IChemE
www.icheme.org/journals
doi: 10.1205/cherd.05098

0263–8762/05/$30.00+0.00

Trans IChemE, Part A, November 2005
Chemical Engineering Research and Design, 83(A11): 1319–1324

INVESTIGATION ON ASSISTED FLUIDIZATION OF A COHESIVE POWDER

A. SCUZZARELLA[1], S. J. R. SIMONS[1]*, C. D. HILLS[2] and P. J. CAREY[2]

[1]*Centre for CO_2 Technology, Department of Chemical Engineering, University College London, London, UK*
[2]*Centre for Contaminated Land Remediation, University of Greenwich, Chatham Maritime, Kent, UK*

Cohesive systems have been largely investigated; however, the capability to predict their characteristics is still limited. A cohesive powder (air pollution control residue, or fly ash) from waste incineration could potentially be treated in a fluid bed unit. The capacity to fluidize this powder with a second fluidizable solid is assessed and the possibility to describe the system with a model is evaluated. A generalized Richardson and Zaki correlation is tested. The form of the correlation is seen to be still valid but with lower values of the exponential index. The experimentation conducted in this work needs to be extended to substantiate preliminary findings and a research path to develop the work further is proposed.

Keywords: assisted fluidization; cohesive powder; binary systems; air pollution control residues; accelerated carbonation.

INTRODUCTION

Cohesiveness and Assisted Fluidization

Many industrial applications for the fluidization of fine powders have been identified, as addressed by some authors (Zhou and Li, 1999), due to the large superficial surface area. Fluidization of a fine powder, however, can be difficult because of increasing inter-particle forces which may give the powder a cohesive characteristic. Geldart, with his well known classification (Geldart, 1973), has distinguished cohesive (group C) powder from aeratable (group A) powder, within fine particles, in relation to the different behaviour in a fluid bed system and basing the classification on size and density ranges. Following this, a detailed description of group C and A powders has been given by Geldart and Wong (1984), who observed that increasing values of n from the Richardson and Zaki (1954) correlation, are determined with increasing cohesiveness. The general form of the Richardson and Zaki expression is:

$$\frac{u}{u_t} = \varepsilon^n \tag{1}$$

Geldart and Wong (1984) related n to the Hausner ratio (ρ_{BT}/ρ_{BLP}) using the following correlation:

$$\frac{n}{4.65} = \left(\frac{HR}{1.11}\right)^{4.16} \tag{2}$$

They then related n to the u_t' (extrapolation of u at infinite dilution in a log u-log ε graph), to terminal velocity u_t ratio using:

$$\frac{n}{4.65} = \left(\frac{u_t'}{u_t}\right)^{0.132} \tag{3}$$

The first correlation can be used to predict n from the cohesiveness of the powder and the second gives u_t' once n is known and u_t is calculated from the Stokes equation.

A review has been recently made by Seville (2004) of the causes, magnitudes and effects of cohesive forces between spherical particles in a fluidized bed. In a fluidization state, with gravity force balanced by drag force, the effect of small inter-particle forces, such as van der Waals (natural effect), liquid bridge (due to the presence of surface liquid) and sintering forces (due to migration of particles to a region of contact) may become noticeable. Different fluidization characteristics are related to the effect or magnitude of cohesive forces considered in turn, e.g., the B to A transition ascribed to van der Waals forces, or the gradual de-fluidization observed through artificially enhanced cohesive effects.

Fluidization of cohesive powders can be achieved using various techniques, as suggested by Geldart (1986) and experimented by some authors (e.g., Alavi *et al.*, 2004; Zhou and Li, 1999). These include mechanically stirred fluidization, vibrated fluidization and fluidization by adding a fluidizable powder. In the work reported here, a cohesive powder is studied in relation to the development of a novel, waste treatment process.

Correspondence to: Professor S. J. R. Simons, Centre for CO_2 Technology, Department of Chemical Engineering, University College London, Torrington Place, London WC1E 7JE, UK.
E-mail: stefaan.simons@ucl.ac.uk

Accelerated Carbonation of Fly Ash from Municipal Solid Waste (MSW) Incineration

Accelerated carbonation (AC) is a controlled and accelerated version of the natural carbonation that affects calcium and magnesium based materials on exposure to atmospheric carbon dioxide (Hills, 1999). It is a technique of emerging interest in the field of waste management and contaminated land remediation as described in Fernandez *et al.* (2004), together with the first results from the AC reaction of fly ash in a batch reactor.

The fly ash employed in this process is technically known as air pollution control (APC) residue. APC residue is a mixture of fine products from combustion of MSW carried in the flue gases and the materials resulting from the flue gas clean-up process, primarily composed of lime and activated carbon.

