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Simulation of Liquid Metal Droplets from Field Emission

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Abstract. Liquid metal droplets are accelerated by electrostatic forces in a process known as field emission. In this study, we simulate the emission of charged indium droplets on a needle in 2D cylindrical coordinates. The boundary element method is used to rapidly and accurately calculate the electric field on the fluid surface, which is then advected forward in time using level sets. This is the first time these methods have been combined, and this combination addresses difficult detachable surface tracking issues successfully. A histogram of droplet charge-to-mass ratio is generated in which it is predicted that smaller satellite droplets are more densely charged. In addition, our model is compared with independent pre- and post-snap off data and produces good agreement with the result.

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1 Introduction

Field emission refers to the process of using a strong electric field to produce a spray of charged liquid droplets or ions. The field comes from a potential difference between an electrode and the liquid surface that is balanced by the surface tension of the fluid. As

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a result, the surface deforms to an equilibrium shape of a cone. The strong field at the tip then causes a propellant jet to form [1]. The phenomenon of droplet and ion evaporation from charged liquid surfaces is of considerable interest in many areas of science and technology. Some of the many realms in which field emission occurs include: electron microscopy, data displays, carbon nanotube fluorescence, ink jets and thermoelectric coolers.

Field emission thrusters are currently considered for a variety of space missions both in the United States and Europe. FEEP thrusters provide a source of high specific impulse, ultra-low impulse bit electrostatic space propulsion. A space-tested indium FEEP has been under development in Austria for over a decade [2]. The liquid metal ion source (LMIS) base consists of a needle covered in the element indium reacting to an applied electric potential from an extractor ring held above the tip at -6 kV. When the field strength at the tip reaches $10^9\,V/m$, indium is then ionized from the surface and accelerated over a fine tungsten needle that is about 1 cm long and 50 μm wide. Depending on the mass flow rates, either ions or droplets are observed to be emitted from the tip. A schematic of a FEEP thruster [3] is shown in Fig. 1.

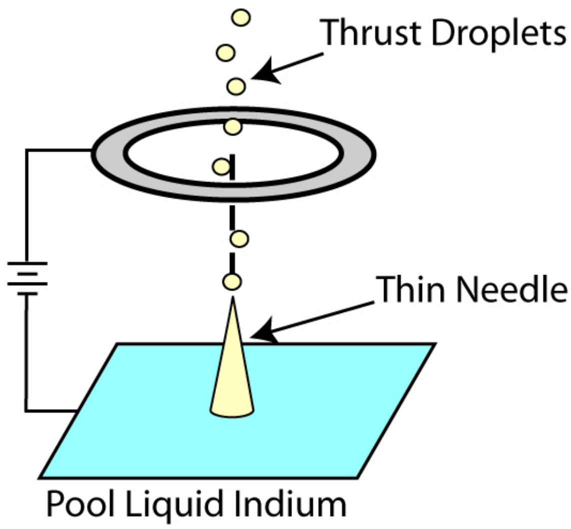

Figure 1: FEEP in droplet production mode.

The existence and corresponding behavior of droplets is of large practical concern in FEEP because as more droplets form, operational efficiency decreases, lifetime is limited due to the electrode clogging and plume divergence is unpredictable due to varying charge distributions. Therefore, a numerical investigation into the formation and charge of these expelled droplets has been undertaken. Experimental efforts indicate that below 20 μA only ion emission occurs in FEEP needles [4]. Above that point, at a current that varies based on the thermal and electrical properties of the fluid, periodic stochastic motions of droplet formation and emission interrupt the steady ion stream.

As the potential on the ring electrodes increases, the liquid curvature increases until