Sampling $PM_{2.5}$ emissions from coal combustion: Effects of dilution ratio and residence time

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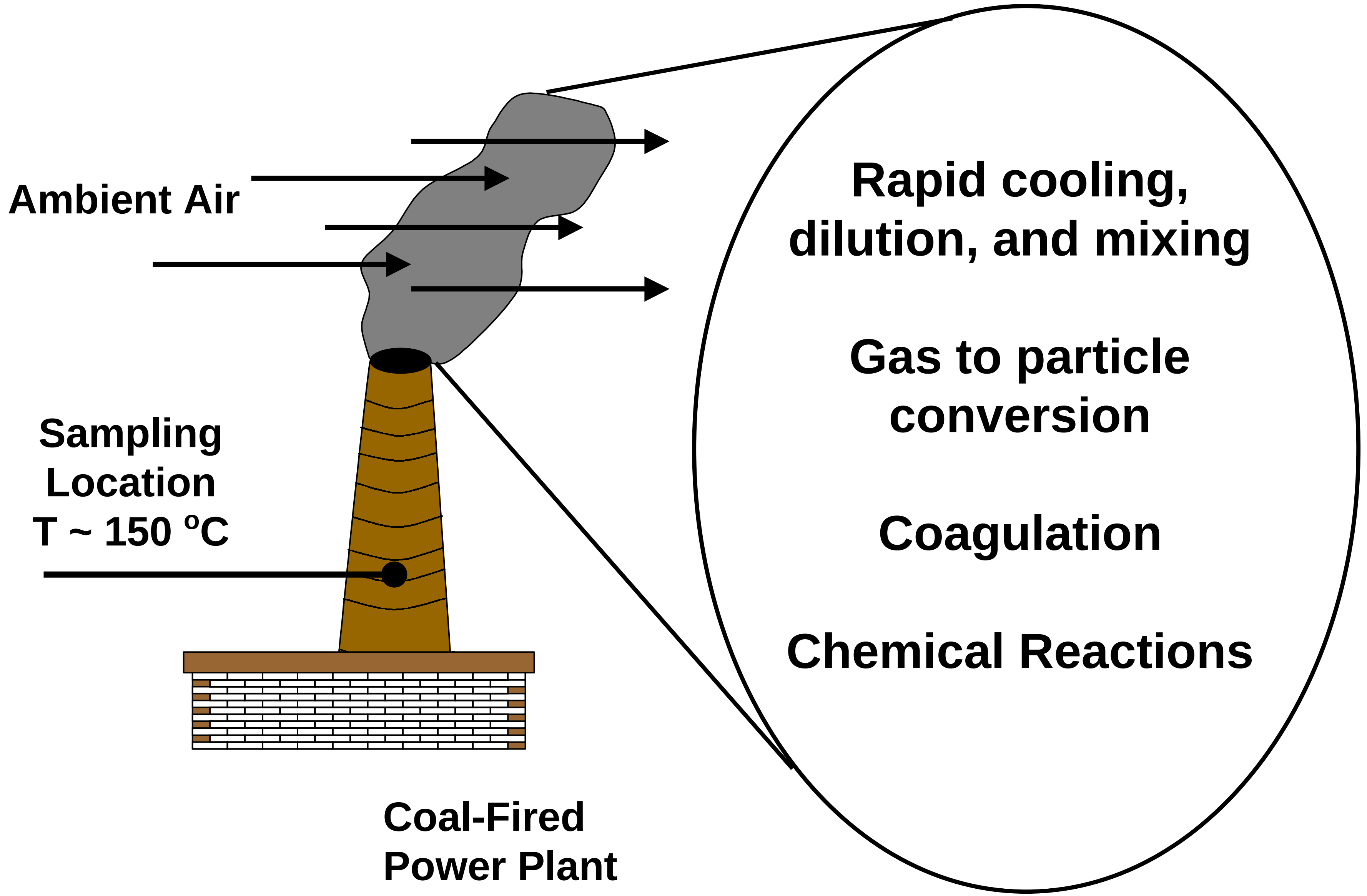
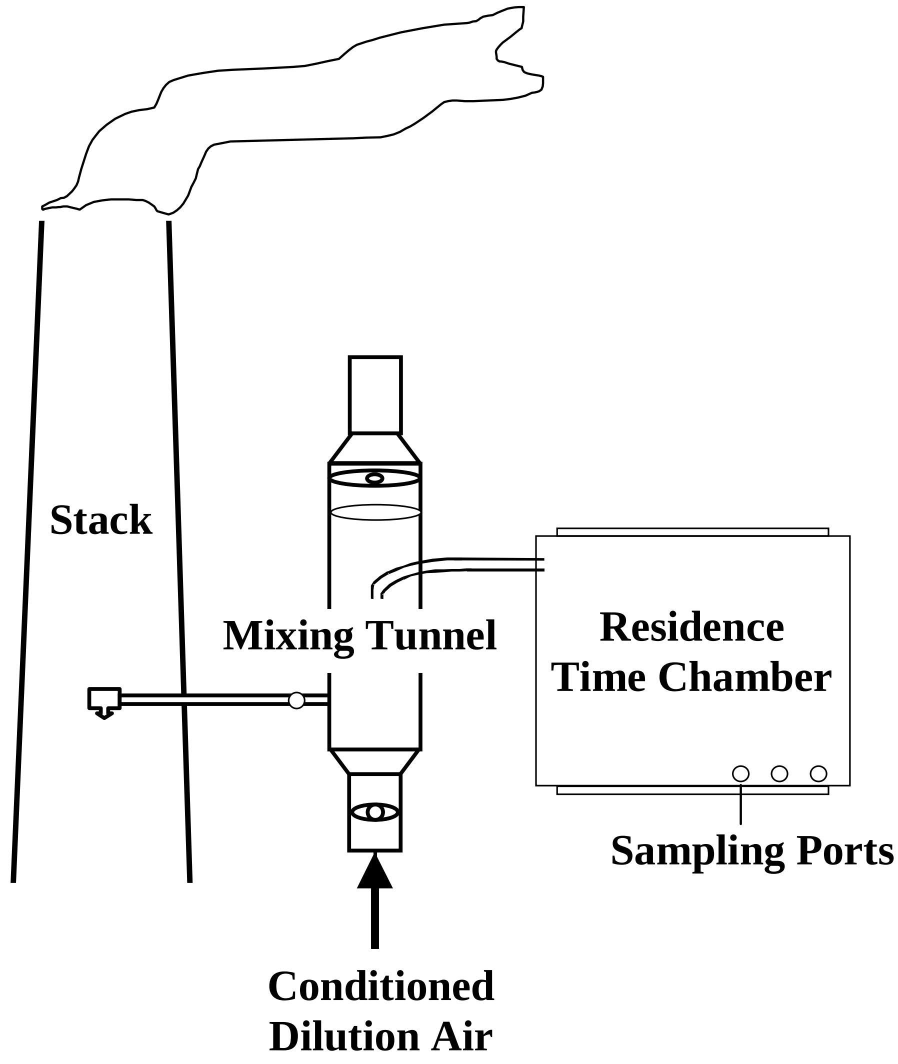
Plume Processes Effect PM Emissions



Dilution Sampling

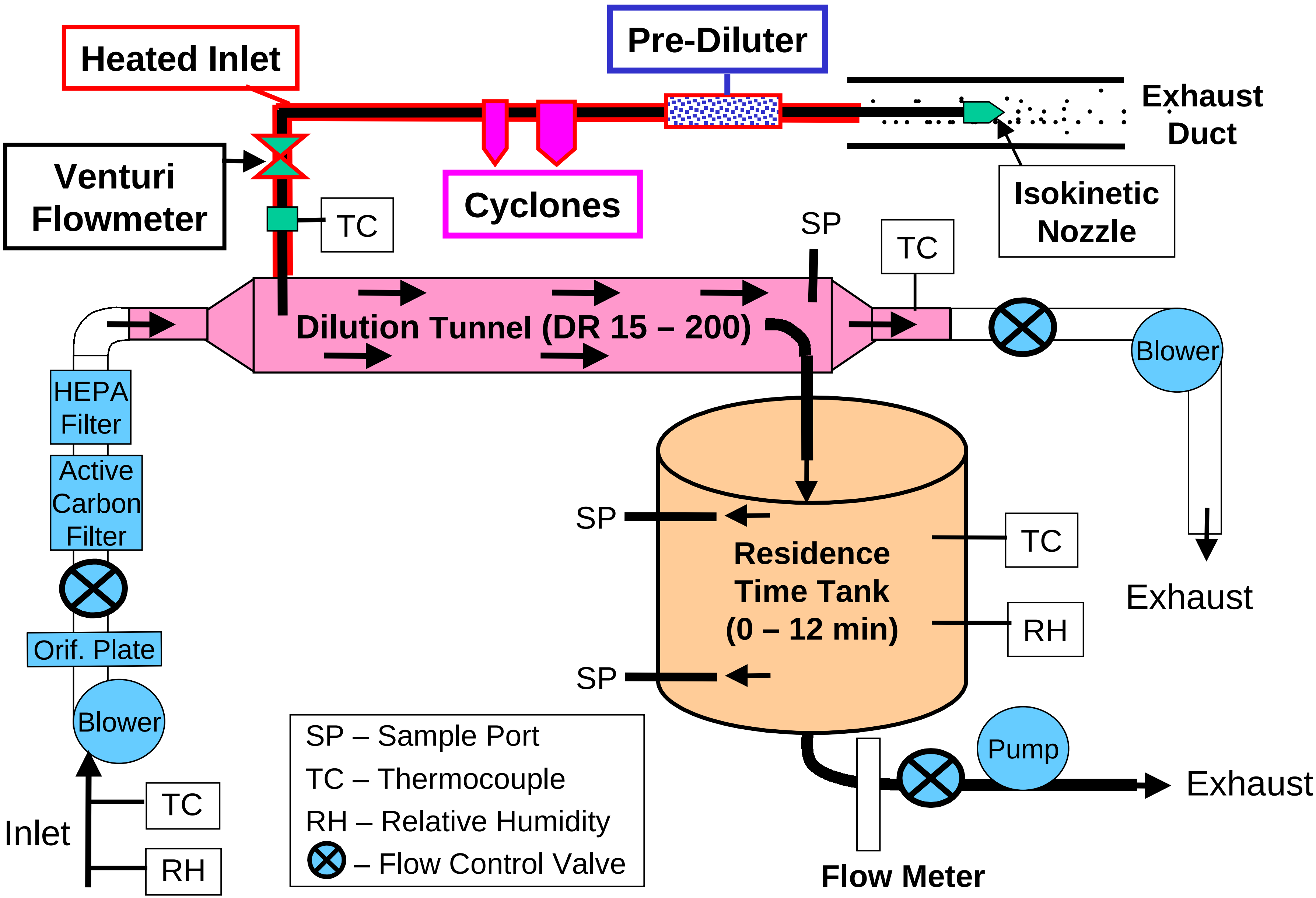


- Simulates plume processes
  - Semi volatile species (Organics, Metals)
  - Size Distribution
- Advanced instrumentation
- Limited data for coal emissions
- Complex

