Electrical conductivity of air related to ion pair production rate from radon and its progeny concentrations in dwellings of Mysore city

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Radon gases released from the ground surface and building materials are the major sources of ionization in the indoor atmosphere. Radon will undergo radioactive decay in the atmosphere by emitting an alpha particle. The alpha and beta particles, and the gamma rays from 222Rn, 220Rn and their decay products give up their energy by ionizing the molecules and aerosol particles in the atmosphere. Radon and its progeny concentrations and the electrical conductivity of air due to both polarities were measured simultaneously at a height of 1 m from the floor inside dwellings of Mysore city, India. Diurnal variations of radon and its progeny concentrations show their peak values in the early morning (0200 to 0600 hrs) throughout the year. Observations show an increase in the concentration of radon and its progeny during night time compared to the daytime values. The electrical conductivity of the atmospheric air also exhibits similar trend. These results are discussed in terms of ionization rate due to radioactivity and the influence of meteorological parameters on radon and its progeny concentrations.

Keywords: Radon; Radon progeny, Ion production, Atmospheric conductivity, Gerdien condenser, Diurnal variation

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1 Introduction

The electrical conductivity of the atmospheric air above 2 km altitude is primarily due to ionization by cosmic rays whereas at lower atmosphere main source of ionization are nuclear radiation from the radioactive minerals, and radioactive gases released from the earth crust. 222Rn and its short lived daughter products are important in the study of atmospheric electricity, not only because of their significant role in the production of ion pairs in the lower atmosphere but also for their use as tracers.

The electrical conductivity of the air is governed by ionizing radiations and aerosol particles present in the atmosphere. Ionizing radiation consists of cosmic rays as a global component but the variation of cosmic ray intensity is very small (1-2 ion-pairs cm⁻² s⁻¹) when compared to the variation of radiation due to radon and its daughters¹. Therefore, any temporal variations observed in the rate of ionization inside dwellings are essentially due to the variations in the concentrations of natural radioactive substances.

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Atmospheric electricity is controlled by numerous factors at global, regional and local scale. Fair weather atmospheric electric parameters are sensitive indicators of changes in climate and air pollution, which make the atmospheric electric measurements a promising source of environmental pollution¹⁴. In spite of a long history of the studies on atmospheric electricity, knowledge of the relations between atmospheric electricity, climate, and air pollution is insufficient for extensive applications. A reason for this is that most of the atmospheric electric measurements have been episodic and the recordings are often not complemented with meteorological background data.

The short-lived daughters of radon (²¹⁸Po, ²¹⁴Pb, ²¹⁴Bi and ²¹⁴Po) are natural tracers in the troposphere, in particular at the boundary layer near the ground. They are electrically charged particles and chemically reactive. Radon daughter elements are carried by aerosol particles of accumulation mode as well as by nanometer particles and clusters⁴⁵. Immediately after the decay of a ²²²Rn atom, the daughter atom, ²¹⁸Po formed is positively charged. These ions cannot
remain stable in atmospheric air at normal conditions, and consequently form clusters of approximately 10-30 molecules. Only then they reach certain stability in the form of small ions. This forms nanometer clusters called small air ions. The behaviour of small air ions is similar to that of aerosols with respect to growth and transport. Hence, the electrical conductivity inside dwellings depends on natural radioactivity, aerosol concentrations and also on meteorological parameters.

This paper deals with variations of radon concentrations, its daughter products, ion pair production rate and electrical conductivity of the atmosphere. The measurements were carried out at a height of 1 m from the floor during 2003-2004 inside dwellings at the university campus, Mysore. The relation between radon concentrations, ion pairs and conductivity and also meteorological parameters such as temperature, humidity etc., are studied and analyzed.

2 Experimental Details

2.1 Atmospheric electrical conductivity

Atmospheric conductivity of both positive and negative polarities is simultaneously measured with a Gerdien condenser, locally fabricated as per Dhanorkar et al. The Gerdien condenser is basically a cylindrical capacitor, with air as the insulator. The schematic diagram of Gerdien condenser is shown in Fig. 1. It consists of two identical cylindrical tubes of 10 cm diameter and 41 cm length joined by a U-shaped tube. The air was sucked in with a single fan. The inner co-axial electrode in both the tubes are of 1 cm diameter and 20 cm length. Opposite, but equal potentials of ± 35 V are applied to the outer electrodes of the two condensers. The critical mobility of ions in the instrument is greater than 10−4 m² V−1 s−1 and capable of resolving the values of conductivity as small as 3±10−16 Ω−1 m−1 (Ref. 8). The Gerdien condenser is insulated and kept in a third cylinder, which is electrically grounded. This cylinder shields the measurements from external disturbances. Usually, the inner cylinder is used as the collector and the outer one as the driving electrode. Each sensor is scanned every one minute, and hourly average values of atmospheric conductivity of both polarities are recorded on a computer.

