



# Contact charging in particulate flows

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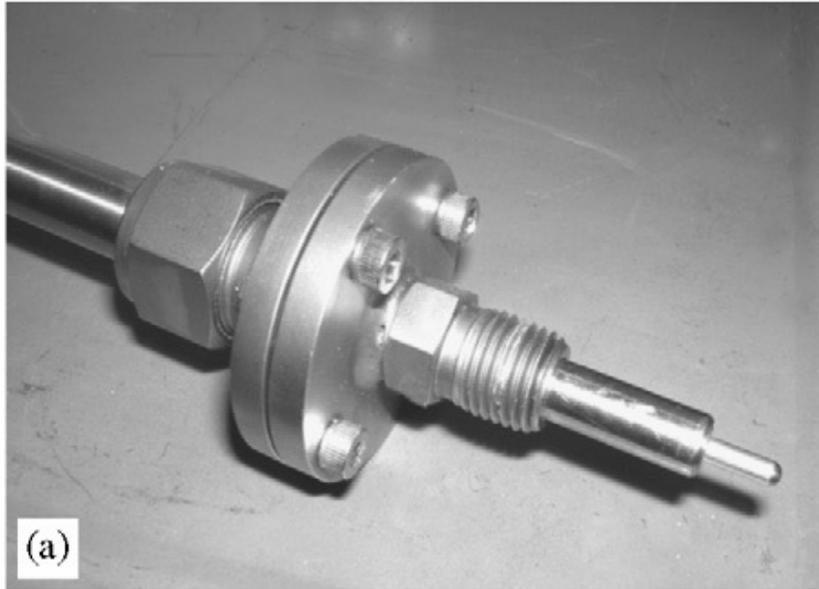
2023 NETL Virtual Workshop on Multiphase Flow Science

# Outline of the talk



- Effects of inter-particle forces on gas-particle flow
  - Van der Waals interaction
  - Liquid-bridge force
  - Electrostatic charging of particles in fluidized beds
  
- A brief review
- Some results on charging and effect of charges
- End with some questions

# Tribocharging causes particles to stick



*Charged particles adhering to a measurement probe [1].*

# Tribocharging causes particles to stick



*Wall fouling of riser column with polyethylene particles [2].*

# Tribocharging affects fluidization quality



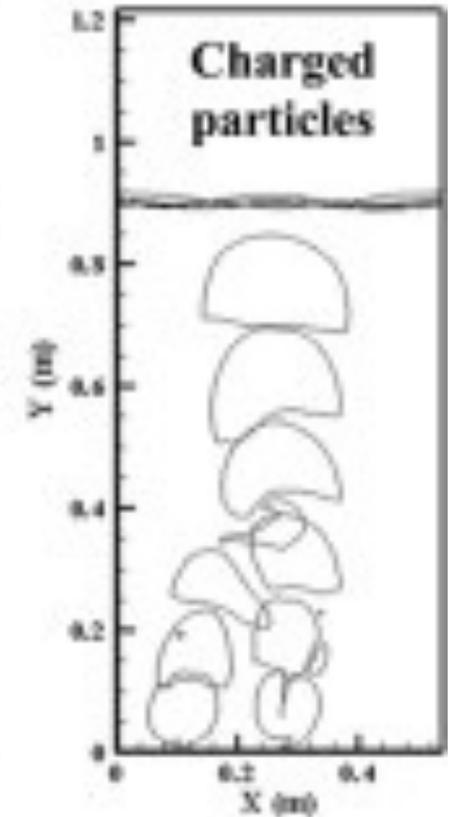
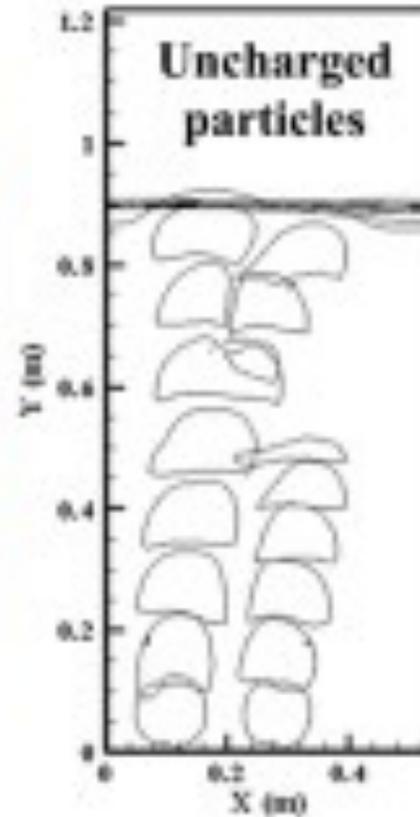
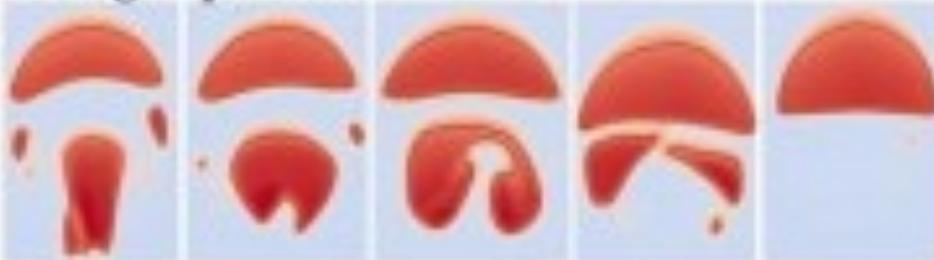
Vertical alignment

