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EXPERIMENTALLY BACKED MODEL OF BUBBLY FLOW IN A CNTP REACTOR

Abstract

A critical function in high performance liquid fuel nuclear thermal propulsion (NTP) is the heat transfer from the molten uranium fuel to the hydrogen gas propellant through a centrifugal fuel element (CFE). This heat transfer is governed by several properties of the bubbly flow including bubble shape, volume, and velocity. Currently, little is known about the properties of liquid uranium in the temperature range of a high performance NTP engine, reducing the fidelity of heat transfer models.

To better refine the authors' model, research was conducted in two phases, the first testing phase consisted of a one-dimensional simulation of the conditions the hydrogen propellant would experience in a CFE. To model the fluid dynamics of propellant bubbling through a liquid metal, nitrogen gas was bubbled through Galinstan ($Ga^{67}In^{20.5}Sn^{12.5}$), a eutectic alloy that is liquid at room temperature and a similar ratio of surface tension to density as uranium at 2100 K. High-speed real time radiography was used to image the bubbly flow through the liquid metal for varying pressures and injector pore diameters. Individual bubbles in the flow were tracked to determine the characteristic bubble shape, equivalent diameter, and velocity as well as average bubble rate, and mass flow rate.

The second phase of experiments used a rotating pressure vessel apparatus to simulate two-dimensional bubbly flow within a CFE. The focus of this phase of the research was on the bubble formation process, the effects of centrifugal body forces on bubble shape and size, and propellant void fraction. Like the first phase, Galinstan and nitrogen were used to simulate the fuel-propellant pairing. A combination of high-speed video and void-detecting instrumentation were used to image the bubbly flow within the pressure vessel. The bubble geometries and trajectories were again tracked using a custom computer vision module for a range of angular velocities, liquid layer heights, injector configurations, and pressures.

The results from both experiments were fed back into a fluid dynamics model of the bubbly flow and the results were compared. Once satisfactory agreement between the fluids model and experimental data was achieved, the fluids model was then coupled with the heat transfer model and several CFE configurations were then simulated. The results of which show that the high thermal conductivity of the uranium creates a lower limit to the uranium layer thickness needed to meet performance objectives, which are limited by the lower and upper thermal bounds of the engine.