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The relationship between fluidized bed electrostatics and entrainment

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The Relationship between Fluidized Bed Electrostatics and Entrainment

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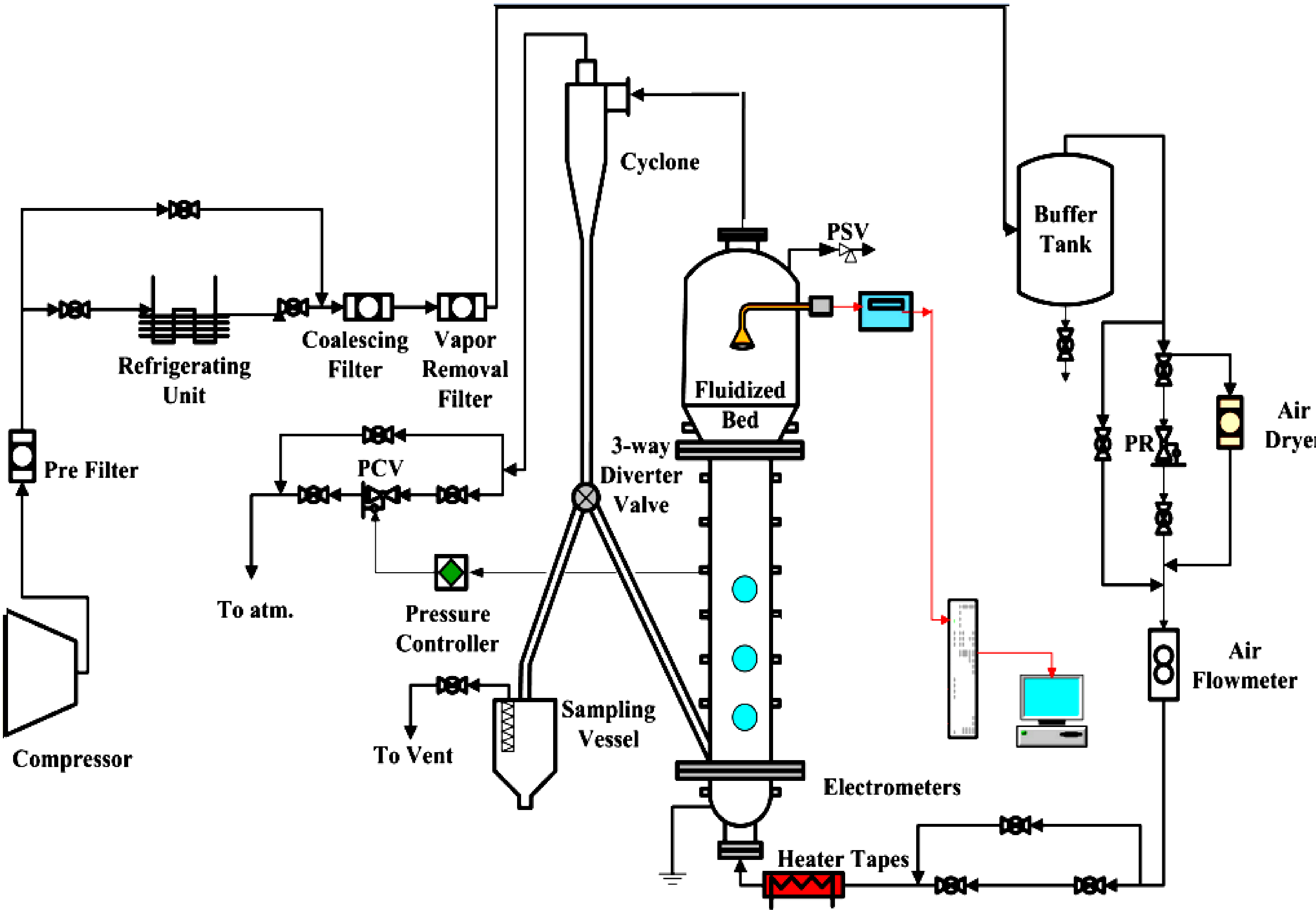
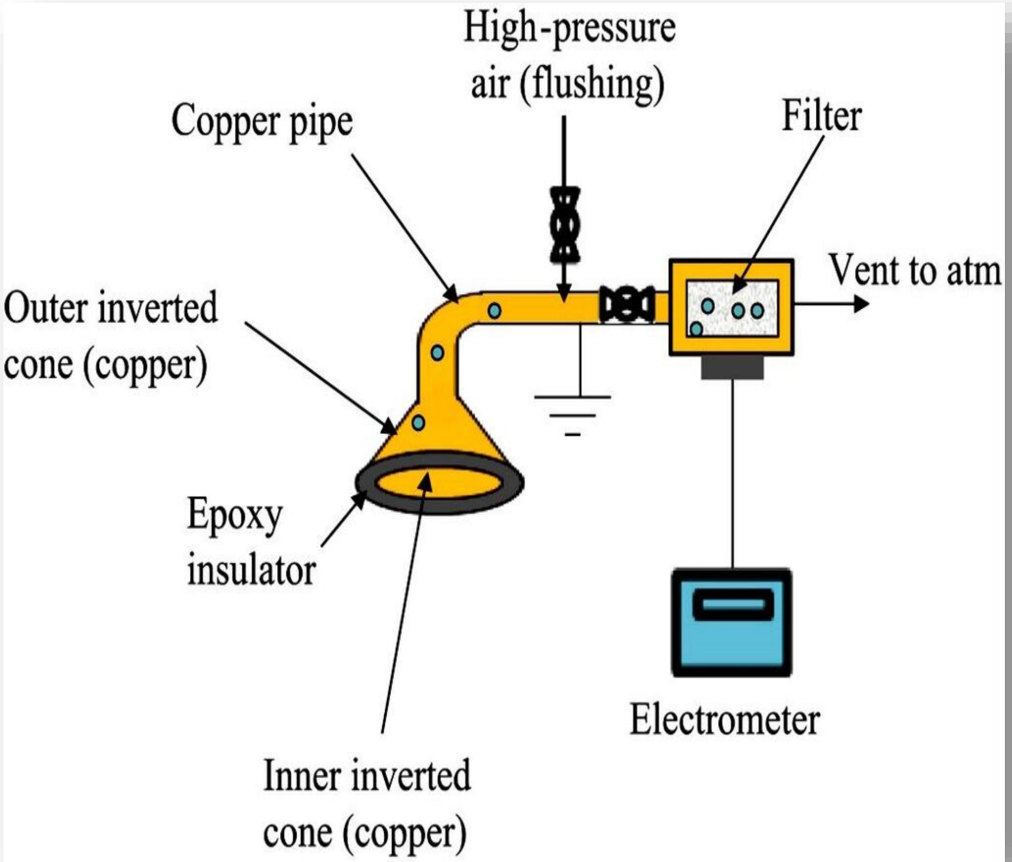
Background

