Lower order representations of evolving particle size distributions for factor simulation of gas-particle mass transfer within ESPs

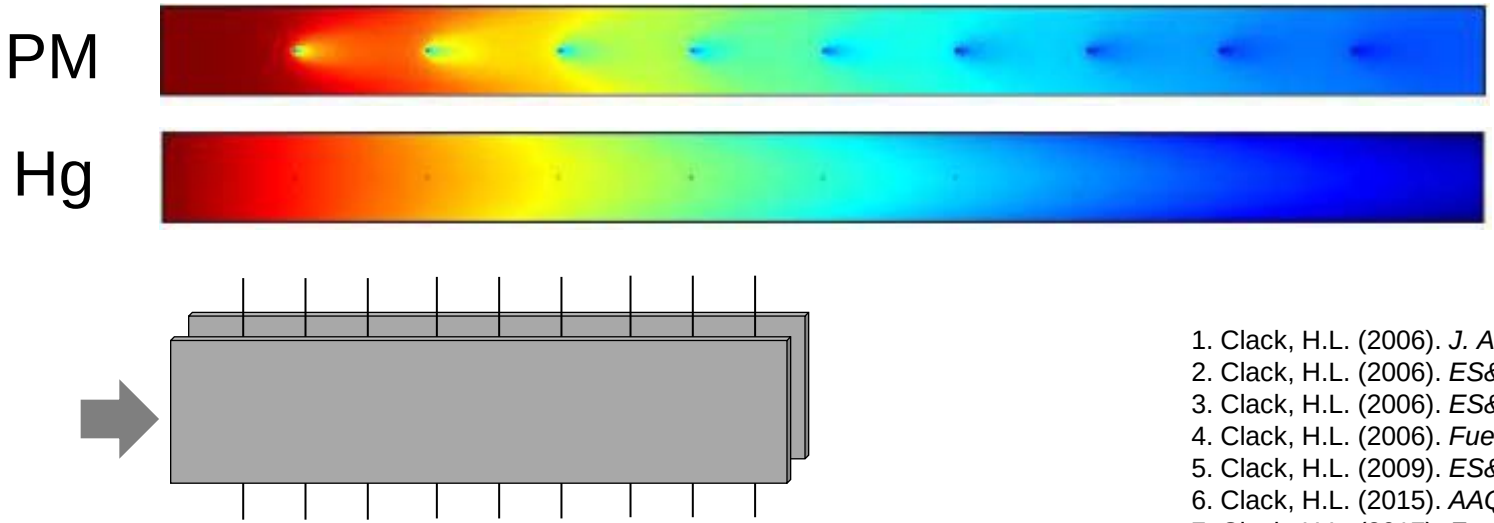
Herek L. Clack
Dept. of Civil & Environmental Engineering
University of Michigan

13th MEC Conference
21-23 May 2018
Krakow, Poland

UNIVERSITY OF MICHIGAN

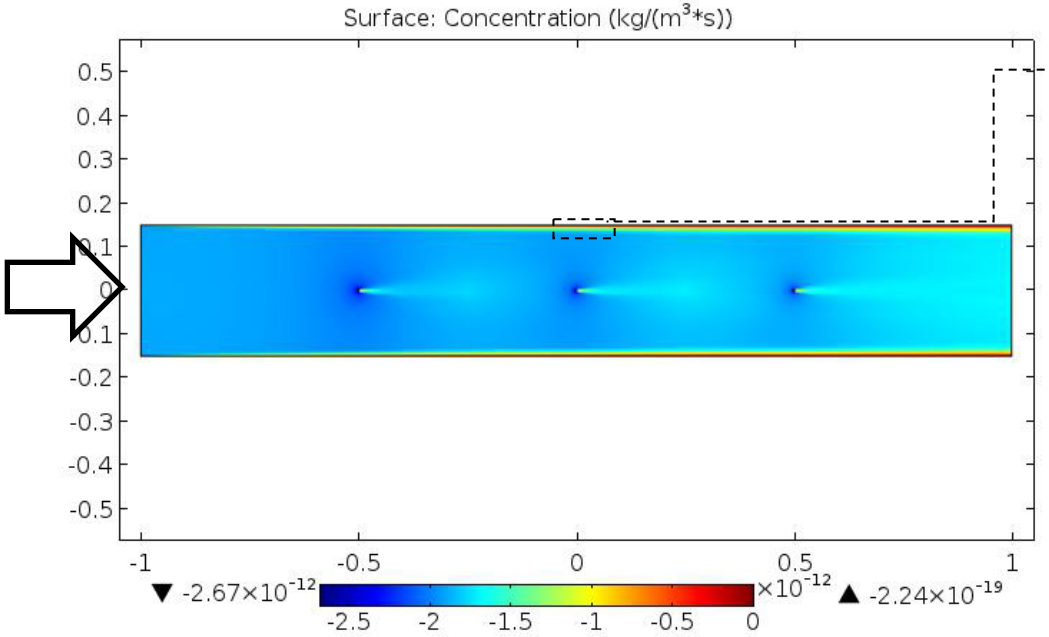
Gas-Particle Mass Transfer Models for Hg Adsorption w/in ESPs

