

Dynamics of rising bubble inside a viscosity stratified medium

Premlata

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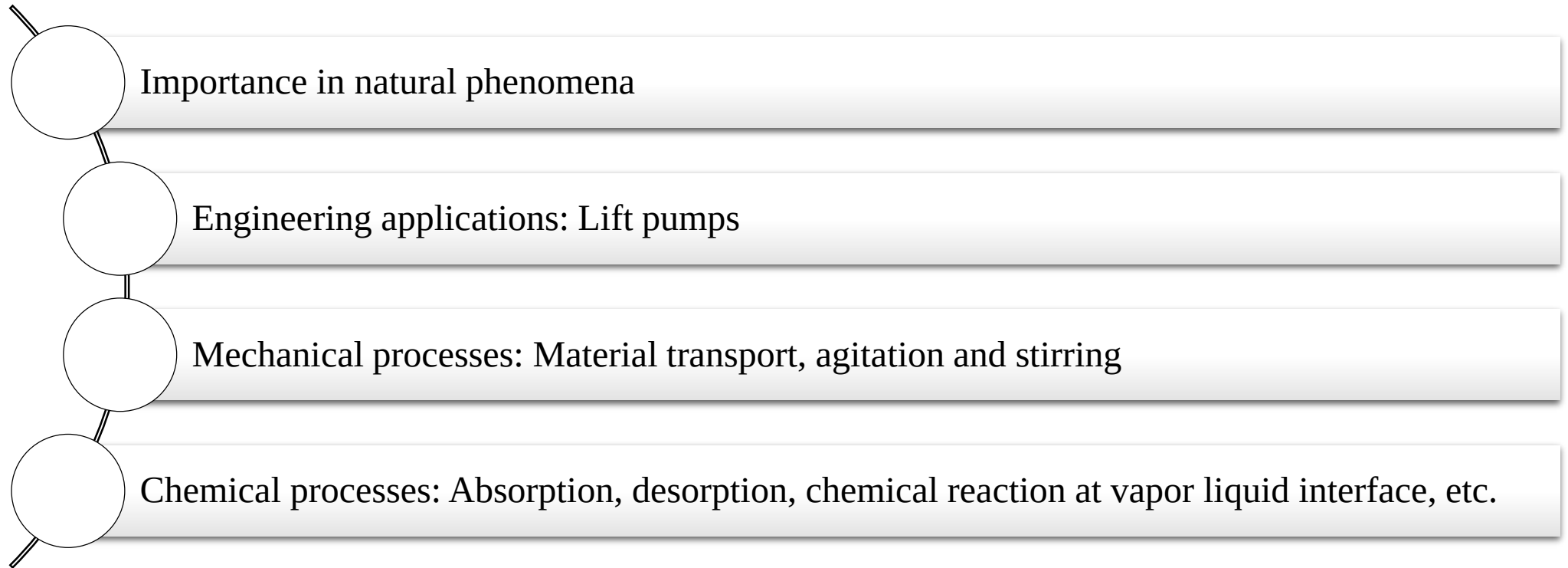
Inter Group Meeting, 2016
IIT Bombay

