MODELING THE EFFECTS OF MOLTEN FUEL–COOLANT INTERACTION ON PLANETARY VOLCANISM: PHASE 1 HYDRODYNAMIC MIXING. E. P. Fitch[1], J. Dufek[2], K. Mitchell[1], R.M.C. Lopes[1]. [1]NASA Jet Propulsion Laboratory, California Institute of Technology, erin.fitch@jpl.nasa.gov, [2]University of Oregon.

Introduction: During about 30% of volcanic eruptions on Earth, magma encounters groundwater or surficial water, ice, or snow, which results in steam explosions that intensify the eruption[1]. Similar explosions generated by lava–water interactions are known to occur on Earth and Mars[2]. The most energetic underlying mechanism of these steam explosions, Molten Fuel–Coolant Interaction[3] (MFCI) almost certainly occurs on other planetary bodies as well. This dynamic process influences any system involving molten materials ("fuel") and external fluids that can be easily volatilized ("coolant"), and can significantly influence the energetics of volcanic eruptions[4,5].

MFCI progresses over four phases[1,4,6]: phase (1) hydrodynamic (ductile) mixing of melt and water, and the development of a vapor film at the melt–water interface; phase (2) natural instabilities in the system result in the collapse of the vapor film and production of stresses that propagate through the cooling melt, which undergoes deformation and fine brittle fragmentation and production of fine ash-sized grains; phase (3) escalating thermal energy transfer through the surface of fine ash-sized grains at the fragmented melt–water interface and super-heating of the water; phase (4) vaporization of the water and continued expansion through the melt[6].

Previous terrestrial work has utilized field and laboratory data to estimate explosion energy during MFCI, however, application of these results to eruptions has plateaued due to the lack of any numerical simulations of MFCI in volcanic systems. Building a simulation of this complex and dynamic process, while difficult, has broad implications for interpreting eruption dynamics, i.e., the degree of fragmentation and dispersal of volcanic ejecta. As part of this effort, we focus in this presentation on the initial, pre-explosion stage of MFCI (i.e., phase 1), which is characterized by the production of a vapor film between the melt and water, and hydrodynamic (i.e., ductile) mixing of the two fluids. Processes that occur during this phase significantly influence the progression of MFCI, and the resulting energetics.

Simulation Setup: To capture vapor film production and hydrodynamic processes, we use ANSYS Fluent with standard fluid dynamics and heat transfer models, and the addition of the Volume of Fluid Method to track the fluid interface. To capture fine-scale processes, the mesh is composed of 50 μm square cells, and the simulation was run using a 0.1 μs timestep.

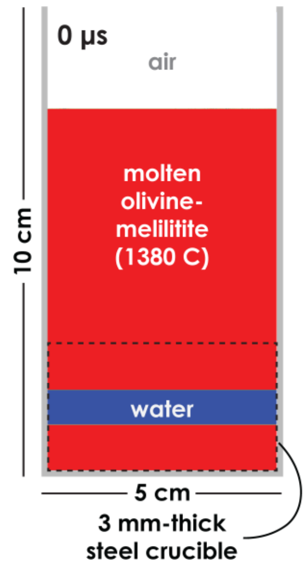

Fig. 1. *The crucible set-up used in laboratory experiments, that we replicate in ANSYS Fluent. The black, dashed line marks the area of the simulation displayed in Fig. 2.*

For the purpose of validation, the simulation is set up similarly to previous MFCI laboratory experiments[7,8], where molten olivine-melilitite is brought to 1380 °C and water around 80 °C is pumped into the melt. Therefore, water is heated at the top and bottom. Experimental melt properties were acquired by previous workers[8] or obtained using RhyoliteMELTS[9]. A 3 mm-thick steel crucible was used in experiments as well, and the simulated crucible was given a temperature of 80 C, to reflect that it is a rapid heat conductor.

Results & Discussion: Initially, we observe the generation of a water vapor film at the interface between the melt and water (Fig. 2a), known as the Leidenfrost effect, as anticipated by MFCI theory[7]. This water vapor film develops a dynamic, irregular boundary as fluid instabilities developed (Fig. 2b).

