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

Shota Masaki, Yuriko Nakano, Kenta Ichiyoshi, Keisuke Kawamoto, Ayaka Takeda, Toshihiko Ohnuki, Michael F. Hochella, Jr. and Satoshi Utsunomiya

H3PO4

H2PO4-

HPO42-

PO43-

**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 Lamdau, 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).

|  |  |
| --- | --- |
| $$V\_{tot}=V\_{vdw}+V\_{ele}$$ | (S) |

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:

|  |  |
| --- | --- |
| $$V\_{vdw}=-\frac{A}{6D}\left(\frac{R\_{1}R\_{2}}{R\_{1}+R\_{2}}\right) $$ | (S) |
| $$V\_{ele}=\left(\frac{R\_{1}R\_{2}}{R\_{1}+R\_{2}}\right)Zexp\left[-κD\right] $$ | (S) |
| $$Z=64πε\_{0}ε\left(\frac{kT}{e}\right)^{2}tanh^{2}\left(\frac{zeψ\_{0}}{4kT}\right) $$ | (S) |
| $$κ^{-1}=0.304 × {10^{-9}}/{\sqrt{M}} \left(in case of mono electrolyte solution\right)$$ | (S) |

A (J): Hamaker constant (A = 5.57 × 10-20 in case of CeO2 (Karimian and Babaluo, 2007))

R1, R2 (m): Radious of two interacting particles

D (m): Distance between surfaces of two interacting particles

$κ $(m-1): Reciprocal of the thickness of the double layer

ε0 (C2J-1m-1): Electric permittivity in vacuum (ε0= 8.854 × 10-12)

ε: Specific inductive capacity (ε = 78.4, in water, T = 298 K)

k: Boltzmann constant (k = 1.381 × 10-23)

T (K): Temperature (T = 298 K)

e (C): Quantum of electricity (e = 1.602 × 10-19)

Ψ0 (mV): Surface potential

M (mol L-1): Electrolyte concentration



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

Figure S3 shows the the *V*tot plot calculated based on the equations (*S1-4*) in the solution with the electrolyte concentration of 0.001 mol L-1.



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