Test-case number 15: Phase inversion in a closed box (PC)

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1 Practical significance and interest of the test-case

The flow induced by the action of the buoyancy force on an oil inclusion in a cavity full of water is considered. While the density difference effect is counteracted by the viscous and surface tension forces, an unsteady turbulent two-phase flow develops leading to strong interface shearing and stretching with drop extraction and collapse. The interest of this test-case is the simplicity of its initial condition and the complexity of the interface structures generated in terms of strong deformations or shear instabilities. In this regard, this test-case is aimed at testing the ability of a numerical method to simulate turbulent two-phase flows with large and complex interface deformations. Due to the complexity of the flow, the detailed structure of the flow cannot be analyzed and compared to any reference solution. The second asset of the problem is the existence of a theoretical solution for sufficiently long times concerning the exact position of the interface, which corresponds to a horizontal oil layer in the top part of the cavity and a horizontal water layer in the bottom part of the square box. At equilibrium, the two fluids are separated by a horizontal interface whose position only depends on the initial volumes of the fluids. In this regard, this test-case is particularly relevant to test the ability of a numerical to conserve mass and volume even for very large and complex interface deformations. To finish with, the independence of the steady solution of the phase inversion problem on the physical parameters such as density, viscosity or surface tension allows to treat various numerical methods and physical configurations.

2 Definitions and physical model description

A square oil inclusion of height H is initially placed in the left corner of a square cavity full of water, whose characteristic length is L. Gravity and surface tension effects are taken into account. The problem can be solved in two- or three-dimensions without loss of generality. $H = L/2$, so that for long time simulations, the equilibrium heights of the oil and water layers are respectively $H/4$ and $3H/4$ in two dimensions and $H/8$ and $7H/8$ in three-dimensions.
Based on the characteristic velocity $u_0 = \sqrt{gH}$, where g is the gravity, the characteristic dimensionless numbers of the problem, are the Weber and the Reynolds numbers defined by

- $We = \dfrac{(\rho_w - \rho_o) u_0^2 L}{\sigma}$

- $Re_w = \dfrac{\rho_w u_0 L}{\mu_w}$
- $Re_o = \dfrac{\rho_o u_0 L}{\mu_o}$

3 Test-case description

The physical parameters chosen as an interesting and characteristic example of turbulent and unsteady two-phase flow are the following:

- $H = 0.1$ m,
- $L = 0.2$ m,
- 0.0002 m $\leq \Delta x \leq 0.001$ m, where Δx is the mesh spacing supposed to be regular and equal in all directions,
- $g = 9.81$ m.s^{-2}.

The corresponding characteristic velocity is $u_0 = 0.99\ m.s^{-1}$.
The physical characteristics of oil and water are the following:

- densities: $\rho_w = 1000$ kg.m^{-3}, $\rho_o = 900$ kg.m^{-3}
- dynamic viscosities: $\mu_w = 5.\ 10^{-3}$ Pa.s, $\mu_o = 10^{-1}$ Pa.s
- surface tension: $\sigma = 0.045$ N.m^{-1}

The corresponding characteristic dimensionless numbers are the following:

- $We = 436$
- $Re_w = 3960$
- $Re_o = 891$

Both phases are initially at rest and no slip boundary conditions are imposed on the walls of the closed cavity.

4 Illustrations of the problem

The numerical simulations are run with a VOF-PLIC method of Youngs (1982) using the CSF method Brackbill *et al.* (1992) for the treatment of the surface tension. The results shown in figure 1 correspond to an example due to Caltagirone & Vincent (2003) when a regular Cartesian 256 x 256 grid is implemented.

References

Brackbill, J.U., Kothe, D.B., & Zemach, C. 1992. A continuum method for modeling surface tension. *J. Comput. Phys.*, **100**, 335–354.

Caltagirone, J.P., & Vincent, S. 2003. Validation of the numerical fluid dynamics library Aquilon. *Internal report*, **1**, 1–250.

Youngs, D.L. 1982. *Time-dependent multimaterial flow with large fluid distortion.* K.W. Morton and M.J. Baines (eds), New-York, U.S.A.

