One-step preparation method of multiple emulsions entrapping reactive agent in the liquid–liquid Couette–Taylor flow

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ABSTRACT
The paper presents a method of multiple emulsions entrapping active agent preparation and stabilization by one-step process in the continuous liquid–liquid Couette–Taylor flow (CTF) contactor. The active agent is a component of the internal phase of multiple emulsions. The CTF flow contactor is characterized by high mass transfer parameters and represents an attractive tool for the multiphase systems. The results showed significant influence of the rotational flow in the CTF contactor on stability and characteristics of multiple emulsions. During the experiments stable O/W/O emulsions have been obtained. The internal droplets have mean size of 5–10 μm and drops of membrane phase: 30–40 μm. The microcapsules of an average diameter about 30 μm were obtained after multiple emulsion chemical stabilization by cross-linking and thermal hardening.

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1. Introduction
Since the multiple emulsions have been discovered a great progress in their uses and applications in the multidisciplinary research areas and in the industry is observed. Controlled reactive agents (drugs, cosmetics and pharmaceutical agents) delivery system is one of these areas. Multiple emulsions are composed at least of three phases of an inner and outer phases separated by a dispersed phase. Three phase emulsions are denoted as O/W/O (oil-in-water-in-oil: water outer-oily globules dispersed-inner water microglobules) and W/O/W (water-in-oil-in-water: oily outer-water globules dispersed-inner oily microglobules). The commonly used techniques for preparing multiple emulsions are: mechanical agitation, phase inversion and two-stage emulsification. Multiple emulsions of type W/O/W or O/W/O are generally prepared using, a two-step procedure. For W/O/W or O/W/O emulsions, the primary emulsion (W/O) or (O/W) is first prepared using water and a low-HLB hydrophilic-lipophilic balance surfactant solution in oil or an oil and an aqueous solution of a high-HLB surfactant. In the second step, the primary emulsion (W/O) or (O/W) is re-emulsified in an aqueous solution of a high-HLB surfactant to produce a W/O/W multiple emulsion or in a low-HLB surfactant solution in oil for O/W/O emulsions type. The first step that is, the preparation of the primary emulsion is usually carried out in a high-shear device to produce very fine droplets. The second emulsification step is carried out in a low-shear device to avoid rupturing the multiple droplets. The stability of multiple emulsions besides their drop size distribution and rheological properties depend on different concentrations of surfactants as well as preparation technique. This work proposes one-step emulsification process in the liquid–liquid Couette–Taylor flow (CTF). The CTF occurs in an annular space between two cylinders, one inner or outer is rotating. This is a steady-state flow consisting of the axial Poiseuille flow and the rotating Couette flow, respectively, with axisymmetric Taylor vortices. The CTF flow, also called helical one, is a rare flow variation combining intense local mixing with a limited axial dispersion due to hydrodynamic flow instability (vortices) taking place in the CTF reactor. Problems of mixing and dispersion effects have been presented in the papers [1–5]. The CTF is characterized by the following features:

• The high values of the heat and mass transfer coefficients at the outer cylindrical shell.
• The low value of the axial dispersion with respect to the radial dispersion when compared to the other types of equipment.
• A constant gas substrate concentration along the whole tubular length of the reactor when it operates as a membrane reactor.
• The independence of the residence time from the mixing intensity.

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