Introduction

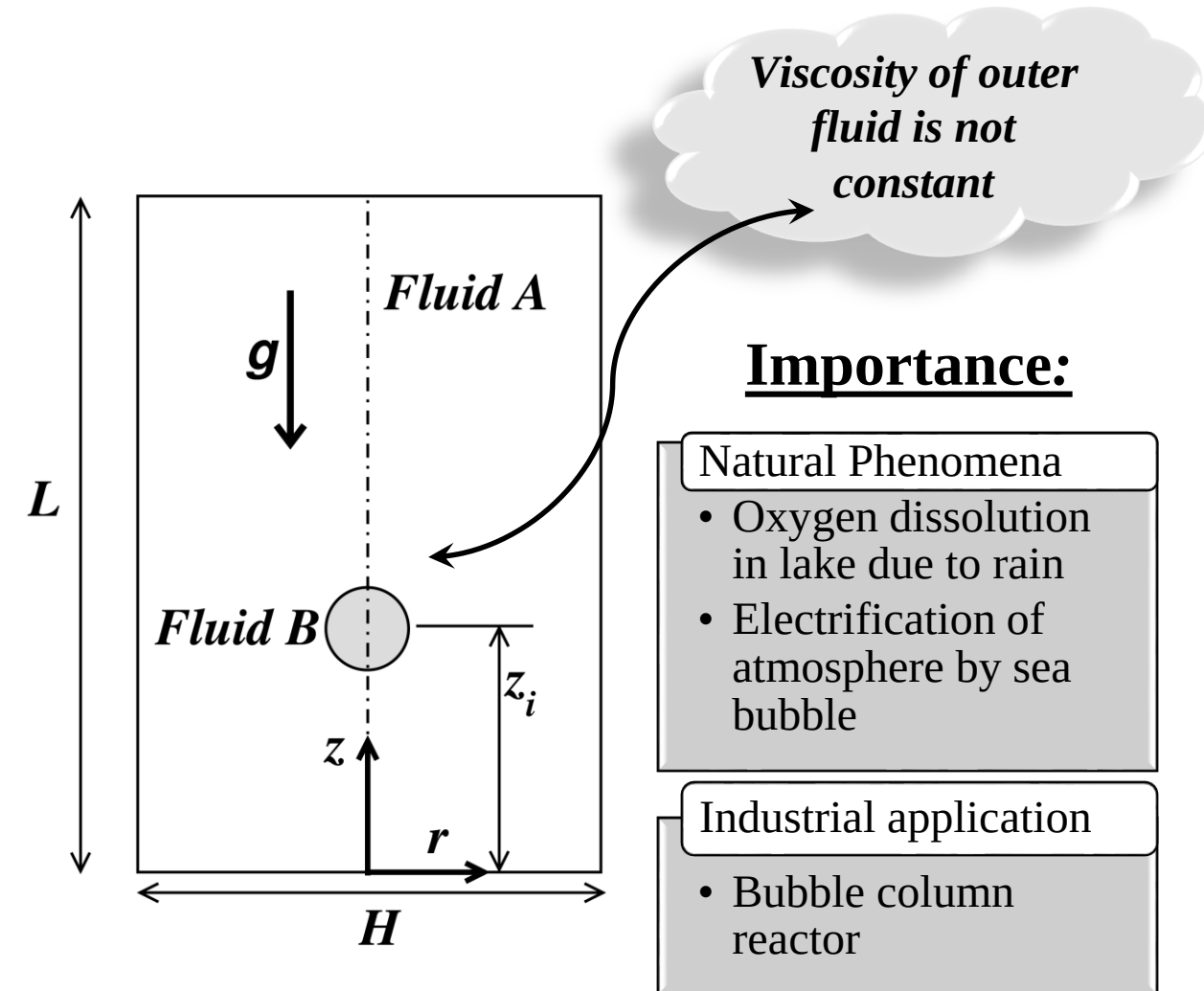
Blob of fluid lighter
than its surrounding

↔ **Bubble**
Drop ↔

Blob of fluid heavier
than its surrounding



Problem Definition



- Initial bubble location $z = z_i = 4R$
 R : radius of the bubble
- Computational domain $(H, L) = (30R, 120R)$

Governing Equations

$$\nabla \cdot \mathbf{u} = 0$$

$$\rho \left[\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right] = -\nabla p + \frac{1}{Ga} \nabla \cdot [\mu (\nabla \mathbf{u} + \nabla \mathbf{u}^T)] + \mathbf{F}$$

$$\mathbf{F} = \frac{\delta}{Bo} \hat{\mathbf{n}} \nabla \cdot \hat{\mathbf{n}} - \rho \vec{e}_z$$

$$\frac{\partial c}{\partial t} + \mathbf{u} \cdot \nabla c = 0 \quad \& \quad \frac{\partial \mu}{\partial t} + \mathbf{u} \cdot \nabla \mu = 0$$

Non dimensional number

$$Ga = \frac{\rho_B \sqrt{g R R}}{\mu_B} \quad \& \quad Bo = \frac{\rho_B g R^2}{\sigma}$$

