ADVANCED CALIBRATION EQUATIONS FOR E-PERM® ELECTRET ION CHAMBERS

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Abstract

The E-PERM® Electret Ion Chambers (EICs) have been widely used for research in indoor and outdoor radon measurements. Calibration factors are not constants because of the continuously decreasing nature of electret voltages during the measurement. Calibration factors are fitted to an equation that relates the calibration factors to the initial and final voltages. The calibration equations currently in use restrict the use of electrets to the initial readings of 750-250 volts. Recent research indicated that it is possible to derive the calibration equations applicable for wider ranges. A detailed procedure is described for calibrating SST EICs and deriving an appropriate equation, applicable over the range of 750 volts to 70 volts. Furthermore, the newly derived equation fits the experimental data with better precision, compared to the currently used equations.

(1) The authors are the developers of E-PERM® electret ion chambers , and have commercial interest, for which these advanced calibration equations are further developed.

Introduction

A detailed publication (Kotrappa, 1990) on the topic of calibration of EICs describes the theory and functioning of the current versions of EICs. An EIC consists of a chamber with filtered inlets that has been loaded with an electret. As radon gas enters the chamber the radon and the decay products formed inside the chamber emit alpha radiation, which in turn generates ions in the air. Negative ions are collected on the positively charged surface of the electret. An EIC functions as an integrating ionization chamber, wherein the electret serves not only as the source of an electrostatic field, but also as the quantitative sensor. The drop in surface voltage of the electret over a known period of time is a measure of the time integrated ionization during that interval. Such data can be converted readily into radon concentration in air. The conversion factors depend upon the thickness of the electret, the volume of the chamber and the exposure period. Typically, the chamber volumes range from 53 ml (L), 210ml (S) and 960 ml (H). The electret thicknesses are 0.156 cm (ST) and 0.0127 cm (LT). The design parameters are chosen depending upon the required sensitivity, dynamic range, and measurement periods. The most widely used EIC is the SST (S chamber with ST electret) type (210 ml chamber volume and 0.156 cm thick electret). It is generally used for a 2 to 7 day measurement. However, it can be used for a longer time when the radon concentration is relatively low or for shorter periods if the radon concentration is relatively higher. The current work deals with the calibration procedures for this type of EIC. However, the procedure is equally applicable to EICs with any other combination of electret and chamber size.

Calibration procedure

Because of the continuously decreasing nature of the electret voltages during a measurement, the calibration factors are not constants and depend upon the initial and final voltages of electrets. Calibration factors are fitted to an equation that relates the calibration factors to the initial and final voltages. The calibration procedure used in this work is similar to that described in an earlier paper (Kotrappa, 1990). The availability of a very well characterized radon test chamber (Kotrappa, 1990) improved the quality of the measurements. Uniformity of radon concentration over the entire testing zone inside the chamber was checked to be within 5% of the average concentration. The test chamber was continuously monitored by a set of calibrated continuous radon monitors and a set of passive monitors. Nine sets of five EICs were prepared for radon measurement. The first set had an initial reading of approximately 750 volts and the successive electrets were with the initial volts of 700, 650, 550, 450, 350, 250, 150, and 70 respectively. All the units were turned to the "on" position and placed inside the radon test chamber at the same time. This was the starting time of the exposure. In approximately three days, all 45 EICs were taken out of the radon test chamber and returned to the "off" position. The average radon concentration (pCi/L) and exposure period were recorded. The electrets of each of the EICs were measured using an appropriate electret reader. These readings were used in conjunction with the initial readings and other parameters to calculate calibration factors using equation 1. Table 1 gives the data obtained during the calibration run. Column 6 is the midpoint voltage (MPV) between the corresponding initial and final voltages. Calibration factors (CF) are calculated for each EIC in a subset using equation 1. An average CF is calculated for each subset and an average midpoint voltage (MPV) is calculated for each subset. This leads to a set of nine calibration factors corresponding to a set of nine MPVs.