Previous MFCI work has followed convention by classifying these fluid instabilities as Rayleigh–Taylor fluid instabilities[10], due to gravitational forces acting on a denser fluid overlying a less dense fluid. Not only would this instability not be as effective on lower-gravity bodies, compared with Earth, but this mechanism has been challenged by recent experimental work on the Leidenfrost effect on Earth[11]. Instead, we propose that vapor-film dynamics may cause impulsive acceleration of the melt and water, which having differing densities, may result in the development of fluid instabilities. A high-energy form of fluid instabilities that operate under these conditions, Richtmyer-Meshkov instabilities, may be the best classification at this time, but have traditionally been associated with much larger and/or more energetic systems, such as supersonic combustion and supernova

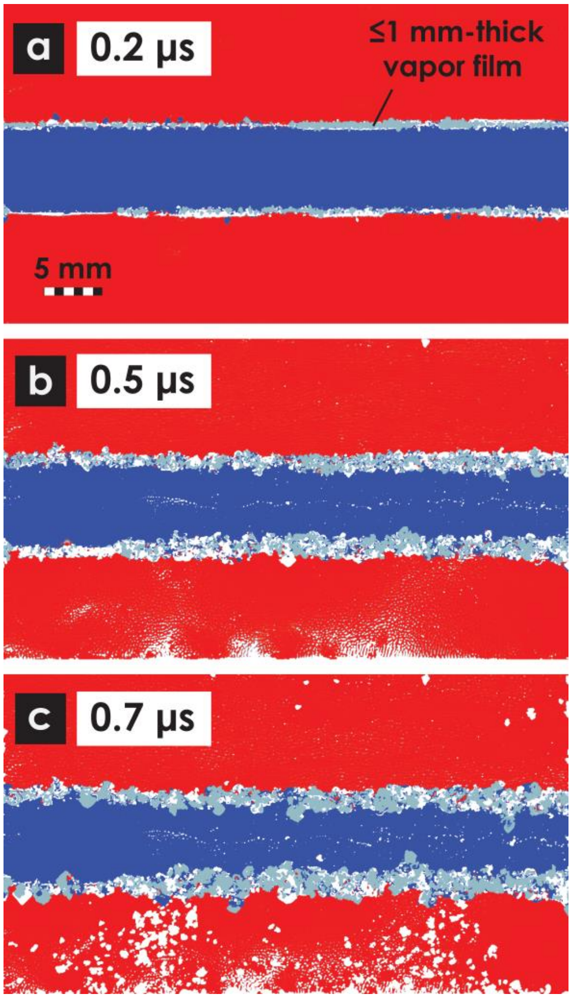

Fig. 2. *MFCI Phase 1 Simulation results. See the Results & Discussion section for details on panels a-c. The black, dashed line in Fig. 1 marks the area of the simulation displayed here.*

expansion. Planned future numerical modeling of MFCI progression will allow us to investigate this further.

As fluid instabilities developed, hydrodynamically fragmented fine ash formed at the interface (Fig. 2b,c), which is theoretically highly dependent on melt viscosity. The experimental melt being simulated here, is derived from basaltic material, but was enriched in iron during experimental preparation. Therefore, it has a lower viscosity than its original basaltic composition would have had, making it more likely to hydrodynamically fragment, than basaltic magma or lava. Therefore, this observation provides an important validation of laboratory experiments, but may not reflect the prevalence of hydrodynamic fragmentation in MFCI Phase 1 in natural systems, unless ultramafic basalt is involved.

As Phase 1 progressed, vapor film turbulence increased and dynamic movement of air, both down and up through the melt, was observed (Fig. 2c). This production of air bubbles can influence hydrodynamic fragmentation and ejection force during the subsequent explosion, especially for lower-gravity bodies like Mars. This potential additional source of energy is not discussed in MFCI theory, nor is it a process that could be observed during MFCI laboratory experiments. Therefore, this simulation provides a novel opportunity to observe and quantify this effect among others fundamental to hydrovolcanic processes across the solar system.

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