# THE EFFECT OF BREATH-HOLDING ON THE DEPOSITION OF HALF-MICRON AEROSOL PARTICLES IN THE HUMAN LUNG

M.C. Subba Ramu
Air Monitoring Section
Bhabha Atomic Research Centre
Bombay-400085, India

## ABSTRACT

Measurements of deposition of particles in the human lung during breath-holding can be made use of to calculate the diameter of the tubular passageways of the respiratory tract in life. When the inspired volume is sufficiently great for most of the aerosol to penetrate beyond the anatomical dead space, the rate of deposition during the breath-holding can be regarded as an index of the average diameter of the alveolar airways. Studies of the effect of breath-holding on deposition and recoveries of o.5 μm particles of unit density in different lung volumes are described in this paper. Based on the results of steady-state breathing experiments, the average diameter of the airways in the alveolar region of the lung has been found to be 0.74 mms.

## INTRODUCTION

Studies on the deposition of particles in human lungs show that it is possible pauses may occur in between inhalation and exhalation and also between successive breaths. The duration of these pauses should have certain effects on deposition of particles in the lung. According to Altshuler[1], breath-holding experiments are useful in assessing an average dimension of the alveolar spatial units in life. When the inspired volume is sufficiently large for most of the aerosol to penetrate beyond the anatomical dead space, the rate of deposition during breath-holding can be regarded as an index of the average dimension of the alveolar space in life.

This paper gives an account of the studies made to find the effect of breath-holding on the deposition of 0.5 μm spherical particles of unit density during the steady-state and single-breath experiments.

## EXPERIMENTAL TECHNIQUES AND RESULTS

The apparatus used for the measurement of deposition is the one used by Davies, Heyder and Subba Ramu[2]. Three different techniques were employed for measuring the effect of breath-holding on aerosol deposition. In the first case, the subject breathed the aerosol till steady-state condition was reached, with a pause for a known period of time between successive breaths. Table 1 gives the results of the measurements for these two cases. Average breath-holding times (t) are given along with the tidal volumes (TV) expiratory reserve volumes (ERV), breathing frequencies (f) and the fraction deposited (D). It can be seen that the deposition increased by about 34% for an average breath-holding time of 1.07 secs in the first case whereas there was negligibly small difference in the second case.

Table-1

The effect of breath-holding on deposition during steady-state breathing

| TV ($Cm^3$) | ERV ($Cm^3$) | f (Breaths/min) | t (secs) | (1-D) (Average) | Remarks |
|---|---|---|---|---|---|
| 678 | 1260 | 16.8 | 0 | 0.906 | Normal; No pause |
| 678 | 1260 | 16.8 | 1.07 | 0.874 | Pause between inhalation and exhalation |
| 696 | 1200 | 17.8 | 0 | 0.905 | Normal; No pause |
| 696 | 1200 | 17.8 | 1.36 | 0.913 | Pause between successive breaths |

In the third case, the subject inhaled about 600 $cm^3$ of aerosol-laden air, held the breath for a known period of time and exhaled more or less the same volume of air. This was followed by inhalation of clean air and maximal exhalation. The total recovery (R), recovery in tidal volume ($R_t$) and the recovery ($R_r/1-R_t$) of aerosol particles are calculated separately as shown in table 2. $R_r$ is the ratio of the number of particles recovered in the

Table-2

The effect of breath-holding on the recovery of 0.5 μm particles in the exhaled air (single-breath experiments)

| TV ($Cm^3$) | ERV ($Cm^3$) | f (breaths/min) | t (secs) | R | $R_t$ | $R_r/1-R_t$ |
|---|---|---|---|---|---|---|
| 660 | 980 | 16.5 | 0.0 | 0.96 | 0.90 | 0.72 |
| 690 | 820 | 15.4 | 3.0 | 0.86 | 0.76 | 0.54 |
| 665 | 941 | 14.4 | 5.7 | 0.79 | 0.67 | 0.42 |
| 615 | 950 | 14.2 | 7.6 | 0.73 | 0.62 | 0.33 |
| 585 | 1010 | 17.0 | 15.3 | 0.57 | 0.46 | 0.18 |
| 635 | 1170 | 15.3 | 24.0 | 0.45 | 0.36 | 0.13 |

reserve air to that in the inhaled air. ($R_r/1-R_t$) is the recovery of particles in the reserve air expressed as a fraction of particles lost from the tidal air into the reserve air. Figure 1 gives the values of R, $R_t$ and $(R_r/1-R_t)$ for different breath-holding times.

