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The Influence Of Metal-Containing Occupational Dust On Pulmonary Surfactant Activity

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Workers can be exposed in their working environment to dust particles containing metals and their compounds. Long-term exposure to those particles can induce pathological disorders of the respiratory system. Pulmonary surfactant is the first barrier between the air inhaled into the alveoli and the lung tissue with pulmonary capillaries. External agents such as inhaled aerosol particles containing metals and their compounds deposited at the alveolar surface can influence the pulmonary surfactant dynamics. The aim of the study was to evaluate the influence of metal-containing occupational dust on the surface activity of the pulmonary surfactant. Dusts emitted during metal machining were used in this study to prepare dust particle suspensions in a model pulmonary surfactant. Survanta (Abbott, France) diluted with physiological salt was used as the model pulmonary surfactant; it represented the physicochemical properties of a natural surfactant. Particle concentrations corresponded to calculated dust contents in the alveolar hypophase after inhalation of dust at a given concentration in the air. Surface phenomena in the alveolus during the breathing cycles were simulated with a pulsating bubble surfactometer. Three quantitative criteria were evaluated to describe the dynamic surface properties of the pulmonary surfactant: the minimum surface tension (σ_{min}), the normalized hysteresis area (HA_n) and the stability index (SI). Changes in HA_n, SI and σ_{min} of the model pulmonary surfactant after contact with dust particles emitted during metal machining suggest deactivation of the pulmonary surfactant dynamics by metal-containing occupational aerosols.

1. Introduction

In their working environment, workers are exposed to inhalation of dust particles containing metals and their compounds. As a result of long-term exposure to those particles workers may suffer an impairment of pulmonary surfactant function and in effect - disorders of the respiratory system functioning (Gehr and Heyder, 2000; Ruediger, 2000; Nordberg et al., 2007).
The term pulmonary surfactant refers to a complex of surface-active agents existing naturally on the surface of liquid lining of end parts of the respiratory system (Zuo et al., 2008; Orgeig et al., 2004). Pulmonary surfactant is a mixture of lipids (ca 90% weight)

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and proteins (ca 10%) (Enhorning, 2008). The largest group of lipids (80–90% weight) consists of phospholipids (PL), where phosphatidylcholines (DPPC) constitute the dominant weight share (ca 80%).

Pulmonary surfactant is associated with significant physiological processes essential for the proper functioning of the organism (Enhorning, 1996; Sosnowski, 2008), which include, eg.:

a) the reduction of the surface tension in pulmonary alveoli, which prevents their collapse in the final stage of exhalation,
b) the increase of the alveoli stability,
c) prevention of pulmonary edema,
d) self-cleansing of alveolar surface from aerosol deposits due to liquid flow being the result of Marangoni effects.

Surfactant capability of reducing surface tension in dynamic conditions caused by breathing (cyclic change of the liquid-gas surface covering the pulmonary alveoli epithelium) is described as pulmonary surfactant activity. Pulmonary surfactant system is characterized by significant surface tension reduction during the liquid-gas surface compression (exhalation) and the occurrence of surface tension hysteresis during expansion - compression cycle (inhalation - exhalation) (Notter et al., 1982). Under the influence of external agents, e.g. deposited particles, there may occur a change in the surface activity of pulmonary surfactant. It is reflected by changes of the hysteresis loops shape and of the quantitative criteria values characterizing these loops: minimum surface tension, normalized hysteresis area or stability index (Sosnowski et al., 2000; Wallace et al., 2007).

The aim of the study was to evaluate the influence of metal-containing occupational dust on the surface activity of the pulmonary surfactant.

2. Methods

The study covered dusts emitted in metal machining processes. Dusts samples were collected at workplaces in a mechanical workshop. Separation into fractions with dimensions of particles smaller than 0.25 µm, within ranges 0.25-0.5 µm, 0.5-1 µm, 1-2.5 µm, and 2.5-10 µm was done with Personal Cascade Impactor Sampler - PCIS (SKC Inc., USA) in a research laboratory stand of fluidized-bed aerosol generator (Kondej and Sosnowski, 2009). The 37-mm PTFE filters with pore size of 2.0 µm (SKC Inc., USA) were used to collect dust particles with dimensions below 0.25 µm. Particles with dimensions within the range 0.25-10 µm were collected onto 25-mm PTFE filters with pore size of 0.5 µm (SKC Inc., USA).

