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An Overview of Multi-Phase Flow Numerical Methods

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Abstract – Numerical simulation of multi-phase flows is complicated and time-intensive. Many investigators have utilized different numerical approaches to describe multi-phase flows in various practical problems, including sprays, cyclones, stratification, etc. This review paper introduces four numerical schemes, including Eulerian–Lagrangian (E–L), Eulerian– Eulerian (E–E), Volume of Fluid (VOF), and front tracking (FT), employed to simulate multi-phase flows. Some advances in the field are introduced and some main characteristics are compared. It is demonstrated that the selection of an appropriate approach depends on the major hydrodynamic properties of the problem.

Keywords – Multi-Phase Flow, Numerical, Eulerian-Lagrangian, Eulerian-Eulerian, VOF, Level Set, Front Tracking

I. INTRODUCTION

Numerical simulation of multi-phase flow using computer codes is time-consuming and too complicated. There are several techniques that have been employed to describe various multi-phase problems based on their particular characteristics [1].

This review paper introduces some multi-phase approaches, including E–L, E–E, VOF, and FT, briefly and presents some advances in the field.

II. EULERIAN-LAGRANGIAN APPROACH

The E–L method can model the behavior of dispersed phases, such as solid particles, in a continuous phase, such as air [2]. The Eulerian framework corresponds to the continuous phase, and the Lagrangian one describes the dispersed phase. Besides, the interaction of particles is determined statistically [3].

The E–L approach has a low computational cost and is utilized for a small number of particles [4]. Many researchers employed the E-L approach to simulate the dynamic collision of particles suspended in a continuous phase, for instance, solid-gas cyclone separators [5-14].

As an example, Gerbino et al. [15] performed E-L simulations to predict the dynamics of a spray due to the initial distribution of droplets, providing a reasonable prediction (Fig. 1).

As mentioned before, cyclone separators have been considered by many researchers. They mostly utilized the E-L scheme to simulate the flow field and performance of cyclones. For instance, Dehdarinejad and Bayareh [10] assessed the impact of wall roughness and twisted guide baffles on cyclone performance and reported a good agreement between the numerical results and experimental data (Fig. 2).

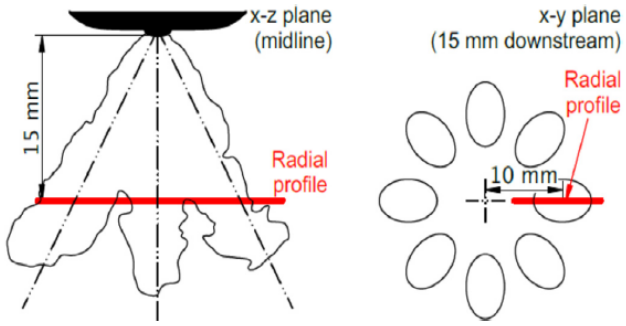

Fig. 1 Schematic of the problem considered by Gerbino et al. [15].

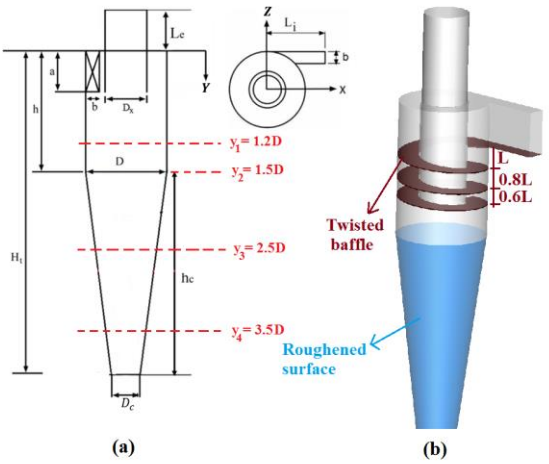

Fig. 2 Schematic of a cyclone simulated using the E-L method [10].

III. Eulerian-Eulerian Approach

The E–E technique assumes that two phases behave as a continuum, and the governing equations are phase-averaged in each control cell. The E–E method has a high computational cost for the simulation of a large number of particles [2]. The two phases are recognized utilizing volume fraction (α). Hence, the density and viscosity of the two phases are estimated as [16]:

$$\rho(x,t) = \rho_1\alpha + \rho_2(1-\alpha) \quad (1)$$

$$\mu(x,t) = \mu_1\alpha + \mu_2(1-\alpha) \quad (2)$$

Here, subscripts 1 and 2 indicate two phases. Najafizadeh et al. [17] employed the E-E scheme to describe the hydrodynamic behavior of air-water flow in a helical vertical tube (Fig. 3). They observed some flow patterns, including bubbly and annular, by changing the air inlet velocity.

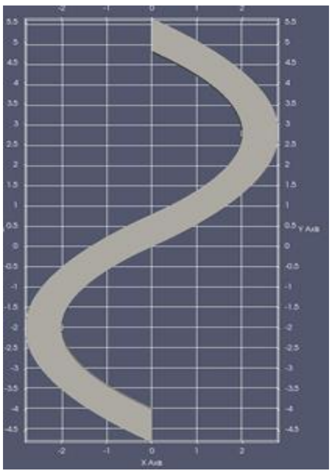

Fig. 3 Schematic of the problem considered by Najafizadeh et al. [15].

