AN ATTEMPT FOR EVALUATION OF THE ALVEOLAR DUST DEPOSITION ON THE BASE OF THE PARTICLE SIZE DISTRIBUTIONS OF LUNG DUSTS

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INTRODUCTION

The experimental and theoretical studies of the way human lungs behave at different size distributions of the offered dusts and form the alveolar depot—the major determinant of the development of lung diseases, did not offer completely defined results. Regardless of the recent advances in this field, such as the derived curves of extrathoracic, tracheobronchial and alveolar deposition of inhaled particles and the lot of unified parameters, the criteria for respirable dust sampling and assessment of dust hazards etc.[9] many problems did not find satisfactory answers.

The progress of technics and electronics eliminates the mass of difficulties in the particle size analysis and in the complicated calculations of the selective deposition of particles in the respiratory tract.

Presently, the most important problems derive from the impossibility to characterize precisely the entire dust inhaled by workers during their lifetime. The experimental studies in vivo on humans and animals, on models of the respiratory tract, as well as mathematical models providing a precise but valid information for the moment,[6] are unable to assess yet the long-term retention of dust in the lungs as a response of the inhaled particles.

A very specious solution of these problems seems to be the study of dusts recovered post mortem from the lung tissue of dust-exposed workers and to compare them with the airborne dusts offered to the respiratory tract. Of course, a method of approach like this also has its disadvantages mainly in the assessment of the inhaled, resp. airborne dust. But it is possible after analyzing a significant number of airborne dust samples, collected in the work environment during a long period of time and including all technological processes used on the areas where employees had worked, to obtain a more or less rough approximation to reality. So, the respiratory tract with its special features and intersubject variability depending on individuals and experimental design, can be considered as a "black box" with known "inlet" and "outlet." Many authors have used lung dusts in their investigations and a lot of them support the reliability of the information received about the alveolar deposition of airborne particles.[2,5,8]

Another important limitation of this experimental design can be the impossibility for assessment of particle aggregations and the kinetic behaviour of aggregates. Possible errors can be eliminated to some extent by analyzing fully dispersed samples of airborne and lung dusts using the same method for particle analysis.[2]

When the results from different studies of dust deposition in the respiratory tract are to be compared, it is particularly important to bear in mind that the main curves used nowadays as criteria for dust hazard evaluation[9] are derived with monodispersed aerosols, while the determination of alveolar dust deposition with lung dust studies (representing a long-term retention of dust in lungs) is based on the inhalation of polydisperse aerosols.

Diu and Yu[3] proposed a new mathematical model of polydisperse aerosol deposition in human respiratory tract, proving more or less considerable differences varying with the polydispersity. The model needs a validation on experimental studies. Investigation of lung dusts should be convenient for this purpose.

The mass particle size distributions of 47 samples of total airborne dust in the work environment of three mines—24 from a polymetal ore mine (PMM), 18 from copper mine A (CMA) and 5 from copper mine B (CMB) were determined. Full-shift sampling was performed at normal passing technological processes according to the actual standard in the country.[1] Samples were collected in different intervals of time during 10 years.

Fifty-nine dusts, recovered post mortem by the formamid method of Thomas and Stegemann[12] from the lungs of miners with entire length of service in the same mine, were analyzed for determination of the particle size distributions. Forty three of them were from the PMM group, 11—from CMA and 5—from CMB groups.

The particle size analyses were performed by two methods based on different principles: centrifugal sedimentation in Joyce-Loebl disc centrifuge[4] analyzing particles in class intervals of Stokes diameters 0.01–20 μm and automatic counting of particles in liquid media with Coulter Counter (CC) using tube aperture 50 μm, analyzing particles in class intervals of UDS diameter 0.7–25 μm. Dust samples were suspended in filtrated 0.1% solution of sodium hexametaphosphate in distillate water. A lot of the analyses were performed with the same suspension. The Stokes particle size distributions were calculated in aerodynamic diameters using the density data for every dust. Particle size distributions were plotted on log-probability graph paper.

Mean values of the groups of airborne and lung dusts from the three mines were calculated, as well as the standard deviations and the confidence limits intervals. The standard deviations of the groups of airborne and lung dust from every mine

were compared statistically by means of the Fischer criterion.

The alveolar deposition was determined by the method described by Leiteritz, Einbrodt and Klosterkötter.[5] The enrichment of fine sizes of each fraction of the lung dust particle size distribution was calculated as a ratio of the corresponding airborne dust fraction. This is the so-called enrichment factor. The relative alveolar deposition of each fraction is the quotient for the enrichment factors and the maximum enrichment factor which is taken to be = 1.