Horizontal alignment

Uncharged particles



Charged particles



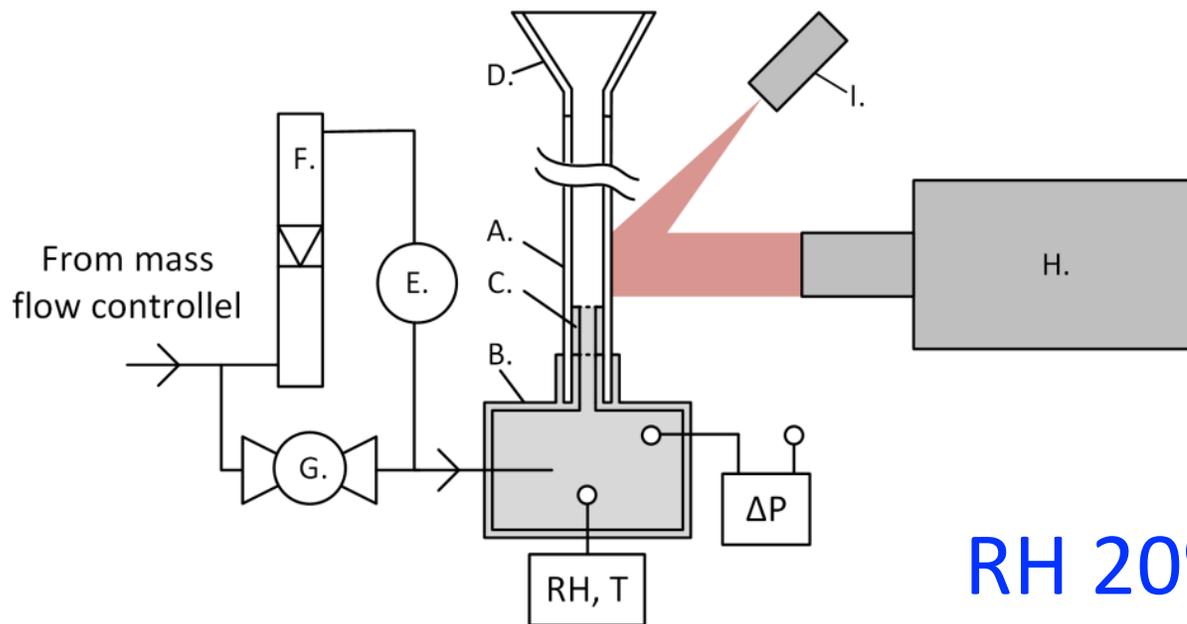
*Charging of particles in fluidization affects bubble shape [3].*

# Tribocharging affects fluidization quality

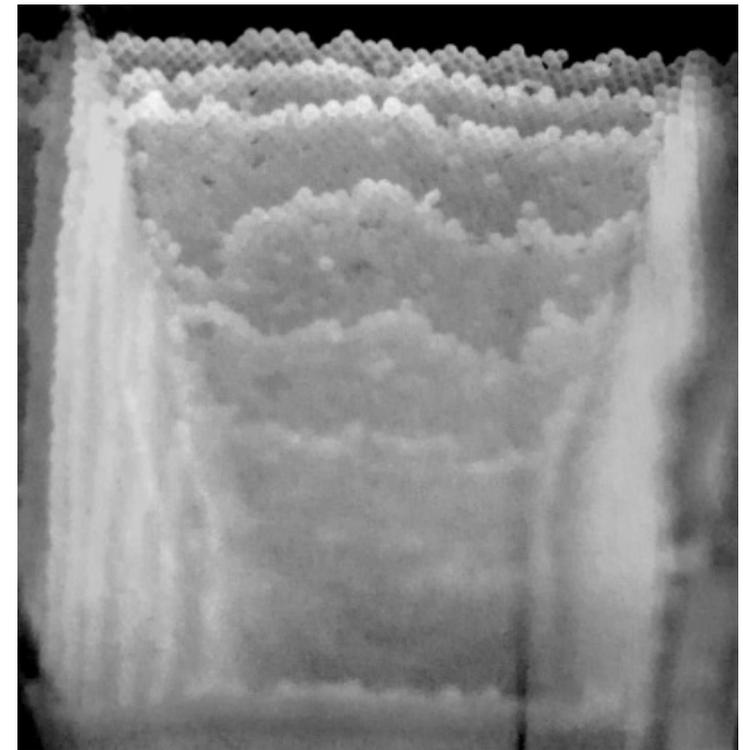


Investigation of Humidity Effects on Electrostatic Behavior of a Small Cold Model Fluidized Bed [4]

Polyethylene particles (250  $\mu\text{m}$ )  
Walls: soda lime glass



RH 20%



*Image taken from the top of the bed showing multiple adhered layers of particles on the wall.*

