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Colloidal particles as liquid dispersion stabilizer: Pickering emulsions and materials thereof

Émulsions de Pickering stabilisées par des particules colloïdales et matériaux dérivés

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ABSTRACT

Solid stabilized emulsions, also referred to as Pickering emulsions, are very diverse owing to the large variety of available colloidal particles from naturally occurring to synthesized ones, from hard to very deformable ones and from spheres to more complex shaped particles. Here we illustrate this variety and, despite this huge diversity, we aim at highlighting the common features. We discuss next the remaining open questions that, in our point of view, should sustain special efforts in the future and we illustrate elaboration of original materials based on Pickering emulsions.

RÉSUMÉ

Les émulsions stabilisées par des particules colloïdales, aussi appelées émulsions de Pickering, présentent une très grande diversité résultant de la grande variété de particules actuellement disponibles. Des particules d'origine naturelle ou synthétique, des particules sphériques rigides, de formes irrégulières ou très déformables peuvent toutes stabiliser des émulsions. Nous proposons dans cet article d'illustrer cette diversité, mais aussi de mettre en exergue leurs propriétés communes. Nous identifions les questions, qui, à notre avis, restent encore sans réponse et qui mériteraient que la communauté consacre des efforts supplémentaires dans un proche futur. Nous donnons des exemples de matériaux originaux élaborés à partir d'émulsions de Pickering.

1. Introduction

Emulsions are metastable colloids made of two immiscible fluids, like oil and water, one being dispersed in the other as droplets [1]. These out-of-thermodynamic equilibrium systems are usually kinetically stabilized by surface active species. When the stabilizers are particles the emulsions are referred to as Pickering emulsions following the name of one of the

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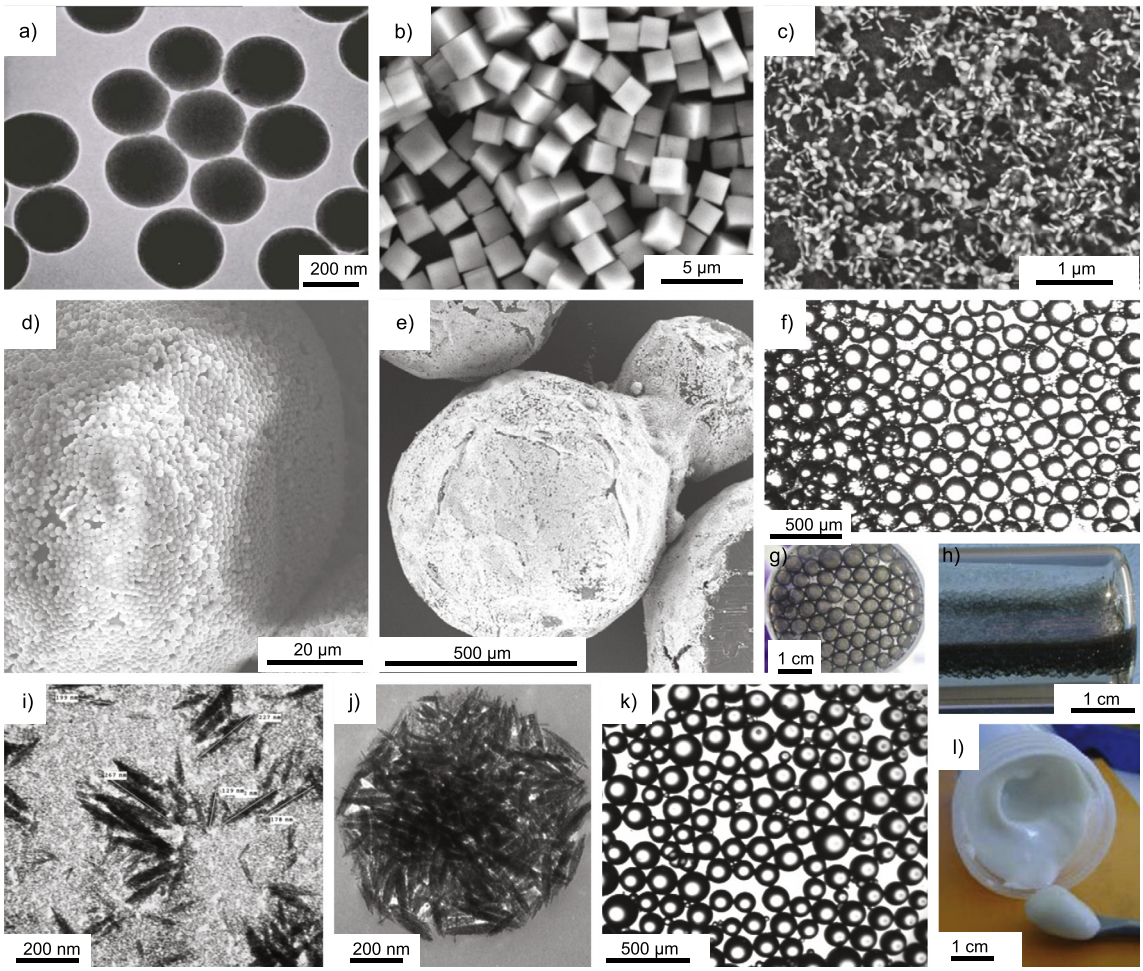

Fig. 1. (Color online.) Overview of diverse particles able to stabilize emulsions. Electronic microscopy images of (a) silica particles obtained from Stöber synthesis, image adapted from [19], (b) neighborite cubes synthesized following the synthesis described in [20], (c) peanut-like iron oxide particles using the synthesis described in [21], (d) a drop of emulsion covered by spherical silica particles like the one reported in (a), (e) a drop of emulsion covered by neighborite cubes from Fig. 1b, (f) an optical microscopy picture of an emulsion stabilized by the peanut particles, (g) macroscopic image of a water-in-dodecane emulsion stabilized by multi wall carbon nanotubes (MWCNT), (h) and (k) macroscopic and microscopic images of dodecane-in-water emulsions stabilized by oxidized MWCNT, (i) and (j) electronic microscopy images of hematites and drops stabilized thereof respectively, (i) example of an unctuous texture of a Pickering emulsion.

pioneering researchers in this field [2]. Pickering emulsions are hence known for a long time but, after the preliminary description by Ramsden [3] and Pickering, they have fallen into oblivion. They regained interest only at the end of the 1990s beginning of the 2000s, likely due to a large development of particle chemistry at that time and to a general context promoting the questioning of classical surfactant and the diversification of stabilizing agents. Then Pickering emulsions have considerably developed both in academic (about 150 publications per year in the last five years) and industrial fields; mainly in cosmetics, phytosanitary products, printing, detergency, laundry, home care, adhesives and nuclear decontamination. An exhaustive review of Pickering emulsions falls out of the scope of the present paper because, due to the very large and constantly rising amount of literature dedicated to Pickering emulsions, such a review would immediately become obsolete at publishing. The aim of the present paper is rather to discuss some of the important concepts in order to contribute to widespread the knowledge in such systems while stressing the main difficulties that should be overcome to increase both the understanding of Pickering emulsions and their use. Indeed, when employed as-made, they possess a strong potential in fields as diverse as food, cosmetics, pharmaceutics, emulsion-based catalysis while, when combined with chemistry, they offer strong insights in materials science highlighting the fields of insulation, heterogeneous catalysis, energy conversion, hydrogen storage and so forth.

2. What kind of particles?

The first necessary condition to produce Pickering emulsions is the particle double affinity for both phases: particles require to be wetted by the two liquids. In the case this condition is not fulfilled, particles will remain dispersed in either