Concentrations of metals in dust fractions were determined by atomic absorption spectrometry (AAS):

a) zinc (Zn), iron (Fe), manganese (Mn), chromium (Cr), magnesium (Mg) – AAS with acetylene/air flame using Atomic Absorption Spectrometer Solaar M (Thermo Electron Corp., USA),
b) nickel (Ni), copper (Cu), lead (Pb), aluminum (Al) – AAS with graphite tube and Zeeman background correction using Atomic Absorption Spectrometer SpectraAA 880 (Varian Inc., USA).

The evaluation of changes of the pulmonary surfactant interfacial properties after contact with dust particles containing metals and their compounds was conducted with the dynamic tensiometric method using Pulsating Bubble Surfactometer - PBS (Electronetics Corp., USA), i.e. in conditions simulating the processes occurring in the pulmonary alveoli during the breathing cycle. Pharmaceutical preparation SURVANTA (Abbott, France) was used as the substance representing physicochemical properties of natural surfactant. The preparation was diluted to concentration of 1.25 mg phospholipids/ml with physiological salt solution containing known mass of dust particles. The study consisted of the determination of surface tension changes during dynamic oscillations (15 min^{-1}, 37 ºC) of air bubble created in the solution of the model surfactant, and the evaluation of surface tension hysteresis as a function of the reduced interfacial surface (A/A_{max}).
In order to evaluate surface activity of pulmonary surfactant during oscillation of the liquid-gas interfacial area, the following quantitative criteria, characterizing the hysteresis loops were used:

- the minimum value of surface tension (σ_{min}) during bubble pulsation (in the compression - expansion cycle)

$$\sigma_{min} = \min\{\sigma(r)\} \qquad (1)$$

where: r – bubble radius

- normalized hysteresis area (HA_n) describing the value of the hysteresis loop area determined for the compression and expansion cycle, referred to unit change of the surface area (A)

$$HA_n = \frac{\left[\int_A \sigma dA\right]_{expansion} - \left[\int_A \sigma dA\right]_{compression}}{A_{max} - A_{min}} \qquad (2)$$

- stability index (SI) describing the difference between the maximum (σ_{max}) and the minimum value of surface tension (σ_{min}) in the cycle, referred to their mean value

$$SI = \frac{\sigma_{max} - \sigma_{min}}{\frac{1}{2}(\sigma_{max} + \sigma_{min})} \qquad (3)$$

Comparison of the values of the above mentioned parameters calculated from measurements conducted with mixtures of the model surfactant and the examined dusts with the control values (for the solution of pure surfactant) was the measure of the influence of dusts emitted at workplaces on the dynamic properties of pulmonary surfactant.

3. Results

Figure 1 presents metal concentrations in the submicrometer fractions of dust emitted during machining of metal part with disk grinder. The largest concentration was found for iron (Fe) and aluminum (Al): 350 and 50 μg/m^3, respectively. The dominant amounts of iron and aluminum arise from the composition of the materials being machined (steel and aluminum alloys).

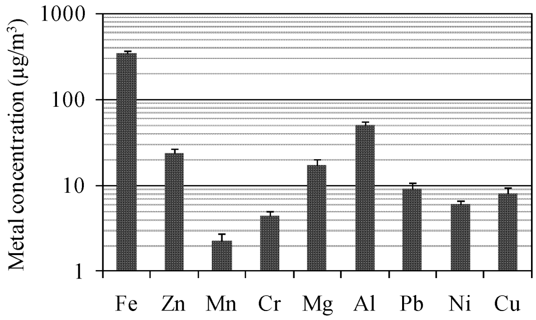

Figure 1 Metal concentration in dust with particle dimensions below 1 μm.

Figure 2 presents surface tension hystereses determined for the surfactant in control conditions and after contact with submicrometer dust particles emitted from disk grinder, at the concentration of 0.086 mg/ml, which corresponds to 6-hour-long exposure to dust with concentration of 4 mg/m^3. The change of shape and position of hysteresis loop suggests an unfavorable influence of the examined dust on the surface activity of the model surfactant.

