Normal Bubbling of Fine Carbon Powders in High-Pressure Fluidized Beds

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Fluidized beds of Geldart group A powders (Geldart, 1973) expand particulately for limited superficial gas velocities, u_o, above the minimum fluidization velocity, u_{mf}. As bubbling commences at the minimum bubbling velocity, u_{mB}, the overall bed voidage, ϵ, decreases because the volume of the dense phase, δ_D, in the bubbling bed is reduced more rapidly than the bubble holdup, δ_B, increases. This region of decreasing ϵ is an unstable bubbling region that is characterized by periodic fluctuations in bed height, L_f. A continued increase in u_o results in an increasing δ_B and, hence, an increasing ϵ. This region of increasing ϵ is characterized by stable, or normal, bubbling. The critical velocity and voidage at which normal bubbling commences are termed the normal bubbling velocity, u_N, and normal bubbling voidage, ϵ_N, and are determined from the intersection of best fit straight lines representing the unstable and stable bubbling regions on a log u_o vs. log ϵ plot (Jacob and Weimer, 1987).

Few data are available that quantify the normal bubbling conditions for group A powders fluidized at high pressure. Such data are of fundamental interest.

Experimental Apparatus and Measurements

The effect of high pressure (to P = 12,420 kPa) on particulate expansion and minimum bubbling for 44 and 112 μm carbon powders fluidized by a synthesis gas mixture was investigated in previous work (Jacob and Weimer, 1987). In this work, normal bubbling velocity, u_N, and normal bubbling voidage, ϵ_N, are determined from analyses of bed expansion measurements carried out at higher u_o, but otherwise identical conditions as those reported earlier. Measurements of relative localized fluctuations in bed density (Weimer and Jacob, 1986) are also reported. All measurements were made by means of a nonintrusive rapid-response nuclear radiation density gauge (Weimer et al., 1985). Physical properties of the powder and gas and a description of the experimental apparatus have been reported previously (Jacob and Weimer, 1987).

Results and Discussion

Bed expansion measurements

Overall bed voidage, ϵ, as a function of u_o and P is shown in Figures 1a and 1b for the 112 and 44 μm powders, respectively. Logarithmic plots of these data are given in Figures 2a and 2b. The normal bubbling velocity, u_N, generally decreases and approaches u_{mB} with increasing P for both powders. Likewise, the normal bubbling voidage, ϵ_N, generally increases and approaches ϵ_{mB} with increasing P for both powders. Hence, the magnitude of the unstable bubbling region (i.e., between u_{mB} and u_N) decreases with increasing P.

It can be seen from Figures 1a and 1b that the rate at which the bubbling fluidized bed expands with u_o for velocities $u_o > u_N$ increases with increasing P due to the formation of smaller and more slowly rising bubbles at higher P. Decreasing bubble size with increasing P results in an increasing bubble holdup rate and, hence, an increasing rate of expansion with u_o for higher P.

The experimentally determined u_N and ϵ_N are summarized in Table 1.

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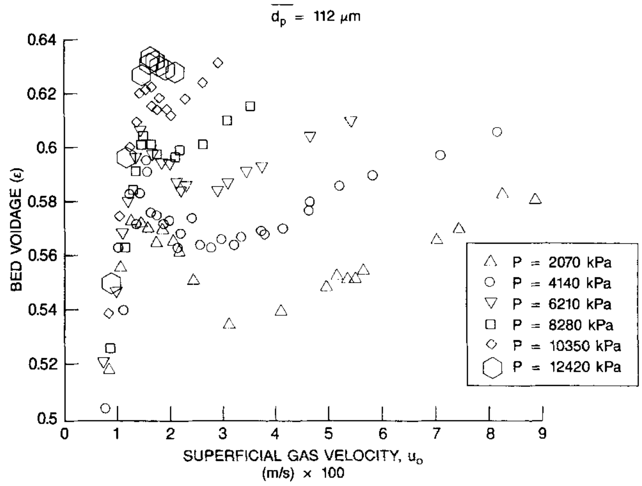

Figure 1a. Effect of pressure and gas velocity on bed voidage, d_p = 112 μm.

