# Simulation Of Gas Injection With The Level Set Method

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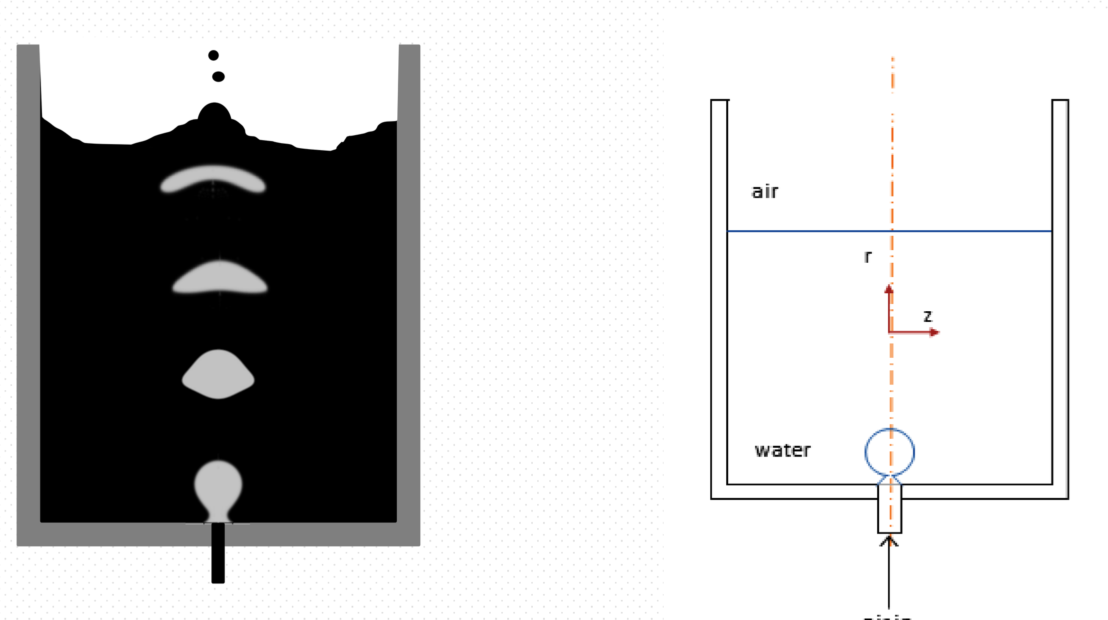
**Introduction**: The bottom injection of gas into liquids at low gas rates to form individual bubbles has been applied in a wide spread applications in process industries. This process has been studied under various conditions, experimentally, analytically and numerically. Experimental studies present difficulties to measure pressure distribution within the bubble and the surrounding liquid without any interference due to the wobbling of the bubble. Analytical models are limited to a few flow regimes only. However, computational fluid dynamics (CFD) has provided an effective alternative for studying the dynamic interactions of gas-liquid flows under a wide range of conditions.

The physical mechanisms that operate in gas injection are complex, since the bubble formation at submerged orifices involves a wide range of length and time scales [1]. Bubble interactions can appear by the wake effect on the previous bubble with its former bubbles and finally coalescence occurs. Rapid pressure variations around the gas bubble interface make the bubble shape to be unstable, and the wobbling effect is present. High velocities are involved in the bubble bursting phenomenon on the free surface, among the others.




(a) (b)

**Figure 1**. (a) Schematic diagram of the bottom gas injection process (b) and computational domain.

**Computational Methods**: To describe the fluid dynamics of both the gas and liquid phase, the Navier-Stokes equations coupled to level set method were solved for incompressible fluids.

$$\rho\frac{\partial \mathbf{u}}{\partial t}-\nabla\cdot\eta\left(\nabla\mathbf{u}+\left(\nabla\mathbf{u}\right)^{T}\right)+\rho\left(\mathbf{u}\cdot\nabla\right)\mathbf{u}+\nabla p=0$$

