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The Influence of Montmorillonite Nanofillers on the Lung Surfactant

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The influence of montmorillonite nanoparticles used as nanofillers in the production process of polymer nanocomposites on the physicochemical properties of the main lipid component of the lung surfactant was studied. Research was done for nanoparticles of natural and surface-modified montmorillonite using the Langmuir-Wilhelmy balance. It was found that montmorillonite nanofillers alter the organization of the surfactant molecules at the air-liquid interface and modify the surface properties of the surfactant monolayer. It may cause the disturbance of surface activity of the lung surfactant and contribute to adverse health effects in the respiratory system of workers involved in the production process.

Keywords: Lung surfactant, Activity, Dipalmitoylphosphatidylcholine, Monolayer, Compression, Montmorillonite, Nanofiller, Nanoparticle, Nanocomposite.

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1. INTRODUCTION

Montmorillonite nanoparticles are added as fillers to conventional polymers to improve their physical and thermal properties. Nanomaterials used in the production process of polymer nanocomposites may have a harmful impact on workers' health, however the complete mechanism of their interaction with the organism after inhalation remains still unrecognized. The presented study is focused on the evaluation of influence of selected montmorillonite nanoparticles on the physicochemical properties of the main lipid component (dipalmitoylphosphatidylcholine; DPPC) of the lung surfactant (LS). LS forms the specialized structure in the breathing zone of the respiratory system and it is responsible for vital physiological functions. The key properties of LS are related to the surface activity which ensures the modulation of surface tension of lung surface during breathing cycle.

2. MATERIALS AND METHODS

2.1 Tested Nanofillers

Research was done for nanoparticles (NPs) of natural montmorillonite clay (MC) and surface-modified montmorillonite (SMM) – Table 1.

Table 1 – Characteristics of the tested nanofillers (acording to Sigma-Aldrich specification)

Sample designation	Name	Composition and CAS*
MC	Montmorillonite clay (bentonite)	$H_2Al_2O_6Si$, CAS: 1302-78-9
SMM	Surface-modified montmorillonite (I.28E)	70-75 % – montmorillonite, CAS: 1318-93-0 25-30 % – trimethyl stearyl ammonium, CAS: 112-03-8

* CAS – Chemical Abstracts Service Registry Number

2.2 Microscopic Analysis

Observations of morphology of the tested particles were conducted with the use of a scanning electron microscope, Zeiss model 1530, upgraded by the use of the Supra optic elements. The test specimens were prepared by placing the sample on a conductive tape and spraying with carbon in an SCD 005 (BalTec AG) sputter-coater with a carbon attachment. An accelerating voltage of 2 kV and image magnifications of 100,000 x were used.

2.3 Surface Properties of DPPC Monolayer

The experiments were conducted using the Langmuir-Wilhelmy balance (KSV, Finland). DPPC monolayer was formed on the surface of the liquid phase (saline) by applying 15 μl of the chloroform solution of 1,2-dipalmitoyl-sn-glycero-3-phosphocholine (CAS: 63-89-8; Sigma-Aldrich, USA) at concentration of 1 mg/ml and evaporating the solvent. The monolayer was compressed isothermally (37 °C) with constant velocity (75 cm^2/min), in order to determine the evolution of the surface pressure and compressibility with decreasing surface area. The surface pressure was described as:

$$\pi = \sigma_c - \sigma , \quad (1)$$

and the compressibility was calculated as:

$$\kappa = -\frac{1}{A}\frac{dA}{d\pi} , \quad (2)$$

where π is the surface pressure, σ_c is the surface tension of the pure liquid phase at the measuring temperature, σ is the current value of surface tension in the test system, κ is the compressibility of the air-liquid interface containing DPPC molecules, A is the area per one molecule of DPPC.

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The influence of montmorillonite nanofillers was studied by measuring similar relationships for DPPC on the surface of saline which contained known amounts of NPs. The comparison of compression isotherms and compressibility curves for DPPC monolayer on the surface of pure liquid (without montmorillonite NPs) and on the surface of the NPs' suspension allowed quantitative assessment of the investigated effects.

3. RESULTS AND DISCUSSION

The microscopic analysis of the tested nanofillers confirmed the layered structure of montmorillonites with the thickness of the plates in the nanoscale – Fig. 1.

