Vortex-induced mixing at 3-phase contact line

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Although the motion of the three-phase contact line on a solid substrate has been extensively studied thus far, the understanding of the dynamics of the contact line of liquid/liquid/gas phases is far from complete. Here we deposit a drop of isopropyl alcohol (IPA) on water whose free surface is exposed to air to observe the flow field around the contact line. By combining the shadowgraph and high-speed imaging techniques, we find that vortices are spontaneously generated at the contact line, which grow in size with time. The flow is attributed to the Marangoni stress that pulls a liquid of lower-surface tension (IPA) toward water surface having a higher surface tension. However, it is not still clear why the entrained lower-surface-tension liquid should whirl rapidly beneath the contact line. We also visualize the flow by the particle image velocimetry (PIV) to find out that the rotational velocity reaches the maximum of 5 cm/s near the free surface.

Key Words vortex, mixing, 3-phase contact line.

Introduction

Mixing of two liquids confined within a small volume is an important issuein many emerging technologies, such as lab-on-a-chip systems, semiconductor cleaning and polymer processing. Despite intensive studies on the mixing of liquids in microscales, most of them are focused oneither passive mixersaiming to enhance the mixing efficiency by changing structures of channel [1] or active mixers which use mechanically moving parts at the expense of external energy [2]. Here we report novel vortex generation mechanism that can achieve efficient mixing of two overlapping liquids without resorting to external energy input.

Experiments

We use dyedisopropyl alcohol (IPA) emitting from a micro-nozzle to generate a liquid drop whose diameter is 2.7 mm. The liquid drop falls due to gravity from the nozzle and then impacts on a horizontal surface with a thin film of deionized water. The mixing process between IPA and DI water is recorded by a high-speed camera at 500 frames per second. In this step, we could observe rapid fluid motion near a contact line where the three phases of liquid/liquid/gas meet.To scrutinizethe detailed flows near the contact line,we use a shadowgraph technique along with high-speed camera to visualize the interfacial flows and also a particle image velocimetry (PIV) to quantify the fluid motion.

Results

When a isopropyl alcohol drop (IPA) impacts onto a horizontal water film, band-shaped mixing zones develop at the 3-phase contact line where the three phases of liquid/liquid/gas meet and the mixing zones propagate radially.Figure 1 shows that motions of eddy help to promote the effective mixing between two liquids.

To figure out how the vortices are generated and evolve with time, we use the shadowgraph and high-speed imaging techniques. As shown in Fig. 2(a), the vortices are generated at the 3-phases contact line and propagateinto a direction of the outer pure water region. This flow is attributed tothe unbalanced forcescaused by IPA/water, IPA/gas and water/gas interfacial tension.Sine the surface tension of the water is larger than that of IPA, the flow is drawn in to the water, which determines the rotating direction of the vortex. We also visualize the flow field in the water using a PIV technique as shown in Fig. 2(b).

References

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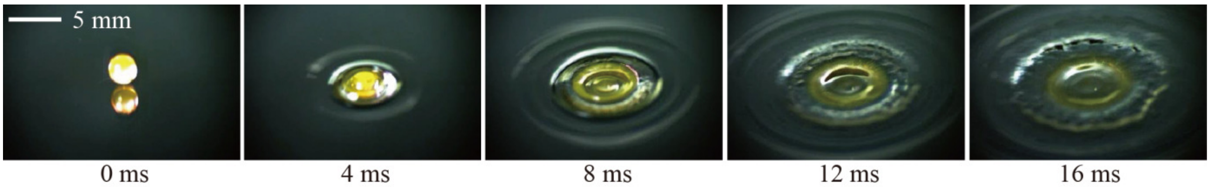

Figure1.Initial stage of mixing between water film and an isopropyl alcohol (IPA) drop.

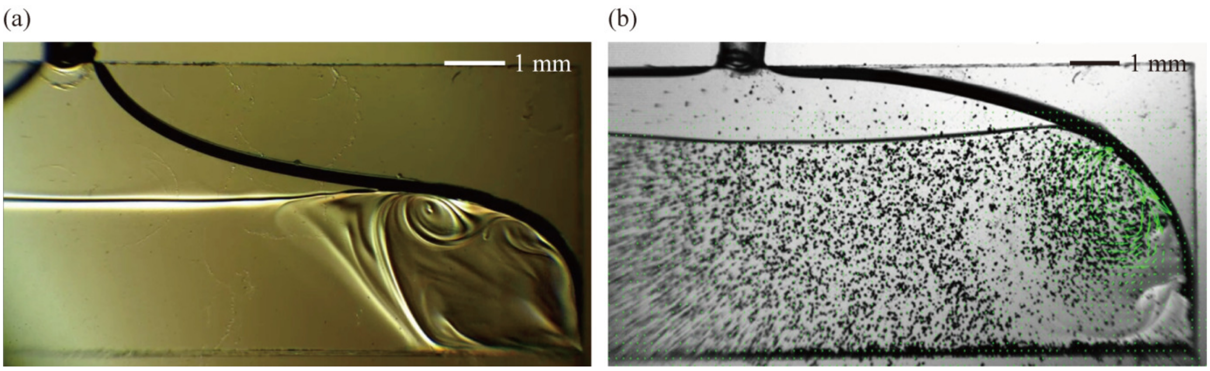

Figure2.Different visualization methods of vortex induced at 3-phase contact line. (a)Shadowgraph method; (b) Particle image velocimetry (PIV).