# KINETIC THEORY BASED CFD SIMULATION OF TURBULENT FLUIDIZATION OF FCC PARTICLES IN A RISER

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Fluidization is widely used industrially because of its continuous powder handling ability and its good heat and mass transfer characteristics. The turbulent fluidization regime occurs between the bubbling and the fast fluidization regimes (Berruti, et al. 1995; Bi, et al. 2000; Du, et al. 2003; Gidaspow, et al. 2004; Andreux, et al. 2005 ). We agree with the recent review by John Grace (2000) that turbulent fluidization and dense suspension flow regimes cover the operations of almost all the key commercial catalytic processes involving gas-solid fluidized beds and that these flow regimes have received very little attention in the literature. L.S. Fan's group (Du, et al, 2003) also stated that much remains to be known about this regime. Particularly there has been almost no computational fluid dynamic (CFD) modeling of this flow regime. The objective of this study is to present a CFD model for this flow regime. The model is the standard kinetic theory CFD model (Gidaspow, 1994) with the drag modified, as suggested by Yang, et al. (2004) using the energy minimization multiscale approach.

A turbulent fluidized bed is characterized by two different coexisting regions: a bottom dense, bubbling region and a dilute, dispersed flow region (Berruti , et al 1995). The solids volume fractions in these two regions can, in principle, be estimated using the drift flux method (Gidaspow, 1994). Unfortunately in this one dimensional approach the slip has to be increased by an order of magnitude above that given by standard correlations to obtain the dense and the dilute volume fractions of solid. In this paper we show that the coexistence of these two regions can be computed using the transient, two-dimensional kinetic theory model.

The second characteristic of turbulent fluidization is the high value of the dispersion coefficients for the solids. Du, et al (2002) show that the dispersion coefficients in the turbulent regime are much higher than in the neighboring flow regimes. Here we show that our model computes such high dispersion coefficients due to high Reynolds stresses.

The granular flow kinetic theory model in this paper was first used by Sinclair and Jackson (1989) to compute the core-annular flow regime in the developed section of the riser. Since the publication of their 1989 classical paper, it has been used by many groups in several countries, -such as by Arastoopour's group (Benyahia, et al, 2000), Sundaresan's group (Agrawal, et al, 2001), Hjertager's group (Mathiesen, et al 2000), Hrenya and Sinclair (1997), Kuipers group (Goldschmidt, et al 2001 ) and by Simonin (2003) for modeling a complete loop. This is the first paper to show that the kinetic theory model can compute the turbulent stresses giving rise to the excellent mixing in this flow regime.

We have shown that the standard kinetic theory based CFD model with a modified drag as suggested by Jinghai Li group, is capable of correctly describing the coexistence of the dense and dilute regimes for flow of FCC particles in a riser in the turbulent regime.

The CFD simulations compare well with the high density riser experiment of Wei, et al. (1998) for three high solid fluxes of commercial interest. The computed void fractions agree within about 10% with the experiment at three different heights. For the three fluxes, we computed the observed core-annular regime at the bottom of the riser (see Fig. 1). However the computed ratio of particle to gas velocity at the center of the riser was considerably below that reported for the measurement of Wei, et al. (1998)(see Fig. 2) similar to that computed by Jinghai Li group. The computed solids and gas velocity were close to each other, as expected for Geldart group A particles (see Fig. 3). The developed slip velocity was, however, almost two times higher than the terminal velocity of FCC particles, reflecting the Li group drag correction.

The turbulent kinetic energy, essentially the total granular temperature, of the FCC particles agreed with the measurements of the granular temperature of Gidaspow and Huilin (1996) determined in the dense-annular region of the riser, where clusters were observed (see Fig. 4). The computed solids pressure also agreed with the measurements done with a special transducer (see Fig. 5). The computed solid viscosity, again, agreed with the measurements in the riser done with the three different instruments: PIV meter, Brookfiled viscometer and pressure drop minus weight of the bed measurements. Near 5% the computed solids viscosity compares well with the correlation for FCC particles of Gidaspow and Huilin (1998), but is about 30% lower at 25% solids holdup (see Fig. 6).

The CFD code also computed the turbulent characteristics of flow, of importance for the dispersion of particles. In the literature (e.g. Du, et al. 2002) it is well known that the radial dispersion coefficient is much smaller than the dispersion coefficient in the direction of the flow. Dispersion coefficients were computed as a function of radial and axial position. The computed dispersion coefficients are similar to the measurements reported in the literature (see Fig. 7).

The computed dispersion coefficients and the normal stresses allow the computation of characteristic lengths of clusters. The length and width agree with snapshot of volume fraction of solids (see Fig. 8).