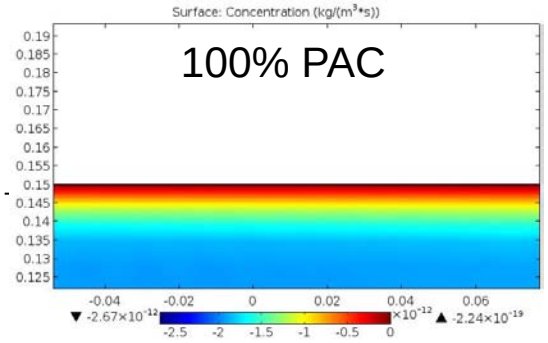
- Analytical 1-D models[1-4] of gas-particle mass transfer within ESPs originally developed & validated against NETL data[5]
- More recent 2-D multi-physics models[6-9] are more complete, reveal more detail than could be measured:

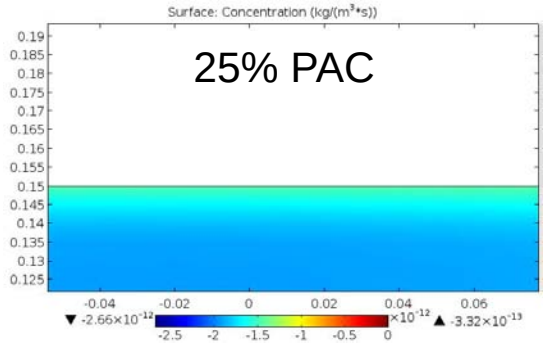


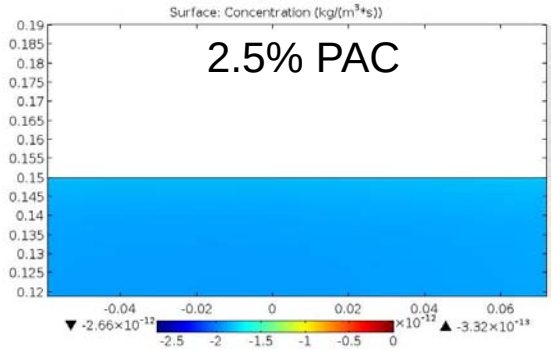
1. Clack, H.L. (2006). *J. A&WMA* **56**:759
2. Clack, H.L. (2006). *ES&T* **40**:3617
3. Clack, H.L. (2006). *ES&T* **40**:3929
4. Clack, H.L. (2006). *Fuel Proc. Technol*. **87**:987
5. Clack, H.L. (2009). *ES&T* **49**:1460
6. Clack, H.L. (2015). *AAQR* **15**:2445
7. Clack, H.L. (2017), *Frontiers in Energy Research: Advanced Fossil Fuel Technologies* doi: 10.3389/fenrg.2017.00003
8. Clack, H.L. (2017), *J. A&WMA* **8**:881
9. Clack, H.L. (2018), *Fuel Proc. Technol.* In press

Simulation Results Reveal Inhibition of Gas-Particle Mass Transfer by Hg-Lean Boundary Layers









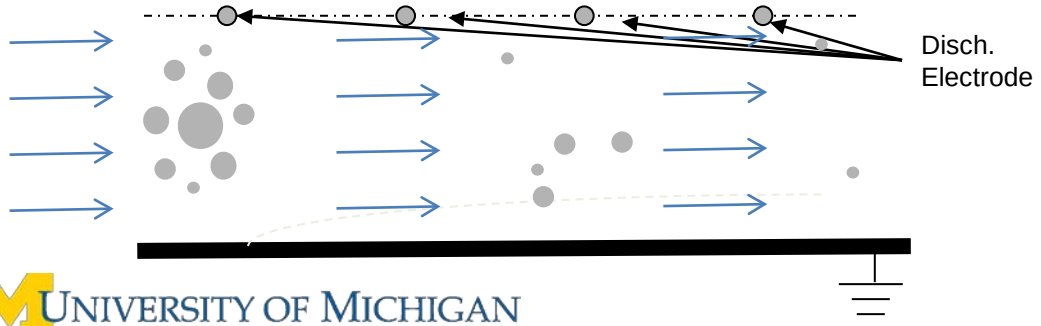
UNIVERSITY OF MICHIGAN

Problem: Multiphase Simulations Are Computationally Intensive

- ***Partial*** simulations of ESPs run for hours (up to 20)
- Strongly size-dependent aerosol phenomena → particles of different sizes rendered, simulated, and accounted separately
  - n_e , $U_{p,slip}$, #/m^3, m^2/m^3, mass xfer rate, precipitation rate

- Aerosol suspensions often statistically represented by *weighted mean* values
- ***Objective***: Evaluate *surface area-weighted mean diameter,* d_{32} as substitute for explicit particle size distribution (PSD).