# Tribocharging affects fluidization quality



RH 20%

RH 60%

- Fluidized bed
  - square cross-section
  - Glass wall
- 250  $\mu\text{m}$  polyethylene particles

11 nC/gm



- Normal slugging fluidization at higher humidity level
- Very different at low humidity; no slugging

0.5 nC/gm



# Tribocharging in gas-particle flows



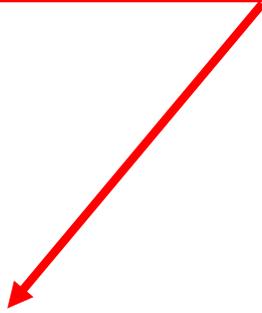
## Questions

- Are these charge levels typical? • **0.1 – 10  $\mu\text{C}/\text{m}^2$**
- **Can particle charge at this level affect the flow behavior?**
- How does one model tribocharging rate (even if it is only in a phenomenological fashion)?
- **How do the gas, humidity, and particle size affect charging?**

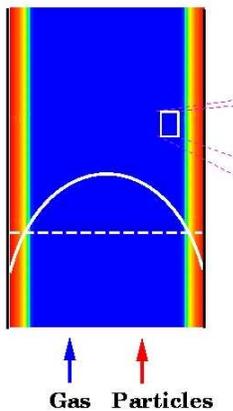
# Fluidization regimes



Can electrostatic charging of particles lead to radial segregation seen experimentally?



## FLOW BEHAVIOR IN FAST FLUID BEDS/RISERS



- Fully-developed flow
- Particles carry a constant charge
- Specify gas and solid fluxes, charge density
- Solve
  - Poisson equation
  - Axial and radial momentum balances
- Determine radial profiles

# Fully-developed gas-particle flow in a riser



Riser radius

Charge density

Solids mass flux

$$Q = \frac{(14400)R^2\sigma^2}{\epsilon_0 d^2 \rho_s U^2}$$

Particle diameter, density

Gas superficial velocity

$$U_g^+ = \frac{U}{V_t}, U_s^+ = \frac{G_s}{\rho_s V_t}$$

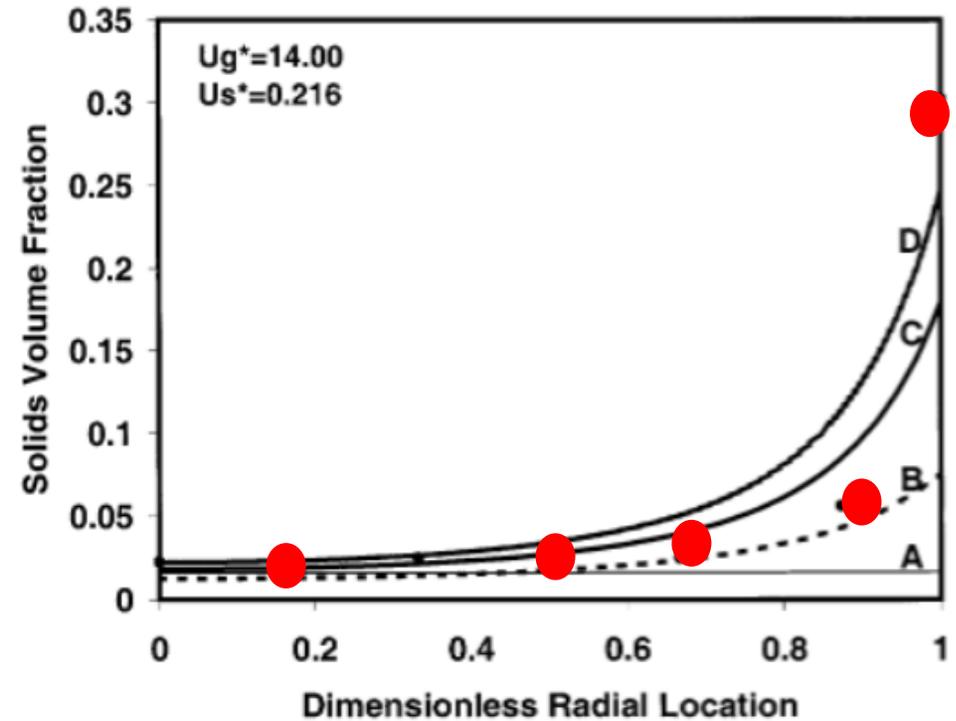
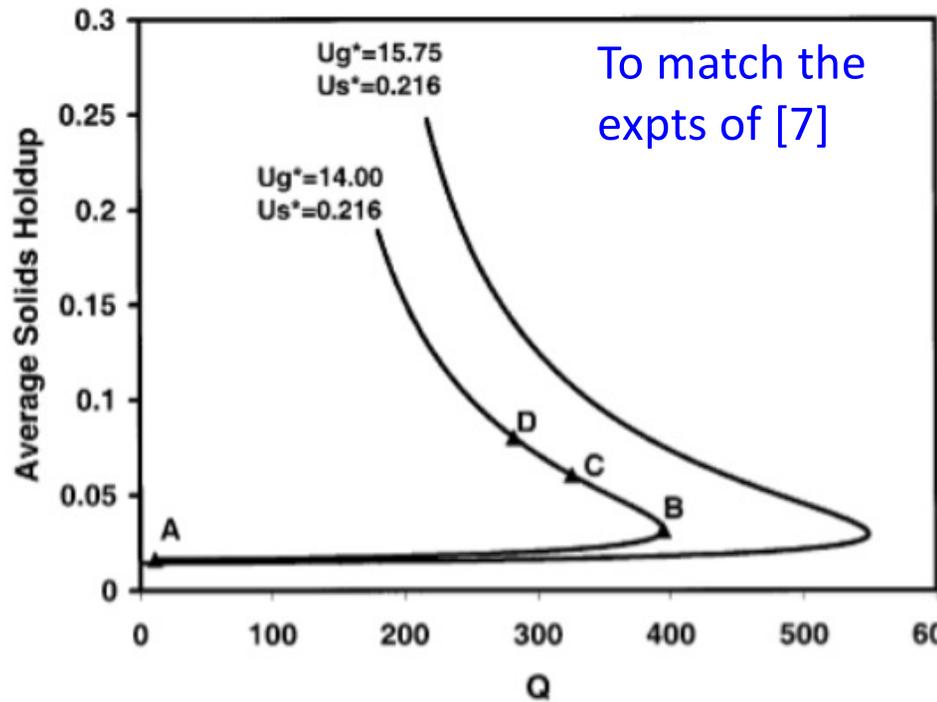
Terminal settling velocity