The build-up of aerosol particles in the lung before steady-state is reached is shown in figure 2 for normal breathing and breathing with pauses. Breath-holding seems to have no effect on the time needed for attaining the steady-state condition. The plot of $R_n/R_{AV}$ against the number of breaths shows that, in all cases, steady-state is reached in four breaths. $R_n$ is given by

$$R_n = E_n/I_n \qquad .....(1)$$

where $I_n$ is the amount of aerosol inhaled in the $n^{th}$ breath during build-up, and $E_n$ the amount of aerosol exhaled in the same breath. $R_{AV}$ is the average fraction recovered during steady-state breathing.

## CALCULATION OF PASSAGEWAY DIAMETER

Landahl[3] gives the following equation for the fraction deposited (D) in the human lung during breath-holding time 't':

$$-R_p \ln(1-D) = (1.8 \times 10^5 d^2\ Ct) + (4 \times 10^{-6} \sqrt{Ct/d}) \qquad .....2$$

where, $d$ = diameter of the particle (cm)

$R_p$ = radius of the tubular passage (cm)

and $C = 1+1.8 \times 10^{-5}/d$, a size correction factor.

Table 3 gives the average diameters of the tidal volume ($D_{TV}$) and the expiratory reserve volume ($D_{ERV}$), calculated using equation (2) and table 2. $D_{(TV+ERV)}$ is obtained from the results of the total recoveries for different breath-holding periods. The diameter of the tidal volume varies from 0.33 to 0.38 mms and that of the expiratory reserve volume from 0.16 to 0.20 mms.

The diameter of the airways in the alveolated region has been calculated using the deposition measured during steady-state breathing. The deposition increased from 9.4%, when there was no pause, to 12.6% when the pause between inhalation and exhalation was, on an average, 1.07 secs (Table 1). Using equation (2), the diameter of the passageway was calculated to be 0.74 mms. The diameter of the passageway calculated in the case of steady-state breathing works out to be more than that calculated in the case of the single-breath experiments.

Table-3

Average diameters of the tidal($D_{TV}$) and the expiratory reserve volumes ($D_{ERV}$) in the lung, calculated using equation (2) and table (2)

| t (secs) | TV ($cm^3$) | $D_{TV}$ (mms) | ERV ($cm^3$) | $D_{ERV}$ (mms) | (TV+ERV) | $D_{(TV+ERV)}$ (mms) | $D_{TV}+D_{ERV}$ |
|---|---|---|---|---|---|---|---|
| 3.0 | 690 | 0.33 | 820 | 0.19 | 1510 | 0.51 | 0.52 |
| 5.7 | 665 | 0.34 | 941 | 0.19 | 1606 | 0.52 | 0.53 |
| 7.6 | 615 | 0.34 | 950 | 0.16 | 1565 | 0.50 | 0.50 |
| 15.3 | 585 | 0.35 | 1010 | 0.17 | 1595 | 0.46 | 0.52 |
| 24.0 | 635 | 0.38 | 1170 | 0.20 | 1805 | 0.48 | 0.58 |
| Average | 638 | 0.35 | 980 | 0.18 | 1618 | 0.50 | 0.53 |

## DISCUSSION

Experiments using 0.5 µm particles, conducted by Palmes, Altshuler and Nelson[4], showed that the passageway diameter varied from 0.3 to 0.4 mms. The results of similar experiments given in table 3 show that the diameter is about 0.5 mms. The diameter of the passageways calculated in the case of steady-state breathing works out to be 0.74 mms (Table 1). The difference in the diameters obtained for these two cases indicate that the most of the aerosol particles lost from the tidal air reach the walls of the lung after passing through the expiratory reserve volume and the residual volume.

Let us consider that the shape of the reserve volume is same as that of residual volume, then the radius (0.09 mms) and the corresponding expiratory reserve volume (980 $cm^3$) are related by

$$0.09 \propto \sqrt[3]{980} \qquad .....(3)$$

and if the radius of the residual volume is denoted by $r_{RV}$ and the residual volume is 2040 $cm^3$ which is the value for the subject under consideration, then we have,

$$r_{RV} \propto \sqrt[3]{2040} \qquad .....(4)$$

Dividing (4) by (3), we get

$$r_{RV} = 0\ 0.09 \times \sqrt[3]{2040/980}$$

Thus, $r_{RV} = 0.12$ mms

Therefore the diameter of the residual volume is 0.24 mms.