Dimensionless density

$$\rho = (1 - c) + \rho_r c$$

Initial viscosity field

$$\mu = (1 - c) + \mu_{r0} (a_1 + a_2 z) c$$

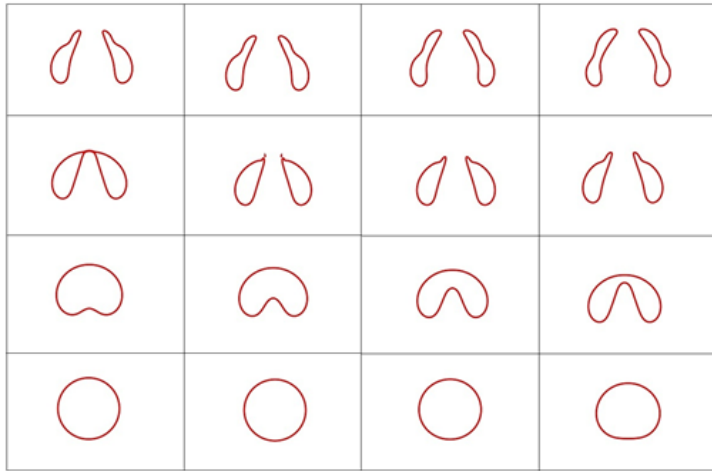
where,

$$\mu_{r0} = \frac{\mu_0}{\mu_B} \quad \& \quad \rho_r = \frac{\rho_A}{\rho_B}$$

μ_0 viscosity of fluid 'A' at z_i

Validations

Time evolution of shape of bubble

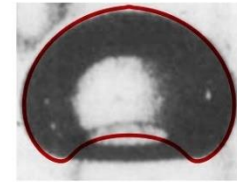


$$Ga = 10, Bo = 0.2, \mu_r = 10^3, \rho_r = 10^2$$

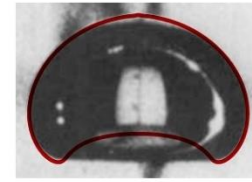
The shapes of the bubble are exactly the same as those presented in **Sussman & Smereka**

Ref.: M. Sussman and P. Smereka, "Axisymmetric free boundary problems," *Journal of Fluid Mechanics* 341, 269 (1997)

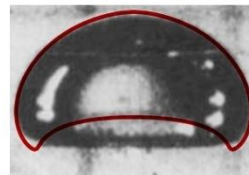
Terminal bubble shape & streamlines comparison



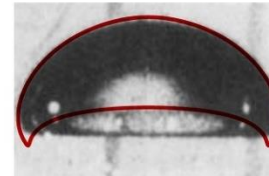
(a)



(b)

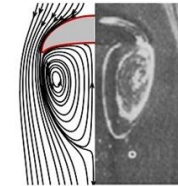


(c)

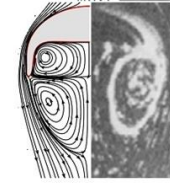


(d)

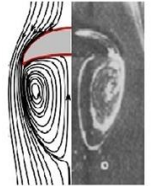
(a) $Ga=0.167$, (b) $Ga=0.222$, (c) $Ga=0.355$ and (d) $Ga=0.586$. The rest of the parameter values are $Bo=0.021$, $\rho_r = 1.39 \times 10^3$ & $\mu_r = 10^2$.



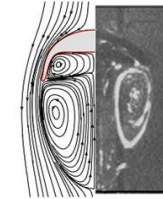
(a)



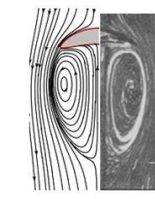
(b)



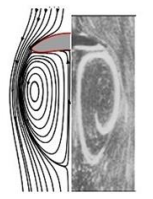
(c)



(d)



(e)



