Characterizing Cryovolcanic Conduit Conditions On Enceladus Using Multiphase Modeling. P.V. Regensburger[1], J. Dufek[1], and C.S. Paty[1], [1]Department of Earth Sciences, University of Oregon, Eugene, OR 97403, USA (pvr@uoregon.edu)

Introduction: The South Polar Terrain of Enceladus possesses fractures that source cryovolcanic eruptions that carry water vapor, ice grains, and salts from the interior onto the surface and the near space environment [1], even feeding the E ring of Saturn. The eruptions consist of both individual jets and a more effusive curtain eruption along the length of the fracture systems [2]. The high velocity jets result from a nozzle structure in the subsurface conduit, accelerating the multiphase flow to supersonic velocities. The jets loft material high enough that spacecraft such as Cassini to capture in-situ samples for analysis. By ejecting subsurface material to heights reachable by spacecraft, the cryovolcanic plumes of Enceladus are able to provide a unique insight into the chemistry and physical processes occurring in the interior. Understanding what is occurring in the subsurface conduit is key to interpreting data collected from observations of the Enceladus plumes.

A cryovolcanic eruption is initiated when a fracture connects the surface to a source of liquid water present within the interior of Enceladus. The exact nature of the source is not well constrained with possible sources being the interior ocean or a subsurface pocket of brine within the ice shell [3]. Fractures propagating downward from the surface may fully penetrate down to the interior ocean for ice shells less than 25km [4]. If a fracture reaches the interior ocean, the water will rise in the fissure to the point of hydrostatic equilibrium ~90% of the height of the fracture. If a subsurface reservoir is the source, then progressive freezing will increase the pressure to the point that a fracture opens to the surface. Either way, an eruption occurs when the liquid water then boils into water vapor with ice grains condensing to generate the multiphase flow. This mixture then accelerates up the conduit and expands above the vent.

While the jets are most relevant to our understanding given they were the source for in-situ observations of the plume by Cassini, the jets are transient features. While the overall output of Enceladus is relatively consistent, individual jets appear to activate and deactivate stochastically. The temporal variability in output is not fully explained by tidal forces and a possible explanation lies in changes in the subsurface geometry of the eruptive conduit [5]. The exact conditions that lead to the transience of the jets as they emerge from or fade into the effusive curtain eruption along the South Polar Terrain fractures is not well defined. By running a suite of simulations, we further constrain subsurface conditions for cryovolcanic eruptions on Enceladus by defining the transition effusive output to jet activity in the South Polar Terrain.

Multiphase Model: To simulate the cryovolcanic eruptions, we use MFIX, a robust physics-based multiphase model which has previously been used to examine a range of volcanic and cryogenic flows on Earth, Mars, Enceladus, and Europa [6]. A cylindrically symmetric 100m section of conduit is modeled with a mixture of water vapor and ice grains flowing into the base of the conduit and accelerating up the fracture. The conduit geometry is set to narrow so as to replicate a potential nozzle structure. The gas and solid particle phases in the multi-continua (Eulerian-Eulerian) approach have separate conservation equations and are drag coupled. A highly refined grid in the conduit simulations reproduces choked flow conditions for multiphase flow by directly solving the momentum equations, resolving interacting shocks and particle collisions in the expansion region. The model is run until a steady state equilibrium flow is reached and the flow's properties are then sampled above the vent.

As subsurface conditions are not well constrained, we explore a wide parameter space of flow properties and geometry conditions. Model input parameters such as vent width, solid-to-gas ratio, particle sizes, temperature, and initial velocities and pressures are constrained by existing observational data of the surface expression of the vent such as from Cassini's Visual and Infrared Mapping Spectrometer (VIMS) data [7], by fitting of physical properties of the plume from Cassini flybys [8], and from existing modeling work of the upper conduit and plume [9].

Characterizing Flow Properties: We measure flux properties of our conduit models as it outflows at the vent, focusing on gas and particle velocities, concentration of ice grains, gas pressure, and other properties that control the dynamics of the eruptive plume. In the case of choked flow, information above the vent is not propagated downward into the conduit. The most distinct delineation between the effusive curtain eruptions and the jets is the transition to supersonic flow. To find this transition, the properties at the vent are used to calculate the local speed of sound for a dusty gas which is then used to determine the Mach Number for the flow, which is the ratio of the flow velocity to the speed of sound. If the Mach Number of the flow is less than one, then the combination of conditions can be characterized as a possible curtain-style eruption. If the Mach Number of the flow is greater than one, then the combination of conditions can be characterized as a possible jet.

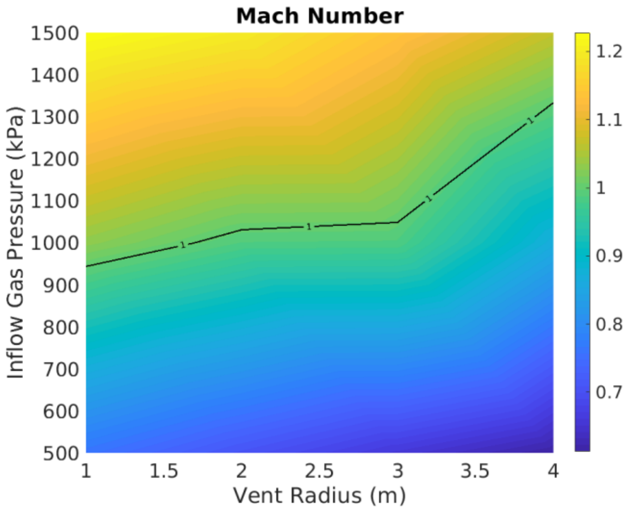

Figure 1: *Contour plot showing the Mach Number just outside of the vent with a set inflow radius of 5 meters before narrowing to the Vent Radius as listed along the x-axis. The y-axis is the varied inflow gas pressure that is driving the eruption, a combined effect of depth and pressurization of the source. A contour line for Mach Number equals 1 is added to delineate the sub- and super-sonic eruptions based on the inflow parameters.*

Mach Line Delineation and Considerations: The acceleration experienced by the multiphase flow is strongly dependent on ratio of cross-sectional areas of the narrowing conduit. In the case of **Figure 1**, we present a regime diagram with an inflow radius of 5m that then narrows to a Vent Radius. The inflow radius is chosen based on the VIMS observation of maximum conduit width [7] although it is possible that the conduit could be significantly wider at depth. Having the conduit wider at depth would lead to more drastic narrowing and further acceleration, effectively lowering the pressure necessary for a given vent radius to reach supersonic flow. Given Enceladus's gravity and the properties of ice, if the inflow pressure is purely due to depth below the surface, then every 100kPa of pressure would be roughly equal to a kilometer of depth. Collimated jets on Enceladus could have jets as fast as Mach 5 or Mach 8 [10] which would necessitate narrower vents and higher gas pressures than presented in **Figure 1**.

Outlook: By presenting physics-based modeling results for the subsurface conduits sourcing the cryovolcanic plumes on Enceladus, we have better characterized a minimum bound for the conditions necessary for supersonic jet eruptions. If variations in subsurface conditions is the basis for transience in cryovolcanic jets, then this work provides a starting point for geometries and pressures in future studies.

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