2.5 Three-Phase Fluidized-Bed Reacting Systems

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The study of three-phase (gas-liquid-solid) fluidized beds continued during this report period. Various packings in 7.62- and 15.2-cm-ID columns were used, and the minimum gas and liquid velocities necessary to fluidize a bed were determined for two additional sizes of glass beads. Dimensionless correlations were developed to predict the minimum

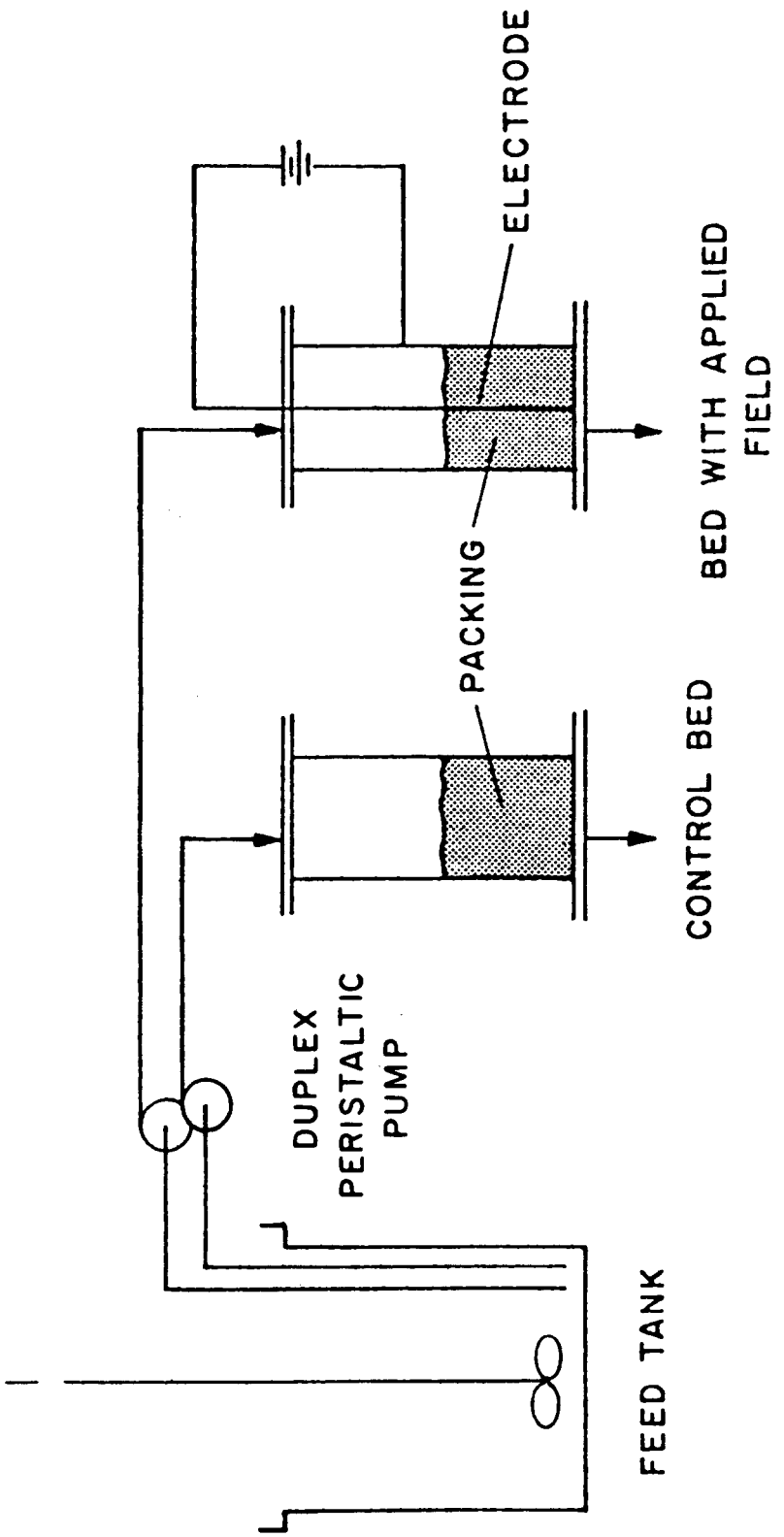

Fig. 2.21. Schematic of apparatus used for testing deep-bed filtration in an electric field.

