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Research Article

Investigation of spherical and concentric mechanism of compound droplets

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Abstract

Polymer shells with high sphericity and uniform wall thickness are always needed in the inertial confined fusion (ICF) experiments. Driven by the need to control the shape of water-in-oil (W1/O) compound droplets, the effects of the density matching level, the interfacial tension and the rotation speed of the continuing fluid field on the sphericity and wall thickness uniformity of the resulting polymer shells were investigated and the spherical and concentric mechanisms were also discussed. The centering of W1/O compound droplets, the location and movement of W1/O compound droplets in the external phase (W2) were significantly affected by the density matching level of the key stage and the rotation speed of the continuing fluid field. Therefore, by optimizing the density matching level and rotation speed, the batch yield of polystyrene (PS) shells with high sphericity and uniform wall thickness increased. Moreover, the sphericity also increased by raising the oil/water (O/W2) interfacial tension, which drove a droplet to be spherical. The experimental results show that the spherical driving force is from the interfacial tension affected by the two relative phases, while the concentric driving force, as a resultant force, is not only affected by the three phases, but also by the continuing fluid field. The understanding of spherical and concentric mechanism can provide some guidance for preparing polymer shells with high sphericity and uniform wall thickness.

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Keywords: Compound droplet stability; Compound droplet deformation; Sphericity; Wall thickness uniformity; Interfacial tension; Density matching

1. Introduction

In recent years, laser inertial confined fusion (LICF), one of the most promising methods to control the reaction of nuclear fusion, has attracted a great deal of interest due to its cleanness and efficiency [1]. In LICF experiments, several kinds of polymer shells such as polystyrene (PS), deuterated PS, poly(α-methylstyrene) (PAMS) and divinylbenzene (DVB) foam shells can be used for preparing LICF targets [2–4]. It has been reported that the shape and symmetry of these polymer shells, specifically, the sphericity and wall thickness uniformity are important to the symmetry and hydrodynamic stability in implosions, thus there are stringent specifications on the sphericity and wall thickness uniformity of these shells [5,6].

Generally, these shells are prepared by the microencapsulation technique, as shown in Fig. 1, in which compound droplets with a W1/O or O1/W structure are formed firstly, and

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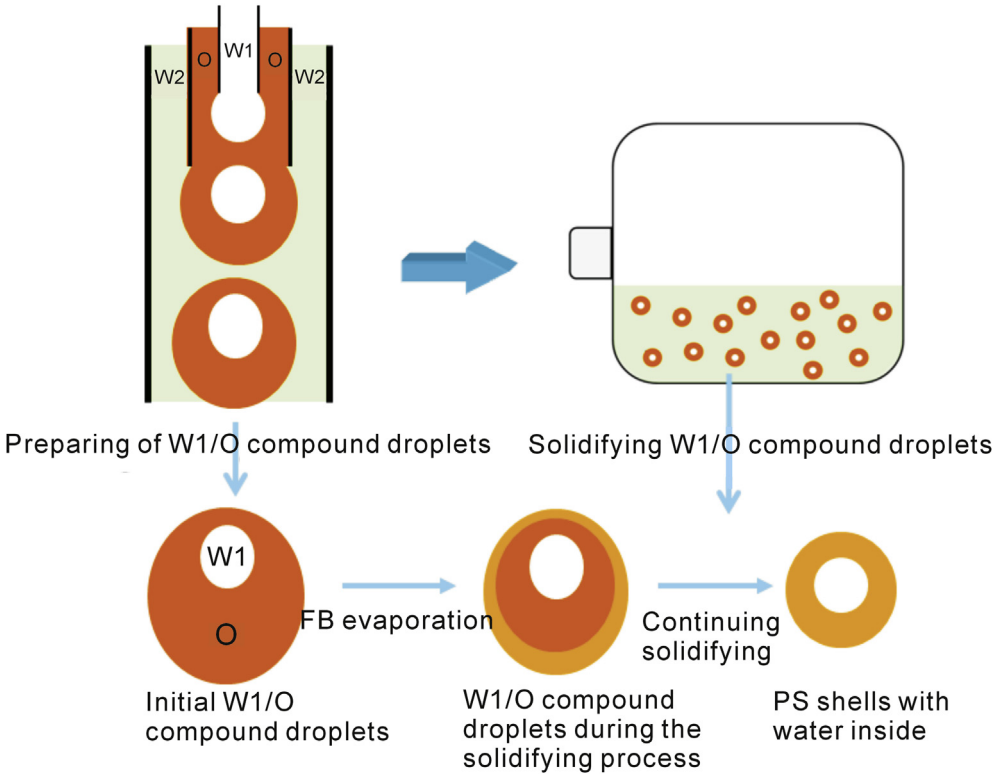

Fig. 1. Schematic of preparing PS shells.

then the solvent in the middle phase is removed by evaporation during solidifying process. Obviously, the key constraint in the sphericity and uniform wall thickness of the shells in turn requires a spherical and centered core compound droplet before its solidifying [7,8]. An initial compound droplet generated by a triple orifice droplet generator is not a perfect spherical drop and the inner phase is not in the center of the middle phase. Due to gravitational force, drag force and so on, the non-spherical and eccentric phenomenon probably becomes worse during the solidifying process. By increasing the wall thickness, both the deformation of the O phase and the moving space of the inner phase increase, thus it becomes more difficult to make a thick-walled compound droplet be spherical and concentric.

Over the past two decades, in order to obtain polymer shells with high sphericity and uniform wall thickness, a lot of research work has been done to control the deformation of droplets. It is found that there are many factors, such as the interfacial tension, density and viscosity, influencing the deformation of droplets [9–12]. For a droplet without inner phase, a simple theory of Taylor shows that the deformation (δ) is [13]:

$$\delta = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}} = \frac{19\lambda + 16}{16\lambda + 16} C_a. \tag{1}$$

where λ is the ratio of the droplet viscosity to the continuous phase viscosity, C_a is the so-called capillary number, defined as

$$C_a = \frac{\eta_c v r}{\gamma} \tag{2}$$

where η_c is the viscosity of the continuous fluid phase, v is the applied shear-rate, r is the undeformed droplet radius, and γ is the interfacial tension of the interface.

Moreover, Cook et al. estimated that the maximum out-of-roundness (δ_{MOOR}) of a drop without inner phase in a continuous phase is related to physical properties such as the density matching level, interfacial tension and viscosity, *i.e.* [9],

$$\delta_{MOOR} = \frac{5 g r^3 \Delta\rho}{4\gamma}, \tag{3}$$

where g is the acceleration of gravity (9.8 $m \cdot s^{-2}$) and $\Delta\rho$ is the density difference between the droplet and the continuous fluid phase.

$$\delta_{MOOR} \cong \frac{8\eta_c v r^2}{\gamma}. \tag{4}$$

For W1/O compound droplet, there are three phases and two interfaces, the structure of which is more complicated than that of a droplet without inner phase. Moreover, the W1 phase can move randomly in the O phase in the initial range of the solidifying process. Therefore, it is difficult to control the shape of compound droplets. It is reported that the physical properties of the W1, O and W2 phases such as their density and viscosity, and the properties of the interfacial film such as the interfacial tension, interfacial film strength and interfacial

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