A Particle-Gridless Hybrid Method for Thermal-Hydraulic Analysis in Complex Geometry

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Abstract

A particle-gridless hybrid method is proposed for thermal-hydraulic analysis in complex geometry. MAFL (Meshless Advection using Flow-direction Local grid) is developed as a new gridless method which is an Eulerian type. MPS (Moving Particle Semi-implicit) is employed as a particle method which is a Lagrangian type. Thus, the present hybrid method, named MPS-MAFL, enables arbitrary Lagrangian-Eulerian calculations without the use of computational grids. A rising bubble in stagnant liquids is simulated using MPS-MAFL. The predicted bubble shapes agree well with the experimental results.

1 Introduction

Numerical methods without the use of grid structure have potential for the analyses of thermal-hydraulic problems having complex geometry and interface where the conventional grid methods suffer from mesh generation. These meshless methods can be roughly classified into the Lagrangian (particle) and the Eulerian (gridless) types. Moving Particle Semi-implicit (MPS) method was proposed as a particle method for analyzing incompressible flows. In this study, a new gridless method MAFL (Meshless Advection using Flow-direction Local grid) is proposed based on a flow directional local grid. Besides, combining the present gridless method with MPS, we developed MPS-MAFL method to allow arbitrary Lagrangian-Eulerian calculations. A rising bubble in stagnant liquids is analyzed using MPS-MAFL.

2 Numerical Method

The mass and momentum conservation equations are

$$\nabla \bullet \mathbf{u} = 0 \ , \tag{1}$$

$$\rho\Big(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \bullet \nabla \mathbf{u}\Big) = -\nabla p + \nu \nabla^2 \mathbf{u} + \sigma\kappa \cdot \mathbf{n} + \mathbf{g} \ . \tag{2}$$

Surface tension is involved in the momentum equation as shown in the third term of the right hand side of Eq.(2).

In MAFL, the convection term is calculated by four stages as follows.

(1) *Generation of Flow Directional Local Grid* : A one-dimensional local grid line is generated at each computing point in the direction of the flow velocity vector as shown in Fig.1. Two upstream and one downstream local grid points are located on this line.

(2) *Local Interpolation* : At the three local grid points on the one-dimensional local grid line, physical quantities are interpolated from neighboring computing points using a weighting function.

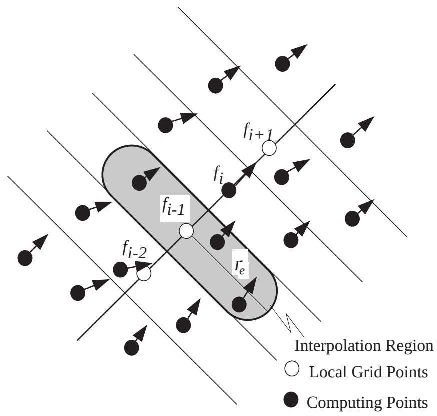

Fig.1: Convection calculation scheme in MAFL.

(3) *Convection Scheme* :
The convection term is calculated by a difference scheme, QUICK, using the three local grid points. Other higher-order difference schemes can be used where necessary number of local grid points are given.

(4) *MMT filtering* :
Usually a higher-order scheme results in oscillatory solutions. To prevent the overshoot and undershoot in the solution obtained in the third stage, a filtering scheme, Min-Max Truncation (MMT), is applied. Maximum and minimum limits are calculated at each time step and the solution of a higher-order calculation is bounded by them.

3 Analysis of a rising bubble in viscous liquids

A rising bubble in stagnant liquids is calculated by MPS-MAFL in two dimensions. The initial bubble shape is circle and the surrounding liquid is represented by computing points. The liquid flows from the top to the bottom to keep the bubble stationary. The inlet and outlet boundaries are located on the top and bottom, respectively, where the computing points are fixed. On the other hand, the computing points on the bubble surface are moved to trace the deformation of the bubble.

Grace et al. provided a map of the experimental data of the shape of a rising bubble in viscous liquids. Figure 2 illustrates the regimes of bubble shape in three dimensions: sphere, ellipsoid and spherical-cap. The shape is determined by, a Reynolds number ($Re = \rho dU/\mu$), an Eotvos number ($Eo = gd^2\rho/\sigma$) and a Morton number ($Mo = g\mu^4/\sigma^3$). The calculation results are shown in Fig.3. Six combinations of parameters are provided from case (1) to (6). Corresponding locations in Grace's map are plotted in Fig.2. We can see that cases (1) and (2) correspond to the spherical-cap, cases (3) and (4) ellipsoid, and cases (5) and (6) sphere. The calculated bubble shapes agree well with the map.

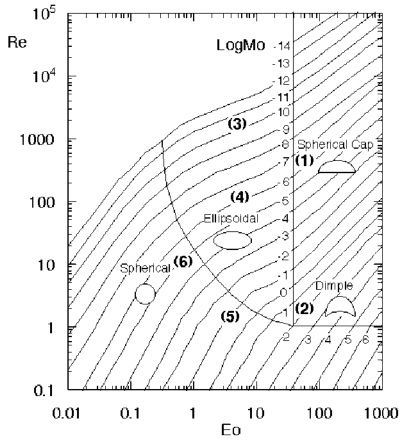

Fig.2: Grace's map of rising bubble shape.

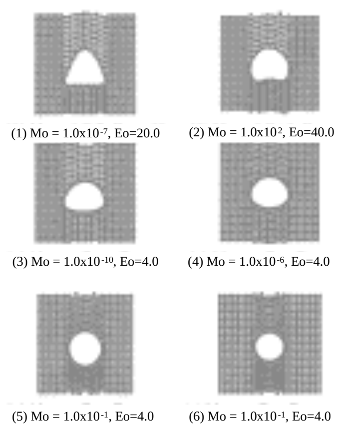

Fig.3: Bubble shapes calculated by MPS-MAFL.

4 Conclusions

MAFL (Meshless Advection using Flow-direction Local grid) is developed as a new gridless method. This method is combined with MPS for the analysis of arbitrary Lagrangian-Eulerian. The combined method, MPS-MAFL, is applied to a rising bubble in stagnant liquids in two dimensions. Spherical-cap, ellipsoid and sphere appear as the bubble shape. These shapes agree well with experimental results.