$$d_{32} = \frac{\sum sa^i d_p^i}{\sum sa^i}$$



Simulation Parameters

ESP

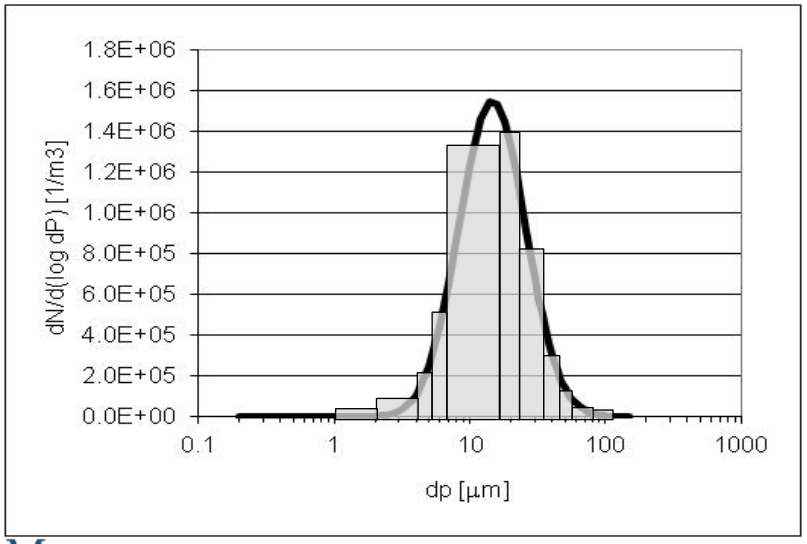
Segment Length: 2 m, 5 m
Discharge Electrodes: 3, 9
Voltage: 50 kV
Current Density: 0.11 mA/m^2
Plate Spacing: 0.3 m
Wire Spacing: 0.5 m

Gas

Velocity: 0.75,1.55, 3 m/s
Temperature: 180 ^{o}C
Inlet Hg^0 conc.: 4 ppb
Pressure: 95 kPa

Particle

Inlet PAC conc.: 6 lbs/MMacf
Inlet PAC size distribution:
Log-normal, 20 μm mean diam.
11 size classifications



Modeling Approach for Gas-Particle Mass Transfer within ESPs

Electric Potential V(x,y)

Fluid/Particle Boundary Conditions

Initial PSD ND(d_p) Particle Charge q(d_p)

Space Charge Density $\rho_{SC}(x,y)$

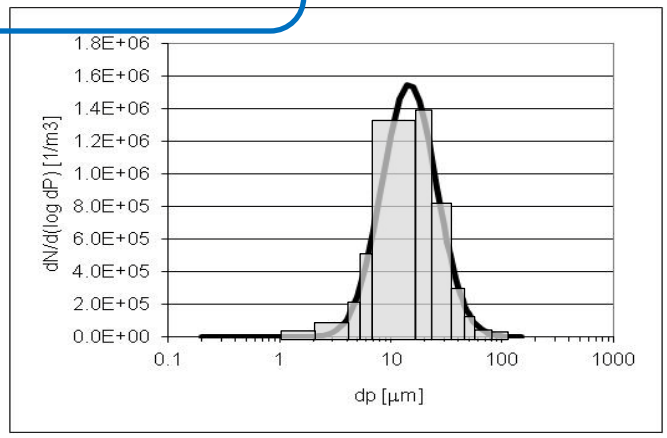
EHD Gas Velocity Distribution $U_{EHD}(x,y)$

Particle Volume Fraction Distribution $\phi(d_p,x,y)$

Poisson's Eqn./ Current Cont.

Particle Drift Velocity w(d_p,x,y)