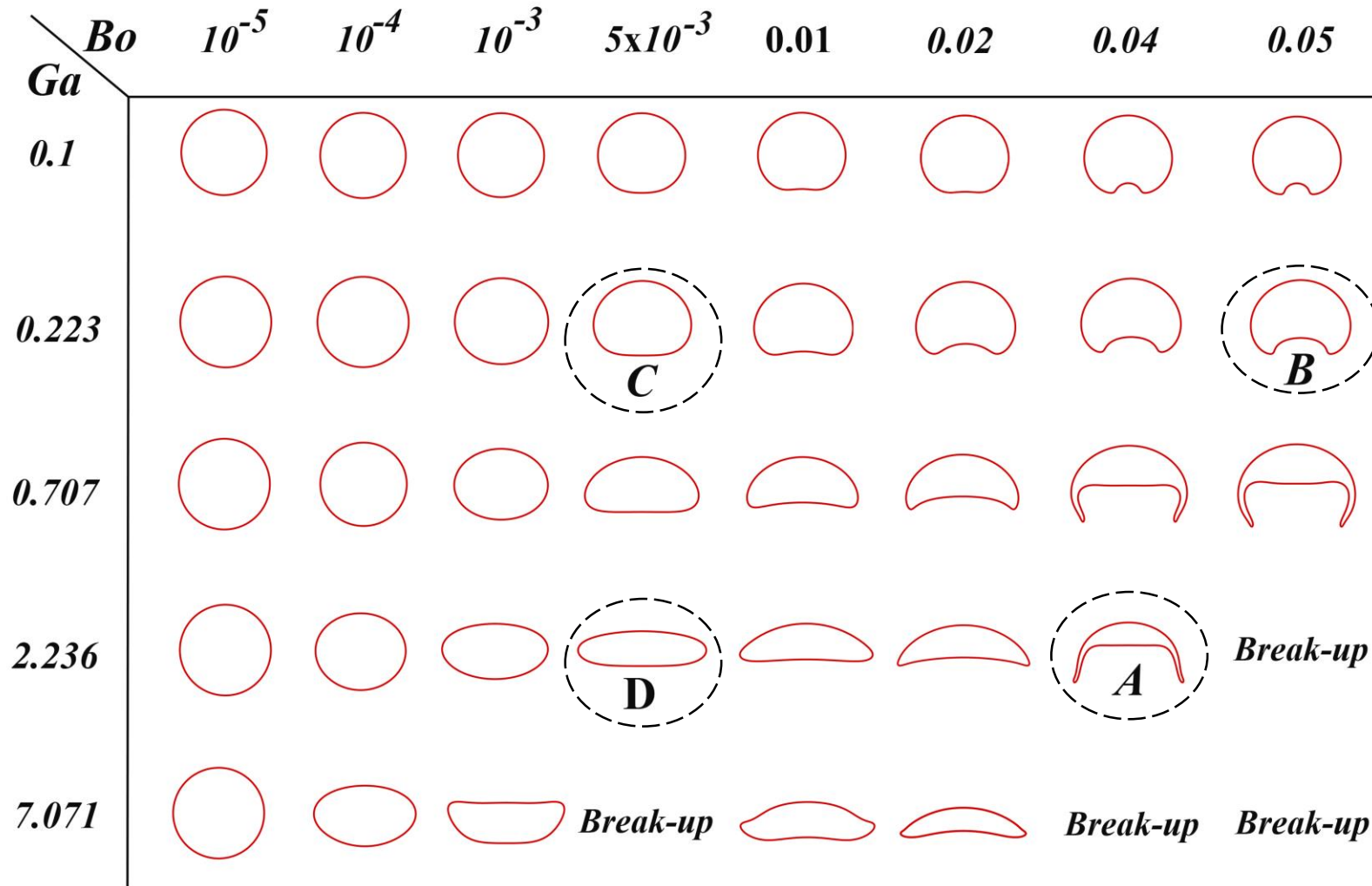
(f)

(a) $Ga=0.79$, $Bo=0.017$, (b) $Ga=0.9$, $Bo=0.021$, (c) $Ga=1.26$, $Bo=0.017$, (d) $Ga=1.78$, $Bo=0.027$, (e) $Ga=2.1$, $Bo=0.017$, and (f) $Ga=3.32$, $Bo=0.011$. The rest of the parameter values are $\rho_r = 1.39 \times 10^3$ & $\mu_r = 10^2$

Ref.: D. Bhaga and M. E. Weber, "Bubbles in viscous liquids: shapes, wakes and velocities," *J. Fluid Mech.* 105, 61 (1981)