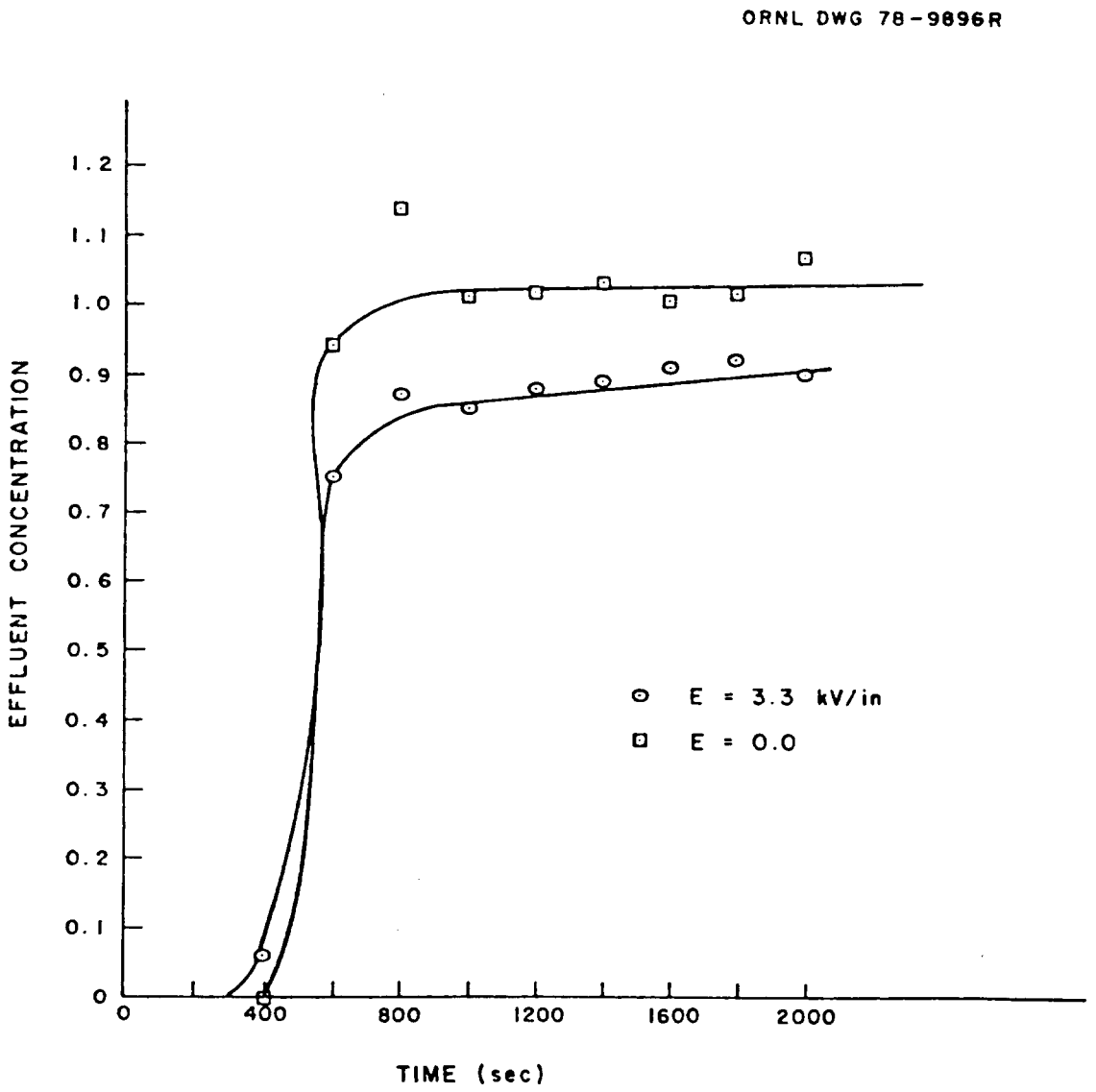

Fig. 2.22. Preliminary results for deep-bed filtration in an electric field.

fluidization (MF) velocity and the five parameters which can be used to completely describe the holdup profiles for the gas, liquid, and solid phases in a column. In addition, overall gas and solid holdups were combined with similar data from the literature to yield dimensional correlations for each of the overall volume fractions.

Residence-time-distribution (RTD) and liquid-phase mass transfer experiments were performed in the 7.62-cm-ID column using three sizes of glass beads and one size of plexiglass beads. The amount of axial dispersion present in the liquid phase was very difficult to characterize. Apparently, the measuring devices used did not have response times short enough to measure the fast-moving tracer pulses. Since axial dispersion coefficients were not available, the liquid-phase mass transfer data were analyzed using both the plug-flow (PF) and continuously stirred tank reactor (CSTR) models. The overall volumetric mass transfer coefficient increased with both increasing gas and liquid velocities and increasing particle size and density.

2.5.1 Experimental procedures

The experimental apparatus and procedures used to obtain MF velocities, overall phase holdups, local phase holdups, and axial dispersion coefficients have been described previously.[1,2,7] Mass transfer experiments were performed by continuously measuring the dissolved oxygen content of water entering the 7.62-cm-ID column and of water at various heights in the bed after cocurrent contact with nitrogen.

Tables 2.3 and 2.4 present the physical characteristics of the solids and the range of experimental conditions used in these experiments. Experiments designed to measure MF velocities used each of the solids

Table 2.3. Physical characteristics of solid beads used in three-phase fluidization studies

Solid	Diameter (mm)	Density (g/cm^3)
Glass[a]	3.2	2.24
Glass	4.6	2.24
Glass[a]	6.2	2.20
Plexiglass	6.3	1.17
Alumina	6.2	1.99
Alumino-silicate[a]	1.9	1.72

[a]Used only in MF experiments.

Table 2.4. Experimental conditions used in three-phase fluidization studies

Superficial gas velocity (U_G), cm/sec	0-17.3
Superficial liquid velocity (U_L), cm/sec	0-12.0
Column diameter (D_c), cm	7.62 and 15.2
Initial bed height (H_o), cm	22-45

listed in Table 2.3 whereas the phase holdup experiments did not use either the 1.9-mm-diam alumino-silicate or the 6.2- and 3.2-mm-diam glass beads. The mass transfer experiments used only the nonporous glass and plexiglass beads.

2.5.2 Results

Minimum fluidization. Figure 2.23 shows MF velocities for each of the systems studied. As the gas velocity was increased, the minimum liquid velocity required to achieve fluidization decreased in all of these systems. The plexiglass beads, which have the same diameter as the alumina beads and one set of the glass beads, also have a much smaller solid-liquid density difference; thus, they fluidized at lower velocities. All three sizes of glass beads have about the same density. As their diameters increased, the MF velocity also increased.

Note the interaction of particle size and density. At zero gas velocity, the curves of the 6.2-mm-diam glass beads and the alumina beads start at essentially the same point (i.e., they fluidize at the same liquid velocity). However, as the gas velocity is increased, the two curves rapidly diverge. Furthermore, at gas velocities greater than 8 cm/sec, the 6.2-mm-diam alumina beads behave much like the 4.6-mm-diam beads. As the gas velocity is increased, the nonporous beads yield MF curves of similar shape, although the curves do not cross each other.

