Microfluid Nanofluid
DOI 10.1007/s10404-013-1259-9

RESEARCH PAPER

Simultaneous visualization of the flow inside and around droplets generated in microchannels

Manuela R. Duxenneuner · Peter Fischer · Erich J. Windhab · Justin J. Cooper-White

Received: 5 March 2013 / Accepted: 22 August 2013

Abstract This paper reports the visualization of droplet formation in co-flowing microfluidic devices using food-grade aqueous biopolymer–surfactant solutions as the dispersed droplet phase and sunflower oil as the continuous phase. Microparticle image velocimetry and streak imaging techniques are utilized to simultaneously recover the velocity profiles both within and around the dispersed phase during droplet formation and detachment. Different breakup mechanisms are found for Newtonian–Newtonian and non-Newtonian–Newtonian model water-in-oil emulsions, emphasizing the influence of process and material parameters such as the flow rates of both phases, interfacial tension, and the elastic properties of the non-Newtonian droplet phase on the droplet formation detachment dynamics.

Keywords Microparticle image velocimetry · Co-flow geometry · Droplet generation · Viscoelasticity · Fluid elasticity · Internal flow

1 Introduction

Particle image velocimetry techniques (PIV) have been used to study flow situation in numerous multiphase systems such as droplet dispersing, droplet evaporation, spraying, bubble flow beside, others (Raffel et al. 1998). PIV is also commonly applied to understanding complex flow behavior in different geometries under various conditions, often in combination with computational fluid dynamics.

Microfluidics utilize micrometer scaled laboratory on a chip devices to investigate the flow behavior in small fluid volumes and fluids under spatial confinement. Flow in microchannels is typically laminar and at low Reynolds numbers, since the magnitude of surface and viscous forces dominate inertial and gravity forces. Microfluidic devices are used widely for fluid dynamical investigations (Nghe et al. 2011; Schoch et al. 2008; Seemann et al. 2012; Squires and Quake 2005; Tice et al. 2003; Woerner 2012; Shui et al. 2007), cell screening and diagnostics (Auroux et al. 2002; Franke and Wixforth 2008; Haeberle and Zengerle 2007; Mark et al. 2010; Mu et al. 2013; Qi et al. 2012; Takinoue and Takeuchi 2011; Yeo et al. 2011; Gijs et al. 2010), single-molecule investigations (Dutse and Yusof 2011; Haenggi and Marchesoni 2009; Mai et al. 2012; van der Graaf et al. 2005), and templating minireactors in, e.g., biotechnology (Marques and Fernandes 2011; Song et al. 2006; Teh et al. 2008).

The simultaneous visualization of the flow behavior during the formation or deformation of droplets, either at the liquid–liquid boundaries or within in both fluid phases, has only be addressed recently, mostly due to the inherent three-dimensionality of the flow. However, the flow patterns inside a rising, falling, or static drop in a quiescent second liquid or into air was studied macroscopically by, e.g., (Horton et al. 1965; Hetsroni et al. 1970; Liu and Zheng 2006; Spells 1952; Hudson 2010). The emphasis of these works was mostly on understanding of the effect of the droplet's internal circulation on mass transfer rates

M. R. Duxenneuner · P. Fischer (✉) · E. J. Windhab
Institute of Food, Nutrition and Health, ETH Zurich, 8092 Zürich, Switzerland
e-mail: peter.fischer@hest.ethz.ch

M. R. Duxenneuner · J. J. Cooper-White (✉)
Laboratory of Tissue Engineering and Microfluidics, Australian Institute for Bioengineering and Nanotechnology, The University of Queensland, St Lucia, Brisbane, QLD 4072, Australia
e-mail: j.cooperwhite@uq.edu.au

Published online: 14 September 2013