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Computation of turbulence and dispersion of cork in the NETL riser

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Abstract

The knowledge of dispersion coefficients is essential for reliable design of gasifiers. However, a literature review had shown that dispersion coefficients in fluidized beds differ by more than five orders of magnitude. This study presents a comparison of the computed axial solids dispersion coefficients for cork particles to the NETL riser cork data. The turbulence properties, the Reynolds stresses, the granular temperature spectra and the radial and axial gas and solids dispersion coefficients are computed.

The standard kinetic theory model described in Gidaspow's 1994 book, Multiphase Flow and Fluidization, Academic Press and the IIT and Fluent codes were used to compute the measured axial solids volume fraction profiles for flow of cork particles in the NETL riser. The Johnson–Jackson boundary conditions were used. Standard drag correlations were used. This study shows that the computed solids volume fractions for the low flux flow are within the experimental error of those measured, using a two-dimensional model. At higher solids fluxes the simulated solids volume fractions are close to the experimental measurements, but deviate significantly at the top of the riser. This disagreement is due to use of simplified geometry in the two-dimensional simulation. There is a good agreement between the experiment and the three-dimensional simulation for a high flux condition.

This study concludes that the axial and radial gas and solids dispersion coefficients in risers operating in the turbulent flow regime can be computed using a multiphase computational fluid dynamics model.

Keywords: Gas-particle flow; Fluidization; Computational fluid dynamics; Reynolds stress

1. Introduction

Reliable design of a gasifier requires the knowledge of dispersion coefficients, as demonstrated by Breault (2006). However, these are known to vary by five orders of magnitude (Gidaspow et al., 2004; Breault, 2006).

Dispersion in reactors can be viewed from two perspectives, macroscopically and microscopically. In either case, the dispersion is the result of meso-scale turbulent phenomena. In the macroscopic view, the view usually discussed in reaction kinetics books such as Levenspiel (1999), a tracer is used to measure the degree of non-ideal behavior of back mixing and bypassing. The microscopic view recognizes that dispersion arises from the local turbulence in the reactor and is modeled within the statistical theory of turbulence, for example see Brodkey (1975).

In this mechanistic approach, the dispersion is a function of the time dependent local velocity vector. This vector can be decomposed into time dependent components. It is through the autocorrelation of these fluctuating time dependent velocities that local dispersion coefficients are calculated. That is for every point in the reactor, there will be three components for the gas and solids velocities. Therefore, there will be three gas dispersion values and three solids dispersion values. It is known that the velocity fluctuations for the solids are not homogeneous (see Tartan and Gidaspow, 2004) which leads us to believe that the fluctuations in the gas velocity will not be homogeneous. Thus, the dispersion coefficients for both gas and solids are a function of the location within the reactor and the conditions at that location.

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It has been reported (e.g. Breault et al., 2008; Gidaspow et al., 2004) using kinetic theory and velocimetry that there are three kinds of fluctuating energies in fluidization:

1. random oscillations (granular temperature) of individual particles,
2. turbulence caused by the motion of clusters of particles and
3. process induced fluctuations.

The first two kinds of turbulence give rise to two kinds of mixing, mixing on the level of particles and mixing on the level of clusters or bubbles. To compute the granular temperature, it must be programmed into the CFD codes. The code itself computes the Reynolds stresses, similar to the calculation of single-phase turbulence by direct numerical computation. Jiradilok et al. (2006) have briefly illustrated how to compute solids dispersion coefficients for flow of FCC particles in the turbulent fluidization regime. Gas dispersion coefficients and the dispersion coefficients in bubbling beds were recently computed by Jiradilok et al. (2007). For flow of FCC particles in the turbulent fluidization regime the standard drag law had to be modified to match the experimentally measured particle concentration profiles.

To simulate coal gasification NETL has built a 0.305 m diameter and 15.45 m riser and obtained apparent voidage profiles for flow of cork particles over a range of particle fluxes and gas velocities (Shadle et al., 2002; Mei et al., 2003; Monazam et al., 2005). More recently they have used a laser doppler velocimetry (LDV) technique to measure the instantaneous particle velocities of cork particles (Breault et al., 2005). The measurements of instantaneous particle velocities enable us to compute the dispersion coefficients using the autocorrelation technique (Breault et al., 2008; Jiradilok et al., 2006, 2007).