$$RnC = \frac{(IV - FV)}{(T)\times(CF)} - BG \qquad \text{Equation 1}$$

Where:

RnC is the average radon concentration in the radon test chamber (15.8 pCi/L)

T is the exposure period in days (2.96 days)

IV and FV are the initial and final voltages respectively

CF is the calibration factor in volts per (pCi/L-days)

BG is 0.59 pCi/L. This is obtained by multiplying the gamma radiation level (6.8 μR/h) by 0.087. The constant 0.087 is the radon concentration (pCi/L) equivalent for 1 μR/h.

Fitting an appropriate equation to the experimental data

Research indicated that a linear regression fit between the experimentally measured calibration factors and the natural logarithm of MPV gave the best fit, with an excellent correlation coefficient of 0.9910. The derived equation is given by equation 2.

$$CF = 0.1318+0.2906 \times LN\ (MPV) \qquad \text{Equation 2}$$

Where:

CF is the calibration factor in volts per (pCi/L days)

LN is the natural logarithm function

MPV is the midpoint voltage

The constants 0.1318 and 0.2906 are the derived constants from the calibration data (see Appendix A).

Table 2 gives the summary data. Column 1 gives the MPV values, Column 2 is the measured CF, Column 3 gives the derived CF using the newly derived equation (equation 2) for CF, and Column 4 gives the percent deviation of the derived CF relative to the measured CF. Table 3 gives the data using currently used calibration equations, also referred to as the old equations. This is given to compare the improvement, if any, by using the new calibration equations. Column 1 gives the MPV values, Column 2 is the measured CF, Column 3 gives the derived CF using currently used (old) equations for CF, and Column 3 gives the % deviation relative to measured CF. Figure 1 is a graphical presentation of the comparison between the old and new calibration equation. This illustrates the advantages of the new calibration equation. Old (currently used) calibration equations are valid only for MPV of greater than 200 volts, to provide a relative percent error of less than 5%. This is the reason for recommending the use of current (old) equations for electrets of greater than 200 volts, and electrets of less than 200 volts need to be replaced. The new calibration equations are more precise for the entire range with no such restrictions.

Discussions and conclusions

Table 1 gives the calibration data of different electrets with different starting voltages. These are grouped into nine sets of similar starting voltages. The last column gives the standard deviation within each set. The standard deviations are in the range of 3 to 5%, indicating consistent results expected for the radon test chamber used. Linear regression analysis is done between the experimental calibration factors and the natural logarithm of the MPV. The data used for linear regression analysis is in Table 1A (appendix A). A standard Microsoft Office program is used to generate the results..

Column 3 of Table 2 gives the calculated CF using the fitted equation 2. Column 4 gives the percent deviation of the fitted results relative to the experimental results. These range from 0.2 to 3 percent, indicating that equation 2 gives accurate calibration factors of less than 3% for the entire range of the MPV used in this study. Table 3 gives similar data when the old calibration equations are used on the same data sets. Column 1 gives the MPV values, Column 2 is the measured CF, Column 3 gives the derived CF using currently used (old) equations for CF, and Column 4 gives the percent deviation relative to measured CF. It is of interest to compare results in Table 2 and Table 3. The old equation fails to give acceptable CF values for MPV of less than 250 volts. But old equations, which are still being used, provide acceptable CF values for MPV of more than 250 volts. This is the reason that the recommendation accompanying the old equation says that electrets should be replaced when they drop below 200 volts. Such limitations do not apply when the new equation is used. One gets very good accuracy even at a MPV of 70 volts. It is interesting to compare the calibration procedure used in the earlier study (Kotrappa, 1990) to the present study. Only 5 sets were used and the linear regression fit was between the average calibration factors and the average of MPV. The fitting was between the MPV of 218 to 643 volts. The reason for using a restricted range was that the linear regression was not fitting well outside this range. Such equations were applicable for midpoint voltages down to 200 volts, limiting the useful range of electrets from 750 to 250 volts. EICs are currently being used with this restriction in place. Additional research indicated that more rigorous equations can be derived to extend the useful range of EICs. The researched procedure was to perform a linear regression fit between the CF and the natural logarithm of the MPV. In the present work, nine groups were used with MPV ranging from 732 to 70 volts. A better characterized radon test chamber is used, compared to the test chamber used in the previous study. The results in the current work are a marked improvement and the useful range of electrets is extendable from 750 volts to 100 volts. Figure 1 also confirms an excellent agreement between experimental and fitted calibration factors. The method used in this study can be used for similar studies for other electret ion chambers.