Now if we add the diameters of the tidal, reserve and residual volumes, we get 0.76 mms which is in close agreement with the diameter (0.74 mms) calculated for the steady-state breathing experiment.

The calculated diameter (0.74 mms) of the alveolar airways works out to be greater than the values given by weibel[5] in his regular dichotomy model of the human lung at 3/4 maximum inflation. If the diameters of the airways are large, it means it takes a longer time for the particles to travel from the main stream towards the walls and if, meanwhile, the subject exhales out, the fraction deposited would be the lowest and in some cases, all the 0.5 µm particles inhaled would be exhaled out as in the case of single-breath experiments.[6]

The theoretical curves (figure 1) calculated by equation (2) do not vary much from the experimental ones, showing that the relationship given by Landahl[3] can be used for obtaining the diameter of the airways in the human lung using 0.5 µm particles as tracers. Better agreement between the theory and experiments would perhaps be possible if a correction is made to account for the inertial movement caused during the breathing cycle in the region of functional residual volume. Another descrepancy pointed out by Palmes, Altshuler and Nelson[4] is the relatively small contribution of the Brownian motion term to the calculated deposition. As has been pointed out by Landahl[7] the difference becomes serious only for particles 0.1 µm or less.

An important implication of these studies is that the dose delivered to the tissues by breathing radioactive particles of different sizes reduces considerably if the airway diameter, especially in the alveolated region of the lung, is larger. This would result in appreciable changes in the m.p.l. values to the advantage of the progress of nuclear industry. The method of measuring the diameter of the airways by breath-holding technique is also useful for diagnostic purposes. Persons suffering from constrictive diseases will have a higher deposition of particles in the lung. Also the breath-holding technique would show the extent of constriction when compared with the airway diameter of a normal lung.


## ACKNOWLEDGEMENTS

The author is grateful to Dr. C.N. Davies for his kind guidance in carrying out the studies in the London School of Hygiene and Tropical Medicine, supported by a fellowship from IAEA. The author is also thankful to Dr. K.G. Vohra for his keen interest and kind encouragements.


## REFERENCES


1. Altshuler, B. 1969. "Behaviour of Airborne particles in the Respiratory Tract", In Circulatory and Respiratory Mass Transport (ed. by Wolstenholme, G.E.W. and Knight, J), p.215.

2. Davies, C.N., Heyder, J. and Subba Ramu, M.C. 1972. "Breathing of Half-micron Aerosols I. Experimental", J. Appl. Physiol. 32, p. 591.

3. Landahl, H.D.1950. "On the Removal of Air-Borne Droplets from the Human Respiratory Tract: I. The Lung". Bull. Math. Biophys. 12. p. 43.

4. Palmes, E.D., Altshuler, B. and Nelson, N. 1967. "Deposition of Aerosols in the Human Respiratory Tract during Breath-Holding", In Inhaled particles and Vapours II (ed. by C.N. Davies), p. 339.

5. Weibel, E.R. 1963. "Morphometry of the Human Lung", Academic Press, New York.

6. Subba Ramu, M.C. 1972. "On the Physiological Implications of Aerosol Inhalation", Paper Presented in the National Symposium on Environmental Pollution, October 28-30, Bombay.

7. Landahl, H.D. 1963. "Note on the Removal of Air-Borne Particles by the Human Respiratory Tract with Particular Reference to the Role of Diffusion". Bull. Math. Biophys. 25, p.29.