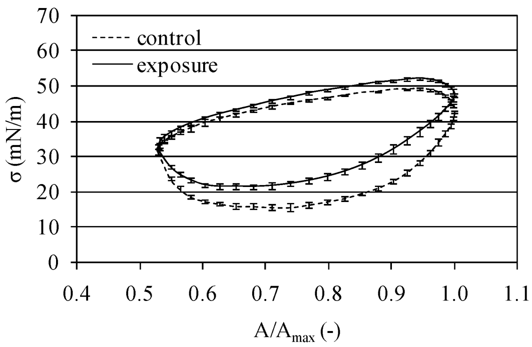

Figure 2 Comparison of surface tension hystereses at oscillation of the liquid – gas surface in the system containing the model pulmonary surfactant.

Changes of quantitative criteria defined by eqs. (1) - (3) as a function of dust concentration in surfactant solution has been presented in Figure 3. The relationships show a reduction of surfactant surface activity already for low concentrations of dust emitted at the stand of grinding of metal parts. For dust concentration of 0.042 mg/ml, which corresponds to 6-hour-long exposure to dust with concentration of 2 mg/m^3 there has been found a decrease of HA_n value by 6% and increase of σ_{min} by 22%. For the concentration of 0.864 mg/ml, which corresponds to 6-hour-long exposure to dust with concentration of 40 mg/m^3, there has been found a decrease of the HA_n value by 22% and SI value by 20% as well as increase of σ_{min} by 46%.

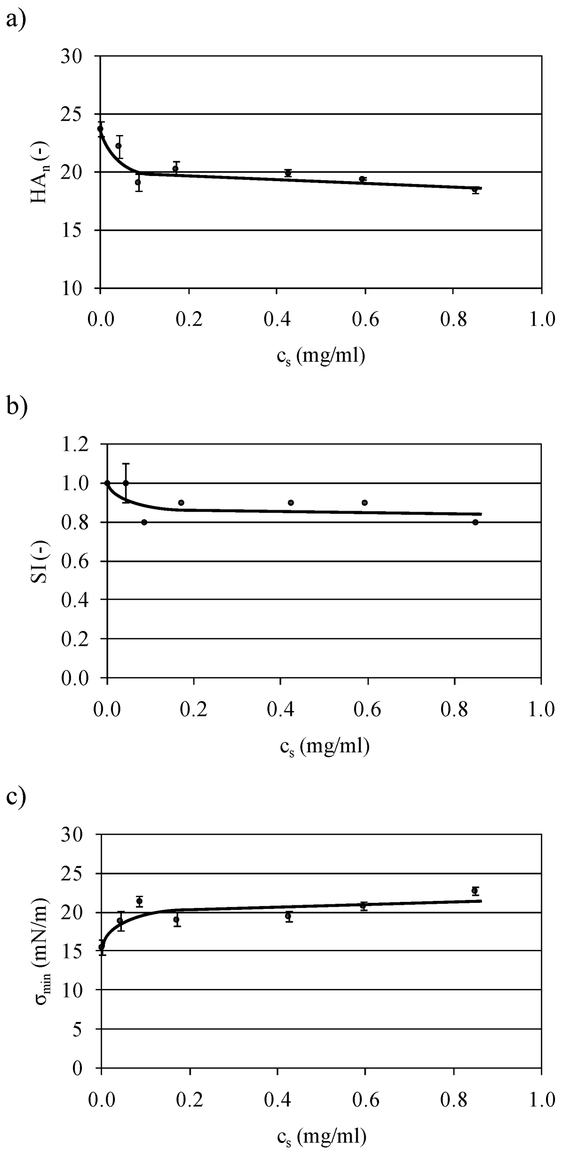

Figure 3 Changes of: a) normalized hysteresis area (HA_n), b) stability index (SI), c) minimum surface tension (σ_{min}) in the function of dust concentration (c_s) in the solution of the model pulmonary surfactant.

4. Conclusions

A reduction of surface activity of the model pulmonary surfactant under the influence of dusts containing metals, emitted in the process of machining metal materials has been found. The changes of surface properties of the surfactant caused by the impact of dust particles with dimensions smaller than 1 μm may impair physiological and protective functions of pulmonary surfactant and may have an influence on the development of occupational diseases of the respiratory system. The inactivation of pulmonary surfactant function may be an important step in induction of undesired health effect following occupational exposures to dusts of metals and their compounds.

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