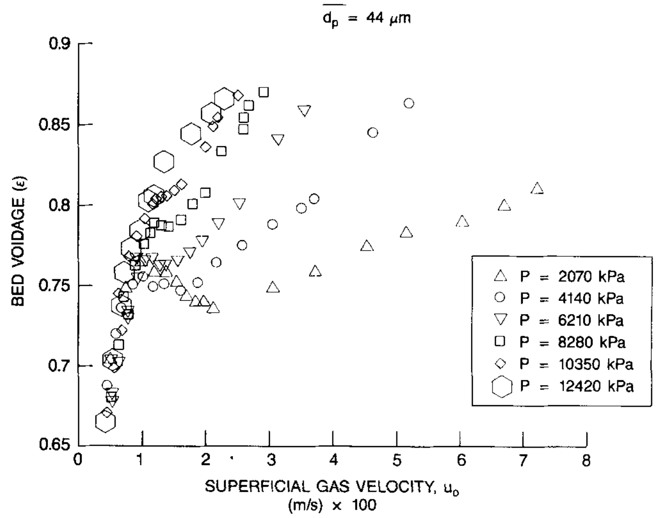

Figure 1b. Effect of pressure and gas velocity on bed voidage, d_p = 44 μm.

It appears from the results shown in Figure 2b that ϵ_N exceeds ϵ_{mB} for the 44 μm powder at P = 10,350 kPa. Under these conditions the appearance of the first bubble is not accompanied by a decrease in bed voidage (Jacob and Weimer, 1987).

It is not clear from these limited data where normal bubbling commences for either powder at P = 12,420 kPa.

Relative localized bed density fluctuations

Relative localized fluctuations in bed density at z = 1.2 m above the gas distributor are quantified by calculating the ratio of the standard deviation of the instantaneous density measurement to the time-averaged density measurement, $\sigma[\rho_{Bed}]_c/[\rho_{Bed}]_c^t$, as described previously (Weimer and Jacob, 1986). Since fluctuations in bed density are indicative of gas bubbles, the results shown in Figure 3a indicate that bubbles are generally smaller at higher P for the 112 μm powder and are always smaller for the finer 44 μm powder at equivalent P, Figure 3b. These findings are in agreement with results previously reported

Table 1. Experimental Normal Bubbling Measurements

Mean Particle Dia. $\bar{d}_p$ μm	Press., P kPa	u_N *m/s × 100*	ϵ_N
44	2,070	2.26	0.735
44	4,140	1.87	0.746
44	6,210	1.60	0.760
44	8,280	1.60	0.785
44	10,350	1.62	0.813
44	12,420	—	—
112	2,070	3.57	0.536
112	4,140	2.98	0.561
112	6,210	2.57	0.579
112	8,280	1.92	0.593
112	10,350	1.98	0.611
112	12,420	—	—

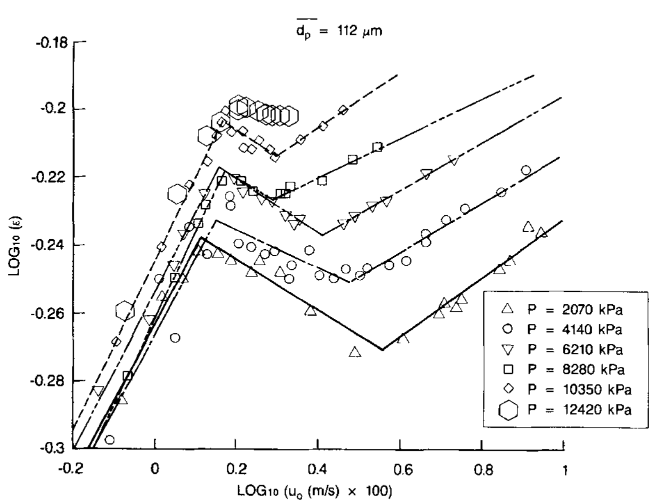

Figure 2a. Log plot of gas velocity vs. bed voidage for data of Figure 1a, d_p = 112 μm.

