Geophysical Research Abstracts
Vol. 16, EGU2014-10614, 2014
EGU General Assembly 2014
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Numerical investigation of gas-particle interaction in polydisperse volcanic jets

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We investigate the problem of underexpanded jet decompression when the injected fluid is a mixture of a gaseous phase and different classes of solid particles. The underexpanded multiphase jet problem is representative of phenomena that can be observed in the first stages of explosive volcanic eruptions. Whereas the case of homogeneous jets has been studied deeply in the literature, both experimentally, theoretically and numerically, the case of multiphase gas–particle jets still presents some open issues.

It has been proven theoretically and experimentally that vents with supersonic or sonic velocity and gas pressure greater than the atmospheric one result in a rapid expansion and acceleration of the fluid to high Mach number. A series of expansion waves form and are reflected as compression waves at the flow boundary. The compression waves coealesce to form a standing normal shock wave (Mach disk), across which the fluid is rapidly compressed and decelerated to subsonic speeds. When solid particles are added to the gas flow, new phenomena associated to kinetic and thermal non-equilibrium between gas and particulate phases arise. Such effects are controlled by drag and heat exchange terms in the momentum and energy equations.

In the present work we carry out two- and three-dimensional numerical simulations with the multiphase flow model PDAC (Neri et al., J. Geophys. Res, 2003; Carcano et al., Geosci. Mod. Dev., 2013), to identify and quantify non-equilibrium effects related to the interaction between the jet decompression structure and solid particles. We quantify, on a theoretical basis, the expected non-equilibrium effects between the gas and the solid phase in terms of the particle Stokes numer (St), i.e. the ratio between the particle relaxation time and a characteristic time scale of the jet (taken as the formation time of the Mach disk shock), for two sample grain-size distributions of natural events (Mount St. Helens, 1980; Vesuvius, aD 79).

The Stokes number condition allows to identify different coupling regimes in polydisperse jets. Particle classes in equilibrium conditions (i.e. with St much less than 1) are tightly coupled to the gas phase and the pseudogas approximation (Ogden et al., J. Geophys. Res., 2008) can be applied. Fine particles affect the jet thermodynamics (by changing the adiabatic coefficient) but do not significantly change the shock wave pattern. On the other hand, the coarsest particles are mostly unaffected by the gas decompression pattern and cross the Mach disk almost undisturbed. Depending on the mass ratio between "fines" (St«1) and "coarse" (St»1) particles, the jet flow pattern can dramatically change, leading to the obliteration of the Mach disk structure.

A hybrid pseudogas-multiphase model has finally been developed to effectively describe non-equilibrium processes in polydisperse volcanic jets while reducing the computational cost of numerical simulations. Results are consistent with the fully multiphase description and highlight the key effect of the total grain size distribution on the jet phase and on the overall stability properties of eruptive column.