To the Editor:

A recent article by Briens et al. on "Minimum Liquid Fluidization Velocity in Gas-Liquid-Solid Fluidized Beds" (AIChE J., May 1997) defines the minimum fluidization condition as one in which particle motion starts to become continuous (or smooth) rather than intermittent (or jerky). Others define it as the point at which particle motion, whether intermittent or continuous, starts, provided that Eq. 4 of Briens et al. applies

$$-\Delta P/\Delta z = \rho_{bed} g = (\rho_L \epsilon_L + \rho_p \epsilon_s) g \quad (4)$$

The preferred definition depends on the purpose to which the bed is to be put. If, for example, good particle mixing is desired, then the Briens definition is preferable. If, on the other hand, close contact between the particles is desired but with some particle mobility, as when the particles act as an extended electrode in an electrochemical application, then the more conventional definition is preferable (referred to by Briens et al. as the minimum agitation condition).

In their Table 1, Briens et al. have listed the contribution of Zhang et al. (1995), but have not included their recommended gas-perturbed liquid model, Eq. 11 in that article

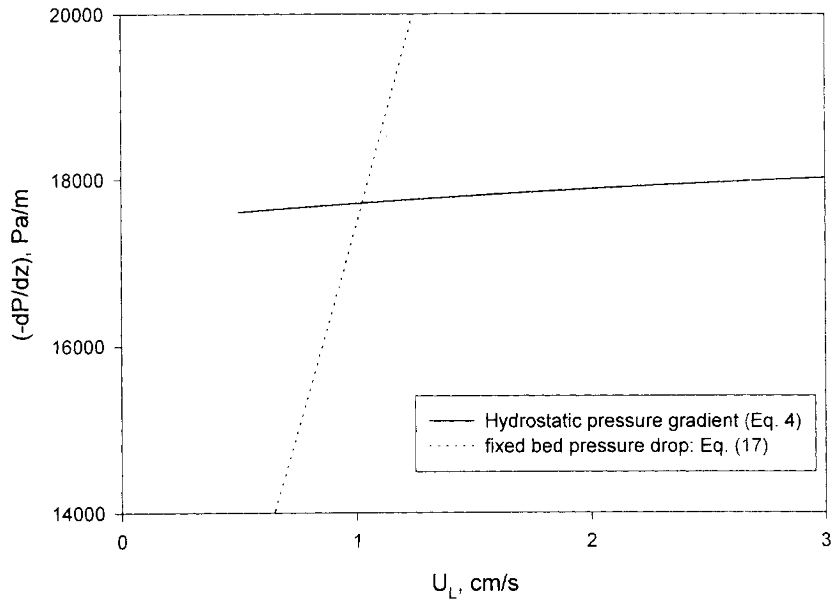

Figure 2. Comparison of the pressure gradient when the bed is fluidized (Eq. 4) with the pressure gradient of the fixed bed (Eq. 17), using ϵ = 0.36 and α from Yang's correlation.

$$U_{Lmf} d_p \rho_L/\mu_L = \sqrt{[42.86(1-\epsilon_{mf})/\phi]^2 + 0.5715\phi\epsilon_{mf}^3(1-\alpha_{mf})^3 Ar} - 42.86(1-\epsilon_{mf})\phi \quad (11)$$

where $\alpha_{mf} = \epsilon_g/\epsilon_{mf}$ and all the other terms are as defined by Briens et al. As recommended by Zhang et al., Eq. 11 should be solved iteratively with

$$\alpha_{mf} = 0.16 U_g / [\epsilon_{mf}(U_g + U_{Lmf})] \quad (11a)$$

to arrive at U_{Lmf}.

From Figure 16 of Briens et al. at U_g = 6 cm/s, U_{Lmf} = 2.0 cm/s (experimentally). From Figures 4 and 5, at U_g = 6 cm/s and U_L = 2.0 cm/s, $\epsilon = \epsilon_g + \epsilon_L = 0.145 + 0.285 = 0.43 = \epsilon_{mf}$. For the conditions of the authors' experiments, Ar = 490,310 and ϕ = 1.0. Solving Eqs. 11 and 11a above iteratively for U_{Lmf}, the result is U_{Lmf} = 2.1 cm/s, which agrees well with the experimental U_{Lmf} = 2.0 cm/s of Figure 16. (If α_{mf} for use in Eq. 11 is obtained from ϵ_g of Figure 4 and ϵ_L of Figure 5, instead of from Eq. 11a above, then Eq. 11 can be solved for U_{Lmf} without iteration, leading to a prediction of U_{Lmf} = 1.8 cm/s.)

