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LUNG DEPOSITION PATTERN OF PM10 PARTICULATE MATTER FOR MANUAL QUARRY WORKERS IN ZARIA

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ABSTRACT

The deposition pattern of PM10 particulate matter in human respiratory tract was determined using EPA lung deposition model and multi-elemental data of PM10 particulate matter collected from manual quarry activities. The deposition of major, minor and trace elements was estimated in terms of three anatomical compartments of the human respiratory system, which have important functional distinctions thus providing a basis for direct hazard evaluations. The results obtained suggest total deposition efficiency ranging from 0.44 to 0.76 for elements Al, K, Ca, Ti, Si, Fe, Cu, Zn and Pb. These values are high and hazardous and thus control measures are recommended.

Key words: PM10 particulate matter; Stacked filter unit; Total reflection X-ray fluorescence; Deposition model; Deposition fraction.

INTRODUCTION

Exposure to particulate matter pollution generated from cement, limestone, fractured rocks etc has been a major concern in public health. For example, the observed irritations of the upper respiratory tract and subsequent lung function impairment among cement workers in Nigeria had been attributed to inhalation of high concentration of particulate matter from cement dust (Oleru 1984). Dusts generated from freshly fractured rocks are also expected to cause similar or even greater harmful effects on the respiratory system since they are highly enriched in silica and other toxic elements. In addition, greater attention is now focussed on the effect of very small particulate matter with aerodynamic equivalent diameter less than or equal to 10μm otherwise known as PM10 rather than the total suspended particulate matter (TSP) of general dimensions. This is as a result of the magnitude of observed linkage between PM10 and human mortality (Calthrop and Maddison 1996). For this reason, this study focuses on deposition of PM10 particulate matter collected during manual quarry activities in human respiratory tract.

In this work, PM10 samples were collected with a Stacked Filter Unit (SFU) aerosol sampler during manual quarrying activities and subjected to total reflection X-ray fluorescence (TXRF) analysis to obtain the elemental composition of the samples following the procedure described elsewhere (Klockenkamper and Von Bolen 1996, Okunade 2000). For the purpose of estimating deposition of different elements in the respiratory tract, the lung itself was divided into three anatomical compartments following the recommendation of the Task Group on lung dynamics (ICRP 1966). The multi-element data obtained from TXRF analysis was thereafter used in the EPA lung deposition model (USEPA 1982) which was itself derived from various deposition models to estimate the deposition fractions for selected elements.

MATERIAL AND METHOD

Sampling

PM10 particulate matter was collected in Zaria during manual quarrying activities involving breaking of rocks into various size aggregates using sledgehammer. This method of quarrying

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results in direct exposure to particulate matter generated along with the rock dust by the worker who was rather unprotected. The sampling was carried out using a Stacked Filter Unit (SFU) aerosol sampling device equipped with PM10 inlet, which permits only PM10 component of TSP that easily penetrates the human respiratory system (Maenhaut et al 1995). The PM10 was subsequently separated into two size fractions by sequential filtration through two Nuclepore membrane filters of pore size 8μm and 0.4μm respectively placed in series. The coarse filter collects 2-10μm particle size expressed in terms of aerodynamic equivalent diameter (AED) while the fine filter collects <2μm AED when the sampler is set at a flow rate of 16 litres per minute (Maenhaut et al 1995, Okunade 2000).

Sample Analysis

The fine and coarse Nuclepore membrane filters of individual samples were analyzed for PM10 particulate matter by gravimetry and for about 12 elements by Energy Dispersive TXRF technique, using procedure described elsewhere (Klockenkamper and Von Bolen 1996, Okunade 2000). Quartz was used as sample substrate for all the elements measured except for Si, which was analyzed using plexi-glass as substrate. This is because of the high silica content of quartz. The mean concentration values of various elements in PM10 samples are presented in Table 1.

DEPOSITION MODEL

Lung deposition models were generally developed based on the compartmentalization of the respiratory system into three anatomical compartments and estimation of the dust deposition in each of these compartments (ICRP, 1966). These anatomical compartments, which have important functional distinctions, include:

(i) the nasopharyngeal region (N-P), which begins with the nose through the mouth and extending downwards to the level of larynx;

(ii) The tracheobronchial (T-B) region, which includes the airways from the larynx to

Table 1: Mean Elemental Concentration of PM10 particulate Matter (Coarse and Fine Fraction) for manual Quarry Activities.