RESULTS AND DISCUSSION

Particle Size Distributions of Airborne and Lung Dusts

It was found that the mean values of the mass median aerodynamic diameters of the particle size distributions (MMAD) of the three groups of mine airborne dusts are in the class intervals 3–5 μm, analyzed by both methods. The mean geometric standard deviations (σg) of the groups were

varying from 4.4 to 5.3 for Joyce analysis and from 2.2 to 2.3 for Coulter Counter analysis. The airborne dust samples analyzed with Joyce were reduced to 5 combined samples for each mine, because the analysis needs about 50 mg of dust.

The mean value of MMAD of the particle size distributions of lung dusts of the three groups of miners was varying from 1.9 to 2.6 μm by both analyses and σg—from 3.3 to 3.6 and from 1.6 to 1.8 by Joyce and CC analyses, respectively.

The maximum frequency percentage of the particle size distributions, as well as the other data about them are presented in Table I.

Relative Alveolar Deposition

It was found that the maximum enrichment factors for the 3 groups of airborne and lung dusts are in the class interval 1.2–2.4μm. The mean values for each size range of the enrichment factor were calculated and a curve of the relative alveolar deposition was derived (Figure 1). The theoretical

Figure 1. Curves of relative regional alveolar retention of airborne dusts from three ore mines derived on the basis of particle size distribution of lung dusts.

LEGEND

————————— Mean retention curve derived by Joyce analysis
— — — — — — — Mean retention curve derived by CC analysis
— · — · — · — Deposition curve of ICRP[9]
· · · · · · · · · · · · · Predictive deposition curve of Yu[13]

Table I

Characteristics of the Mass Particle Size Distributions
of Airborne Dusts and Lung Dusts of Miners from Three Ore
Mines Analyzed with Joyce-Loebl Disc Centrifuge and
Coulter Counter

Mine	Para-meters	Airborne dusts		Lung dusts	
		Joyce	Coulter	Joyce	Coulter
PMM	Mean MMAD, μm	3.30	3,95	2.13	2.49
	Confid. lim. μm	± 3.01	± 2.45	± 1.60	± 1.50
	σ_g	5.30	2.08	3.60	1.66
	Confid lim.	± 2.68	± 0.66	± 2.26	± 0.41
	Anal.No	5	24	43	43
	Max.fr.%	32	37	23	53
	Int.,μm	1.6-6.5	3.2-6.5	1.6-3.2	1.6-3.2
CMA	Mean MMAD, μm	2.90	3.74	1.86	2.31
	Confid. lim. μm	± 2.49	± 2.48	± 1.70	± 1.08
	σ_g	5.00	2.00	2.35	1.83
	Confid. lim	± 2.66	± 0.71	± 1.52	± 0.51
	Anal.No	5	18	11	11
	Max.fr %	34	36	42	44
	Int;μm	1.6-6.5	3.2-6.5	0.8-3.2	1.6-3.2
CMB	Mean MMAD	3.92	4.82	2.53	2.57
	Confid. lim. μm	± 3.61	± 3.45	± 3.48	± 2.34
	σ_g	4.40	2.10	3.60	1.63
	Conf.lim.	± 2.61	± 1.01	± 2.57	± 0.66
	Anal.No	5	5	5	5
	Max.fr.%	36	37	21	50
	Int; μm	1.6-6.5	3.2-6.5	1.6-3.2	1.6-3.2

curve of Yu[13] and the ICRP curve of Task Group[9] were also plotted on Figure 1 for comparison, recalculated in the same way.

The relative alveolar depositions with the minimum and maximum values of airborne and lung dusts of the three mines were calculated separately. The values' dispersion is shown on Figure 1 and the data are presented in Table II.

DISCUSSION

The data obtained showed some differences in the particle size distributions of the same dusts, analyzed by both methods. The MMAD determined by Joyce are finer than those determined by CC, while for σg the contrary was proved. In principle this was expected because the instrumental limitations of CC in sizing of fine particles (smaller than $0.7 \mu m$) as well as Joyce unreliability in sizing of coarse particles (larger than 15–20 μm) are known. But it is necessary to emphasize the fact for two reasons: on one hand to demonstrate the considerable influence on the calculated relative alveolar deposition of the different particle size distributions used, and, on the other hand—to draw the attention of specialists on the need of good knowledge about the limitations of every method or instrument used for particle size analysis, when interpretation of data has to be performed. Thereby useless contradictions due to underestimation of the last reason could be avoided.