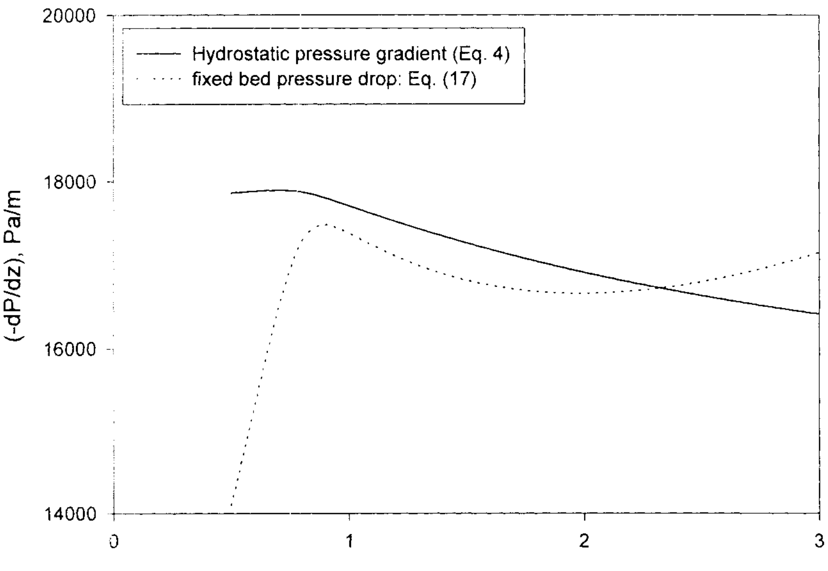

Figure 1. Comparison of the pressure gradient when the bed is fluidized (Eq. 4) with the pressure gradient of the fixed bed (Eq. 17), using the measured ϵ and α from Yang's correlation.

Similarly, from Figure 16 of Briens et al., at $U_g = 6$ cm/s, $U_{Lma} = 1.0$ cm/s (experimentally). From Figures 4 and 5, at $U_g = 6$ cm/s and $U_L = 1.0$ cm/s, $\epsilon = \epsilon_g + \epsilon_L = 0.143 + 0.217 = 0.36 = \epsilon_{ma}$. Again $Ar = 490{,}310$ and $\phi = 1.0$. Solving Eqs. 11 and 11a above iteratively for U_{Lma} (after replacing the subscript *mf*, denoting minimum fluidization, by the subscript *ma*, denoting minimum agitation, throughout the two equations), the result is $U_{Lma} = 1.04$ cm/s, which agrees well with the experimental $U_{Lma} = 1.0$ cm/s of Figure 16. (If α_{ma} for use in Eq. 11 is obtained from ϵ_g of Figure 4 and ϵ_L of Figure 5, instead of from Eq. 11a above, the prediction is $U_{Lma} = 0.96$ cm/s.)

Thus, the Gas-Perturbed Liquid Model (Eqs. 11 and 11a) can predict both U_{Lma} and U_{Lmf} if the correct values of ϵ_{ma} and ϵ_{mf} are used in this model. This is no doubt aided by the fact that Eq. 4 is valid for both the "agitated bed" and the subsequent fluidized bed regimes.

Literature cited

Zhang, J. P., N. Epstein, J. R. Grace, and J. Zhu, "Minimum Fluidization Velocity of Gas-Liquid Fluidized Beds," Trans. IChemE, 73(A), 347 (1995).