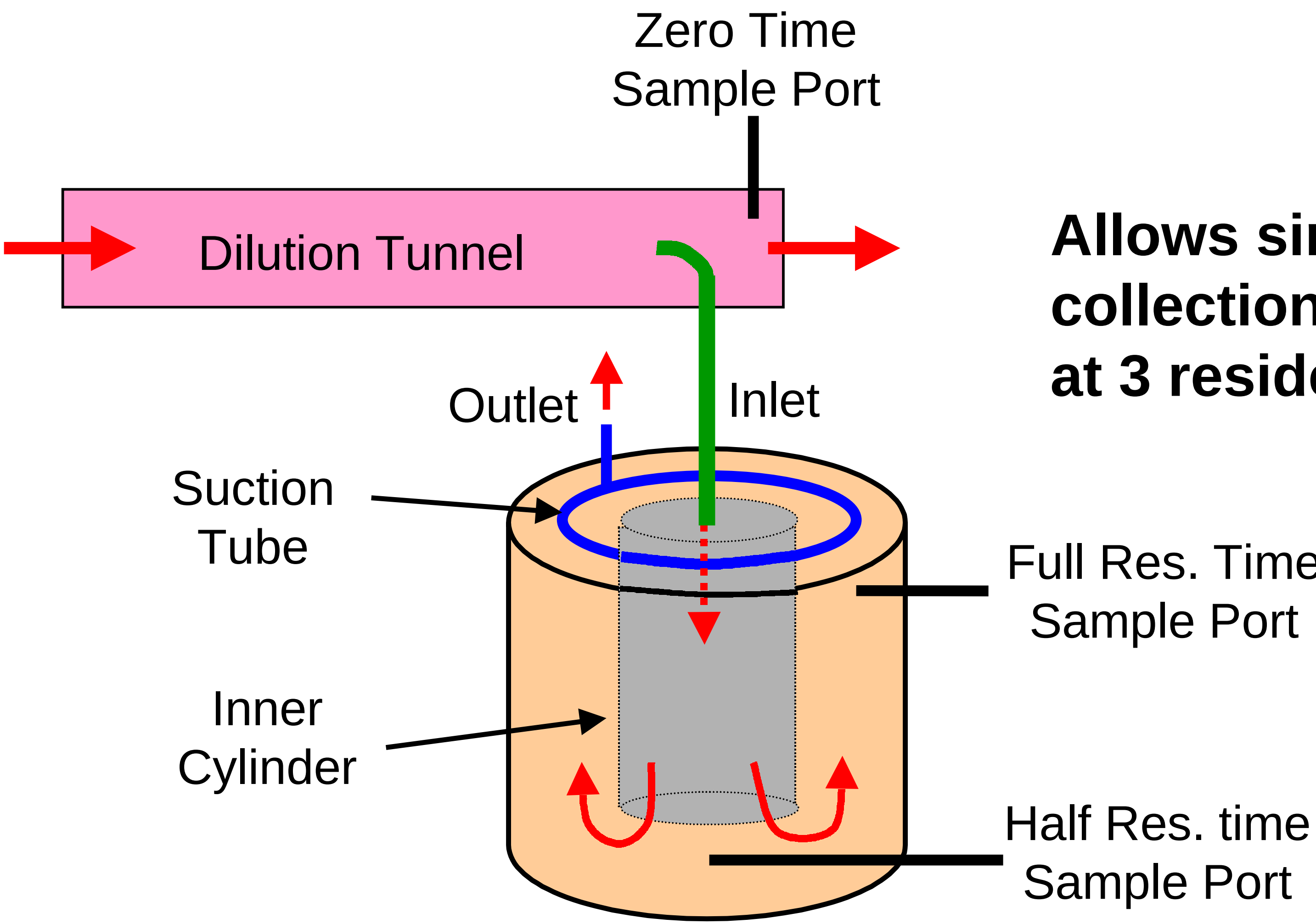
Overview

- CMU dilution sampler
- CERF - pilot-scale pulverized coal combustor.
- Effects of dilution & residence time on:
  - Size Distribution
  - Nucleation
  - Mass emissions
- Before and after bag-house
- Hot filters vs. dilution

Schematic of CMU Dilution Sampler



Residence Tank Design



Allows simultaneous collection of samples at 3 residence times

Instrumentation

- **Size Distribution measurements**
  - **Two Scanning Mobility Particle Sizers (SMPS)**
    - **Nano-DMA: 0.003 μm – 0.075 μm**
    - **Long-DMA: 0.015 μm – 0.65 μm**
  - **Aerodynamic Particle Sizer (APS): 0.5μm – 5 μm**
- **Teflon Membrane filters**

Normalize Emissions to an Exhaust Basis:

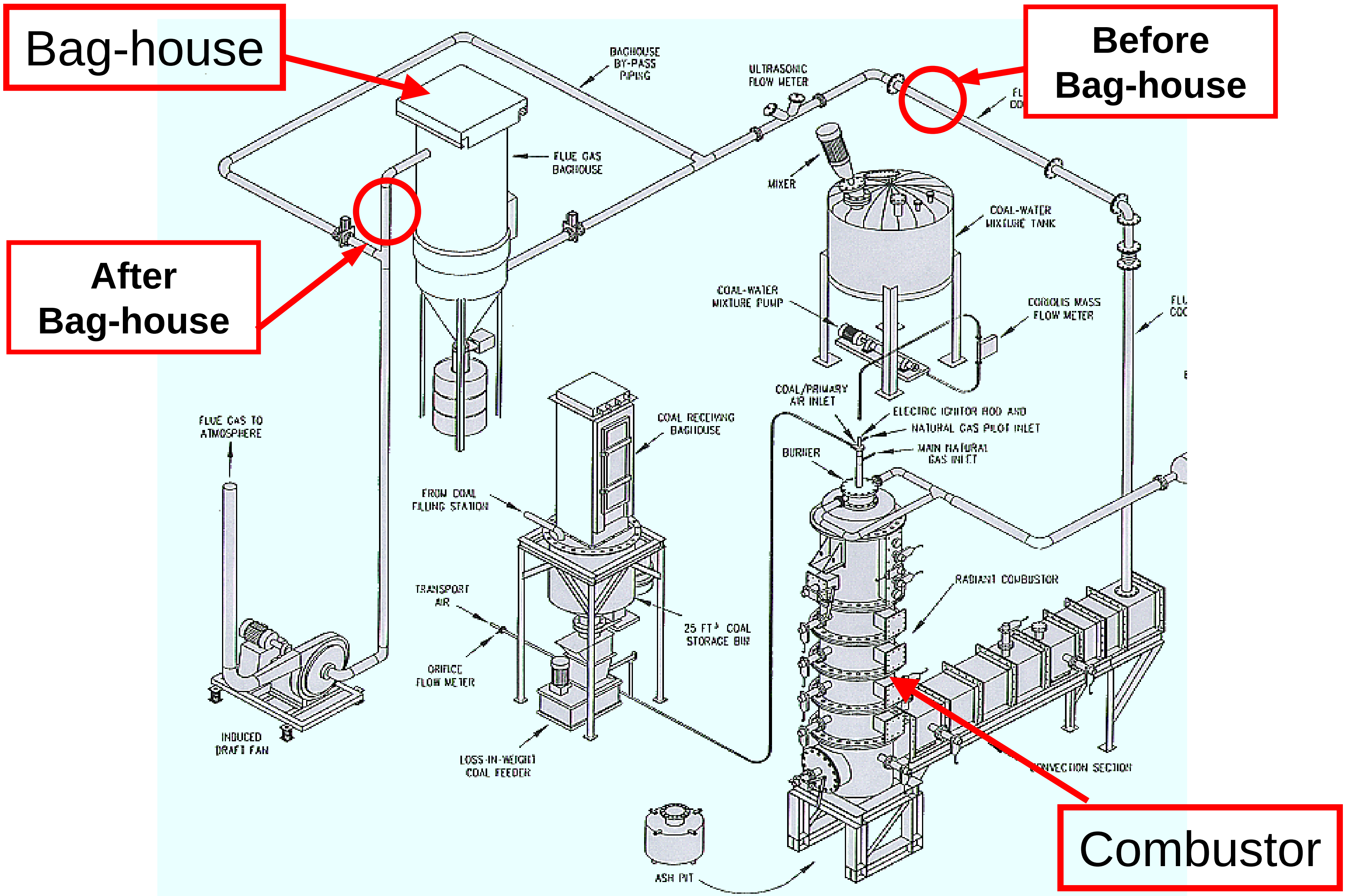
$\rightarrow PM_{norm} = PM_{meas} \times DR$