Results

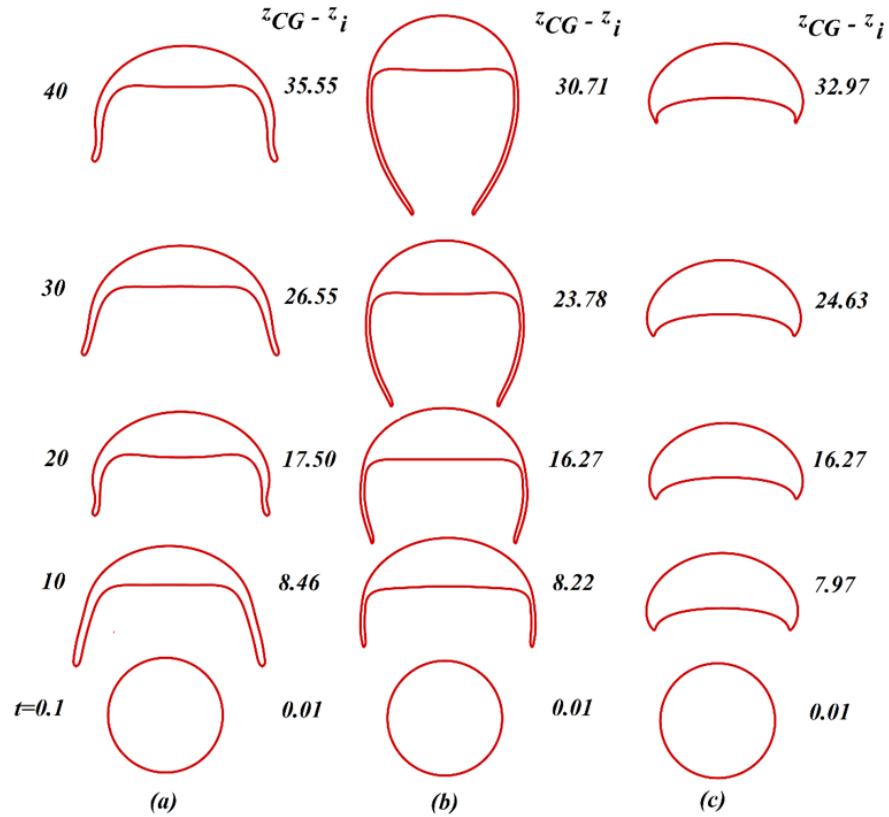
Terminal shape of the bubble



$\mu_A = \mu_r(a_1 + a_2 z)$
 constant viscosity case
 $(a_1 = 1, a_2 = 0)$
 $\rho_r = 10^3, \mu_r = 10^2$

Point A: $Bo=0.04$, $Ga=2.236$

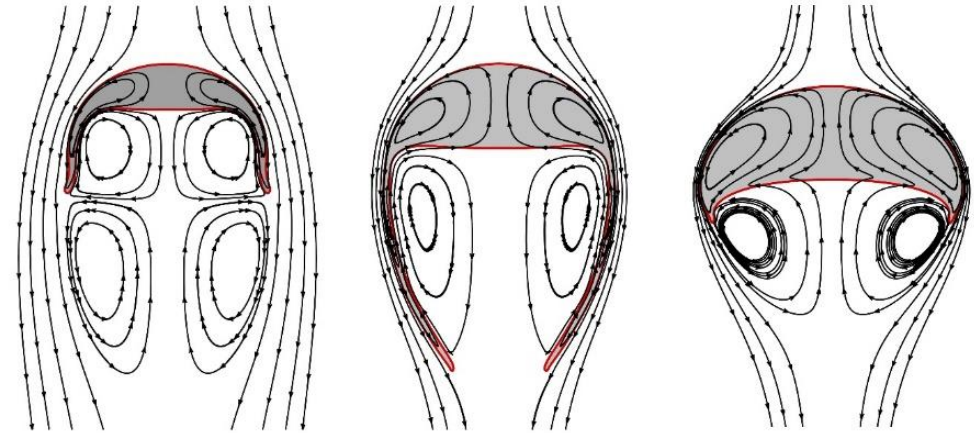
Time evolution



$$\mu_A = \mu_r(a_1 + a_2 z)$$

- (a) constant viscosity ($a_1 = 1, a_2 = 0$)
- (b) linearly increasing viscosity ($a_1 = 0.2, a_2 = 0.2$)
- (c) averaged constant viscosity

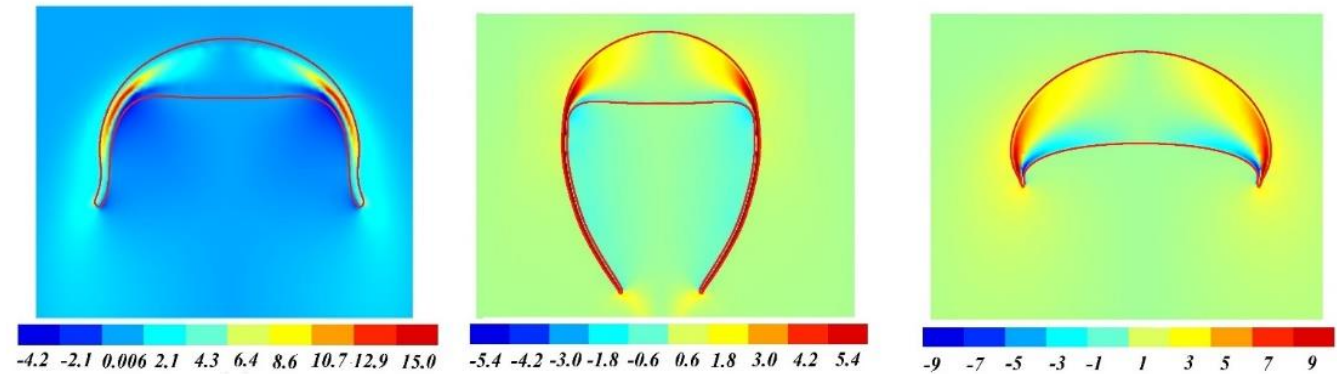
Streamlines



(a)