Norman Epstein
John R. Grace
Junping Zhang
Dept. of Chemical Engineering
University of British Columbia
Vancouver, BC V6T 1Z4, Canada

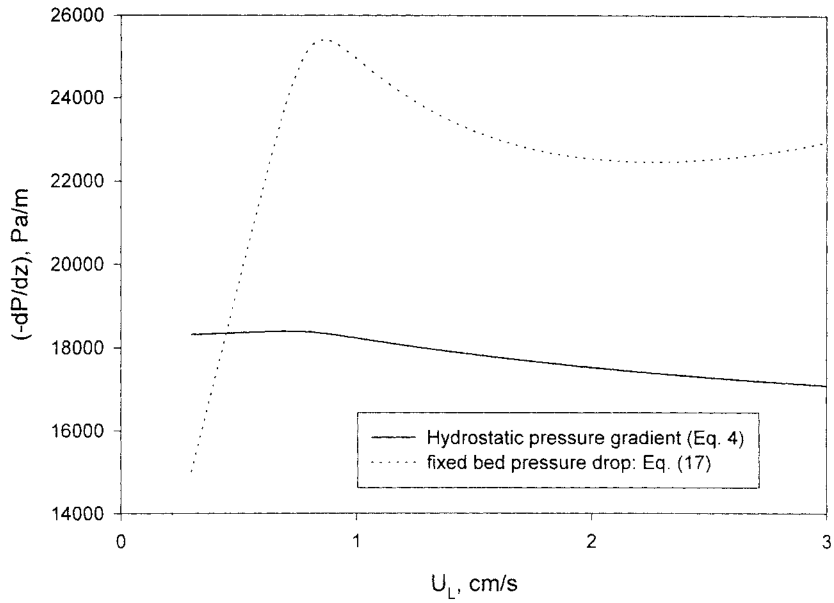

Figure 3. Comparison of the pressure gradient when the bed is fluidized (Eq. 4) with the pressure gradient of the fixed bed (Eq. 17), using ϵ equal to 90% of its measured value and α from Yang's correlation.

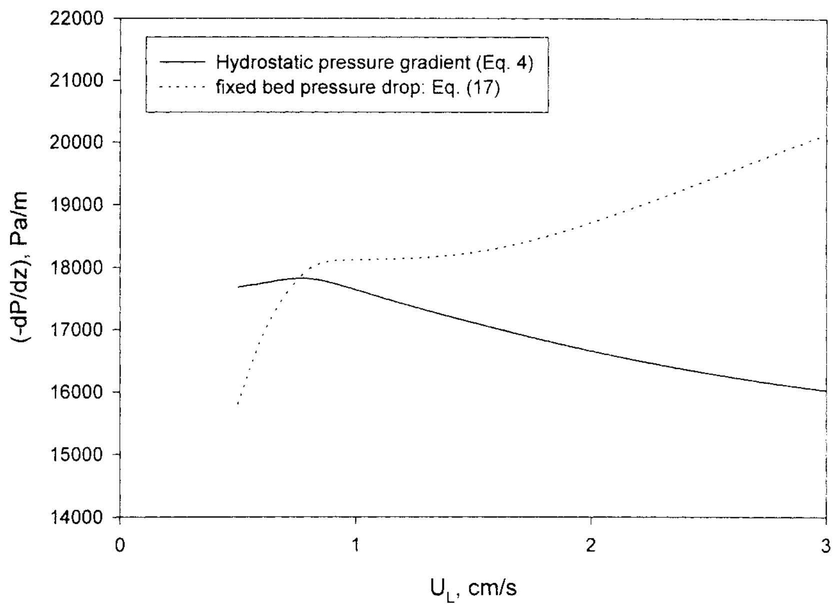

Figure 4. Comparison of the pressure gradient when the bed is fluidized (Eq. 4) with the pressure gradient of the fixed bed (Eq. 17), using the measured ϵ and α calculated from the measured values of ϵ_g and ϵ_L.

Reply:

We appreciate the interest and comments from Epstein et al. on our article. We agree with him that the regime which we identified and named "agitated bed" regime has unique properties and may make it attractive in some applications. Epstein et al. agree with us that for a bed to be fluidized, Eq. 4 should be verified:

$$-\frac{\Delta P}{\Delta z} = \rho_{\text{bed}}\, g = (\rho_L \epsilon_L + \rho_s \epsilon_s) g \quad (4)$$

They applied to our experimental data the gas-perturbed liquid model which Zhang et al. (1995) derived to predict the minimum fluidization velocity in gas-liquid-solid fluidized beds (Eq. 11 of their letter). Using the bed voidage (ϵ) of 0.36 which we measured at the transition from fixed to agitated bed regimes ($U_{Lma} = 1$ cm/s), this equation gives a minimum fluidization velocity of 1 cm/s. Epstein et al. therefore conclude that the bed was fluidized at $U_{Lma} = 1$ cm/s.

