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Drag Force Simulation in Explosive Volcanic Flows

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Abstract. This paper focuses on the interphase drag force simulation of volcanic flows by means of mixture formulation with velocity nonequilibrium. Numerical simulations are performed on a volcanic gas-ash mixture collision and the influence of the drag force is verified on a number of cases. These simulations have implications for improving the ability to capture the complex nature of two-phase flow during volcanic eruptions.

Keywords: multiphase flows, nonequilibrium processes, volcanology, simulations
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INTRODUCTION AND EQUATIONS

The relationship between the drag force with which a relative velocity between phases is considered has been always described by the momentum exchange. This drag force may be written in the following general form

$$\pi = \kappa(u_2 - u_1) = \kappa\, u_r. \tag{1}$$

Here, u_1, u_2, u_r and κ denote the velocity of the first phase, velocity of the second phase, relative velocity and a drag function which is a flow regime-dependent. Although the above form is not new and many papers have been dedicated to such form, they do not offer computations that allow one to systematically investigate the effect of this drag force on mixture formulations that involve velocity nonequilibrium. Consequently, a mixture model based on the theory of thermodynamically compatible systems of hyperbolic conservation laws is used to predict such drag force. The model is described by the balance of mass (ρ), momentum (ρu) and energy (E) for the mixture with a relative velocity (u_r) between phases and volume and mass fraction, α and c equations for the second phase. These equations are as follows in process without mass transfer [1]:

$$\partial_t(\rho) + \partial_x(\rho u) = 0 \quad \text{and} \quad \partial_t(\rho u) + \partial_x(\rho u^2 + P + \rho u_r E_{u_r}) = 0, \tag{2}$$

$$\partial_t(\rho E) + \partial_x\Big(\rho u E + P u + \rho u u_r E_{u_r} + \rho E_c E_{u_r}\Big) = 0 \quad \text{and} \quad \partial_t(u_r) + \partial_x(u u_r + E_c) = \pi, \tag{3}$$

$$\partial_t(\rho\alpha) + \partial_x(\rho u \alpha) = 0 \quad \text{and} \quad \partial_t(\rho c) + \partial_x(\rho u c + \rho E_{u_r}) = 0, \tag{4}$$

with E_c and E_{u_r} are found using the mixture energy $E = e + \frac{u^2}{2} + c(1-c)\frac{u_r^2}{2}$. Herein, e denote the mixture internal energy that depends on different equations of state (EOS) of any type for the two phases. The drag function κ appearing in (1) is defined in several forms depending on the properties of two-phase system under observations. For the purposes of this paper, we assume phase one as a fragmented magma, 1, and phase two as a volcanic gas, 2, with negligible gas exsolution. Magma fragmentation occurs when the gas volume fraction reaches a critical value. Fragmentation also causes an explosive volcanic eruption that forms a mixture of ash suspended in gas. Within such situation, fragmentation effect plays a major part in the dynamics of volcanic eruptions. For instance, fragmentation can play a significant role for the large relative velocity between volcanic ash and gas phases during such eruptions. Fragmentation also marks the interfacial friction which is evaluated by means of the drag function κ. In this case, fragmentation generates a wide range of particle sizes from microns to meters in diameter. This paper, therefore, considers the drag interphase aspects with respect to the relative velocity equation. The effects of the drag coefficient on the relative velocity within the context of volcanic gas-ash mixture collision will be examined for different cases of particle sizes. As we shall see later, the volcanic gas-ash mixture collision is investigated on the basis of the Riemann problem and without any drag force influence. We then show numerically how the mixture collision wave structure changes as the drag force varies during the simulations. It is found that the flow fields are significantly affected by magma fragmentation. As a result, it is shown that the two phases will move nearly at equal velocities when the interphase drag force is added to the current model equations.

