Chemical Engineering Science 63 (2008) 3560–3563

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Shorter Communication

A novel Hele-Shaw cell design for the analysis of hydrodynamic instabilities in liquid–liquid systems

Ying Shi[a], Kerstin Eckert[b,*]

[a]State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, 710049 Xi'an, PR China
[b]Institute for Aerospace Engineering, Technische Universität Dresden, D-01062 Dresden, Germany

ARTICLE INFO

Article history:
Received 14 December 2007
Received in revised form 4 March 2008
Accepted 3 April 2008
Available online 9 April 2008

Keywords:
Fluid dynamics
Interface
Chemical reactors
Laminar flow
Transport processes

ABSTRACT

A novel Hele-Shaw cell design for accurate experiments in liquid–liquid systems with and without chemical reactions is hereby presented. It allows the formation of a stably pinned, plane liquid–liquid interface in less than one second with a minimum shear flow. The underlying working principle and the performance for different solvent systems and gap widths are discussed.

The analysis of hydrodynamic instabilities strongly benefits from well-chosen limit cases. One of them is the quasi-two-dimensional setup, provided by a pair of transparent glass plates separated by a small gap, *b*, first introduced by Hele-Shaw (1898). Since the pioneering work of Saffman and Taylor (1958) the Hele-Shaw cell is an accepted setup to study interfacial pattern formation during viscous fingering.

To apply the Hele-Shaw cell efficiently to liquid–liquid systems, an elegant solution for the superposition of both liquids with a minimum of flow-induced perturbations and a controlled interface position is mandatory. Several approaches have been discussed in the literature. The simplest one is the injection of both phases (Takahashi et al., 2002) using a syringe. Since the mass transfer is most advanced at the place of injection, an inhomogeneous onset of convection occurs. Furthermore, it leads to a deformation of the interface due to the momentum of the injected liquid. To avoid the interfacial deformation and a dispersion of one phase into the other, a separation of both phases by means of a slide was undertaken in Bakker et al. (1966), Berg and Haselberger (1971) and Brückner (1991). Since the removal of the slide to start the experiment takes at least 5 s (Berg and Haselberger, 1971), the problem remains of an imposed concentration gradient along the interface. Due to the shear flow, created by the motion of the slide, a further delay of at least 15 s (Bakker et al., 1966) has to be accounted for until the system is in an unperturbed state. An alternative to the moving slide is a step (Berg and Morig, 1969) formed inside the sealing material. The upper phase was directed onto this step from which it spread out onto the surface of the lower phase. Finally, we refer to a Hele-Shaw cell setup (Fernandez et al., 2002), successfully applied to the study of density fingering. It integrates two flow channels into which both miscible fluids are injected at identical flow rates.

The setups mentioned so far are not suited for systems with chemical reactions, especially when they occur at the interface. The necessary tight separation between the phases excludes a moving slide for technical reasons. Furthermore, the reaction starts to a considerable extent before filling is completed.

For that reason a novel concept is proposed. The new Hele-Shaw cell, abbreviated as IHSC (integrated Hele-Shaw cell), ensures (i) precise control of the interface positions via pinning at sharp edges, (ii) formation of a plane liquid–liquid interface within a short time interval and (iii) with a minimum of shear flow. The concept was originally developed for a microgravity project (Maser 10). Here a rapid filling of the HS cells was required to have most of the microgravity time (6 min) available for the experiment itself.

The IHSC layout is shown in Fig. 1. The two glass plates of the HS cell are made of borofloat glass in optical quality with the dimensions 96 mm × 55 mm × 8 mm. The upper plate contains four bores for injection and exhaust ports as detailed later on. Each glass plate is placed on a Viton-O-ring located in a groove of an aluminum frame. The gap between the glass plates is formed by a PTFE foil, see Fig. 2.

---

* Corresponding author.
E-mail address: Kerstin.Eckert@tu-dresden.de (K. Eckert).

0009-2509/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2008.04.013

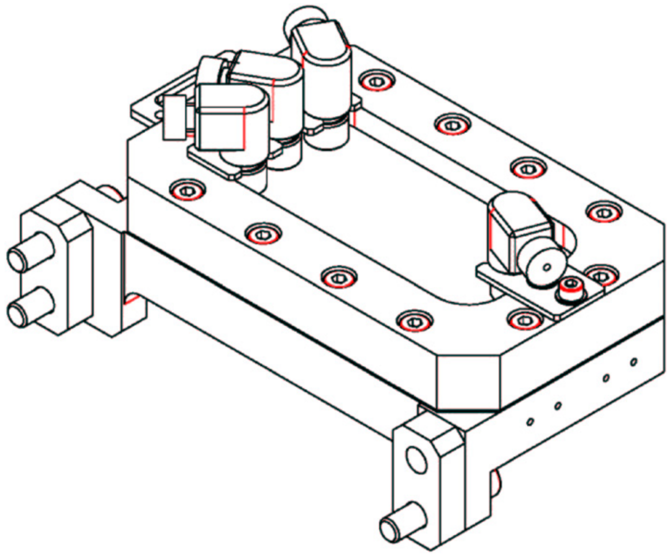

Fig. 1. The IHSC design. The PTFE connectors (three for the organic side, one for the aqueous one) are visible on top.

