Test-case number 22: Axisymmetric body emerging through a free surface(PE)

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1 Practical significance and interest of the test-case

The current test-case concerns the free surface deformation due a body that emerges from a liquid; the study is restricted only to the surge effect. While this problem has been numerically studied for the large scales case where capillary effects are negligible, the present work provides experimental results when small scales (of the order of 1 *cm*) are considered. Therefore, it would certainly be a good case for testing the full Navier-Stokes numerical simulations, including capillary effects : enclosed photos and experimental data (which systematically include uncertainties) may be used to compare interface position and qualify the implementation of surface tension forces.

2 Experimental setup description

A circular cylindrical body, equipped with an hemispherical head, vertically submerged in a liquid tank, rises upwardly and uniformly towards the free-surface.

All the geometry is axisymmetric. The body is only characterized by its radius R, because its length is very large in comparison with R (see fig. 1). The tank size is considered as infinite. Two different radius values have been used :

- $R = 5$ mm, $R = 10$ mm

Gravity reads, as usual :

- $g = 9.81$ m s^{-2}

The upward body velocity is denoted by V :

- 0.1 m s$^{-1} < V < 1$ m s^{-1}

Lastly, the physical properties of liquids that were used (water and aqueous glucose solution) are the following :

- water :

  density : $\rho = 1000$ kg m^{-3}
  viscosity : $\mu = 10^{-3}$ Pa s
  surface tension : $\sigma = 72 \cdot 10^{-3}$ N m^{-1}

- glucose :

  density : $\rho = 1210$ kg m^{-3}

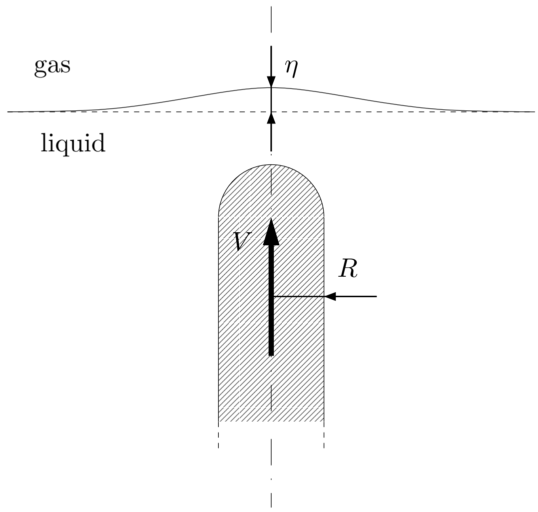

Figure 1: Definition sketch of surging interface problem.

viscosity : $\mu = 26.3 \cdot 10^{-3}$ Pa s

surface tension : $\sigma = 59 \cdot 10^{-3}$ N m^{-1}

The interface deformation is determined from digital video frames taken from a CCD camera. The present test-case shows only the surge effect, excluding the liquid exit, piercing and wetting-off stages; it is described in detail by Liju (1997) and Liju *et al.* (2001).

Reported sequences are limited to weakly distorted interface, when the residual film on the top of the body is not too thin; for this reason, viscous effects are negligible for Reynolds numbers larger than about 200. Indeed, for large Reynolds numbers, viscous effects are confined in a thin layer surrounding the body head. However, for small Reynolds numbers, momentum convective and diffusive times are of the same order and then, interface position is slightly perturbed by viscous forces.

3 Test-case description

Initially, the shape of the gas/liquid interface is horizontal, and the body is far under the free-surface.

The following non dimensional parameters, Froude, Weber and Reynolds, are introduced :

$$Fr^2 = \frac{V^2}{gR} \qquad We = \frac{\rho V^2 R}{\sigma} \qquad Re = \frac{\rho R V}{\mu}$$

In all experiences provided by the attached literature, the ranges of the previous parameters are :

$$0.1 < Fr^2 < 20 \qquad 0.6 < We < 200 \qquad 46 < Re < 6000$$

Experimental results are presented under a dimensionless form and make systematically use of uncertainties. The main reference scales are, for length and time, respectively :

$$L_{ref} = R \qquad t_{ref} = \frac{R}{V}$$

The dimensionless time origin $t^* = 0$ corresponds to the instant where the top of the body head reaches the position of the non deformed free surface.