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COMPUTATIONAL SIMULATION

As mentioned, a thermodynamically compatible hyperbolic conservative model of compressible two-phase flows is applied to simulate the interphase drag force. Due to magma fragmentation, the following drag function is considered for the current simulations

$$\kappa = \frac{3}{8}\frac{C_D}{r_b}\rho c(1-\alpha)|u_r|, \tag{5}$$

where C_D is the drag coefficient for a single volcanic ash and r_b denotes its radius, respectively. In order to achieve an approximated solution of (2)-(4), we need a specific numerical method that can handle accurately the jumps of the relative velocity and correctly simulate the above drag function. As already mentioned, the model equations include conservative terms and can be written in a mixture conservation laws form $\partial_t \mathbb{U} + \partial_x \mathbb{F}(\mathbb{U}) = \mathbb{S}$. Within the framework of finite-volume methods, we apply splitting procedure for simulating the interphase drag force in the current model equations. In this respect the non-source terms problem is solved numerically using Godunov method of centered-type. It is important to note that the current mixture conservation laws are independent of the type of numerical method used to implement it. To this end, we generate a numerical test case, namely, a volcanic gas-ash mixture collision. The results of the main flow variables with final time $t = 0.0008$ are displayed in figures 1, 2, 3 and 4. For such test case we observe that the wave structure exhibits two left shock waves and two right shock waves propagating in opposite direction and separated by a multiple contact discontinuity propagating with mixture velocity u as shown in figure 1. This configuration is representative of the Riemann problem corresponding to the absence of drag force interphase within the model equations. The relative velocity profile is significantly affected by magma fragmentation and phase velocities leading to large enough relative motion between the gas and ash phases. The results shown in figure 2 demonstrate the effect of the source term addition in the relative velocity process, where the r_b is fixed to 8.0 μm for different values of C_D [2, 3]. Figure 3 shows the solutions corresponding to the model equations computed in different values of r_b for a fixed drag coefficient, C_D, of 2.0 . It is clear that the wave structure profiles are significantly affected by the interphase drag force. There is also a considerable effect of both the radius of the fragmented magma particles and the drag coefficient on the relative velocity profiles as seen in figures 2 and 3. Figure 4 shows the relative velocity profile at different values of r_b and C_D with a coarse and very fine meshes, respectively. The results indicate that the waves take finer and finer structure as the number of cells is increased. Further, the numerical results shown in figures 2, 3 and 4 which are computed at time $t = 0.0008$ show that the relative velocity decreases, i.e. the two phases will move at equal velocities, when C_D is increased or r_b decreased.