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

$$\frac{\partial\phi}{\partial t}+\mathbf{u}\cdot\nabla\phi=\gamma\nabla\cdot\left(\varepsilon\nabla\phi-\phi\left(1-\phi\right)\frac{\nabla\phi}{\left|\nabla\phi\right|}\right)$$

Due to the symmetry of the system about the vertical axis, a two dimensional axisymmetric problem was used, as shown in figure 1 (b). For the boundary conditions, at the bottom orifice a constant gas inlet velocity was prescribed. The gas is let to go out from the solution domain at the upper part of the vessel. Initial position of the interface gas-liquid was prescribed. The contact angle between the liquid and solid was se to 110° .

**Results**: The computed results for bubble rising behavior, and bubble formation were validated against theoretically and numerically results reported in the literature [2]. Figure 2 shows the evolution of the bubbles while rising through the liquid. According with the bubble regime map of Clift et al. [3], an Eo = 9.8 and a $Re_b$ = 2666 computed numerically with the actual operation conditions, the map shows an intermediate spherical cap + wobbling regime.

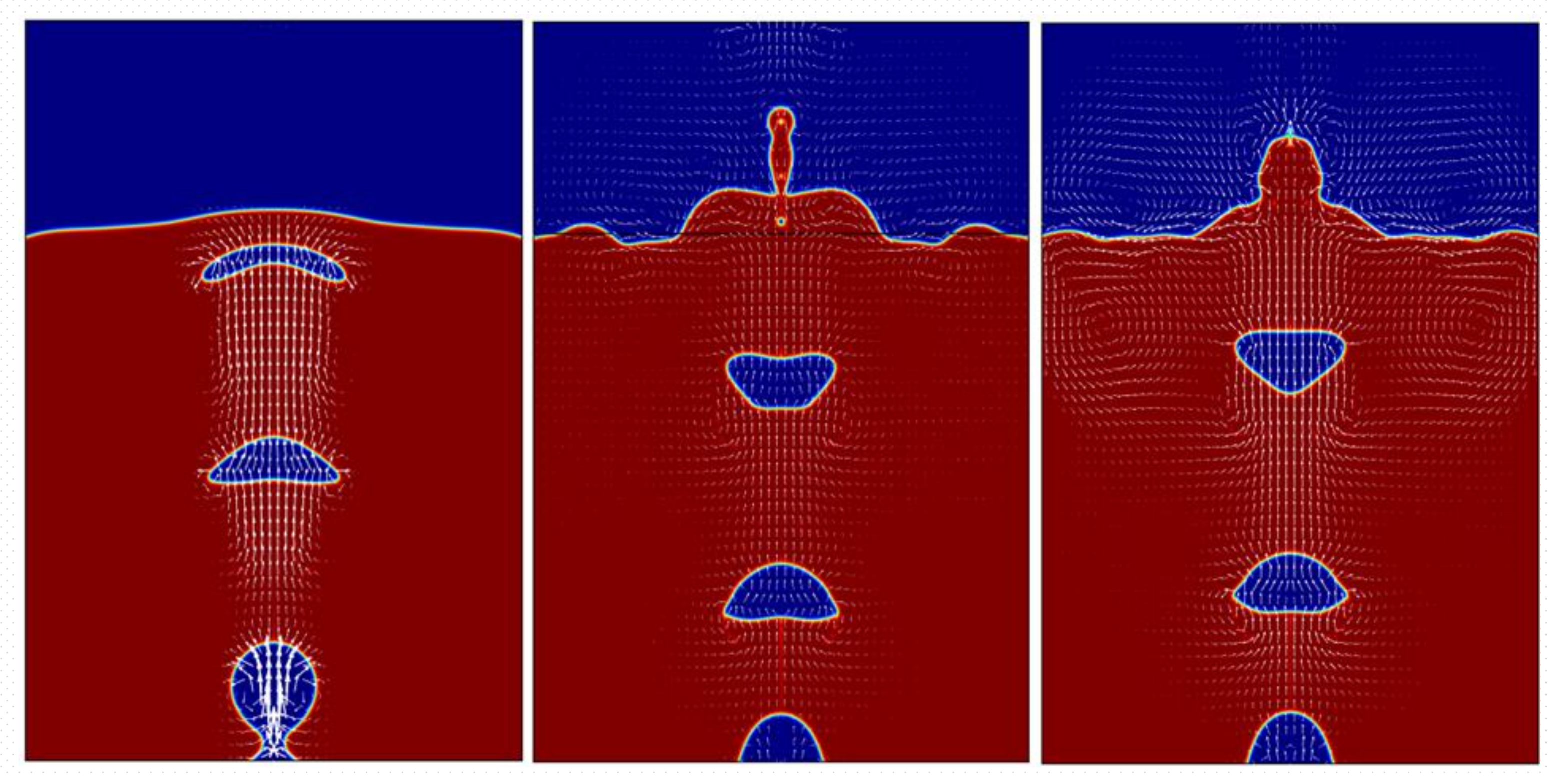


**Figure 2**. Evolution of the bubbles shapes after 0.26, 0.39 and 0.9 s of injection time

Theoretical values for bubble frequency formation under current operations conditions are 12.2 (1/s) [2]. Evolution of the air-water free surface is shown in figure 4, when two subsequently bubbles impinge onto the free surface while coalescence of the bubbles occurs.

