NUMBER 44
OCTOBER 29, 1979

This Week's Citation Classic

Levenspiel O & Smith W K. Notes on the diffusion-type model for the longitudinal mixing of fluids in flow. *Chem. Eng. Sci.* **6**:227-33, 1957. [Bucknell University, Lewisburg, PA]

Turbulence, velocity gradients, and molecular diffusion —all these cause material to move at different speeds in a flowing stream. The overall effect of these factors can be accounted for by a single quantity, a sort of diffusion coefficient. This paper shows how to find this coefficient by a pulse tracer experiment. [The *SCI*® indicates that this paper has been cited over 150 times since 1961.]

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June 22, 1979

"The ideas for this paper came in the middle 50s, before Sputnik, and it represented my first timid exploration into research beyond what I learned in my formal studies. I was at a small undergraduate university which encouraged library browsing, and the idea for this paper came from my casual readings of the *Proceedings of the Royal Society.* I doubt if a young teacher today would have the time to 'waste' on this sort of nonpurposeful reading, what with the pressure to publish and bring in research money.

"The paper itself is quite simple and it asks the following question: If you introduce a perfect pulse of tracer into a flowing stream such as a river, a pipe, or a blood vessel what would be the shape of the tracer curve as it passes a point far downstream? My mathematician neighbor Bill Smith helped me answer this question. In essence, our paper gave equations for both the shape and spread of the output curve in terms of a *longitudinal dispersion coefficient,* a quantity which characterizes the extent of mixing which occurs during flow

"Why should so simple a paper be widely referred to? First, because it was useful for experimenters in many fields It suggested the type of experiment to do, and how to interpret the results in terms of a simple model.

"Second, there is a curious feature to this experiment and model which turns out to be a veritable Pandora's box. Let me explain. The shape of your calculated output curve depends on how you visualize your experiment; in effect, your choice of boundary conditions. For example, there is a subtle but definite distinction between *injecting* a perfect pulse of tracer and *seeing* a perfect pulse in time at the point of injection. In addition, what happens just upstream and downstream of the experimental section, and how you, measure the tracer curve, also influence the shape of the calculated tracer curve. One can imaging the dozens upon dozens of combinations of boundary conditions that can be selected.

"Soon others extended our paper. Lack of awareness and confusion over boundary conditions saw frequent claims that earlier workers had done it all wrong, when in fact the trouble was an unknowing choice of different premises. This led to chaos in the field. For a discussion of the proper boundary conditions see *Chemical Reactor Om-nibook.*[1] But even more distressing, papers appeared which used mathematically attractive but physically absurd boundary conditions.

"Looking back, this discussion seems to suggest one likely way of developing a 'Citation Classic.' When you write a paper do not solve everything completely. Leave something for others to complete or extend or get confused about."

1. **Levenspiel O.** *Chemical reactor omnibook.* Corvallis, OR: OSU Book Stores, 1979. 672 p.