particle diameter  
particle density  
terminal velocity  
riser radius

76  $\mu\text{m}$   
1714  $\text{kg/m}^3$   
26.42  $\text{cm/s}$   
15  $\text{cm}$

$$Q \sim 10^3 \text{ for } \sigma \sim 0.1 \frac{\mu\text{C}}{\text{m}^2}$$

# Fully-developed gas-particle flow in a riser

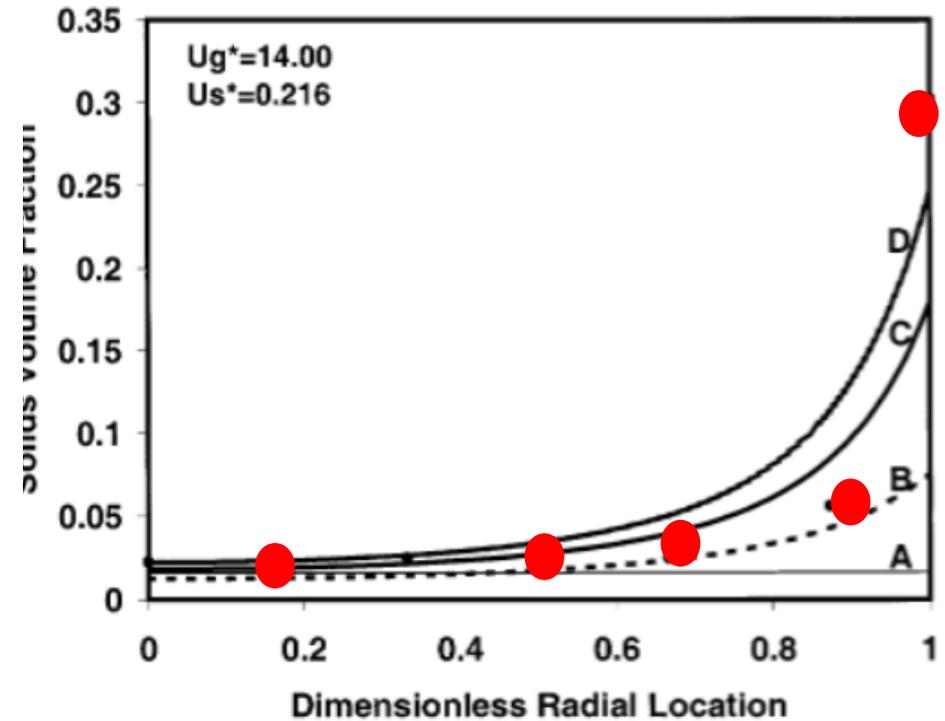
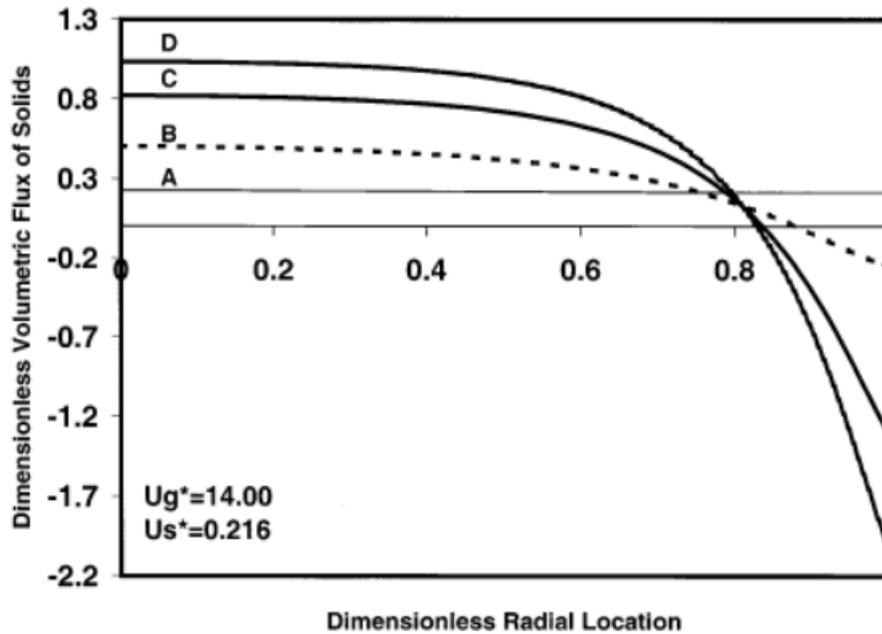