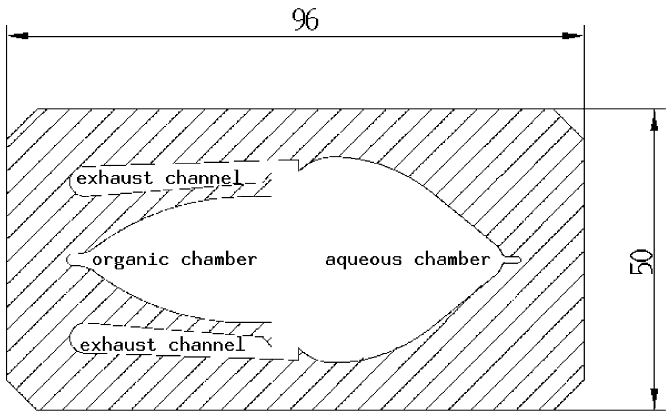

Fig. 2. Design of the PTFE sheet.

PTFE is chemically inert and is used in thicknesses between 0.25 and 2 mm. The PTFE foil not only acts as a spacer and sealant but also accommodates the two liquid chambers. After adjusting the PTFE foil, both half frames of the IHSC are screwed together in a crosswise manner.

Finally, four L-shaped PTFE connectors (manufactured by DTM/Modena, Italy) are tightly pressed into the four bores of the upper glass. They contain a female thread into which the corresponding PTFE tube end fitting (Bohlender, Germany) with a male thread is screwed. The connectors guide the liquid via an internal cylindrical channel (0.8 mm diameter) to the inlet ports of the PTFE sheet having the same diameter. From there two conical liquid chambers extend to either side to avoid the entrainment of air bubbles.

The aqueous phase is filled first until its interface is pinned on the two tips to form a plane interface (Fig. 3a). Then, the organic phase is manoeuvered forward so that a more and more convex meniscus shape is formed (Fig. 3b). As soon as the apsis of the organic meniscus touches the aqueous phase, a spontaneous spreading of the organic phase above the aqueous one sets in (Fig. 3c). This spreading is sustained by further injection until the liquid enters sufficiently far into the exhaust channels (Fig. 3d). Then, the valves of the exhausts are closed to prevent evaporation and a further spreading of the organics in the PTFE tubes.

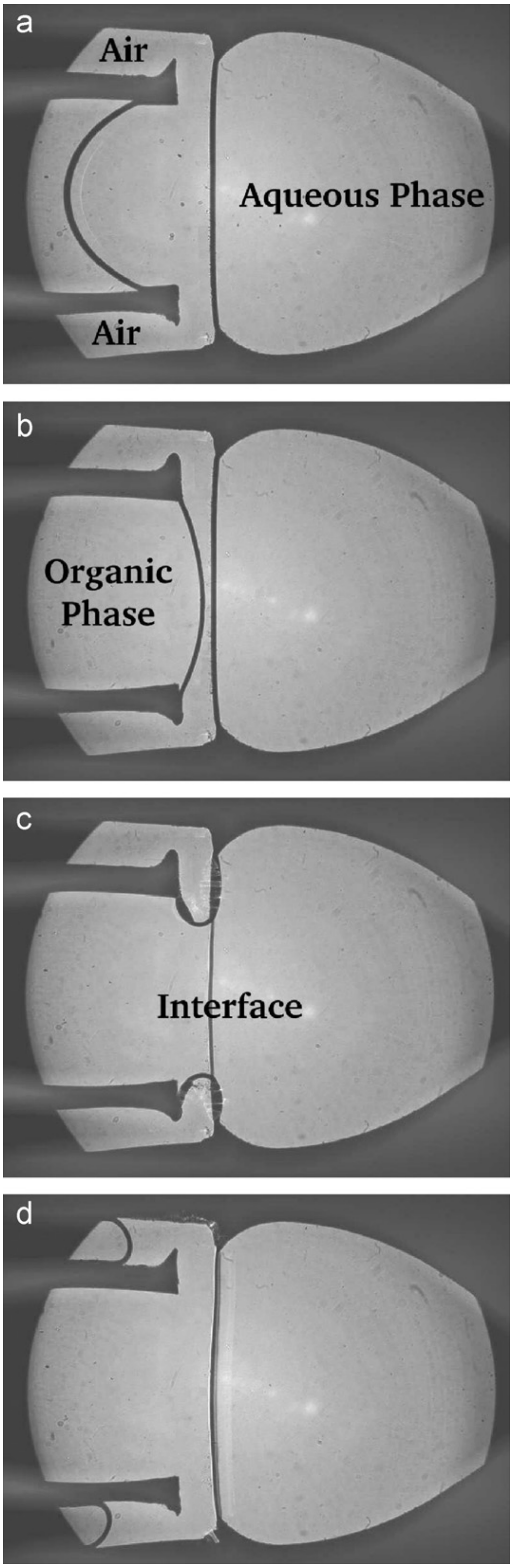

Fig. 3. The IHSC filling process (see text). The chemical system is that of Shi and Eckert (2006).

The critical part of the filling which is the formation of the interface can be achieved via spreading in less than 0.5 s. This is the fastest way of all existing concepts to bring both liquids into contact. It runs spontaneously since the system can decrease its free surface