# Electrically Driven Technologies for Radioactive Aerosol Abatement

(EMSP Project 65328)

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# Objectives

**Generate scientific basis for development of innovative electrically based filtration  systems that can be applied to DOE processes.**

**Extend understanding of aerosol interactions and coalescence in acoustic and electric fields.**

**Develop simulation and design tools for aerosol coalescence and agglomeration systems.**

**Design prototype electrical filtration system.**

# Motivation

## Aerosols present problems for waste treatment

- **Tanks**
  - Sludge retrieval in high level radioactive waste tanks produces radioactive droplets
  - Tank exhaust systems utilize demisters, heaters, and filters to reduce aerosol loading
  - Wetting, contamination, and clogging of HEPA filters has been a problem
    - (Example - ORNL In-Tank Evaporation)
- **Thermal treatment processes**
  - Vitrification and calcining processes produce aerosols in offgas
- **Electrical methods that aid in filtration and do not require frequent maintenance are attractive.**

# Filtration Enhancement Physics

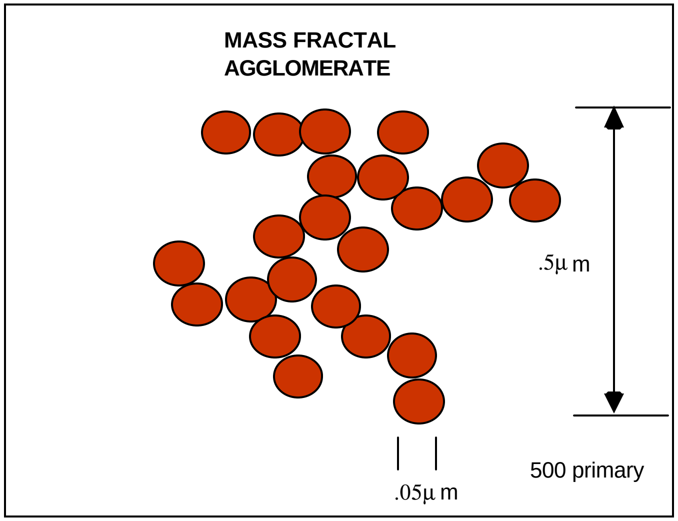
Regardless of the separation mechanisms or equipment utilized, aerosol filtration is generally easier for larger particles.

Both passive and active means can be used with high efficiency to remove larger particles from a carrier gas.

Technologies being developed in this project focus on size enlargement of microscopic particles.

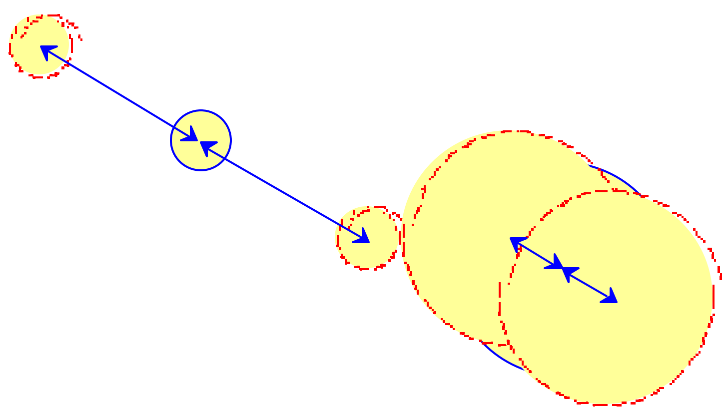
Processes that promote agglomeration include

- **Brownian motion**
- **Turbulence in fluids**
- **Gravitational sedimentation**
- **Acoustic processes**
- **Electrostatic interactions**



# Coalescence/Agglomeration

Collision and coalescence/agglomeration of particles essentially involves two steps. Step one, relative motion induced individually or collectively by external forces may bring the particles close to one another and possibly result in their collisions.

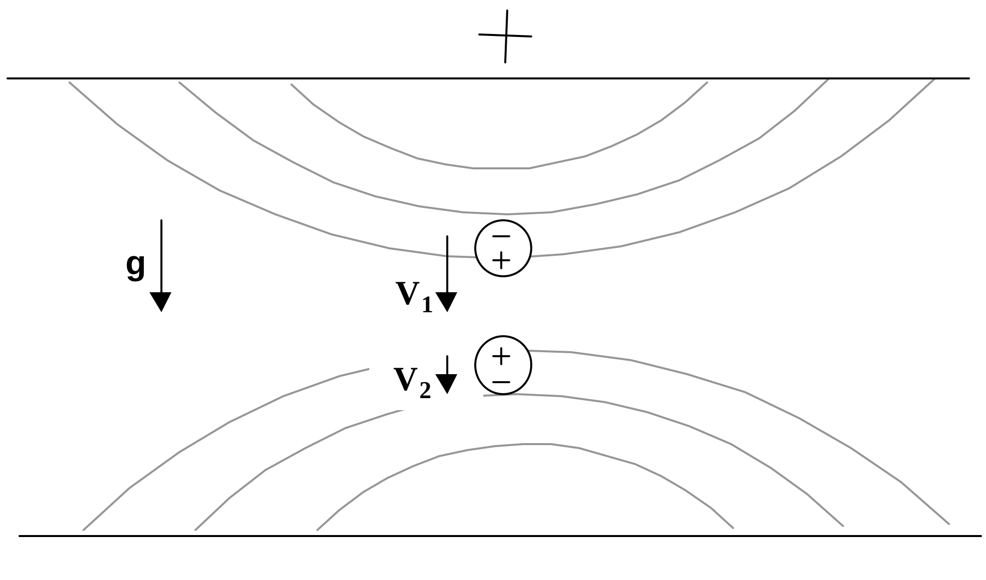


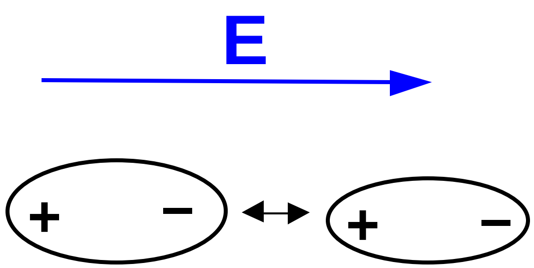
Step two, the thermodynamic driving force of minimizing the surface area and energy of contacting particles causes them to coalesce or agglomerate into either a single, larger drop or an aggregate particle.

# Electro Coalescence

Electric fields, commonly used for particle removal in electrostatic precipitators, have also been studied for

particle agglomeration (Loffler & Gutsch 1993),
droplet coalescence (Zhang et al., 1995), and
electrified bed filtration (Luckner, 1995).




**Droplets are charged and/or polarized in an electric field, causing an attractive force.**

# Electro Coalescence

As two drops approach one another, the strength of the electric field in the region between their closest points can attain values many times that of the imposed electric field and thus possibly accelerate the agglomeration process.

Electrical coalescence of aqueous droplets suspended in an insulating liquid under an electric field has been shown to be strongly influenced by the field strength, the size of the droplets, and the viscous resistance (Zhang et al., 1995**).**

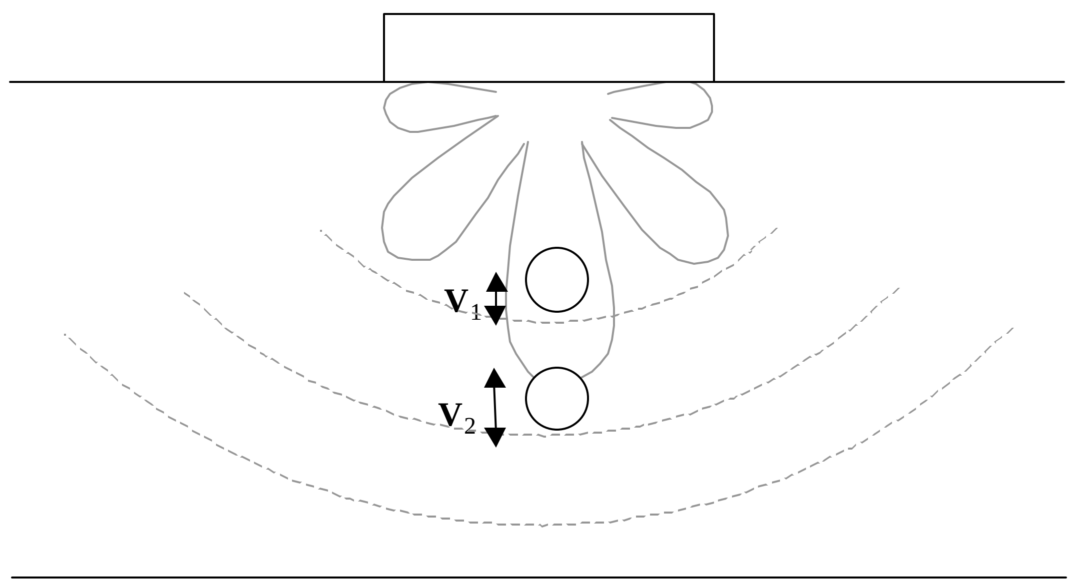
# Acoustic Agglomeration

While it has been clear that application of acoustic fields to aerosol distributions reduces the aerosol number concentration, the basic mechanisms controlling the processes have been somewhat obscure (Friedlander, 1977).

In the literature, the two primary mechanisms postulated to enhance aerosol agglomeration in the presence of a sound source are believed to be "orthokinetic" and "hydrodynamic" effects (Dain et al., 1995; Hoffman & Koopman, 1996).