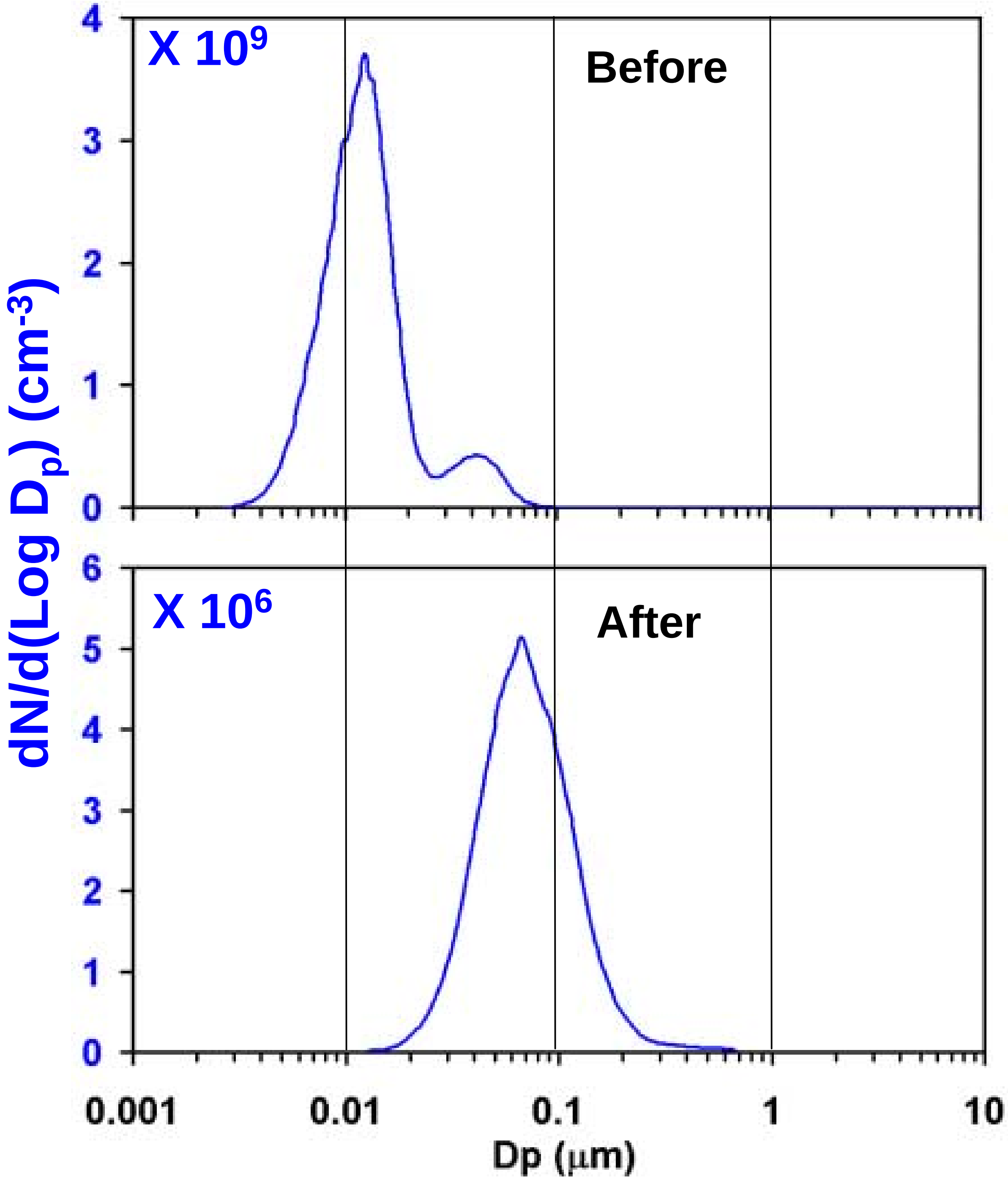
Pilot-Scale Coal Combustor (CERF)

- Pilot-scale: 50 lbs/hr
  (~500,000 Btu/hr)
- Simulates:
  - Gas temperature
  - Gas composition
  - Residence time

  of a Utility Boiler
- Eastern Bituminous Coal
  (low ash, low S)