2.2 Radon concentration

The concentration of radon in the atmospheric air is measured using Low Level Radon Detection System (LLRDS) following the well-established procedure. The procedure briefly consists of sampling the air in a pre-evacuated collection chamber and exposing a circular metallic disc to the radon inside the collection chamber. A delay of at least 10 minutes is normally allowed for any thoron, which may be present in the chamber to decay completely. The positively charged 218Po (RaA) atoms created in the chamber get collected on the metallic plate maintained at an optimum negative potential that should be sufficient to force all the RaA atoms onto the plate. The collection is carried out for an optimized period and thereafter the charged plate is removed from the chamber and alpha-counted. The concentration of radon (in Bq m−3) is calculated with the expression:

\[ R_n = \frac{1000C}{EFVZ} \]

where \( C \) is the total number of counts observed during the counting period, \( E \) the efficiency of alpha counting system (26%) determined using a standard source, \( F \) the efficiency of collection of RaA atoms on the metallic disc and is empirically related to humidity \( H \) by \( F = 0.9 \left( 1 - e^{(0.036H-4.118)} \right) \) (Refs 9-11), \( V \) the volume of LLRDS chamber (litres), \( Z \) is the correction factor for build-up and decay of radon daughter atoms on the metallic disc during the exposure and counting period (\( Z=3000 \)).

2.3 Radon progeny concentration

Air flow meter consists of 15 cm long and 1 cm diameter tube made up of Perspex. The tube is embedded in a perspex block of square cross-section of side 3 cm. A scale is marked on the block to enable the flow rate - reading in units of liters per minute. At one end of the tube a metallic device is provided for fixing the filter paper and a facility to control the air flow. At the other end, there is a provision for
connecting an air pump. A steel ball is placed inside the tube. The position of the ball indicates the flow rate.

An air flow meter kept at a height of 1 m above the floor surface is used to measure the radon progeny concentration. Air is drawn through a glass fiber filter paper by means of a suction pump at a known flow rate. The radon progeny in air sample is retained on the filter paper. The filter paper is then alpha-counted at any specific delay time. Total activity on the filter paper is measured at three different counting intervals of 2-5, 6-20 and 21-30 minutes. Activities of RaA, RaB and RaC are calculated using the modified equations:\(^\text{12}\):

\[
\begin{align*}
RaA & = \frac{4.249019\ (C_1) - 2.062417\ (C_2) + 1.949949\ (C_3)}{VE}\quad \text{(Bq m}^{-3}\text{)} \\
RaB & = \frac{-0.355129\ (C_1) + 0.006232\ (C_2) + 0.240618\ (C_3)}{VE}\quad \text{(Bq m}^{-3}\text{)} \\
RaC & = \frac{-0.215175\ (C_1) + 0.371319\ (C_2) - 0.502945\ (C_3)}{VE}\quad \text{(Bq m}^{-3}\text{)} \\
R_d & = \frac{0.048445\ (C_1) - 0.019335\ (C_2) + 0.037053\ (C_3)}{VE}\quad \text{(mWL)}
\end{align*}
\]

where, \(C_1, C_2\) and \(C_3\) are the gross counts during the three counting intervals, \(E\) the efficiency of alpha counting system (26%), \(V\) the sampling rate in litres per minute (LPM), \(R_d\) is the concentration of radon progeny (m WL). Working Level (WL) is defined as the concentration of radon progeny such that the total alpha energy released in one litre of air equals to \(1.3 \times 10^5\) MeV. The working level is also known as the Potential Alpha Energy Concentration (PAEC).