- Entrainment from gas-fluidized beds is complex.
- Correlations for entrainment from gas-fluidized beds work poorly: Up to 20 orders of magnitude variation + Unphysical trends!
- Previous work (e.g. Baron et al. 1987; Briens et al. 1992; and our own) has indicated that freeboard electrostatic charges and relative humidity can affect entrainment. However, existing correlations contain only hydrodynamic factors.



System for simultaneously measuring entrainment and charge per unit mass.

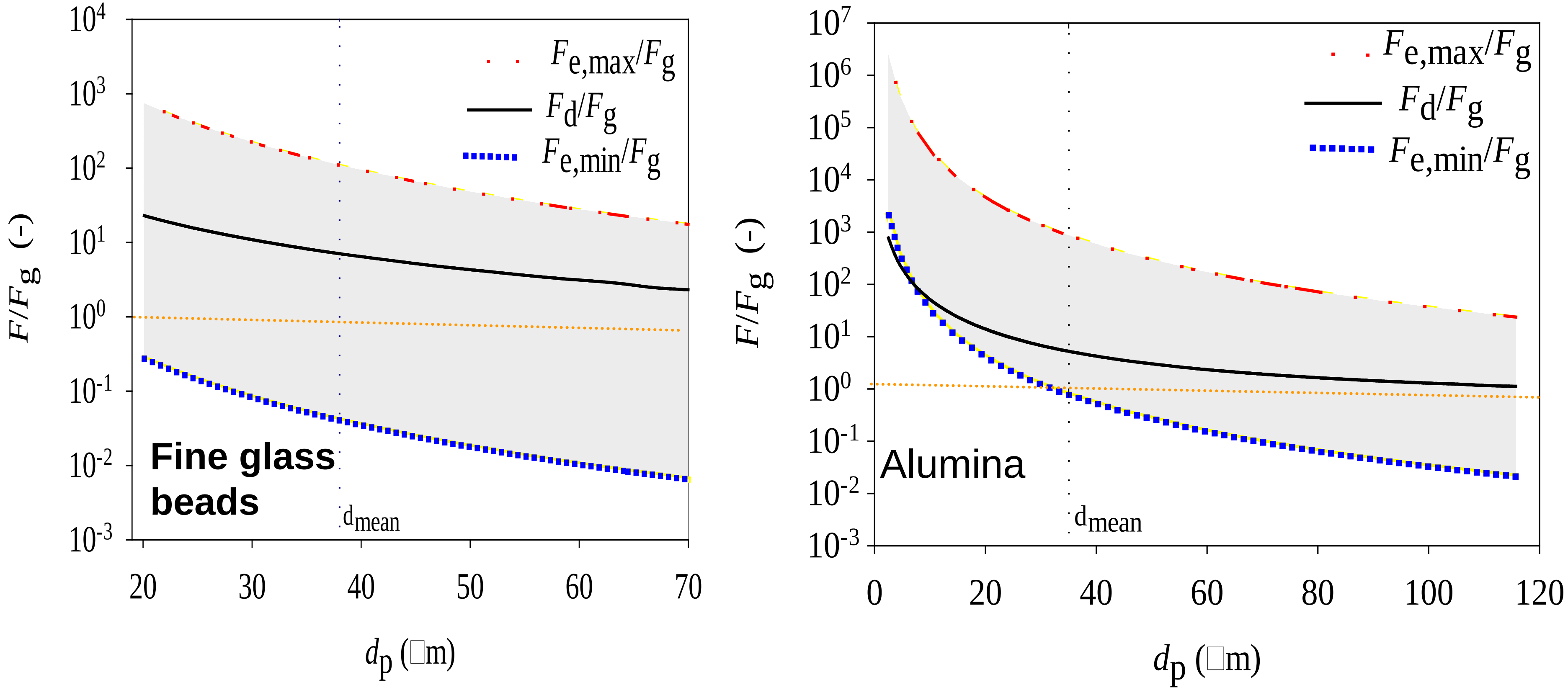


Freeboard sampling system

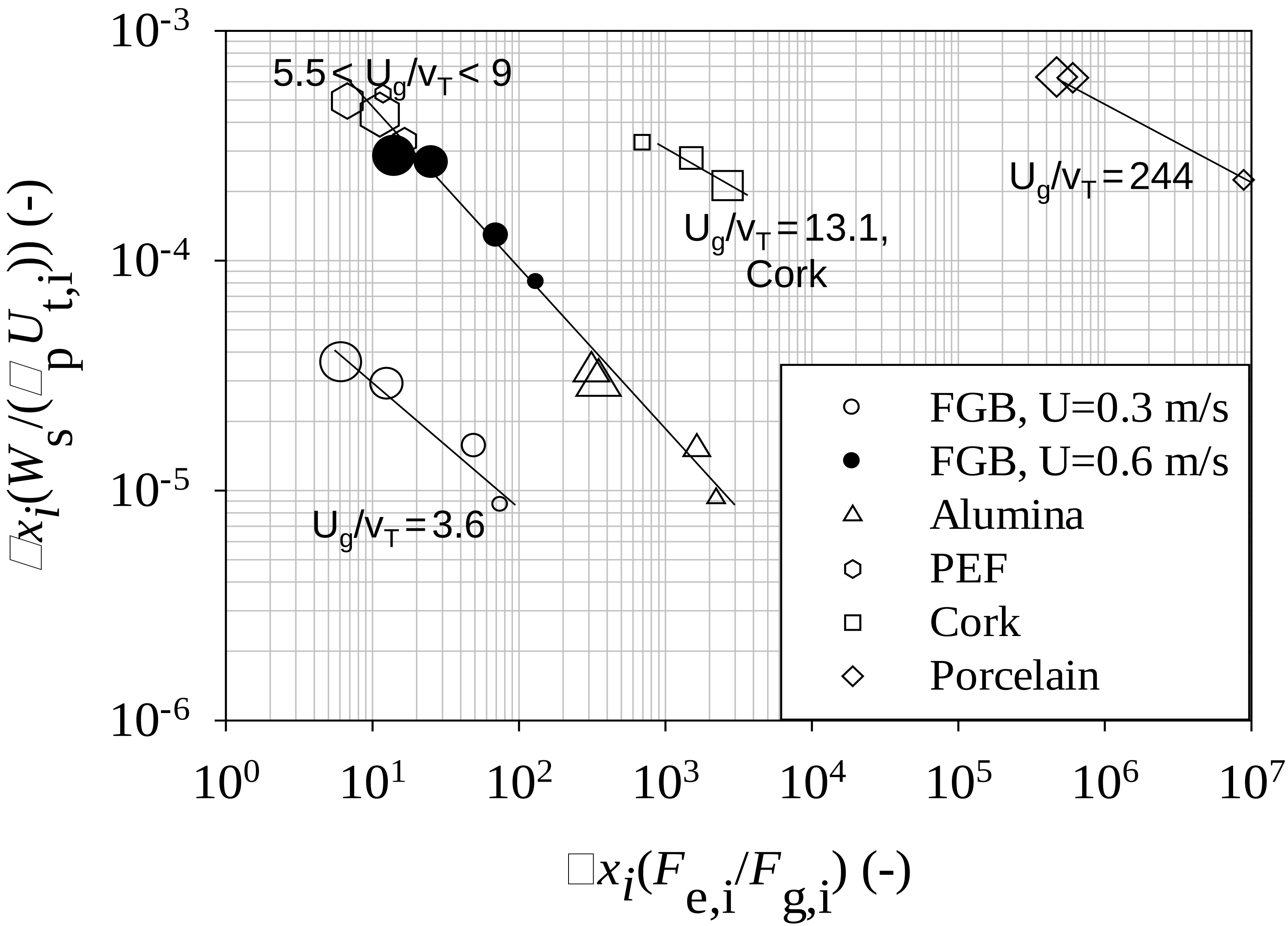
Sample vessel

Binary Mixture Experimental Details

- In all cases. 90-95 wt.% coarse glass beads of mean diameter 528 μm were fluidized by air at 20°C and pressures up to 214 kPa.
- H_o = 0.4 m; U_g = 0.3-0.6 m/s; RH = 5-30%.
- Fine dielectric particles (5-10 wt.%):
  - fine glass beads 25-50 μm
  - polyethylene 23-72 μm
  - cork 3-480 μm
  - alumina 18-73 μm
  - porcelain 1-725 μm



Drag-to-gravity force ratio (solid line) compared with Electrostatic-to-gravity ratio (band) for two of the fine particle types tested.



Normalized entrainment flux vs. electrostatic-to-gravity force ratio for fines.
Symbols increase in size with increasing relative humidity.