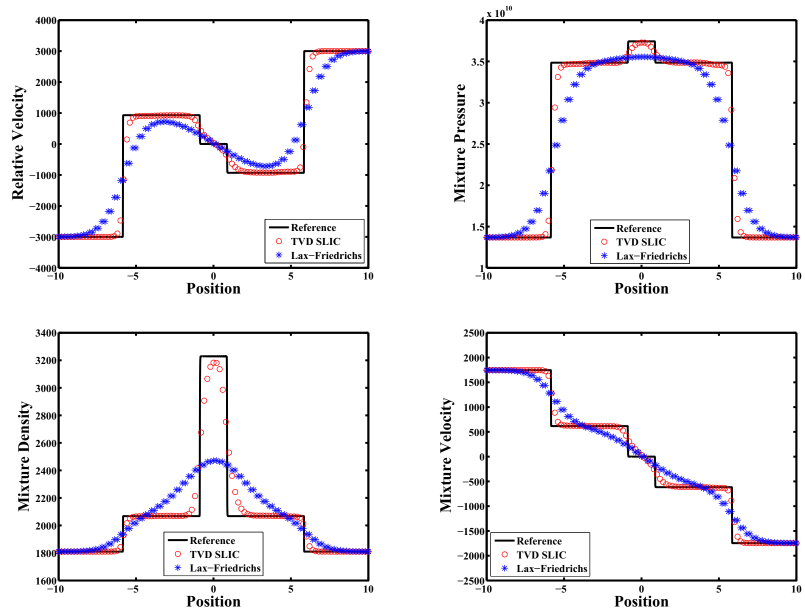

FIGURE 1. Volcanic gas-ash mixture collision. Simulations of the Riemann problem with left and right data as: $(\alpha, \rho_2, \rho_1, u_2, u_1, S_2, S_1) = (0.85, 1600.0, 3000.0, 1000.0, 4000.0, 12658.879, 7556.5895)$ and $(\alpha, \rho_2, \rho_1, u_2, u_1, S_2, S_1) = (0.85, 1600.0, 3000.0, -1000.0, -4000.0, 12658.879, 7556.5895)$. Reference solution (TVD SLIC - line) and numerical resolutions (computed - symbols) at time $t = 0.0008$ obtained on 100 mesh cells, SUPERBEE limiter and CFL $= 0.9$. Numerical solutions are carried out using the TVD SLIC and Lax-Friedrichs methods.

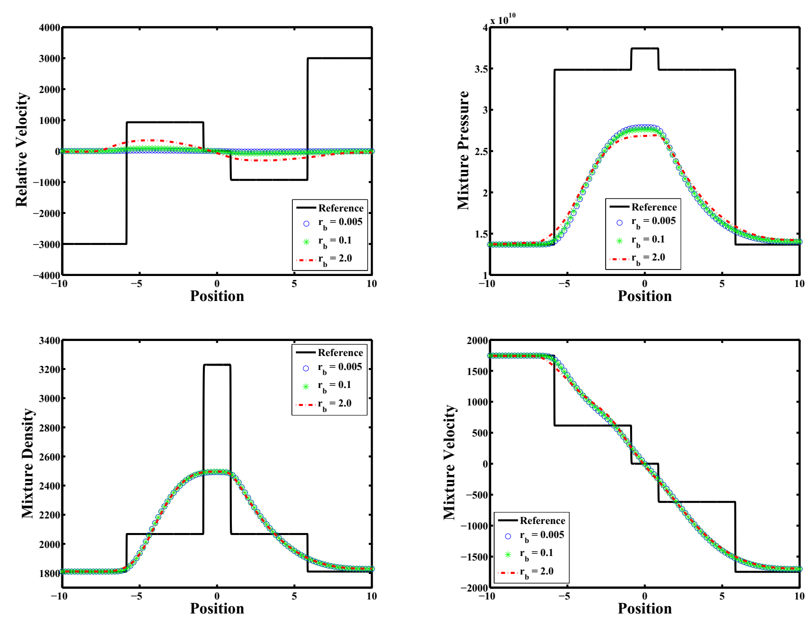

FIGURE 2. Influence of C_D on the behavior of volcanic gas-ash mixture collision. Results obtained using the splitting procedure (computed - symbols) for the lowest possible value of C_D, 0.1, to the highest possible value of 8.0 for a fixed r_b of 8.0 μm along with a coarse mesh of 100 cells at time $t = 0.0008$ and a CFL value of 0.01.

