

Cd Adsorption Onto Bacterial Surfaces: A Universal Adsorption Edge

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Introduction

Bacteria are present in a wide range of geologic and aquatic environments. The adsorption of aqueous metal cations onto bacterial surfaces can affect the global cycling of elements, biomineralization, heavy metal contaminant mobility in surface and ground water systems, and the effectiveness of bioremediation techniques. Surface complexation modelling can successfully quantify metal and proton binding onto bacterial surfaces, but such an approach has been tested for only two bacterial species^{1,2}. Bacteria-bearing systems can contain a wide variety of species. Surface complexation modelling of realistic systems depends on our knowledge of the thermodynamic stabilities of the surface complexes involving each bacterial species present. Here we show that a wide range of bacterial species exhibit identical Cd adsorption behaviour as a function of pH. We measure the thermodynamic stability constants for proton and Cd adsorption onto a variety of different gram positive and gram negative bacteria, and propose that metal-bacteria adsorption is not dependent on the bacterial species involved.

Materials and Methods

We conducted potentiometric titrations and Cd adsorption experiments with the gram positive bacteria *Bacillus megaterium*, *Streptococcus faecalis*, *Staphylococcus aureus*, *Sporosarcina ureae*, *Bacillus cereus* and the gram negative bacteria *Escherichia coli* and *Pseudomonas aeruginosa*. Titrations were performed in a N₂ atmosphere with 0.1 g (dry wt.) of bacteria in a 10 ml N₂ purged 0.1 M NaNO₃ electrolyte solution. The cells were titrated using an automated burette assembly with aliquots of 1.00 N NaOH titrant. Cd adsorption experiments were conducted with 10 ppm Cd and 1.0 g/L bacteria in a 0.1 M NaNO₃ electrolyte solution in contact for 2h. The extent of adsorption was determined by analysing the filtrate (0.45 µm) for dissolved Cd using an ICP-AES matrix-matched technique.

Results and Discussion

Potentiometric titration curves show that bacteria provide substantial buffering capacity over a wide pH range. We use the surface equilibrium program FITEQL 2.0 to solve for the deprotonation constants and absolute concentrations of each surface functional group type on the bacteria cell wall. A three site model is required in order to fit the data from experiments

conducted from pH 3.5 to 11, indicating that there are at least three types of proton-active surface functional groups. These functional groups likely correspond to carboxyl, phosphate, and hydroxyl sites that are displayed on the bacteria cell wall. Although the structure and chemical composition of gram positive and gram negative bacteria cell walls are not identical, the concentration and deprotonation constants for the surface functional groups show remarkable similarities. For example, our measurements indicate that the values for the first pK_a (corresponding to carboxyl functional groups) range from 4.8-5.2 and site concentrations range from 0.89-3.11 x 10⁻³ moles/gram. Cd-bacteria stability constants were determined by conducting Cd adsorption experiments as a function of pH. Aqueous metal cation adsorption is strongly pH dependent and is controlled by the surface speciation of the bacterial cell wall. We observed one common Cd adsorption edge for a wide variety of bacterial species. Our results suggest that the structures that give rise to metal and proton adsorption onto bacteria cell walls are common over a wide range of bacterial species. The calculated site concentrations, deprotonation constants and Cd adsorption constants vary slightly between the different bacterial species. However, these variations offset each other, such that, within experimental uncertainties, the different bacterial surfaces adsorb virtually identical amounts of Cd as a function of pH. The reproducibility of the Cd adsorption edge for such a wide range of bacterial species indicates that Cd adsorption experiments conducted using only a limited number of types of bacteria can be extrapolated to model Cd adsorption onto complex mixed bacterial populations. Based on the observed species-independent behaviour, we conclude that the average thermodynamic parameters and site concentrations can be used to predict Cd adsorption onto carboxyl sites for all bacterial species (or consortia) over a wide range of conditions. Therefore, our results greatly simplify the task of quantifying the effects of bacterial adsorption on mass transport in realistic geologic systems.

- [1] Fein JB, Daughney CJ, Yee N & Davis T, *Geochim. Cosmochim. Acta*, **61**, 3319-3328, (1997).
- [2] Daughney CJ, Fein JB & Yee N, *Chemical Geology*, **144**, 161-176, (1998).