Gas-Particle Interfacial Area Distribution $A_s(x,y)$



Gas-Particle Mass Xfer $\dot{m}(x,y)$

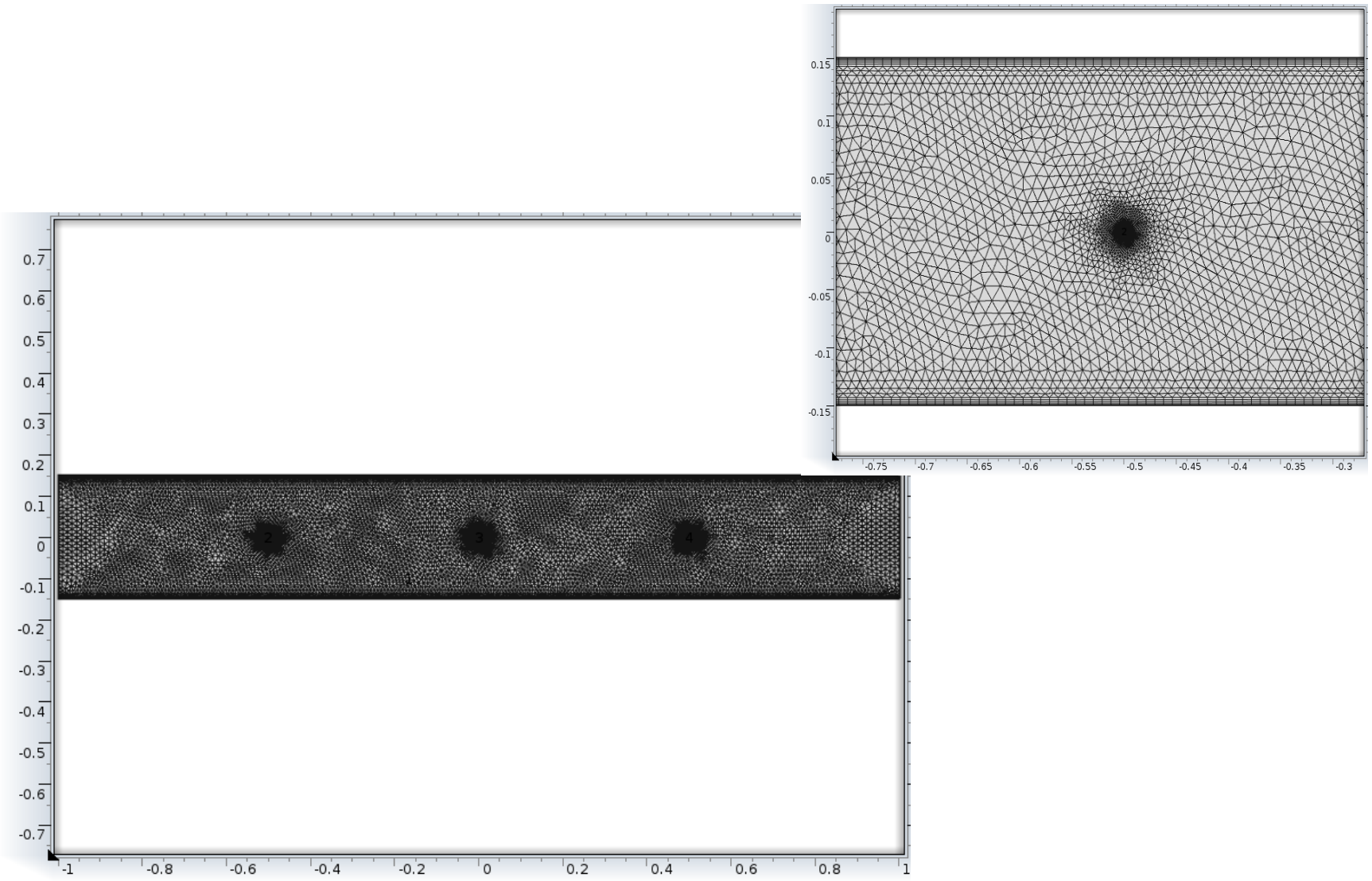
Electric Boundary Conditions

Geometry & Mesh

[Hg](x,y)

