Tables 19 to 21 list batch experiments that were conducted using water, tetralin and glycol. The range of gas velocities and solid concentrations included those of expected in the SRC-I dissolver.

5.3.2 Fine particles (Batch, 140/170 Mesh Glass Beads and -140 Mesh Sand)

Figures 59 to 73 graph the axial distribution of fine particles in the 5-in. and 12-in. columns. In general all these profiles are flat, with very small slopes, which is expected because the terminal velocity of small particles is usually small. In fact, as the particles become smaller, the interfacial drag per unit volume usually increases, thus decreasing the terminal velocity. Particles of this size, therefore, will stay well-mixed in the dissolver under a wide range of gas velocities.

In addition, the distribution of solids concentration was independent of gas velocity which implies that the solid dispersion coefficient is also independent of gas velocity. However, if the effective V_p in Equation 4 varies with gas velocity, the solid dispersion coefficient will be proportionally dependent on gas velocity.

The V_p/E_{zp} values measured from the slopes of the straight line plots shown in Figure 59 through 73 are summarized in Tables 22 through 25. The results obtained from the air/water/solid system (Table 22) showed that the glass beads had consistently higher V_p/E_{zp} values than sand for both concentrations; the V_p/E_{zp} value for sand is about 10-15% of that for glass beads. This difference can be attributed to a higher settling velocity for glass beads because the average particle size for the 140/170 mesh glass beads were at least a factor of two larger than that of the 140 mesh minus sand. Based upon Stoke's Law, the V_p for glass beads would be at least a factor of four higher than the sand. Therefore, the V_p/E_{zp} values for sand is expected to be at least less than 25% of the value for glass beads for constant E_{zp}. This will explain the difference in V_p/E_{zp} values observed between glass beads and sand particles.

Table 19

List of Batch Experiments

Liquid Phase-Water

Table No.	Column diameter, (in.)	Type of solid particles	Particle size (mesh)	Solid concn. (lb/ft^3)	Range of gas velocities, (ft/sec)
B-1	5	Glass beads	60/70	7.4	0.05-0.43
B-2	5	Glass beads	60/70	28.2	0.05-0.43
B-3	5	Glass beads	140/170	7.6	0.05-0.33
B-4	5	Glass beads	140/170	28.6	0.05-0.33
B-5	5	Sand	60/70	7.6	0.05-0.43
B-6	5	Sand	60/70	29.4	0.05-0.43
B-7	5	Silica	-140	7.6	0.05-0.43
B-8	5	Silica	-140	29.4	0.05-0.43
B-9	12	Sand	60/80	6.2	0.05-0.37
B-10	12	Sand	60/80	25.2	0.05-0.37
B-11	12	Silica	-140	6.2	0.05-0.43
B-12	12	Silica	-140	25.2	0.05-0.43

Table 20

List of Batch Experiments

Liquid Phase-Tetralin

Column diameter, (in.)	Type of solid particles	Particle size (mesh)	Solid Concn. (lb/ft^3)	Range of gas velocities (ft/sec)
5	Glass beads	140/170	8.32	0.1-0.40
5	Glass beads	140/170	25.1	0.1-0.40
5	Glass beads	60/70	8.28	0.1-0.40
5	Glass beads	60/70	26.41	0.1-0.40
5	Sand	-140	8.28	0.1-0.4
5	Sand	-140	25.74	0.1-0.4
5	Sand	60/80	8.295	0.1-0.4
5	Sand	60/80	26.11	0.1-0.4
12	Sand	-140	6.19	0.133-0.392
12	Sand	-140	22.01	0.133-0.392
12	Sand	60/80	6.65	0.133-0.392
12	Sand	60/80	23.66	0.133-0.392

Table 21

List of Batch Experiments

Liquid Phase-Glycol/Water Mixture

Column diameter (in.)	Type of solid particles	Particle size (mesh)	Solid concn (lb/ft^3)	Mixture type	Range of gas velocities, (ft/sec)
12	Sand	-140	20.75-22.93	90% glycol by wt	0.043-0.392
12	Sand	-140	21.43-24.3	70% glycol by wt	0.043-0.392
12	Sand	-140	6.66-21.68	50% glycol by wt	0.05-0.4
12	Sand	60/80	22.885-23.079	90% glycol by wt.	0.043-0.392
12	Sand	60/80	17.39-23.17	70% glycol by wt.	0.043-0.392
12	Sand	60/80	4.32-28.35	50% glycol by wt.	0.05-0.4

Table 22

Summary of V_p/E_{zp} for Fine Particles as a Function of Gas Velocity

Particle Size = 140/170 Mesh for Glass Beads Experiments

Particle Size = -140 Mesh for Sand Experiments (Water)

