INORGANIC NANOPARTICLES ON BACTERIA: THE KEY FACTORS RULING THE INTERACTION

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Introduction

Nanoparticles (NPs) of various materials (metals and metal oxides), shapes (rods, plates, cubes, etc.) and sizes (1-100 nm) exhibit different physical and chemical properties, including adsorption of biomolecules and surface functionalization. It allows to adjust specific NPs for better NPs-bacteria interactions. The interactions between bacteria cell wall and NPs are influenced by several factors, e.g. size, charge and pH, surface functional groups, adsorbed peptides/proteins and other potential adsorbing compounds which all have an effect on the aggregation degree and the dispersion of NPs. In the literature there are usually pointed out two key factors responsible for the NP-bacteria cell wall adhesion: chemical affinity and NPs surface area [1]. There are some studies revealing size-specific affinity as NPs attached to the bacterial membrane within a narrow size distribution, e.g. for the interaction of *E. coli* with Ag NPs the optimal size is 5.4 ± 0.7 nm [2]. NPs-bacteria interaction can be obtained by surface adsorption and/or internalization, controlled by the surface charge and cell wall structure [3], because bacteria cell wall has a complex chemistry and significantly differ between Gram-positive and Gram-negative bacteria strains. Usually Gram-positive bacteria are highly negatively charged due to the exposure of teichoic acid brushes on the cell wall surface. The aim of the work was to investigate the key factors ruling the adhesion of various inorganic NPs on typical bacteria strains.

Materials and Methods

The nanoparticles of cryptomelane (KMn_8O_{16}), cobalt spinel (Co_3O_4), ceria (CeO_2) and α–hematite (Fe_2O_3) were synthesised with standard hydrothermal and/or precipitation methods. The structures of synthesised materials were characterized by Raman spectroscopy and X-ray diffraction. The shapes of NPs were determined with transmission electron microscopy and NPs size distribution with Nanoparticle Tracking Analysis (NTA). Bacterial cell surface (*S. aureus, S. maltophilia*) electric net charges were characterized by the zeta potential, which is the electrical potential of the interface between the aqueous solution and the stationary layer of fluid attached to the bacterial cell. The isoelectric point of NPs and bacteria in water suspensions were calculated based on zeta potential measurements.

Results and Discussion

It was revealed, that using different synthesis methods it is possible to obtain inorganic nanoparticles with different size and shape. The preliminary results showed that the interaction between nanoparticles of typical functional oxides (CeO_2 and Fe_2O_3) and bacteria cell walls (*S. aureus, S. maltophilia*) depends on several factors, especially the concentration of NPs and bacteria suspension, time of incubation and electric charges of microorganisms and NPs. The measured zeta potential values of ceria and investigated bacteria strains are presented in TABLE 1. The bacteria–NPs surface interactions can be interpreted in terms of mutual interactions – electrostatic (Coulomb) and dispersive (van der Waals) which provides the basis for the energetic profile in DLVO (Derjaguin–Landau–Verwey–Overbeek) theory [4]. This approach can be used for controlled deposition of nanoparticles on bacteria. The proposed model of bacteria interaction with nanoparticles surface is presented in FIG. 1 showing the main three steps in the interaction upon NPs approaching the bacteria cell surface.

TABLE 1. Energetic model of nanoparticles-bacteria interactions.

NPs/bacteria strain	ζ potential (H_2O) / mV
CeO_2	+28
S. aureus	-13
S. maltophilia	-4

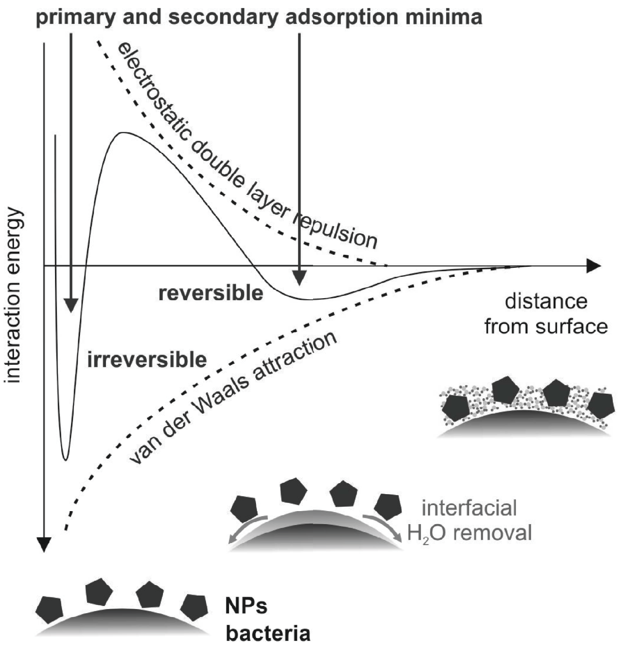

FIG. 1. Energetic model of nanoparticles-bacteria interactions.

Conclusions

It was found out that the electrostatic interactions play a key role in NPs adsorption on the bacteria surface. Specifically, positively charged nanoparticles are easily adsorbed on negatively charged bacteria cell walls. Such findings may play an important role in several applications, e.g. designing antimicrobial surfaces and biosynthesis of nanoparticles. The studies provide basis for the in–depth investigations of NPs-bacteria interactions on both levels, molecular and macroscopic.

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