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A level set approach for computation of bubble dynamics in airlift reactors.

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Highlights

- Resolution of 2D incompressible Navier-Stokes equations to study the velocity field.
- Use of level set method to dynamically track bubble interfaces.
- Simulation of bubble trajectories and shapes in the ALR riser.

1. Introduction

In this work, we employ the so-called level set approach to simulate the rising of gas bubbles in a pilot-scale external loop airlift photobioreactor in which microalgae are used to capture CO_2 from flue gas and to treat wastewater.

For the growth of microorganisms, airlift reactors (ALRs) are considered to be superior to both tubular bubble reactors and open ponds, with shear distribution homogeneous throughout the ALR translating in a relatively constant environment, with minimization of sharp changes in the mechanical forces acting on suspended particles. Moreover, in ALRs it is possible to obtain very fast light/dark cycles and a good mixing without high energy demand.

Knowledge of the bubble flow regime is a crucial information to optimize processes inside ALRs. Moreover, when biological reactants such as microalgae are used and bubble flow could damage the cells, the possibility to manipulate the bubble flow regime during microalgae growth becomes a major goal. All this motivates the study and simulation of the phenomenon in detail.

2. Methods

A coupled level set and finite difference method is adopted in this work to track the moving gas-liquid interfaces in the ALR riser. Level set methods implicitly represent dynamic fronts by solving an Hamilton-Jacobi partial differential equation such as the normal flow equation, in turn dependent on a flow function that can be regarded as a speed vector field. This latter, for the case at hand, is obtained by solving the non-dimensional Navier-Stokes equations through a Chorin type projection technique on a staggered grid[1]. Since the level set method is an Eulerian one, it allows to take into account topology variations, i.e. the possibility of bubble coalescing and splitting. This constitutes a significant aspect, as to increase CO_2 exchange between flue gases and microalgae the knowledge of shape and trajectory of the rising bubbles is crucial.

A previous experimental campaign was carried out in the airlift reactor, where the main dynamic parameters were measured[2]. Tracer tests and imaging techniques were used to compute mean bubble dimension, gas and liquid velocities.

Numerical simulations are carried out on a rectangular domain representing the section on the vertical axis of the riser; the values of gas flowrates and incoming fluid velocity are taken in the range obtained from the experimental campaign, in order to compare computation results with the acquired images. The radius of the orifices chosen for simulations is the real dimension of the holes in the stainless steel plate diffuser.

The rise, shape dynamics and coalescence process of the bubbles of flue gas are studied. Reynolds numbers of both liquid and gas phases, as well Eötvös, Morton and Weber numbers of rising bubbles and the liquid velocity distribution inside the riser are computed. Surface tension is modeled as a force concentrated on the interface, in a form ascribable to Unverdi and Tryggvason[3], which takes into account the curvature of the interface, the coefficient of surface tension and hinges on the Dirac delta function of the signed distance function from the interface.

As it is well known, level set methods suffer of a mass loss issue. Nevertheless, by introducing a mass balance correction, the problem is bypassed and computation results are in agreement with the experimental ones.

3. Results and discussion

The airlift reactor under study is shown in Figure 1, and some simulations of the bubble flow regime inside the riser with the method proposed are shown in Figure 2.

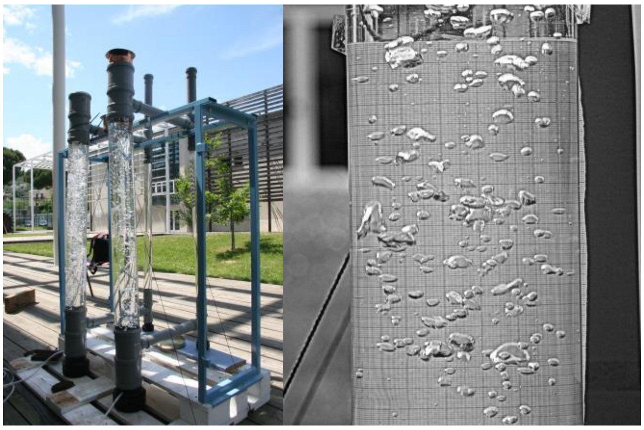

Figure 1. a) airlift rector, b) bubble flow inside the riser;

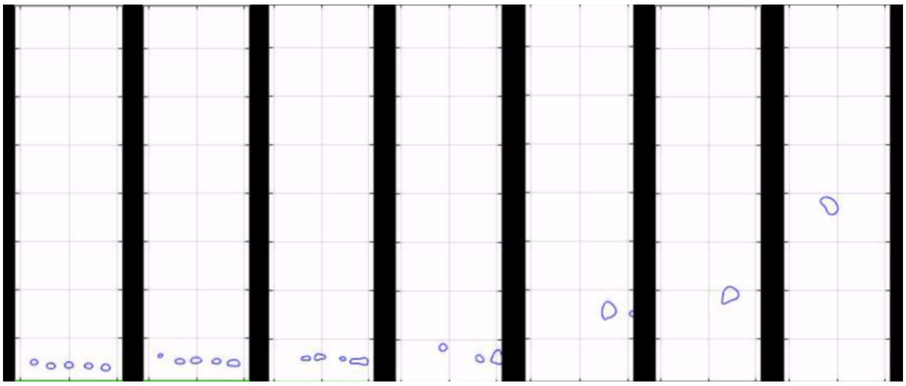

Figure 2. Simulation of instantaneous puff behavior for a 5 bubbles flow inside the riser.

4. Conclusions

The level-set method works well for simulating bubble flow inside the riser of an airlift photobioreactor. Future works will be devoted to introducing CO_2 absorption from gas to liquid phase in the bubbles gas balance.

References

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Keywords

Airlift; level set method; bubble dynamics, optimization.