References

1. Kotrappa, P., Dempsey, J.C., Ramsey, R.W. and Stieff, L.R. *A practical E-PERM™ (electret passive environmental radon monitor) for indoor 222 Rn measurements*. Health Physics **58,** 461-467, 1990.

2. Kotrappa, P and Stieff, F. *One cubic meter NIST traceable radon test chamber*. Radiation Protection Dosimetry **128,** 500-502 (2008)

Table 1 Calibration data for SST E-PERM® EIC

No.	Serial No.	Initial Volts (IV)	Final Volts (FV)	Voltage Drop	Midpoint Voltage MPV	Calibration Factor (CF)	Average Midpoint Voltage	STDEV of Average MPV	Average Calibration Factor	% STDEV of Average CF
1	SGB227	780	684	96	732	1.978601				
2	SGB343	780	678	102	729	2.102263				
3	SGB437	783	684	99	733.5	2.040432				
4	SGB513	780	684	96	732	1.978601				
5	SFX703	779	685	94	732	1.93738	731.7	1.643168	2.0074554	0.064521
6	SGB673	748	650	98	699	2.019822				
7	SGB483	747	645	102	696	2.102263				
8	SGB687	747	645	102	696	2.102263				
9	SGB546	748	652	96	700	1.978601				
10	SGB530	749	644	105	696.5	2.164095	697.5	1.870829	2.0734087	0.073738
11	SGB645	696	598	98	647	2.019822				
12	SGB623	695	600	95	647.5	1.95799				
13	SGB539	694	593	101	643.5	2.081653				
14	SGB646	702	606	96	654	1.978601				
15	SGB506	701	605	96	653	1.978601	649	4.401704	2.0033333	0.049207
16	SGB493	595	503	92	549	1.896159				
17	SGB662	601	503	98	552	2.019822				
18	SGB689	590	495	95	542.5	1.95799				
19	SGB455	598	506	92	552	1.896159				
20	SGB542	601	506	95	553.5	1.95799	549.8	4.396021	1.9456241	0.051732
21	SGB466	497	402	95	449.5	1.95799				
22	SGB635	497	399	98	448	2.019822				
23	SFD044	498	402	96	450	1.978601				
24	SGB526	498	399	99	448.5	2.040432				
25	SGB680	501	412	89	456.5	1.834328	450.5	3.446012	1.9662345	0.080618
26	SGB443	398	306	92	352	1.896159				
27	SGB439	393	308	85	350.5	1.751886				
28	SGB630	402	315	87	358.5	1.793107				
29	SGB629	398	309	89	353.5	1.834328				
30	SGB461	404	316	88	360	1.813717	354.9	4.144273	1.8178395	0.053349
31	SGB657	302	219	83	260.5	1.710665				
32	SGB571	299	211	88	255	1.813717				
33	SGB498	301	222	79	261.5	1.628224				
34	SGB618	301	216	85	258.5	1.751886				
35	SGB681	304	217	87	260.5	1.793107	259.2	2.588436	1.7395198	0.073738
36	SGB486	202	120	82	161	1.690055				
37	SGB471	203	127	76	165	1.566392				
38	SGB584	203	123	80	163	1.648834				
39	SGB478	204	129	75	166.5	1.545782				
40	SGB591	202	123	79	162.5	1.628224	163.6	2.162175	1.6158573	0.059378
41	SGB699	104	37	67	70.5	1.380898				
42	SGB507	103	34	69	68.5	1.422119				
43	SGB536	102	38	64	70	1.319067				
44	SGB501	102	38	64	70	1.319067				
45	SGB671	105	38	67	71.5	1.380898	70.1	1.083974	1.3644101	0.044682

