

# Supplementary Materials for Adsorption of Extracellular Polymeric Substances Derived from *S. cerevisiae* to Ceria Nanoparticles and the Effects on Their Colloidal Stability

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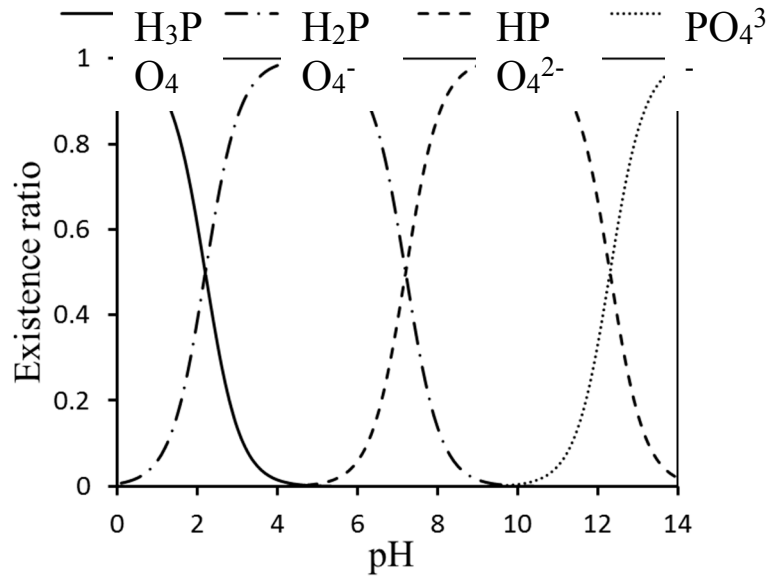


Fig. S1. Fraction of phosphate species in solution as a function of pH.

## Interpretation of particle-particle interaction by DLVO theory

The DLVO theory is a useful tool to explain the agglomeration behaviors of particles under various aqueous conditions (Derjaguin and Landau, 1941; Verwey and Overbeek, 1948). Here, the agglomeration behaviors of CeNPs are considered based on the DLVO theory. The DLVO total interaction energy ( $V_{tot}$ ) is determined by the sum of van der Waals attractive energy ( $V_{vdw}$ ) and electric double layer repulsive energy ( $V_{ele}$ ) that exist between particles as they undergo Brownian motion (Elimelech et al., 1995).

$$V_{tot} = V_{vdw} + V_{ele} \quad (S1)$$

In the case of the particle-particle interaction, the van der Waals attractive energy and electric double layer repulsive energy are expressed as the follow:

$$V_{vdw} = -\frac{A}{6D} \left( \frac{R_1 R_2}{R_1 + R_2} \right) \quad (S2)$$

$$V_{ele} = \left( \frac{R_1 R_2}{R_1 + R_2} \right) Z \exp[-\kappa D] \quad (S3)$$

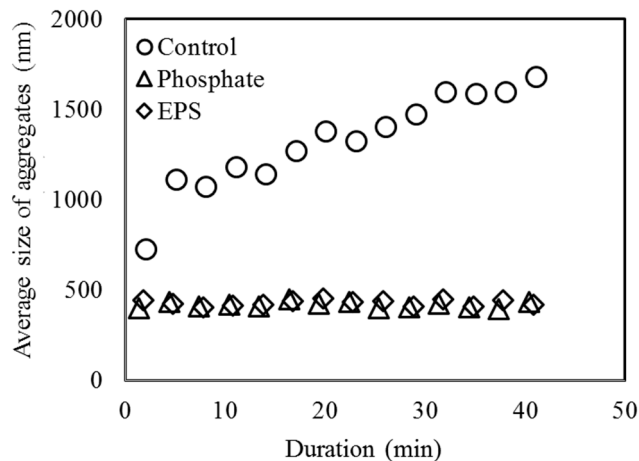
$$Z = 64\pi\epsilon_0\epsilon \left( \frac{kT}{e} \right)^2 \tanh^2 \left( \frac{ze\psi_0}{4kT} \right) \quad (S4)$$

$$\kappa^{-1} = 0.304 \times 10^{-9} / \sqrt{M} \quad (\text{in case of mono electrolyte solution}) \quad (S5)$$

A (J): Hamaker constant ( $A = 5.57 \times 10^{-20}$  in case of CeO<sub>2</sub> (Karimian and Babaluo, 2007))

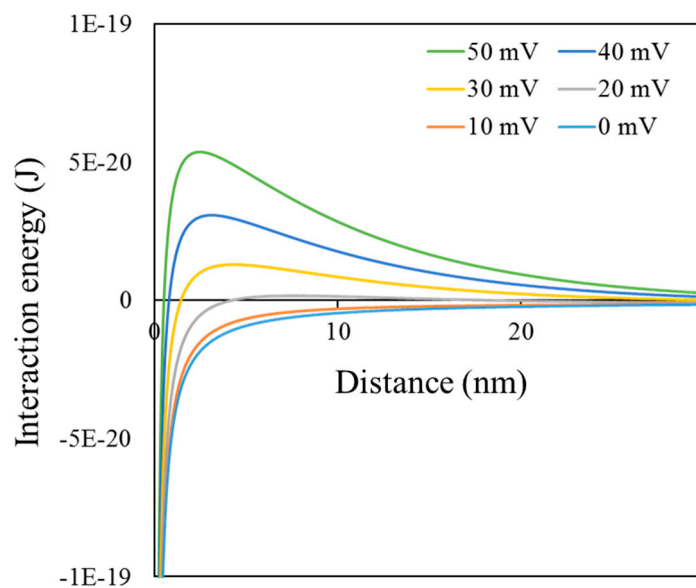
$R_1, R_2$  (m): Radius of two interacting particles

$D$  (m): Distance between surfaces of two interacting particles  
 $\kappa$  (m<sup>-1</sup>): Reciprocal of the thickness of the double layer  
 $\epsilon_0$  (C<sup>2</sup>J<sup>-1</sup>m<sup>-1</sup>): Electric permittivity in vacuum ( $\epsilon_0 = 8.854 \times 10^{-12}$ )  
 $\epsilon$ : Specific inductive capacity ( $\epsilon = 78.4$ , in water,  $T = 298$  K)  
 $k$ : Boltzmann constant ( $k = 1.381 \times 10^{-23}$ )  
 $T$  (K): Temperature ( $T = 298$  K)  
 $e$  (C): Quantum of electricity ( $e = 1.602 \times 10^{-19}$ )  
 $\Psi_0$  (mV): Surface potential  
 $M$  (mol L<sup>-1</sup>): Electrolyte concentration



**Fig. S2.** Time-dependent variation in the average size of CeNP aggregates at 100 mg L<sup>-1</sup> CeNP concentration monitored by dynamic light scattering (DLS): (○) control solution, (Δ) inorganic orthophosphate solution, and (◇) EPS solution.

Figure S3 shows the the  $V_{\text{tot}}$  plot calculated based on the equations (S1-4) in the solution with the electrolyte concentration of 0.001 mol L<sup>-1</sup>.



**Fig. S3.** Net energy of interaction for particles with various surface potentials at the constant ionic strength.