Entrainment Flux Correlations

- Empirical correlation:

$$\frac{W_s}{\rho_p U_t} = 1.94\times10^{-5}\left(\frac{U_g - U_t}{U_t}\right)^{1.78} Ar^{0.30}\left(1+\frac{F_e}{F_g}\right)^{-0.61}$$

- Original Choi (1999) correlation:

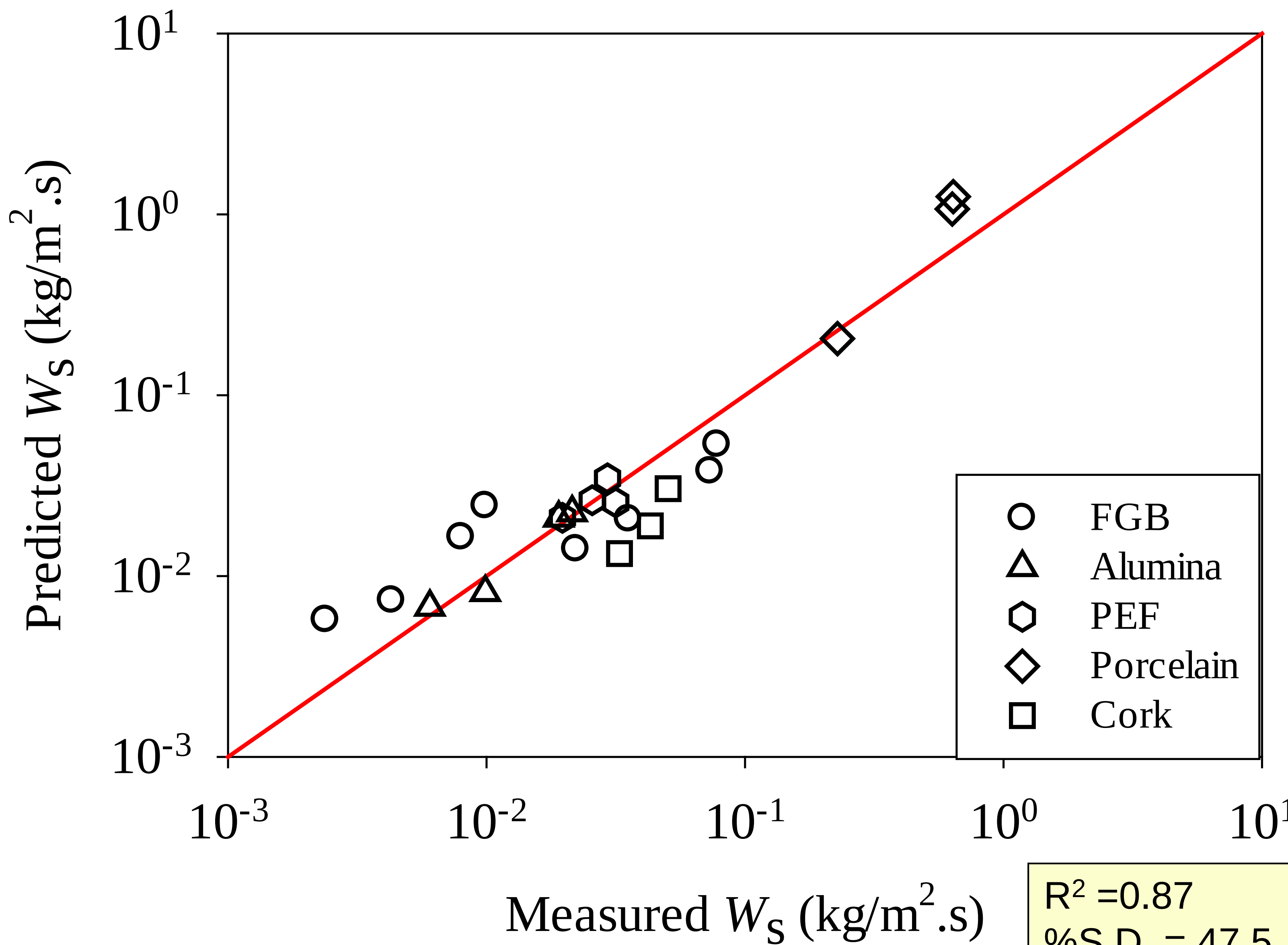
$$\frac{W_s d_p}{\mu} = Ar^{0.50}\exp\left\{6.92 - \frac{13.1}{f_d^{0.90}} - 2.11 f_g^{0.30}\right\}$$

