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RESEARCH PAPER

Pinch-off mechanism for Taylor bubble formation in a microfluidic flow-focusing device

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Abstract The present work aims at studying the nonlinear breakup mechanism for Taylor bubble formation in a microfluidic flow-focusing device by using a high-speed digital camera. Experiments were carried out in a square microchannel with cross section of 600 × 600 μm. During the nonlinear collapse process, the variation of the minimum radius of bubble neck (r_0) with the remaining time until pinch-off (τ) can be scaled by a power–law relationship: $r_0 \propto \tau^{\alpha}$. Due to the interface rearrangement around the neck, the nonlinear collapse process can be divided into two distinct stages: liquid squeezing collapse stage and free pinch-off stage. In the liquid squeezing collapse stage, the neck collapses under the constriction of the liquid flow and the exponent α approaches to 0.33 with the increase in the liquid flow rate Q_1. In the free pinch-off stage, the value of α is close to the theoretical value of 0.50 derived from the Rayleigh–Plesset equation and is independent of Q_1.

Keywords Microfluidics · Multiphase flow · Nonlinear dynamics · Interface · Confinement · Pinch-off

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List of symbols

p	Capillary pressure, Pa
Q_1	Liquid volumetric flow rate, mL h^{-1}
Q_g	Gas volumetric flow rate, mL h^{-1}
Q_F	Liquid volumetric flow rate through the flow-focusing region, mL h^{-1}
Q_N	Liquid volumetric flow rate calculated from the pictures, mL h^{-1}
r	Radius of the bubble neck, μm
r_0	Minimum radial radius of the neck, μm
r_c	Minimum axial radius of the neck, μm
t	Neck collapse time, μs
t_c	Moment of bubble pinch-off, μs
t_{cap}	Capillary time, μs
V_N	Volume of the neck, mL
w_b	Width of the bubble neck, μm
w_d	Depth of the channel, μm

Greek letters

α	Exponent for radial curvature
β	Exponent for axial curvature
λ	Slenderness of the neck (r_c/r_0)
η	Viscosity, m Pa s
ρ	Density, kg m^{-3}
σ	Surface tension, m N m^{-1}
τ	Remaining time to pinch-off, μs

Dimensionless groups

Ca	Capillary number ($u\eta_1/\sigma$)
Re	Reynold number ($\rho_1 r_0 r_0'/\eta_1$)
We	Weber number ($\rho r_0 (r_0')^2/\sigma$)

Subscripts

c	Critical time for bubble pinch-off
cap	Capillary time
F	Flow-focusing region