IV. Volume of Fluid Method

The VOF method which is a surface-capturing technique assesses the dynamic behavior of the interface between two phases. Similar to the E-E method, the volume fraction of each fluid in each computational cell is captured in the computational domain. The same as the E-E method, $\alpha = 0$ when the computational cell is occupied by the dispersed phase, $\alpha = 1$ when the computational cell is occupied by the continuous phase, and $0 < \alpha < 1$ when the cell involves the interface between the two dispersed and continuous phases [18-21]. For instance, Hassanzadeh et al. [19] employed the VOF to simulate the head-on collision of two drops falling in a vertical channel (Fig. 4). They verified the numerical results with the lattice Boltzmann results and reported good agreement between the findings.

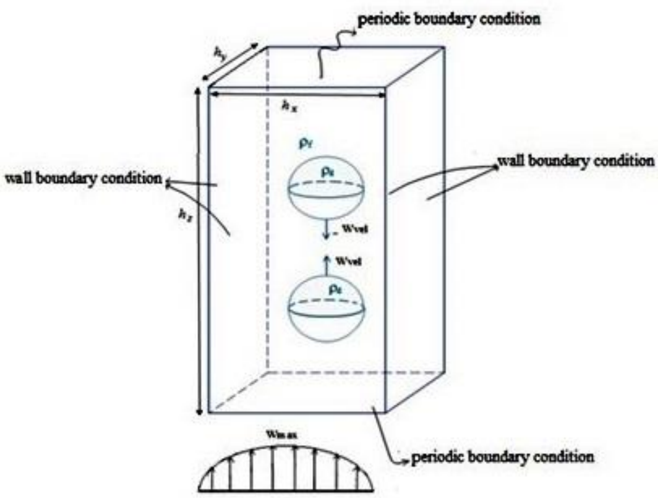

Fig. 4 Schematic of the problem considered by Hassanzadeh et al. [15].

V. Front Tracking Method

The FT scheme based on the projection method is utilized to describe the two-phase flows in different problems. In this method, a Lagrangian grid tracks the interface between the phases, and the flow is solved on a fixed, structured, and staggered grid. It should be pointed out that the governing equations are solved in the whole computational domain [22].

Many researchers utilized the FT approach to simulate two-phase flows [23-34]. For instance, Bayareh et al. [23] used the FT to demonstrate the dynamic behavior of a drop ascending in a stratified fluid (Fig. 5). They validated their results with three numerical and experimental cases, reporting an excellent agreement between the results.

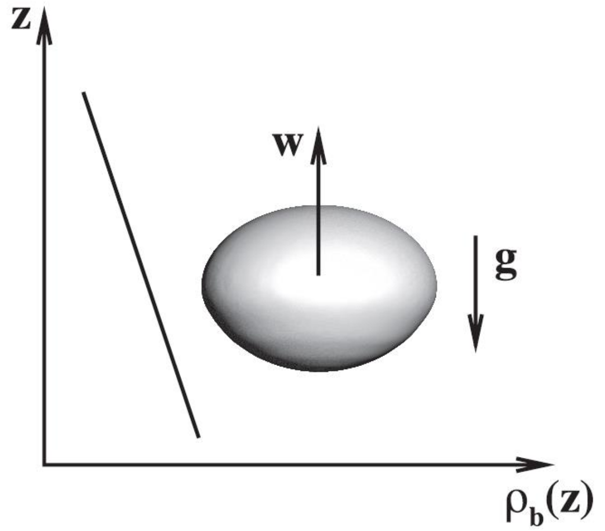

Fig. 5 Schematic of the problem considered by Bayareh et al. [15].

Masiri et al. [25] used the FT scheme to examine the impact of non-Newtonian shear-thinning fluid on the interaction between two drops (Fig. 6). It was demonstrated that the FT method can predict the various stages of drop collision in an inelastic fluid.

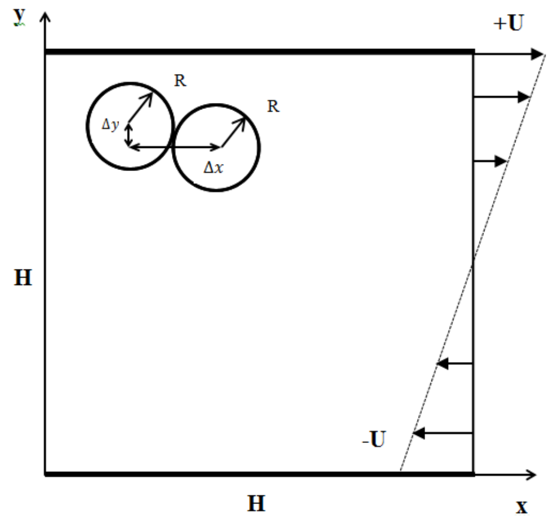

Fig. 6 Schematic of the problem considered by Masiri et al. [25].

VI. CONCLUSION

Multi-phase flows exist in many industrial applications. Numerical simulation of these kinds of flows is costly and complicated. This review paper explains four numerical schemes, including E–L, E–E, VOF, and FT, used to simulate multi-phase flows. Some advances in the field are introduced and some main characteristics are compared. It is revealed that the selection of a suitable method depends on the major hydrodynamic characteristics of the problem.

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