- Modified (refitted) Choi correlation:

$$\frac{W_s d_p}{\mu} = Ar^{-0.07}\exp\left\{2.90 - \frac{25.10}{f_d^{2.55}} - 5.18 f_g^{0.24}\right\}$$

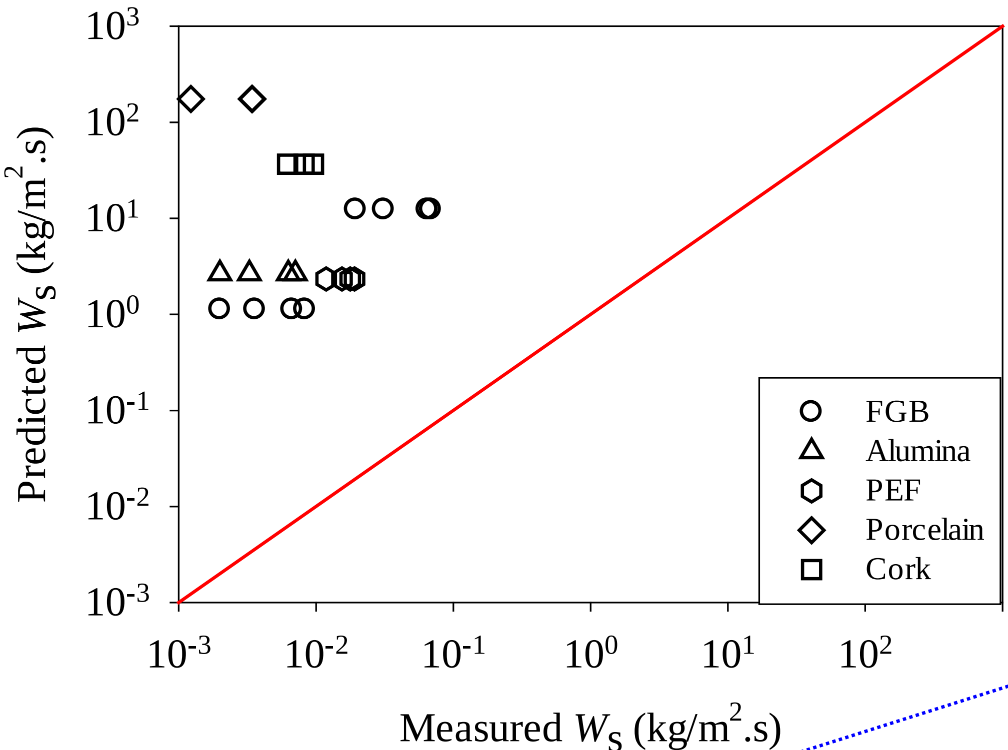
- Dimensionally consistent correlation:

$$\frac{W_s d_p}{\mu} = Ar^{-2.57}\exp\left\{18.82 - 1862\left(\frac{\rho_p}{\rho_g}\right)^{-1.18} - 56240 C_d^{-3.53} - 4.81\left(\frac{q_m^2 \rho_p d_p^2}{\varepsilon_0 U_g^2}\right)^{0.27}\right\}$$