CERF Sampling Locations

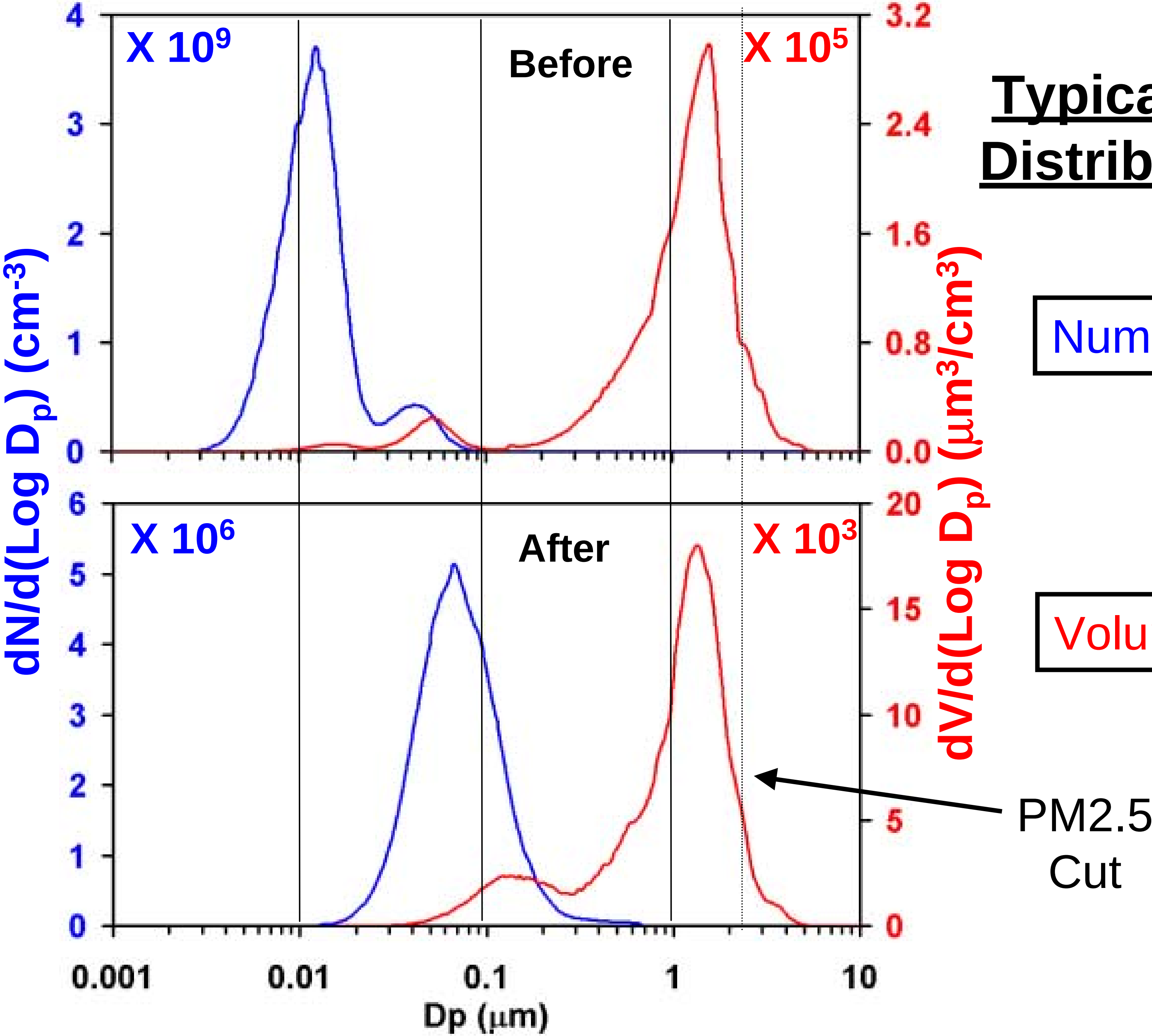




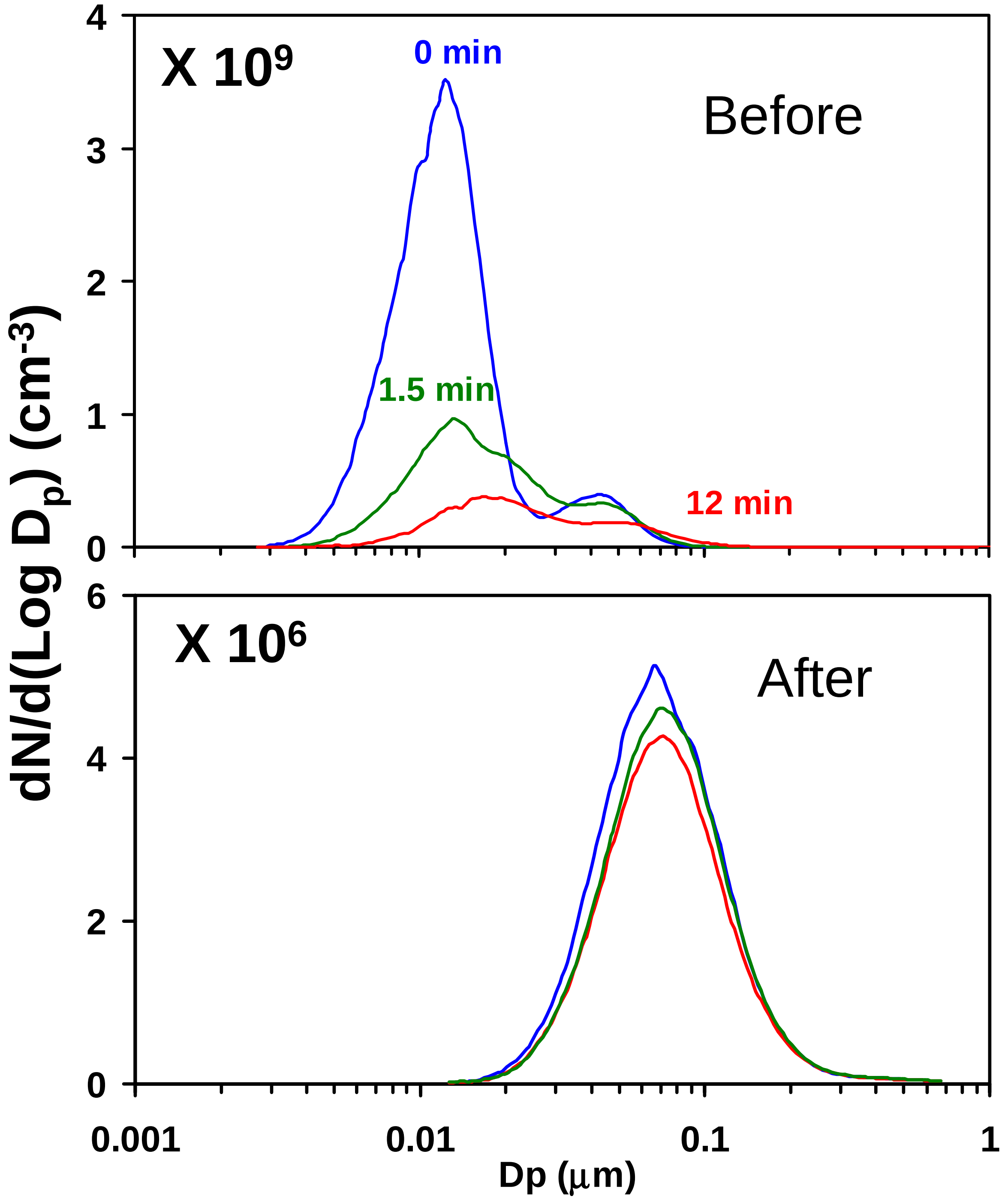
Typical Size Distributions

Number

Typical Size Distributions



Effects of Residence Time on Size Distribution

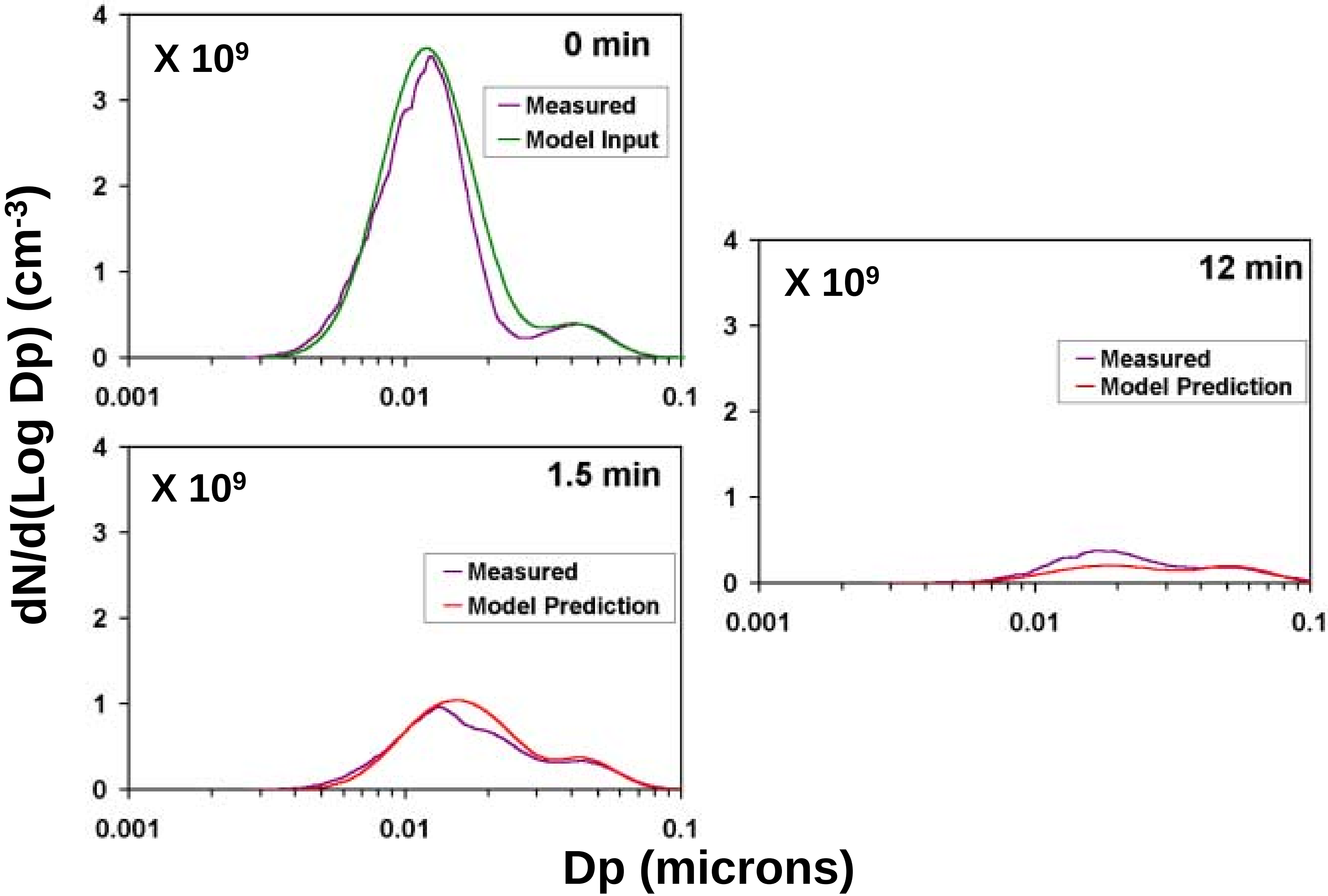


Analysis of Size Distribution Data

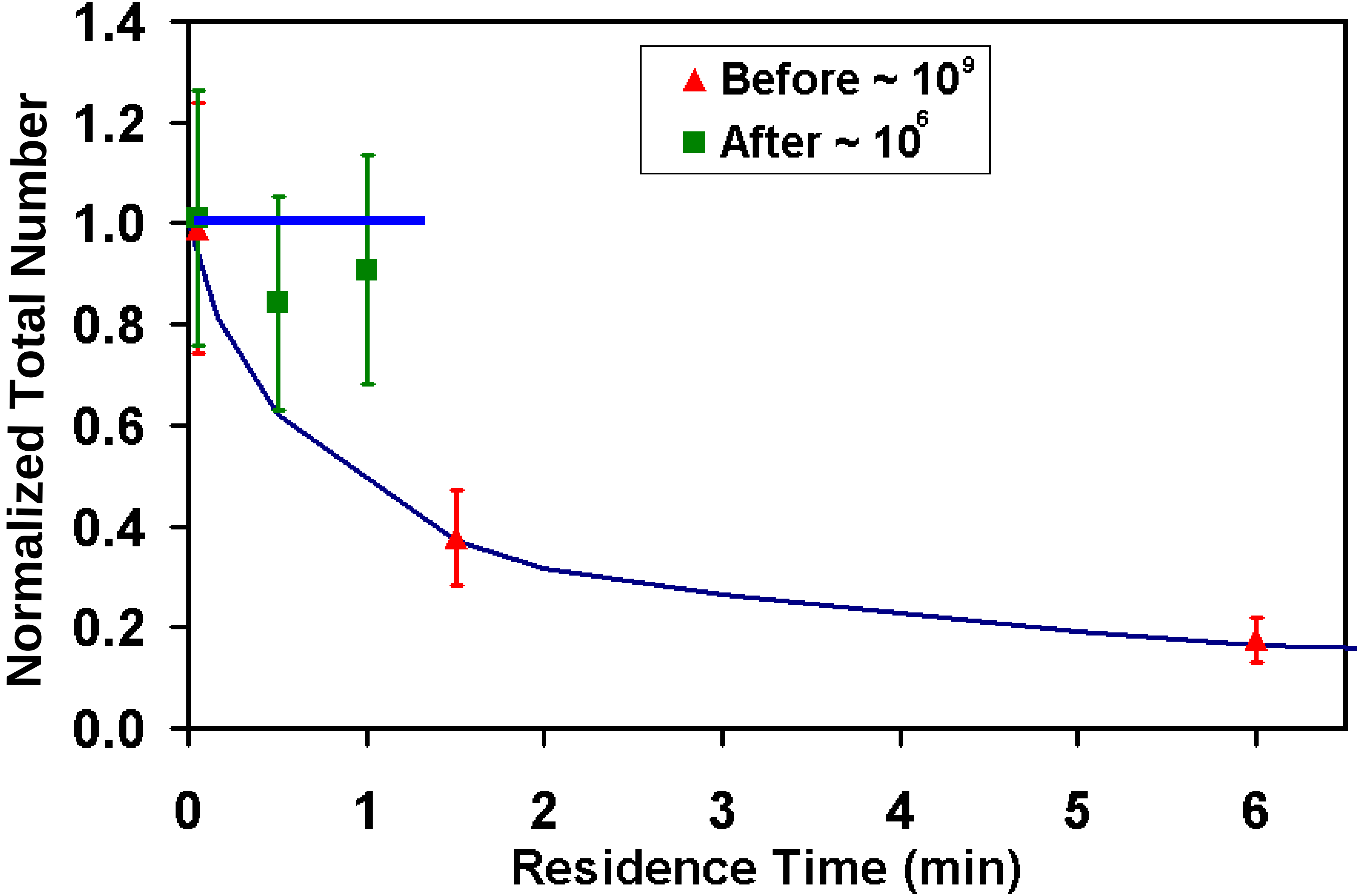
- **Coagulation simulations**
  - $$\frac{dN_k}{dt} = \frac{1}{2}\sum_{j=1}^{k-1} K_{j,k-j} N_j N_{k-j} - N_k \sum_{j=1}^{\infty} K_{k,j} N_j$$
- **Will Coagulation Occur?**
  - **Characteristic Times:** $\tau_c = \dfrac{2}{K N_0}$
    - **Before Bag-house: τ_c ~ 25-170 sec → Coagulation**
    - **After Bag-house: τ_c ~ 45,000 sec → No Coagulation**

Seinfeld & Pandis, 1998

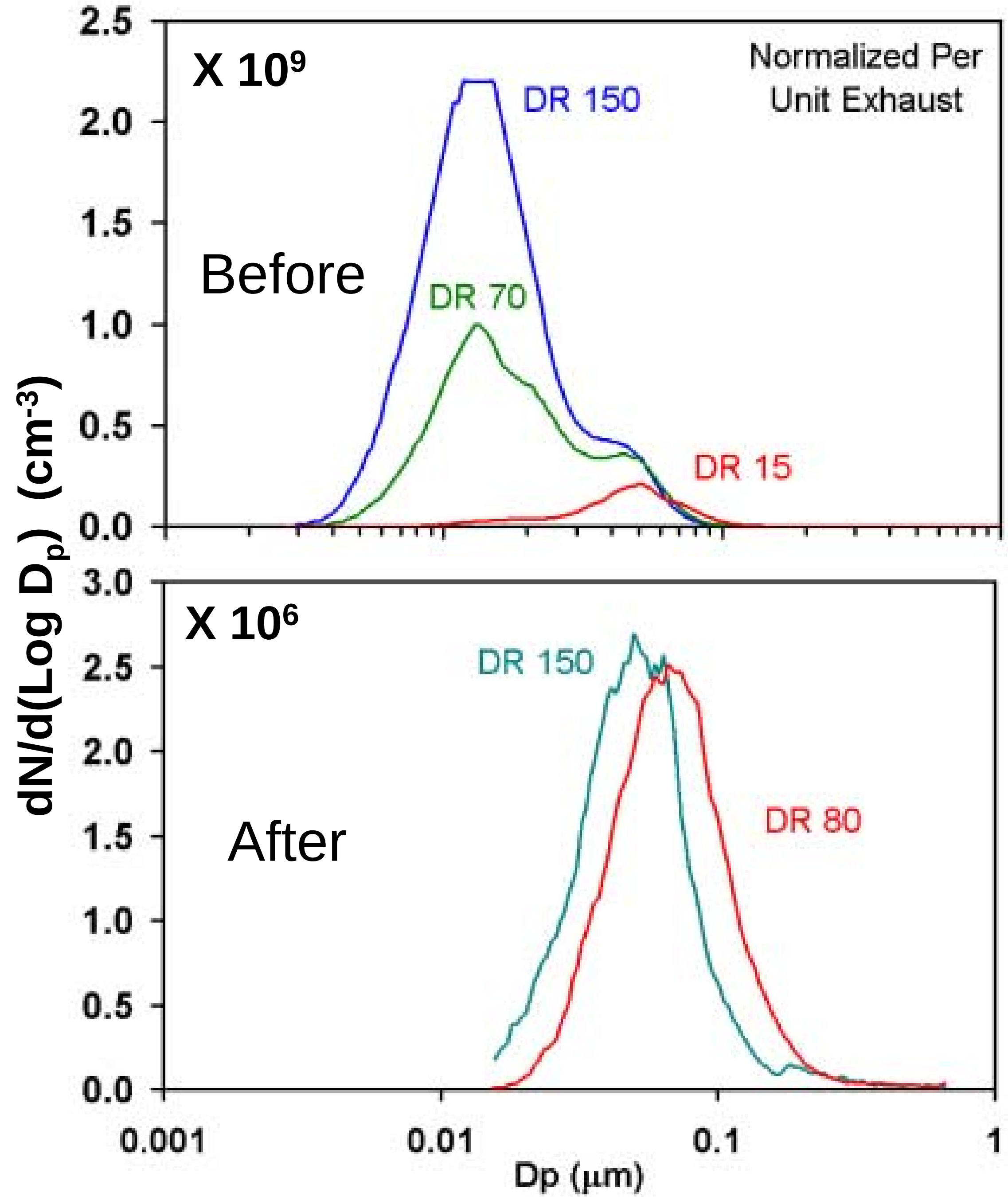
Coagulation Theory Predicts Evolution of Size Distribution



