Pickering Emulsions and Microcapsules Stabilized by Solid Particles and Biological Lipids

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We succeeded in preparing emulsions and microcapsules stabilized by solid particles and biological lipids. The biological lipids prevent the collapse of the microcapsules.

Solid particles are adsorbed at interfaces and form stable emulsions, called Pickering emulsions, when the particles have suitable wettability for both liquids.[1,2] In recent years, some scientists have used these emulsions as templates for microcapsules for application in drug delivery systems.[3,4] The particles were assembled and joined in the two- or three-dimensional spaces provided by emulsion droplets.[5] When the water-in-oil type emulsions are transferred to a large amount of water, the resultant structures are hollow elastic shells whose permeability and elasticity can be precisely controlled.[4] In this system, polymer binders are added to keep the ordered structures of the solid particles. For drugs and cosmetics, emulsions and microcapsules covered by biological lipids, such as phospholipids, fatty acids, or cholesterol, are more useful formulations because of their nontoxicity and compatibility with the human body.[6]

In this paper, we describe a method of preparation of stable emulsions and microcapsules consisting of solid particles and biological lipids (Figure 1). The microcapsules covered with hydrophobic mica and cholesterol were obtained through an emulsification process.[7,8] These ingredients are nontoxic and form stable water-in-oil type Pickering emulsions owing to their hydrophobic properties. Addition of thickener improved the stability of the microcapsules. The composition and surface state of the microcapsules were characterized by elemental analysis, infrared spectroscopy, and scanning electron microscopy.[9]

In a ternary system comprising hydrophobic mica, silicone oil, and water, the hydrophobic mica was adsorbed at the oil–water interface and stabilized water-in-oil type emulsions when $0 < \alpha < 0.4$ and $0.005 \leq \beta < 0.4$. Here, α and β are weight compositions, i.e., $\alpha =$ powder/(oil + powder) and $\beta =$ water/(water + oil + powder). The size of the water droplets was 60–330 μm. The emulsion state was maintained for more than 30 days; however, emulsion formation collapsed after filtration. The inner water phase drained by breaks on the surface layer of the emulsion droplets. By comparison, the emulsions stabilized by hydrophobic mica and cholesterol retained their form after filtration. For example, spherical microcapsules 100 μm in diameter were obtained when the ratio was 15:5:80 hydrophobic mica/cholesterol/water (wt/wt/wt). The surfaces of the microcapsules were covered with the plate-shaped solid particles. The results of infrared spectroscopy and elemental analysis indicated that the surface layer of the microcapsules contained about 25 wt % of cholesterol.[9] In this case, the emulsion state is more stable than that stabilized only by the solid particles, because the cholesterol wax binds the solid particles to the microcapsule surfaces. However, all the microcapsules obtained by this procedure had collapsed three days after preparation. The surface layers of the microcapsules buckled because of evaporation of the inner water phase.

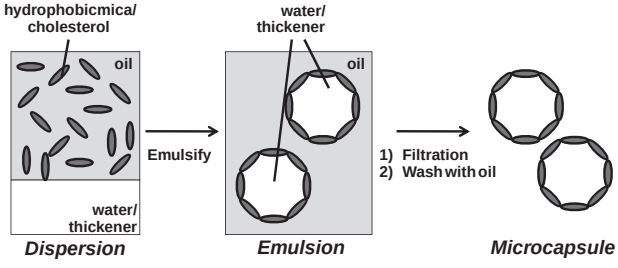

Figure 1. Schematics of the method for preparation of the microcapsules covered by solid particles and biological lipids.

Addition of thickener improved the stability of the microcapsules. The microcapsules comprising hydrophobic mica/cholesterol/thickener/water in the ratio of 15:5:14:66 (wt/wt/wt/wt) retained their forms for more than a week. Figure 2 shows the optical microscopic and scanning electron microscopic photographs of the microcapsules, which were spheres 200–800 μm in diameter and were covered with a solid shell.[8] The elemental analysis and infrared spectra indicated that the capsules contained not only hydrophobic mica particles but also cholesterol and a thickener.[9] The characteristic absorption bands (2932, 2900, 2867, and 2843 cm^{-1}) of the infrared spectra indicate the presence of cholesterol in the microcapsule, while 0.9 wt % nitrogen indicates the presence of the thickener.

Our previous theoretical study led us to expect that the plate-shaped surface-active particles are adsorbed evenly and lie flat at the oil/water interface, thus stabilizing the emulsion droplets.[10] Our assumption is supported by the present results. Microscopic observations showed that the emulsion droplets, on which the plate-shaped particles are adsorbed evenly, remained stable for more than one month after preparation. However, these droplets collapsed in filtration and the water phase was expelled. The fragility of these emulsion droplets is attributed to two factors. First, the wettability of the solid particles allows the adsorbed particles to escape the droplet surface in the filtration process because the wettability of the particle is suitable for the silicone oil/water interface, but is unsuitable for the air/water interface. The second factor is the specific gravity differences. Capillary forces between the solid particles prevent the deformation of the spherical shape of the emulsion droplets.[5] The droplets might have deformed because these forces could not sustain the pressure caused by the specific gravity difference between the water and air.