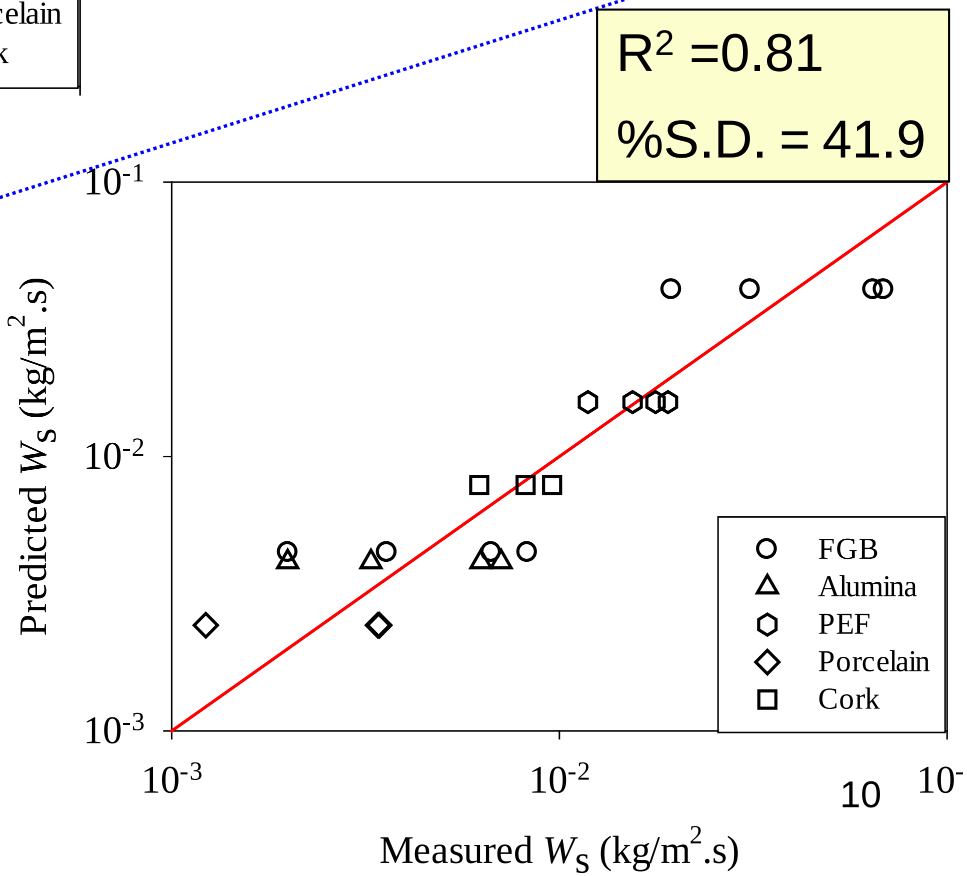
R^2 =0.87
%S.D. = 47.5

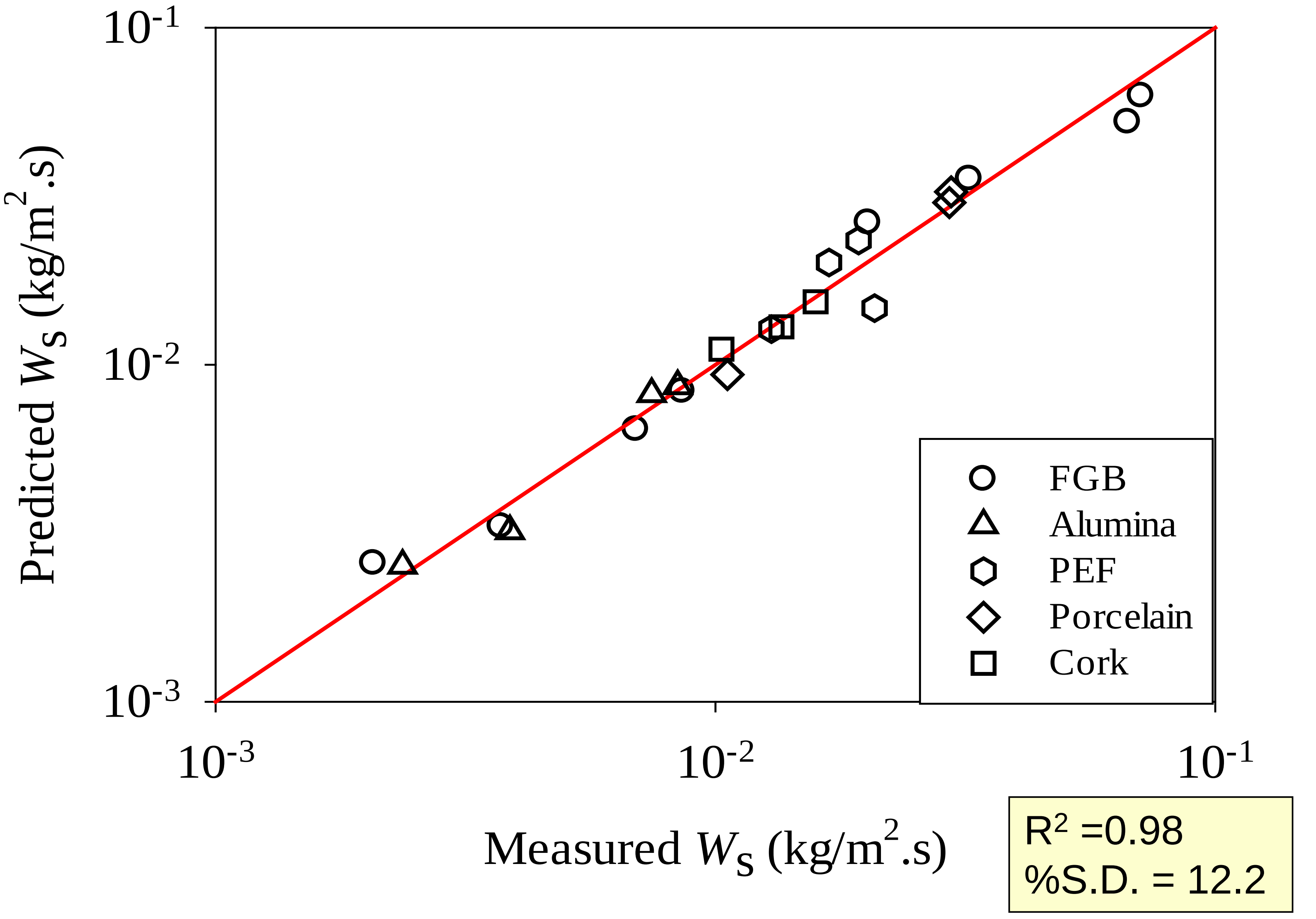
Fit with first empirical correlation



Comparison of measured entrainment flux with predictions of original Choi (1999) correlation.

Comparison of measured entrainment flux with predictions of equation of same form as Choi(1999), but with constants refitted to our data.





Comparison or experimental entrainment flux with modified correlation which includes a term related to measured charge density in the freeboard region.[11]

Cautionary Notes

- The intent of comparing and improving the correlation of the results is not to provide a correlation that will be useful to those predicting entrainment, but instead to illustrate that failure to include the electrostatic charge results in much poorer fitting.
- Van der Waals inter-particle forces were not very significant in this study, but are likely to also be important for finer fines.

Other Relevant Findings

In a separate submitted paper, we report that:

- Electrically conductive particles have significantly higher entrainment rates than dielectric ones.
- For example, entrainment rate is 6 times higher for silver-coated glass beads than for uncoated beads of almost identical size, density and shape.
- The enhanced entrainment of conductive particles is likely due to particles equalizing charges when they make contact with each other, then repelling and acting independently.

Conclusions

- Much of the huge discrepancies in predicting and modelling entrainment from gas-fluidized beds is due to failure to account for electrostatics.
- For fine dielectric particles, electrostatic forces can be of similar magnitude as the gravity forces, likely causing particles to aggregate, and reducing their entrainment.
- Including measured charge densities leads to greatly improved ability to correlate entrainment.
- Electrical conductivity, a non-hydrodynamic property, also affects entrainment.

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