# Acoustic Agglomeration

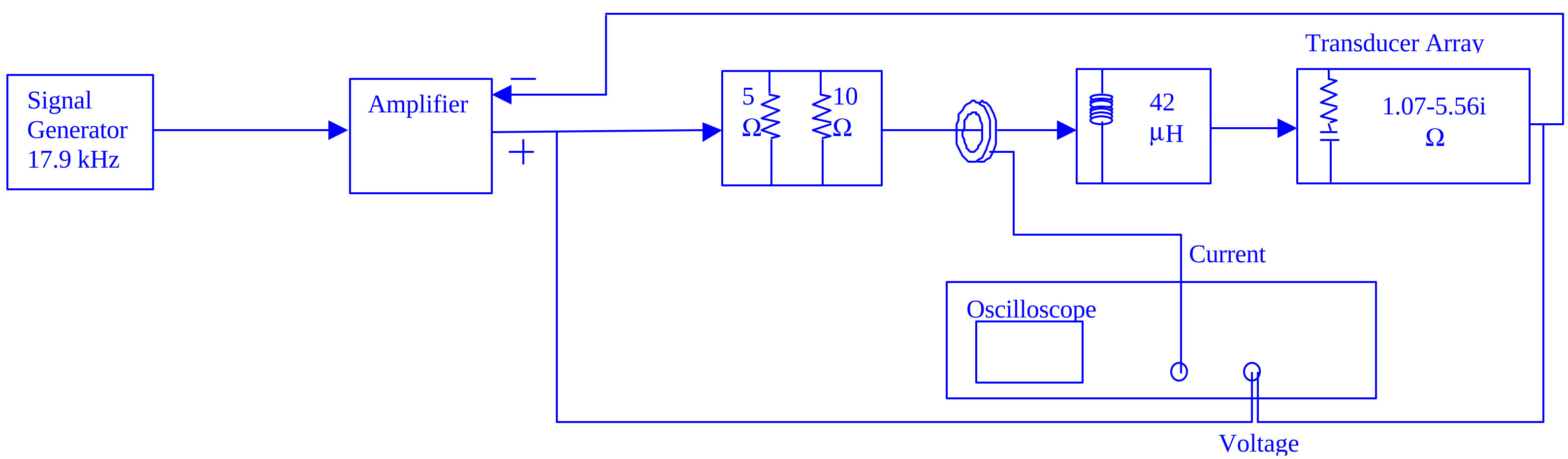
**An increased collision frequency between smaller and larger sized particles is obtained by the selective vibration/entrainment of dissimilar sized aerosol particles in an acoustic field.**



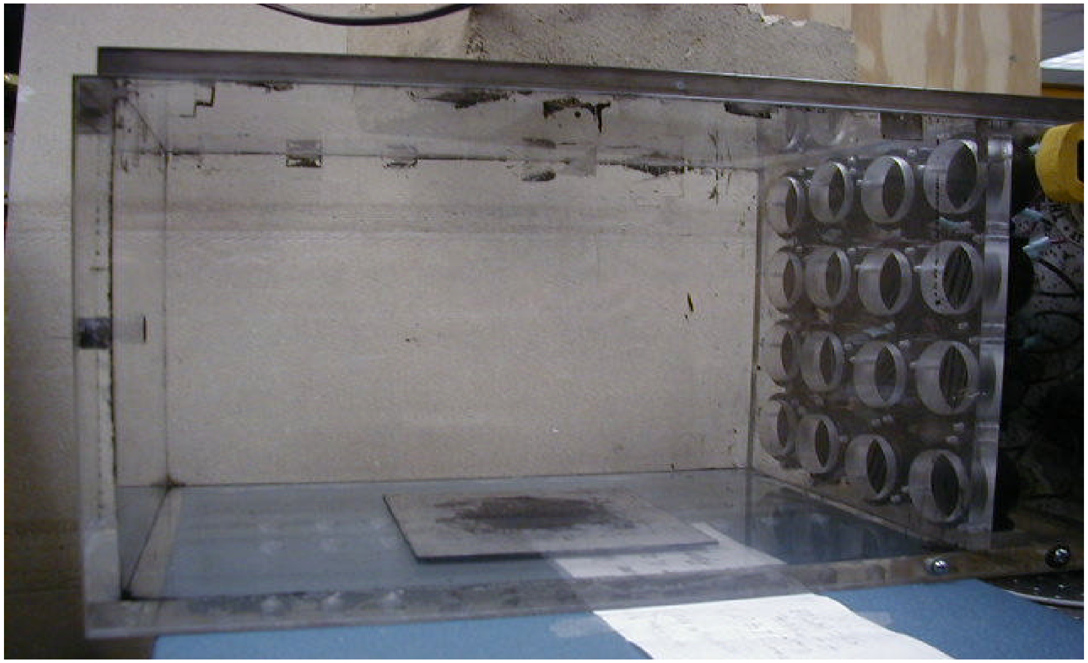

**The following slides depict an experiment producing acoustic agglomeration.**

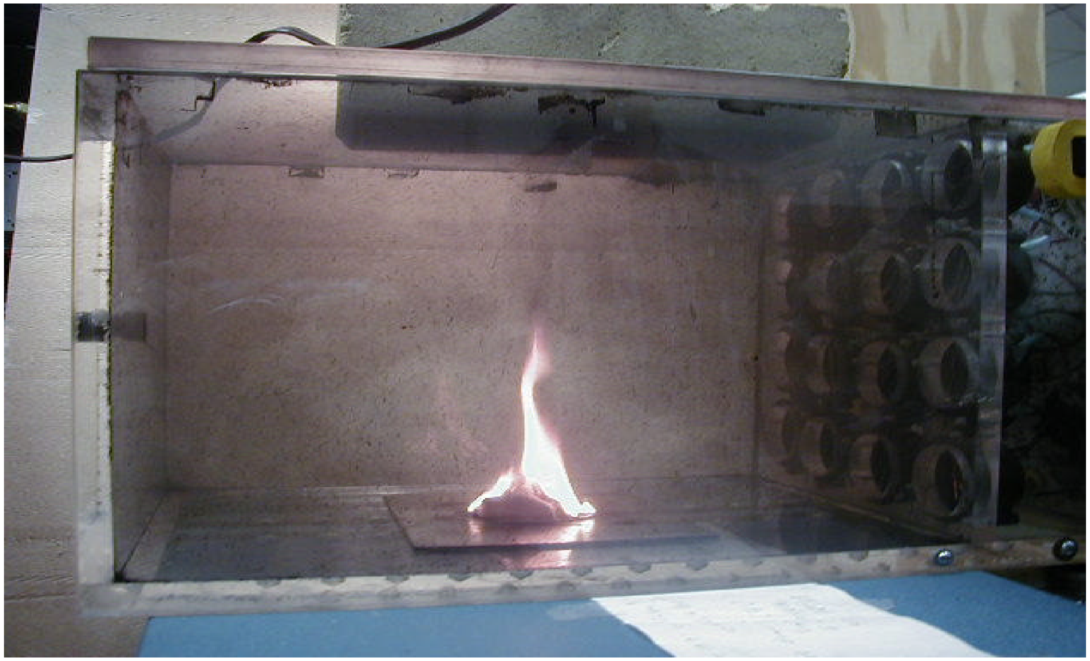
# Experimental Methodology - Acoustic Field

- A signal generator producing a 17.9 kHz sine wave is fed into an audio amplifier.
- The amplifier is connected to a balancing circuit and an array of 16 piezoelectric tweeters mounted on one end of chamber. Voltage and current readings are taken using an oscilloscope, and the power is monitored.
- The chamber is filled with soot and the amplifier is turned on.
- Agglomerating disks begin to levitate within the chamber.



# Soot Production

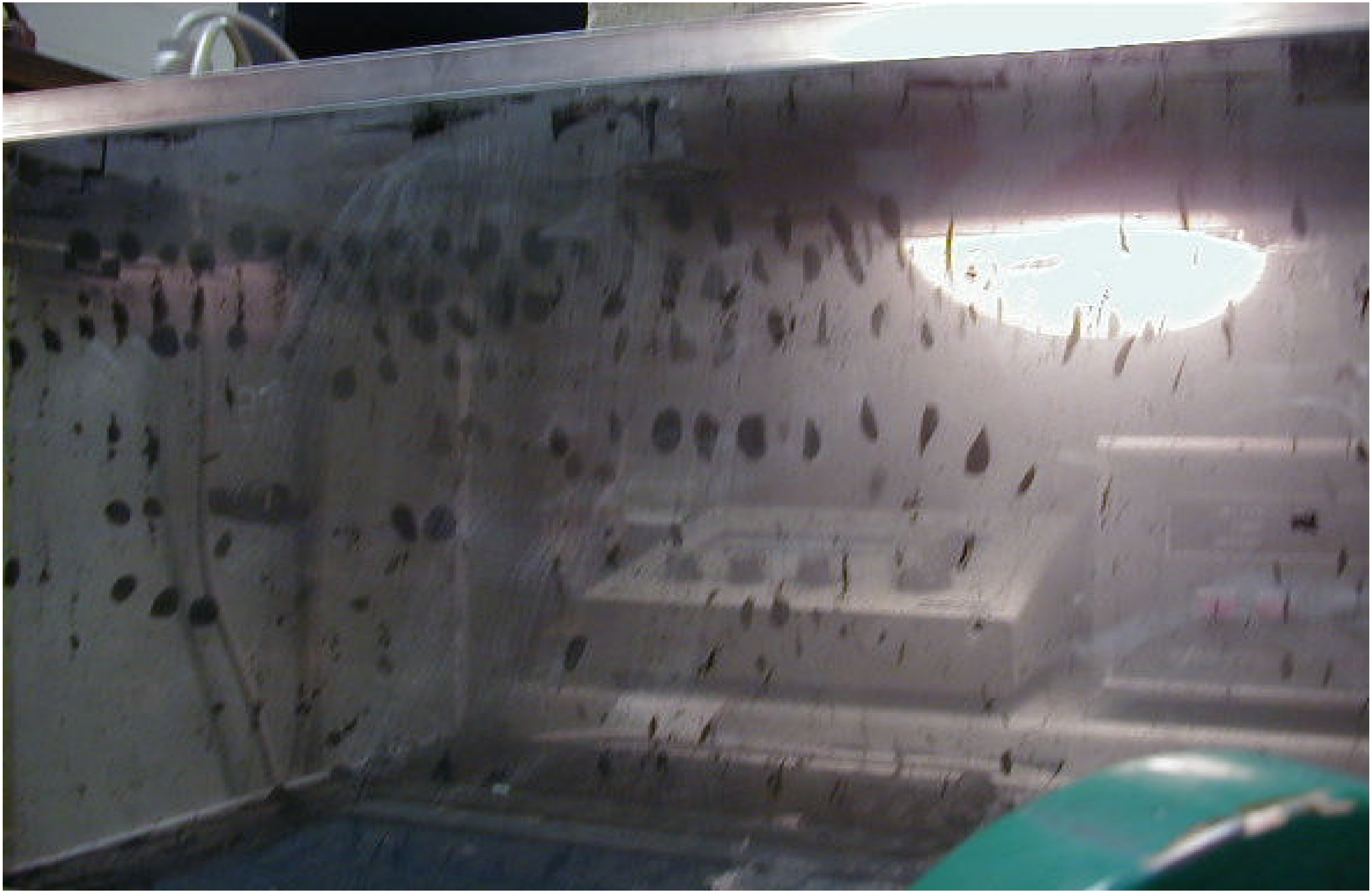




**Submicron particles characteristic of thermal treatment processes are generated by controlled burning of flammable solids, including cigarettes, styrofoam, incense, and paper**

# Chamber Filled with Soot

# Acoustic Agglomeration



# Unit Reactor

- An experimental apparatus was constructed to evaluate the effects of electrical and acoustic fields on particle coalescence and aggregation. Laser extinction measurements are being used to determine the rate of sedimentation, which gives indirect characterization of the rate of coalescence/aggregation.