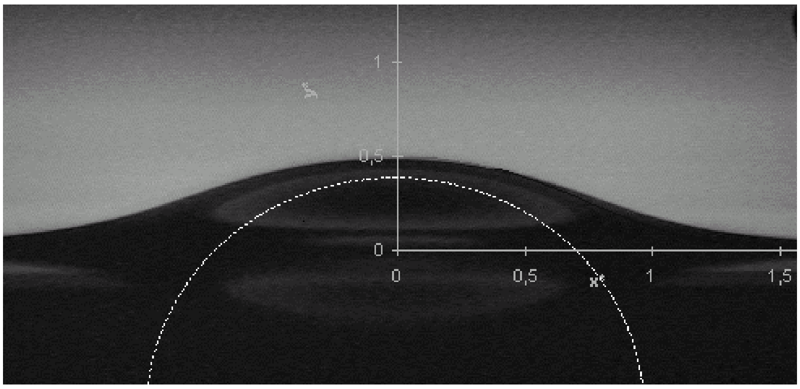

Figure 2: glucose/air, $V = 0.2\,m/s$, $R = 10\,mm$
$Fr^2 = 0.4$, $We = 8.2$, $Re = 92$
$t^* = 0.41$

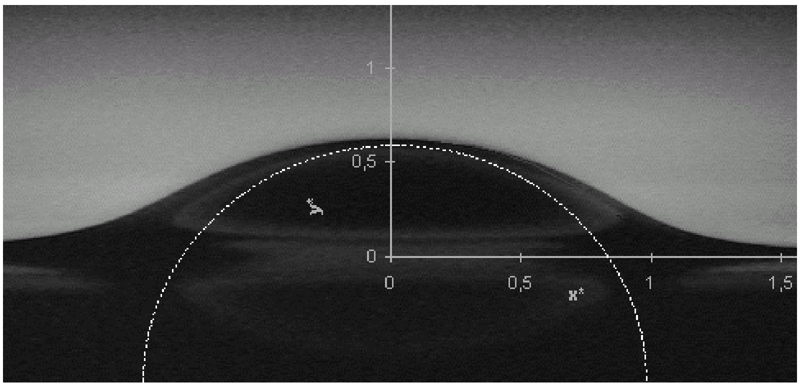

Figure 3: $t^* = 0.58$ (same parameters as in figure 2)

Two kinds of results are presented :

- interface shape $\eta^*(r^*)$ at different instants (figures 2 and 3). The y^* origin corresponds to the initial position of the free surface (the dashed line shape is the contour of the body head).
- position of the interface apex $\eta^*_{r^*=0}(t^*)$ versus time (figures 4 to 7). Two series of measurements are superimposed on each figure, while uncertainties are reported by thin cross bars.

