LETTERS TO THE EDITOR

To the Editor:

Weimer and Quarderer (1985) report no change in dense phase voidage when their coarsest powder ($\bar{d}_p = 171\ \mu m$) was fluidized by gas at pressures up to 83 bar. This is surprising because the theory of Foscolo and Gibilaro (1984) clearly predicts a transition from Group B to Group A powder behavior with increasing pressure (strictly, increasing gas density) a fact clearly seen with even larger particles ($\bar{d}_p = 450\ \mu m$) at quite modest pressures (Rowe et al., 1983). With this powder at pressure in excess of 80 bar, X-ray photographs show that the bubble structure is lost and the whole appears as a "turbulent emulsion," again in accordance with prediction.

In contrast, the change in voidage with the finest powder ($\bar{d}_p = 66\ \mu m$) is greater than previously reported with roughly similar powder at pressures up to 20 bar (Rowe et al., 1982), and this may be a consequence of the experimental technique used. Readers are not told the volume of the wind box below the porous distribution plate in Weimer and Quarderer's apparatus, but this must always be at higher pressure than that above the bed. When the bed is isolated to measure its rate of collapse, gas flow must continue until pressure is equalized. This can alter the rate of fall of bed height by as much as a factor of two (Rowe et al., 1986) leading to a false estimate of initial dense phase voidage. The error of course, diminishes with increasing pressure but is confounded with the true change of steady state voidage with pressure. This would result in a low voidage at atmospheric pressure as is suggested by Weimer and Quarderer's Figure 4.

The rate of fall of bed surface for the finest powder at 41.4 bar was found to be 13.6 mm/s. According to experimentally confirmed theory (Didwania and Homsy, 1980 and 1981) this should be equal to minimum bubbling velocity, U_{mb}, which, using the relationship between voidage and interstitial fluid velocity (Richardson and Zaki, 1954) and the reported values for voidage, is expected to be about 9 mm/s. The error resulting from pressure equilization referred to above would lead to a slower rate of fall while the observed rate is faster than expected. This could arise if the reported voidages were larger than their true values.

The absolute values of voidage for the finest powder at all pressures appear rather high. The reported density suggests that the particles are porous but we are not told how their density was measured. Pycnometric methods can give misleading results (Knight et al., 1980; Knight and Rowe, 1980) and an error in particle density leads to a calibration error in all subsequent estimates of voidage. If the true particle density is less than reported, all voidages would be reduced.

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Reply:

I appreciate the interest Professor Rowe has shown in results from the high pressure collapsed bed experiments reported by Weimer and Quarderer (1985). These data are truly unique for they have resulted from measurements made in an industrial, pilot scale, fluidized bed operating at pressures to $P = 8{,}300$ kPa. All previously reported collapsed bed experiments have been performed in either smaller diameter beds or two-dimensional beds and at pressures equivalent to or below $P = 2{,}200$ kPa. In view of the lack of high pressure data available, I am somewhat dismayed by Professor Rowe's contention that these data can be predicted so accurately. In fact, the reason such a fundamental investigation was carried out in an industrial environment, was the lack of confidence in predicting fluidization behavior at such high pressures.

The bed/plenum pressure equalization time, to which Professor Rowe refers, was negligible during the collapsed bed experiments. This resulted from the combination of a small plenum volume and a small distributor pressure drop. The plenum section was designed for a minimum gas volume, which totalled $V_p = 6.3 \times 10^{-4}$ m^3. On the other hand, the average bed gas volume during the 66 μm particle collapsed bed experiments was $V_B = 2.7 \times 10^{-2}$ m^3. Hence, the plenum gas volume was approximately 2% of the gas volume above the distributor. For a superficial gas velocity of $u_o = 5 \times 10^{-2}$ m/s, typical of the steady state gas velocity before bed enclosure, the pressure drop across the porous distributor was approximately 3 kPa. It is inconceivable that the pressure equalization time for this system could have significantly affected the accuracy of the collapsed bed experiments. Furthermore, the instantaneous solenoid ball valves, utilized for enclosing the reactor at pressure, were tested at the highest pressures and found to be gas tight. They ensured complete shut off of pressurized feed gas during the collapsed bed experiments.