ELEMENT	COARSE FRACTION	FINE FRACTION
Al	10.757±0.621	-
Si	26.172±1.410	-
K	7.632±0.044	1.349±0.040
Ca	7.172±0.037	1.620±0.022
Ti	0.865±0.015	0.011±0.006
V	0.097±0.007	-
Mn	0.176±0.007	-
Fe	6.652±0.017	0.714±0.007
Cu	0.330±0.009	0.373±0.012
Zn	0.310±0.010	0.363±0.013
Sr	0.321±0.020	-
Pb	0.382±0.026	0.453±0.030

Table 2: Fractional Deposition Estimates for Fine and Coarse Fraction of PM10 Particulate Matter from the Quarry Industry

RESPIRATORY COMPARTMENT	MASS DEPOSITION FRACTION	
	>2µm	2-10µm
Naso-Pharyngeal region (N-P)	0.039	0.264
Tracheo-Bronchial region (T-B)	0.060	0.232
Pulmonary region (P) (low estimate)	0.159	0.134
Pulmonary region (P) (high estimate)	0.289	0.260

the terminal bronchioles;

(iii) The pulmonary region (P), which consists of several structures, respiratory bronchioles, alveolar ducts, atria, alveoli and alveolar sacs.

In determining deposition estimates for each of the anatomical compartments important factors to be considered are the aerodynamic characteristics of the air-borne dust particles and activity condition of the subject because of their roles in deposition processes. The amount of particles deposited in a particular anatomical compartment and mechanism of deposition strongly depends on aerodynamic particle size. Also, the activity condition of the subject affects ventilation, which also plays important role in deposition. Since the change in deposition throughout the respiratory tract depends on the increase in tidal volume in relation to respiratory frequency, application of more than one ventilatory state at a constant respiratory frequency (e.g. 15cycles per min) will be considered in the determination of deposition.

Determination of Fractional Deposition Estimates

The mass deposition fraction f_i for the various compartments of the human respiratory tract is determined using standard deposition curves, which relate deposition in the respiratory tract to aerodynamic equivalent diameter, which is a parameter of aerosol distribution. Since in practice, calculations cannot be carried out for all possible breathing patterns or for all possible aerosols, the fit to the standard deposition curves constructed by the US Environmental Protection Agency (USEPA 1982) for different breathing patterns and variety of size distributions were used in calculating regional deposition estimates. For the pulmonary region, high and low estimates were determined (because of wide variations of data) using two curves that envelope the data. All of the data were based on mouth breathing with respiration rates of 7.5-30 litres per minute and tidal volume of between 1.0 and 1.5 litres.

The deposition fraction for particles with aerodynamic equivalent diameter of 2µm up to 10µm was obtained from the US EPA curves. The average value was then calculated to obtain deposition fraction for particles in the size range 2-10µm that are deposited on the coarse filter in the SFU. Similar procedure was used in determining the mass deposition fraction for particles in the size range <2 µm which are deposited on the fine filter. The average values were adopted as a result of uniform deposition of mass on the Nuclepore membrane filter as a result of its regular structures and uniform pore size distribution (Spurny et al 1969). The fractional deposition estimates (f_i values) for fine fraction (<2µm AED) and coarse fraction (2-10µm AED) of PM10 particulate matter from manual quarrying activities are presented in Table 2.

Determination of Regional Deposition Estimates

The overall deposition fraction F for any of the above anatomical compartments of human respiratory tract is given by Milford and Davidson (1985) as:

$$F = \frac{\sum f_i \Delta C_i}{\sum C_i} \qquad (1)$$

Where:

f_i is the mass deposition fraction in a compartment of the lung corresponding to size range i and ΔC_i is the airborne elemental concentration in that size range.

Values of the overall deposition fraction F thus calculated therefore represents the ratio of total mass of an element deposited in a specific compartment of the respiratory system to the total mass of element inhaled. Using the elemental composition of individual PM10 samples whose average values for fine and coarse fractions are given in Table 1 and the fractional deposition estimates in Table 2 as inputs in equation (1), the regional deposition fractions for selected elements were calculated.

