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Project Title: Electrohydrodynamic Atomization of Fuels Using Charge-Injection for Efficient Flameless Catalytic Combustion at Small Scale

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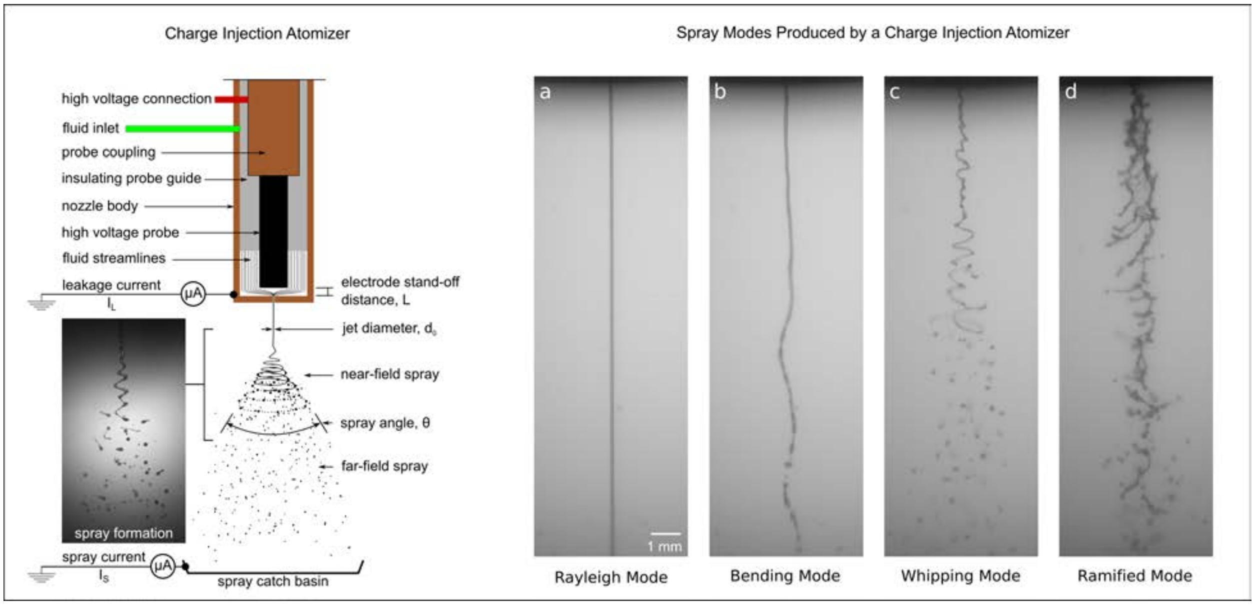
Project Summary

In this research, atomization of a dielectric micro-jet is achieved via an electrohydrodynamic charge injection process. The atomizer is comprised of a grounded nozzle housing and an internal high voltage probe concentric with the emitting orifice. The internal probe is held at electric potentials up to 20 kV. A pressurized reservoir drives dielectric fluid (e.g. diesel fuel) at a desired flow rate, typically less than 5 mL/second, through the nozzle with an orifice ranging from 100 to 500 µm in diameter. Fluid fills the cavity between the electrodes as it passes through the atomizer, impeding the transport of electrons from the probe to ground. It is in this inter-electrode region that charge is imparted to the fluid. A portion of the charge traverses the electrode gap, through the fluid to ground, and is defined as the leakage current. The remaining charge is advected out of the nozzle and into the fluid micro-jet; this is defined as the spray current.

Volumetric charge density, determined by the spray current and flowrate, plays a critical role in the jet breakup dynamics and atomization morphology. At low Reynolds numbers, $Re < 500$, and with increasing volumetric charge density, the jet deforms via a bending instability which transitions into a whipping instability. The whipping instability produces a sparse, wide angle spray of bi-modal sized charged droplets. The bi-modal droplet distribution consists of highly charged primary and satellite droplets located on the outside of the spray, and low charge primary and satellite droplets located in the spray core. Plotting volumetric charge density versus applied voltage provides a characteristic curve of spray mode progression. At Reynolds numbers between $500 < Re < 1600$, the jet initially experiences a bending instability and then moves to a ramified atomization mode as the volumetric charge density increases. At these larger Reynolds numbers, there is no occurrence of the whipping mode. The ramified mode causes the jet to form an elliptical cross section (a lamella) which proceeds to atomize via sheet breakup. This produces a smaller average drop size than the whipping instability. The jet remains laminar at these higher Reynolds numbers and the spray is generated purely by electrohydrodynamic effects.

We have found that the different jet morphologies and spray types have a Reynolds number dependence and are associated with specific regions on the characteristic volumetric charge density curve. Additionally, we have demonstrated that electrohydrodynamic roll structures are induced inside the nozzle at voltages that also produce the bending, whipping, and ramified jet modes.



Graphical Abstract: (left) Schematic of setup used for the electrohydrodynamic atomization of dielectric fluids. (right) Spray mode progression for increasing applied potential.