Scaling of jetting from bubble collapse at a liquid surface

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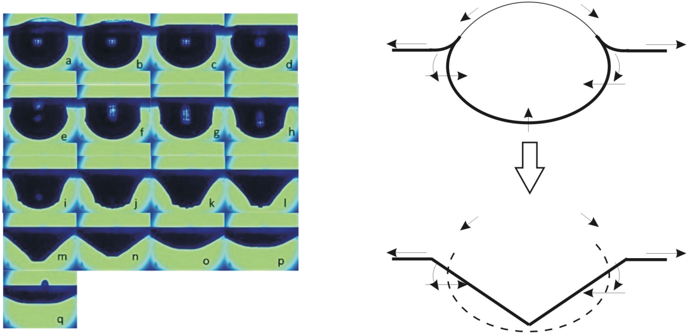
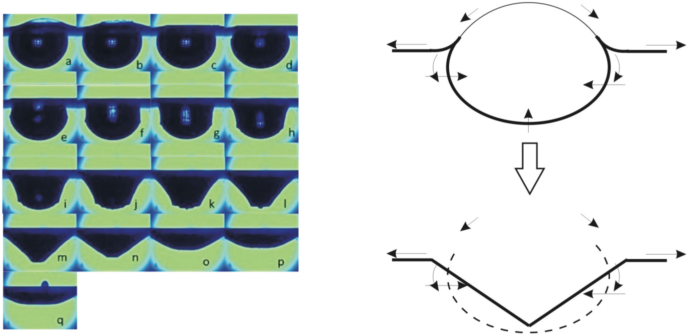


(a) Bursting sequence of 2.15mm air bubble in water (b) Schematic of the collapse motions



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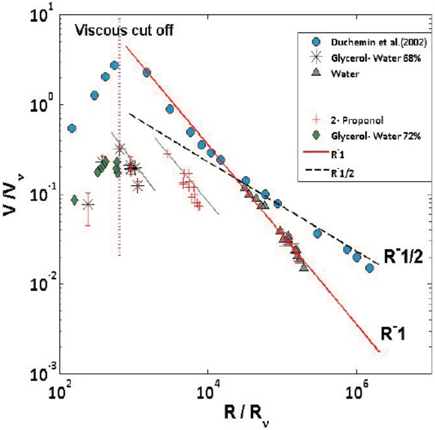
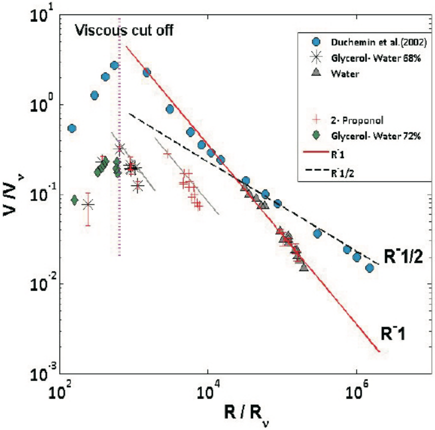
Main processes: (a) film retraction (b) propagation & expansion of kink along cavity surface



Viscous-Capillary scaling *(Duchemin et al. , POF, 14(9), 2002)*

- $R_\nu = \rho\nu^2/\sigma, \; V_\nu = \sigma/\rho\nu,$
- $V/V_\nu = Ca = \mu U_j/\sigma,$
- $R/R_\nu = 1/Oh^2$
  where, $Oh = \mu/\sqrt{\sigma\rho R}$



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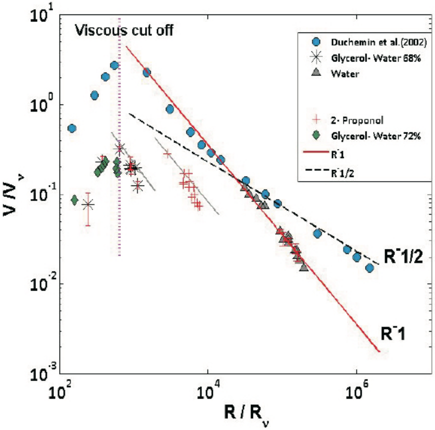
- For $R/R_\nu > 10^4$, discrepancy between experiments and simulation, possibly due to gravity effects.



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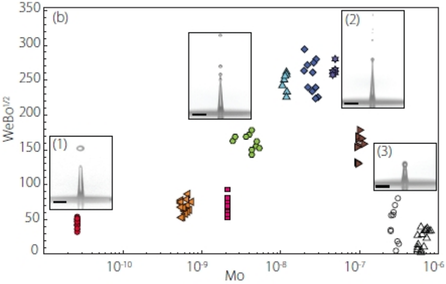
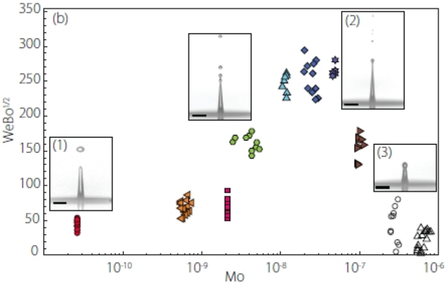
Capillary-viscous scaling incomplete.



