SPH simulation tool for micro-fluidics problems with different density ratios

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Abstract: *The multiphase flow is a significant role in numerous applications in microfluidic e.g. mixing, separation and selection. An alternative to the flow simulation for two or more phases is to employ the Navier-Stokes equations in a Lagrangian formalism using Smoothed Particle Hydrodynamics (SPH) method. Thus, problems with flow with emulsion droplet formation and the Rayleigh-Taylor instability were modeled for different density ratios. In this way, the implementation with SPH was validated and showed good results.*

Key-words: *Microfluidic, Emultions, Meshfree, Smoothed Particle Hydrodynamics.*

Introduction: Multiphase interfaces in fluids are often unstable when there are high density ratios in flow with droplets or emulsions. Additionally, in presence of instabilities at the interfaces can generally occur during the flow of breakable fluids and recombination between phases. Therefore, multiphase flows are complex and difficult to predict. [1]. The SPH method seems well suited for multiphase flow problems with interfaces [2], [3]. However, using SPH for multiphase flows with high density ratios is recent, and still requires adequate validations, especially in cases with surface tension and the influence of forces on the body such as gravity [4].

This work shows the implementation of the SPH simulator in the multiphase microfluidics problems, for a density ratio of up to 10 times. Thus, for the validation and comparison, problems with flow in emulsion droplet formation for several cases is presented in addition to the study of the Rayleigh-Taylor instability problem at different density ratios [2], [4]

Results and discussion: The instability that develops and evolves at the interface between two horizontal parallel fluids of different viscosities and densities with the heavier fluid at the top and the lighter at the bottom is known as Rayleigh-Taylor instability. [2]. The instability in fluids begins when a multiphase system with different densities experiences gravitational force. As a result, an unstable perturbation tends to grow in the direction of the gravitational field releasing and thus reducing the potential energy of the system as shown in **Figure 1**. The perturbation between phases is increased and subsequently the heavier fluid, moving downwards, develops a peak in the interface. While the lighter phase moves upwards, two droplets at the sides of the heavier phase's peak were formed (**Figure 1**). In the Rayleigh-Taylor instability problems, the square domain is 1x4 (**Figure 1**) and the gravitational force for all cases equals 0.1. Fluids are confined by four solid walls with no-slip condition.

The initial conditions for the case of a droplet flow, at the beginning, a fluid of rectangular domain 1x2 in the presence of the gravitational force in the vertical direction (g = -0.1), confined by four walls in no-slip condition and in the lower part a circular drop with radius R = 0.25 of smaller density [4], [3]. For this problem the kinematic viscosity is $\eta = 10^{-3}$ and the density of the fluid ρ_f= 1,0. The density ratio between the droplet (d) and fluid (f) is defined as ρ_d/ρ_f. **Figure 2** shows the velocity profile for $\rho_d/\rho_f = 0.8$, where the right droplet does not present surface tension, but the left drop has surface tension equal $\alpha = 2{,}5\text{x}10^{-3}$. **Figure 2** shows the distribution of the velocity profiles for the two different time instants for the cases with and without surface tension. The velocity field in both cases are similar, which indicates the low incidence in the flow. However, the effect of α on morphology is showed by containing the second lateral instabilities and the formation of tails in the droplet.