- The chamber has two parallel copper plates, one on top and one on bottom. A high-voltage power supply is wired across these plates.

- The photo detector's output is a voltage reading proportional to the intensity of the laser. The intensity of the laser was tested and determined to be constant.

# Unit Reactor

The chamber is first filled with smoke, which decreases the intensity of the laser seen at the detector.

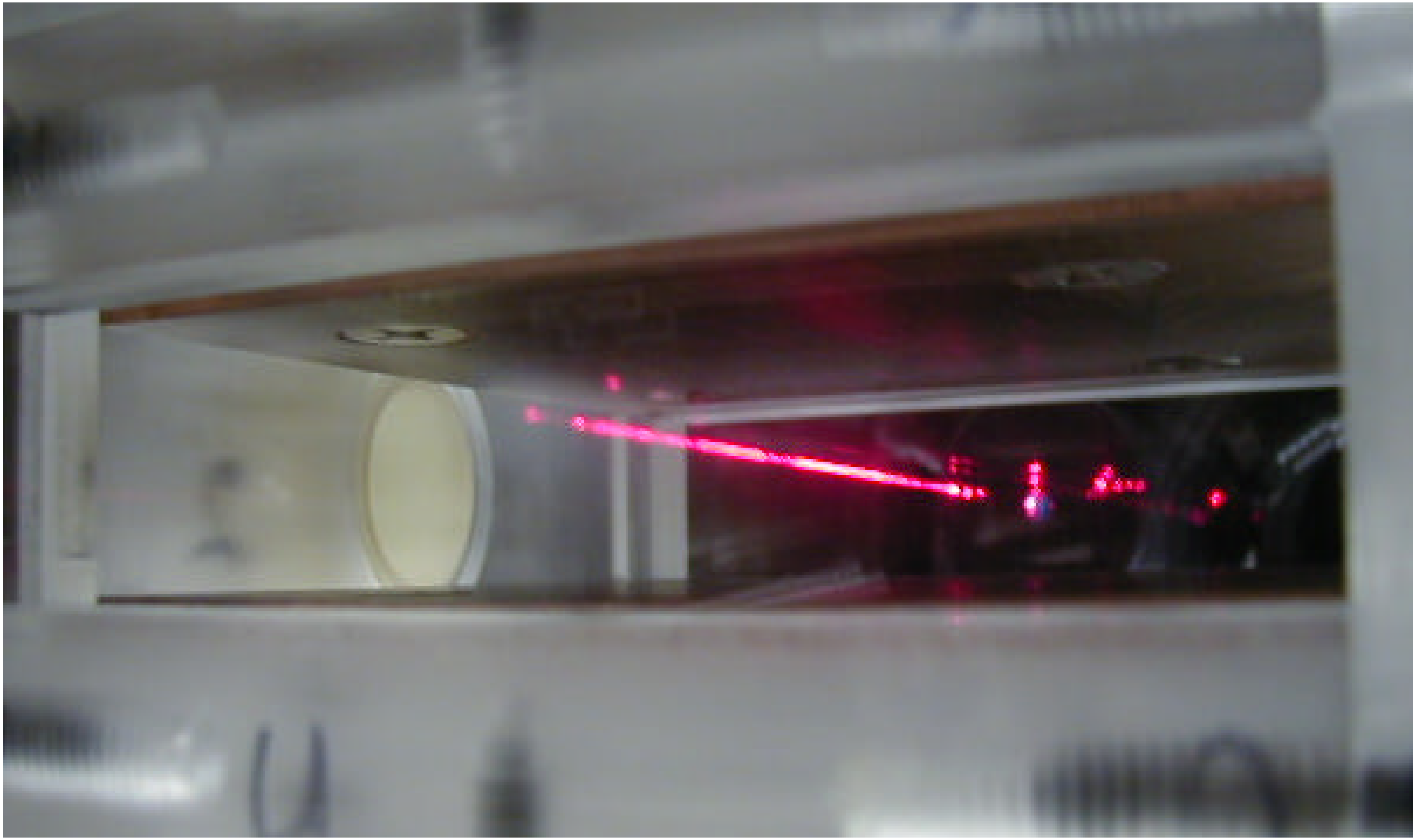
The extinction process is assumed to obey Beer's Law

$$\frac{V}{V_o} = \frac{I(t)}{I_o} = \exp(-a_l \ L)$$

The corresponding voltage output from the detector is fed into a computer, via Labview software and a data acquisition board, at 1 second intervals.

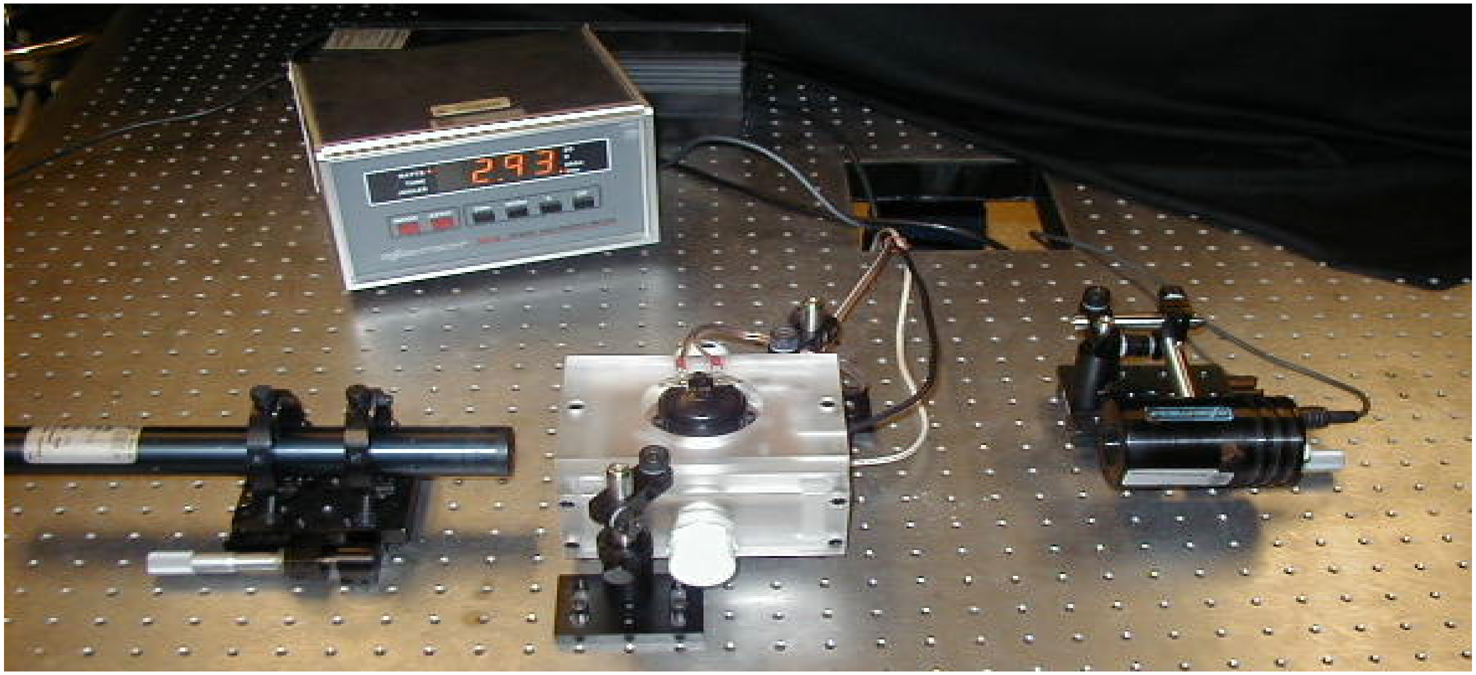
This data is plotted as a time vs. voltage graph.

