LETTERS TO THE EDITOR

To the Editor:

In modelling the combustion of coal volatiles in a fluidized bed, Bywater and Chung (1983) have made certain assumptions about the values of the controlling parameters. Their assumptions of $u_g \sim 1$ m/s, $u_s/u_g = 0.1$, $D_g \sim 1$ cm²/s and $\hat{D} \sim 1$ imply that $D_s \sim 0.1$ cm²/s. This value for the radial dispersion coefficient of solid particles is too low for the large particles (~1 mm) used in fluidized bed combustors. From the data of Highley and Merrick (1971) and Mori and Nakamura (1965), the value of D_s for these particles should be ~100 cm²/s, so that the ratio D_s/D_g should be ~100 rather than the 0.1 assumed by Bywater and Chung. It would be interesting to see what effect changing D_s/D_g to a more realistic value would have on their results.

To explain why $D_s \gg D_g$, we need to consider the mixing processes that control the particle and gas dispersion. Particle dispersion is induced by bubbles rising through the bed, whereas the combustion of hydrocarbons is governed by molecular diffusion (Stubington and Davidson, 1981), which is much slower than the radial dispersion measured by steady-state tracer gas experiments. Such tracer experiments provide a measure of the large-scale mixing caused by plume fluctuations, whereas molecular scale mixing is required for the combustion reactions.

NOTATION

D_g = radial gas diffusion coefficient, m²/s

D_s = radial solid particle dispersion coefficient, m²/s

$$\hat{D} = \frac{D_s u_g}{D_g u_s}$$

u_g = upward gas velocity, m/s

u_s = upward solid particle velocity, m/s

LITERATURE CITED

Bywater, R. J., and P. M. Chung, "Effect of Pressure Fluctuation on Coal Combustion in Large-Particle Fluidized Beds," *AIChE J.* **29**, 396 (1983).

Highley, J., and D. Merrick, "The Effect of the Spacing Between Solid Feed Points on the Performance of a Large Fluidized Bed Reactor," *AIChe Symp. Ser.*, **67**, 219 (1971).

Mori, Y., and K. Nakamura, *Kagaku Kogaku.*, **29**, 868 (1965).

Stubington, J. F., and J. F. Davidson, "Gas-phase Combustion in Fluidized Beds," *AIChE J.* **27**, 59 (1981).

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Reply:

Three comments are in order. First, Eq. 40 and the numerical example given in the subject paper are the particular results for $\hat{D} = 1$ evaluated from the general closed-form solution, Eq. 39. Certainly, the reader is encouraged to evaluate the results for other values of $\hat{D}$ from the general solution provided. Indeed, the advantage of a closed-form solution is to enable the other investigators to readily utilize it for different conditions.

Second, the authors thank Dr. Stubington for noting that an incorrect value for D_g found its way into the numerical example and happened to be of the order of the molecular diffusion rate, rather than true gaseous turbulent transport rate, characteristic of the large-particle bed. However, the basic results and physical conclusions are unaltered since the solution is non-dimensionalized and only dimensionless ratios remain. No statement regarding the absolute value of D_s was made in the paper but rather only regarding its ratio to D_g.

Third, in regard to the ratio $D_s/D_g = 0.1$, for $\hat{D} = 1$ and $u_s/u_g = 0.1$, used in the subject publication as well as the reference to Bywater cited therein, the value used is believed to be reasonable and is supported both by arguments on turbulent mixing and by experimental data. Generally in turbulent flows, the turbulence scales with the generating mechanism, which is the bubble in this case. Since for large-particle fluidization, the gas flows interstitially and then somewhat "short-circuits" through bubbles (where bubble velocities are not vastly greater than fluidization velocity in contrast to small-particle beds), the lateral gas movement and hence turbulent length scale is similar to the solids turbulent length scale.

The turbulent diffusion coefficients scale with a turbulent velocity times a turbulent length scale. Therefore, the ratio D_s/D_g should scale with the respective turbulence generating velocities as u_s/u_g which is ≈ 0.1. As noted in the above cited reference to Bywater, $D_s/D_g \approx 0.1$ was used by private communication with T. Fitzgerald based on solids and gas tracer experiments detailed in a Ph.D. thesis from Oregon State University. One of the widely published results of those experiments by the OSU staff is that the turbulent gas diffusion coefficient ranges from 50 cm²/s to in excess of 300 cm²/s. Based on $D_s/D_g \approx 0.1$, D_s would be as high as 30 cm²/s, which is not vastly different from the value suggested by Stubington.

Unfortunately, the error in the value for D_g used in the numerical example of the paper led to some confusion which caused Stubington to inadvertently comment on a ratio of turbulent solids diffusion to molecular gas diffusion as governing the physical behavior of the combustion phenomena. This, of course, would be incorrect as we are sure that Dr. Stubington is aware. This would imply that the turbulent gaseous combustion depends only on molecular diffusion and that laminar and turbulent diffusion flames burn at the same rate, which is, of course, far from the truth.

It is true that chemical reactions occur when the reactants mix at a molecular level. However, the molecular-level mixing (turbulent dissipation) rate is governed by, and of the order of, the decay (break down) rate of the larger eddies that control the turbulent mixing. Therefore, the overall combustion rate in a *turbulent diffusion* flame is of the order of the turbulent mixing rate.

The rigorous treatment of turbulent combustion in the fluidized bed would be much more complex than what is presented in the subject paper. However, to the order of magnitude appropriate to the current understanding of turbulent structure of such beds and for the purpose of delineating the basic physics of the problem, the use of the simple turbulent diffusion coefficients, D_s and D_g, is adequate.

The authors have published a number of fundamental papers on turbulent combustion including some of the first work that identified the complex turbulent-chemical coupling, which occurs in diffusion flames as discussed above. A few of those papers listed below are recommended for a more detailed description of the basic physics of turbulent combustion, which was only briefly discussed in this letter.

The authors thank Dr. Stubington for this opportunity to clear up some of the more elusive features of turbulent combustion in large-particle fluidized beds.

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