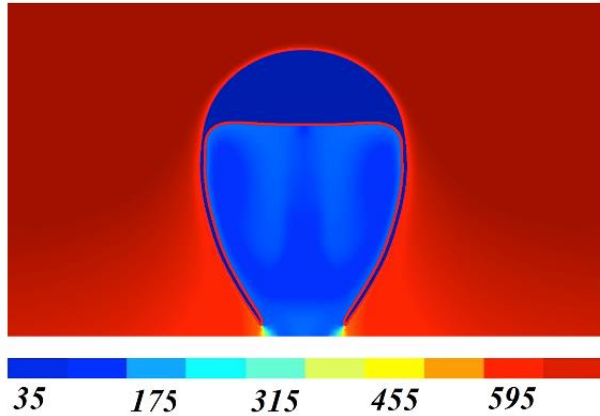
(b)

(c)



Vorticity

A possible explanation of this contour-intuitive phenomena



Beneficiary to processes

low viscosity fluid is required to be carried through a high viscosity fluid with the help of a carrier bubble

Recirculation zone in the wake of the bubble carries the lower viscosity fluid

Contrast in viscosity increases

Stress generation

Physical separation of region

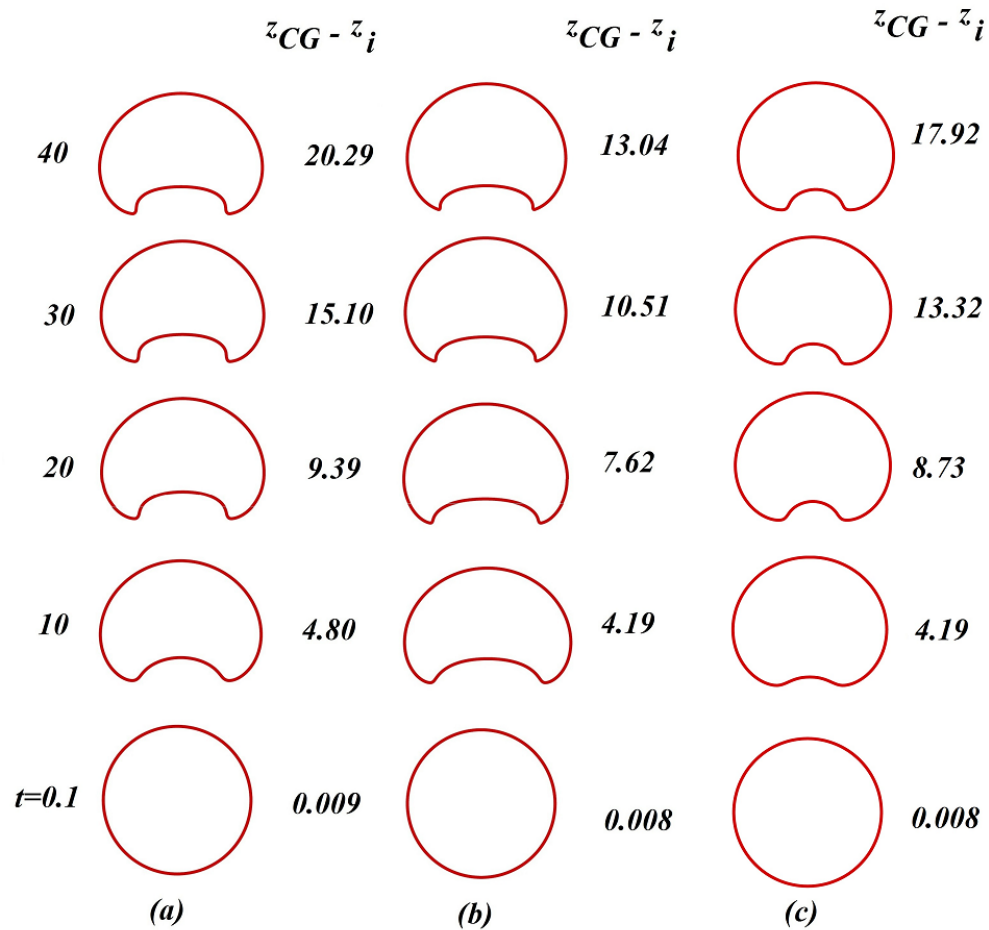
Fast circulation – wake of bubble

Slow flow – outside skirt

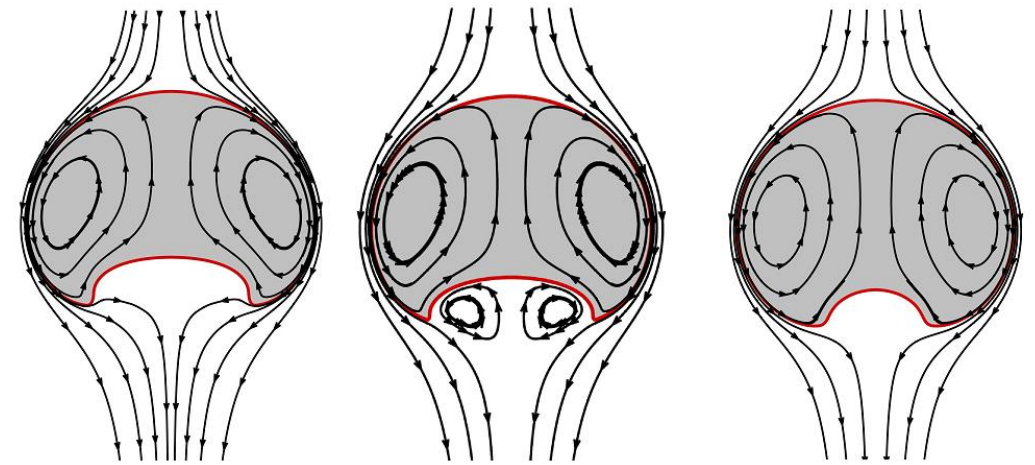
Creating contrast in Reynolds number

Point B: $Bo=0.05$; $Ga=0.223$

Time evolution



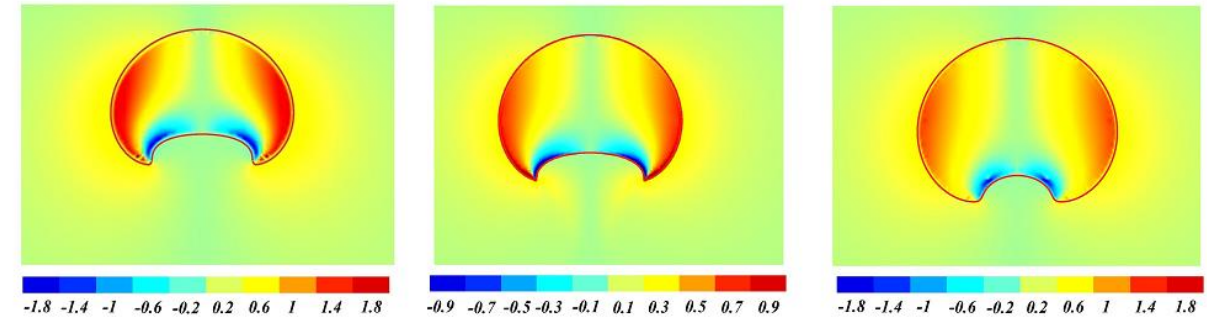
Streamlines pattern



(a)

(b)

(c)

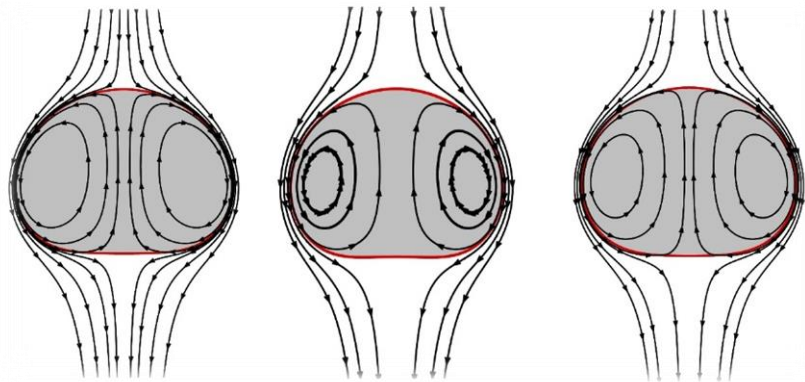
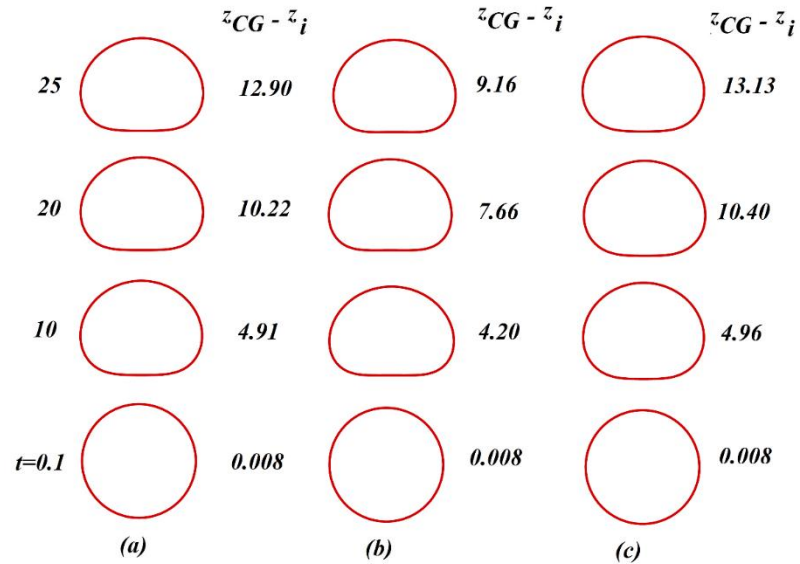