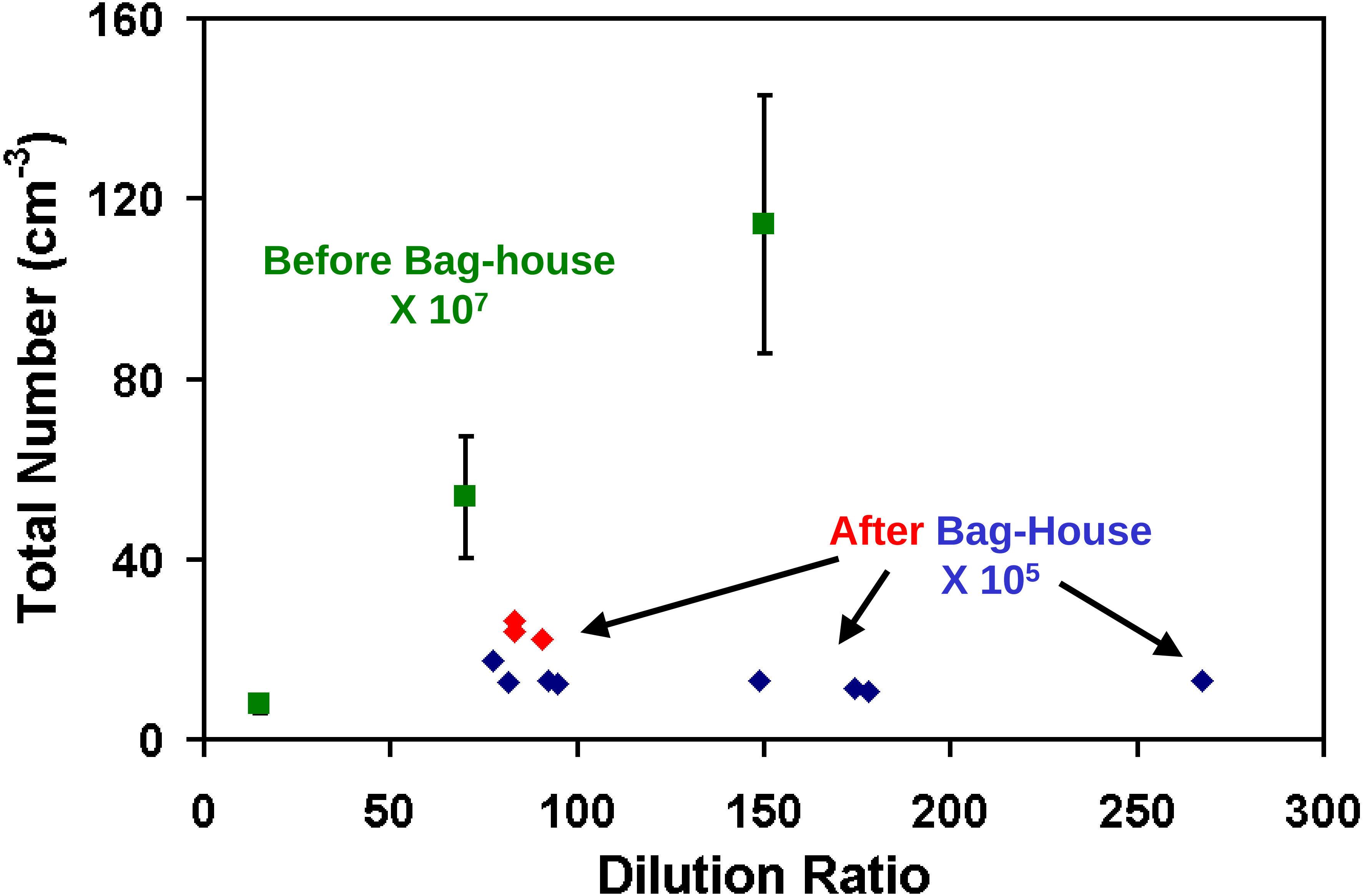
Total Number vs. Residence Time



Effect of Dilution Ratio on Size Distribution



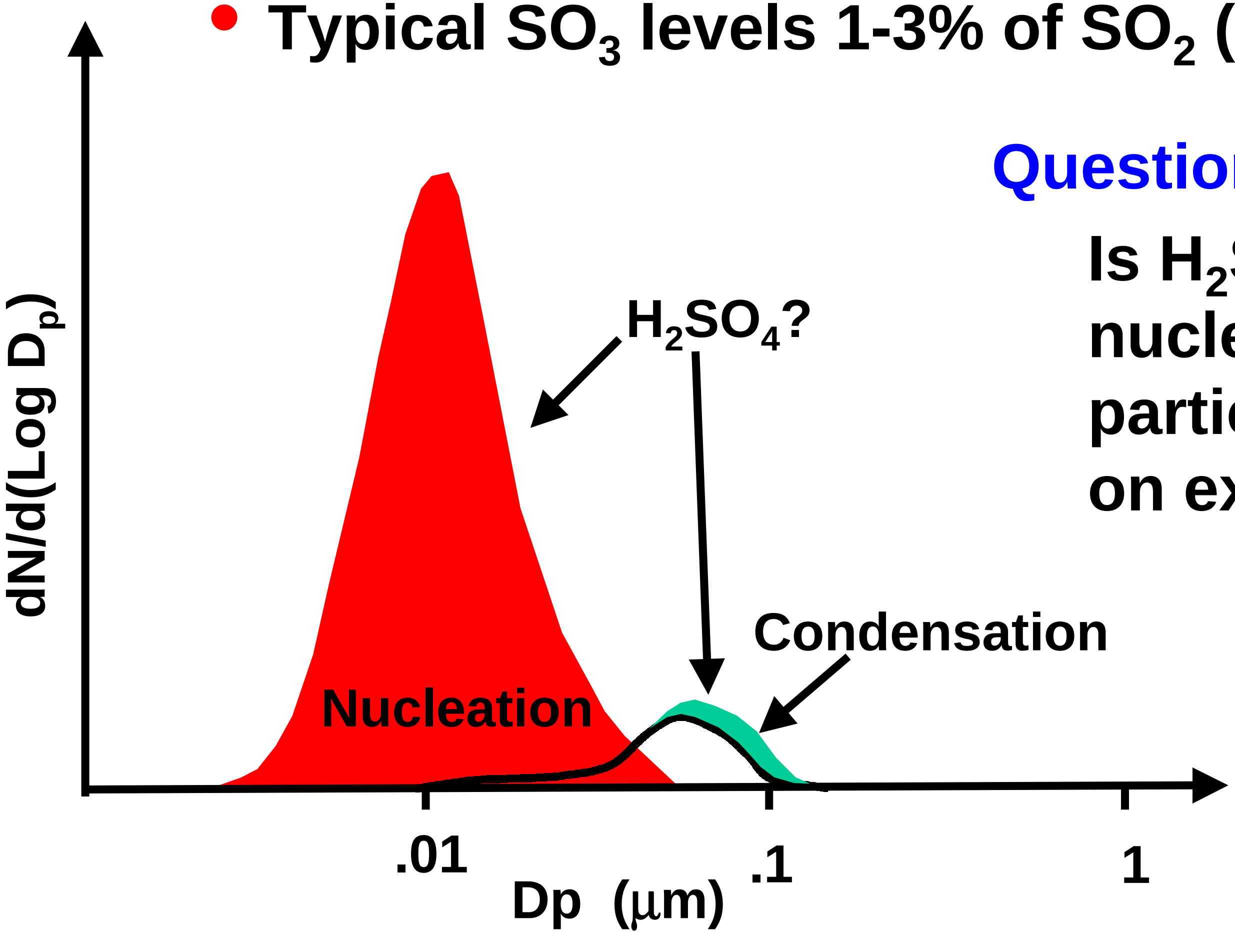
Total Number Emissions as a function of Dilution Ratio



Gas to Particle Conversion

As combustion products cool

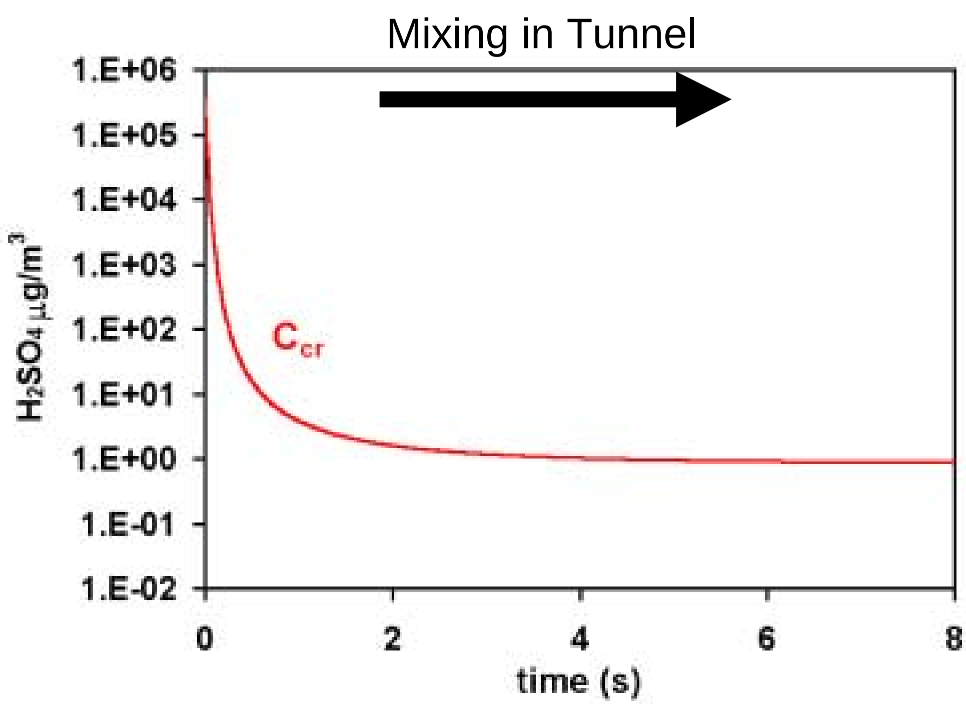
- $SO_3 + H_2O \rightarrow H_2SO_4 \rightarrow$ particles
  - Typical SO_3 levels 1-3% of SO_2 (~ 50 ug/m^3)



Question:

Is H_2SO_4 going to nucleate to form new particles or condense on existing particles?