RNC:	15.8
Time:	2.96
BG:	6.8

Table 2. Percent deviation of CF relative to measured CF using new equation

MPV	Measured CF	Fitted CF	% Dev(relative to measured)
731.7	2.0075	2.0484	2.0
697.5	2.0734	2.0345	1.9
649	2.0033	2.0136	0.5
549.8	1.9456	1.9654	1.0
450.5	1.9662	1.9075	3.0
354.9	1.8178	1.8382	1.1
259.2	1.7395	1.7468	0.4
163.6	1.6159	1.6131	0.2
70.1	1.3644	1.3668	0.2

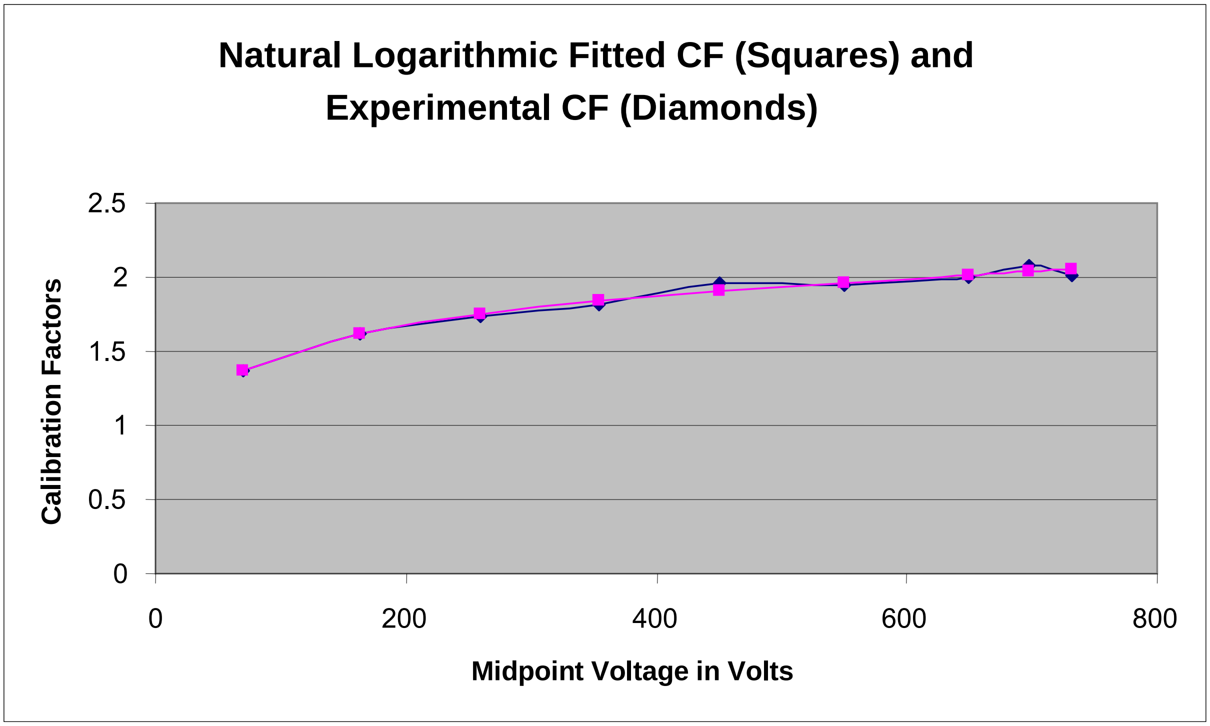

Figure (2): Graphic presentation of Table 2

Table 3. Percent deviation of CF relative to measured CF using current (old) equation