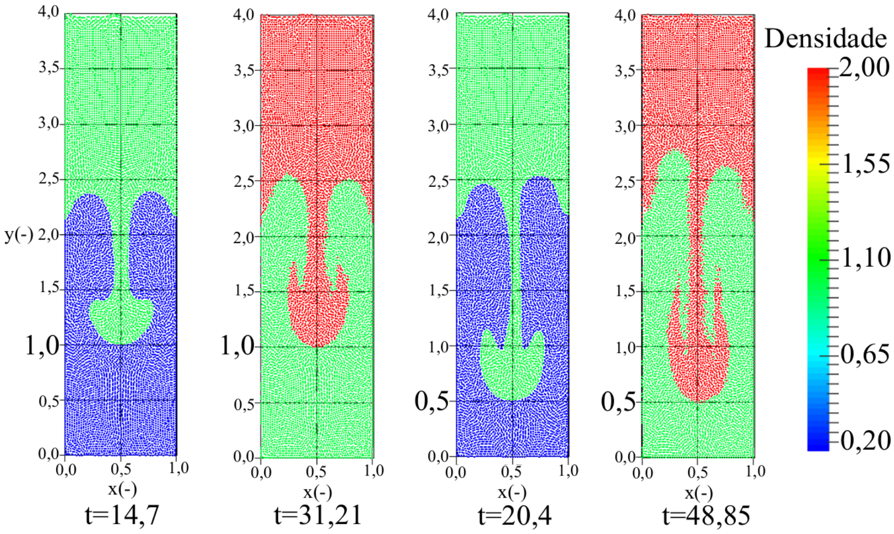

Figure 1. Rayleigh-Taylor example, for the comparison of density ratios (ρ) for different instant in the vertical position (y). Fluid of particles: blue with ρ = 0,2, green with ρ = 1,0 and red ρ = 2,0.c (a) Heavier fluid penetrating to the position y = 1,0; (B) Heavier fluid penetrating to position y = 0.5.

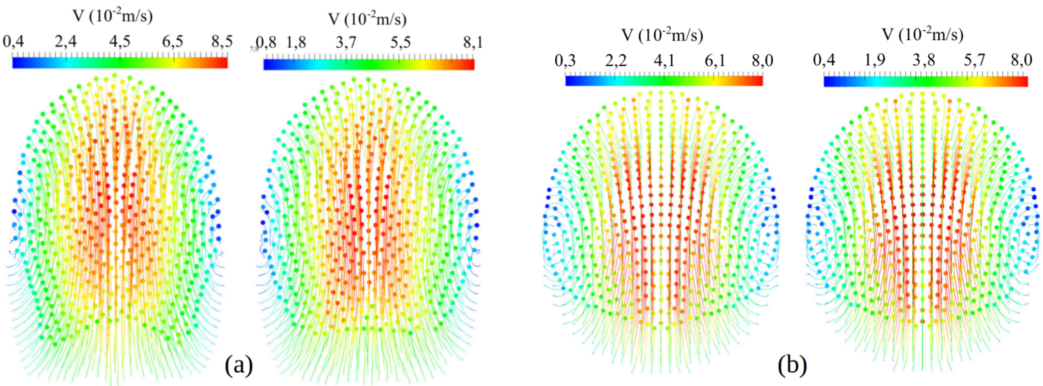

Figure 2. Problem of flow of gutícula. Profile of velocities for relation of ρd / ρf = 0,8. The right droplet does not present surface tension, but the left drop has surface tension α = 2.5x10-3, for the time instants (t): (a) t = 2.45; (B) t = 0.82.

Conclusions: The implementation of the SPH simulator was validated with the problems of flowing droplet and the instability of Rayleigh-Taylor for multi-fluid cases with different density ratios, with promising results. Also, it shows agreement with theoretical results and other simulations.

Reference:

[1] M. van Sint Annaland, N. G. Deen, and J. A. M. Kuipers, “Numerical simulation of gas bubbles behaviour using a three-dimensional volume of fluid method,” *Chem. Eng. Sci.*, vol. 60, no. 11, pp. 2999–3011, 2005.

[2] M. S. Shadloo, A. Zainali, and M. Yildiz, “Simulation of single mode Rayleigh-Taylor instability by SPH method,” *Comput. Mech.*, vol. 51, no. 5, pp. 699–715, 2013.

[3] Z. Chen, Z. Zong, M. B. Liu, L. Zou, H. T. Li, and C. Shu, “An SPH model for multiphase flows with complex interfaces and large density differences,” *J. Comput. Phys.*, vol. 283, pp. 169–188, Feb. 2015.

[4] K. Szewc, J. Pozorski, and J.-P. Minier, “Simulations of single bubbles rising through viscous liquids using Smoothed Particle Hydrodynamics,” *Int. J. Multiph. Flow*, vol. 50, pp. 98–105, Apr. 2013.