High-Resolution Differential Mobility Analysis (HR-DMA) of Naturally Charged Nickel Oxide Nanoparticles Synthesized in a Flat Premixed Droplet Seeded Flame (FPDSF)

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The Flat Premixed Droplet Seeded Flame (FPDSF) Reactor

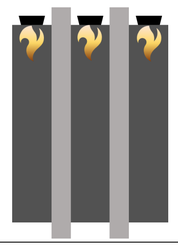
Synthesizes metal-based nanoparticles smaller than 10nm from inexpensive precursors such as nitrates.

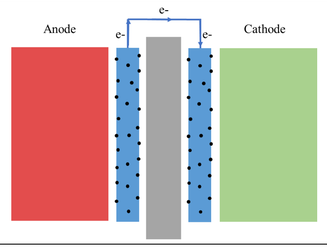
Metal-based nanoparticles can:

- Increase the efficiency and longevity of electrochemical devices
- Lower the activation energy of thermochemical processes
- **Reduce costs and intensify the adoption of sustainable energy technologies**

Electrochemical devices:
Fuel cells, batteries, and electrolyzers

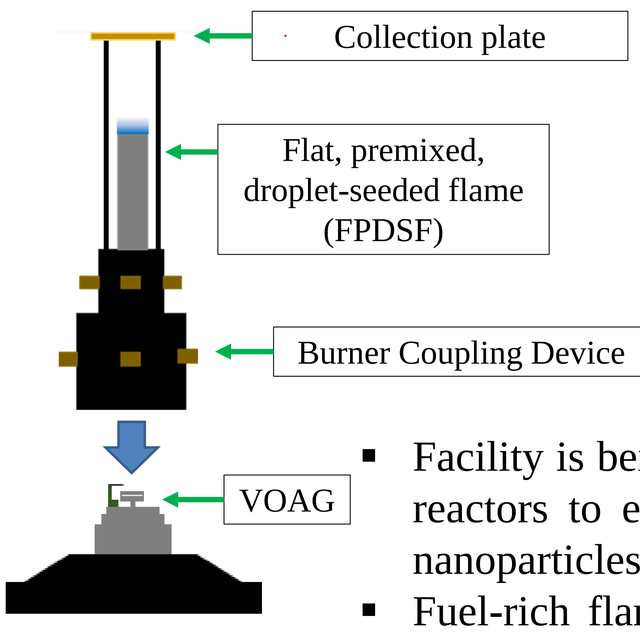
Thermochemical process
Methane reforming for hydrogen production





FPDSF Reactor Experimental Facility

1. *Berglund-Liu Type Vibrating Orifice Aerosol Generator (VOAG):* Produces a monodisperse droplet aerosol of a liquid containing a precursor compound.
2. *Burner Coupling Device:* Mixes combustion reactants with monodisperse droplets, conveys mixture to a flat, premixed flame.



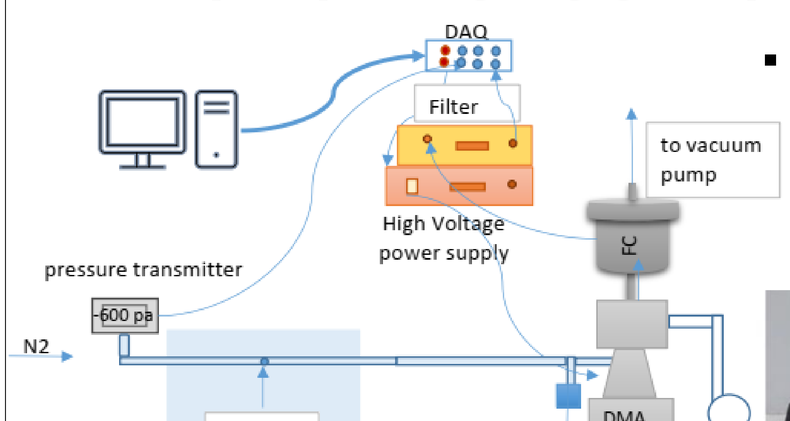
FPDSF seeded with monodisperse droplets of a 4%$_{wt}$ $Ni(NO_3)_2$ water solution

- Facility is being equipped with several FPDSF reactors to explore the layered deposition of nanoparticles with different composition
- Fuel-rich flames can synthesize nanoparticles with hybrid metal and carbon structure

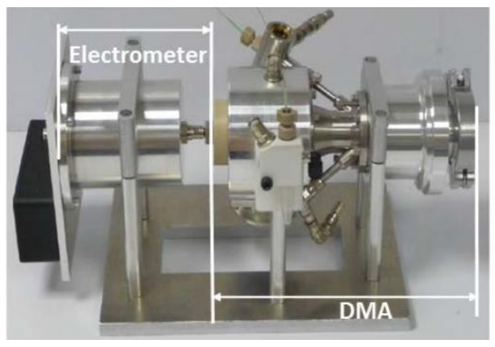
- **Capabilities demonstrated by synthesizing Nickel Oxide (NiO) nanoparticles from a nickel (II) nitrate aqueous solution.**

High-Resolution Differential Mobility Analysis (HR-DMA)