In the dense portion of the riser, the power spectrum of solid volume fraction is almost flat, in agreement with measurements reported in the literature (e.g. Gidaspow, et al. 2001). However, in the dilute phase of the riser, there was a distinct peak at a frequency of about 0.28 Hz. This is an indication of a distinct core-annular structure (see Fig 9).

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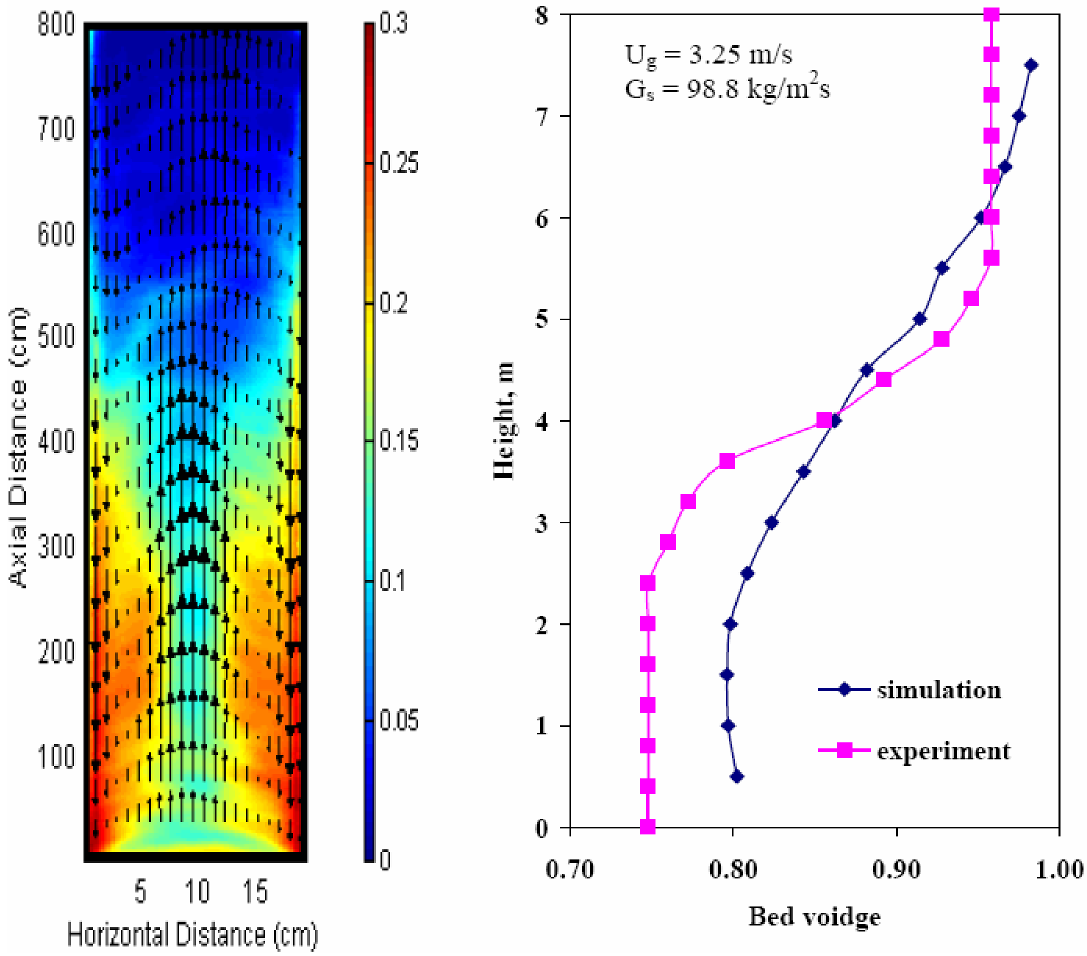



(a) (b)

Figure 1. (a) The computed solid volume fraction structure. (b) A comparison of experimental and computed void profiles. Solids flux = 98.8 $kg/m^2s$ and superficial gas velocity = 3.25 m/s. averaged from 6 sec to 13 sec