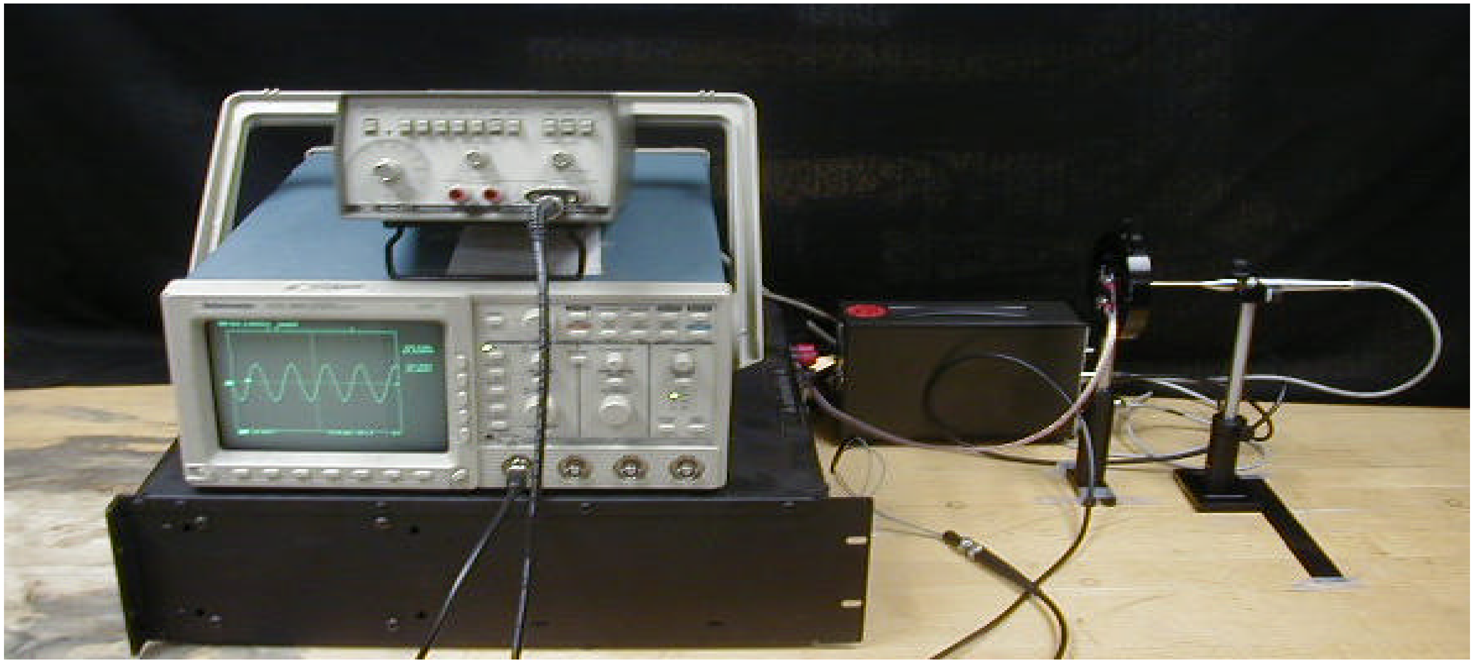
# Experimental Apparatus - Unit Reactor



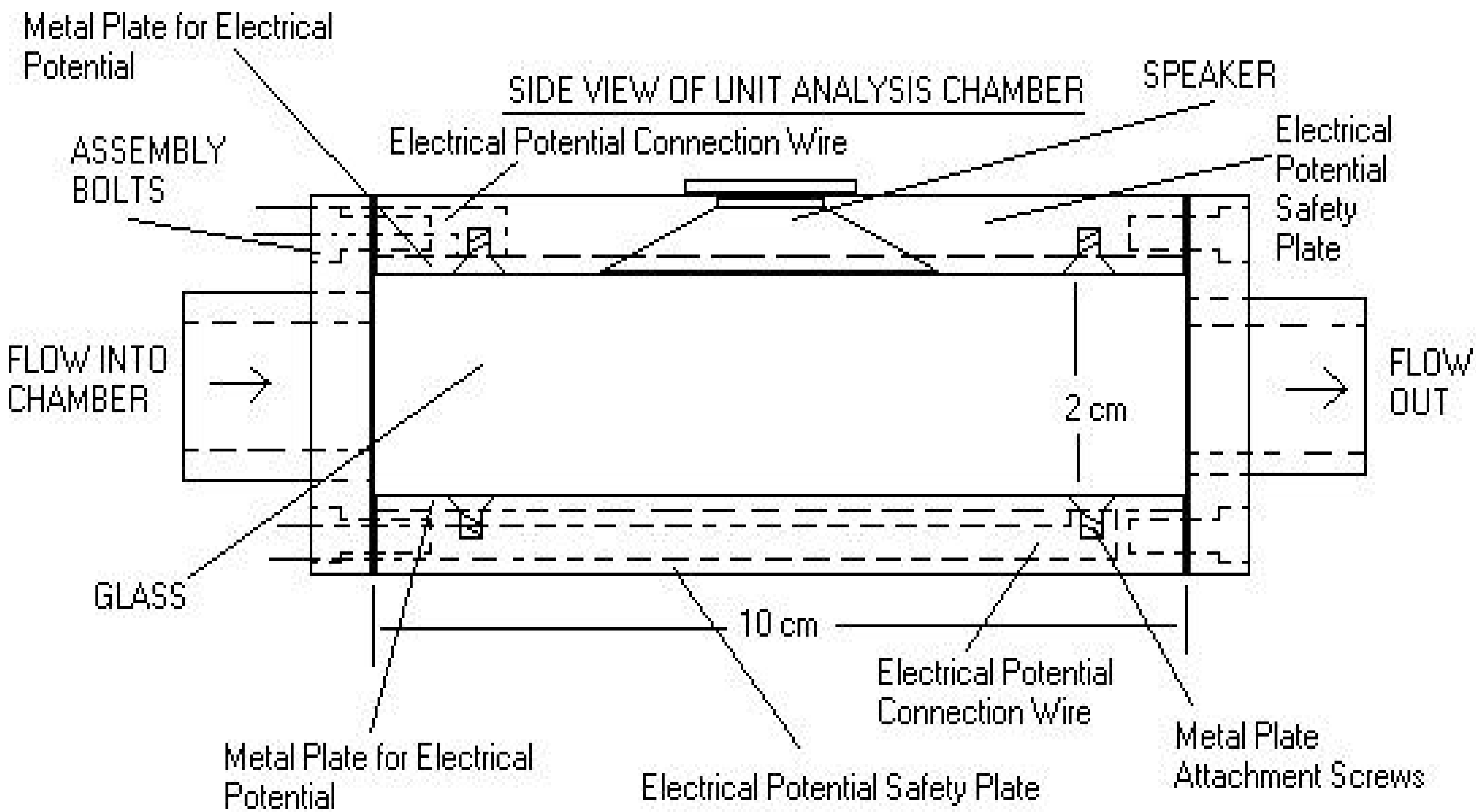
**Concentration of suspended particles is measured by intensity of laser beam passing through chamber.**

# Experimental Apparatus - Unit Reactor



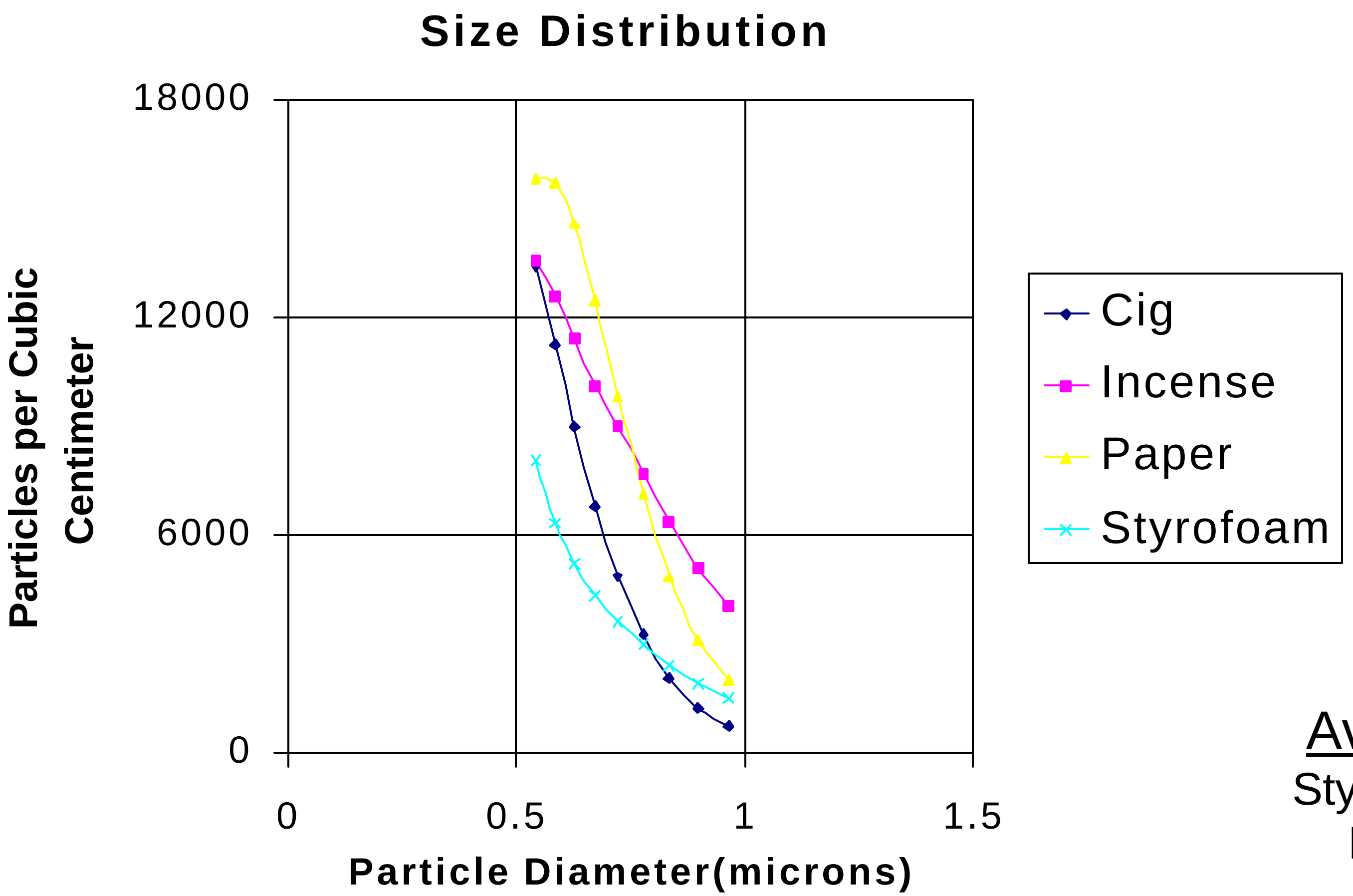



# Schematic of Unit Reactor



# Particle Sizing

**Size distribution and number concentration of aerosol particles determined using a TSI-Aerodynamic Particle Sizer (APS).**