The electric field induced by the charges drives the particles to the wall region

[6] Al-Adel, et al., Ind. Eng. Chem. Res., (2002)

[7] Bader et al., CFB II, (1988)

# Fully-developed gas-particle flow in a riser



- Net up-flow of gas and particles
- Up-flow in the core
- Down-flow in the annular region

[6] Al-Adel, et al., Ind. Eng. Chem. Res., (2002)

[7] Bader et al., CFB II, (1988)

# Tribocharging in gas-particle flows

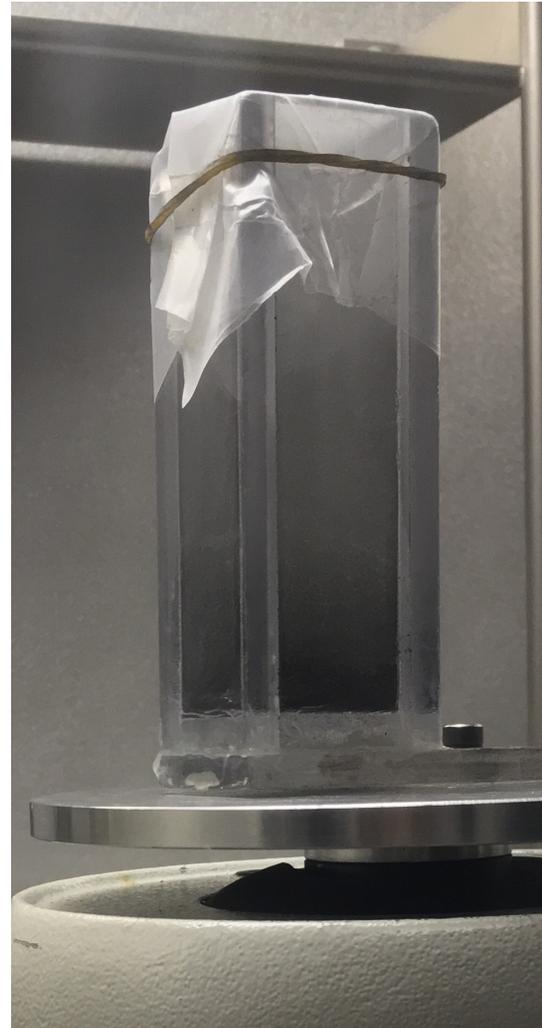


## Questions

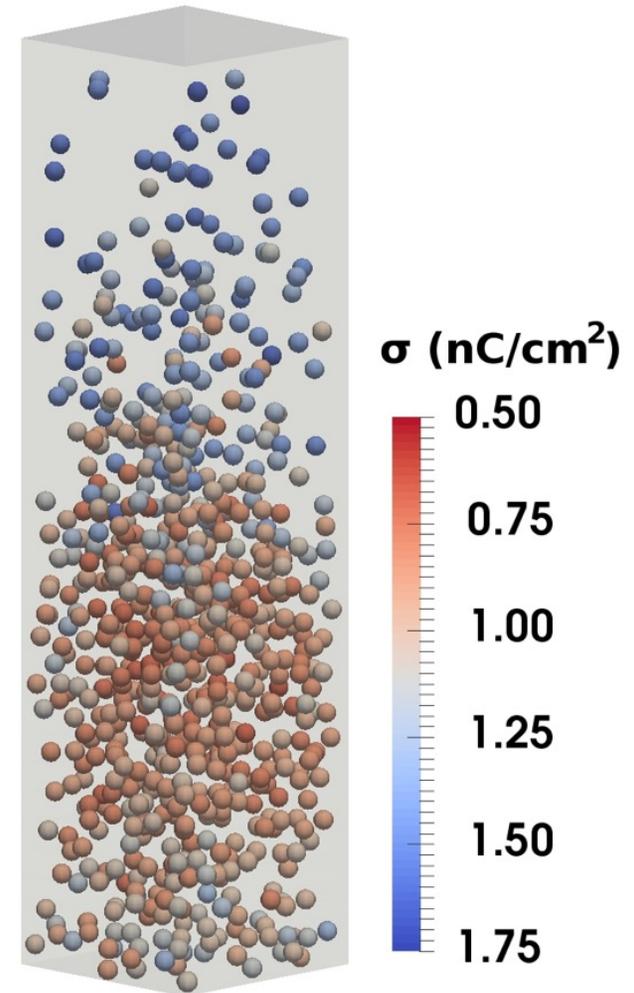
- Are these charge levels typical? • **0.1 – 10  $\mu\text{c}/\text{m}^2$**
- Can particle charge at this level affect the flow behavior? **YES**
- How does one model tribocharging rate (even if it is only in a phenomenological fashion)?
- How do the **gas**, humidity, and particle size affect charging?

