Computation of turbulence and low Sherwood numbers in fluidized beds

Benjapon Chalermsinsuwan[1], Pornpote Piumsomboon[1], Dimitri Gidaspow[2], Mayank Kashyap[2] and Ronald W. Breault[3],

1. *Chemical Technology, Chulalongkorn University, Phayathai Road, Patumwan, Bangkok, 10330, Thailand, (2) Chemical and Biological Engineering, Illinois Institute of Technology, 10W 33rd St., Perlstein Hall, Chicago, IL 60616, (3) Gasification and Combustion Projects Division, National Energy Technology Laboratory, 3610 Collins Ferry Rd, Morgantown, WV 26507*

Abstract

We have already shown (Gidaspow, 1994) that the kinetic theory based CFD code is capable of predicting the turbulent behavior of fluidized bed risers (Jiradilok et al., 2006). For FCC particles, it predicted the Kolmogorov -5/3 law at high frequencies. In dimensionless form the computed spectrum was that of single phase flow at a Reynolds number of 21,500. To get agreement with experiments we had used the modified EMMS drag law. We used a similarly modified drag law for modeling the flow in the PSRI riser "challenge problem one" summarized in this study.

Dispersion coefficients

The objective of this study is to develop predictive theories for the dispersion and mass transfer coefficients and to measure them in the turbulent fluidization regime, using existing facilities.

The dispersion coefficient is a measure of the quality of mixing. We have identified two types of solids dispersion coefficients: those due to random particle oscillations, "laminar" type, and those due to cluster or bubble motion, "turbulent" type. A literature review (Breault, 2006) shows that dispersion coefficients in fluidized beds differ by more than five orders of magnitude. To understand the phenomena, two types of hydrodynamics models that compute turbulent and bubbling behavior were used to estimate radial and axial gas and solids dispersion coefficients. The autocorrelation technique was used to compute the dispersion coefficients from the respective computed turbulent gas and particle velocities.

The computations show that the gas and the solids dispersion coefficients are close to each other in agreement with measurements. The simulations show that the radial dispersion coefficients in the riser are two to three orders of magnitude lower that the axial dispersion coefficients, but less than an order of magnitude lower for the bubbling bed at atmospheric pressure. The dispersion coefficients for the bubbling bed at 25 atmospheres are much higher than at atmospheric pressure due to the high bed expansion with smaller bubbles. The computed dispersion coefficients are in reasonable agreement with the experimental measurements reported over the last half century and those measured at IIT and in the NETL riser in Morgantown (Jiradilok et al., 2007, 2008).

Some typical measurements for the IIT two dimensional bed shown in Figure 1 are shown in Figure 2 and Table 1. Computations for this configuration are in progress.

Figure 3 shows a summary of granular temperatures. For the two dimensional bed, the measured granular temperature is low due to small particle velocity. For the IIT riser, the granular temperature is high. The computed and experimental values agree.

Figure 4 shows the axial and radial solids dispersion coefficients. Consistent with the granular temperature, the dispersion coefficients are low in the two dimensional bed due to low solid velocity. For the IIT riser, the computed and measured dispersion coefficients agree with literature values.

Mass transfer coefficients

It was known for half a century that the Sherwood and Nusselt numbers in fluidized beds are often three orders of magnitude lower than the classical diffusion controlled limit of two. We have shown (Chalermsinsuwan et al., 2008a, 2008b) that our kinetic theory based computer codes correctly compute low Sherwood numbers in agreement with published experimental data. For tall fluidized bed risers the computed behavior is similar to that for convective diffusion in a channel, but with a greatly reduced mass transfer.

Figure 3 shows our comparison of the computed Sherwood number to Kato et al. (1970) results. Clearly, our CFD code predicts these low Sherwood numbers. However, the low Sherwood number has nothing to do with the diffusion to the particles as is implied in its definition. It simply reflects the difference in the radial concentration distributions in the fluidized bed of fine particles.