<u>Average particle sizes:</u>

Styrofoam (cup) – 0.825 µm

Engine oil – 0.760 µm

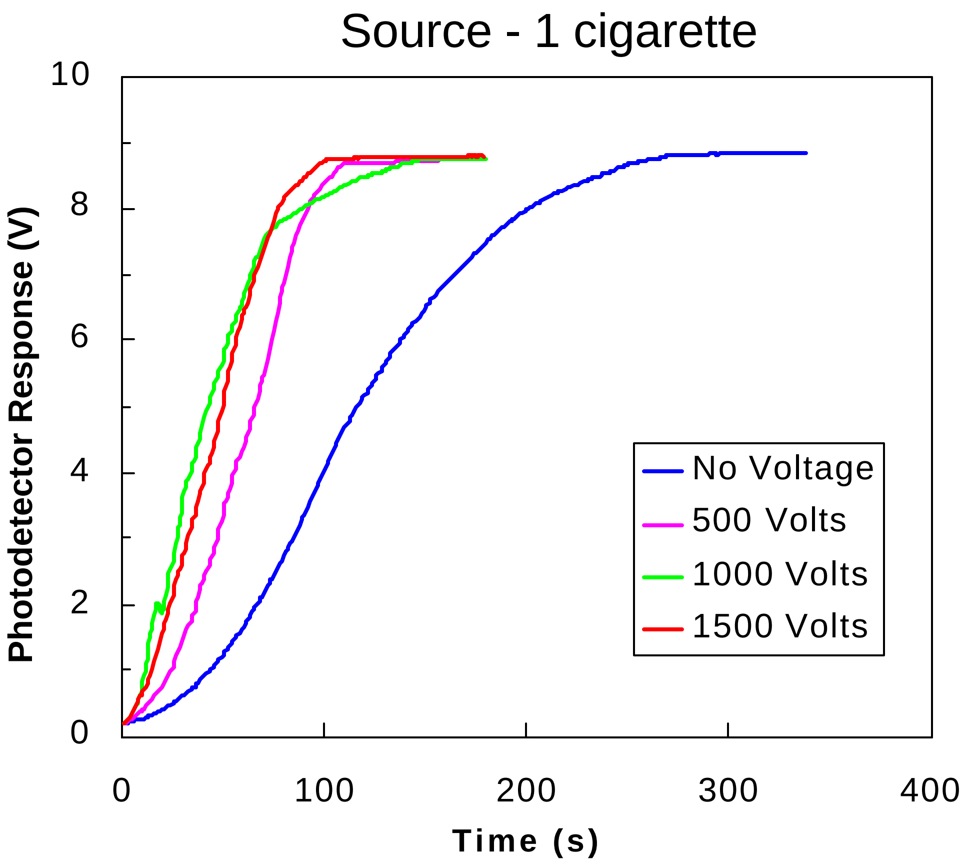
Incense – 0.746 µm

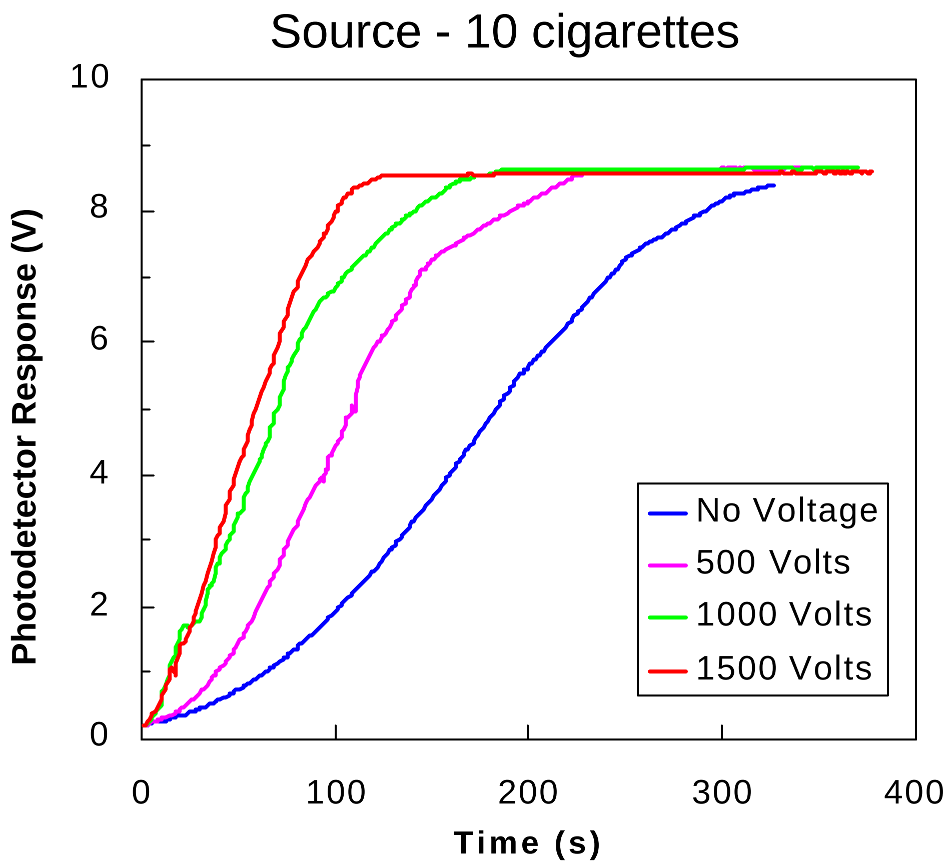
Paper (notebook) – 0.678 µm

Cigarette – 0.657 µm

# Unit Reactor Results

## Electrocoalescence of cigarette smoke

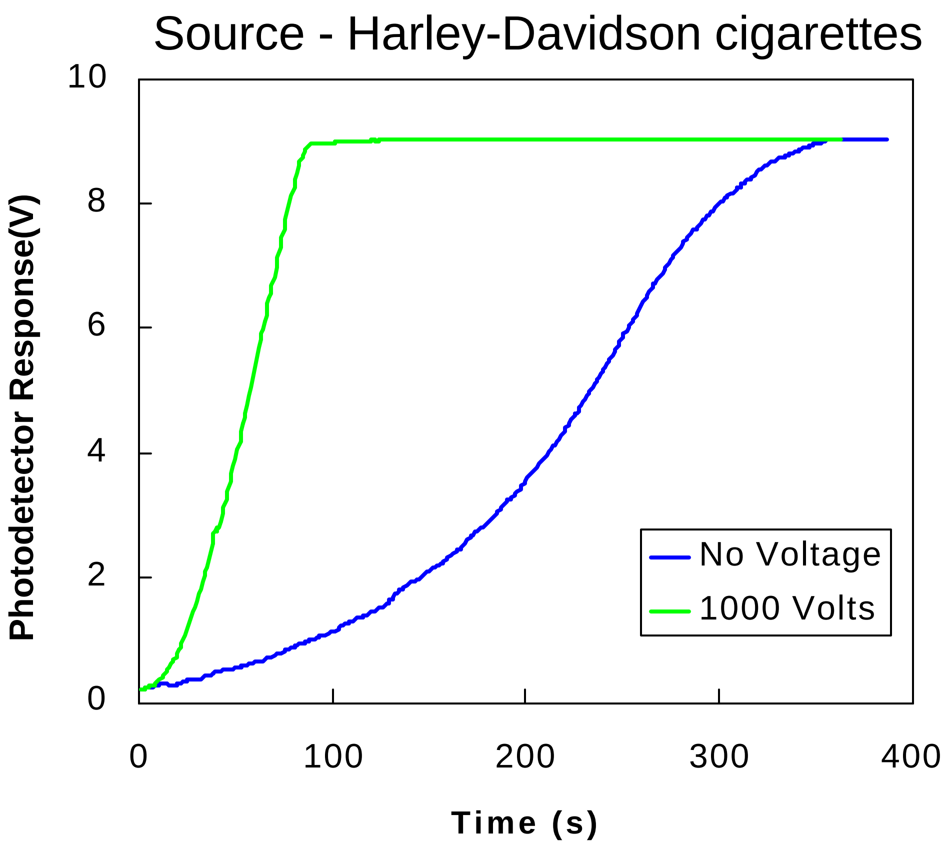


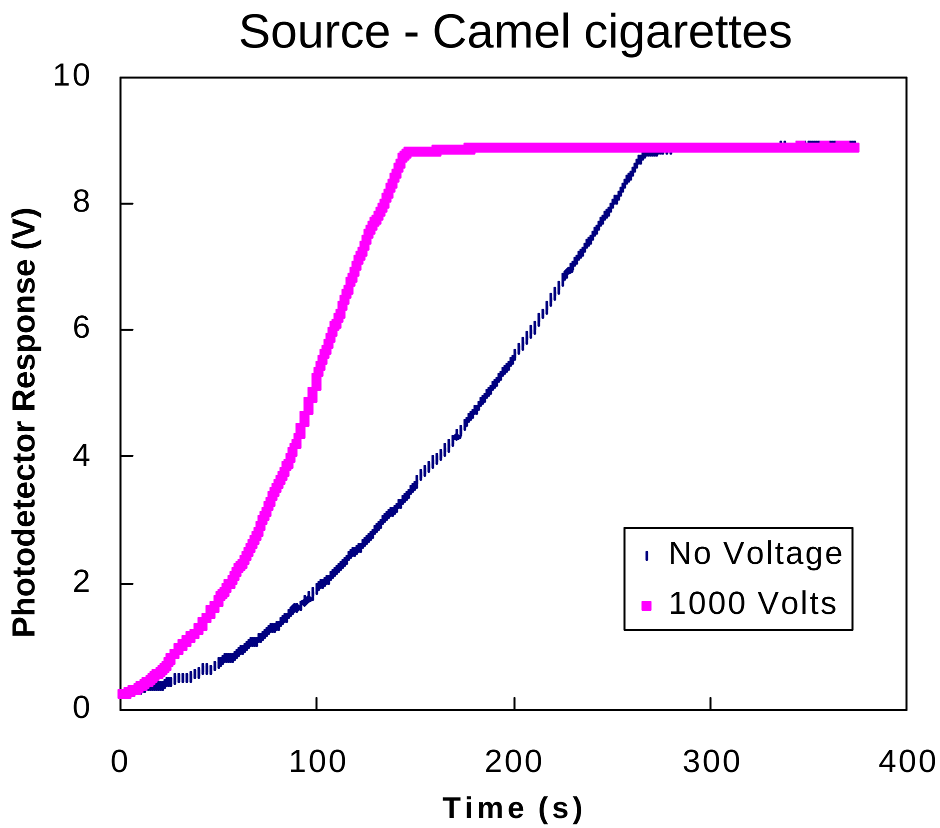