Liquid-phase axial dispersion. The amount of axial dispersion present in the liquid phase was determined by analyzing the spread of a tracer injected into the liquid phase.[34] The tracer was monitored over the column increment of electrode spacing. Three sizes of glass beads and various mass loadings were tested in the 7.62-cm-ID column and yielded

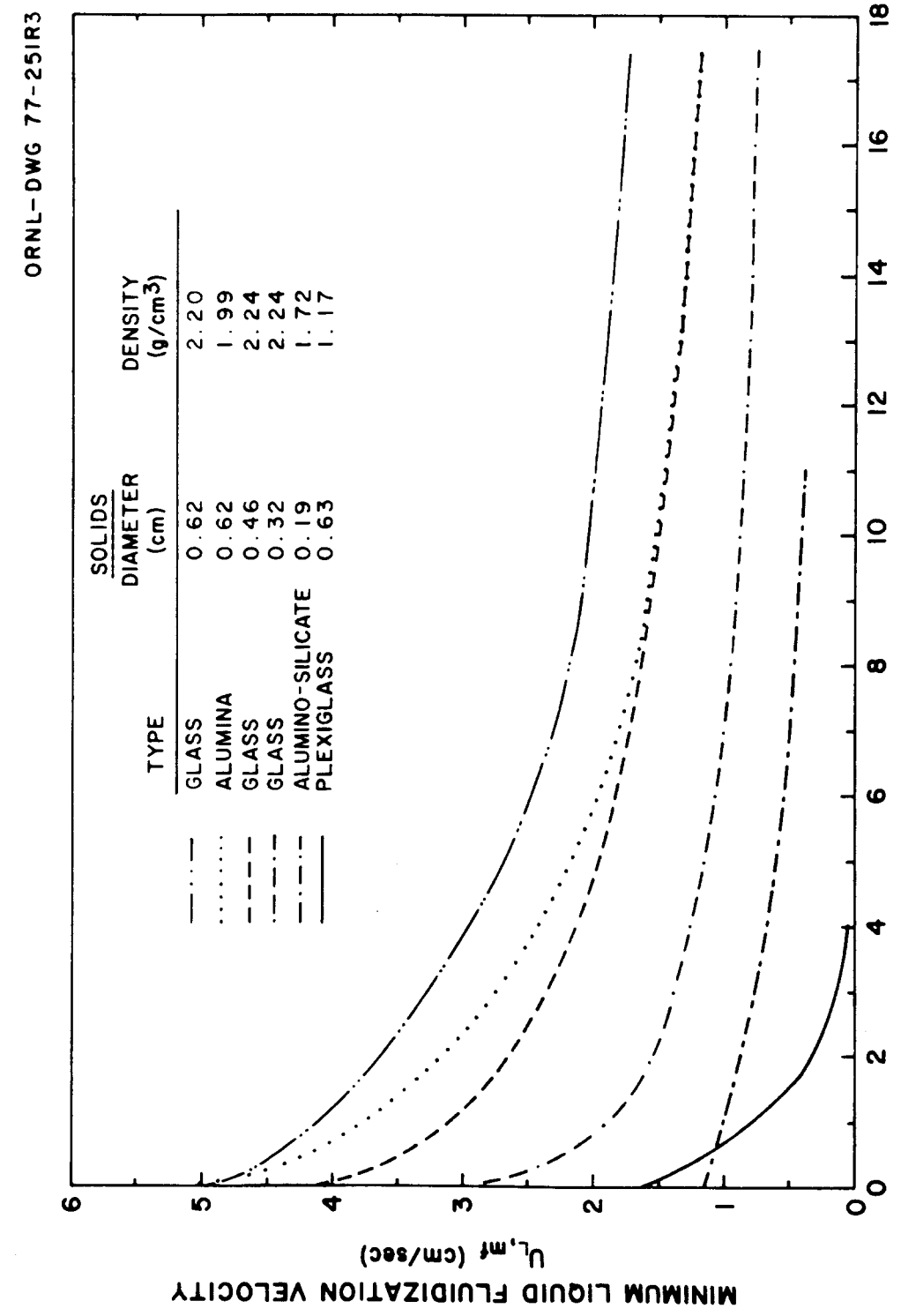

Fig. 2.23. Effect of particle size and density on MF velocities.

the results presented in Tables 2.5-2.11.[35] The holdups were determined in two ways: from the RTD curve and from the pressure gradient.[7]

Monitoring the conductivity of the liquid in the column at two points generates two curves of conductivity vs time each time a tracer pulse is injected. The first moment of each curve is referred to as its mean and is calculated as follows:

$$\mu_i = \frac{\int_0^\infty ct\ dt}{\int_0^\infty c\ dt} \simeq \frac{\Sigma\ c_j t_j\ \Delta t}{\Sigma\ c_j\ \Delta t}\ , \qquad (1)$$

where

μ_i = mean of curve,

c = concentration,

t = time,

and subscript j refers to time j.

The difference in means of the two curves is equal to the mean residence time, τ, of the liquid between the two measurement points:

$$\tau = \mu_2 - \mu_1\ , \qquad (2)$$

where subscripts 1 and 2 refer to the first and second measurement prints respectively.

The liquid holdup is the volume fraction of the bed made up of liquid and is found from the following:

$$\varepsilon_L = \tau U_L / L\ , \qquad (3)$$

Table 2.5. RTD measurements using 1500 g of 4.6-mm-diam glass beads

Run No.	Electrode spacing, L (cm)	Superficial gas velocity, U_G (cm/sec)	Superficial liquid velocity, U_L (cm/sec)	From pressure gradient: Gas holdup, ϵ_G	From pressure gradient: Liquid holdup, ϵ_L	From RTD curve: Gas holdup, ϵ_G	From RTD curve: Liquid holdup, ϵ_L	Peclet number, Pe	Axial dispersion coefficient, D_L (cm^2/sec)
1	8.3	0	4.18	0.057	0.344	0.055	0.348	[a]	[b]
2	8.3	4.39	4.18	0.108	0.338	0.099	0.354	44.6	2.19
3	8.3	7.91	4.18	0.145	0.254	0.115	0.354	0.354	850
4	8.3	11.9	4.18	0.185	0.271	0.155	0.326	1.41	75.2
5	8.3	15.9	4.18	0.214	0.280	0.247	0.220	3.61	43.6
6	8.3	0	5.96	-0.007	0.517	0.090	0.343	[a]	[b]
7	8.3	4.03	5.96	0.050	0.426	0.396	[c]	[a]	[d]
8	8.3	7.90	5.96	0.131	0.362	0.373	[c]	[a]	[d]
9	8.3	11.9	5.96	0.136	0.391	0.251	0.183	0.484	560
10	8.3	15.9	5.96	0.149	0.406	0.095	0.504	1.88	52.2
11	12.7	0	7.99	-0.013	0.539	0	0.516	[a]	[b]
13	12.7	7.86	7.99	0.116	0.440	0.009	0.632	0.869	185
14	12.7	11.9	7.99	0.154	0.469	0.162	0.455	0.599	373
15	12.7	15.9	7.99	0.169	0.455	0.189	0.408	0.556	448
16	16.0	0	10.0	-0.003	0.589	-0.028	0.635	16.5	15.3
17	16.0	4.01	10.0	0.082	0.541	0.107	0.496	1.24	260
18	16.0	7.85	10.0	0.104	0.551	0.344	0.118	6.16	220
19	16.0	11.8	10.0	0.146	0.520	0.399	0.065	[a]	[b]
20	16.0	15.8	10.0	0.194	0.469	0.315	0.250	2.14	300
21	20.5	0	11.9	-0.002	0.635	-0.015	0.658	24.6	15.1
22	20.5	4.02	11.9	0.098	0.589	-0.094	0.936	1.94	135
23	20.5	7.87	11.9	0.131	0.569	0.172	0.496	3.53	140
24	20.5	11.9	11.9	0.162	0.556	0.214	0.462	6.16	85.9
25	20.5	15.8	11.9	0.175	0.554	0.329	0.275	[a]	[b]

[a] $Pe < 0$.
[b] D_L is very small.
[c] $\epsilon_L < 0$.
[d] D_L is very large.

Table 2.6. RTD measurements using 2250 g of 4.6-mm-diam glass beads

Run No.	Electrode spacing, L (cm)	Superficial gas velocity, U_G (cm/sec)	Superficial liquid velocity, U_L (cm/sec)	From pressure gradient: Gas holdup, ϵ_G	From pressure gradient: Liquid holdup, ϵ_L	From RTD curve: Gas holdup, ϵ_G	From RTD curve: Liquid holdup, ϵ_L	Peclet number, Pe	Axial dispersion coefficient, D_L (cm^2/sec)
26	19.5	0	4.18	0.115	0.290	0.034	0.436	26.4	7.07
27	19.5	4.02	4.18	0.091	0.330	0.102	0.309	12.1	21.8
28	19.5	7.87	4.18	0.136	0.307	0.120	0.336	6.20	39.1
29	19.5	11.9	4.18	0.124	0.358	0.143	0.323	1.90	132
30	19.5	15.9	4.18	0.120	0.360	0.089	0.414	1.58	124
31	22.5	0	5.96	0.028	0.435	-0.014	0.511	126	2.08
32	22.5	4.02	5.96	0.066	0.403	0.382	c	a	b
33	22.5	7.87	5.96	0.115	0.373	0.105	0.372	2.66	129
34	22.5	11.9	5.96	0.145	0.381	0.198	0.287	1.45	323
35	22.5	15.8	5.96	0.176	0.318	0.103	0.449	1.52	197
36	27.0	0	7.99	-0.003	0.530	-0.020	0.561	36.0	10.7
37	27.0	4.02	7.99	0.074	0.467	0.017	0.571	2.64	143
38	27.0	7.86	7.99	0.114	0.441	0.229	0.235	a	b
39	27.0	11.9	7.99	0.150	0.434	0.079	0.562	1.49	258
40	27.0	15.8	7.99	-0.023	0.622	-0.003	0.587	1.00	368
41	32.0	0	10.0	-0.001	0.581	0.014	0.555	a	b
42	32.0	4.02	10.0	0.061	0.559	0.214	0.284	a	b
43	32.0	7.86	10.0	0.125	0.520	0.227	0.336	2.30	415
44	32.0	11.8	10.0	0.154	0.499	0.185	0.444	2.38	304
45	32.0	15.8	10.0	0.186	0.476	0.241	0.376	6.99	122
46	32.0	0	11.9	0.004	0.632	0.032	0.582	a	b
47	32.0	4.02	11.9	0.094	0.608	0.396	0.064	0.049	d
48	32.0	7.87	11.9	0.133	0.575	0.192	0.469	1.92	425
49	32.0	11.9	11.9	0.177	0.533	0.312	0.290	0.934	1410
50	32.0	15.8	11.9	0.192	0.537	0.144	0.624	2.49	246

[a] $Pe < 0$.

[b] D_L is very small.

[c] $\epsilon_L < 0$.

[d] D_L is very large.