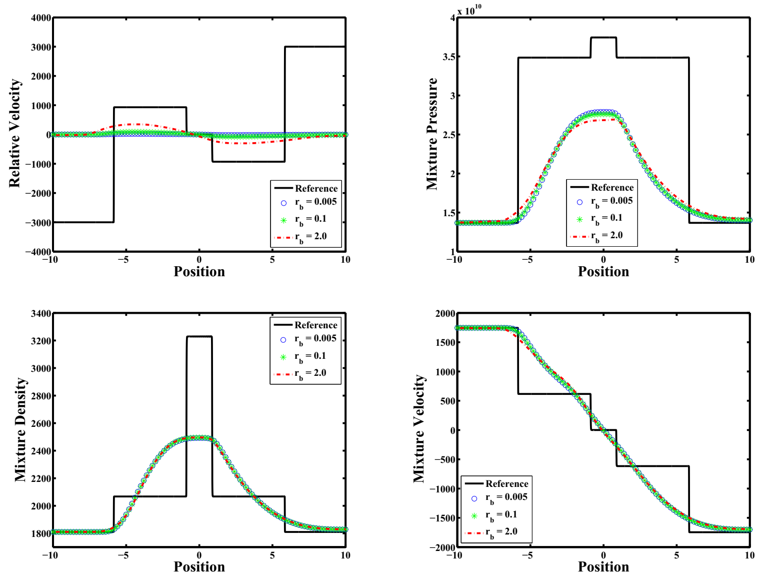

FIGURE 3. Influence of the radius, r_b, on the behavior of volcanic gas-ash mixture collision. As in figure 2, simulations are carried out for a fixed C_D of 2.0 and varying radius r_b from the lowest possible value of 0.005 μm to the highest possible value of 2.0 μm. Symbols indicate the radius, r_b, while the solid lines indicate the reference solutions provided on a very fine mesh using the TVD SLIC scheme.

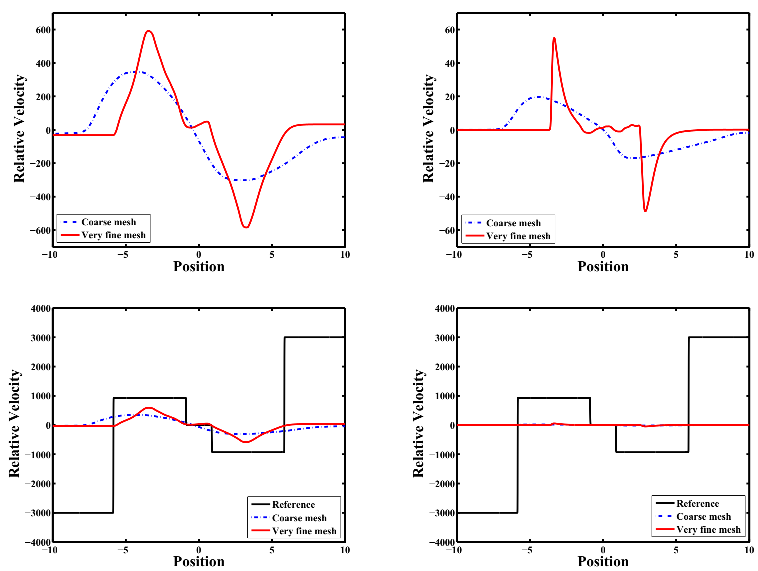

FIGURE 4. Top left refers to the highest possible value of C_D, 8.0, and r_b, 0.8 μm, respectively, on the solution of volcanic gas-ash mixture collision. Top right indicates the lowest possible value of C_D, 2.0, and r_b, 0.005 μm, respectively. Resolution for the relative velocity on a very fine mesh of 3000 and coarse mesh of 100 using the splitting techniques at time $t = 0.0008$ with a CFL$= 0.01$. Bottom left and right panels indicate comparisons of the interphase drag force with the reference solutions.

CONCLUDING REMARKS

The effect of interphase drag force on the relative motion of volcanic two-phase flows is studied within the framework of mixture formulation. These simulation results demonstrate the broad applicability and robustness of the current mixture model. Results also show the great potential of mixture formulations for understanding of the physical phenomenon and can therefore be used as an assessment tool for future volcanic eruption studies. Further developments will include crystals and dissolved gases moving with magmatic mixtures in one and multiple dimensions.

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REFERENCES

1. D. Zeidan, R. Touma and A. Slaouti, Application of Thermodynamically Compatible Two-Phase Flow Model to the High-Resolution Simulations of Compressible Gas-Magma Flow, *Int. J. Numer. Meth. Fluids*, in press, DOI: 10.1002/fld.3936 (2014).
2. M. de' Michieli Vitturi, A. Neri, T. Esposti Ongaro, S. Lo Savio and E. Boschi, Lagrangian Modeling of Large Volcanic Particles: Application to Vulcanian Explosions, *J. Geophys. Res.,* 115: B8:8206-18 (2010).
3. U. Niemeier, C. Timmreck, H.F. Graf, S. Kinne, S. Rast, S. Self, Initial Fate of Fine Ash and Sulfur from Large, *Volcanic Eruptions. Atmos. Chem. Phys.*, 9, 9043-9057 (2009).