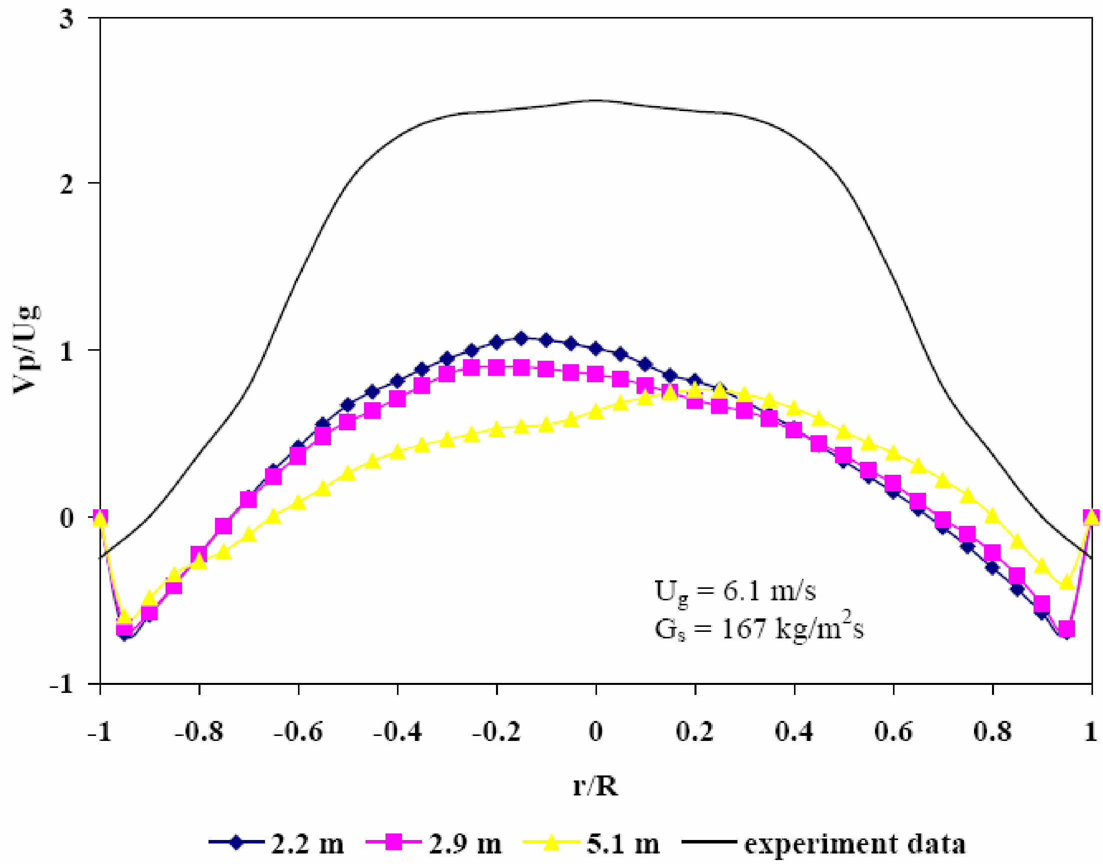



Figure 2. A comparison of radial distributions of dimensionless solids axial velocity to the experiment of Wei, et al. (1998).

