Sujet de thèse de l'école doctorale de chimie de Lyon

Title : Modelling the preparation and the stability of double emulsions

Titre : *Modélisation de l'élaboration et de la stabilité des émulsions doubles*

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Summary:

Double emulsions consist of small droplets of one fluid suspended in larger droplets of another immiscible fluid. They are widely spread in food, cosmetic, pharmaceutical and chemical industries. The final product quality in these applications is determined by the size of micro- (i.e. internal) and macro- (i.e. external) droplets as well as the encapsulation efficiency of the internal phase. They are usually prepared by two steps[1]. The first step consists of preparing a primary emulsion where the internal phase is dispersed into the intermediate phase under high shear energy to form small micro-droplets. In the second step, the primary emulsion is dispersed into a continuous external phase to form the macro-droplets. During this second preparation step, different phenomena may occur, including macro-droplet breakage and coalescence, escape of micro-droplets, swelling or shrinkage, and over-swelling leading to macro-droplet explosion[2–7]. These phenomena are governed by physico-chemical parameters as well as the energy dissipation by the emulsification device. These conditions need to be optimized in order to maximize the encapsulation rate and ensure a longer physical stability of the double emulsion.

The first objective of this project is to investigate double emulsion preparation using different emulsification devices, such as impeller-stirred tanks, Ultra-Turrax rotor-stator and static mixers and to develop models to describe the evolution of the internal and external droplet size distributions as well as the release rate of solutes from inner droplets or of entire micro-droplets to the external continuous phase as a function of the operating conditions, including the energy dissipation, emulsifiers, the amount of salt (and its effect on the surfactant and on the release rate), the viscosity ratio between the internal and external phases and the volume fractions of both phases. Two population balances will be developed to describe the droplet size distribution of the micro- (so internal) and macro-droplets (external) that will include the different phenomena affecting the droplet size (mainly breakage, coalescence, release of micro-droplets). Besides, these balances will be combined to a model describing the release rate (mainly due to leakage of micro-droplets, while accounting for surface tension and osmotic pressure). The predictions of the model in terms of droplet size distributions, water and salt uptakes by double emulsion droplets will be validated by comparison to experimental results. The relative contributions of different phenomena (breakage, coalescence events, osmotic swelling) will be varied by changing the composition of the emulsions (viscosity of oil, internal water content, salt concentration type and amount of emulsifiers). The outcome of modeling is a disclosure of the most relevant parameters pertaining to the emulsification process and the formulation, such that advantages and limitations of the each can be highlighted.

The second objective of this project is to monitor the release rate and the droplet size during storage of these emulsions. During storage, changes in the size are due to swelling, coalescence, over-swelling leading to droplet explosion as well as diffusion of internal droplets, while the release mechanism is governed by diffusion. These tasks will be supported by experimental measurements of the droplet size by granulometry, the release of salt by conductivity, online *in situ* measurements

of the droplet size by video probe as well as observations by microscopy. A high speed camera will be used to observe individual droplets to identify breakage and coalescence events of individual macrodroplets and eventually the leakage of microdroplets. The simulations will be done in Matlab®.

As a final aim of this project, the change of phase of the encapsulating matrix will be considered. In pharmaceutical applications, the oil phase is made of a biocompatible polymer dissolved in an organic solvent to prepare double emulsions. During a second step, the solvent diffuses out of the globule which leads to the precipitation of the polymer as a "membrane" separating to aqueous compartments. Therefore, it becomes necessary to account for supplementary phenomena related to solvent extraction as well as phase changes from liquid to solid in the oil phase in the diffusion model.

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