Another fact of interest is the fine dispersity of airborne dusts (mean MMAD vary from 3 to 5.0 μm, with real maximal value of the groups examined—5.2 μm by CC analysis). In most of the studies known these values are much higher but they concern coal mine dusts.[2,5,8] Ore mine dusts are expected to be finer and the authors of this paper have many studies in this field.[4,10] They have found a considerable presence of submicron fraction of mineral origin in ore mine airborne dusts, as proved with X-ray analysis,[11] the same being evidenced for lung dusts, also.

The determination of the alveolar dust deposition by using lung dusts and work environment airborne dusts is connected with some preliminary assumptions: the particle sizes are the leading factor for the dust deposition in the respiratory tract; the "inlet" and the "outlet" dusts, e.g. the airborne and lung dusts are representative and reliable; alveolar deposition, the retention, respectively, of dust is more real when lung dusts are used because the long-term clearance as a total and the changes of dust parameters after continued staying in lung are included.

The data obtained for alveolar deposition (more correctly it should be called alveolar long-term retention) differ to some extent from the referred in the main studies performed—experimental, calculated and predicted. The maxima of the relative alveolar retentions calculated as mentioned above, are

Table II

Size Range Intervals of the Calculated Maximal Enrichment
Factors with the Mean and Real Values of MMAD and σg of
the Particle Size Distributions of Airborne and Lung Dusts
from Three Ore Mines by Joyce and CC Analyses

Mine	Values of parameters used	Calculated maximal enrichment factors	
		Joyce analysis size intervals	CC analysis size intervals
PMM	Mean	1.6–3.2 μm	1.6–3.2 μm
	Min	0.4–0.8 μm	0.4–0.8 μm
	Max	1.6–3.2 μm	3.2–6.5 μm
CMA	Mean	0.8–1.6 μm	0.8–1.6 μm
	Min	0.1–0.2 μm	0.2–0.4 μm
	Max	1.6–3.2 μm	0.4–0.8 μm
CMB	Mean	0.8–1.6 μm	1.6–3.2 μm
	Min	0.1–0.2 μm	0.8–1.6 μm
	Max	0.8–1.6 μm	1.6–3.3 μm

found to be in the same size range intervals as the maxima of the particle size distributions of lung dusts or are removed toward the fine size ranges—Figure 1 and Table II.

These results are in correspondence with the mathematical model of Diu and Yu.[3] To airborne dust with σg significantly higher than 2 results a different alveolar dust retention in comparison with the deposition curve of Yu,[13] predicted for monodispersed aerosols—retention curve calculated with Joyce data on Figure 1. This curve is quite similar in the size range interval 0.5-1.6 μm to the ICRP curve[9] derived from a lot of different studies. On the contrary, the CC retention curve does not differ in some of the size range intervals considerably from the curve of Yu. The values of σg of airborne dusts analyzed by CC are about 2. Morrow[7] affirms that inhaled dust with σg < 2 have similar deposition in respiratory tract to this of monodispersed aerosols.

CONCLUSIONS

The experimental curve of long-term alveolar retention of inhaled dust from the working environment derived on the basis of the particle size distributions of miners' lung dusts from three ore mines proved that the real alveolar deposition and retention is different from the predicted deposition of monodispersed aerosols.

The study was performed with a comparatively great number of airborne and lung dust samples and can be regarded as reliable.

It is obvious that the polydispersity of dust samples has more considerable influence on the alveolar deposition and retention than it was estimated till now—a problem disregarded to some extent in the experimental studies.

Modern technologies and the mechanizing and automation of working processes lead to increasing of the polydispersity of airborne dusts and namely of the fine particles share. This fact

inevitably will lead to some changes in the understandings about the evolution of the hazard and imposes more attention to be paid to the problems of particle size analyses and the interpretation data.

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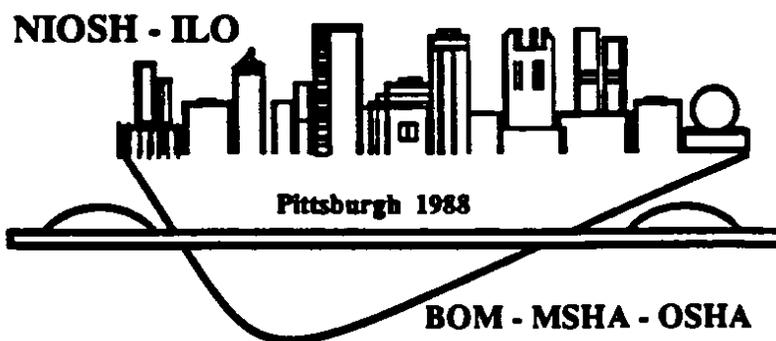
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