# Vibrated bed: experimental setup

- Vibrated Bed experiments conducted in argon and nitrogen:
  - Glass particles
  - Polyethylene particles
  - Bed made with PMMA
- Complementary DEM simulations



*Experimental setup of the vibrated bed experiments*



*Simulation snapshot taken from DEM simulations*

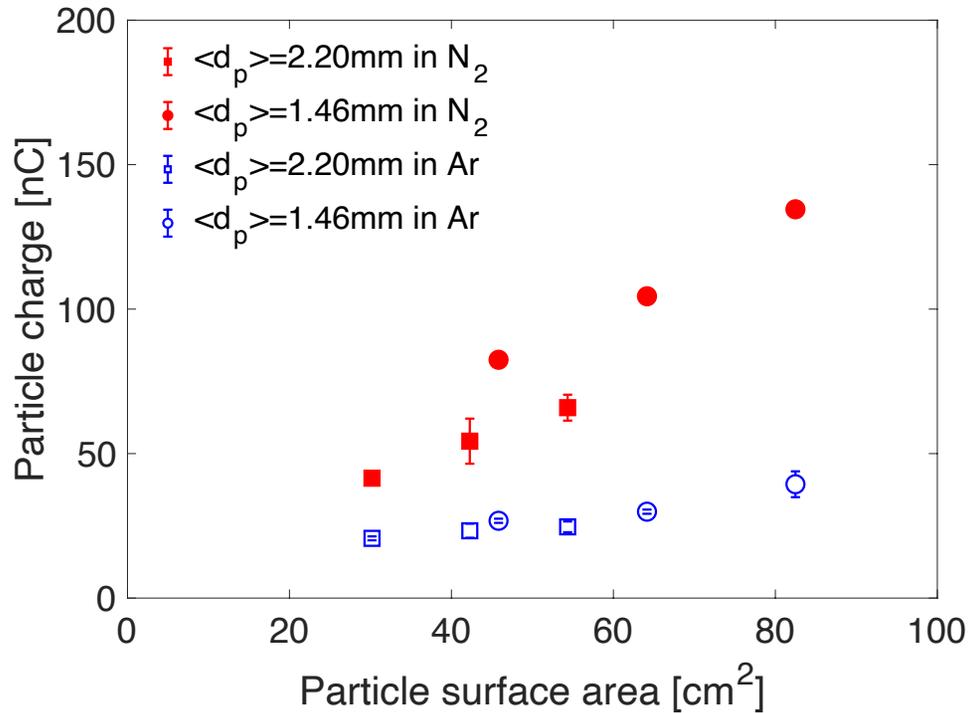
[8] Liu et al., Powder Tech., (2020)

[9] Liu and SS., Powder Tech., (2022)

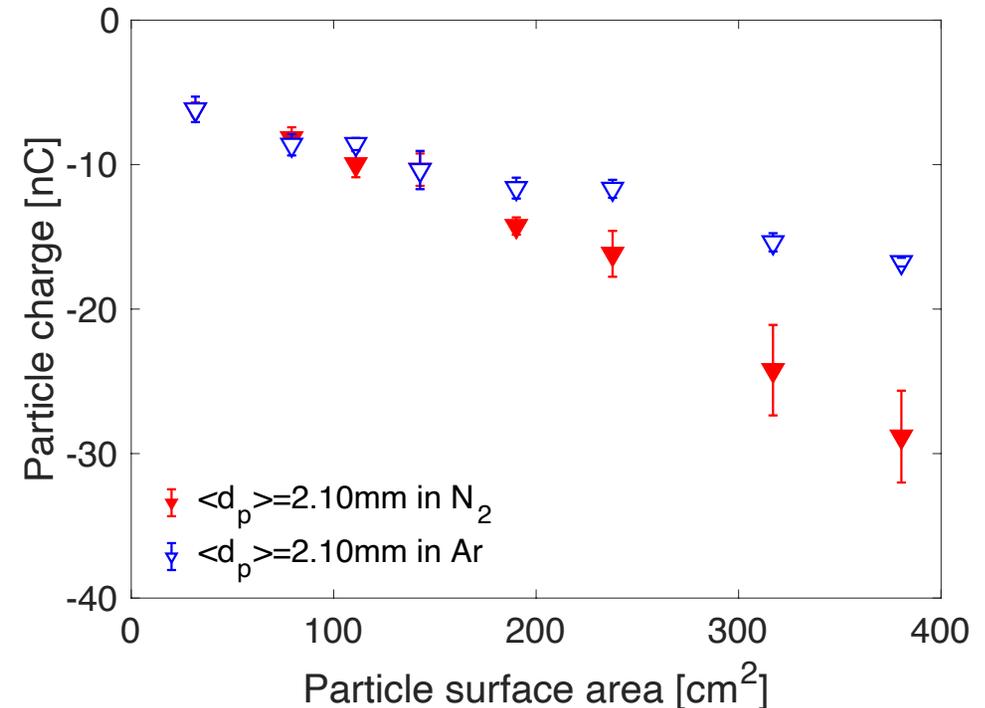
# Effect of Gas: Argon vs Nitrogen

Vibrated bed experiments are conducted in 2-inch acrylic bed, in **dry nitrogen** (RH = 2~5 %) and **dry argon** (RH = 2~5 %) using glass particles and polyethylene (PE) particles.