MPV	Measured CF	Fitted CF	% Dev
731.7	2.0075	2.1181	5.5
697.5	2.0734	2.0985	1.2
649	2.0033	2.0707	3.4
549.8	1.9456	2.0137	3.5
450.5	1.9662	1.9567	0.5
354.9	1.8178	1.9018	4.6
259.2	1.7395	1.8468	6.2
163.6	1.6159	1.7919	10.9
70.1	1.3644	1.7383	27.4

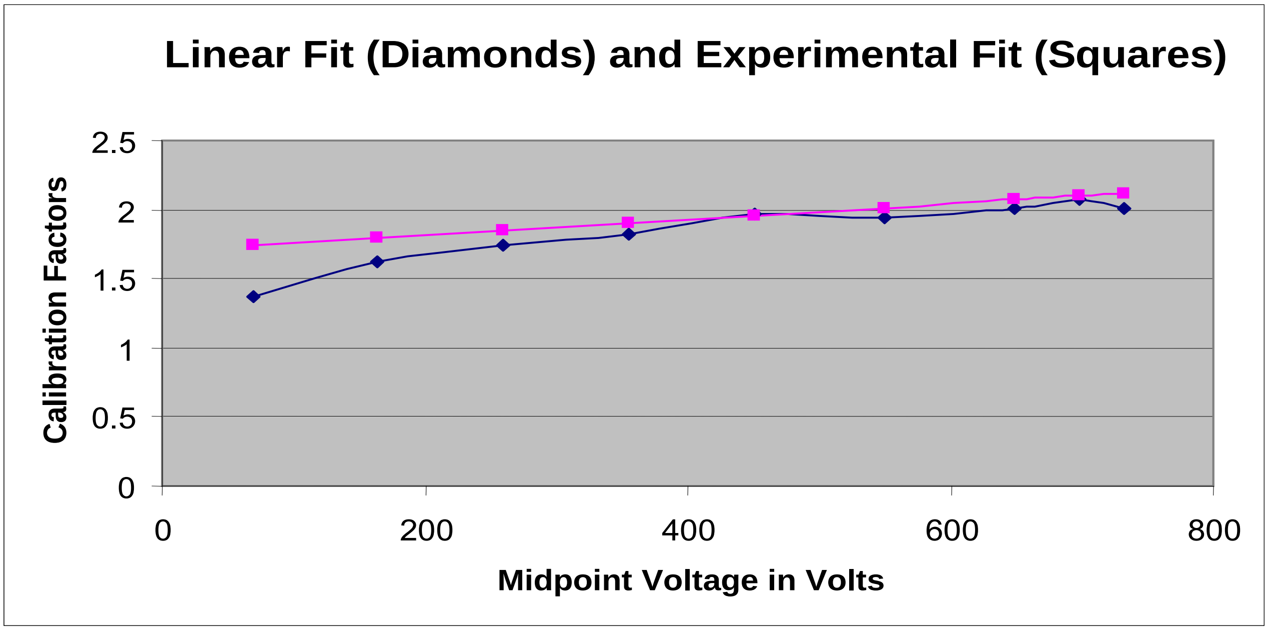

Figure (3): Graphic presentation of Table 3

Table 4. Percent deviation of CF relative to measured CF using current (old) equation and new equation

MPV	Measured CF	% Dev New Equation	% Dev Old Equation
731.7	2.0075	2.0	5.5
697.5	2.0 734	1.9	1.2
649	2.0033	0.5	3.4
549.8	1.9456	1.0	3.5
450.5	1.9662	3.0	0.5
354.9	1.8178	1.1	4.6
259.2	1.7395	0.4	6.2
163.6	1.6159	0.2	10.9
70.1	1.3644	0.2	27.4

