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The penetration of respiratory protective devices by respirable solid particles

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ABSTRACT

In certain industrial settings, for example, mining and quarrying, people must work in atmospheres containing large amounts of dust. This increases their chances of developing pneumoconiosis in some form or another. Even after taking all possible preventive measures against lung disease, the Spanish National Institute of Safety and Hygiene at Work still recommends the use of respiratory protective devices (RPDs). Unfortunately, some workers are reticent to use these devices since they cause them thermal stress and breathing difficulties etc. The selection of RPD should be made taking into account the job to be performed, the physical condition of the user, the degree of occupational exposure, and the concentration of the contaminant to be avoided (gases, vapours, particles, etc.) Given the concern expressed by worker representatives and safety delegates with respect to the use of the most appropriate device for different activities, several RPDs were tested experimentally, simulating extreme conditions to which workers might be exposed. Unexpected significant variation was seen between devices of the same category with respect to their penetration by dust particles.

1. Introduction

In some industries, workers are continually exposed to dust. For example, dust is produced in the mining industry during the extraction and grinding of ore, in the food industry during transport, milling and packaging, and in workshops during cutting, sawing and polishing operations, etc. (Vrins & Hofschreuder, 1988; Jones et al., 1993). This dust is composed of particles of different shape and size; while larger, denser particles may fall to the ground, smaller, less dense particles may be suspended in the air for long periods of time and be transported far away from their point of origin.

People whose work places them in continual contact with dust can suffer pneumoconiosis in some form or another (Vallyathan et al., 1997; Schins & Born, 1999). The inhalation of dust and the associated deposition of solid inorganic (and sometimes even organic) residues in the bronchioles and on the lung parenchyma eventually result in respiratory dysfunction. One of the most common forms of industrial pneumoconiosis is silicosis, a disease caused by the inhalation of silicon (SiO_2) dust (Seemayer et al., 1988; Castranova & Vallyathan, 2000; Flynn & Susi, 2003).

One preventative solution is for workers to use respiratory protective devices (RPDs) that filter the inhaled air. Different types of RPDs are available, including full-face masks, half masks, quarter masks, etc. The active parts of these devices are

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their filters, and these have undergone much improvement in recent years. The newest filters are mainly made from synthetic fibres (polypropylene, polyethylene or polyester). These non-woven products take the form of beds of fibres packaged and stuck together by a thermochemical process.

When solid particles suspended in the air enter RPDs they may be captured in two ways (Hinds, 1999):

(1) By mechanical attraction, in which the particle enters into contact with a fibre and is trapped. The mechanisms are sedimentation, interception, impact and diffusion. Sedimentation occurs when the particle falls down due to gravity. Interception occurs when a particle following a streamline touches a filter fibre. Impact occurs when the particle size is big enough that it is unable to quickly adjust to the abrupt changes in the streamline direction near a filter fibre. Diffusion mechanism of particle retention is the result of random motion of small aerosol particles (<0.5 μm) due to collisions with gas molecules. The smaller the particle size, the higher the chance of hitting and sticking to a filter fibre, due to a more vigorous movement.

(2) By electrostatic attraction, the result of the particles and fibres carrying different charges.

Research has shown that applying an electrostatic charge to a filter significantly improves its particle-capturing potential (Hyatt et al., 1974); indeed, charged filters may trap up to 60% more particles than uncharged filters (mainly those in the 0.1–0.6 μm range).

The effectiveness of a filter as a barrier to solid, respirable particles also depends on its shape and size, the mineralogical characteristics of the particles it must trap (Wake et al., 1992; Veranth et al., 2000), the depth of breathing of the user (Majchrzycka, 2000), and the degree of adjustment of the mask to the face (Willeke & Krishnan, 1990).

Both European and American standards (UNE-EN 143, 2001; UNE-EN 149, 2001; 42 CFR 84, 1995) require that RPDs be tested for the penetration/capture of solid particles at a determined pressure and depth of breathing, although they differ in terms of the percentage that must be captured for classification into use categories. The concerns of the Spanish mining industry regarding which type of RPD is most adequate for use in its context led to the proposal that a series of commercially available RPDs be tested (Grima-Olmedo et al., 2012).

2. Materials and methods

2.1. Materials

2.1.1. The tested respiratory protective devices

The tested devices were 15 commercially available anti-particle RPDs (the best known in Europe), including 10 auto-filtering masks of efficacy classes FFP1 ($n=3$), FFP2 ($n=4$) and FFP3 ($n=3$), and five masks with replaceable filters of efficacy level P1 ($n=1$) and P3 ($n=4$). Three of the P3 devices were half masks, and one was a full-face mask. The selection of these RPDs was made from among material sent to our laboratory for the confirmation of quality standards.

2.1.2. Dust used in testing

The dust particle-capturing capacity of the different RPDs was tested in aerosol tests using fine coal dust (lignite with a content of volatiles about 46% and a calorific value about 23.5 MJ/kg) – a dust that poses respiratory health risks (note: the methodology followed could be used with any dust or powder). Workers are exposed to this material in the mining, electricity generation, cement manufacturing industries, etc.

2.2. Methods

2.2.1. Characterisation of the size and shape of the coal dust particles

Digital imaging analysis (DIA) was performed to examine the shape and size of the dust particles. A block of resin impregnated with the coal dust (Fig. 1) was polished, removing layers little by little with a silicon carbide (SiC) abrasive. Impurities were removed from the polished surface by ultrasound. The edges of the block were bevelled to prevent breakages. Once a perfectly flat surface was obtained, the surface of the block was examined using a Leica reflex DMRXP microscope (objectives $5\times$, $10\times$ and $20\times$), to which a Sony Dophinsa XC-003P CCD video camera was attached. The captured images were converted into binary images using a PC with a Matrox Meteor II digitising card, and carbon particle length, roundness and convexity examined using Aphelion 3.1 software.

Particle size distribution was determined using a Malvern Mastersizer 2000 low angle laser light scattering device (sensitivity range 0.02–2000 μm). All analyses were performed at the Applied Microscopy and Image Analysis Laboratory at the Department of Geological Engineering, School of Mines, *Universidad Politécnica de Madrid*.

2.2.2. Dust penetration tests

The effectiveness of the RPDs was tested in a specially designed installation in which the atmosphere was controllable. This consisted of the following main parts: an air circulation chamber, air propulsion, aspiration and conduction units, monitoring and measuring instruments, and dust capturing units (see Fig. 2).