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A HUMIDITY CONTROL TECHNIQUE BASED ON NAFION MEMBRANE AND ITS APPLICATION ON THE EVALUATION OF HUMIDITY RESPONSE FOR RADON MONITOR

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Electrostatic collection technique is widely used in various radon monitors. The mechanism of this kind of radon monitor is that the positive Po particles, produced by decay of radon, can be collected on the surface of detector in electric field. Collection efficiency, therefore, could be affected by air humidity. Calibration under different humidity conditions or test of humidity response is necessary consequently. In this study, a humidity control technique based on Nafion membrane tube (NMT) is developed. Under a consistent flowrate with a certain stable level of radon concentration and humidity of main-path inlet, the humidity of outlet sample gas from the main-path can be adjusted and stably controlled at a certain level by changing side-path's flowrates of NMT. By adjusting main and side-path flowrate, RH of outlet gas of the main-path can be controlled from 5.3 to 80.0%. Theoretical study were also performed. Based on this, humidity influence calibration of an electrostatic radon monitor was performed, and a relationship between the sensitivity of the radon monitor and relative humidity was obtained.

INTRODUCTION

Radon exposure is the main contributor to the public of all naturally occurring radiation[(1)]. Radon, on the other hand, is also an effective tracer and widely used in atmospheric and geological studies[(2)]. Thus, precise measurement on radon is highly requested from the view of dose evaluation and environmental science studies.

Electrostatic collecting technique is widely used in various radon monitors. This kind of radon monitor has an electrostatic collection cell, with a silicon surface detector mounted at the centre[(3)]. The positive ^{218}Po particles, produced by decay of radon, can be collected on the surface of detector in electric field, then radon concentration can be derived from counts of α-spectrum.

It is understood that the fraction of positive ^{218}Po is depended on the neutralisation of the unattached ^{218}Po ions[(4)], which displays a positive correlation with humidity[(5)]: the higher humidity, the higher neutralisation; leading less positive ^{218}Po and ^{214}Po collected, and leading lower collection efficiency of monitor as a consequence.

To solve this problem, up to now, many measures are employed to keep humidity in a certain stable level during measurement when adopting this kind of radon monitors, such as RAD7 (Durridge, USA). Considering the limitation of desiccants effects in field measurement, laboratory calibration under different humidity conditions is necessary and important. To adjust and control air humidity in collection chamber in certain stable levels for calibration, mixing different fractions of dried and humidified air is widely used in past studies[(5–7)].

In this paper, by means of the development of material science, a humidity control technique based on NMT (PermaPure, USA, PD-50T) is demonstrated. With this technique, a test of humidity response of electrostatic radon monitor with 16.8 L collection chamber and Si-PIN detector (Sairatec, China, ARM-Pin01) was performed, and the relationship between the sensitivity of radon monitor and the relative humidity was obtained. This technique can be used in humidity control and humidity influence calibration for both radon monitor system and other gases measuring devices.

THEORY AND METHODS

The whole calibration system is illustrated as Figure 1. This system is consisted of the following three sections.

Radon source section

Radon of soil in a depth of some 0.5 m underground surface, as radon source, is pumped out into a 300 L radon source buffer tank[(8)]. An AlphaGuard monitor is set inside it to confirm the stability of radon concentration in the tank, while a refrigeration type dehumidifier (Zhengxin, China, DH-1) was set to ensure the stability of gas humidity in the source tank.

Humidity control section

Nafion membrane is a newly developed material through which water vapour diffuses due to the difference in absolute humidity of both sides of the membrane[9]. Furthermore, radon gas cannot pass through the membrane with humidity exchanging, thus NMT has been used in the Radon concentration measurement[10]. The humidity of main-path outlet sample gas adjusted by NMT is determined by the flowrates of main and side paths, pressure difference between them, length of tube, etc.[11]. The theoretical model of NMT was simplified and explained, with the following conditions in our system:

- The gas humidity after the buffer tank before the NMT is invariable.
- The flowrate of side-path is the only one dependent variable in our experiment, and the pressure of both main-path and side-path is nearly atmospheric pressure.
- The temperature measured by four sensors are the same. Thus the factors we concern are limited to the flowrates of main-path (V_m) and side-path (V_s).