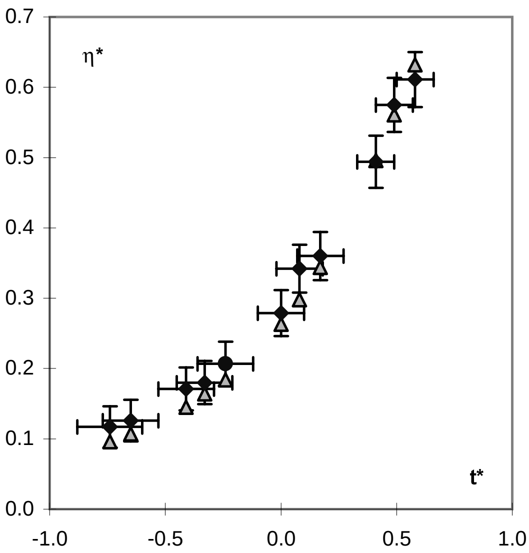

Figure 4: glucose/air

$V = 0.2\,m/s \quad R = 10\,mm$

$Fr^2 = 0.4 \quad We = 8.2 \quad Re = 92$

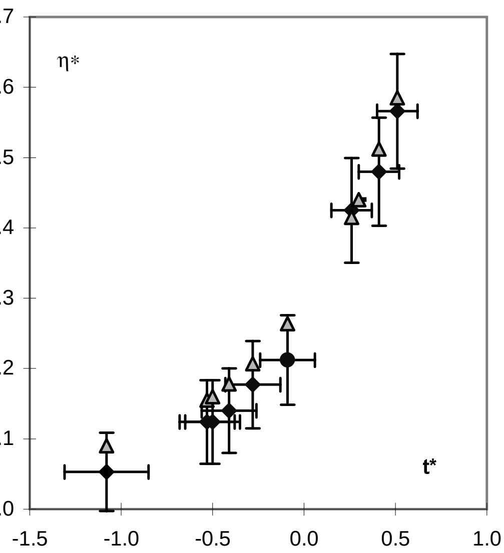

Figure 5: water/air

$V = 0.2\,m/s \quad R = 5\,mm$

$Fr^2 = 0.8 \quad We = 2.8 \quad Re = 1000$

References

Liju, P.-Y. 1997. *Caractérisation expérimentale de la traversée d'une interface fluide/fluide par un corps solide.* DEA Mécanique des Fluides et Transferts, Institut National Polytechnique de Grenoble, France.

Liju, P.-Y., Machane, R., & Cartellier, A. 2001. Surge effect during the water exit of an axisymmetric body traveling normal to a plane interface : experiments and BEM simulation. *Exp. in Fluids*, **31**(3), 241–248.

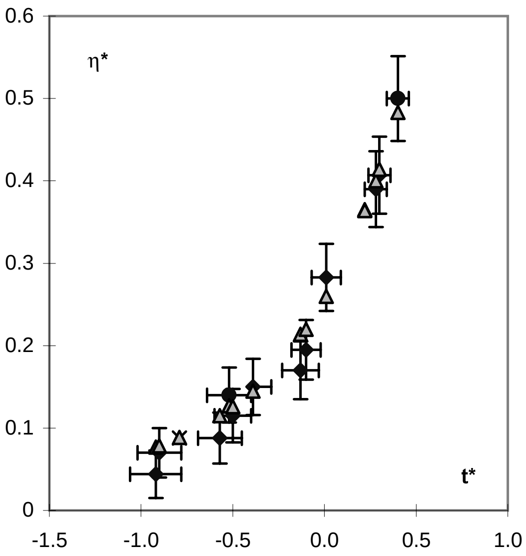

Figure 6: water/air

$V = 0.2\,m/s \quad R = 10\,mm$

$Fr^2 = 0.4 \quad We = 5.6 \quad Re = 2000$

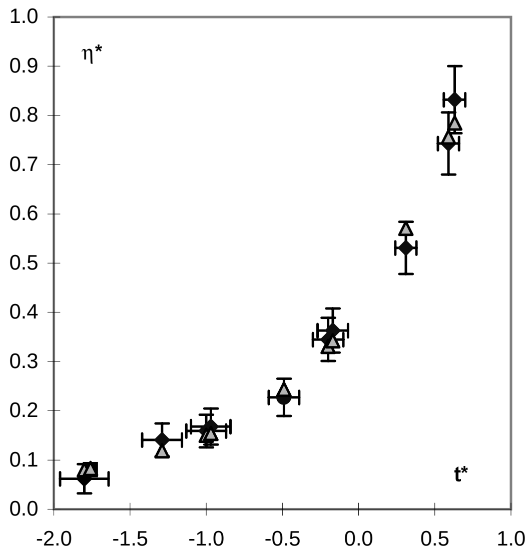

Figure 7: water/air

$V = 0.4\,m/s \quad R = 10\,mm$

$Fr^2 = 1.6 \quad We = 22.2 \quad Re = 4000$