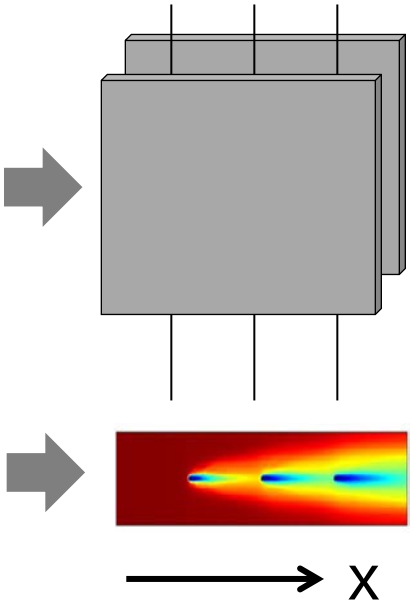
UNIVERSITY OF MICHIGAN

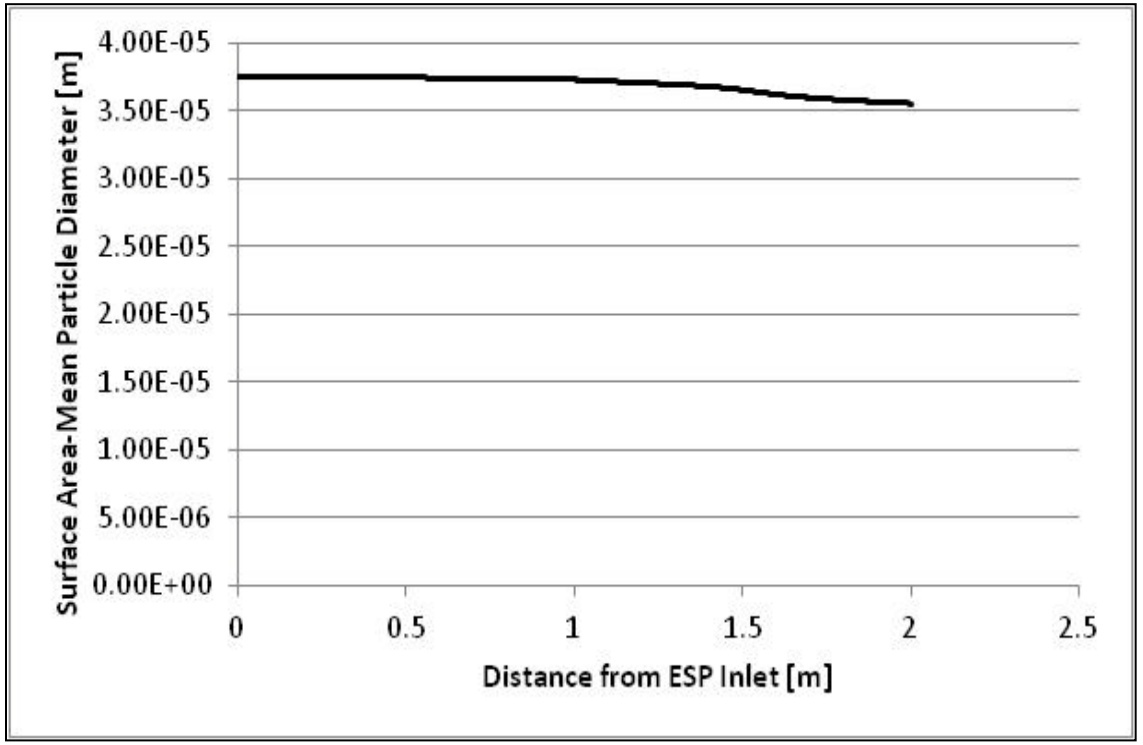
Computational Mesh



d_{32} Evolution Along a 3-Wire ESP Channel

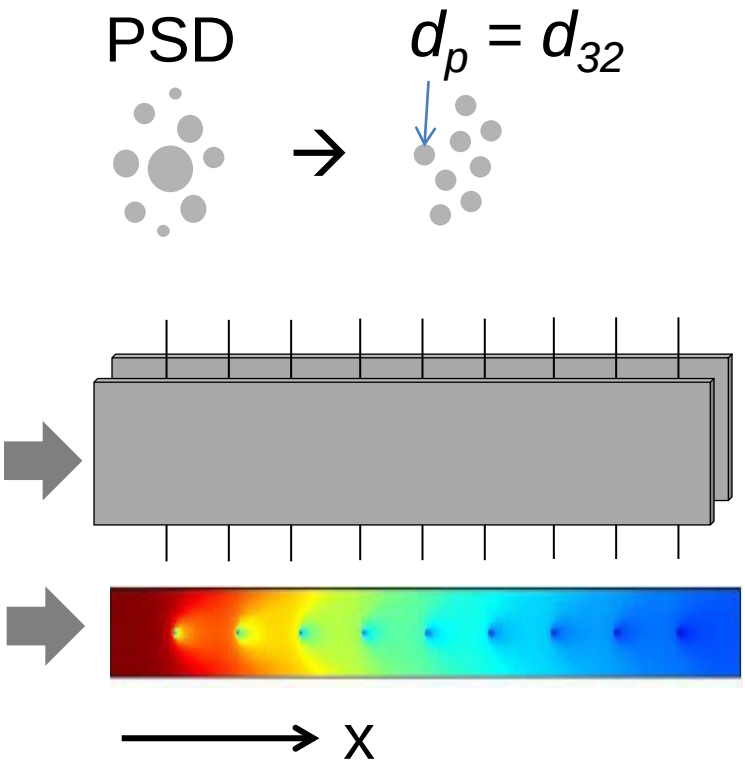
PSD → $d_p = d_{32}$

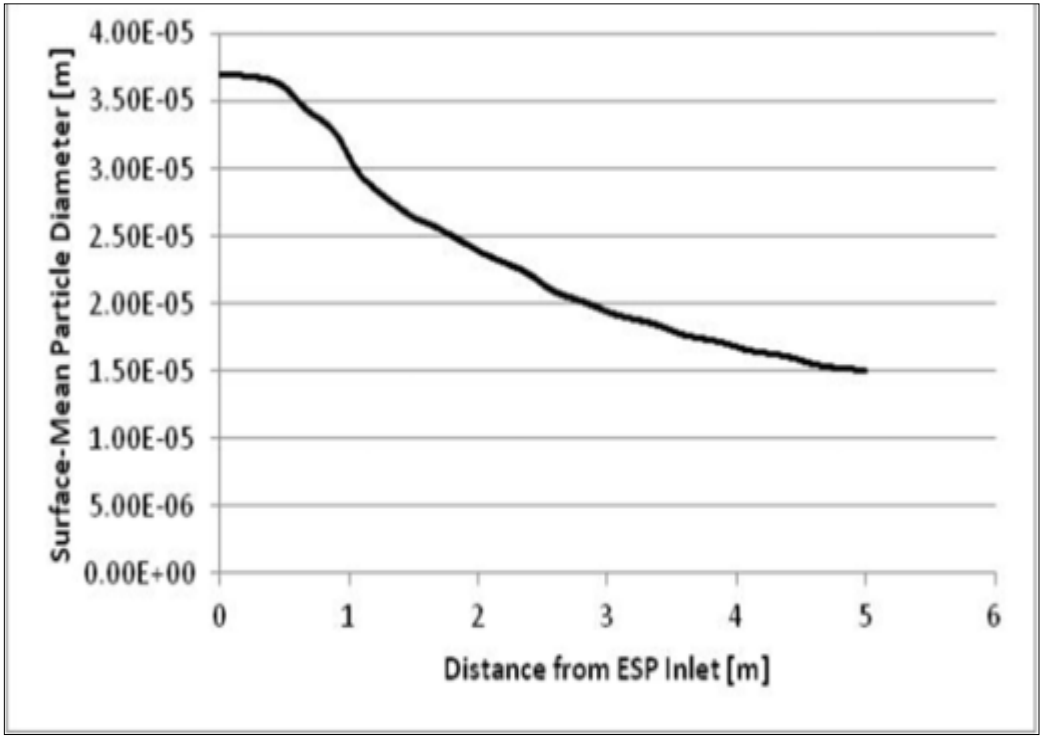




$d_{32}(x) \sim C$