Then, we have the tube model as Figure 2 shows.

Owning to balance for water vapour, we obtain,

$$X_4 = X_1 - \frac{V_s}{V_m}(X_2 - X_3) \quad (1)$$

Symbols X_{1-4} stand for humidity measured by four different temperature and humidity sensors (Sensirion, Switzerland, SHT11) connected to joints. Since the temperature is the same in our system, relative humidity and absolute humidity share a one-to-one mapping. For convenience, following this paper, the RH data style description is used. From Eq. (1), we know that the outlet sample gas humidity (X_4) is a function of flowrate of side-path (V_s), which is the only one dependent variable.

By adopting the NMT, sample gases in different stable humidity were produced for calibration by adjusting the side-path flowrate and switching the desiccant to bubbler with stable inlet gas humidity.

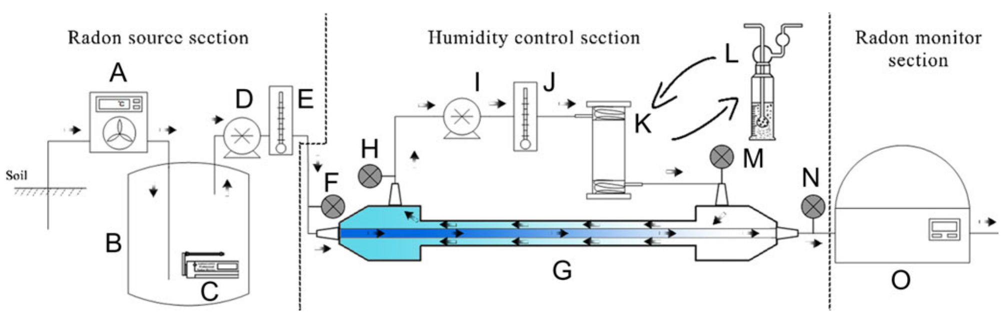

Figure 1. Schematic of radon monitor humidity calibration system, consisted of radon source, humidity control and radon monitor sections. And drying or humidifying modes can be controlled by switching desiccant with bubbler. (**A**) Refrigeration type dryer; (**B**) 300 L radon source tank; (**C**) AlphaGuard; (**D**) & (**I**) pumps; (**E**) & (**J**) rotary flowmeters; (**F**), (**H**), (**M**), (**N**) temperature and humidity sensors; (**G**) Nafion membrane tube; (**K**) desiccant; (**L**) bubbler; (**O**) ARM-Pin01 radon monitor.

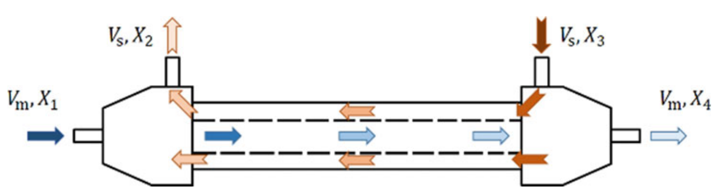

Figure 2. Schematic diagram of a NMT for removing water vapour from a radon stream. The brown colour arrows stand for the purge gas in side-path, and the lighter arrows stands for the higher humidity. Conversely, the lighter blue arrows stand for the lower humidity of sample gas in main-path.