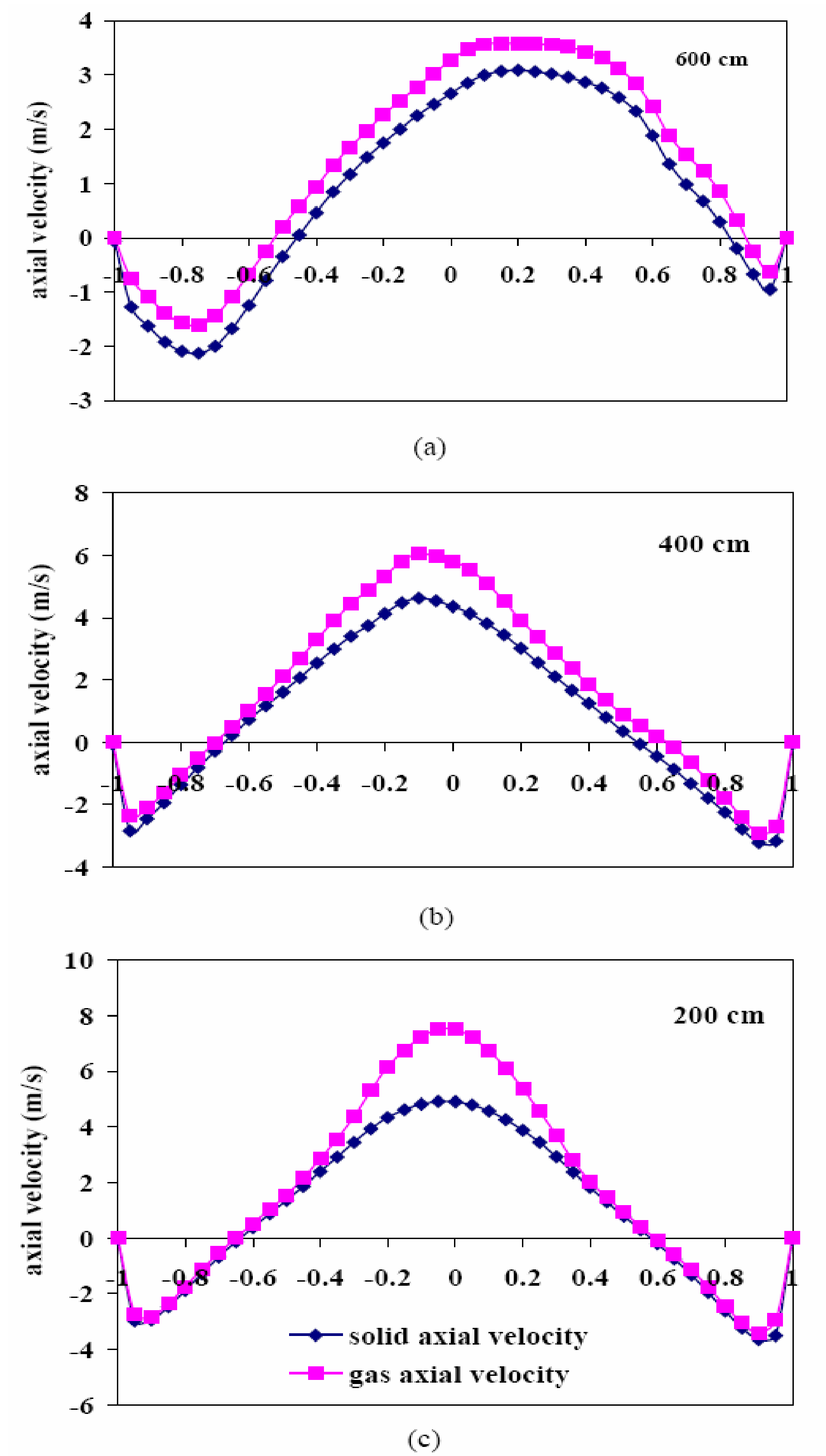



Figure 3. Radial distributions of axial velocity of solid and gas phases at (a) 600 cm, (b) 400 cm and (c) 200 cm