References:

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Figure 1: Circulating fluidized bed showing clusters formed by 75 μm FCC particles

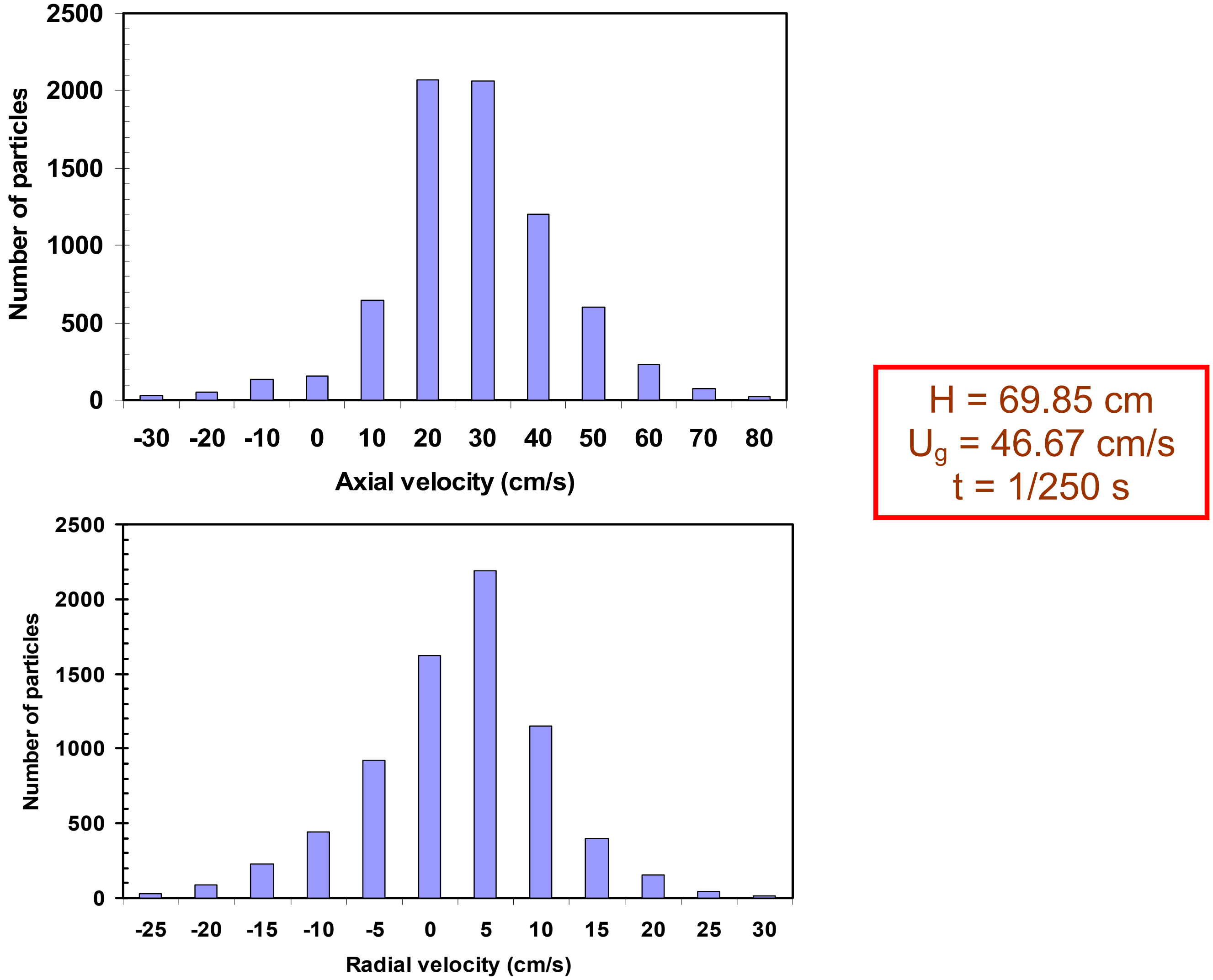


Figure 2: Overall instantaneous velocity distribution for 75 µm FCC particles in the system shown in Figure 1

Table 1: Comparison of laminar and turbulent granular temperatures in IIT 2- D circulating fluidized bed and IIT riser

Granular Temperature, m^2/s^2			
System	Radial Position	Laminar due to individual particle oscillations	Turbulent due to cluster oscillations
2-D CFB, 75 μm FCC particles	Center	1.27×10^{-2}	6.73×10^{-3}
2-D CFB, 75 μm FCC particles	Right Wall	6.67×10^{-3}	2.54×10^{-3}
IIT Riser, 1093 μm	Wall	9.48×10^{-2}	2.61×10^{-2}

