Nanoparticle Synthesis with Air-Assisted Ultrasonic Spray Pyrolysis

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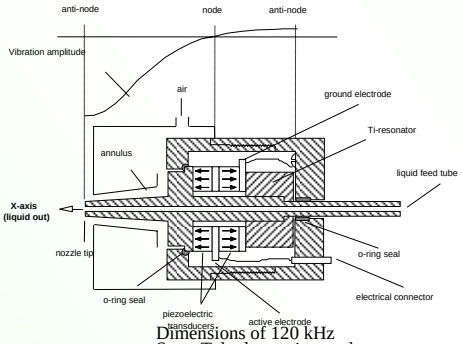
- **UMTF (Ultrasound-Modulated Two-Fluid) atomization is capable of producing uniform drops much smaller than the conventional ultrasonic atomization.**
- **An UMTF atomizer consists of an annulus for airflow and an ultrasonic nozzle with a central channel for liquid flow.**
- A capillary wave is excited as the liquid jet issues from the nozzle tip that vibrates at the ultrasonic frequency, and amplified by the high-velocity air. Atomization occurs the wave amplitude becomes too great to maintain wave stability.



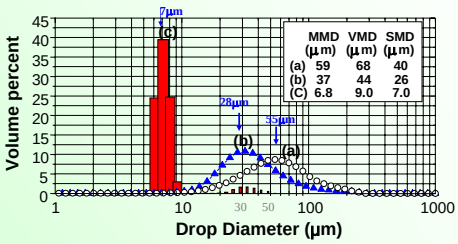
Dimensions of 120 kHz Sono-Tek ultrasonic nozzle:
Back horn 29mm L, 13mm Dia.
Front horn 14mm L, 3mm Tip Dia.
Total horn length 43mm

Tsai et al, Phys. of Fluids, 2909-18, 1997

Size Distributions of Precursor Drops

(a) Ultrasonic atomization, Sono-Tek @120kHz, 2.3W
(b) Air-Assisted Ultrasonic or UMTF Atomization @120kHz, 2.3W, 150m/s air, 4.1 mA/mL
(c) Ultrasonic atomization, nebulizer @ 1.65MHz, 23.5W

(UMTF Atomization: Ultrasound-Modulated Two-Fluid Atomization)



- Drop size distribution (b) is much narrower (half width 40μm versus 70μm) than (a)

➢Why High Ultrasonic Frequency ?

High-frequency ultrasonic nozzles have the following potential applications:

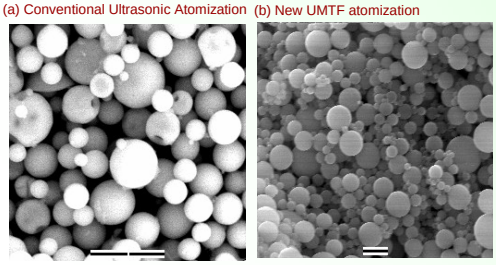
- ***Spray Pyrolysis*** of < 10 μm ***uniform*** precursor drops to produce mass quantity of nanoparticles of functional advanced materials
- ***Hand-held Nebulizer*** to produce ***uniform*** 5 μm drops for alveolar delivery of medicine
- ***Spray Coating and Spray Drying***

Commercial Potential of Air-Assisted Ultrasonic Spray Pyrolysis (UMTF-SP)

- Traditional Spray Pyrolysis (SP) is a continuous, ambient pressure process. However, the product particles are in general >0.5 μm in diameter, and often with hollow or irregular shape.
- Other dry processes such as Chemical Vapor Condensation (CVC), Combustion Flame (CF) CVC, CFSP are capable of producing spherical nanoparticles 15-30 nm in diameter, but they all require high temperature (>1000°C) and vacuum pressure (<60 mbar).
- Electro Spray Pyrolysis is capable of producing nanoparticles 15 nm in diameter, but requires very high dc voltage (~20 kV).
- UMTF-SP is a continuous process that utilizes high-frequency UMTF atomization to produce uniform precursor drops (<5 μm-diameter) that undergo pyrolysis at temperature <750°C and ambient pressure to produce nanoparticles via gas-to-particle conversion mechanism.

SEM Micrographs of ZrO_2 from Spray Pyrolysis @ 650°C of Precursor Drops (5 wt% zirconium hydroxyl acetate)

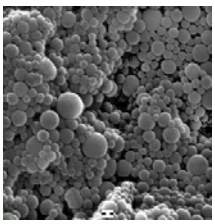
(a) Conventional Ultrasonic Atomization (b) New UMTF atomization



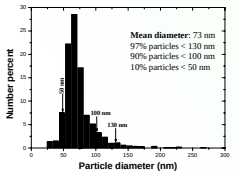
10 μm
Mean particle diameter: 3.5 μm

1μm
Mean particle diameter: 0.35 μm

SEM Graph & Size Distribution of Prod. Particles Spray Pyrolysis @750°C, 6-9 μm-Diameter Drops, 0.01wt% Precursor Concentration



100 nm
Mean particle diameter 73 nm



Simulation Results for a Silicon-Based 5-Fourier-Horn Ultrasonic Nozzle @ 0.5 MHz Design Frequency