On the other hand, our direct measurements indicate that at $U_{Lma} = 1$ cm/s, the bed pressure drop was only about 95% of what it should have been if the bed had been fluidized, as shown in Figure 6 of our article. There is a problem either with our measurements or the model from Zhang et al. A definite answer requires an experimental study which will measure independently, as we did, the pressure gradient and the phase holdups.

There are three problems with the model from Zhang et al.:

(1) It gives erroneous results if the variation of the bed voidage with the liquid superficial velocity is not taken into account.

(2) Its predictions are extremely sensitive to the assumed value of the bed voidage.

(3) Its predictions are extremely sensitive to minor variations in the gas holdup on a solids-free basis [$\alpha = \epsilon_g/(\epsilon_L + \epsilon_g)$].

Effect of neglecting the variation of the voidage with the liquid velocity

Zhang et al. assumed that since minimum fluidization represents the transition between fixed and fluidized regimes, the pressure gradient for a fluidized bed given by Eq. 4 is then equal to the pressure gradient for a fixed bed, which can be obtained from Eq. 17 of their article [please note a minor typographical error in this equation: $(-dP/dz)_f$ should read $(-dP/dz)$].

Figure 1 presents the variation with the superficial liquid velocity of these two pressure gradients. For this figure, α was obtained from the correlation (Eq. 11a) from Yang, which was used by Zhang et al. The voidage $\epsilon = (\epsilon_L + \epsilon_g)$ for each velocity was obtained from our experimental data at $U_g = 6$ cm/s (see Figures 4 and 5 of our article). In our experiments, the voidage varied with the liquid velocity (from 0.36 at $U_L = 1$ cm/s to 0.43 at $U_L = 2$ cm/s). Figure 1 shows that the two pressure gradients were only equal for $U_L = 2.3$ cm/s. In Figure 2, the bed voidage was assumed to be independent of the liquid velocity and equal to 0.36, the value measured at $U_L = 1$ cm/s. In this case, the two pressure gradients are equal at $U_L = 1.05$ cm/s, as calculated by Epstein et al. The difference results from the great sensitivity of the model predictions to the assumed value of the bed voidage.

Effect on the predicted value of the minimum fluidization velocity of the assumed value of the bed voidage

Figure 3 shows how sensitive the model is to minor variations in the bed voidage ϵ. Its results were obtained as for Figure 1 with a bed voidage of 90% of the measured value. This reduction corresponds to the difference between the voidage which we measured at minimum fluidization (0.43) and the voidage measured by Zhang et al. (0.39). At present, even for a system as well known as the air, water, and monosize, spherical glass beads, one cannot predict whether the voidage at minimum fluidization will be 0.39 or 0.43. Figure 3 shows that the predicted minimum fluidization velocity would then be 0.5 cm/s instead of 2.3 cm/s as in Figure 1.

Effect on the predicted value of the minimum fluidization velocity of minor variations in α, the gas holdup on a solids-free basis

Figure 4 presents the same plots as in Figure 1 when calculated with α obtained from the measured values of ϵ_g and ϵ_L. It indicates a minimum fluidization velocity of 0.75 cm/s. This demonstrates how sensitive the model from Zhang et al. is to minor variations in this parameter, which cannot be easily measured in an industrial column.

The gas-perturbed liquid model from Zhang et al. demonstrates the difficulty of predicting the minimum fluidization velocity from the physical properties of the gas, liquid and solid phases. There is at present no substitute for the direct measurement of the minimum fluidization velocity.

Lauren A. Briens
Cedric L. Briens
J. Hay
A. Margaritis
Dept. of Chemical and
Biochemical Engineering
University of Western Ontario
London, Ont. N6A 5B9, Canada