As mentioned above, the emulsion droplets containing cholesterol can be separated as microcapsules. This result indicates that addition of cholesterol strengthens the elasticity of the shell of the microcapsule or the emulsion droplets. This solid lipid connects solid particles effectively, because cholesterol forms

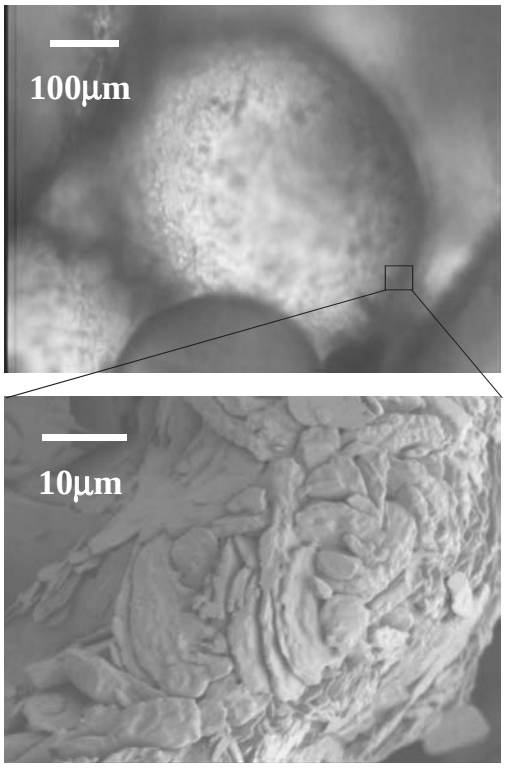

Figure 2. An optical microscopic photograph (the upper picture) and a SEM image (the lower picture) of the capsules consisting of hydrophobic mica, cholesterol, and thickener (15:5:14, wt/wt/wt).

an hydrated solid.[11] However, these microcapsules collapsed three days after preparation because of the evaporation of the water phase. Further addition of the thickener was effective in the preparation of rigid microcapsules. The spherical shape of the microcapsule was retained even after evaporation; this stability results from the mechanical strength of the inner viscous water. Noble et al. reported that the viscous core of the microcapsule supports the particle shell and gives the shell enough stiffness to be separated from the dispersion media.[12] In addition, the thickener might connect solid particles after evaporation of the inner water phase.

In summary, we report the preparation of emulsions stabilized by solid particles and cholesterol. The addition of the thickener was effective in the preparation of rigid microcapsules. We have designed and fabricated novel microcapsules that comprise a viscous water phase and shells of solid particles and cholesterol. Such microcapsules may find applications as delivery vehicles and for controlled release of drugs, cosmetics, and food supplements.

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7 Mica particles SA-KS220 treated with a silicone agent polymethylmethoxysiloxane were obtained from Miyoshi Kasei Co. The plate-shaped particles had an average particle diameter of 8 μm. Silicone oil (cyclopentane siloxane, SH245, Dow Corning Toray Co., Ltd.), cholesterol (reagent grade, Kanto Chemical Co.), and a thickener (*O*-(2-hydoroxy-3-(trimethylammonio)propyl)hydroxy cellulose chloride, POIZ C-60H, Kao Co.) were used as received.
8 The powder (1 g) and silicone oil (5 g) were stirred using a mixer (AS ONE Co. DX type) at 7000 rpm for 5 min at 298 ± 1 K. After adding 4 g of water, the mixture was stirred again under the same conditions. The microcapsules were obtained from the emulsions by a filtration procedure after washing with silicone oil. Before the emulsification process, 0.75 g of the hydrophobic mica was covered with 0.25 g of cholesterol by mixing in 3 g of chloroform and evaporating the medium. When the thickener was added to the emulsion system, POIZ C-60H powder was first dissolved in the aqueous phase.
9 Anal. Found: (microcapsules consisting of hydrophobic mica and cholesterol) C, 20.04; H, 3.345%. Calcd for mica/cholesterol = 75:25 (wt/wt): C, 20.95; H, 2.998%. Anal. Found: (microcapsules consisting of hydrophobic mica, cholesterol, and thickener) C, 33.14; H, 5.58; N, 1.57%. Calcd for mica/cholesterol/thickener = 15:5:14 (wt/wt/wt): C, 31.17; H, 5.145; N, 0.90%. IR (cm^{-1}): (microcapsules consisting of hydrophobic mica and cholesterol) 2932, 2903, 2868, and 2847. (microcapsules consisting of hydrophobic mica, cholesterol, and thickener) 2932, 2900, 2867, and 2843.
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