ± SE		$(2.07 \pm 0.71) \times 10^{-8}$	0.10 ± 0.02

Table 6 — Radon Diffusion Coefficient and Radon Diffusion Length with Thermocol Sheet Thickness difference of 0.08 m

S. N.	X1 (m)	X2 (m)	(X2-X1) (m)	N1 ($Bq.m^{-3}$)	N2 ($Bq.m^{-3}$)	Diffusion coefficient (m2 s-1)	Diffusion length (m)
1.	0.09	0.01	0.08	40	19	2.43×10^{-8}	0.11

RDL for the sample were investigated to be ~$(2.56 \pm 0.72) \times 10^{-8}$ ($m^2. s^{-1}$), and ~ 0.10 ± 0.01 (m) respectively. Fig 5 and Fig 6 are bar graph of RDC and RDL obtained from the calculations by considering the different thickness difference *i.e.* (X2-X1) of the sheets and it is observed that there is not significance variation in RDC and RDL values, means independent of material thickness difference. The mean RDC and RDL for thermocol sheets were compared with air and other radon resistive building materials reported in literature and shown in Table 7

According to the present experimental study, the investigated material can be considered radon-tight. The experimental study on radon diffusion through thermocol sheets of different thicknesses shows that using thermocol to cover the radon exhalation surfaces may reduce radon transportation from the wall to the indoor environment. Thermocol may reduce radon-related radiation exposure to humankind in an indoor environment. The optimal thickness of the thermocol sheet as a radon-resistive material is 0.07 m.

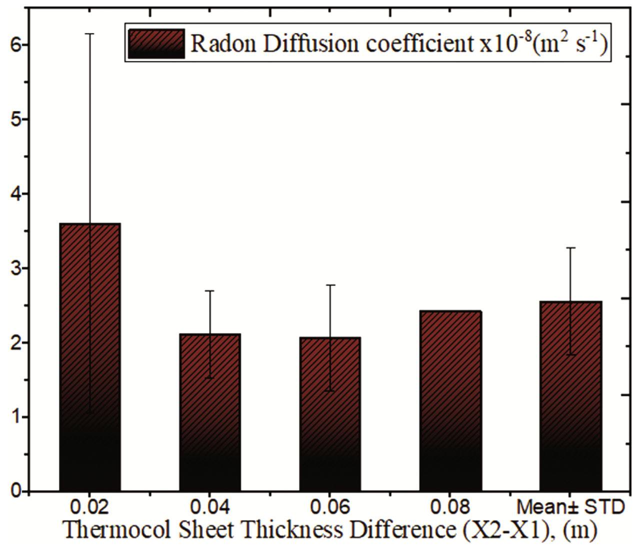

Fig. 5 — Bar graph of RDC ((m^2. s^{-1}) as a function of (X2-X1) m.

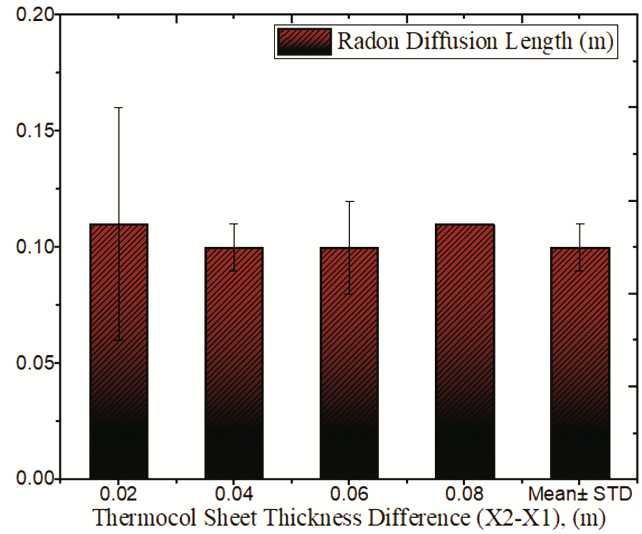

Fig. 6 — Bar graph of RDL (m) as a function of (X2-X1) m.

Table 7 — Comparison for Radon Diffusion Coefficient and Radon Diffusion Length of Thermocol Sheet with previously reported radon resistive building materials

S. N.	Diffusive Material	Diffusion Coefficient (m^2. s^{-1})	Diffusion length (m)	Reference
1	Air	2.26 x 10^{-5}	3.28	Surinder et al. (1999)
2	Air	(1.04 ± 0.58) x 10^{-5}	2.22 ± 3.96	Chauhan et al. (2008)
3	Air	(9.98 ± 0.33) x 10^{-6}	2.17 ± 0.03	Narula e al. (2009)
4	Bitumen	<10^{-6}	<0.7	Keller et al. (2001)
5	PEHD foil	<10^{-6}	<0.7	Keller et al. (2001)
6	Silicone rubber	<10^{-6}	<0.7	Keller et al. (2001)
7	Butyl rubber	10^{-5}	2	Keller et al. (2001)
8	Polyurethane coating	<10^{-6}	<0.7	Keller et al. (2001)
9	Plastic foil	<10^{-6}	<0.7	Keller et al. (2001)
10	Epoxy resin	<10^{-6}	<0.7	Keller et al. (2001)
11	Xerox Paper	1.48 x 10^{-8}	0.08	Amit et al (2014)
12	Polyethylene	1.93 x 10^{-10}	0.01	Amit et al (2014)
13	Cardboard	(1.80 ± 0.03) x 10^{-7}	0.29 ± 0.04	Amit et al (2014)
14	Thermocol	(2.56 ± 0.72) x 10^{-8}	0.10 ± 0.01	Present Work

4 Conclusions

The radon gas diffusion study through different decorative and construction building materials is essential to propose RTR building materials. The passive measurements were performed with diffusion setup, uranium ore, and SSNTD LR-115, Type-II. In this study, thermocol sheets with variable thicknesses were analyzed. The present study for the measurement of radon diffusion across the thermocol sheet yielded the following experimental results:

(1) Alpha track density for 0.01 m, 0.03 m, 0.05 m, 0.07 m, and 0.09 m thickness of thermocol sheet was measured to be 25 ± 5, 20 ± 1, 18 ± 4, 12 ± 2, and 12 ± 2 (Tracks.cm^{-2}), respectively.

(2) Measurement results for radon concentration near the surface (Detector side) of thermocol sheet (m) for 0.01 m, 0.03 m, 0.05 m, 0.07 m, and 0.09 m thickness of thermocol sheet were found to be 40 ± 8, 32 ± 1, 29 ± 6, 19 ± 3 and 19 ± 2 (Bq.m^{-3}), respectively.

(3) The mean RDC and RDL values for the investigated sample were found to be (2.56 ± 0.72) x 10^{-8} (m^2. s^{-1}) and 0.10 ± 0.01 (m).

(4) Thermocol may reduce radon-related radiation exposure to mankind in an indoor environment.

The optimal thickness of the thermocal sheet as a radon-resistive material is 0.07 m. The study would be helpful to researchers for investigating best Radon Transportation Resistive (RTR) Building Materials.

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