MODELING OF PARTICULATES AND CONDENSATES IN IO'S PELE-TYPE VOLCANIC PLUMES. C. Moore, J. Zhang, D. B. Goldstein, P. L. Varghese, L. Trafton, *The University of Texas at Austin, Austin, TX 78712, (chris@cfdlab.ae.utexas.edu).*

Introduction: Volcanic plumes on Io consist mainly of SO_2 gas, but are made visible by the presence of either non-volatile dust or condensed particles. Photometric studies of one plume (Loki) by Collins [1] indicate that particles of sizes from 0.01 μm to 1000 μm are present. Strom and Schneider [2] suggested that the bright envelope that appeared in the ultraviolet brightness images of Io's largest volcano, Pele, may be the result of a concentration of particles at a shock front. In the present work the direct simulation Monte Carlo (DSMC) method is used to show that dust particulates up to 0.1 μm can reach the canopy shock. A computational overlay technique is used to examine the feasibility of condensing volatiles forming the entrained particulates observed in Io's volcanic plumes. Preliminary results show that it may be possible to form condensates of 0.1 μm at the shock front.

Model: The volcanic plume is assumed to be axisymmetric, have a uniform vent velocity of 1 km/s, and emerge in thermal equilibrium at 650 K. The assumed vent diameter is 16 km for the current simulation; the effects of a smaller vent diameter will be presented in the poster. More detail about the rarefied gas dynamics model may be found in [3].

A computational overlay method, in which the particles are treated as a separate species, is used to model the gas/particle flow. We distinguish between inert dust grains convected along with the flow (via a free molecular drag coefficient) and actively growing condensate clusters (treated simply as large molecules). For dust, drag on the particles is calculated from a pre-calculated frozen gas flowfield and the dust particles are allowed to move accordingly; implicit in this method is the assumption that the particles have no effect on the overall gas flow (low dust mass loading). The Knudsen number based on the diameter of the particulate is 10^5-10^6 for micron sized particles and so it is reasonable to assume a free-molecular drag coefficient (eqn. 7.71 in [4]). The particulates are also assumed to be cold, spherical, have a density of 1500 kg/m^3, and be dilute enough so that they would not collide with each other.

The growing clusters, however, are represented as a separate species in the DSMC overlay method, and cluster growth occurs in the plume via monomer-cluster collisions. The cluster species collides either elastically or inelastically with the gas molecules in a pre-calculated flowfield. During a collision, a sticking coefficient, $0<\alpha<1$, is compared against a random number to determine if the monomer will congeal inelastically onto the cluster or collide elastically. The sticking coefficient could, in principle, be a function of several variables including relative collision velocity, cluster size, and internal cluster temperature. In that these dependencies are unknown, the range over which α could produce cluster sizes thought to exist in the plume's shock front is examined parametrically. In order to determine the maximum possible cluster size for a given cluster density, the sticking coefficient is set to one. It is further assumed that the clusters congealed as tight packed spheres as opposed to diffuse snowflakes (as could be the case). This meant that the clusters formed would have as small a cross section as possible and therefore suffer the fewest collisions possible representing the lower limit of condensate sizes that could be produced.

Results: Example dust results are shown in Figs. 1 and 2. Figure 1 illustrates the shape of the gas and particle jets. Fig. 2 shows the trajectories of the dust in the plume. A concentration of particles at or near the canopy shock clearly appears for 0.01 μm particles as a result of the deceleration of particles near the shock. The 0.1 μm particles, however, are heavier and therefore the increased inertia allows the dust to rise well above and then fall back through the shock. These results provide strong support to Strom and Schneider's suggestion as to the cause of the bright envelope appearing in the ultraviolet smoothed brightness images of Pele.

Fig. 3 shows the trajectories of several clusters for an α=0.1. The trajectories are qualitatively the similar to those of the 0.05 μm dust (Fig. 2). The clusters, like the dust, pass through the gas shock and continue up to an altitude of 350 km and then fall back through the shock; however, they do not form a distinct underside canopy. Therefore, the cluster's behavior seems to indicate that they are larger than 0.05 μm at the shock. Also, Fig. 3 shows that the molecules created further from the vent center tended to intersect the shock at larger R. The cluster size as a function of altitude is shown in Fig. 4 for two values of α. For a sticking coefficient of 0.1, the size of a representative cluster at its maximum altitude is seen to be approximately 0.05 μm. Furthermore, the majority of cluster growth is seen to occur in the first 50 km (where the gas density is greatest) with a second, smaller growth period coming at the shock. As one would expect, for α=1 the cluster grows much faster and the final size is larger, though the same general trend is observed in both cases. An idea of the size distribution along the shock front can also be obtained from Fig. 4: the largest particles are those which spend the most time in the dense plume core along the symmetry axis.