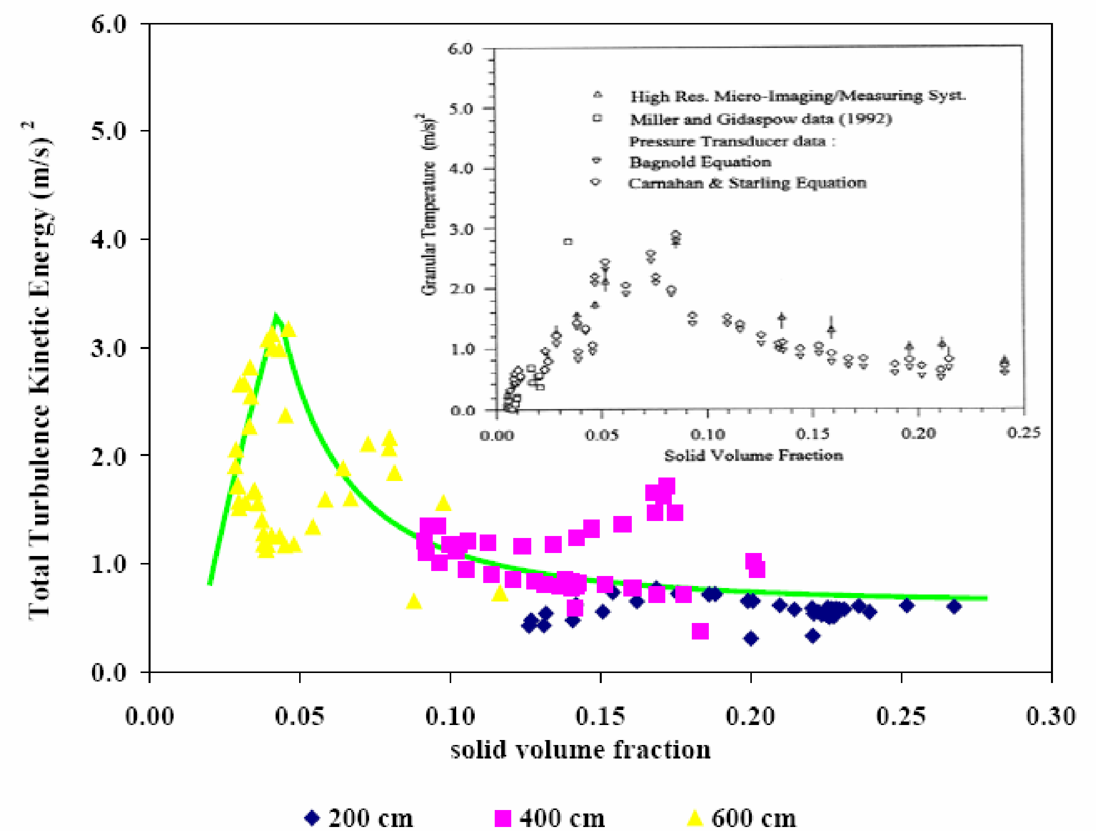



Figure 4. Computed turbulent kinetic energy as a function of solid volume fraction. Solids flux = 98.8 $kg/m^2s$ and superficial gas velocity = 3.25 m/s

The box shows experimental granular temperature values (Gidaspow and Huilin, 1998)

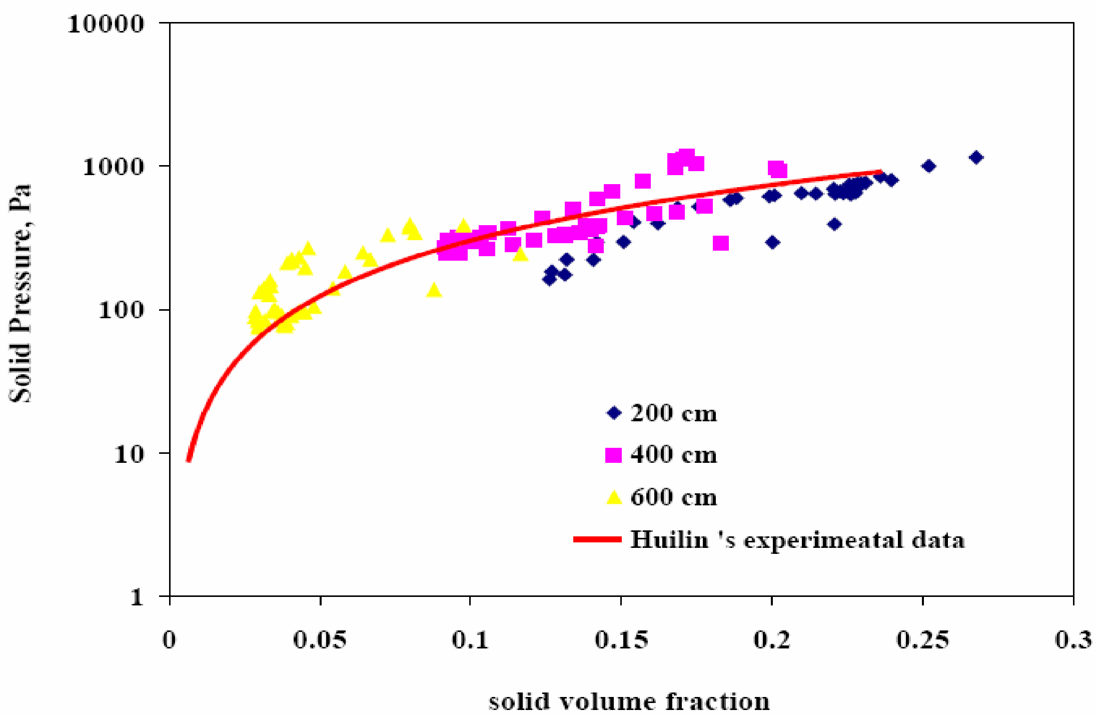



Figure 5. Computed solid pressure using the kinetic theory model as a function of solid volume fraction.
Solids flux = 98.8 kg/m$^2$s and superficial gas velocity = 3.25 m/s