Gravity-capillary-viscous scaling *(Gabache et al. , POF, 26(12), 2014)*

- $We = \rho U_j^2 R/\sigma$, $Bo = \rho g R^2/\sigma$,
- $Mo = Oh^4 Bo$
- Proposes
  1. low viscosity regime where $We \sim 1/\sqrt{Bo}$
  2. two other regimes with log dependence of $We\sqrt{Bo}$ on Mo.



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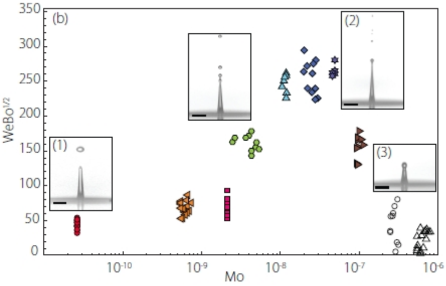

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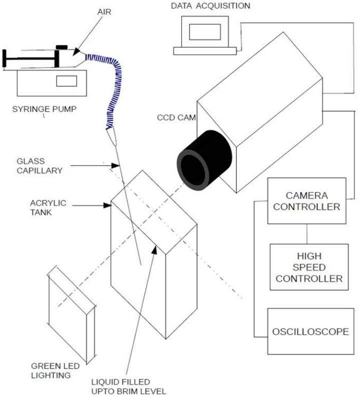
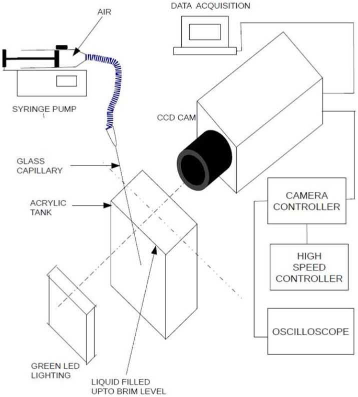
Gravity-capillary-viscous scaling needs to be improved

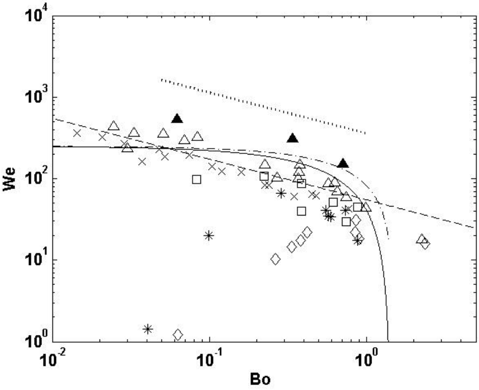


Experimental Setup



Experimental Setup

- Experiments with water, Glycerine-water 48% (GW48) , GW55, GW68 and GW72
- $0.4 \text{ mm} < R < 4.08 \text{ mm}$, $0.025 < Bo < 2.36$,
- $14 < Re < 4276$, $0.002 < Oh < 0.08$

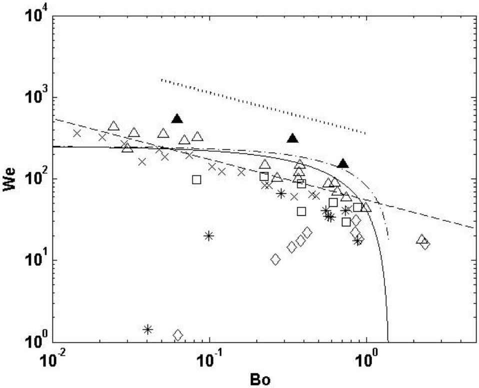


△, Water; ▲, GW48; □, GW55; $*$, GW68; ◊, GW72; $\times$, Gabache et al (water).

- - , $We = 55Bo^{-1/2}$;
-.-, $We = 62.5\ (Z_c/R)^2$;
—, $We = 62.5\ (Z_{cd}/R)^2$.

Dimensionless jet velocity vs Bo.

- Data deviates from $We \sim 1/\sqrt{Bo}$ at low and large Bo
- Low Bo : We becomes independent of Bo
- Large Bo : We reduces fast
- Viscosity causes vertical shift of We vs Bo curve.