Recently published results (Piepers et al., 1984), not cited by Professor Rowe, support the substantial effect of pressure on dense phase voidage, ϵ_D, for the 66 μm powder reported by Weimer and Quarderer (1985). As shown in Figure 4 (Weimer and Quarderer, 1985), dense phase voidage, ϵ_D, increased 23% from $\epsilon_D = 0.53$ at a gas density of $\rho_g = 1.7$ kg/m^3 to $\epsilon_D = 0.65$ at $\rho_g = 15.2$ kg/m^3 for the 66 μm powder ($\rho_p = 850$ kg/m^3). Recently, Piepers et al. (1984) found ϵ_D to increase 15% from $\epsilon_D = 0.52$ at $\rho_g = 1.7$ kg/m^3 to $\epsilon_D = 0.60$ at $\rho_g = 15.0$ kg/m^3 and to increase 21% to $\epsilon_D = 0.63$ at $\rho_g = 24.9$ kg/m^3 for a 59 μm powder ($\rho_p = 887$ kg/m^3). Although the gas density effect is consistent with that reported by Weimer and Quarderer (1985) for a similar powder, it is far greater than the approximate 2 to 3% voidage increase (ϵ_{mb} increased from $\epsilon_{mb} = 0.615$ at $\rho_g = 5.7$ kg/m^3 to $\epsilon_{mb} = 0.63$ at $\rho_g = 25.9$ kg/m^3) for a 70 μm powder ($\rho_p = 819$ kg/m^3) reported by Rowe et al. (1982). Also, contrary to Professor Rowe's contention that the atmospheric ϵ_D appears too low, the value reported by Weimer and Quarderer (1985) for the 66 μm powder ($\epsilon_D = 0.53$) is almost identical to that reported by Piepers et al. (1984) for a similar powder ($\epsilon_D = 0.52$).

The measured bed surface collapse rate of $u_{Do} = 0.0136$ m/s presented in Figure 3 by Weimer and Quarderer (1985) and the minimum bubbling velocity, $u_{mb} = 0.009$ m/s, calculated by Professor Rowe, are both within an unstable region where bubbles begin to form (Jacob and Weimer, 1986) at the $P = 4{,}140$ kPa pressure. Within this gas velocity region the expanded bed height decreases with increasing gas velocity. In light of the fact that previous investigators (Guedes de Carvalho, 1981; Abrahamsen and Geldart, 1980) have reported different experimental values for dense phase and minimum bubbling properties, it is understandable that u_{Do} measured via the bed collapse rate may not be the same as u_{mb}.

It is unlikely that the particle density reported by Weimer and Quarderer (1985) is in error. All powders (66, 108, and 171 μm) were granular, porous, activated carbon powders in which the particle density was reported by the vendor as $\rho_p = 850$ kg/m^3, determined by Hg displacement. Since the pycnometric measurement was made on a powder lot having an average particle size exceeding 500 μm, it is inconceivable that the density measurement was incorrect. Pore size for these powders was such that particle density for the ground and screened 66 μm particles should not have differed from the lot particle density.

The "essentially no pressure effect," reported by Weimer and Quarderer (1985) for the 171 μm powder (for gas density to $\rho_g = 44.2$ kg/m^3), is supported by previously reported experiments (King and Harrison, 1980, 1982; Sobreiro and Monteiro, 1982). Weimer and Quarderer (1985) report that dense phase voidage, ϵ_D, is "essentially" identical to the minimum fluidization voidage, ϵ_{mf}, measured at each pressure. Sobreiro and Monteiro (1982) investigated the fluidization of 125 μm ballotini, alumina, and pyrrhotite particles with N_2 in the pressure range 100 kPa ($\rho_g = 1.2$ kg/m^3) < P < 3,500 kPa ($\rho_g = 40.8$ kg/m^3). For all cases, they reported essentially identical experimental values for ϵ_{mf} and ϵ_{mb}, indicating a negligible pressure effect (to $\rho_g = 40.8$ kg/m^3) for the 125 μm particles. King and Harrison (1980, 1982) investigated a wide size range of ballotini powders and concluded that the fluidization of powders of diameter $d_p > 100$ μm is insensitive to pressure for pressures to $P = 2{,}500$ kPa ($\rho_g = 29.1$ kg/m^3). For these Group B powders, u_{mf} was coincident with u_{mb} and decreased with increasing pressure while ϵ_{mf} was coincident with ϵ_{mb} and was unaffected by pressure. These results are consistent with those shown in Figures 4 and 5 (Weimer and Quarderer, 1985) for the 171 μm powder.

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