RESULTS AND DISCUSSION

Calculated values of the total regional deposition fraction F for N-P, T-B and P compartments for elements Al, K, Ca, Ti, Si, Fe, Cu, Zn and Pb based on workplace air concentration data for the manual quarrying activities are presented in Table 3. The table shows that the regional deposition fraction for N-P is greater than for T-B compartment for all the elements. This is because the former is characterized with higher mass deposition fraction (of about 13.8%) in the coarse

Table 3: Regional Deposition Fraction for N-P, T-B and P Compartments of the Human Respiratory System for Various Elements.

ELEMENT	N-P	T-B	P-LOW	P-HIGH	TOTAL-LOW	TOTAL-HIGH
Al	0.264±0.085	0.232±0.082	0.134±0.042	0.260±0.082	0.63±0.125	0.756±0.143
K	0.225±0.064	0.202±0.064	0.138±0.038	0.265±0.074	0.565±0.098	0.692±0.117
Ca	0.223±0.064	0.201±0.064	0.139±0.039	0.265±0.075	0.563±0.099	0.689±0.118
Ti	0.243±0.110	0.216±0.108	0.136±0.060	0.263±0.116	0.595±0.165	0.722±0.193
Si	0.264±0.086	0.232±0.082	0.134±0.042	0.260±0.083	0.630±0.125	0.756±0.145
Fe	0.242±0.069	0.215±0.068	0.137±0.038	0.263±0.073	0.594±0.104	0.72±0.121
Cu	0.147±0.043	0.143±0.047	0.147±0.055	0.275±0.099	0.437±0.084	0.565±0.117
Zn	0.150±0.044	0.145±0.048	0.147±0.053	0.275±0.098	0.442±0.084	0.57±0.118
Pb	0.147±0.046	0.142±0.050	0.147±0.058	0.275±0.105	0.436±0.089	0.564±0.125

particle size range than the latter according to Table 2 and equation 1. The fact that the mass deposition fraction in the fine particle size range for T-B greatly exceeds that of N-P (by 57.8%) not withstanding. In addition, the coarse particle size range is itself characterized with much higher mass deposition fraction than fine particle size range, and thus it can be deduced from equation 1 that for N-P and T-B compartments, the regional deposition fractions for all the elements increase with particle size. The deposition fraction in the pulmonary region is however consistent for all of the elements. For example, Al and Pb have highest and lowest deposition fractions respectively in the N-P and T-B regions and yet virtually similar pulmonary deposition. In general, the results obtained suggest total deposition fraction ranging from 0.44 to 0.76 for elements Al, K, Ca, Ti, Si, Fe, Cu, Zn and Pb.

The result obtained for total deposition is comparable to that obtained from previous estimates of lung deposition by Natusch and Wallace (1976). These investigators used the model developed by the Task group on lung dynamics (ICRP 1966) in conjunction with log-normal distribution fit to particle size data to estimate deposition fractions. For example the total deposition (high) for Pb and Fe were estimated as 0.55 and 0.77 respectively as compared to the values of 0.56 and 0.72 respectively for the same elements obtained in the present study. However, there is considerable difference in regional deposition estimates obtained for some of the elements in N-P, T-B, and P compartments. The values of 0.17, 0.06 and 0.32 for Pb and 0.48, 0.07 and 0.22 for Fe obtained by Natusch and Wallace (1976) for N-P, T-B and P compartments respectively are significantly different from values obtained in Table 3. The disparity primarily indicates the difference between US EPA standard deposition curves and ICRP model, with the later predicting higher deposition fractions for particles in N-P and P- compartments and smaller deposition fractions in the T-B region.

CONCLUSION

The total deposition fractions for various elements in human respiratory tracts for manual quarry workers had been determined using multi-element data and EPA lung deposition model. Good agreement was observed between these results and those obtained by previous workers. The rather high deposition fraction ranging from 0.44 to 0.76 for various elements (Al, K, Ca, Ti, Si, Fe, Cu, Zn and Pb) implies that the manual quarry workers are easily predisposed to lung function impairment arising from high concentration of toxic elements from quarry dust. It is thus recommended that appropriate legislation be put in place to minimize dust emission and inhalation in the work area.

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