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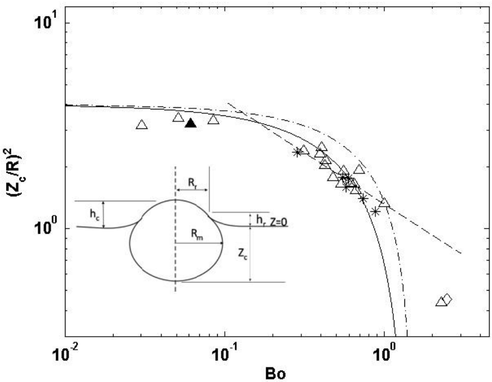
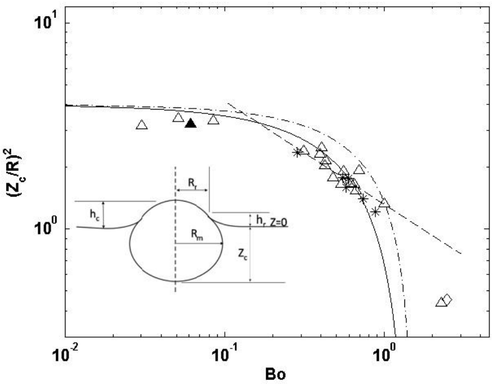
No power law dependency of *We* on *Bo*.



Dimensionless cavity depth vs *Bo*.

△, Water; ▲, GW48; $*$, GW68; ◊, GW72.

- -, $1.32Bo^{1/2}$; -.-, $(Z_c/R)^2$;
—, $(Z_{cd}/R)^2$



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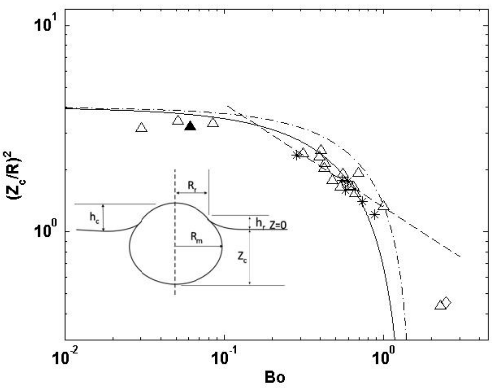
Functional form of $(Zcd/R)^2$ vs *Bo* and *We* vs *Bo* is the same.



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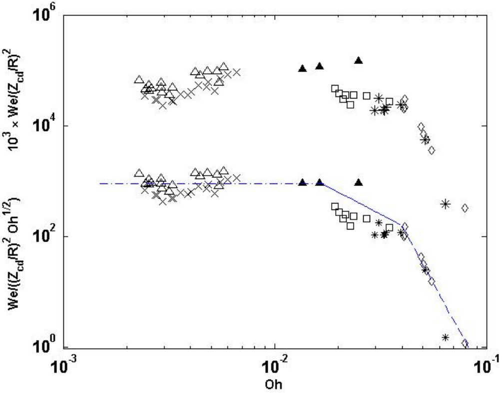
Functional form of $(Zcd/R)^2$ vs Bo and We vs Bo is the same.

From geometry and static force balance,

- $(Z_c/R)^2 = 4(1-(2/3)Bo)$, neglecting bubble deformation for $Bo < 1$.

Including deformation into an ellipse

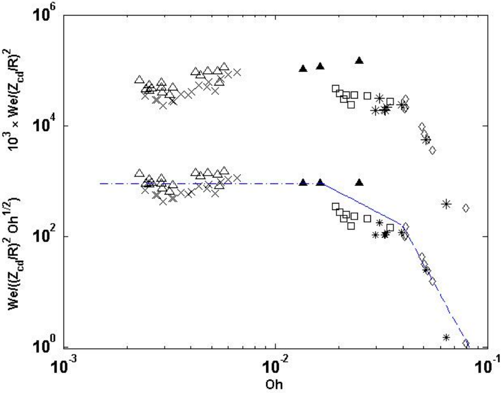
- $(Z_{cd}/R)^2 = 4(\sqrt{1-(2/3)Bo} - 0.17Bo^{0.8})^2$.



Proposed Capillary-gravity-viscous scaling.

△, Water; ▲, GW48; □, GW55; $*$, GW68; ◊, GW72; $\times$, Gabache et al (water); -.-, $We^* = 900$.

- For $Oh < 0.013$, $\frac{We}{(Z_{cd}/R)^2}$ increases with Oh, possibly due to damping of capillary waves.