Mixing is on the level of particles

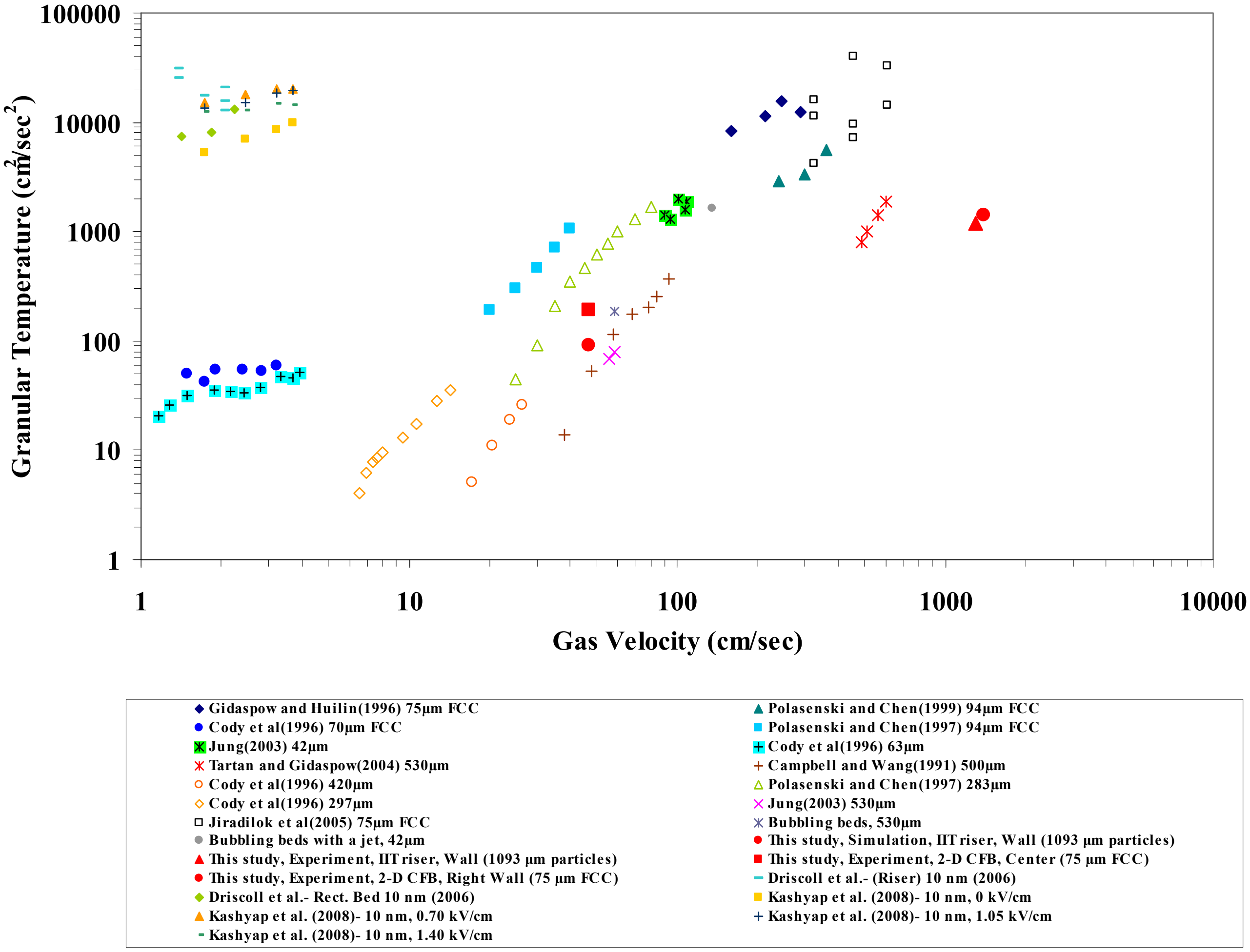