Table 2.7. RTD measurements using 3000 g of 4.6-mm-diam glass beads

Run No.	Electrode spacing, L (cm)	Superficial gas velocity, U_G (cm/sec)	Superficial liquid velocity, U_L (cm/sec)	From pressure gradient: Gas holdup, ε_G	From pressure gradient: Liquid holdup, ε_L	From RTD curve: Gas holdup, ε_G	From RTD curve: Liquid holdup, ε_L	Peclet number, Pe	Axial dispersion coefficient, D_L (cm^2/sec)
51	26.5	0	4.18	-0.026	0.374	-0.034	0.387	57.0	5.01
52	26.5	4.01	4.18	0.095	0.323	0.089	0.335	9.51	34.7
53	26.5	7.85	4.18	0.133	0.313	0.162	0.260	4.27	99.6
54	26.5	11.8	4.18	0.159	0.292	0.148	0.312	3.91	90.8
55	26.5	15.8	4.18	0.177	0.289	0.187	0.270	2.03	202
56	26.5	0	5.96	-0.007	0.458	-0.023	0.486	a	b
57	26.5	3.96	5.96	0.080	0.386	0.250	0.080	1.85	1069
58	26.5	7.75	5.96	0.120	0.365	0.200	0.221	0.815	879
59	26.5	11.7	5.96	0.139	0.372	0.134	0.381	1.49	279
60	26.5	15.6	5.96	0.172	0.369	0.107	0.487	1.93	168
61	35.5	0	7.99	0.004	0.515	-0.013	0.544	65.0	8.02
62	35.5	4.01	7.99	0.073	0.478	0.155	0.328	0.909	954
63	35.5	7.84	7.99	0.110	0.446	0.161	0.354	4.42	182
64	35.5	11.8	7.99	0.142	0.419	0.168	0.372	2.39	319
65	35.5	15.8	7.99	0.182	0.410	0.201	0.377	4.58	164
66	42.0	0	10.0	-0.005	0.586	-0.022	0.615	83.0	8.24
67	42.0	4.00	10.0	0.095	0.523	0.275	0.199	10.1	210
68	42.0	7.84	10.0	0.131	0.506	0.210	0.365	2.31	500
69	42.0	11.8	10.0	0.147	0.502	0.180	0.442	7.14	133
70	42.0	15.7	10.0	0.190	0.474	0.220	0.421	6.52	153
71	48.0	0	11.9	-0.003	0.641	-0.026	0.681	30.2	27.9
72	48.0	4.00	11.9	0.099	0.595	0.202	0.410	5.95	235
73	48.0	7.83	11.9	0.134	0.563	0.176	0.489	8.01	146
74	48.0	11.8	11.9	0.175	0.536	0.191	0.507	4.38	258
75	48.0	15.7	11.9	0.216	0.500	0.258	0.424	2.70	500

[a] Pe < 0.

[b] D_L is very small.

Table 2.8. RTD measurements using 1500 g of 3.2-mm-diam glass beads

Run No.	Electrode spacing, L (cm)	Superficial gas velocity, U_G (cm/sec)	Superficial liquid velocity, U_L (cm/sec)	From pressure gradient: Gas holdup, ϵ_G	From pressure gradient: Liquid holdup, ϵ_L	From RTD curve: Gas holdup, ϵ_G	From RTD curve: Liquid holdup, ϵ_L	Peclet number, Pe	Axial dispersion coefficient, D_L (cm^2/sec)
76	7.0	0	3.22	0.048	0.364	0.029	0.399	[a]	[b]
77	7.0	4.04	3.22	0.123	0.333	0.207	0.182	0.962	129
78	7.0	7.91	3.22	0.135	0.359	0.135	0.359	1.24	50.7
79	7.0	11.9	3.22	0.136	0.390	0.245	0.195	[a]	[b]
80	7.0	15.9	3.22	0.187	0.323	0.183	0.332	0.819	83.0
81	9.5	0	4.18	0.078	0.378	0.017	0.488	30.7	2.64
82	9.5	4.04	4.18	0.011	0.455	0.161	0.186	0.224	953
83	9.5	7.91	4.18	0.109	0.410	0.304	0.058	[a]	[b]
84	9.5	11.9	4.18	0.116	0.397	0.171	0.300	0.541	245
85	9.5	15.9	4.18	0.151	0.391	0.007	0.650	1.29	47.3
86	9.5	0	5.96	0.013	0.528	0.085	0.399	[a]	[b]
87	9.5	4.04	5.96	0.060	0.450	-0.166	0.857	1.29	51.3
88	9.5	7.90	5.96	0.107	0.419	0.412	[c]	0.394	343
89	9.5	11.9	5.96	0.154	0.394	0.271	0.185	1.39	221
90	9.5	16.0	5.96	0.157	0.391	0.124	0.451	0.579	217
91	14.5	0	7.99	0.005	0.618	0.029	0.576	2.98	67.5
92	14.5	4.04	7.99	0.079	0.524	-0.002	0.670	1.51	114
93	14.5	7.90	7.99	0.100	0.513	0.188	0.355	1.35	242
94	14.5	11.9	7.99	0.115	0.493	0.135	0.458	1.17	216
95	14.5	15.9	7.99	0.159	0.483	0.231	0.353	3.02	109
96	26.0	0	11.9	0.010	0.702	0.022	0.681	179	2.54
97	26.0	4.04	11.9	0.093	0.678	0.243	0.407	[a]	[b]
98	26.0	7.90	11.9	0.119	0.659	0.408	0.137	[a]	[b]
99	26.0	11.9	11.9	0.159	0.622	0.298	0.372	19.1	43.7
100	26.0	15.9	11.9	0.218	0.547	0.234	0.517	3.57	168

[a] Pe < 0.

[b] D_L is very small.

[c] ϵ_L < 0.