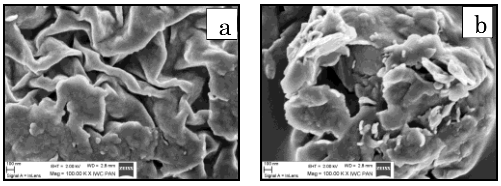

Fig. 1 – SEM picture of nanofiller particles: a) MC, b) SMM

The study carried out with the use of the Langmuir-Wilhelmy balance showed that MC and SMM NPs present in the liquid phase affected on the organization of DPPC molecules at the air-liquid interface and modified the surface properties of DPPC monolayer. Differences in the configuration of the compression isoterms (Fig. 2) and the compressibility curves (Fig. 3) indicate the dissimilar effect of MC and SMM on the activity of the main component of LS.

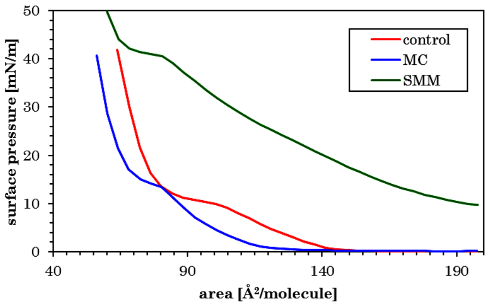

Fig. 2 – Compression isoterms of DPPC monolayer formed on the surface of liquid without NPs (control) and on the surface of the NPs' suspension (with MC and SMM) at concentration of 1 mg/ml

The compression isoterm for the system containing MC is shifted towards lower values of the surface pressure while the compression isoterm for the system with SMM is situated clearly above the control isoterm (Fig. 2). In this case, the surface pressure at the start of compression is approximately 10 mN/m. The presence of MC nanoparticles causes a reduction in the activity of DPPC at the air-liquid interface which may be attributed to the adsorption of DPPC molecules on the surface of the NPs investigated. In turn, SMM NPs induce increase of the surface pressure in the system which can be explained by a release of surface-active compounds from SMM particles.

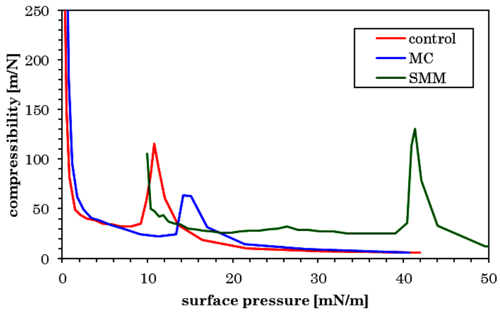

Fig. 3 – Compressibility curves of DPPC monolayer formed on the surface of liquid without NPs (control) and on the surface of the NPs' suspension (with MC and SMM) at concentration of 1 mg/ml

The displacement of the local minimum and maximum at the compressibility curves for test systems containing NPs (Fig. 3) and the change of their values (Table 2) confirm notable modification in the organization of the surfactant molecules at the air-liquid interface.

Table 2 – The minimum and maximum values of the compressibility of DPPC monolayer and the corresponding values of the surface pressure

Test system	κ_{min} [m/N]	π_1 [mN/m]	κ_{max} [m/N]	π_2 [mN/m]
without NPs (control)	31.5 ± 0.5	7.0 ± 0.8	114.0 ± 3.9	10.9 ± 0.1
with MC	22.7 ± 0.6	11.4 ± 0.9	62.3 ± 0.8	14.9 ± 0.1
with SMM	23.9 ± 1.1	37.4 ± 0.4	129.0 ± 6.5	41.3 ± 0.1

4. CONCLUSION

It was found that montmorillonite nanofillers alter the surface properties of DPPC monolayer under dynamic conditions related to lung behaviour during air exhalation (surface compression). These changes depend on the type of NPs and on their composition. Inhalable NPs used in the production of polymer nanocomposites may cause the disturbance of surface activity of LS. By this mechanism NPs may contribute to adverse health effects in the respiratory system of workers involved in the production process. These findings correspond to the observations from studies done with the oscillating bubble tensiometry technique [1, 2].

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