Formation of Nano-emulsions by Low-Energy Emulsification Methods at Constant Temperature

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Formation of nano-emulsions has been studied in the system water/Brij 30/decane at 25 °C by three low-energy emulsification methods: (A) stepwise addition of oil to a water–surfactant mixture, (B) stepwise addition of water to a solution of the surfactant in oil, and (C) mixing all the components in the final composition. Nano-emulsions with average droplet size of 50 nm and high kinetic stability have been obtained only at oil weight fractions, *R*, lower than 0.3 by emulsification method B. Independent of the oil weight fraction, *R*, emulsions obtained by method B have lower polydispersity than those obtained by methods A and C. Phase behavior studies have revealed that compositions giving rise to nano-emulsions consist of W_m, (O/W microemulsion), L_α (lamellar liquid crystalline), and O (oil) phases, at equilibrium. It has been shown that equilibrium properties cannot fully explain nano-emulsion formation. Low values of equilibrium interfacial tensions and phase equilibrium involving a lamellar liquid crystalline phase are probably required but not sufficient to obtain nano-emulsions in this system. The key factor for nano-emulsion formation has been attributed to the kinetics of the emulsification process. The change in the natural curvature of the surfactant during the emulsification process may play a major role in achieving emulsions with small droplet size.

Introduction

Emulsions, colloidal dispersions of at least two immiscible liquids, are nonequilibrium systems.[1–3] Consequently, they are not formed spontaneously and their properties depend not only on thermodynamic conditions (i.e., composition, temperature, or pressure) but on preparation methods and the order of addition of the components.[4–6] The structure of emulsions consists of droplets of the dispersed (or internal) phase in the continuous (or external) phase. Simple emulsions are classified as water-in-oil (W/O) or oil-in-water (O/W) depending on which phase constitutes the disperse phase. Generally, emulsion droplet size lies in the micrometer range, a size range in which droplets are attracted by gravity forces. An important aspect in the preparation of emulsions from both fundamental and technological viewpoints is to obtain a desired droplet size and a narrow size distribution.[1–5,7,8]

Microemulsions, on the other hand, are equilibrium structures distinctly different from emulsions.[9–11] They form spontaneously (their properties are independent of the order of addition of the components) and show a wider structural variety than emulsions.[12–14] Although microemulsions are advantageous over emulsions from a formulation point of view, the relatively high surfactant concentration required for their formation limits their widespread use in practical applications.[15,16]

In recent years, attention has been focused on emulsions with submicrometer droplet size, that is with sizes between those of conventional emulsions and microemulsions. These emulsions have been termed miniemulsions,[7,17] nano-emulsions,[18,19] fine-disperse emulsions,[20] submicron emulsions,[21] unstable microemulsions,[22] translucent emul-

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