Table 2.9. RTD measurements using 2250 g of 3.2-mm-diam glass beads

Run No.	Electrode spacing, L (cm)	Superficial gas velocity, U_G (cm/sec)	Superficial liquid velocity, U_L (cm/sec)	From pressure gradient: Gas holdup, ε_G	From pressure gradient: Liquid holdup, ε_L	From RTD curve: Gas holdup, ε_G	From RTD curve: Liquid holdup, ε_L	Peclet number, Pe	Axial dispersion coefficient, D_L (cm^2/sec)
101	18.5	0	3.22	0.024	0.373	-0.007	0.428	74.5	1.87
102	18.5	4.04	3.22	0.122	0.313	0.074	0.401	3.65	40.8
103	18.5	7.89	3.22	0.149	0.300	0.065	0.452	2.83	46.6
105	18.5	15.9	3.22	0.199	0.257	0.330	0.022	a	b
106	18.5	0	4.18	0.009	0.454	-0.004	0.476	540	0.300
107	18.5	4.02	4.18	0.082	0.368	0.228	0.105	0.329	2240
108	18.5	15.9	4.18	0.128	0.348	0.069	0.453	1.36	126
109	18.5	11.9	4.18	0.149	0.326	0.252	0.142	0.421	1290
111	25.0	0	5.96	0.016	0.515	0.009	0.529	34.5	8.16
112	25.0	4.02	5.96	0.065	0.457	0.291	0.050	a	b
113	25.0	7.87	5.96	0.098	0.384	0.272	0.071	a	b
114	25.0	11.9	5.96	0.118	0.382	0.198	0.237	1.01	621
115	25.0	15.8	5.96	0.141	0.381	0.214	0.248	6.07	99.1
116	25.0	0	7.99	0.045	0.569	0.085	0.497	22.3	18.1
117	25.0	4.02	7.99	0.072	0.521	0.166	0.351	1.57	362
118	25.0	7.87	7.99	0.100	0.507	0.171	0.379	1.67	317
119	25.0	11.9	7.99	0.129	0.491	0.307	0.170	0.561	2090
120	25.0	15.8	7.99	0.173	0.454	0.230	0.351	1.39	408
121	41.0	0	11.9	0.019	0.716	0.008	0.735	22.4	29.7
122	41.0	4.03	11.9	0.088	0.668	0.268	0.344	a	b
123	41.0	7.86	11.9	0.129	0.631	0.230	0.450	3.80	286
124	41.0	11.9	11.9	0.175	0.583	0.236	0.473	3.54	292

[a] $Pe < 0$.

[b] D_L is very small.

Table 2.10. RTD measurements using 3000 g of 3.2-mm-diam glass beads

Run No.	Electrode spacing, L (cm)	Superficial gas velocity, U_G (cm/sec)	Superficial liquid velocity, U_L (cm/sec)	From pressure gradient: Gas holdup, ϵ_G	From pressure gradient: Liquid holdup, ϵ_L	From RTD curve: Gas holdup, ϵ_G	From RTD curve: Liquid holdup, ϵ_L	Peclet number, Pe	Axial dispersion coefficient, D_L (cm^2/sec)
126	25.0	0	3.22	-0.126	0.487	-0.069	0.385	40.5	5.17
127	25.0	4.00	3.22	0.119	0.342	0.136	0.313	6.41	40.2
128	25.0	7.84	3.22	0.159	0.292	0.176	0.261	2.04	151
129	25.0	11.8	3.22	0.197	0.279	0.263	0.160	0.748	674
130	25.0	15.8	3.22	0.223	0.271	0.247	0.227	1.17	302
132	25.0	4.00	4.18	0.089	0.367	0.274	0.033	0.064	c
133	25.0	7.82	4.18	0.134	0.342	0.279	0.081	0.408	3180
134	25.0	11.8	4.18	0.175	0.332	0.347	0.022	a	b
135	25.0	15.7	4.18	0.204	0.307	0.212	0.292	0.797	449
136	33.0	0	5.96	0.013	0.529	-0.008	0.565	76.2	4.58
137	33.0	3.98	5.96	0.075	0.436	0.022	0.530	42.4	8.76
138	33.0	7.82	5.96	0.114	0.409	0.287	0.097	a	b
139	33.0	11.8	5.96	0.149	0.393	0.241	0.226	54.3	16.1
140	33.0	15.7	5.96	0.191	0.364	0.245	0.267	2.00	367
141	39.5	0	7.99	0.009	0.604	0.031	0.565	79.2	7.05
142	39.5	3.99	7.99	0.069	0.508	0.083	0.484	3.09	211
143	39.5	7.82	7.99	0.121	0.490	0.137	0.461	2.78	246
144	39.5	11.8	7.99	0.157	0.455	0.230	0.321	41.1	23.9
145	39.5	15.7	7.99	0.189	0.468	0.269	0.323	12.4	79.0
146	62.0	0	11.9	0.006	0.734	0.018	0.713	42.4	24.5
147	62.0	3.99	11.9	0.110	0.622	0.073	0.688	8.43	128
148	62.0	7.81	11.9	0.187	0.513	0.159	0.564	12.0	109

[a] Pe < 0 .

[b] D_L is very small.

[c] D_L is very large.

Table 2.11. RTD measurements using 1500 g of 6.2-mm-diam glass beads

Run No.	Electrode spacing, L (cm)	Superficial gas velocity, U_G (cm/sec)	Superficial liquid velocity, U_L (cm/sec)	From pressure gradient: Gas holdup, ϵ_G	From pressure gradient: Liquid holdup, ϵ_L	From RTD curve: Gas holdup, ϵ_G	From RTD curve: Liquid holdup, ϵ_L	Peclet number, Pe	Axial dispersion coefficient, D_L (cm^2/sec)
170	8.0	0	4.89	0.028	0.343	0.051	0.301	7.29	17.8
171	8.0	4.03	4.89	0.092	0.349	0.106	0.324	2.70	44.7
172	8.0	7.88	4.89	0.120	0.359	0.262	0.256	3.90	38.2
173	8.0	11.9	4.89	0.162	0.359	0.203	0.284	2.23	62.0
174	8.0	15.9	4.89	0.180	0.317	0.208	0.266	1.86	78.9
175	8.0	0	5.96	-0.012	0.432	0.010	0.391	1.94	62.8
176	8.0	4.03	5.96	0.101	0.404	0.223	0.179	0.922	289
177	8.0	7.89	5.96	0.133	0.364	0.230	0.186	37.8	6.80
178	8.0	11.9	5.96	0.169	0.360	0.206	0.291	0.863	190
179	8.0	0	7.99	0.209	0.354	0.331	0.129	a	b
180	11.5	0	7.99	-0.003	0.532	0.115	0.313	8.33	35.2
181	11.5	4.03	7.99	0.069	0.481	0.192	0.253	0.490	740
182	11.5	7.88	7.99	0.126	0.430	0.241	0.219	5.91	71.1
183	11.5	11.9	7.99	0.157	0.406	0.254	0.227	0.722	561
184	11.5	15.9	7.99	0.175	0.411	0.284	0.220	1.81	240
185	12.5	0	10.0	-0.003	0.578	0.064	0.455	3.49	78.8
186	12.5	4.03	10.0	0.072	0.541	0.236	0.146	1.42	601
187	12.5	7.88	10.0	0.132	0.486	0.312	0.153	0.977	835
188	12.5	11.9	10.0	0.155	0.486	0.128	0.536	3.00	78.1

[a] Pe < 0.