The particulate nature of the material and the physics and thermodynamics of the reaction have led to the suggestion of carrying out the carbonation reaction of APC residue in a fluidized bed reactor, provided that the material properties are compatible.

APC residue is a cohesive powder and does not fluidize on its own. The ash is made up of deformable, irregularly-shaped fragments and it is likely that interlocking has to be taken into account together with the other inter-particle forces previously mentioned when describing the system.

The first issues to address when dealing with the above system are the possibility to achieve satisfactory fluidization of the powder and, in such a case, the prediction of the behaviour of the system, for example in terms of its expansion during the fluidization.

Gas Fluidized Binary Solid Systems

Gas fluidized binary solid systems have been broadly investigated, especially regarding segregation and mixing of their components (see, e.g., Gibilaro and Rowe, 1974; Nienow *et al.*, 1987). Here a method is suggested to extend our capability to predict the homogeneous expansion of a specific binary solid system and the like.

The well known Richardson and Zaki correlation (1) has been developed to describe the homogeneous expansion of liquid–solid systems and has subsequently been applied to gas–solid systems (Godard and Richardson, 1968; Foscolo *et al.*, 1987). Several other correlations have been proposed since to improve or generalize the correlation, such as, for example, by Hirata and Bulos (1990), who developed an explicit expression for the bed voidage, correlating data from 51 experimental runs, and Wen and Fan (1974), who wrote an empirical correlation in terms of particle Reynolds number and particle Galileo number applicable from the onset of fluidization to the dilute phase.

Lockett and Alhabboo (1974) investigated the effect of density on the relative settling velocity of two particle fractions. They extended equation (1) to liquid fluidized multiparticle systems, correcting the calculated terminal velocity with the particle concentration. They applied this model to the prediction of boundaries settling in batch sedimentation. The expansion characteristic of binary solid systems has been further investigated by Epstein *et al.* (1981), for the two-phase (liquid–solid) case and has been extended by Jean and Fan (1986), to the case of three-phase systems. Epstein *et al.* (1981) also demonstrated that the relative velocity approach is not correct.

A simple approach, based on the Epstein observation (Epstein and Leclair, 1985), has been recently proposed by Asif (1998). The Richardson and Zaki correlation is extended to liquid fluidized binary solid systems, calculating the average density and particle diameter to use in the correlations. The method of calculating the average density comes from hydrodynamic considerations:

$$\bar{\rho}_s = x_1\rho_1 + (1 - x_1)\rho_2 \tag{4}$$

The mean diameter used is the surface-volume mean diameter:

$$\bar{d} = \frac{1}{x_1/d_1 + (1 - x_1)/d_2} \tag{5}$$

Mean values of u_t and n are predicted using the Khan and Richardson (1990) correlation, chosen because of its simplicity, since it avoids the prior calculation of $\overline{Re}_t$. [A review of different correlations to evaluate the parameters of the Richardson and Zaki correlation is included in Di Felice (1995)]. The Khan and Richardson correlation is rewritten in equations (6)–(9) using the average density and particle diameter calculated in equations (4) and (5).

$$u - \bar{u}_t\varepsilon^{\bar{n}} = 0 \tag{6}$$

$$\overline{Re}_t = (2.33\overline{Ga}^{0.018} - 1.53\overline{Ga}^{-0.016})^{13.3} \tag{7}$$

$$\frac{4.8 - \bar{n}}{\bar{n} - 2.4} = 0.043\overline{Ga}^{0.57} \tag{8}$$

$$\overline{Ga} = \left(\frac{(\bar{\rho}_s - \rho_f)\rho_f \cdot \bar{d}^3 \cdot g}{\mu^2}\right), \quad \overline{Re}_t = \left(\frac{u_t \cdot \rho_f \bar{d}}{\mu}\right) \tag{9}$$

The model has been successfully applied to the prediction of the layer inversion phenomenon of the liquid fluidization of binary solid mixtures by Asif (1998).

Larger values of n than values predicted by Richardson and Zaki are reported in the literature (Mogan and Taylor, 1971; Lettieri *et al.*, 2002), for fine solid systems. Capes (1974) used (1) with an 'effective' bed voidage ε_e higher than the 'apparent' bed voidage ε_a measured experimentally to take into account the effect of agglomeration within the system. ε_e is defined in equation (10), where K has the physical meaning of volume of aggregates per unit volume of solid.

$$K = \frac{1 - \varepsilon_e}{1 - \varepsilon_a} \tag{10}$$

This assumption also determines a reduction in the value of n.

MATERIALS AND METHODS

Sand (Group B) was tested as the carrier solid to fluidize the system, but because of the high difference in density with APC particles the system resulted in segregation. Fluidization of APC residue has been achieved with the use of a fluidizable powder [a group A powder, namely fluid cracking catalyst (FCC)], which has already been