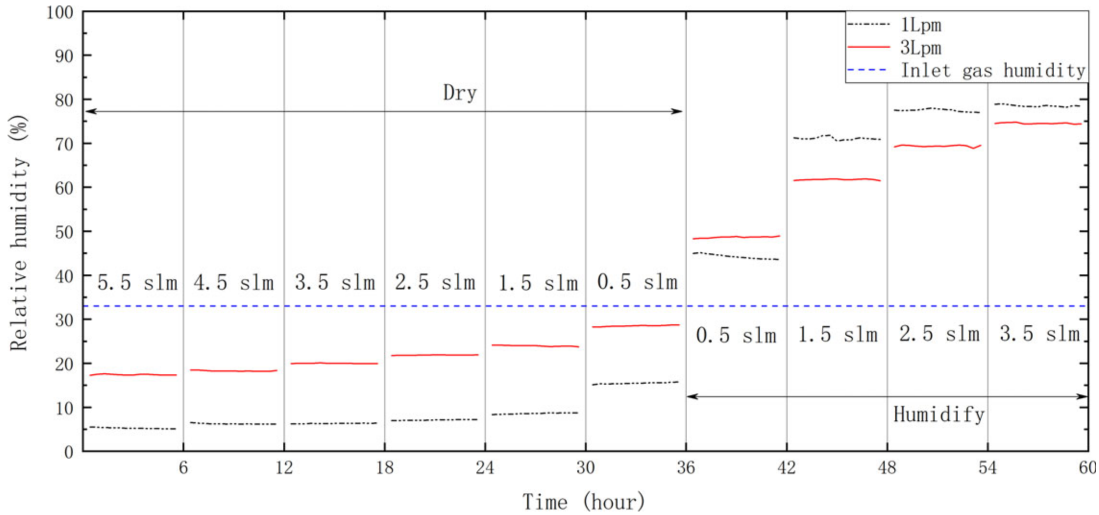

Figure 3. Different humidity levels produced by NMT.

Radon monitor section

As a test, an ARM-Pin01 radon monitor was calibrated using the calibration system. ^{218}Po and ^{214}Po particles were collected in a 16.8 L hemispheric electrostatic chamber, and counted by a Si-PIN detector located in the centre. To assess the quality of radon monitor, sensitivity of radon monitor is defined:

$$1/CF_i = N_{\mathrm{Po}\ i}/t{\cdot}A_{\mathrm{Rn\ AG}} \quad (i = 1, 2) \tag{2}$$

CF_i stand for the calibration factor of different measurement modes. CF_1 is used in the fast mode, in which the count of ^{218}Po ($N_{\mathrm{PO}\,1}$) is used for calculating radon concentration. Similarly, CF_2 is used in the accurate mode, in which the total counts of ^{218}Po and ^{214}Po ($N_{\mathrm{PO}\,2}$) is used. t is the time of counting. And $A_{\mathrm{Rn\,AG}}$ stands for the radon activity concentration measured by AlphaGuard.

RESULTS AND DISCUSSION

By adjusting flowrates of side-path of the NMT and using desiccation (or a bubbler) on side-path, different humidity levels are achieved at 1 L/min and 3 L/min main-path flowrate, respectively. In the drying mode, 12 humidity levels were obtained at six different side-path flowrates (from 5.5 to 0.5 L/min) with desiccant on the side-path, and eight levels were obtained in humidifying mode at four different side-path flowrates (from 0.5 to 3.5 L/min) with bubbler. The results are illustrated in Figure 3. Those humidity levels we produced varied from about 5.3 to 80.0% RH in the environment with 33% RH and 23°C. And every humidity levels can stay quite stable for over 6 h. With the developed humidity control technique, calibration for electrostatic collecting radon monitor in different humidity levels can be realised easily.

To assess the theory model of NMT, comparison between experimental value of main-path outlet gas humidity and predicted value calculated by humidity and flowrate data from other three joints is shown in Figure 4.

The experimental values are measured by the N sensor in Figure 1, and the calculated values are calculated by Eq. (1) with flowrates and humidity data from other sensors. As we can see, both experimental and calculated values indicated that in drying mode, the produced gas humidity rose with side-path flowrate decreasing, while in humidifying mode, humidity rose with flowrate increasing. Because the larger flowrate of side-path is, dryer or wetter the purge gas in side-path will be, which led to the larger humidity difference on both sides of the Nafion membrane. There are some deviations over the errors between calculated and experimental values, and the tendency of both values matched well. Considering those values come from four different sensors and the calculation will amplifier error, the deviation is under prediction and reasonable.

Based on the developed humidity controlled technique, a radon monitor was tested and calibrated in two different measurement modes as a confirmation, and the calibration results are shown in Figure 5.