d_{32} Evolution Along a 9-Wire ESP Channel

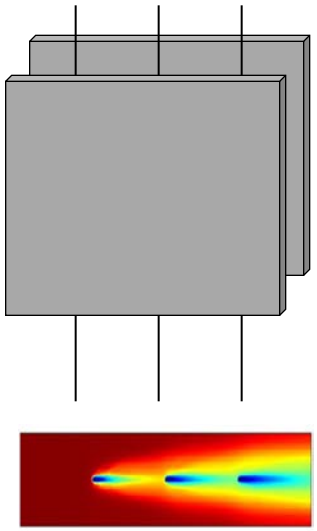


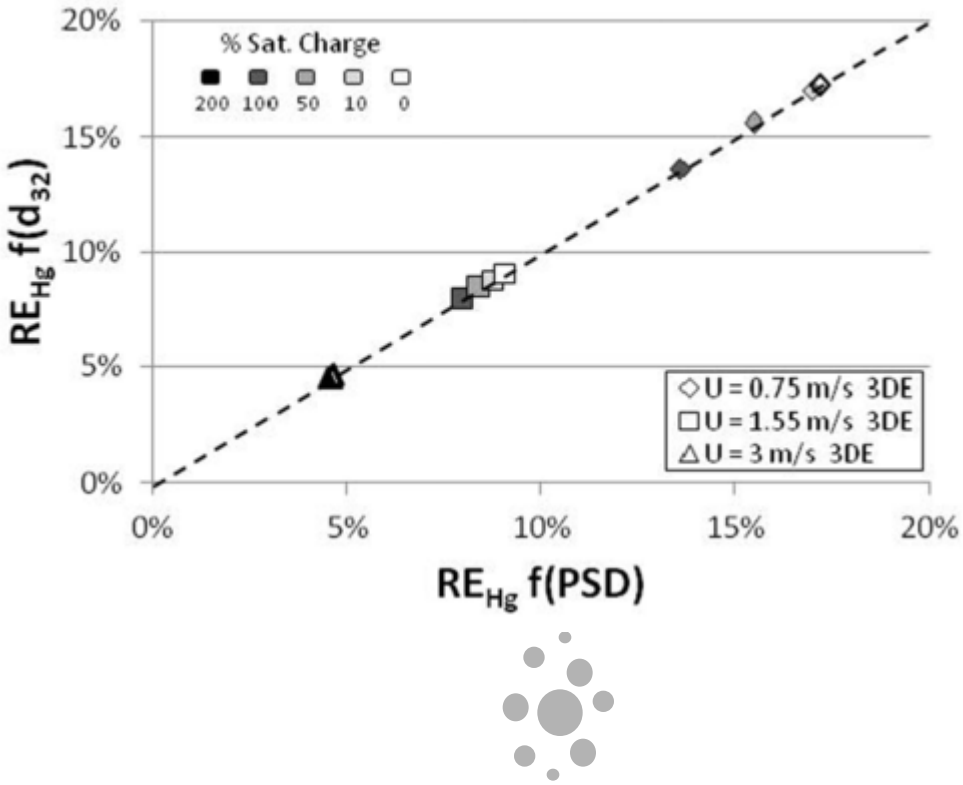


Mean value of $d_{32}(x)$: $\frac{1}{L}\int_0^L d_{32}(x)dx$

Predictions of RE_{Hg}: Explicit PSD versus d_{32}

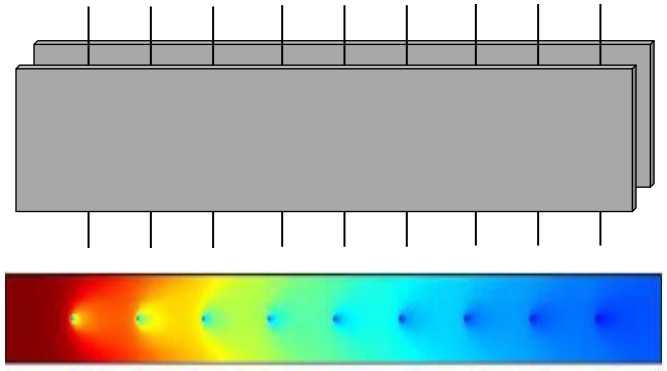
3-wire ESP segment

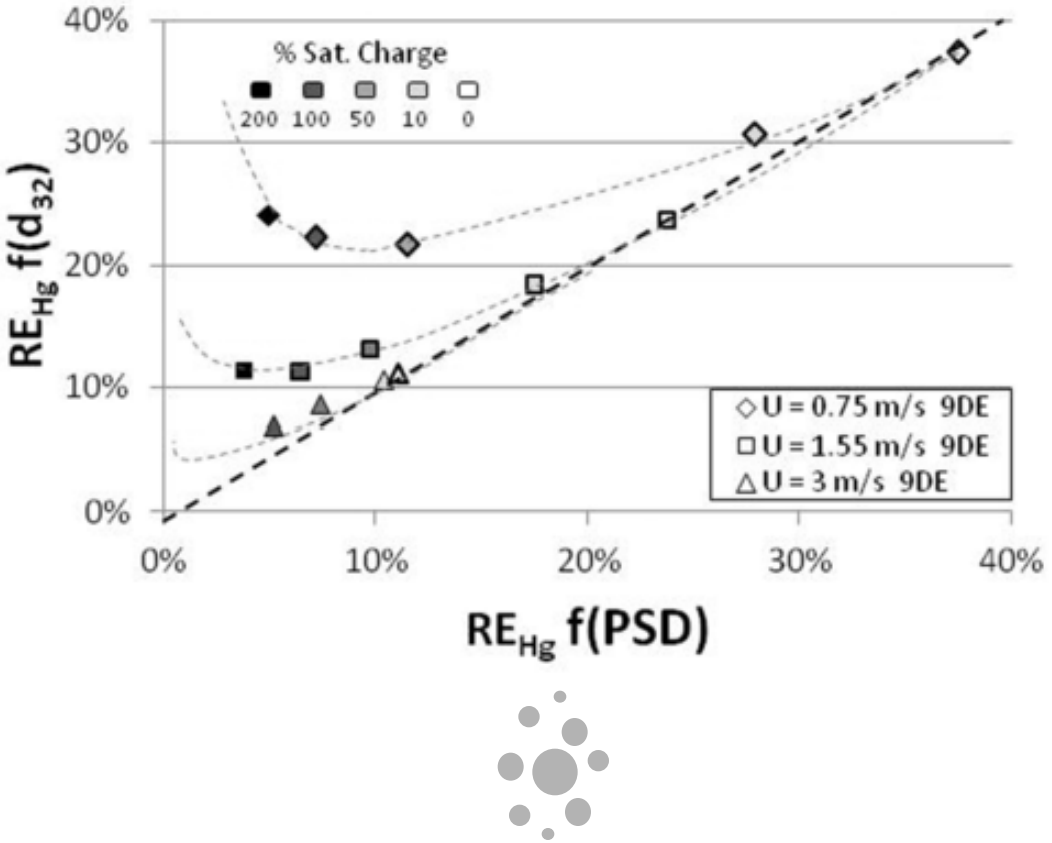