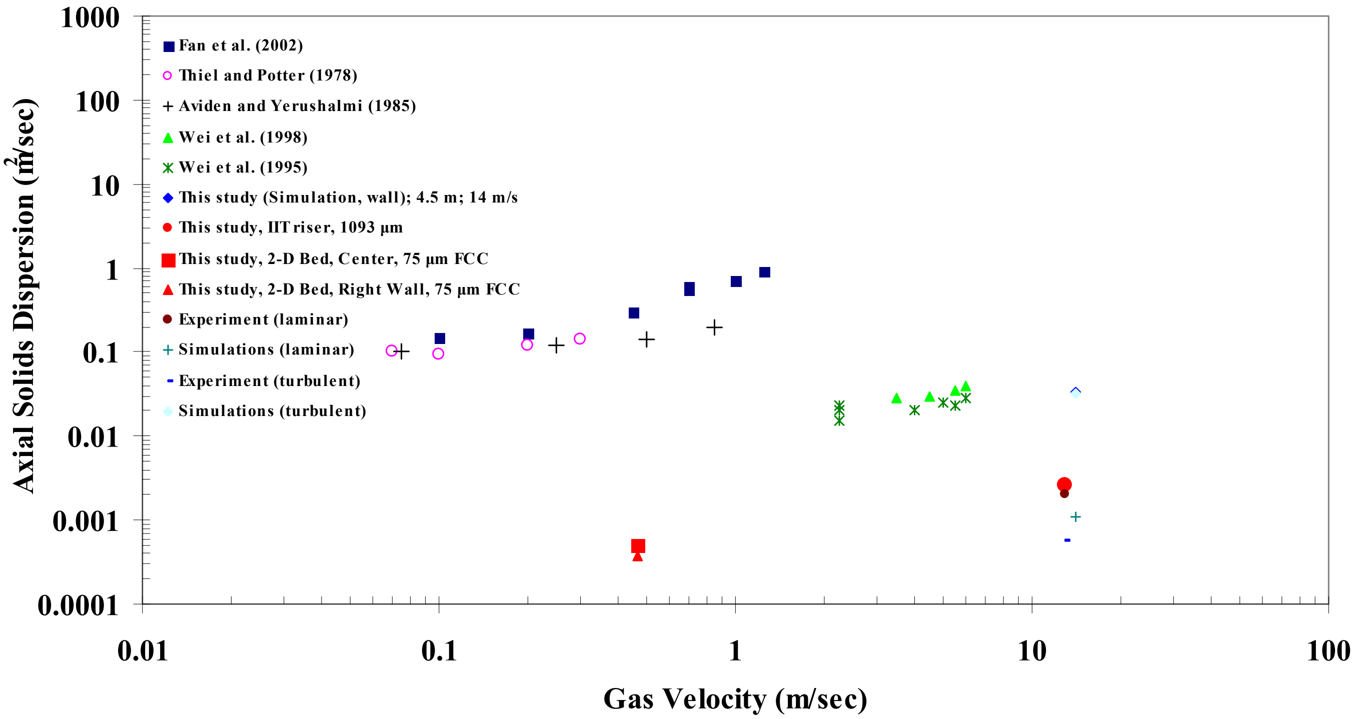
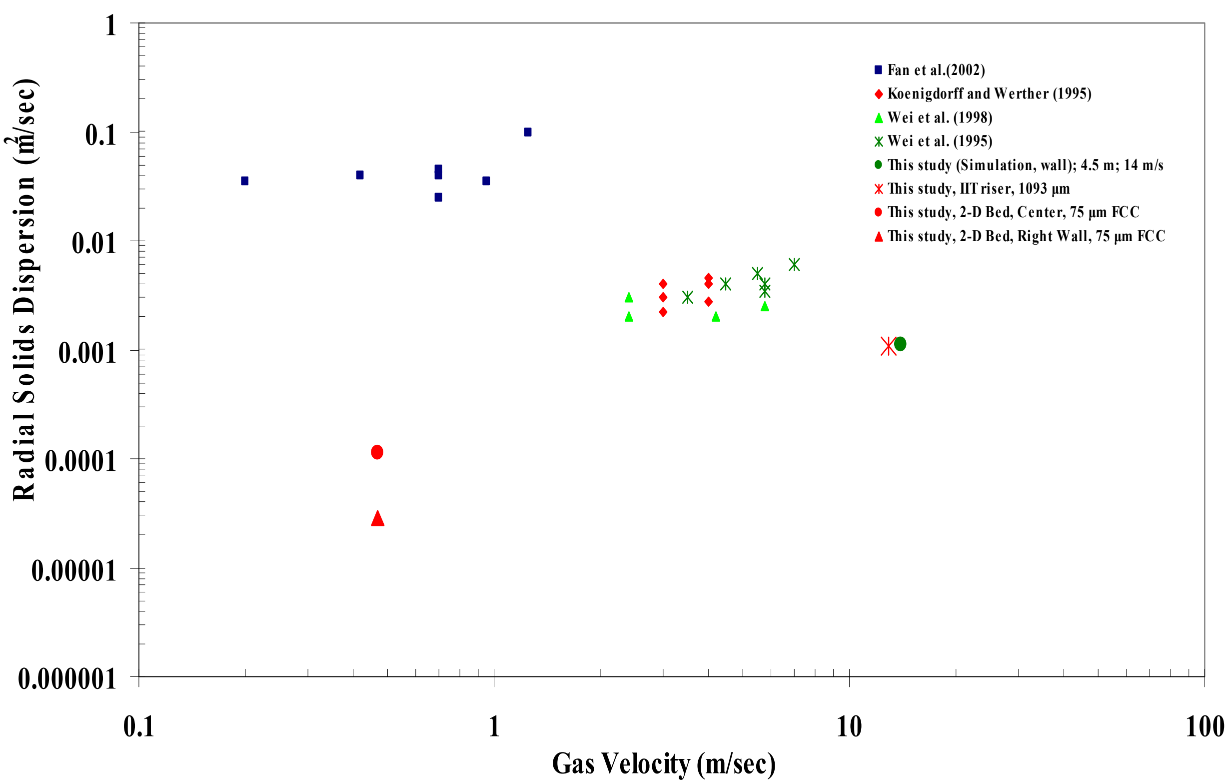