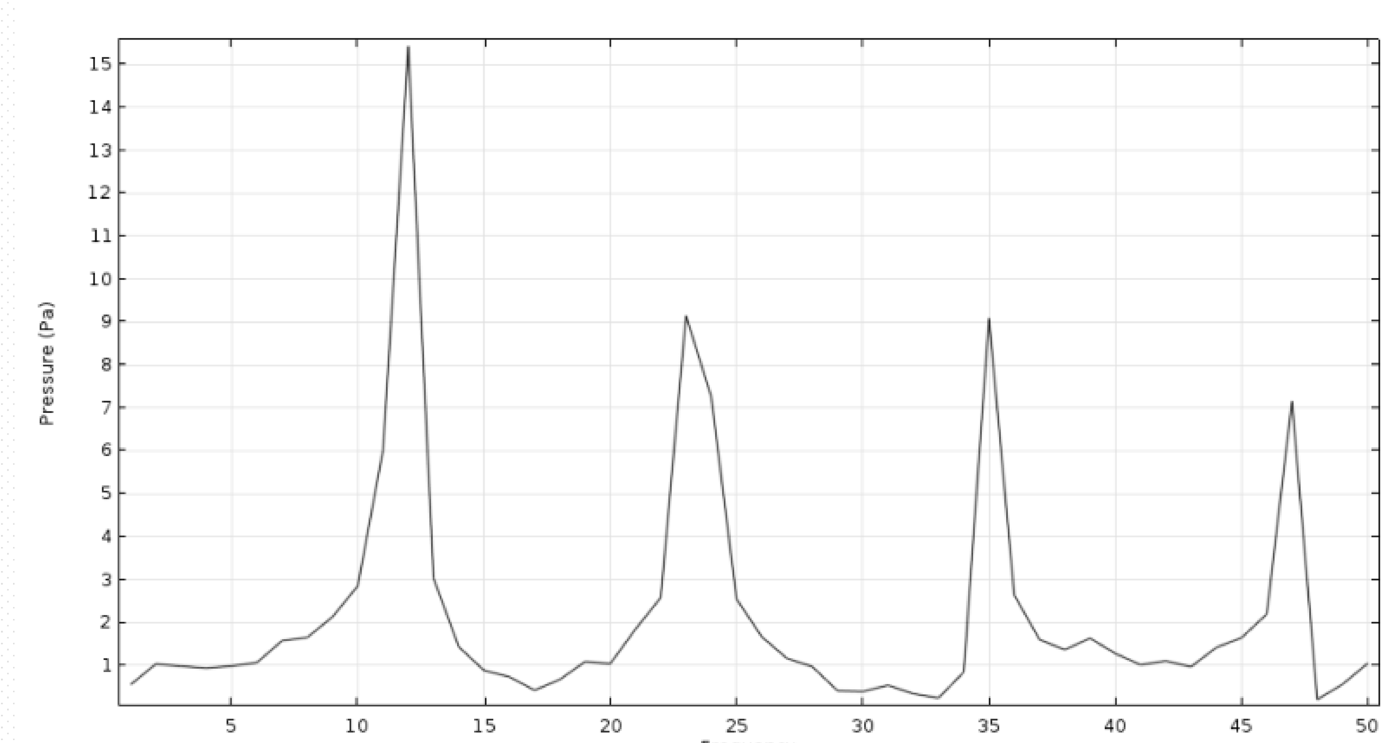



**Figure 3**. Fourier transform of the dynamic pressure at the nozzle.

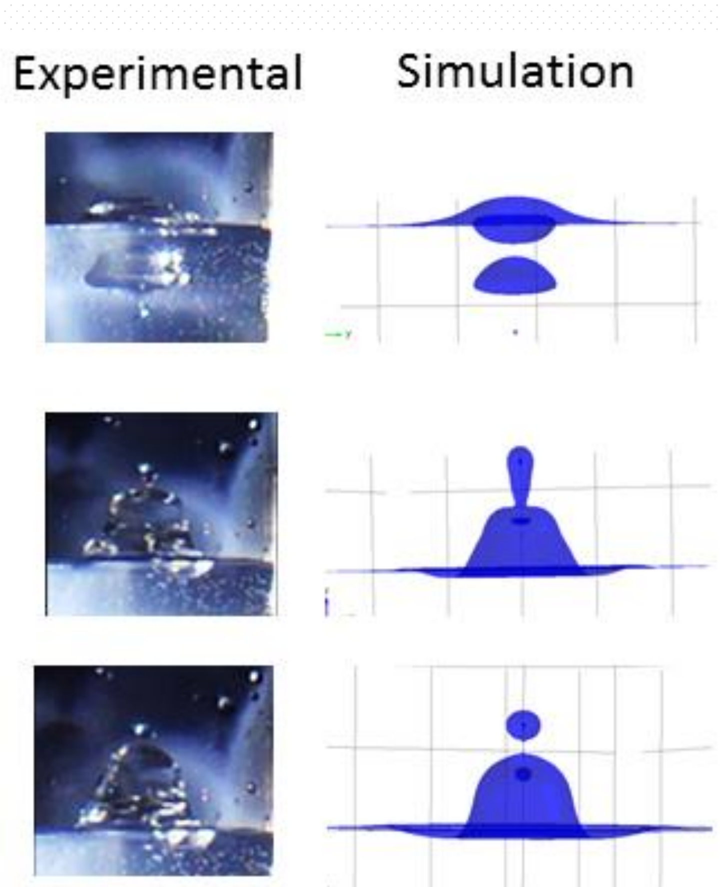



**Figure 4**. Free surface behavior.

**Conclusions**: The complex physical mechanisms that operate in the gas injection process are suitable simulated with the level set method, a method seldom used to study complex industrial applications. Computational fluid dynamics provides an effective means to get better insight into the gas injection process and to accurately predict the dynamic behavior of the bubbles and the free surface deformation.

**References**:
1. C. E. Brennen, Fundamentals of multiphase flows, Cambridge University Press, 2005.
2. A. Valencia, M. Cordova and J. Ortega, Numerical simulation of gas bubble formation at submerged orifice in a liquid, Int. Comm. Heat Mass Transfer, 29, 821-830, 2002.
3. R. Clif, J. R. Grace and M. E. Webber, Bubble, drops and particles, Academic Press, New York, 1978.