In this paper we show how to compute the instantaneous hydrodynamic velocity profiles of the cork particles in the NETL riser using the standard kinetic theory model (Gidaspow, 1994) without any drag modification. The simulated volume fractions will be shown to agree approximately with the measurements at NETL using a simplified two-dimension geometry for the riser. A three-dimensional simulation was conducted to improve the agreement at the riser outlet where flow asymmetry cannot adequately be described in two-dimensions. Once, an experimentally verified flow pattern has been established, the IIT computer code computes gas and solids Reynolds stresses and dispersion coefficients. The calculation methodology of the dispersion coefficients is identical to that used at NETL for conversion of their measured velocity data into dispersion coefficients (Breault et al., 2008). The agreement between the CFD computations and the experiments is reasonable in view of the simplification of the three-dimensional geometry, particularly the asymmetry caused by the blind tee on top of the NETL riser.

2. Experimental setup and data

Experimental data were generated at the National Energy Technology Laboratory (NETL). The solids volume fractions and the solids velocity distributions were measured. Fig. 1 shows a sketch of NETL circulating fluidized bed (CFB) unit. The cork characteristics are summarized in Table 1. Cork is an excellent bed material which when tested at ambient conditions in air yields a similar density to that of coal converted to 15 atm and 1000 °C.

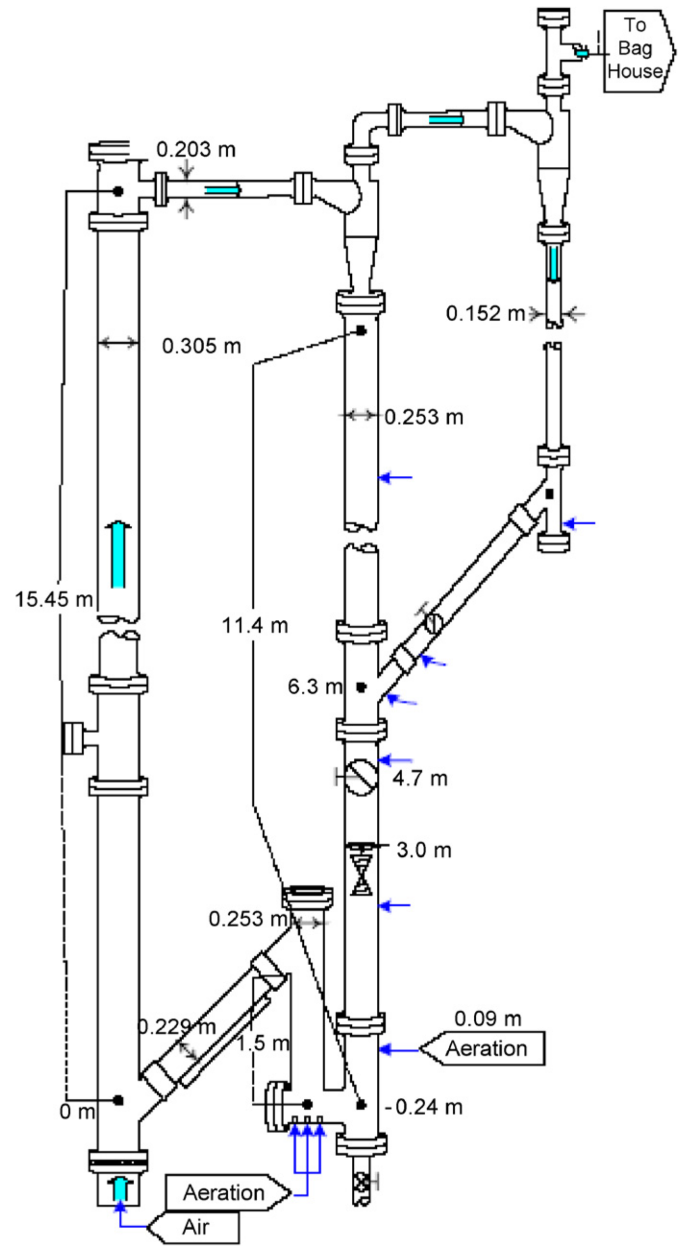

Fig. 1. Sketch of NETL CFB unit.

Table 1
Cork characteristics

Particle density (kg/m^3)	189
Particle diameter (μm)	812
Terminal velocity (m/s)	0.86
Minimum fluidization velocity (m/s)	0.07
Packed bed voidage	0.49