Figure 3: Comparison of granular temperatures versus gas velocities for various particles

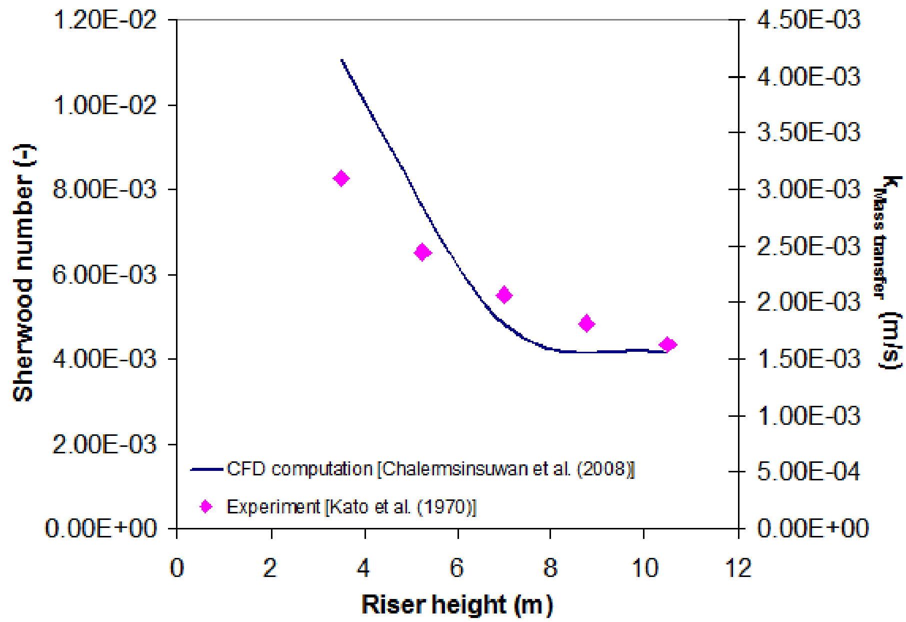


(A)



(B)

Figure 4: (A) Axial and (B) radial solids dispersion coefficients for various particles



Low mass transfer coefficients in PSRI riser with $k_{reaction}$ = 39.6 s^{-1}

Figure 5: Variation of Sherwood number with height in the PSRI riser