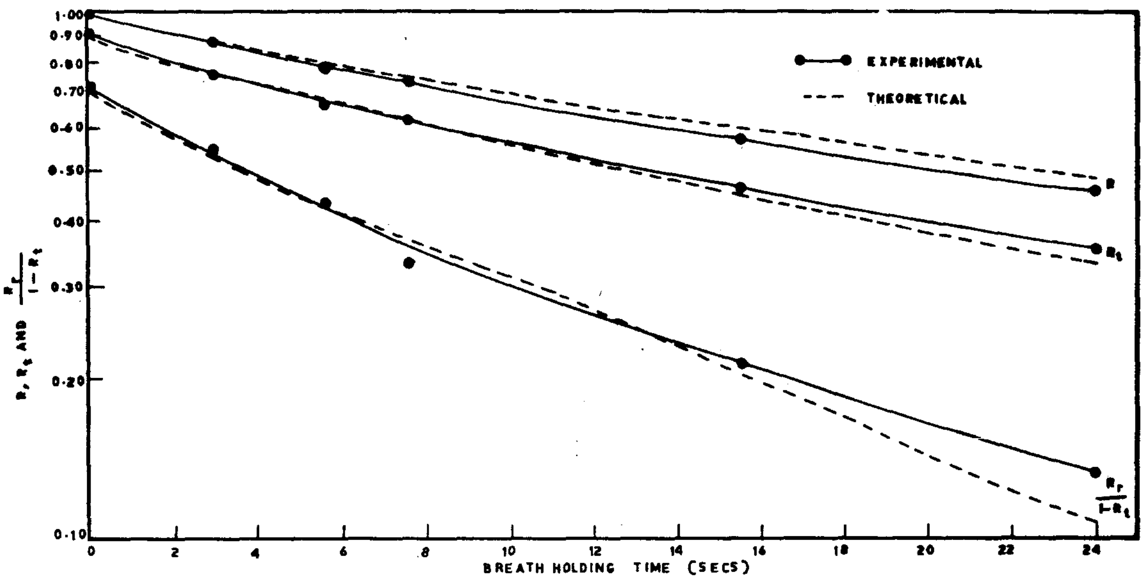


FIGURE: 1. THE EFFECT OF BREATH HOLDING ON R, $R_t$ AND $\frac{R_r}{1-R_t}$ (SINGLE BREATH EXPERIMENTS)

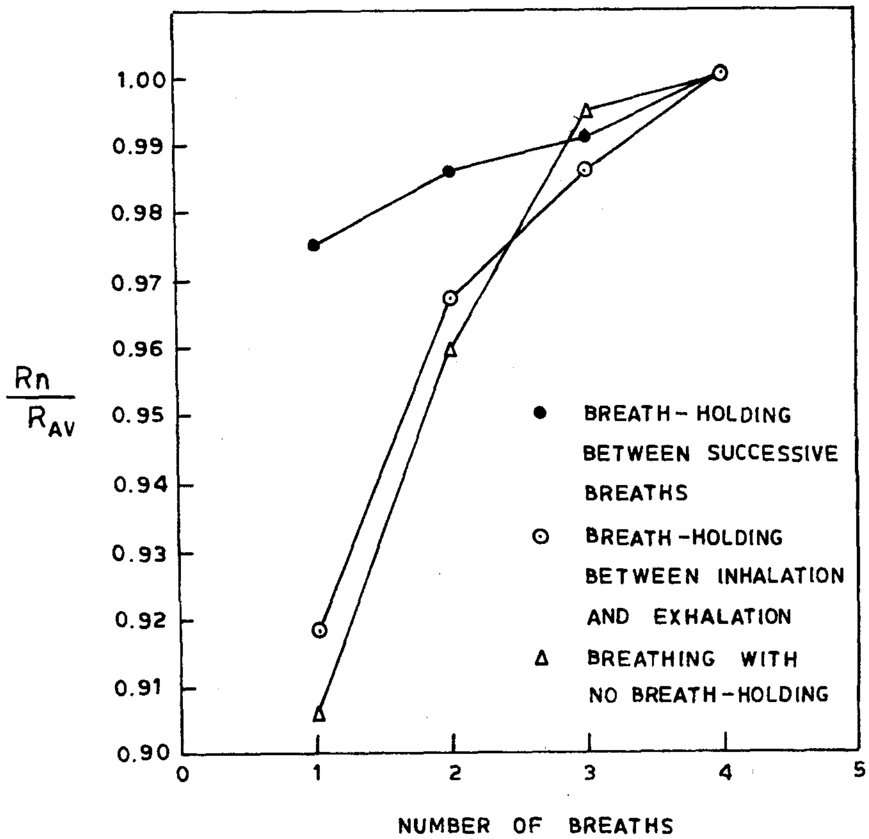


FIGURE: 2. BUILD-UP OF AEROSOL PARTICLES IN THE LUNG DURING THE STEADY-STATE BREATHING.