COMMUNICATIONS TO THE EDITOR

Detector Effects in Packed Bed Measurements

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The mixing and mass transfer characteristics of packed beds have been the subject of many studies. Chung and Wen (*4*) provided an excellent review of studies involving many different kinds of experimental systems. The vast majority have been of the input-response type.

In such systems, the detectors used, their placement and their interaction with the flow in the bed are important to the results but have received little attention in the literature. Such factors may have contributed significantly to the persistent variability of results from packed bed studies.

Two basically differing types of detectors have been employed in studies of phenomena in packed beds. Firstly, there have been those which measure a cross-sectional averaged property at a particular axial position; these are of principal interest to designers since they are related to the residence time distribution in the bed. Secondly, there have been the radially specific detectors designed to provide information about the gross velocity profile and its effect on the mixing. Radial dispersion will effect both types of detectors and will act to mask the velocity profile effects.

Bischoff and Levenspiel (*1*), assuming a dispersion model and specifically neglecting hydrodynamic end effects, developed a criterion for the placement of detectors so that Peclet numbers calculated assuming infinite bed length agreed well with those calculated using the more cumbersome and accurate boundary conditions suggested by Wehner and Wilhelm (*9*). They found that for a two detector system the detectors should be at least one tenth as far from the ends of the bed as they are from one another.

Criteria can be developed for limits on the effect of the detector on the apparent concentration. The holdup time of a detector (volume/volumetric flow rate) can be taken as the characteristic time of a detector. This will be a lower limit on the characteristic time as any instrumentation lags and/or finite heat or mass transfer rates will increase the characteristic time. Limits can also be placed on the flow patterns in the detectors. The actual pattern will lie between plug flow and perfect mixing.

If one assumes that the actual concentration (or temperature) pulse reaching the detector is Gaussian, the apparent concentrations seen by the detectors may be calculated for a known holdup time and an assumed flow pattern.

For a perfectly mixed detector

$$\hat{c} = \frac{1}{\sigma\theta\sqrt{\pi}} \int_{-\infty}^{t} \exp\left[-\frac{1}{\theta}(t-\tau) - \frac{(\tau-\mu)^2}{2\sigma^2} \right] d\tau \qquad (1)$$

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TABLE 1. APPARENT MOMENTS RESULTING FROM DETECTOR TIME CONSTANT

	Plug Flow	First-Order Time Constant	
θ/σ	σ^2	σ^2	π^3
0	1.000	1.000	0.0
0.1	1.001	1.005	0.019
0.3	1.008	1.09	0.069
0.5	1.021	1.25	0.255

while for a plug flow detector

$$\hat{c} = \frac{1}{\sigma\theta\sqrt{\pi}} \int_{t-\frac{\theta}{2}}^{t+\frac{\theta}{2}} \exp\left[-\frac{\tau^2}{2\sigma^2} \right] d\tau \qquad (2)$$

where $\theta = v/q$, is the holdup time of the detector and σ is the standard deviation of the input pulse and is a characteristic time of the pulse. It is actually the ratio θ/σ which is important as a measure of the detector's ability to follow a system transient. Figures 1 and 2 show the apparent measured concentration vs. a reduced time for finite plug flow and perfectly mixed detectors respectively. Finite heat/mass transfer coefficients will act like time constants of the mixed tank type.

Those time constants will also affect the apparent moments of the concentration pulse. (This consideration can become important when the data is to be treated by a moments analysis). Plug flow detectors will indicate a larger than real standard deviation but will not affect the skewness (symmetry) while first-order time constants for example, mixing, will affect both the standard deviation and skewness.

Table 1 shows the apparent moments from plug flow and perfectly mixed detectors as a function of θ/σ.

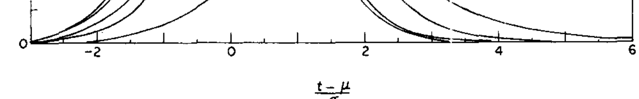

Fig. 1. Effect of finite length of detector cell on apparent measured concentration.

TABLE 2. EXPERIMENTAL CHARACTERISTIC DETECTOR TIME

References	Detector Hold Up Time θ	Characteristic Pulse Time σ	Worst θ/σ	Reynolds Number $N_{Re} = udp/\nu$	Comments
2	0.995 sec.	2.79 sec.	0.356	100	Photometer beam 3 mm. long in direction of flow
5	0.365	0.55	0.665	0.06-1.6	$L/dp = 7{,}400$ $Dt/dp = 250$ Curve appears Gaussian
8	4.7-12.9	30-60	0.428	16-40	Sine input—estimated
6	0.27-1.66	10-84	0.166	37-125	Nonvoid cell
3	0.345-.755	1.58-5.65	0.479	0.58-3.75	Sine input—estimated Nonvoid cell

One can conclude from Figures 1 and 2 and Table 1 that the holdup time of the detector must be less than 0.1σ if the measurements are to reflect accurately the actual pulse. Table 2 indicates the θ/σ ratios for some experimental studies. The ratio in most is seen to approach unfortunately large values. The time constants of the detectors in addition to the holdup time can only increase these values.