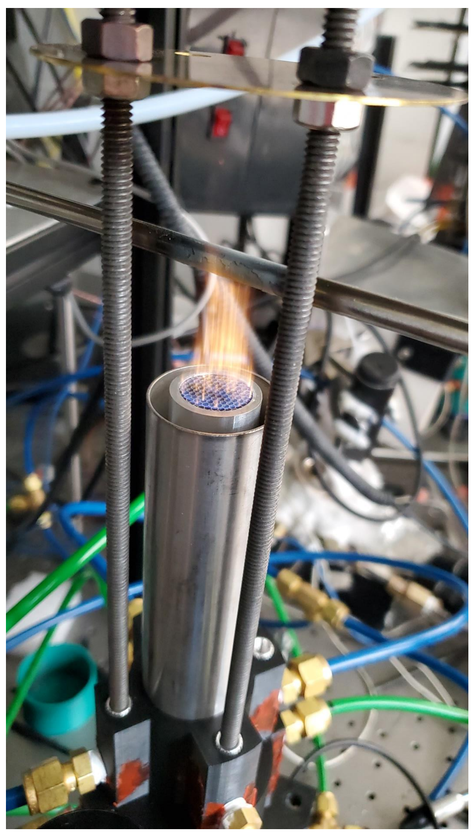
- Measures Size Distribution Function (SDF) of charged materials in the 0.5nm-30nm interval based on their electrical mobility
- Measurements can rely on natural charging provided by flame chem-ions and/or upon implementing charging with a predictable efficiency



- HR-DMA enables the monitoring of the collision growth and charging kinetics of the sampled nanoparticles



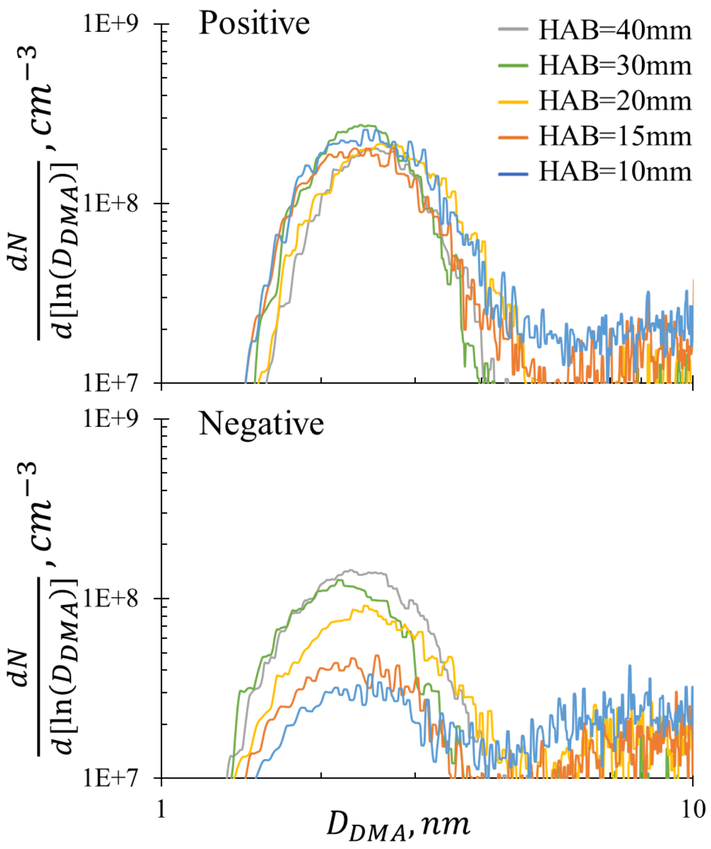
Results



HR-DMA dilution sampling of FPDSF, doped with nickel (II) nitrate precursor droplets

- The chemiluminescent streaks above blue layer of the premixed flame visually indicate the synthesis of nanoparticles.
- HR-DMA indicates bimodal SDF at HAB lower than 15mm
- Second mode of SDF disappears progressively with increasing HABs, resulting in an approximately lognormal SDF centered near 2.5nm
- Nanoparticles emerge from the flame prevalently with a positive rather than negative charge

- Future measurements with controlled collision charging will quantify the concentration of nanoparticles that are electrically neutral within the flame



Tracking the nanoparticles as thermal catalysts

Capillary sampling from FPDSF with water droplets for GC/MS

- Capillary sampling for DMA followed by GC/MS analyses of combustion products from a lean FPDSF seeded with pure water droplets was used for baseline validation.
- GC/MS can characterize the thermo-catalytic activity of the synthesized nanoparticles (e.g., for methane reforming)

Conclusions

- FPDSF provides a relatively inexpensive method for synthesizing metal-based nanoparticles smaller than 10nm under well-controlled conditions.
- HR-DMA monitors the performances of the FPDSF experimental facility by measuring the size and charge distributions, as well as the growth and charging kinetics, of the synthesis products.
- Future work will investigate depositing nanoparticles on substrates using the thermophoretic effect, the synthesis of hybridize Nickel/Carbon nanoparticles, and the layering of nanoparticle generated by two FPDSFs.

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References

[1] Carbone, "Physicochemical characterization of combustion generated inorganic nanoparticles," 2010.

[2] Carbone *et al*, "Coagulation and adhesion of nanoparticles generated in flame from droplets of nickel nitrate aqueous solutions," *Chemical Engineering Transactions*, vol. 16, pp. 87-94, 2008.

[3] Carbone et al., "Challenges of measuring nascent soot in flames as evidenced by high-resolution differential mobility analysis," Aerosol Science and Technology, vol. 50, pp. 740–757, 2016

[4] Fernandez de la Mora, "Expanded flow rate range of high-resolution nanoDMAs via improved sample flow injection at the aerosol inlet slit," Journal of Aerosol Science, 113: 265–275, 2017