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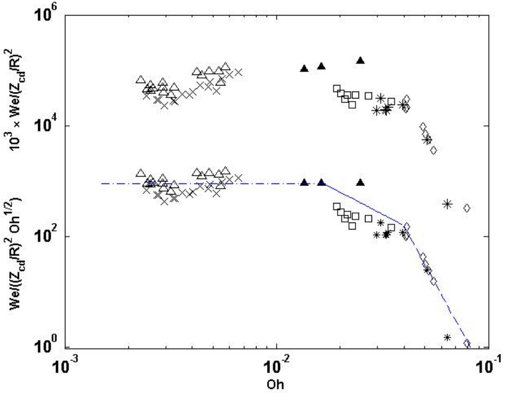
- Since $\lambda/R < \sqrt{10 Oh}$ are damped for any Oh, $We^* = \frac{We}{(Z_{cd}/R)^2 \sqrt{Oh}}$ counters this effect



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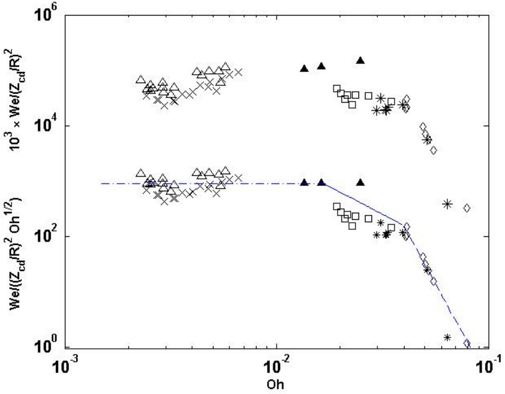
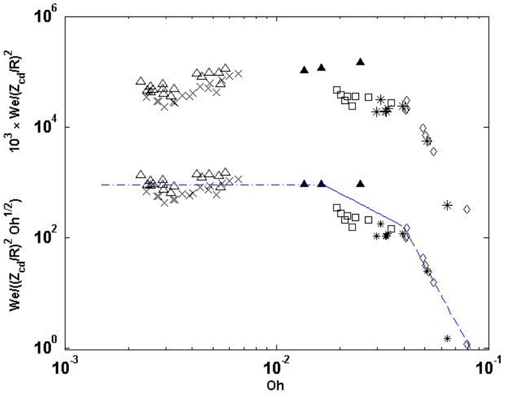


Proposed Capillary-gravity-viscous scaling.

- For $Oh > 0.036$, $We^* \sim Oh^{-7}$: viscosity affects jet formation & dynamics.
- For $0.013 < Oh < 0.036$, a transition regime where jet Re decreases by an order ($Re \sim 100$)



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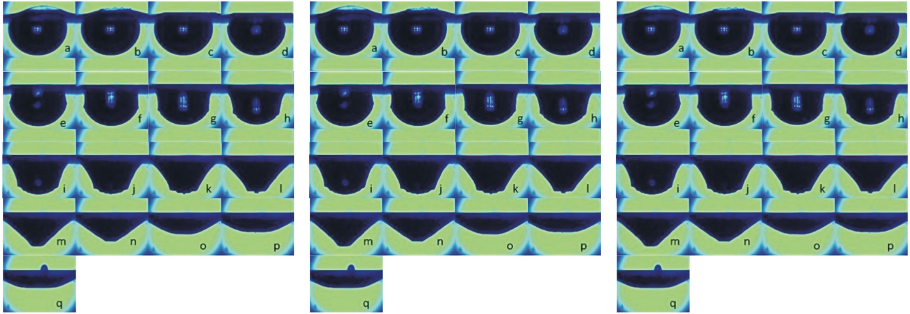
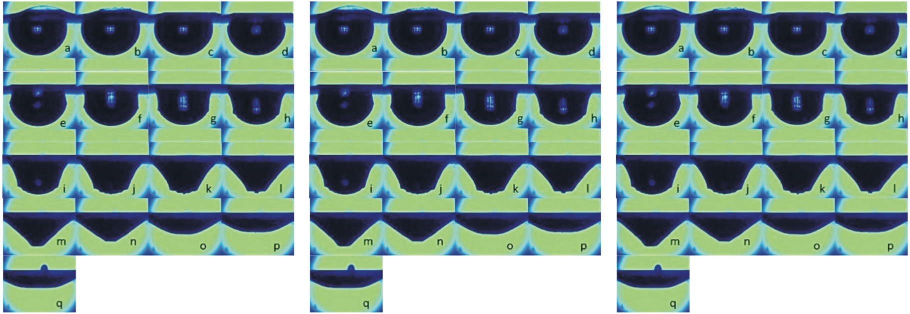
Three regimes of jet velocity scaling

- $Oh < 0.013$: no viscosity effect, except by capillary wave damping,
- $0.013 < Oh < 0.036$: jet Re affect We,
- $Oh > 0.036$: viscosity damps jet formation and dynamics, no jetting for $Oh > 0.1$.



Bursting sequence in the three regimes



Bursting sequence in the three regimes

- Bo dependence of jet We same as that of $(Zc/R)^2$; no power law dependence of We on Bo;
- Viscosity effects better represented in terms of Oh
- Three regimes demarcated by $Oh = 0.013$ and 0.036 due to viscosity effects.

- E. J. Hopfinger, for his main contributions
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Thank you for your attention!