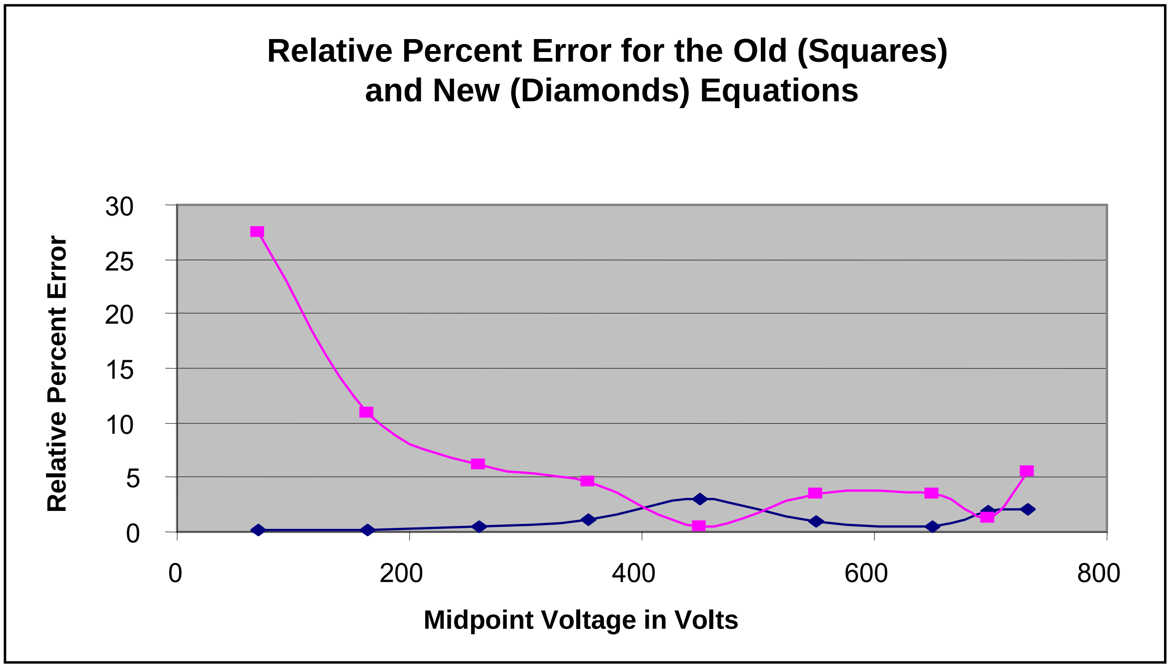

Figure (4): Graphic presentation of Table 4

Appendix A

Linear regression fit between the calibration factor and the natural logarithm of the midpoint voltage (MPV):

Fitted Equation: CF=0.1318+0.2906 x LN(MPV)

Table A 1

Data for Regression Analysis

MPV	LN MPV	CF
731.7	6.5954	2.0075
697.5	6.5475	2.0734
649	6.4754	2.0033
549.8	6.3096	1.9456
450.5	6.1104	1.9662
354.9	5.8718	1.8178
259.2	5.5576	1.7395
163.6	5.0974	1.6159
70.1	4.2499	1.3644

Table A 2

Data for Graph

MPV	CF	Fitted CF
731.7	2.0075	2.0482
697.5	2.0734	2.0343
649	2.0033	2.0134
549.8	1.9456	1.9652
450.5	1.9662	1.9073
354.9	1.8178	1.8380
259.2	1.7395	1.7467
163.6	1.6159	1.6130
70.1	1.3644	1.3667

Linear Regression Analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9910
R Square	0.9820
Adjusted R Square	0.9794
Standard Error	0.0330
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.4156	0.4156	381.8868	0.0000
Residual	7	0.0076	0.0011		
Total	8	0.4232			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.1318	0.0880	1.4985	0.1777	-0.0762	0.3398	-0.0762	0.3398
X Variable	0.2906	0.0149	19.5419	0.0000	0.2554	0.3258	0.2554	0.3258