[b] D_L is very large.

where

U_L = superficial liquid velocity,

L = length between measurement points.

The second moment about each mean, calculated from the following, gives the variance, σ^2, of each curve:

$$\sigma_i^2 = \frac{\int_0^\infty c(t - \mu_i)^2 \, dt}{\int_0^\infty c \, dt} \simeq \frac{\Sigma \, c_j (t_j - \mu_i)^2 \, \Delta t}{\Sigma \, c_j \, \Delta t} \quad . \tag{4}$$

The difference between the variance of the two curves for an open system is then related to the Peclet number, Pe, as follows:

$$Pe = (\sigma_2^2 - \sigma_1^2)/2\tau^2 \quad , \tag{5}$$

where

$Pe = \overline{U}_L L/D_L$,

$\overline{U}_L = U_L/\varepsilon_L = L/\tau$ = real liquid velocity.

Thus the liquid-phase axial dispersion coefficient, D_L, is found from

$$D_L = L^2/\tau Pe \quad . \tag{6}$$

Figure 2.24 shows the effect of gas velocity on D_L for the 4.6-mm-diam glass beads. While no clear differences exist for the gas velocities used, the amount of axial dispersion present in the liquid phase was increased by one to two orders of magnitude where gas was present in the bed (as compared to a liquid-fluidized bed only). For the case of no gas flow, the degree of axial dispersion increased slightly as the liquid velocity was increased.

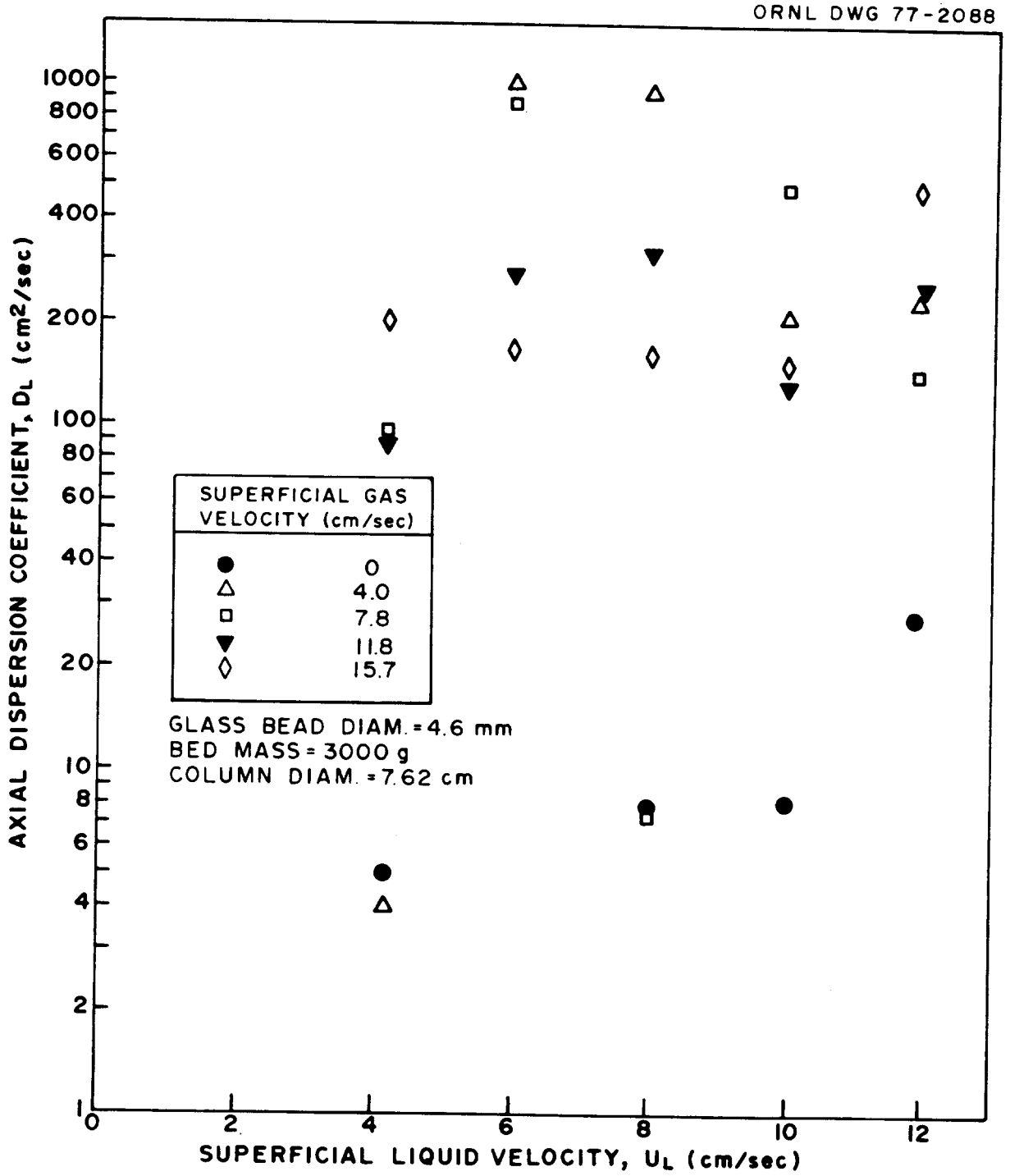

Fig. 2.24. Effect of gas velocity on the liquid-phase axial dispersion coefficient.