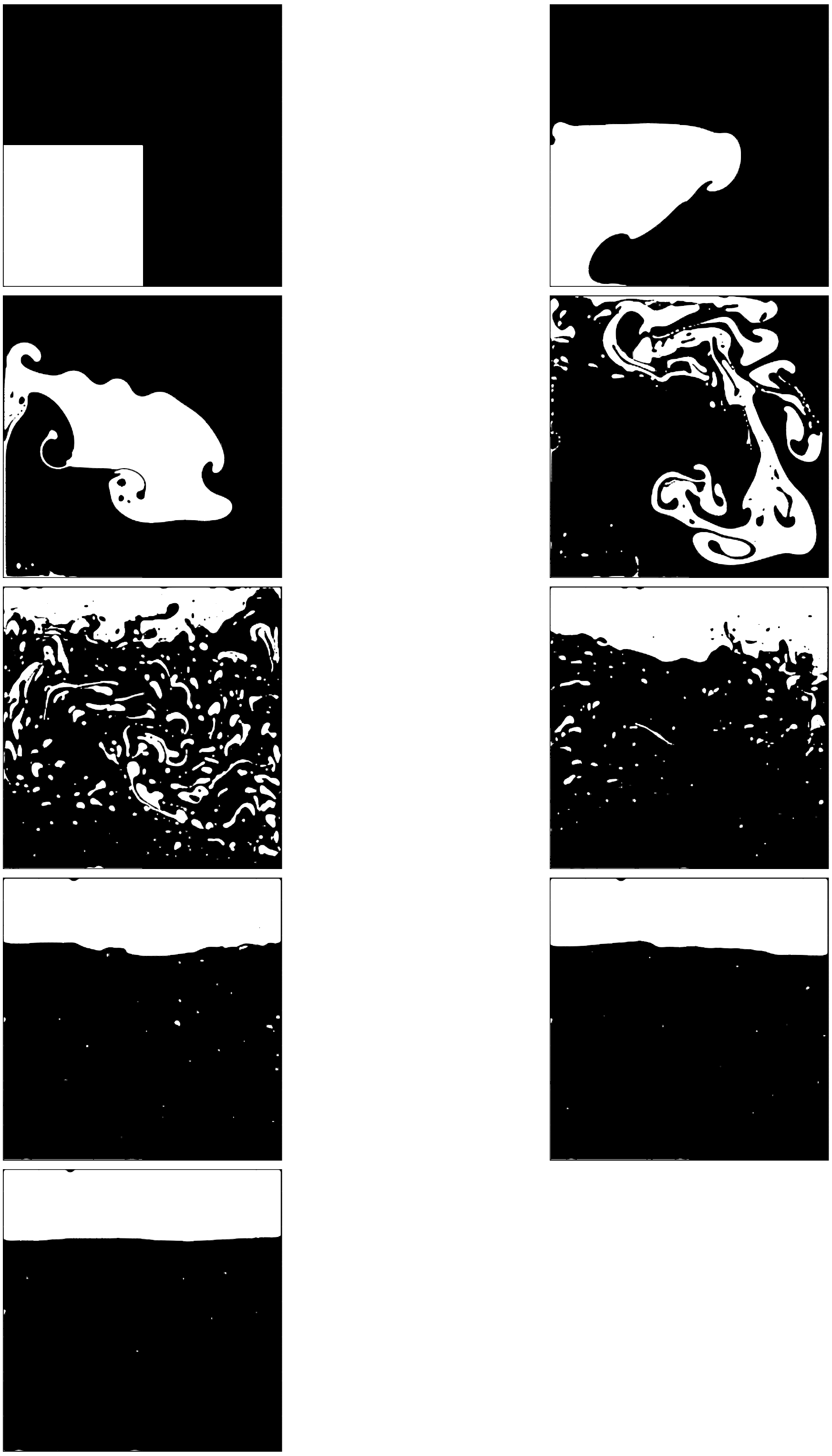

Figure 1: Direct numerical simulation of the phase inversion problem in two-dimensions for oil and water. With $\Delta x = 0.390625$ mm, the results show the interface profiles corresponding to times $t = 0$, 1.2, 2.4, 4.8, 10, 20, 30, 36 and 44 s (from left to right and from top to bottom). The simulations are stopped after thousands of iterations. For longer times, a steady state with two horizontal layers should be obtained.