Fig. 5 shows the dependence of the average cluster size upon α at a constant altitude (300 km) just below the shock. For small α the growing cluster escapes the dense core of the plume before growing appreciably and therefore the final size is very small; however, as α increases the growth is limited more by the time spent in the core region rather than the value of α. It appears that even if α=1, the clusters cannot grow larger than 0.1 μm. If larger grains are observed, they likely contain nonvolatile material or are diffuse snowflakes.

References: [1] Collins, S.A., J. Geophys. Res., **86**, 8621-8626.

[2] Strom, R.G., and Schneider, N.M., *Satellites of Jupiter*, pp. 598-633.

[3] Zhang, J., et al. (2002) 23rd International Symposium on Rarefied Gas Dynamics.

[4] Bird, G.A. (1994) *Molecular Gas Dynamics and Direct Simulation of Gas Flows*.

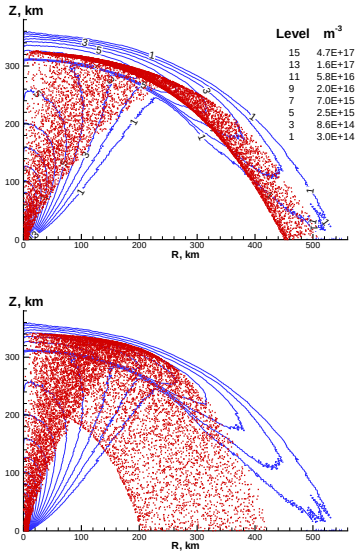

Figure 1: Shape of the gas and dust particle jets for different particle sizes: d=0.01μm (top) and d=0.1μm (bottom). Note that particle locations are represented by small dots and the blue contours indicate gas density field. A gas shock occurs at 310km and dust concentration features may occur at widely different altitudes.

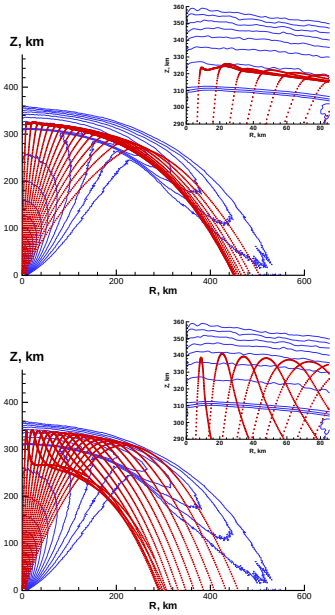

Figure 2: Trajectory of different size dust particles (d = 0.01 μm (top) and 0.05 μm (bottom)) with insets showing the vicinity of the canopy shock near the symmetry axis. Note the deposition ring's size dependence on the dust size. The gas density contours are the same as in Fig. 1

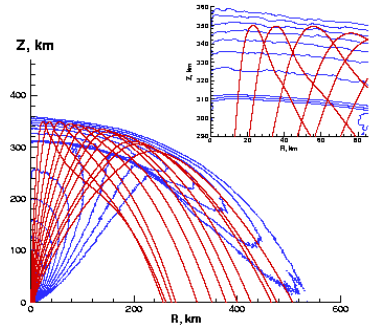

Figure 3: Trajectory of different condensates (α=0.1) with inset showing the vicinity of the canopy shock (blue) near the symmetry axis. The gas density contours are the same as in Fig. 1

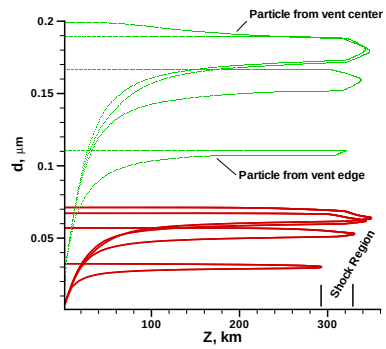

Figure 4: Condensate size vs. Altitude for varying initial condensate radial positions at the vent and two different values of α. Green Lines are α=1, Red are α=0.1.

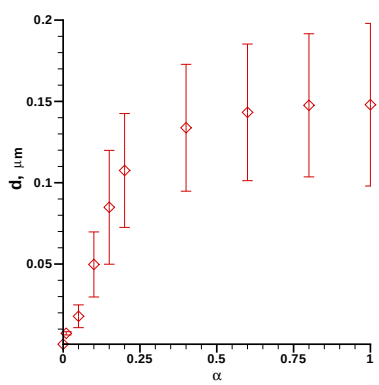

Figure 5: Average condensate size vs. α at the shock. The bars represent the range of sizes obtained.