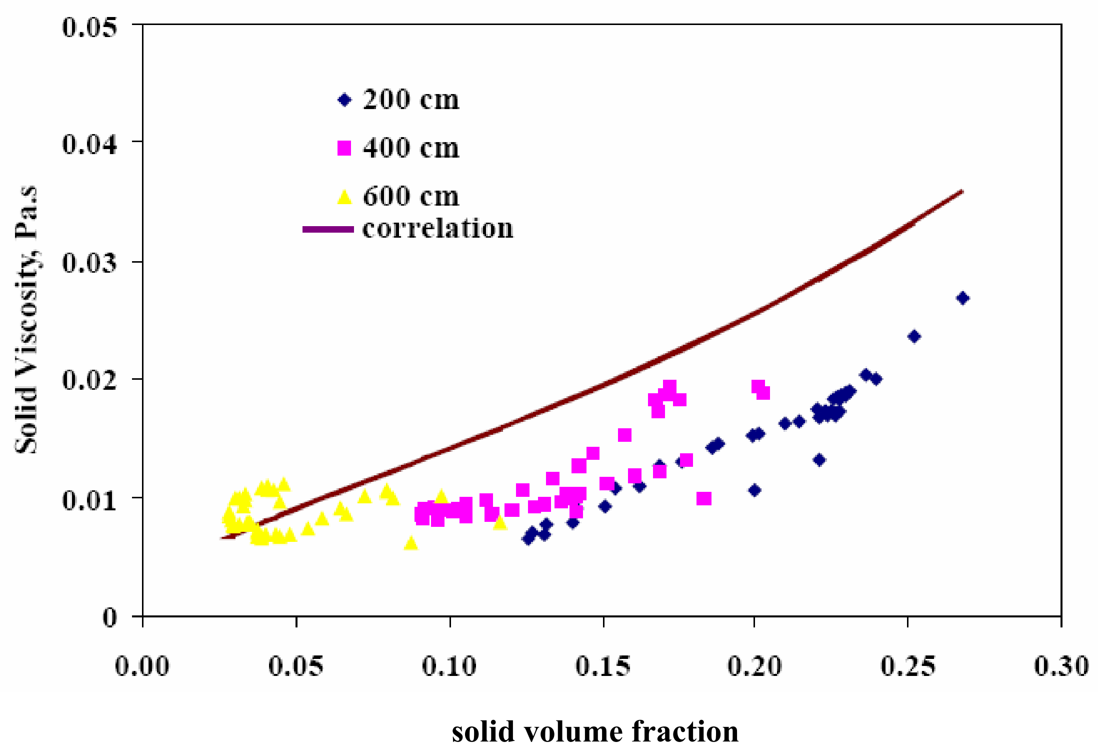



Figure 6. Computed solid viscosity using the kinetic theory model
as a function of solid volume fraction.
Solids flux = 98.8 kg/m$^2$s and superficial gas velocity = 3.25 m/s