For a constant gas velocity and bed mass loading, Fig. 2.25 indicates results scattered over about three orders of magnitude. Similarly, the results shown in Fig. 2.26 for experiments with different bed mass loadings at zero gas velocity are scattered over two orders of magnitude. Even the effect of liquid velocity on D_L is difficult to determine for these two figures.

Because of the scatter in the dispersion data, as well as the disagreement in the liquid holdup calculated by the two methods (Tables 2.5-2.11), RTD experiments were conducted in the 7.62-cm-ID column with liquid only (i.e., with no gas or solid phases present). In a liquid-only system, the liquid holdup is equal to unity. Liquid holdups are fairly well centered around unity for liquid velocities of 6 cm/sec and higher; they are very much below unity for liquid velocities of less than 4.2 cm/sec. Such results could result from laminar flow if the tracer were injected principally into the center of the column where the velocity would be twice the mean velocity. However, based on a liquid density of 1 g/cm^3 and a liquid viscosity of 0.01 g/cm·sec, the liquid velocity necessary to achieve a Reynolds number of 2100 in the 7.62-cm-ID column would be 2.8 cm/sec. Although a liquid velocity of 2.8 cm/sec does not agree exactly with Fig. 2.27, the lower holdups are undoubtedly influenced, in part, by velocity profiles. In any case, in two- and three-phase beds, the presence of the solids reduces the liquid holdups and thus causes the real liquid velocities to be high enough so that laminar flow is avoided.

Rather than being related to the velocity profile in the column, the scatter in the RTD data, especially with solids present, may be attributed to two other causes: (1) interaction between the two sets of electrodes

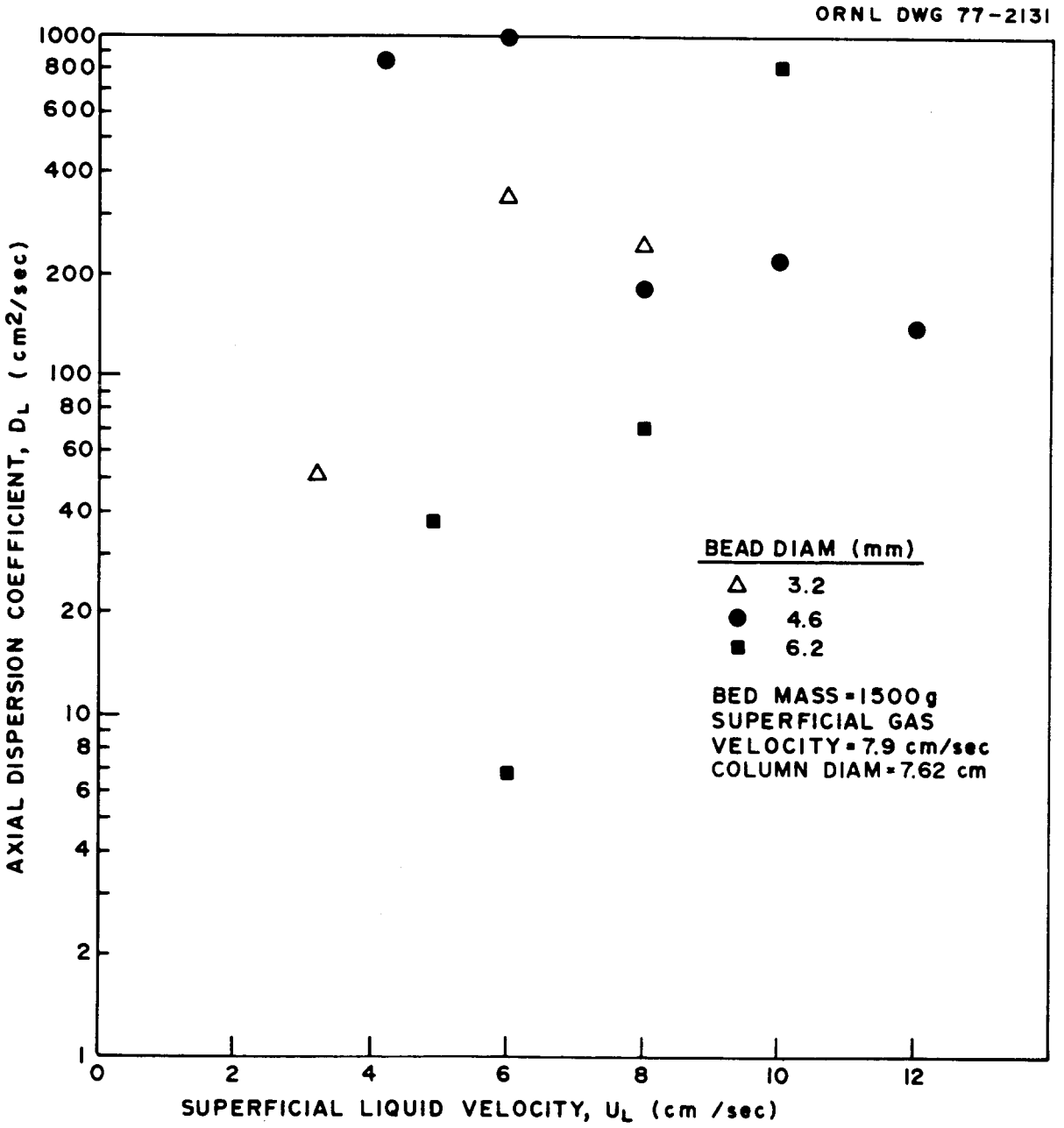

Fig. 2.25. Effect of particle diameter on the liquid-phase axial dispersion coefficient.