Will nucleation occur?



Critical H_2SO_4 concentration

$$C_{cr} = 0.16 \exp(0.1T - 3.5rh - 27.7)$$

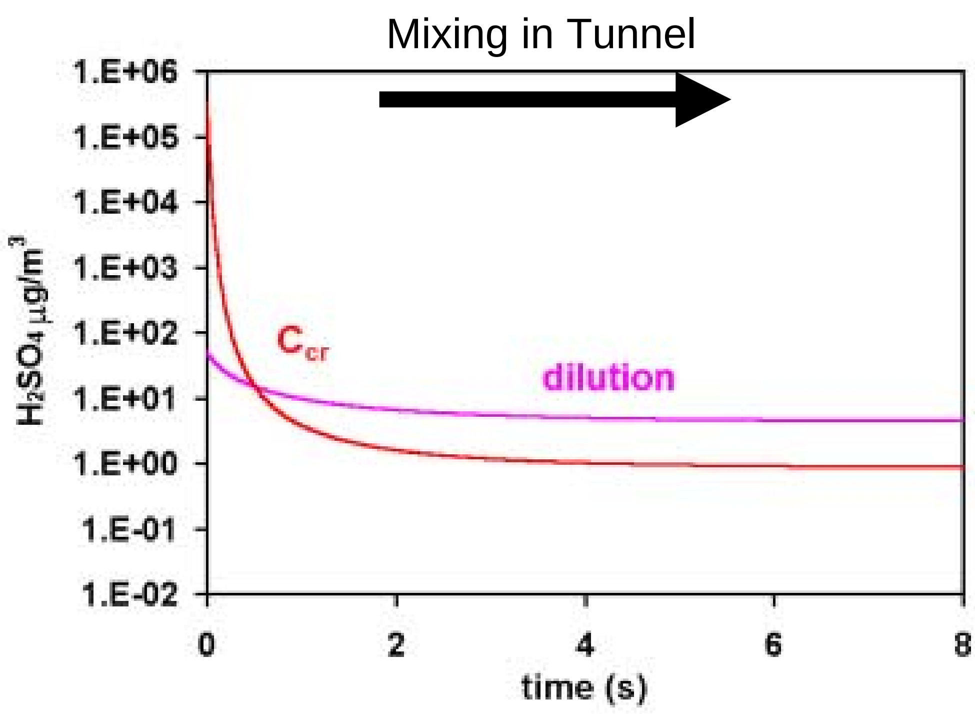
Concentration of H_2SO_4 in tunnel

$$\frac{dC}{dt} \approx \cancelto{0}{P} - \frac{C}{\tau_{cond}} - \frac{C}{\tau_{dilute}}$$

If $\frac{C}{C_{cr}} > 1$ → **Nucleation!**

Kerminen & Wexler, 1994

Will nucleation occur?



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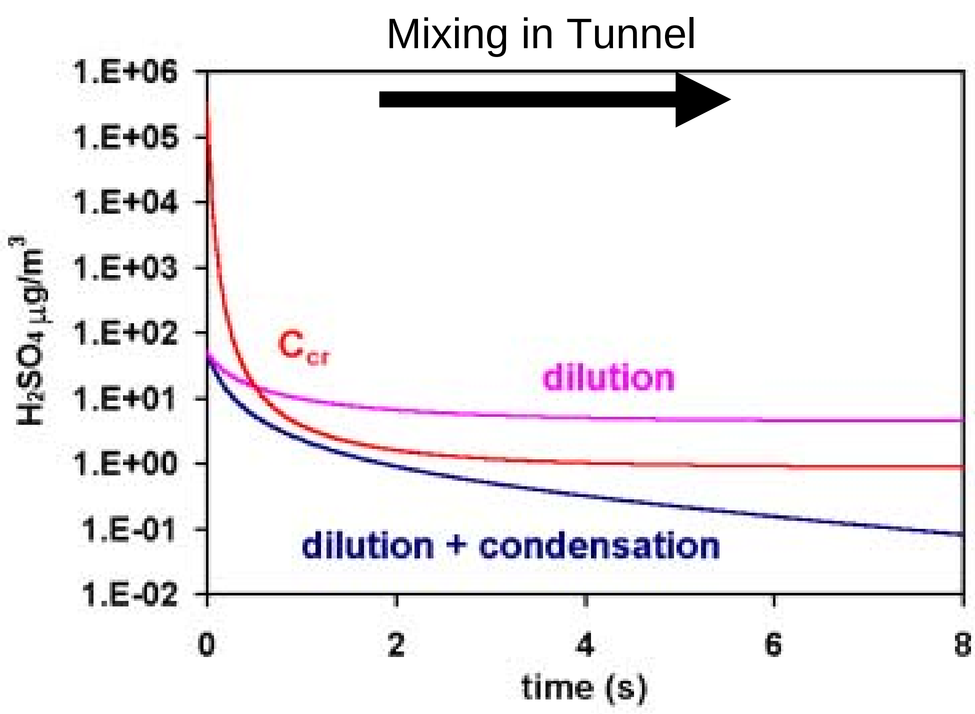

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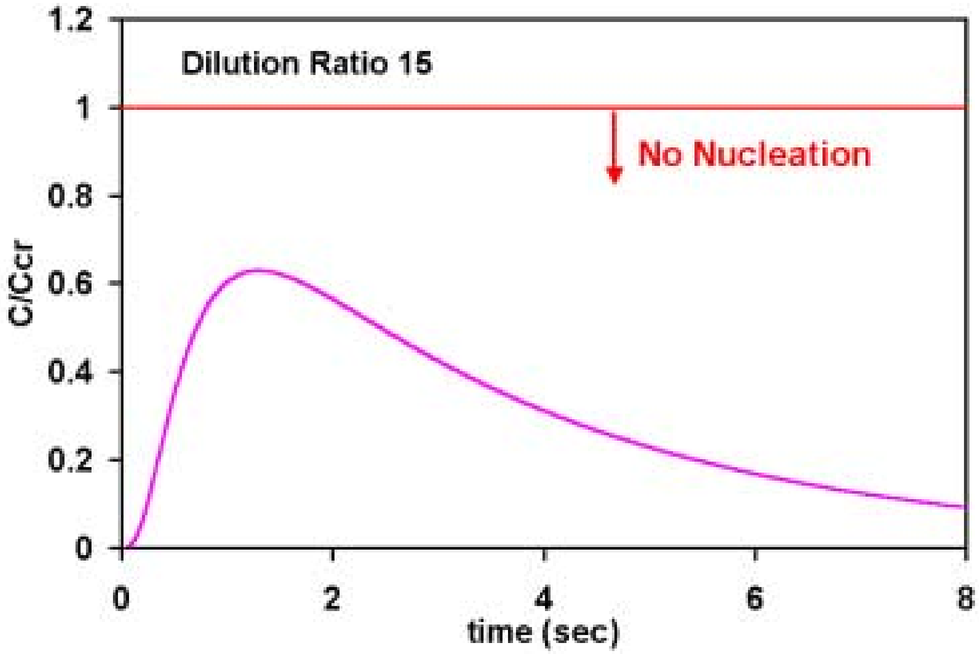
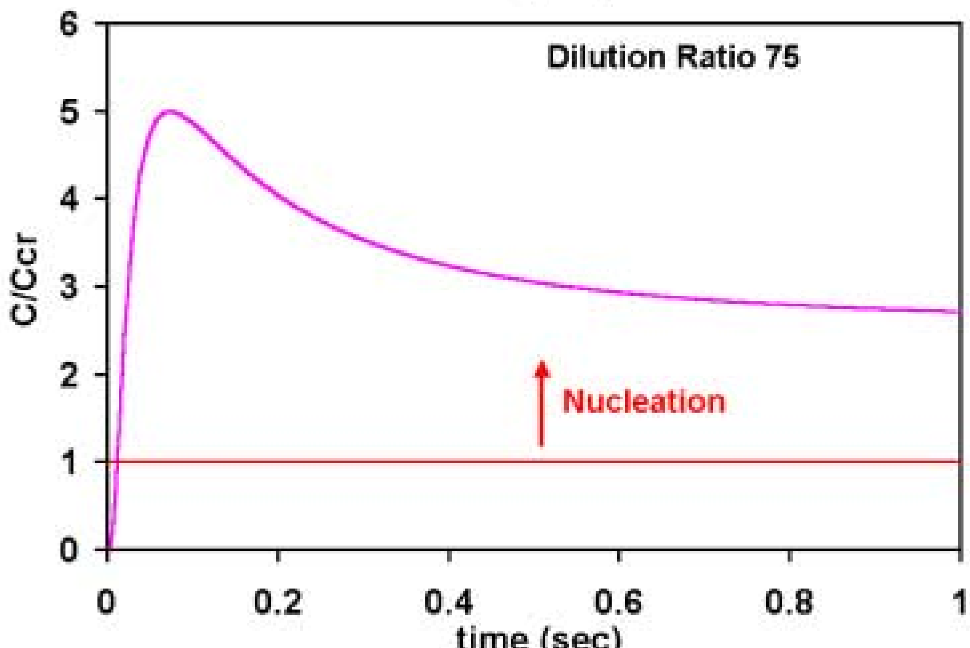
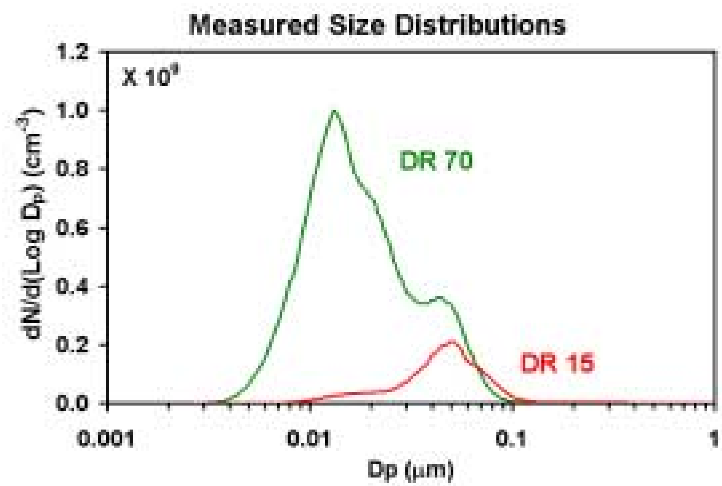
Before the Bag-house