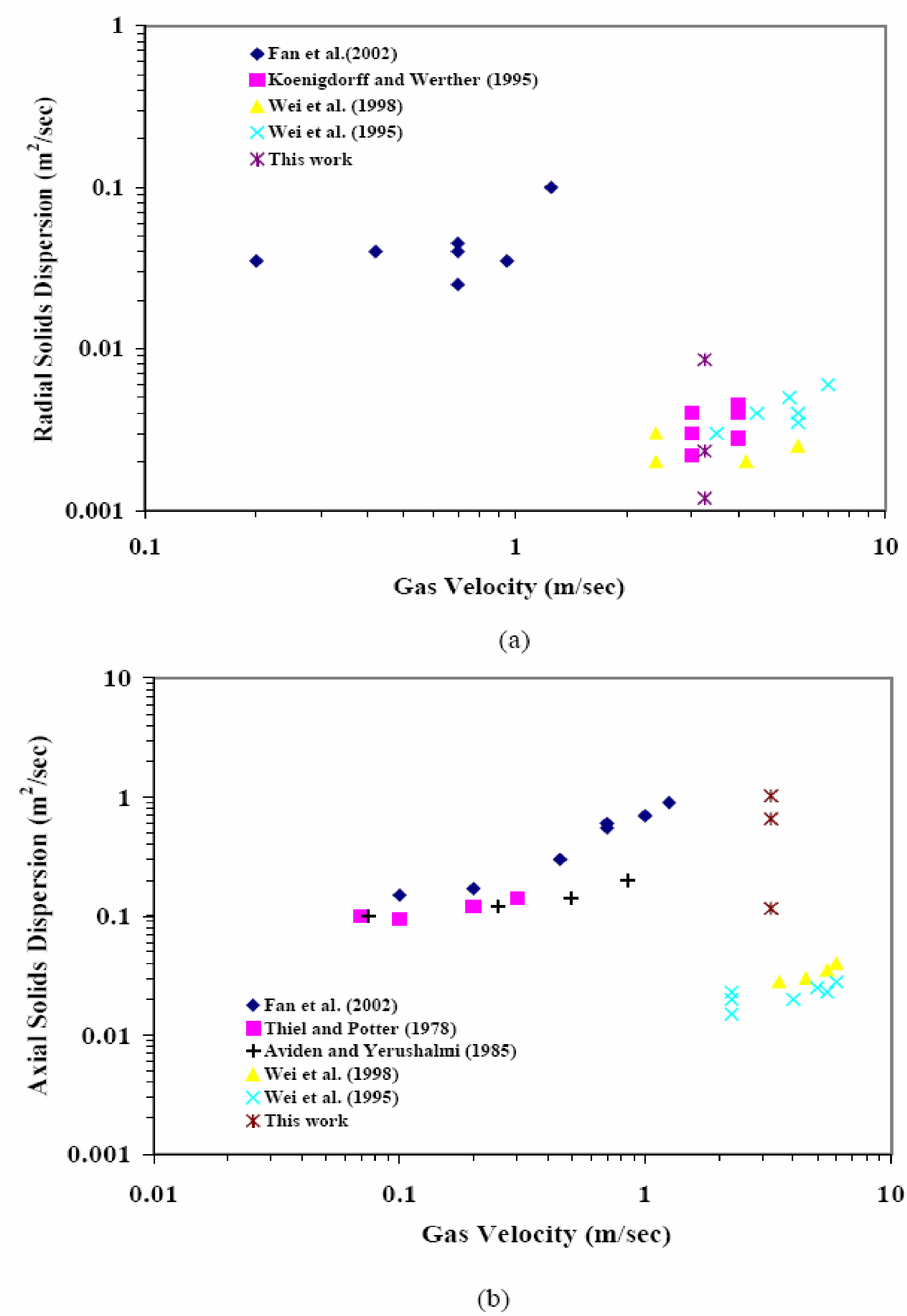
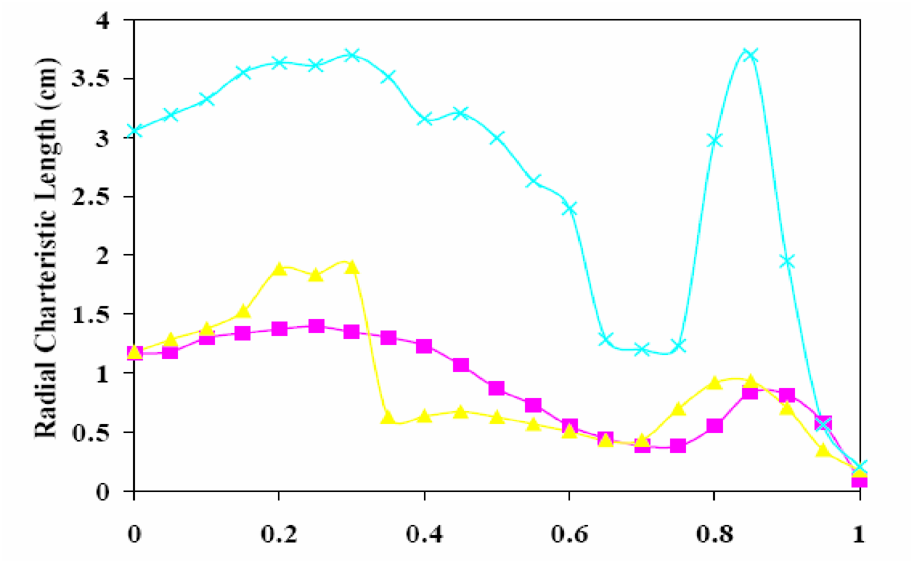
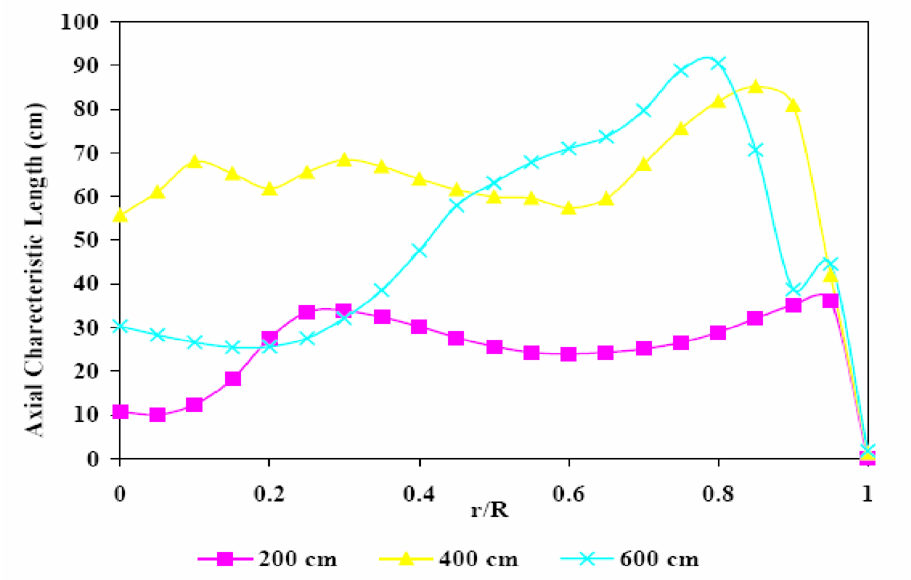