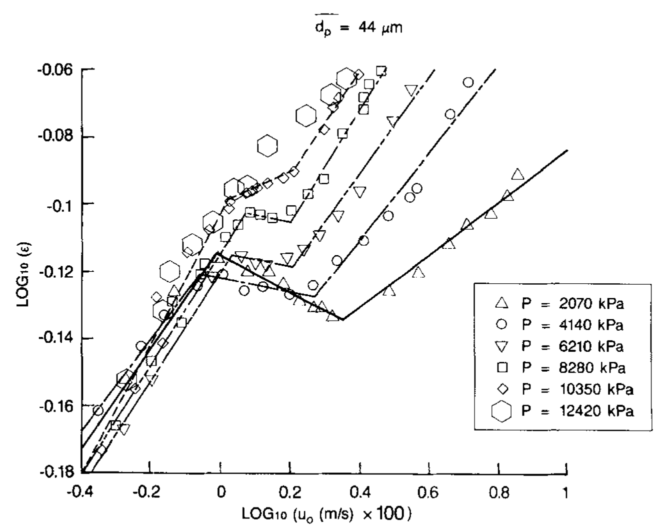

Figure 2b. Log plot of gas velocity vs. bed voidage for data of Figure 1b, d_p = 44 μm.

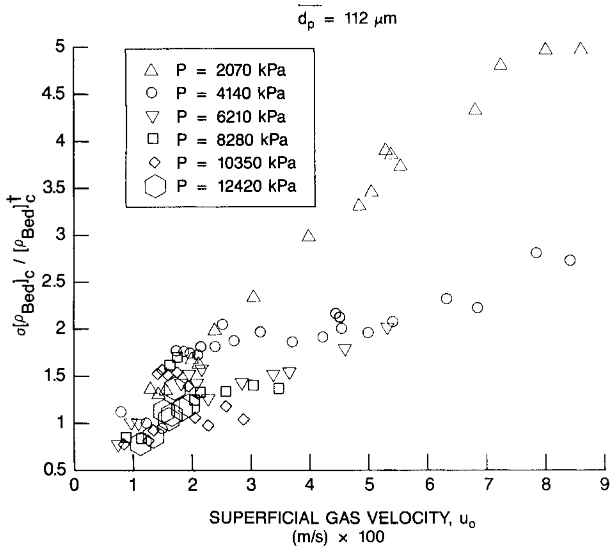

Figure 3a. Effect of pressure and gas velocity on relative localized bed density fluctuations,
$z = 1.2$ m; $d_p = 112\ \mu$m

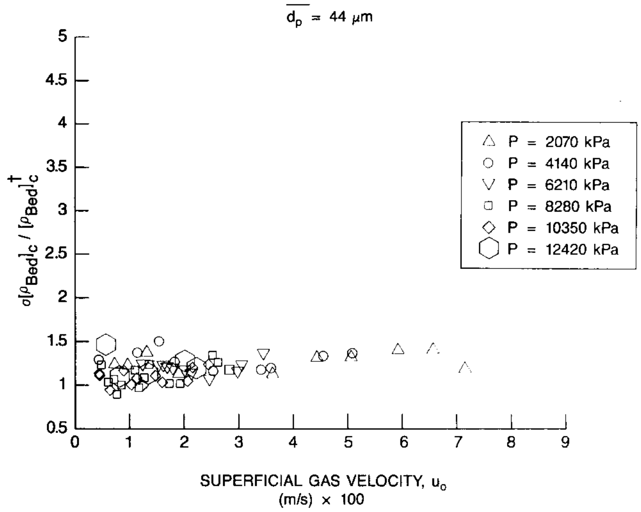

Figure 3b. Effect of pressure and gas velocity on relative localized bed density fluctuations,
$z = 1.2$ m; $d_p = 44\ \mu$m

(Weimer and Quarderer, 1985) from cross-correlations of fluctuating differential pressure measurements for similar carbon powders fluidized over a smaller pressure range.

Notation

$\overline{d}_p$ = mean particle diameter
L_f = expanded bed height
P = pressure
u_o = superficial gas velocity
u_{mB} = minimum bubbling velocity
u_{mf} = minimum fluidization velocity
u_N = normal bubbling velocity

Greek letters

δ_B = bubble phase volume fraction
δ_D = dense phase volume fraction
ϵ = overall bed voidage
ϵ_N = normal bubbling voidage
ϵ_{mB} = bed voidage at minimum bubbling
$[\rho_{Bed}]_c$ = cross-sectional centerline instantaneous bed density
$[\rho_{Bed}]_c^t$ = time-averaged cross-sectional centerline bed density
$\sigma[\rho_{Bed}]_c$ = standard deviation of instantaneous bed density

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