**Coalescence/sedimentation depends on applied field strength and particle concentration**

# Unit Reactor Results

## Electrocoalescence of cigarette smoke

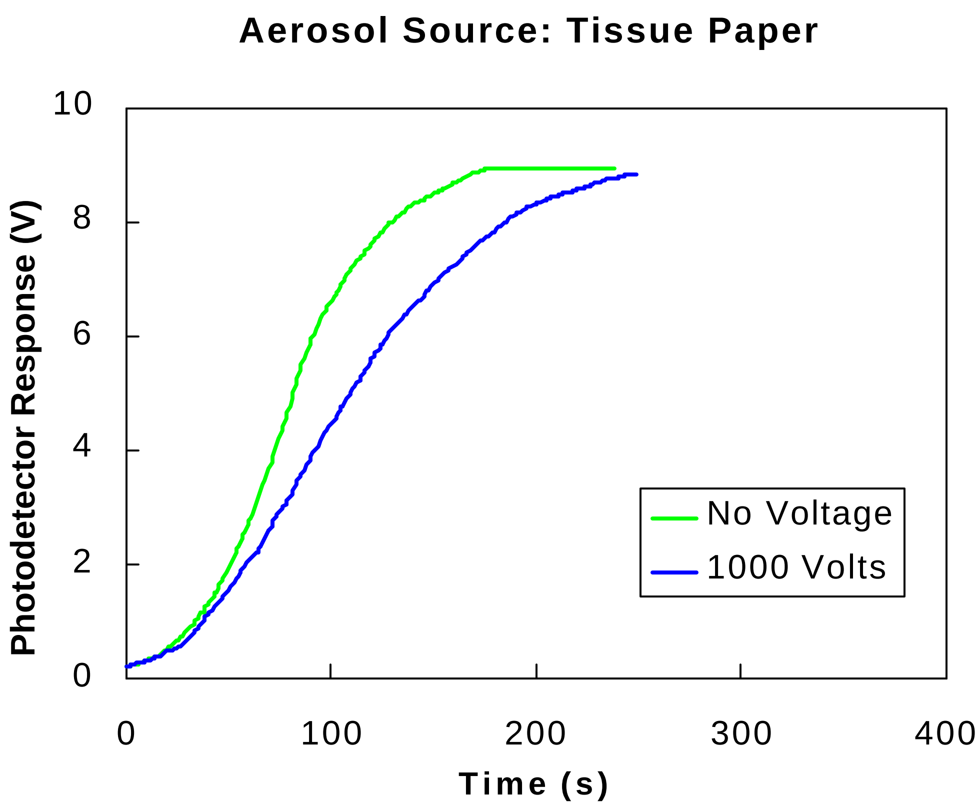


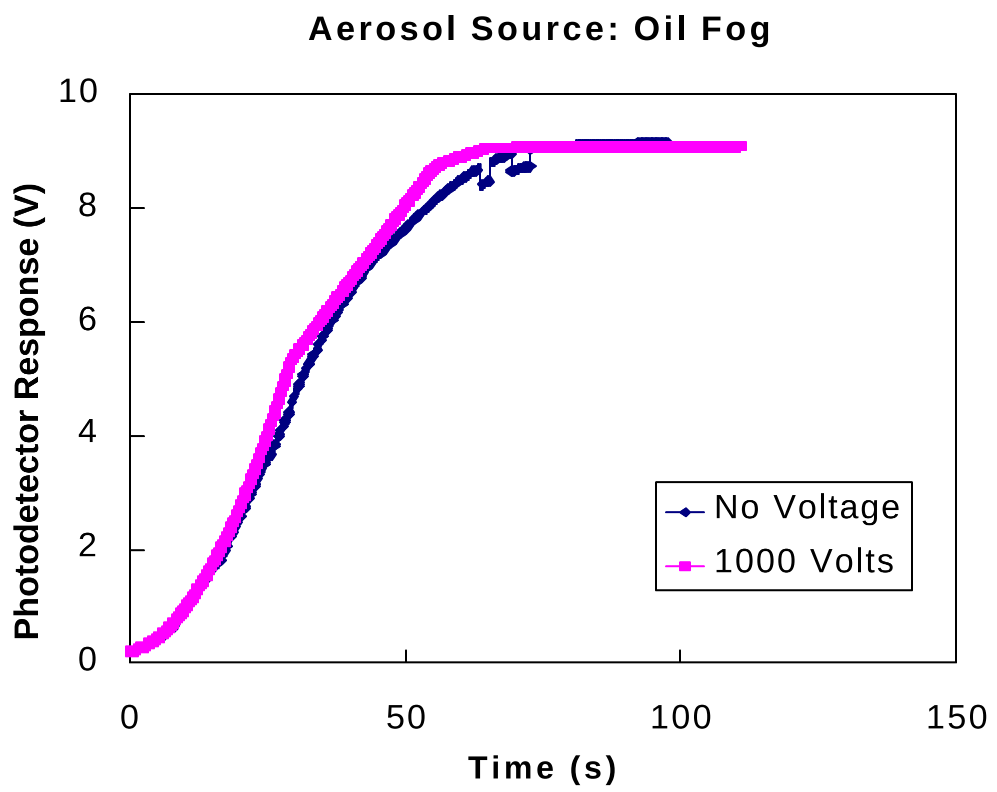




**Significantly different results for 2 different types of cigarettes - electrocoalescence performance sensitive to particle characteristics**