Predictions of RE_{Hg}: Explicit PSD versus d_{32}

9-wire ESP segment



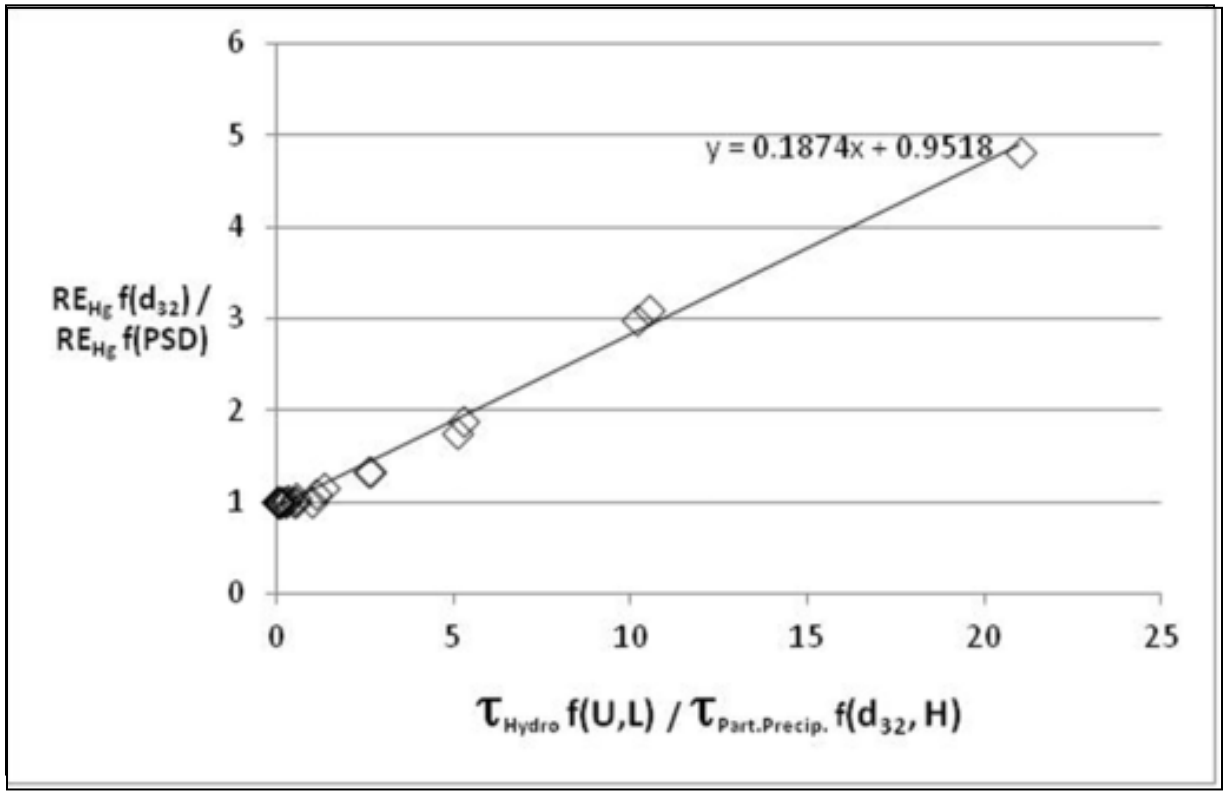


Characteristic Timescales Reveal Common Correlation

- Taking the ratio of competing hydrodynamic (τ_{Hydro}) and particle precipitation (τ_{Part}) time scales collapses results:

$\tau_{Hydro} = L / U_{inlet}$

$\tau_{Part.} = H / U_{drift}(d_{32})$



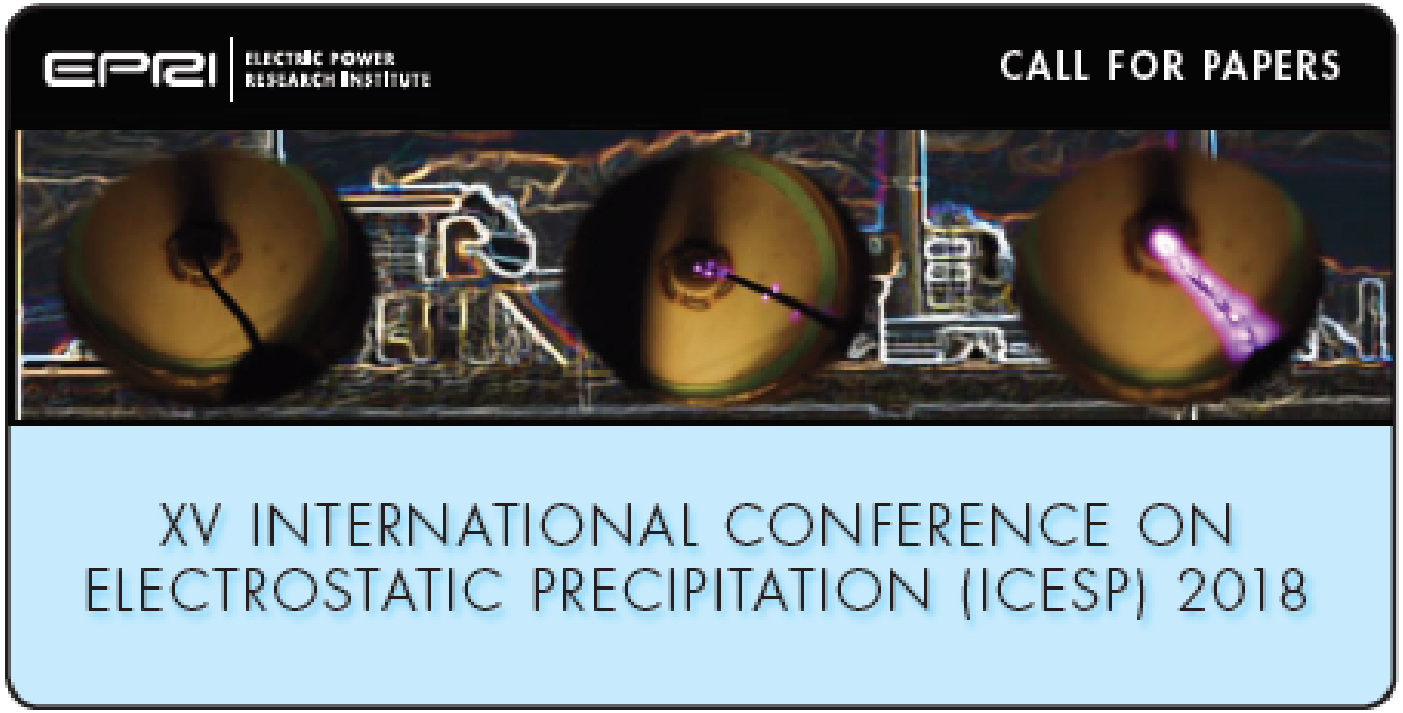
Conclusions

- Simulations of gas-particle mass transfer within ESPs can, conditionally, represent polydisperse particles as monodisperse with $d_p = d_{32}$.
- Computational times cut by 10X, making it (more) feasible to:
  - Accelerate or broaden optimization studies of ACI/DSI
  - Incorporate heterogeneous reaction kinetics
  - Simulate entire ESP

Thank You

COMSOL Multiphysics™ was used in the completion of this work

15th Int'l Conference on Electrostatic Precipitation



Tuesday, October 9, 2018–Thursday, October 11, 2018 • Charlotte, NC

http://www.cvent.com/events/xv-international-conference-on-electrostatic-precipitation-icesp-2018/

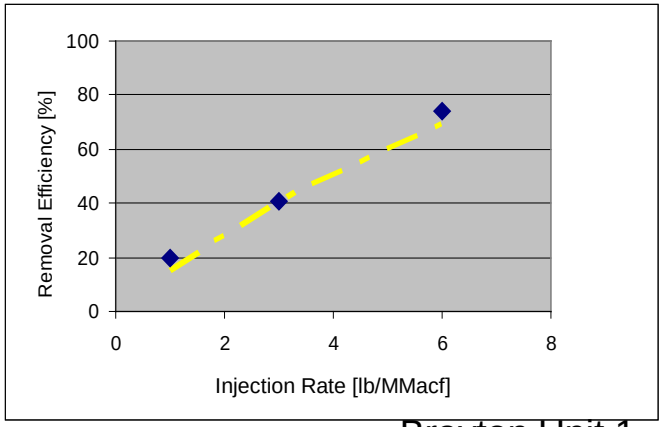
hclack@umich.edu

UNIVERSITY OF MICHIGAN

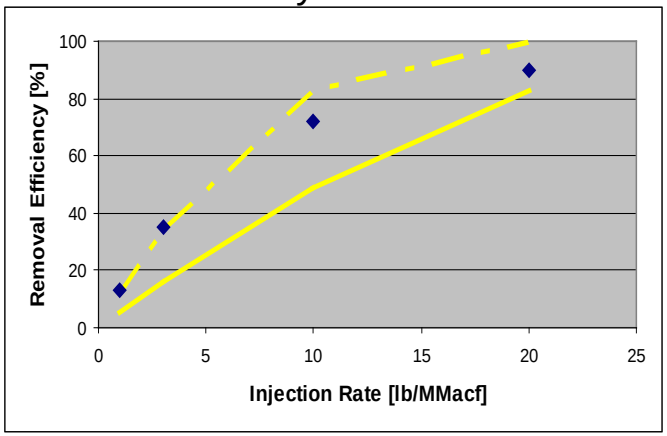
Mass Transfer Models Developed for Hg Removal w/in ESPs

- Analytical models of both mechanisms[1-4] have been validated against NETL data[5]
- Recent success with CFD models[6]

Monroe Unit 4



Brayton Unit 1



- In-flight >> Wall-bounded
  - Aerosols present high surface area
  - Plates present low surface area (c/w SCR)
  - Ash dilutes PAC in dustcake
- **Tacit assumption is that the mechanisms are additive. Prove/Disprove using CFD.**