The curves shows the sensitivity will decrease rapidly in low humidity range (under $5\,\mathrm{g\,m^{-3}}$) and slowly in higher humidity range. This result agrees well with past studies[7, 12, 13]. Because the monitor need to run in different humidity and temperature conditions and the mechanism of humidity influence

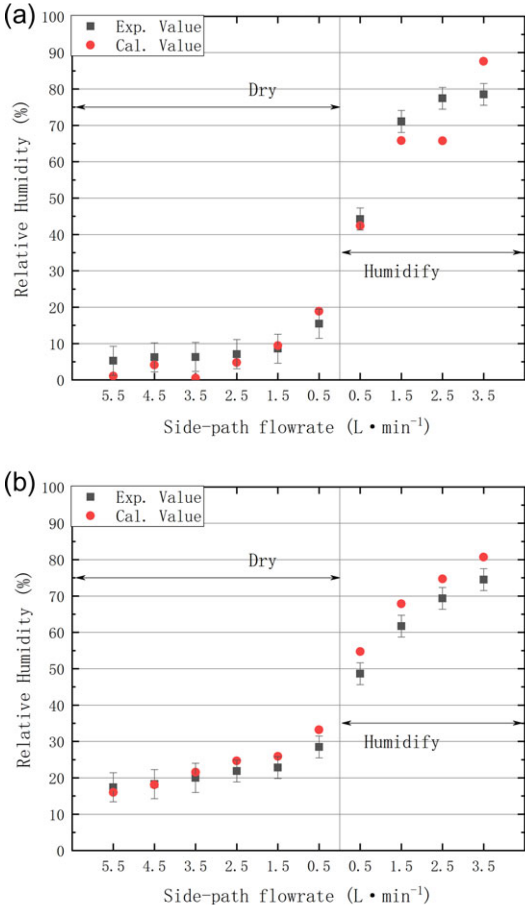

Figure 4. Comparison of the experimental and calculated relative humidity of outlet radon gas with 1 L/min (**a**) and 3 L/min (**b**) main-path flowrate

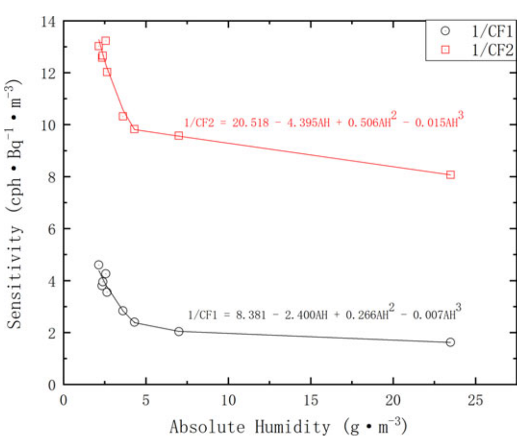

Figure 5. Sensitivities of fast and accurate modes in different humidity and fitlines.

is a function of water vapour concentration, we calculated and illustrated curves with absolute humidity's *X*-axis in Figure 5. With these fitting lines and formulas, we can calibrate radon monitors, and make monitors can be applied in different humidity conditions.

To sum up, this technique based on NMT is convenient and easily realised, and it can be used in electrostatic radon monitor's calibration of humidity's effects.

CONCLUSION

To ensure precise measurements on radon concentration, monitors with electrostatic collection should be calibrated under different levels of sample air humidity. A calibration system with a new and easy-realised technique on base of a NMT is developed by this study. With stable humidity of inlet air, humidity of outlet sample air can be adjusted and controlled in the range of 5.3 and 80.0% RH with the main-path flowrate of 1 L/min, and from 16.1 to 74.4% RH with the main-path flowrate of 3 L/min, respectively. The humidity of outlet sample air can be kept for a long time at different levels, to ensure calibration condition can be satisfied.

As a test, an electrostatic radon monitor was calibrated using the calibration system in different measurement modes, influence of humidity on ^{218}Po and ^{214}Po electrostatic collection was accurately assessed.

FUNDING

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