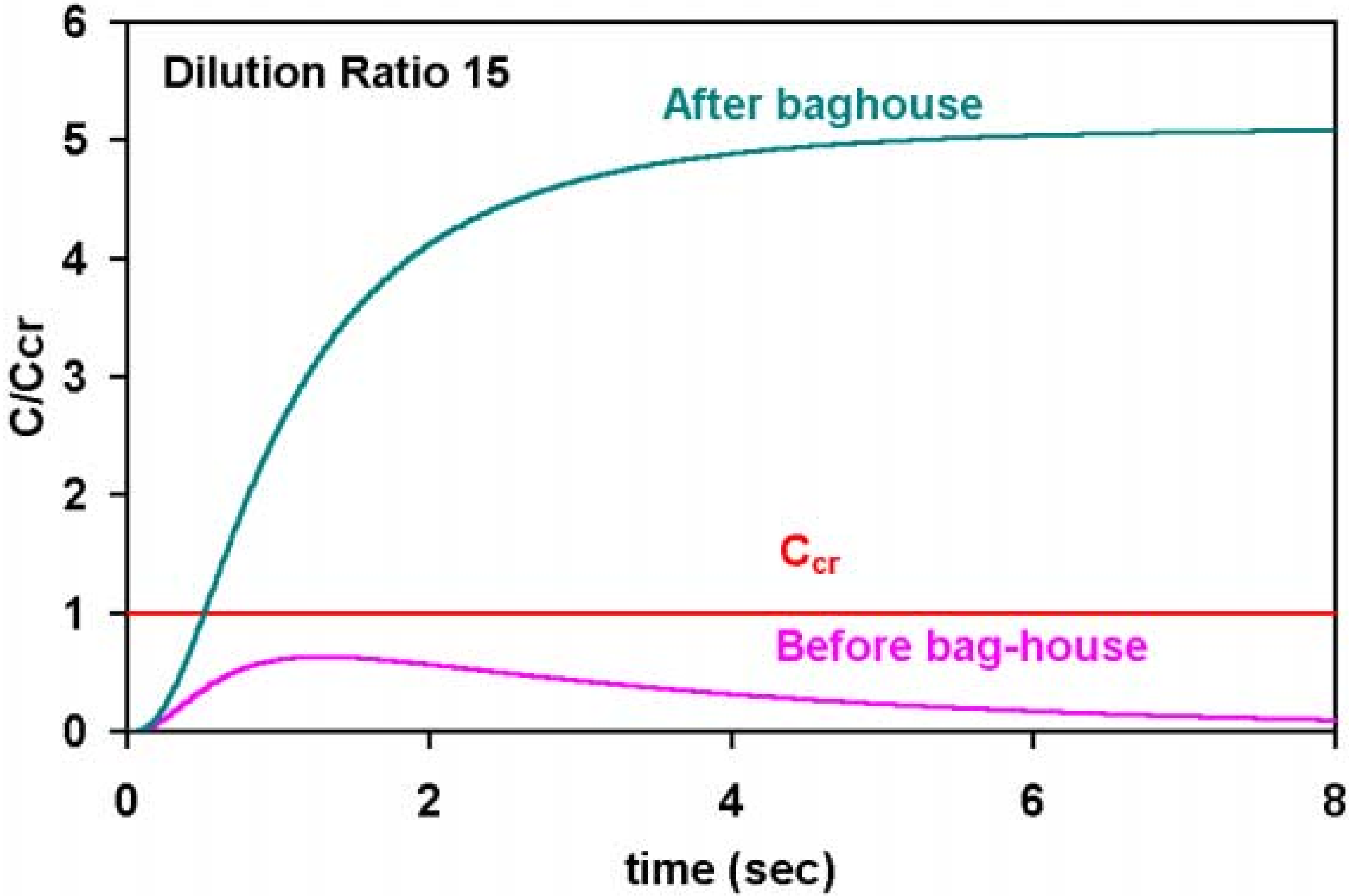
- **Nucleation depends on dilution ratio**
  - **Low dilution ratio → no nucleation**
  - **High dilution ratio → nucleation**