Figure 7. Effect of gas velocity on radial solids dispersion
(a) Radial; (b) Axial




(a)




(b)

Figure 8. Radial distributions of characteristics lengths
(a) Radial; (b) Axial
Solids flux = 98.8 kg/m$^2$s and Superficial gas velocity = 3.25 m/s

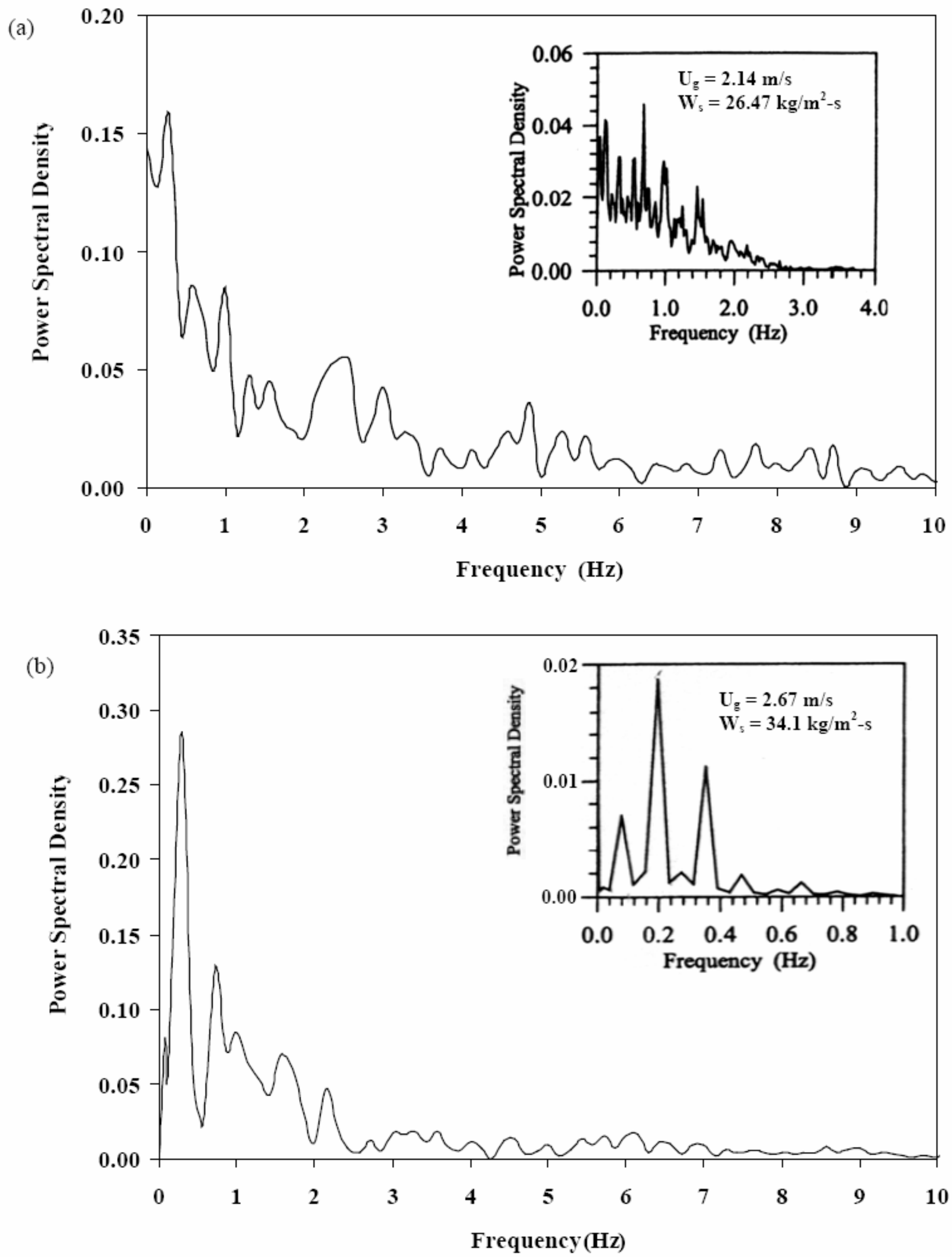



Figure 9. Power spectrums of solid volume fraction at
(a) 200 cm (b) 600 cm on right hand side wall
for solids flux = 98.8 kg/m$^2$s and superficial gas velocity = 3.25 m/s

The box represents power spectrum density diagram (Gidaspow et al. 2001)