# Unit Reactor Results

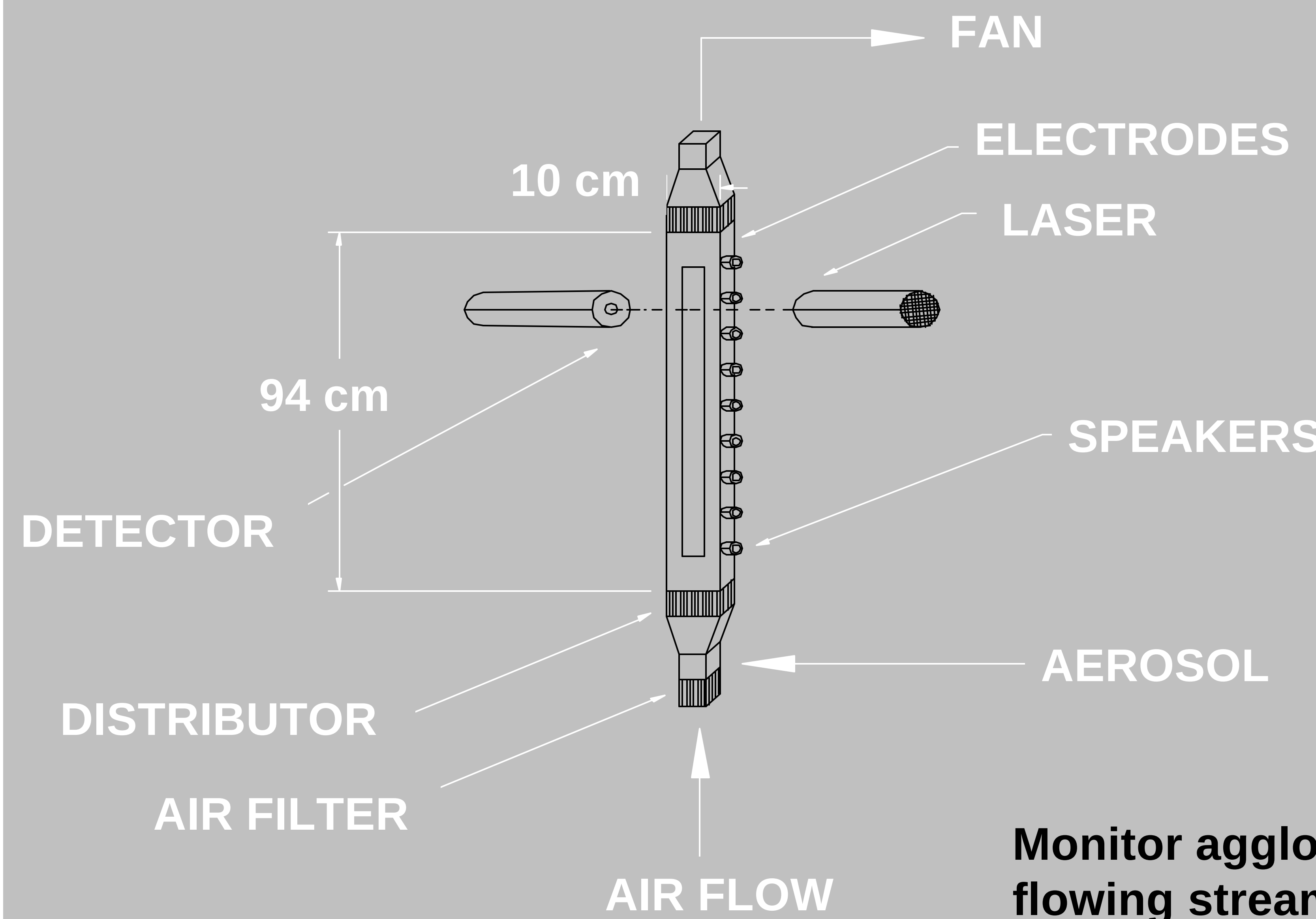
## Electrocoalescence of other aerosols



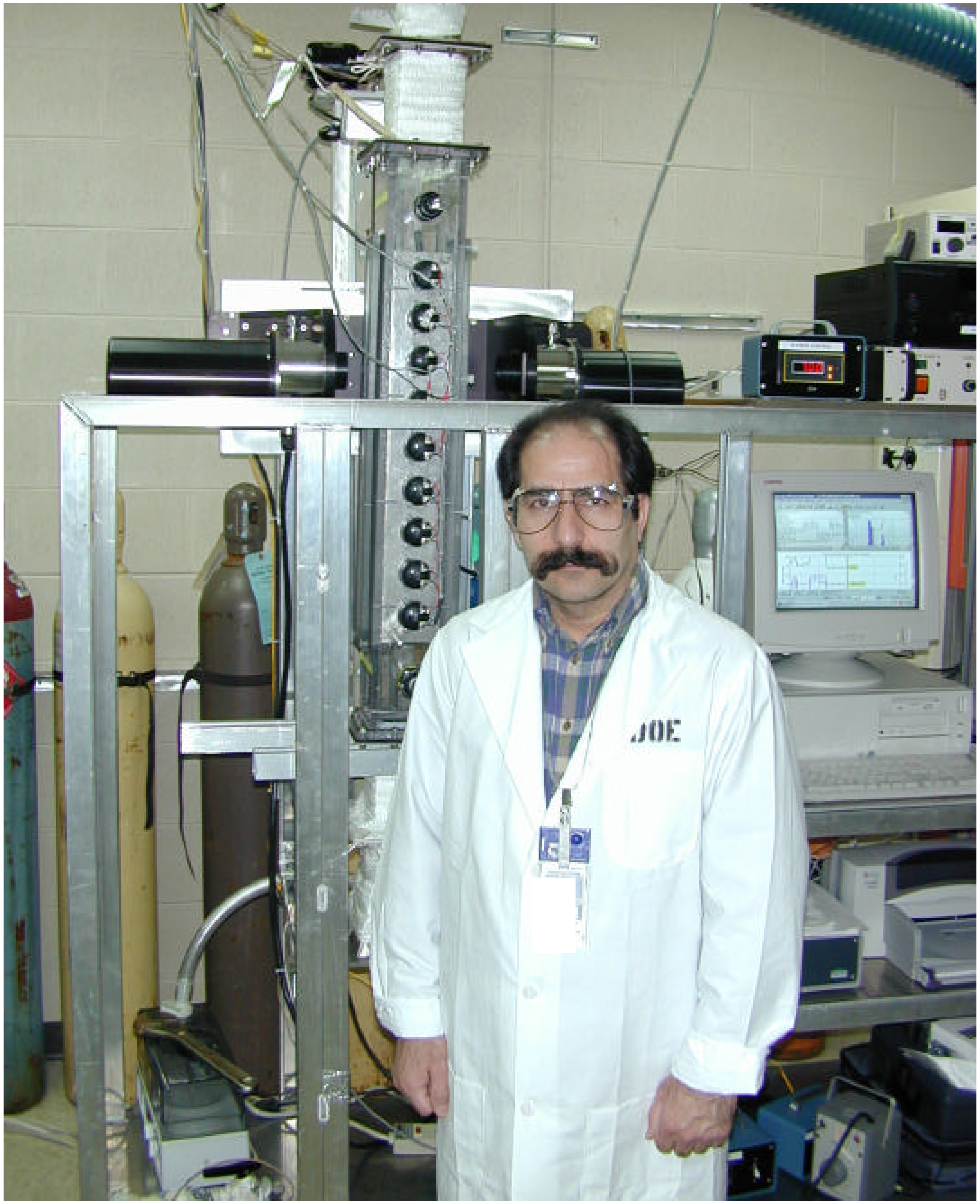

**Electrocoalescence performance sensitive to particle characteristics**

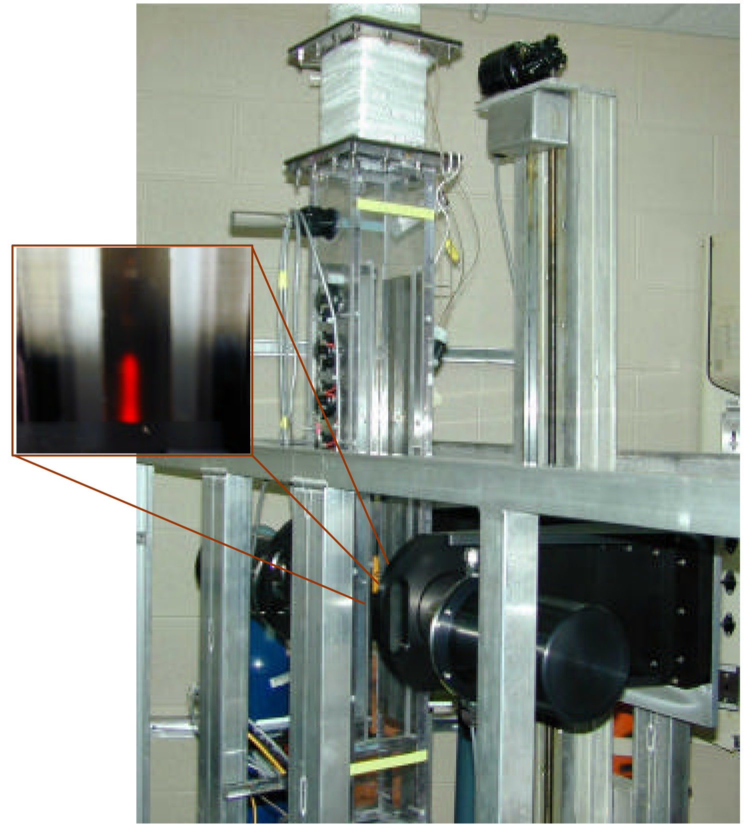
# Electroacoustic Agglomeration Flow Chamber




**Monitor agglomeration in flowing stream under controlled conditions**

# Electroacoustic Agglomeration Flow Chamber

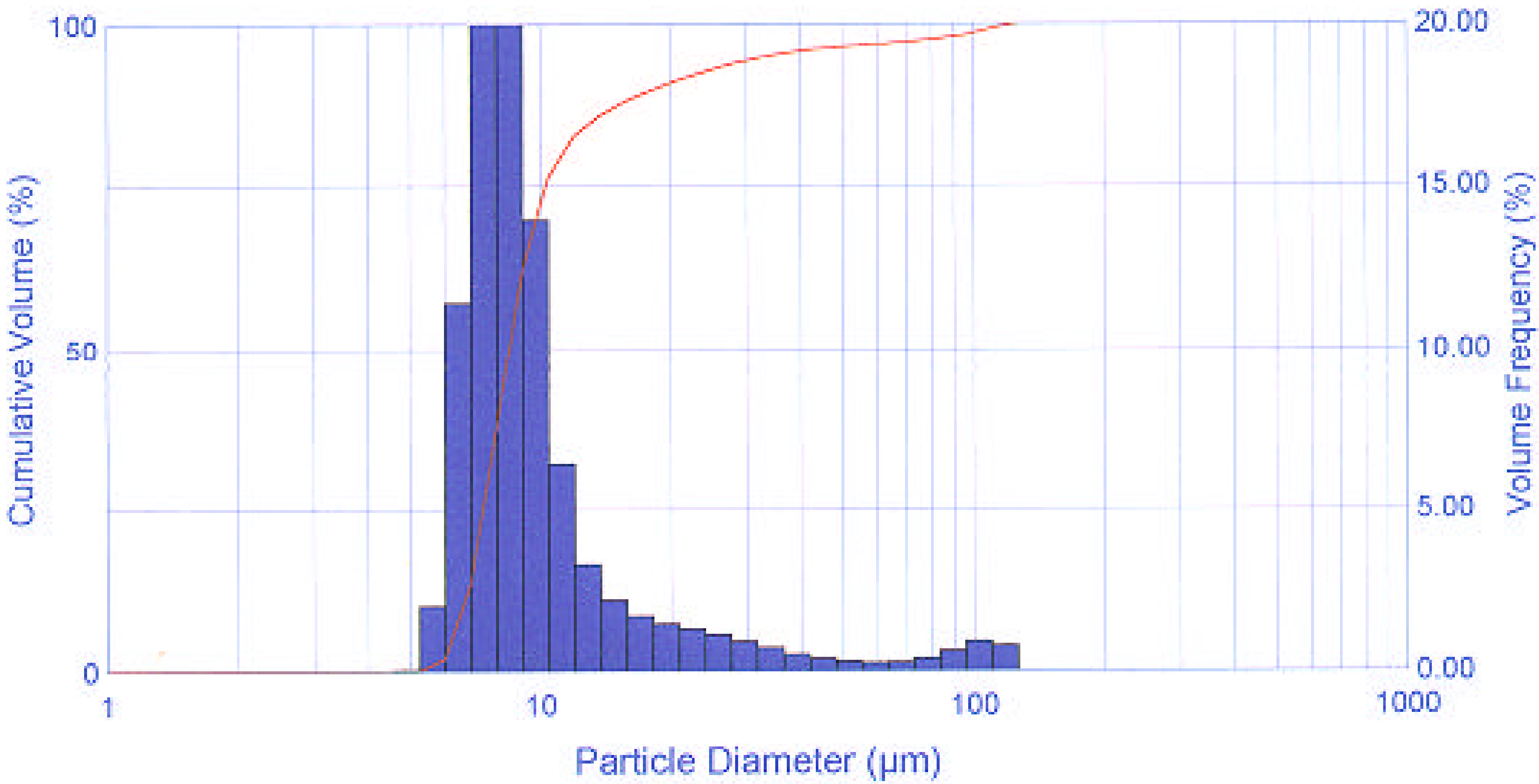


**Malvern Spraytec RTS5006 mounted to traverse length of electrode/speaker zone**
(continuous measure of particle size distribution in range 0.4-200 microns)

# Typical Source Aerosol for Flow Tests

**Experiments conducted injecting stream containing water droplets from ultrasonic humidifier into inlet air flow**




$D_v(10) = 6.63\ \mu m$
$D_v(50) = 8.51\ \mu m$
$D_v(90) = 18.5\ \mu m$

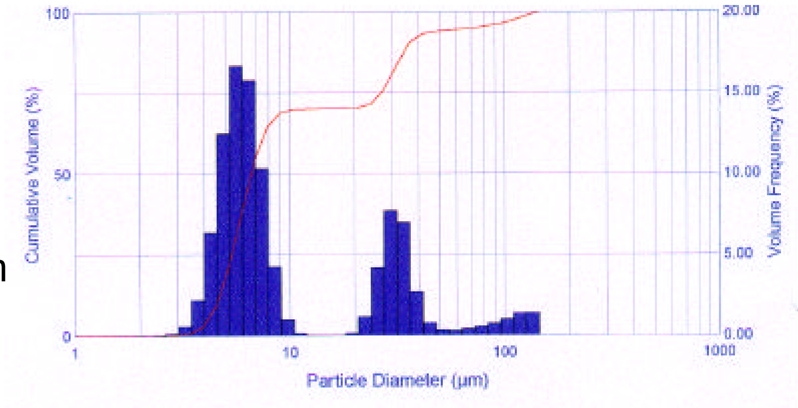
$D_{32} = 8.99\ \mu m$
$D_{43} = 12.9\ \mu m$

# Electrocoalescence in Flow Chamber

Constant flow rate; measurement 90 cm down electrodes; dc voltage applied.