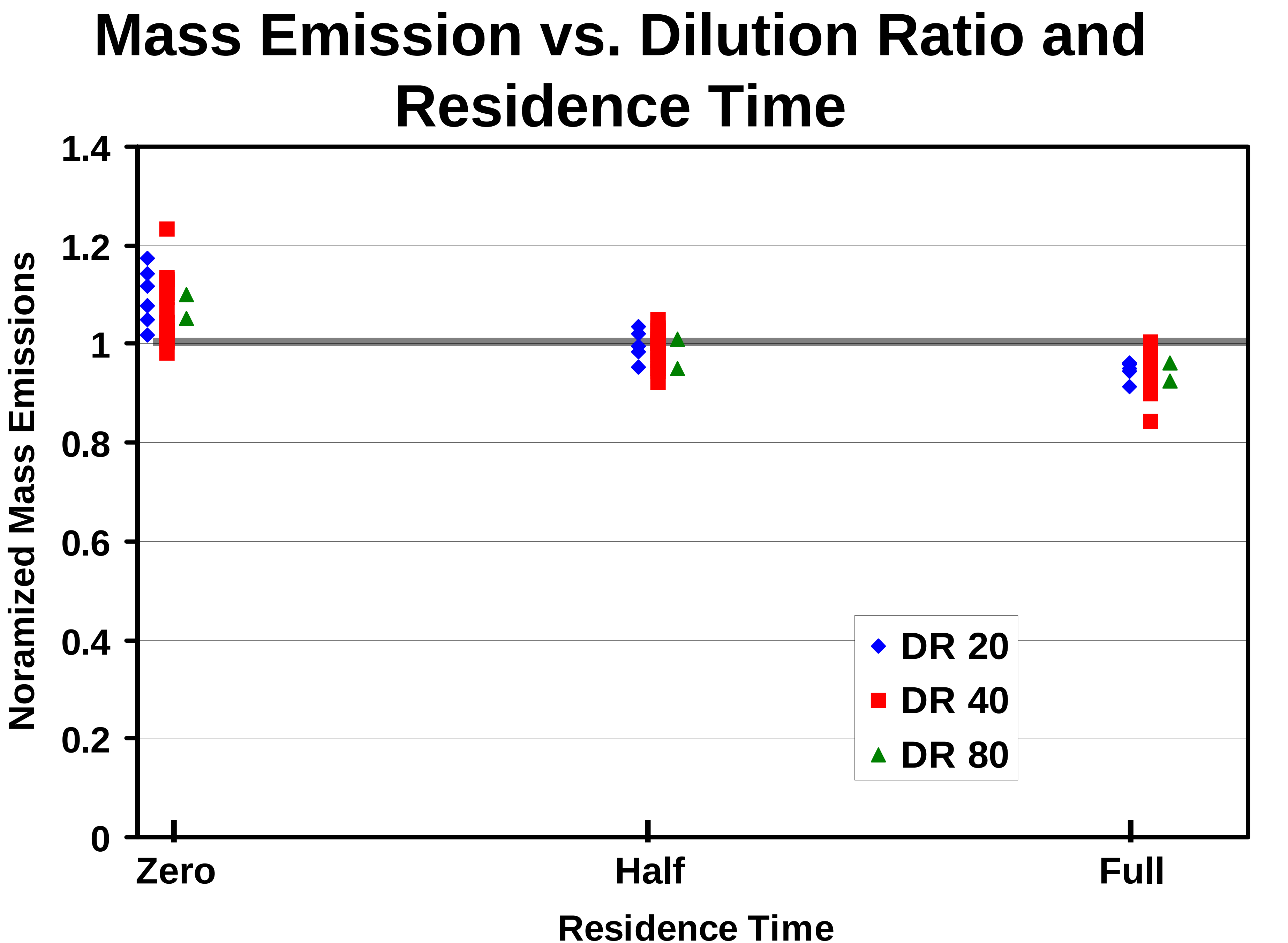




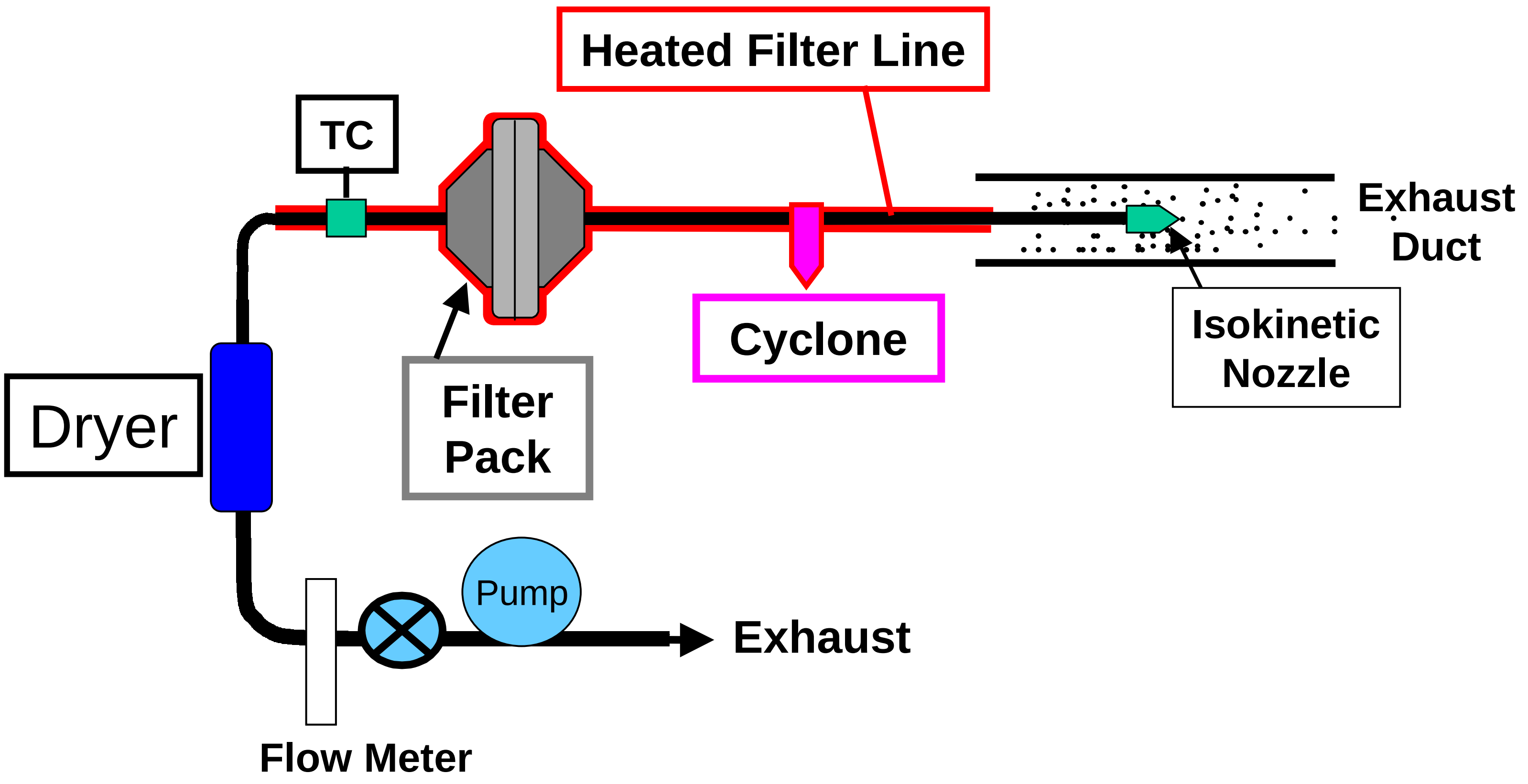


Theory Predicts Nucleation after the Bag-house

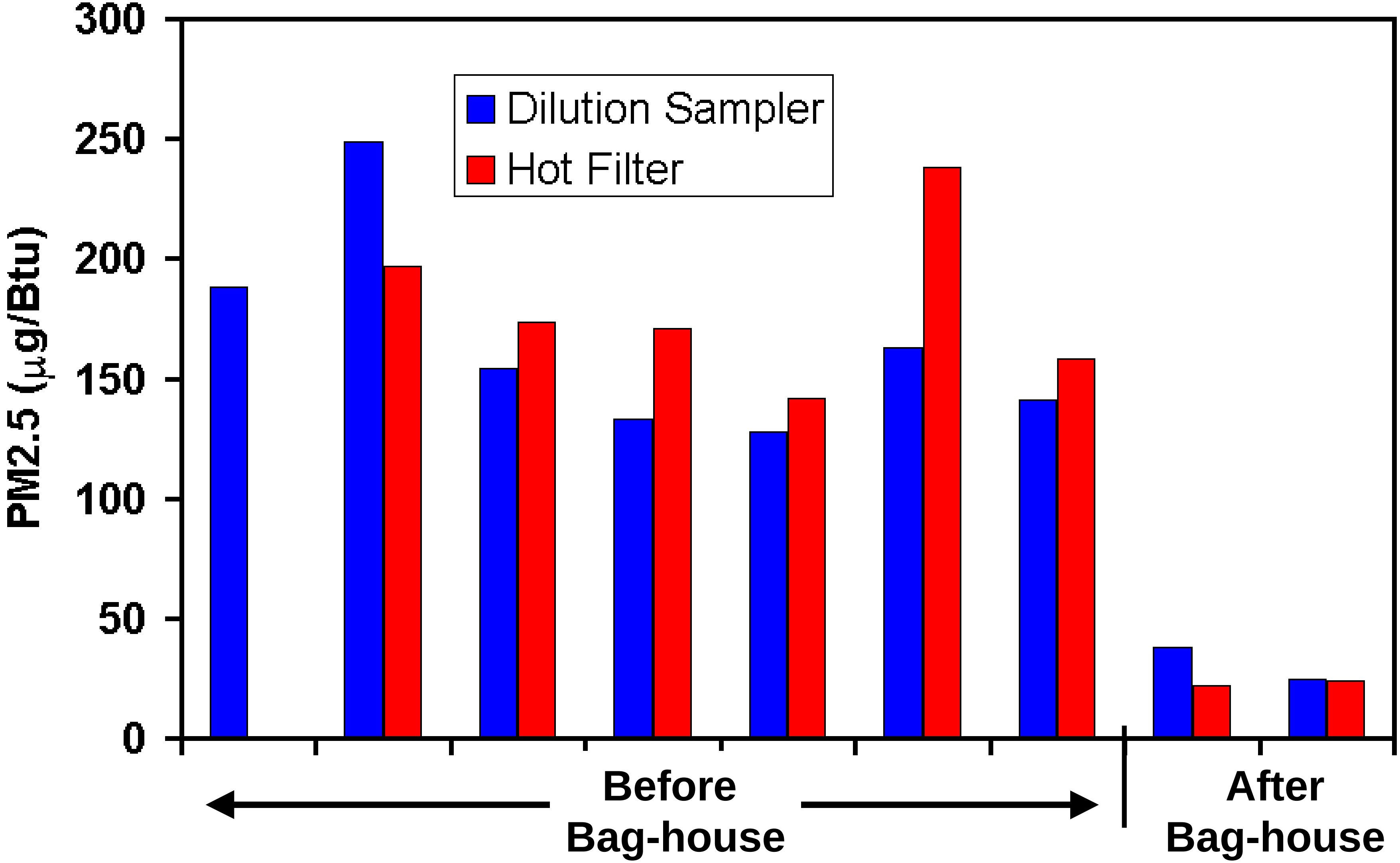



Mass Emission vs. Dilution Ratio and Residence Time
Noramized Mass Emissions
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Zero
Half
Full
Residence Time
DR 20
DR 40
DR 80

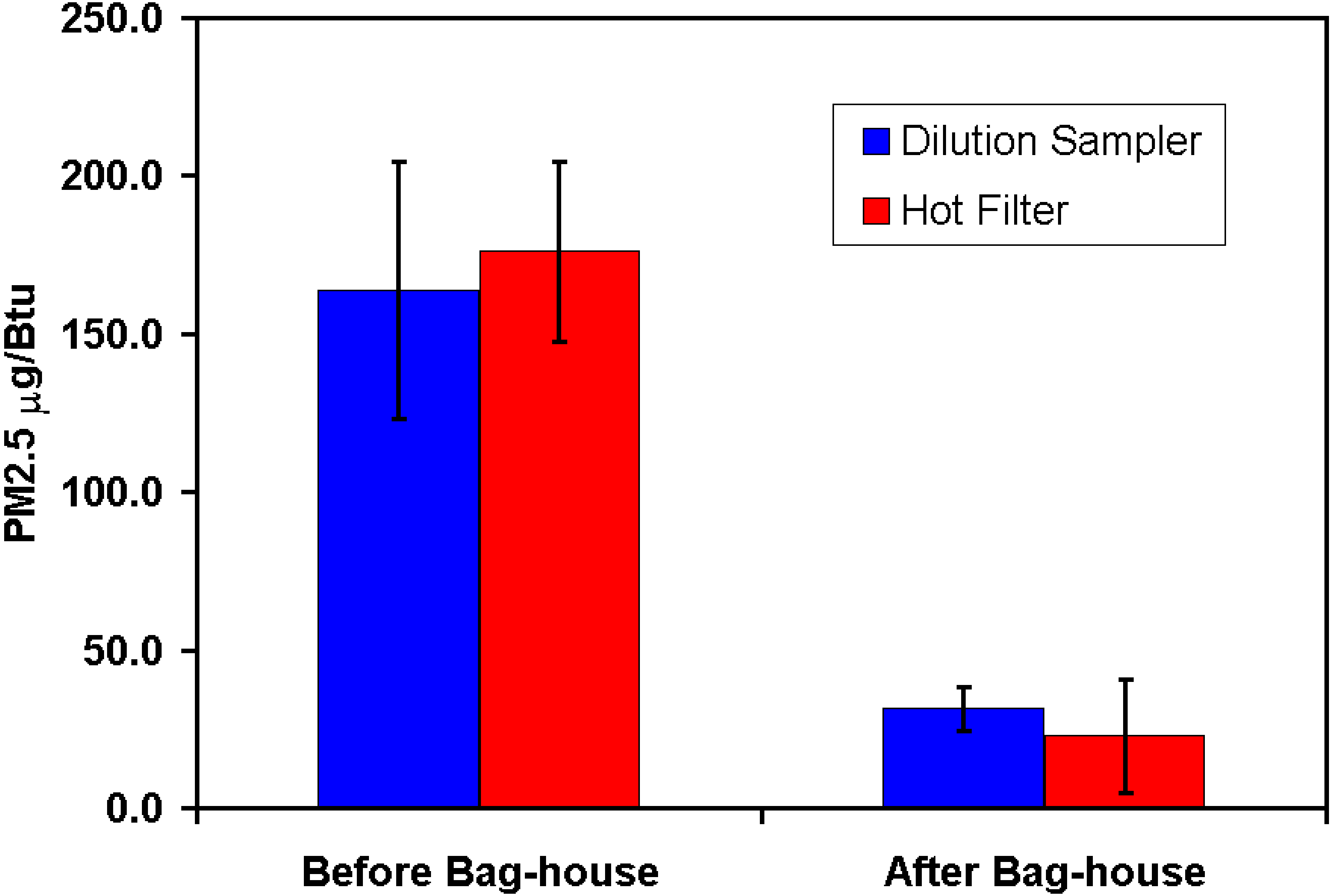
Hot Filter Set-up



Hot vs. Diluted Mass Emissions



Hot and Diluted Agree



Conclusions

- **Before Bag-house**
  - **Coagulation in Tank**
    - **High concentrations → fast coagulation rates**
    - **No generation of new particles**
    - **Particle number decreases with residence time**
  - **Nucleation in tunnel**
    - **Strong function of dilution ratio**
      - High dilution → high number concentrations
      - Low dilution → no nucleation
- **After Bag-house**
  - **Very intermittent Nucleation**
  - **Low concentrations → slow coagulation rates**

Conclusions

Mass Measurements:

- **Mass emission rate not affected by dilution ratio or residence time**
- **Good agreement between hot filter and diluted samples**
- **No significant gas to particle conversion in dilution system**

Acknowledgements

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