Detectors placed into the bed are more difficult to evaluate. They have consisted of short parallel wires or pellets fused into an arrangement suitable for implanting electrical conductivity probes. These probes must cause at least short range ordering of the packing and concomitant variation of flows. The probe used by Miller and King (7) consisted of two parallel pins. The probe to tube diameter ratio was 0.38 to 0.60. If one uses the diameter or hydraulic ratio, other numbers are obtained. Any such calculation yields values indicating the strong probability that the flow field was significantly affected by the probe..

Small detectors inherently average over a small fluid element, a volume on the order of that of one interstice. This gives rise to the opposite problem, namely the integration of the detector signals. This will be particularly significant if the results are to be compared with those predicted by the dispersion model which treats the bed as a continuum. This, in turn, implies that measurements on the bed must be over a volume large with respect to that of one interstice, and can be accomplished by suitable auxiliary instrumentation to average the detector response over a sufficient time for a large volume of fluid to have passed the detector.

The larger problem of the effects of the detectors on the mixing upstream and downstream from them will require further experimental study. Present results (3, 8) indicate that detectors providing approximately the same voidage as the bed are less disruptive of flow patterns than void detectors. This is in agreement with what one would intuitively expect; it does not, however, provide a quantitative guide to detector effects. Such information awaits detailed studies of bed-detector interactions.

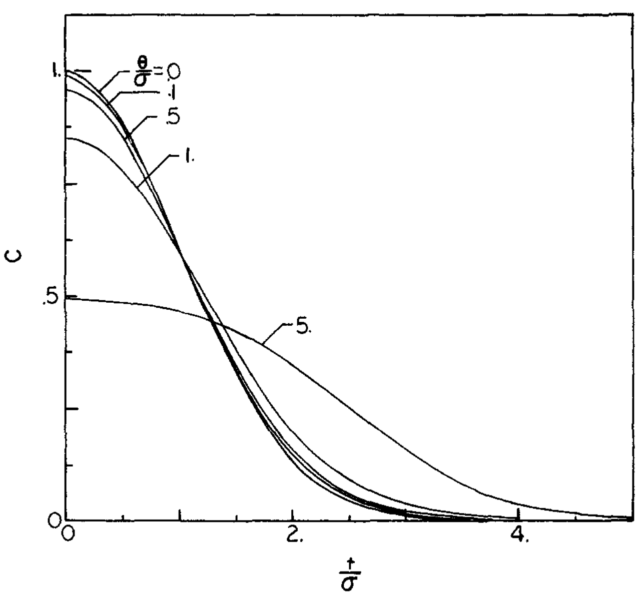

Fig. 2. Effect of first-order time constant on apparent measured concentration.

NOTATION

$\hat{c}$ = apparent concentration
d_p = particle diameter
D_t = tube diameter
L = bed length
N_{Re} = udp/ν, particle Reynolds member
q = volumetric flow rate
t = time
u = mean interstitial velocity
v = detector volume

Greek Letters

θ = v/q, detector holdup time
μ = first moment (mean) of pulse
ν = kinematic viscosity
π = 3.1416
π^3 = third central moment of pulse
σ = standard deviation of pulse
σ^2 = second central moment of pulse
τ = dummy variable

LITERATURE CITED

1. Bischoff, K. B., and O. Levenspiel, *Chem. Eng. Sci.*, **17**, 245 (1962).
2. Carberry, J. J., and R. H. Bretton, *AIChE J.*, **4**, 367 (1958).
3. Chao, R., and H. E. Hoelscher, *ibid.*, **12**, 271 (1966).
4. Chung, S. F., and C. Y. Wen, *ibid.*, **14**, 857 (1968).
5. Ebach, E. A., and R. R. White, *ibid.*, **4**, 161 (1958).
6. Liles, A. W., and C. J. Geankoplis, *ibid.*, **6**, 591 (1960).
7. Miller, S. F., and C. J. King, *ibid.*, **12**, 767 (1966).
8. Strang, D. A., and C. J. Geankoplis, *Ind. Eng. Chem.*, **50**, 1305 (1958).
9. Wehner, J. F., and R. H. Wilhelm, *Chem. Eng. Sci.*, **6**, 89 (1956).