

Supplementary Material

The deformation of marine snow enables its disaggregation in simulated oceanic turbulence

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1 Supplementary Data

1.1 Determination of Lewis acid-base energy for sulfate polystyrene microspheres

The PS microspheres in this study were stabilized by sulfate charges, which notably changes the hydrophobic properties. Therefore, we used results from contact angle measurements to determine the Lewis acid-base energy ΔG^{AB} . For the contact angle measurement with a single liquid, we refer to the Young Dupre Equation (van Oss, 2008) that links the contact angle θ to polar surface free energy ΔG_{SL} between a solid and liquid,

$$-\Delta G_{SL} = \gamma_L \left(1 + \cos \theta \right) = 2 \left(\sqrt{\gamma_S^{LW} \gamma_L^{LW}} + \sqrt{\gamma_S^+ \gamma_L^-} + \sqrt{\gamma_S^- \gamma_L^+} \right)$$
(S.1)

where subscripts *S* or *L* represent solids or liquids, and γ_L , γ^{LW} , γ^+ and γ^- are liquid surface tension, Lifshitz-van der Waals surface energy (apolar energy), electron accepticity, and electron donicity, respectively. Researchers have also implemented contact angle measurements at fluid interfaces to predict the surface energy of materials (Maestro *et al.*, 2014; Snoeyink *et al.*, 2015). Neglecting the equilibrium spreading pressure and any absorption of components from the fluid phases, the equation for measurements at fluid interfaces (Landau and Lifshitz, 1987; Neumann et al., 2010) is given as,

$$\gamma_{p,f_1} - \gamma_{p,f_2} - \gamma_{f_1,f_2} \cos \theta = 0, \tag{S.2}$$

where f_1 and f_2 represent the lower and upper fluid phases, $\gamma_{p,f}$ is particle-fluid interfacial tension and

 γ_{f_1,f_2} is the interfacial tension between the fluid phases. The particle-fluid and the fluid-fluid interfacial tensions, $\gamma_{p,f}$ and $\gamma_{f1,f2}$, consist of apolar and polar components and are given as,

$$\gamma_{p,f} = \left(\sqrt{\gamma_p^{LW}} - \sqrt{\gamma_f^{LW}}\right)^2 + 2\left(\sqrt{\gamma_p^+ \gamma_f^+} + \sqrt{\gamma_p^- \gamma_f^-} - \sqrt{\gamma_p^+ \gamma_f^-} - \sqrt{\gamma_p^- \gamma_f^+}\right),\tag{S.3a}$$

$$\gamma_{f_1,f_2} = \left(\sqrt{\gamma_{f_1}^{LW}} - \sqrt{\gamma_{f_2}^{LW}}\right)^2 + 2\left(\sqrt{\gamma_{f_1}^+\gamma_{f_1}^-} + \sqrt{\gamma_{f_2}^+\gamma_{f_2}^-} - \sqrt{\gamma_{f_1}^+\gamma_{f_2}^-} - \sqrt{\gamma_{f_1}^-\gamma_{f_2}^+}\right).$$
(S.3b)

Van Oss (2008) mentioned at least three contact angle determinations with different liquids are required to solve for the three unknowns for solids, γ^{LW} , γ^+ , and γ^- . Maestro *et al.* (2014) measured contact angles of sulfate polystyrene latex microspheres with a mean diameter of 2.9 µm using gel trapping techniques with methanol. They observed contact angles of 76° and 120° at an air-water interface and water-octane interface, respectively. Snoeyink *et al.* (2015) applied the same technique and obtained 116° at a waterglycerol interface for sulfate PS particles with a mean size of 1.0 µm. We employed these results since our PS particles have the same surface modification and similar mean size. With the values in Table S1, we compute the γ^{LW} , γ^+ , and γ^- for sulfate PS microspheres to be 47.6, 1.34, and 15.86 mJ·m⁻², respectively. The last procedure is to calculate the polar surface energy of PS particles in water, which can follow the equation (van Oss, 2006),

$$\Delta G_{131}^{AB} = -4 \left(\sqrt{\gamma_1^+} - \sqrt{\gamma_3^+} \right) \left(\sqrt{\gamma_1^-} - \sqrt{\gamma_3^-} \right), \tag{S.4}$$

where subscripts 1 and 3 represent plastic particles and water. We obtained $\Delta G^{AB} = -16.6 \text{ mJ} \cdot \text{m}^{-2}$ for our sulfate PS microspheres.

1.2 Aggregation kinetics characterization of polystyrene and polyethylene microspheres

The salt concentrations used in this study were all high enough to effectively screen the electrostatic repulsive force component in the XDLVO analysis. More explicitly, using CaCl₂ and NaCl in our experiments with the given concentrations, the Debye lengths in Eq. (4) were smaller than one nanometer. Therefore the repulsive force was negligible regardless of the surface potential on microspheres. Fig. S1 plots the attraction interaction with the van der Waals force and Lewis acid-base force as functions of separation distance. The Lewis acid-base force rapidly diminished with the separation distance l, while the van der Waals interaction decayed at a lower rate. The larger size and stronger hydrophobicity of PE microspheres contributed to the stronger adhesive force between primary particles. In other words, detachment of two primary PE microspheres required more powerful hydrodynamic forces than PS bonds. It is noted that the assumed characteristic length scale of separation distance was on the order of 10 nm for both polymer types. The separation distance depends on the surface roughness (Li et al., 2011) and the fluid lubrication forces between particle surfaces (Davis et al., 1986) and is not trivial to determine; however 10 nm is an accepted value for similar microparticles in the literature (Gregory, 1981; Israelachvili & Tabor, 1972; Li et al., 2011; Tabor & Winterton, 1969). The attractive force between microspheres was O(10⁻¹¹ N) for PS and O(10⁻¹⁰ N) for PE at a separation distance of 10 nm.

2 Supplementary Figures and Tables

2.1 Supplementary Figures



Figure S1. Interfacial interaction forces of PS and PE microspheres during the experiment. Solid lines represent the attraction force of two material types between primary particles. Dashed lines are components of the van der Waals and Lewis acid-base forces.

2.2 Supplementary Tables

Liquids	γ_L	γ^{LW}	γ^+	γ-
Octane	21.6	21.6	0	0
Water	72.8	21.8	25.5	25.5
Glycerol	64.0	34.0	3.92	57.4

Table S1.Surface energy γ_L , γ^{LW} , γ^+ , and γ^- values for water, octane, and glycerol, in mJ/m² (van Oss, 2008).

3 Other Supplementary Materials

Supplemental Movies S1

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