Efficient algorithm for viscous two-phase flows with real gas effects

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Abstract: A discrete equation method (DEM) for the simulation of compressible multiphase flows including viscous and real-gas effects is illustrated. Simulation results are validated with well-known results in literature. The importance of viscous effects is then analyzed comparing with some Euler solutions. Potentialities in improving the quality of the numerical prediction by using a more complex equation of state are thus drawn.

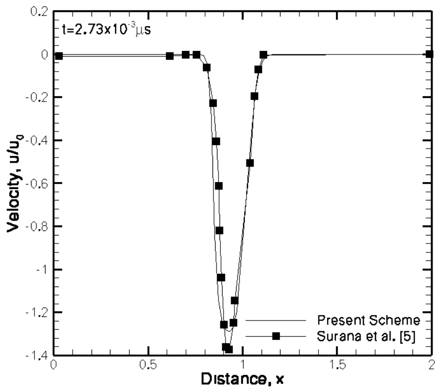
Keywords: DEM, real gas, viscous effects.

1 Introduction

Modeling the two-phase flows is of great interest in CFD community. Two aspects are fundamental: (i) how to model the interface between two fluids with different thermodynamic properties and (ii) to characterize the mechanisms occurring at the interface as well as in zones where the volume fractions are not uniform. The DEM method (see [1]) has been developed to solve multiphase problems without conservation errors, to avoid the computation of average variables and the numerical approximation of the non conservative terms. It is based on a probabilistic approach and has been extensively applied for unsteady, wave propagation inviscid flows using generally a stiffened gas equation of state (SG) for the definition of the thermodynamic (TD) properties. In order to remove some numerical difficulties of DEM, an asymptotic expansion of the scheme has been proposed [2]. The aim of this paper is to develop a general formulation for viscous multiphase flows taking into account complex equation of state. The starting point consists in enriching the discrete scheme of [1] introducing the viscous effects. Then, an asymptotic development is applied as in [2] in order to obtain the discrete form of a reduced multiphase viscous model. Moreover, a SG and a Peng-Robinson (PR) equations of state are implemented. While SG allows preserving the hyperbolicity of the system, real-gas effects are taken into account by using the more complex PR equation.

2 Methodology and Results

The discrete scheme (based on [1]) developed in this work is a finite volume method type. It is solved by a MUSCL scheme and a relaxation Riemann solver for the extension to the second



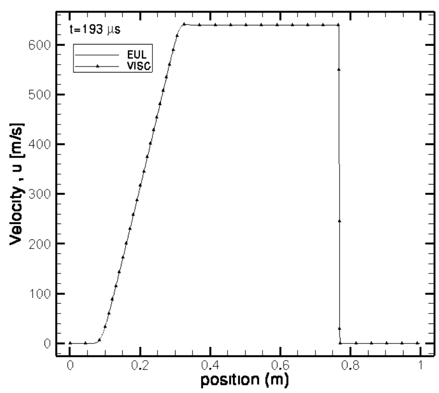


Figure 1: Comparison of the velocity profiles. Left: results of [4] and DEM, right: results with DEM of Euler and viscous formulations.

order:

$$\frac{\left(\alpha_i^{(1)}U_i^{(1)}\right)^{n+1}-\left(\alpha_i^{(1)}U_i^{(1)}\right)^{n}}{\Delta t}+\frac{\mathcal{E}\left(XF\right)_{i+\frac{1}{2}}-\mathcal{E}\left(XF\right)_{i-\frac{1}{2}}}{\Delta x}-\frac{\mathcal{E}\left(XF_v\right)_{i+\frac{1}{2}}-\mathcal{E}\left(XF_v\right)_{i-\frac{1}{2}}}{\Delta x}=$$
$$=\mathcal{E}\left(F^{lag}\tfrac{\partial X}{\partial x}\right)_{i,bound}+\tfrac{1}{\epsilon}\mathcal{E}\left(F^{lag}\tfrac{\partial X}{\partial x}\right)_{i,relax}-\mathcal{E}\left(F_v\tfrac{\partial X}{\partial x}\right)_i \quad (1)$$

where α is the phase volume fraction, $U=(\rho,\rho u,\rho E)$ is the conservative variables vector, F and F_v are the convective and viscous fluxes respectively. $F^{lag}=F(U_{LR}^{+})-\sigma(U_L,U_R)U_{LR}^{+}$ represents the fluxes across the contact discontinuity between the left (U_L) and right (U_R) states, $1/\epsilon$ is related to the interfacial area between fluids. With the asymptotic expansion of (1), *i.e.* $\epsilon\to\infty$, the relaxation term disappears, obtaining in this way the reduced discrete scheme of [2].

Results of two test cases, using SG, are shown. The first is the viscous simulation of a shock tube configuration filled out only with air (left side at a pressure of $10^5 Pa$ and the right side at a pressure of 10^6). A good agreement (see Fig. 1(a)) is obtained between the results obtained in [4] and the DEM method. The second test-case is a shock tube filled out with water and air at the same volume fraction equal to 0.5 (left pressure is equal to 10^9Pa and the right one to 10^5Pa). The comparison between the results obtained with the Euler formulation and the viscous one (see Fig. 1), displays there is a negligible difference between the two models, as it is known in literature [3].

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