**0 V/cm**

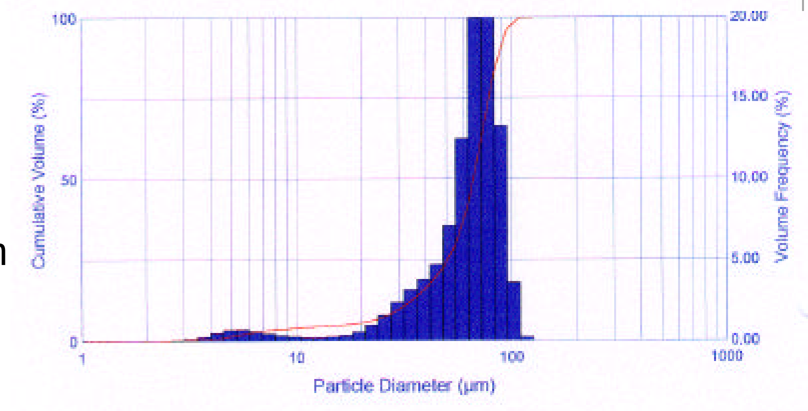
$D_v(50)=6.66\ \mu m$




**Larger droplets detected after flow down duct - attribute to collision and coalescence of drops in flow field**

**500 V/cm**

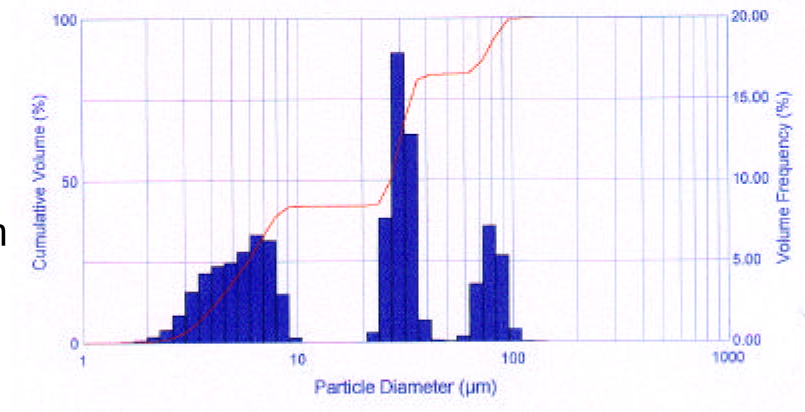
$D_v(50)=66.8\ \mu m$




**A significant shift in droplet size is seen with a moderate electric field - attribute to enhanced coalescence**

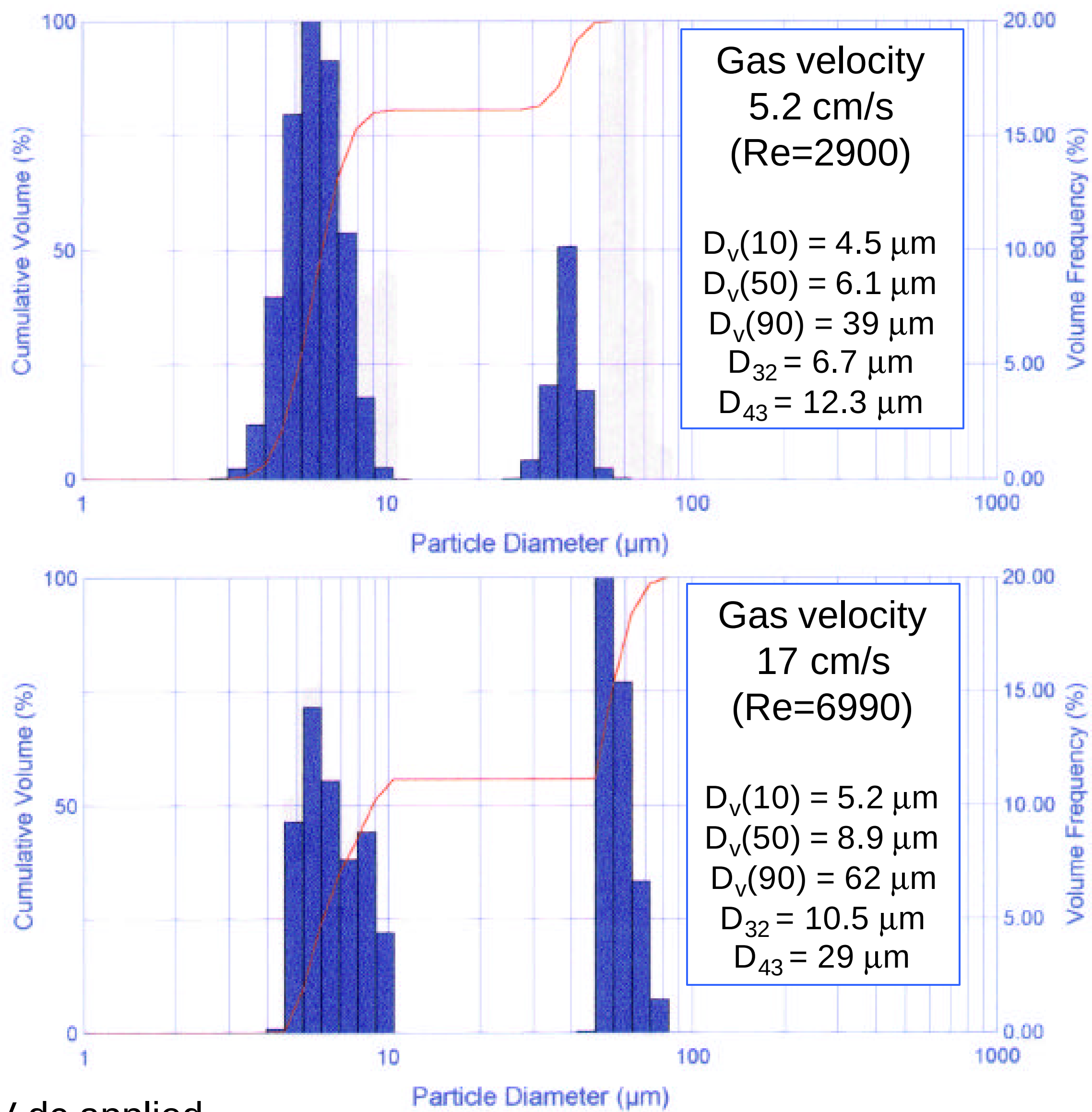
**1000 V/cm**

$D_v(50)=27.4\ \mu m$




**Smaller drops are evident at higher field strength - attribute to breakup of large drops**

# Effect of Flow Rate at Constant Voltage




20kV dc applied

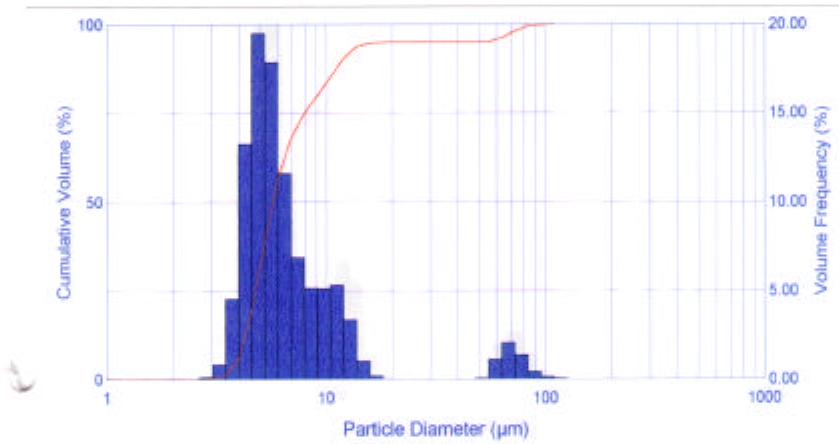
**<u>Multiple Effects:</u>**

- Higher velocity increases drop collision rate
- Higher flow rate decreases drop concentration at constant injection rate, decreasing collision rate
- Higher velocity decreases time in electric field

# Effect of Voltage at Constant Flow Rate

**0 V/cm**

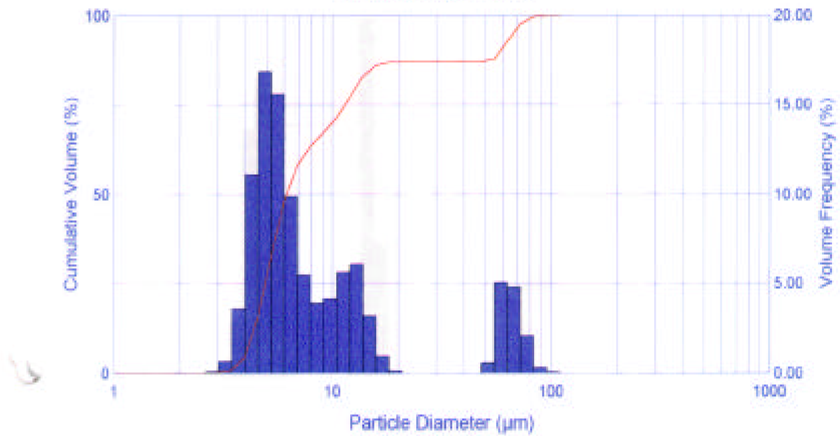
$D_v(10) = 4.2\ \mu m$
$D_v(50) = 5.7\ \mu m$
$D_v(90) = 11.9\ \mu m$
$D_{32} = 6.0\ \mu m$
$D_{43} = 9.8\ \mu m$




**Re = 2900; reduced aerosol loading**

**1.5 kV/cm**

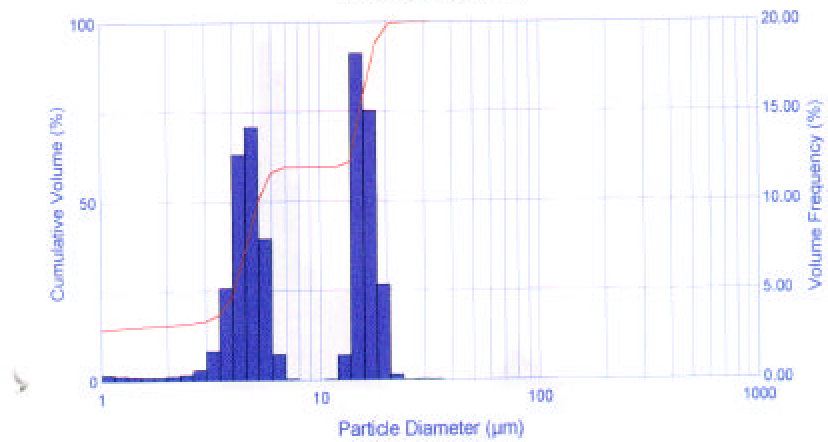
$D_v(10) = 4.3\ \mu m$
$D_v(50) = 6.2\ \mu m$
$D_v(90) = 59\ \mu m$
$D_{32} = 6.8\ \mu m$
$D_{43} = 14.6\ \mu m$




**At reduced aerosol loading, lower electrocoalescence rate**

**2.0 kV/cm**

$D_v(10) = 0.45\ \mu m$
$D_v(50) = 5.2\ \mu m$
$D_v(90) = 17.5\ \mu m$
$D_{32} = 1.9\ \mu m$
$D_{43} = 8.7\ \mu m$




**Significant field-induced droplet breakup at higher field strength**

# Discussion of Preliminary Experimental Results

- Qualitatively see significant effects of acoustic agglomeration. Further work is needed with unit reactor and flow chamber to determine controlling parameters, provide data for model validation.

- Results indicate that electrocoalescence performance depends significantly on a number of factors. Further work with unit reactor and flow chamber will be aimed at elucidating effects of:
  - particle size
  - particle concentration
  - density of particles
  - polarizability of particles
  - surface charge
  - flow rate
  - electric field strength

# Low Reynolds Number Particle Interactions

Essential to both the electro-coalescence and acoustic agglomeration work is characterization of Low Reynolds Number (LRN) particle-flow interactions.

Kernel formulation in General Dynamic Equation requires specification of the relative particle motion.

Relative motion is formulated by considering the fluid mechanic interactions.

We are investigating these interactions through combined experimental and theoretical studies.

Experiments: Low Re particle pairing processes

Theory: Low Re particle calculations

# Publications and Presentations

“Electrically Driven Technologies for Radioactive Aerosol Abatement”, presentation at DOE EMSP/TFA Workshop, Richland, WA, November, 1998.

“Computations of Sedimentation Rates for Acoustically Enhanced Agglomeration,” AIChE CCPS Annual International Conference and Workshop on Modeling Consequences of Accidental Releases of Hazardous Materials, San Francisco, CA Sept. 1999

“Design of an Oscillating Flow Apparatus for the Study of Low Reynolds Number Particle Dynamics,” in review, *Experiments in Fluids*

# Summary

- Fundamental work is aimed at understanding whether acoustic and/or electric fields can be employed to improve aerosol removal
- Experiments and computational studies in early stages
- Preliminary results show significant effects of acoustic and electric fields in coalescence/agglomeration of particles/droplets; several contributing variables
- We plan to run experiments/simulations that match aerosol conditions (size distribution, concentration, flow rate, etc.) of potential end-users as closely as possible.
- Need to develop contacts with potential end-users
  - technology not ready for demonstration or implementation, but can focus study better