Glass



Polyethylene

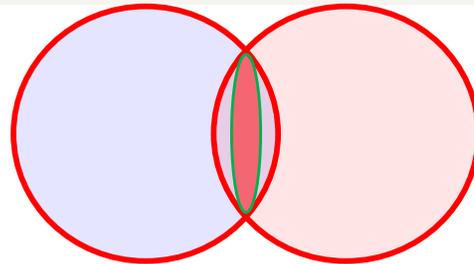


Charge levels measured in argon are lower than that in nitrogen.

# Tribocharging Model



**Effective work function** is a lumped parameter for modeling surface charging properties.



**Rate of charge transfer**

Take into account the possibility of dielectric breakdown of the gas

Gas	Dielectric strength (MV/m)
N <sub>2</sub>	3.4
Ar	0.6

**Charge Transfer [10]:**

- **effective work function** difference
- electric field at the contact point

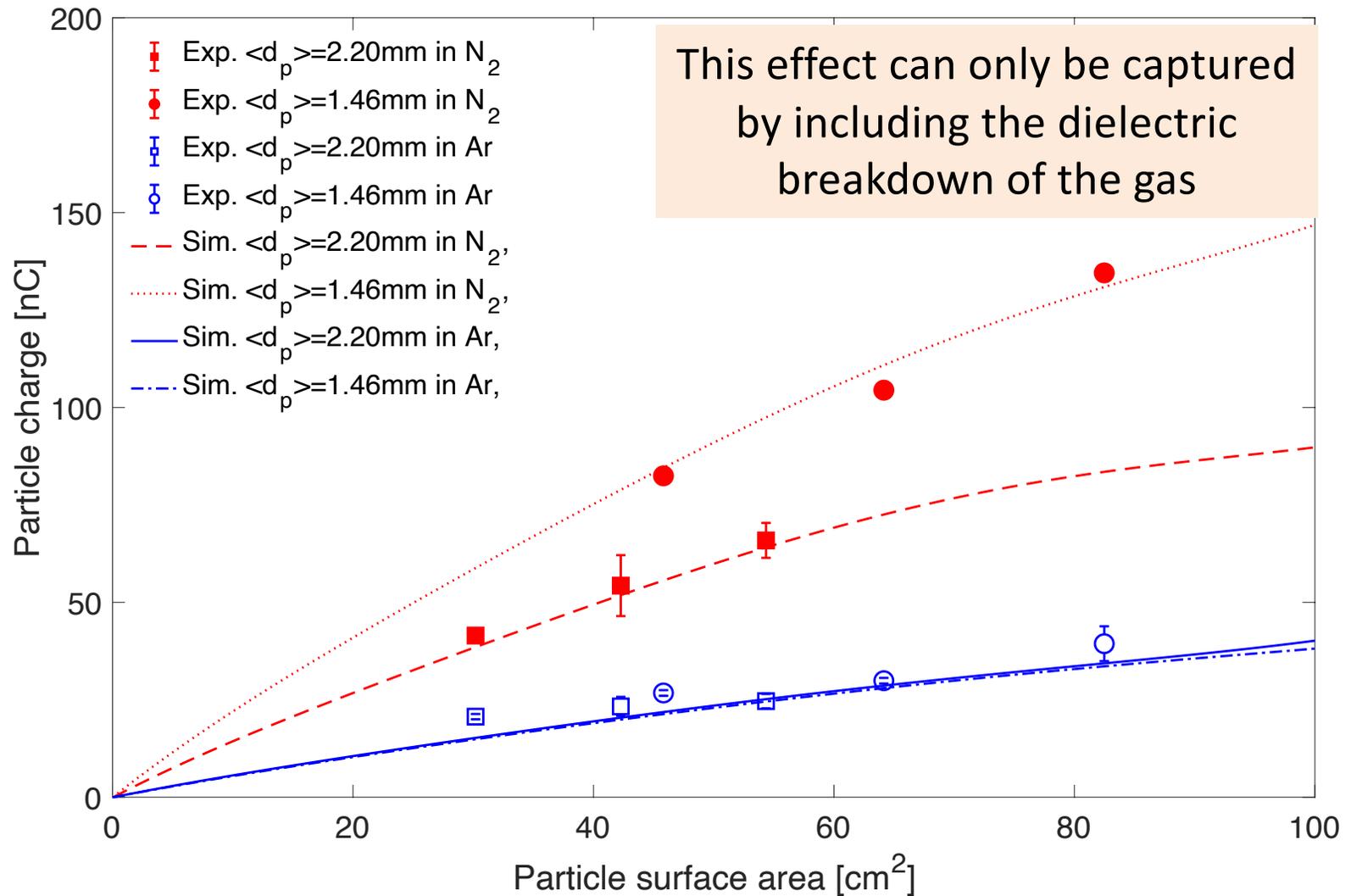
**Charge Relaxation [11]:**

- resistivity at the contact point
- electric field at the contact point

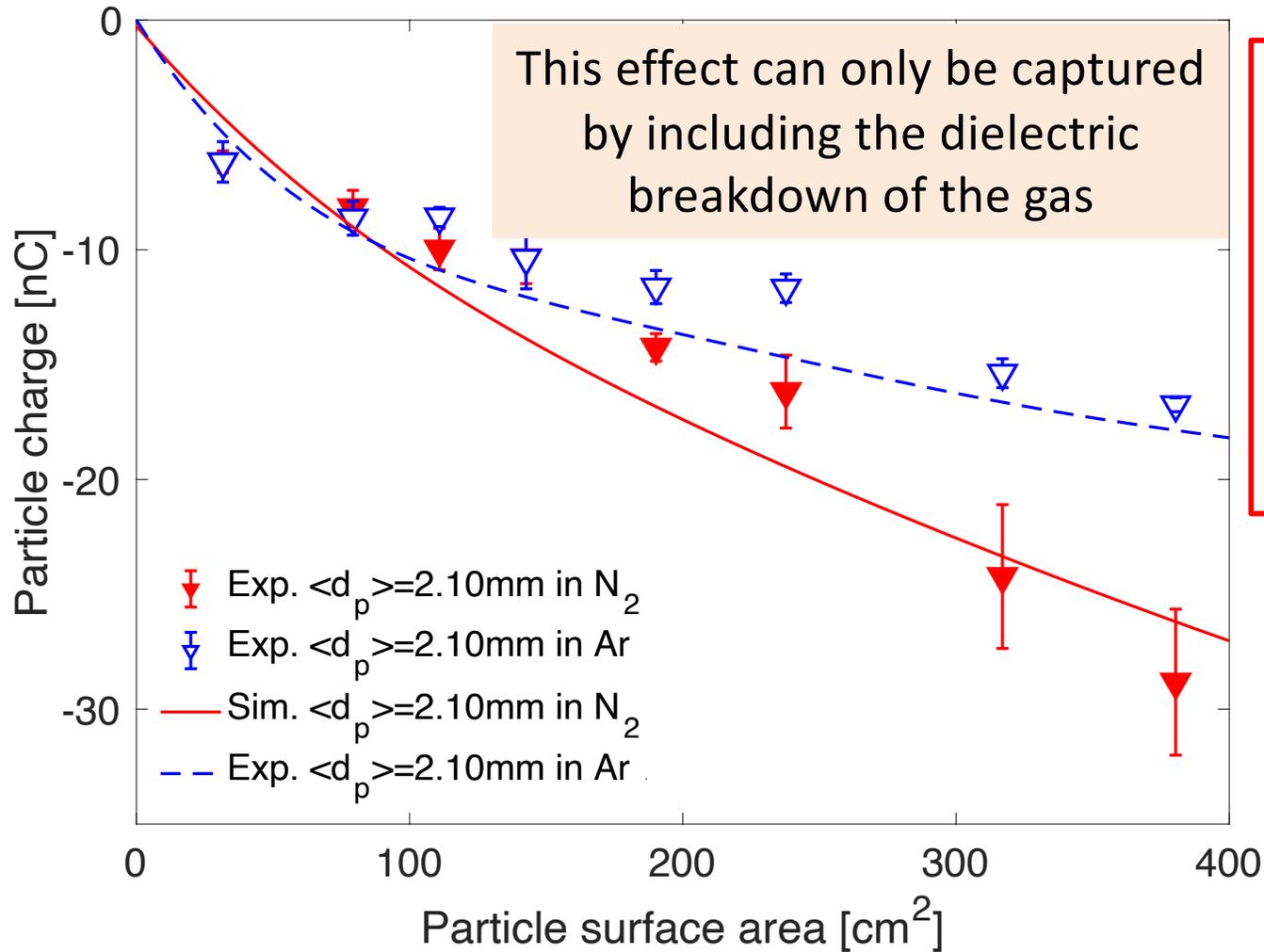
[10] Laurentie et al., *J. Electrostatics* (2013)

[11] Itakura et al., *J. Electrostatics* (1996)

# Simulation Results (Glass Particles)



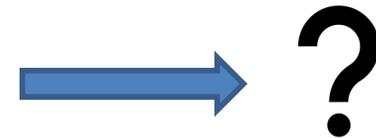
# Simulation Results (PE Particles)



Our current hypothesis:

In large process vessels, the particle charge level is at the cusp of dielectric breakdown in most systems

[12] Hou et al., CJChE, (2022)



# In closing



- Effects of inter-particle forces on gas-particle flow
  - Electrostatic charging of particles in fluidized beds

**Need:** Better understanding of:

- (a) the charge transfer mechanism,
- (b) the effect of humidity\*,
- (c) the effect of particle size\*, and
- (d) the effect of scaleup.

Thank you for listening!

[13] \*Troth et al., Ind. Eng. Chem. Res. (2017)

[14] \*Cruise et al., J. Phys. D: Appl. Phys., (2022)