Vorticity plots

(a) constant viscosity ($a_1 = 1, a_2 = 0$) ; (b) linearly increasing viscosity ($a_1 = 0.2, a_2 = 0.2$) ; (c) averaged constant viscosity

Point C : $Bo = 5 \times 10^{-3}$; $Ga = 0.223$

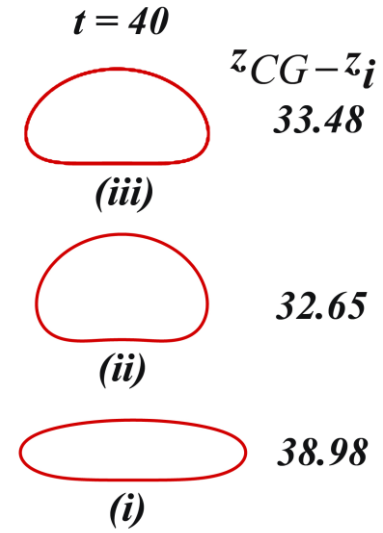
Time evolution



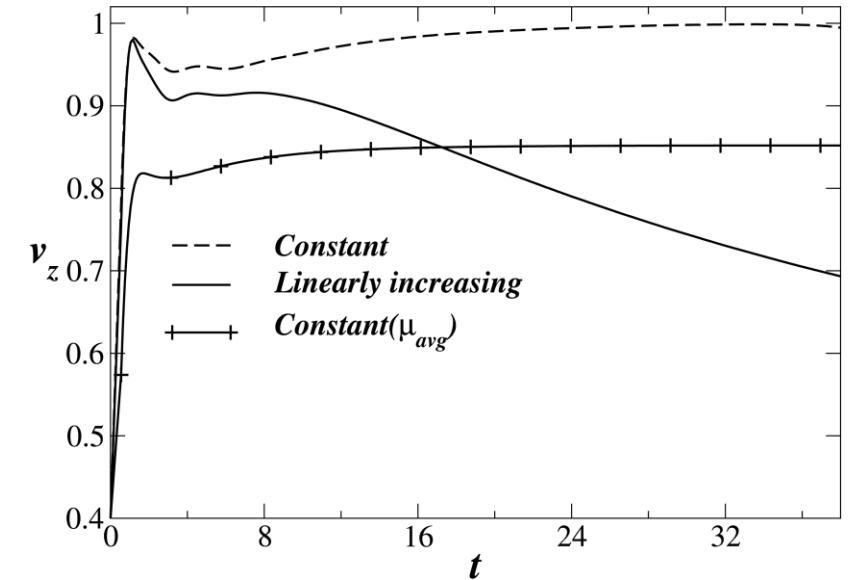
Streamlines pattern

Point D: $Bo = 5 \times 10^{-3}$; $Ga = 2.236$

Terminal shape of the bubbles

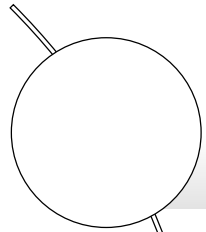


Velocity variation

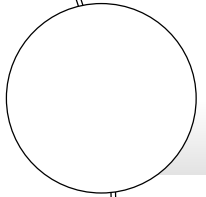


- (a),(i) constant viscosity ($a_1 = 1, a_2 = 0$)
 (b),(ii) linearly increasing viscosity ($a_1 = 0.2, a_2 = 0.2$)
 (c),(iii) averaged constant viscosity

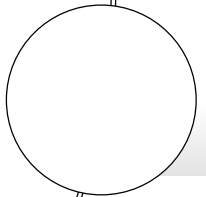
Conclusions



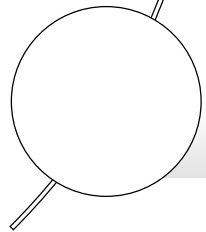
Bubble rising inside a viscosity stratified medium is investigated numerically using Gerris



The solver is validated by comparing the results with the previous numerical and experimental results



A phase plot has been prepared in the $Ga - Bo$ space for constant viscosity system



The effect of viscosity stratification on the bubble dynamics is investigated for some typical points in the phase plot.

Acknowledgement

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Thank You