### 2.4 Ion pair production rate

The total energy released \(\varepsilon\) (eV cm\(^{-3}\) s\(^{-1}\)) due to both radon and its progeny is computed from radon and its individual progeny concentrations and used to calculate ion-pair production rate \(Q\) (No. cm\(^{-3}\) s\(^{-1}\)) (Ref. 11):

\[
\varepsilon = 5.49 \times 10^6\ Rn + 6.00 \times 10^6\ RaA + 0.85 \times 10^6\ RaB + 7.69 \times 10^6\ RaC' \quad \text{and} \quad Q = \varepsilon/32\ \text{ion pairs cm}^{-3}\text{s}^{-1}
\]

where Rn, RaA, RaB and RaC' are the concentrations (Bq m\(^{-3}\)) of \(^{222}\text{Rn}, \ ^{218}\text{Po}, \ ^{214}\text{Pb}\) and \(^{214}\text{Po}\), respectively.

### 3 Results and Discussion

Radium present in soil, rocks and building materials, decay resulting in radon atom. Soil moisture plays an important role in the emanation of radon and its diffusion in soil. The rate of exhalation of radon from soil to the atmosphere also depends on the temperature gradient between the layers of the soil and other meteorological conditions. The magnitude of indoor \(^{222}\text{Rn}\) concentration depends primarily on the materials used for construction of buildings. \(^{222}\text{Rn}\) and its decay products show a large temporal and local fluctuation in the indoor atmosphere due to meteorological variables.

The diurnal variation of radon and its progeny concentrations in the air at a height 1 m from floor of the building for a typical day of March 2004 are shown in Fig. 2. Concentrations of radon and its progeny in the indoor environment are affected not only by the magnitude of the exhalation rates but also by atmospheric mixing phenomena and ventilation conditions. Solar heating during the day time tends to induce some turbulence, so that radon is more readily transported to outdoors and away from the ground. During night, doors and windows are normally closed and atmosphere is relatively calm. Radon exhaled from the soil accumulates near the floor leading to gradual increase in the concentrations. The concentrations reach a maximum value in the early morning hours (0200–0600) and decrease after sunrise reaching a minimum during 0700–1000 hours. After sunrise, as temperature increases, the relative humidity decreases (Fig. 3) resulting in the decrease of moisture content in the atmosphere. This causes
increased vertical mixing that results in lower concentration of radon and its progeny at the ground level. As a consequence, the aerosol to which radon and its daughters are attached will be present at larger concentrations during night and in the early morning hours at ground level, which in turn increases the ionization rate in the atmosphere.\textsuperscript{4,11,13,14}

Figure 4 shows the diurnal variation of both positive and negative electrical conductivity for a typical day during March 2004. For comparison, the ion pair production rate from the radon and its progeny concentrations is also shown in the Fig. 4. The positive and negative conductivity value varies from $2.5 \times 10^{-14}$ to $3.7 \times 10^{-14}$ $\Omega^{-1}m^{-1}$, respectively and ion-pair production rate varies between 3.7 to 13.9 ion-pairs cm$^{-3}$ s$^{-1}$ over a day. The estimated ionization rate shows a maximum in the early morning 0200-0600 hours and minimum during 0700-1000 hrs and polar conductivities show a maximum in the early morning 0200-0500 hours and minimum during 0700-0900 hrs. The positive and negative conductivities are approximately equal and their diurnal variations are generally mirror images of each other. It is observed that the conductivity of both polarities shows maximum in the early morning hours and attain minima during 0700-0900 hrs.

In the indoor atmosphere ionization due to radioactive gases and their short-lived daughter products is predominantly caused by alpha particles. The rate of ionization due to radioactivity also exhibits the diurnal variation as that of concentration of radon and its progeny.\textsuperscript{11} Variation of ion-pair production rate also exhibits a similar trend with maximum in the early morning hours and minimum during 0700-0900 hrs.

The increase in conductivity during the early morning hours is mainly because of the ionization produced by radioactive substances present in the atmosphere. After sunrise the temperature increases (Fig. 3) and hence the turbulence increases. This will reduce radon and its progeny concentrations, leading to the decrease of ionization rate and conductivity during 0700-0900 hrs. Hence, the diurnal variation of conductivity follows the trend of ion-pair production rate as shown in the Fig. 4. The electrical conductivity shows a good correlation with ion production rate, with radon and its progeny concentrations having a correlation coefficient of 0.80, 0.76 and 0.78, respectively.

4 Conclusion

The measured concentrations of radon, its progeny, and polar conductivity show a maximum in the early morning hours and a minimum during 0700-0900 hrs. The stable atmosphere during night helps more accumulation of radon, and hence higher conductivity during night than the day. The concentrations are minimum during 0700-0900 hrs when the atmosphere is unstable or during convective period. A good correlation between electrical conductivity and ion production rate due to radon and its progeny concentrations is observed.

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