Gas velocity ft/sec	V_p/E_{zp} (ft^{-1})					
	C_s = 7.5 lb/ft^3			C_s = 28.6 lb/ft^3		
	5" Column		12" Column	5" Column		12" Column
	Glass Beads	Sand	Sand	Glass Beads	Sand	Sand
0.10	0.307	0.029	0.016		0.013	
0.15	0.312		0.018	0.156	0.014	0.006
0.20	0.292	0.047	0.017	0.157	0.016	0.005
0.24			0.019			0.007
0.28			0.016			0.005
0.30		0.034				
0.33	0.330	0.043	0.017	0.162	0.019	0.006
0.37			0.015			0.006
0.43	0.275	0.073	0.021	0.148		0.006

Table 23

Summary of V_p/E_{zp} for Fine Particles as a Function of Column Diameter and Gas Velocity

Particle Size = 140/170 Mesh for Glass Beads

Particle Size = -140-Mesh for Sand (Tetralin)

Gas velocity ft/sec	V_p/E_{zp} (ft^{-1}) C_2 = 6.19-8.32 lb/ft^3 5-in. column Glass beads	Sand	12-in. column Sand	C_s = 22.01-25.74 lb/ft^3 5-in. column Glass beads	Sand	12-in. column Sand
0.100	0.147	0.29		0.101	0.008	
0.133			0.0123			0.0038
0.150	0.182	0.64		0.115	0.032	
0.200	0.203	0.67		0.117	0.023	
0.216			0.0150			0.0052
0.250	0.179	0.48		0.114	0.032	
0.308			0.0180			0.0045
0.330	0.183	0.70		0.109	0.028	
0.365			0.0172			0.0049
0.392			0.0160			0.0031
0.400	0.172	0.42		0.121	0.030	

Table 24

Values of V_p/E_{zp} for -140-Mesh Sand in Glycol/Water Mixtures (12-in. diameter column)

Gas velocity (ft/sec)	V_p/E_{zp} (ft^{-1}) (90% glycol)	V_p/E_{zp} (ft^{-1}) (70% Glycol)
0.216	0.0043	0.0050
0.392	0.0040	0.0046
0.043	0.0030	0.0044
Viscosity (cp)	13.08	6.2

Table 25

Summary of V_p/E_{zp} for Fine Particles as a Function of Gas Velocity in a 12-in. diameter column

Particle Size = -140 Mesh
Liquid = Glycol Mixture (50% by Wt)

Gas velocity (ft/sec)	C_s (lb/ft^3)	V_p/E_{zp} (ft^{-1})
0.2	6.57	0.0210
	18.37	0.0096
	20.76	0.0065
0.4	6.57	0.0161
	18.37	0.0107
	20.76	0.0071
0.5	6.57	0.0163

Effect of column diameter and solid concentration on V_p/E_{zp} are quite obvious as shown in Table 22. V_p/E_{zp} decreased with both increasing column diameter and solids concentration. The dependence on column diameter is not surprising because the degree of liquid backmixing and liquid dispersion coefficient increased with increasing column diameter, hence the solid dispersion coefficient will be expected to increase if there is any column diameter effect. The observed decrease in V_p/E_{zp} value with increasing column diameter directly reflects an increase in E_{zp} which is in qualitative agreement with the above expectation. The reason for the dependence on solid concentration is not clear, however. It is speculated that the particle settling velocity is hindered by the neighbor particles. This will qualitatively explain the decrease in V_p/E_{zp} with increased solids loading.

The fine particles behave similarly in tetralin (Table 23) and glycol-water mixtures (Tables 24 and 25) as in the aqueous system (Table 22). The V_p/E_{zp} values were consistently higher when glass beads were used instead of the fine silica (sand) particles. The V_p/E_{zp} ratio decreased as the sand concentration and the column diameter were increased. Consistently the V_p/E_{zp} ratio was found to be independent of gas velocity in all three system.

In the 5-in. column with glass beads, the values of V_p/E_{zp} decreased by 30 to 40% when water was substituted by tetralin at the same velocities. This result shows the effect of viscosity on solids distribution and V_p/E_{zp}. As viscosity increases, the solid settling velocity (V_p) decreases, thereby decreasing the V_p/E_{zp} values.

However, the viscosity effect is less distinct with the fine sand particles. For an order of magnitude increase in viscosity from 1 cp (pure water) to 13 cp (90% glycol solution), only a two-fold difference in V_p/E_{zp} was measured. For this fine particle size sand, the concentration profiles were almost completely flat. The value of V_p/E_{zp} measured from the slope of a flat curve is a very small quantity. Therefore the viscosity effect is less apparent. It is also likely that E_{zp} decreases with increasing viscosity, further dampening the viscosity effect on V_p/E_{zp} ratio.

5.3.3 Large Particles (Batch, 60/70-Mesh Glass Beads and 60/80 Mesh Sand)

Marked differences are seen in the behavior of large particles compared to fine particles. Significant gradients in the solids concentration were measured for both sand and glass beads. Complete suspension of these large particles could not be achieved at low gas velocities. Sampling from the bottom port is extremely difficult and the reliability of this sample is questionable. Hence, data from the lowest sampling port were excluded from the analysis.

The V_p/E_{zp} values for these large particles measured from the slopes of the plots shown in Figures 74-88 at different solids concentration and column diameter are summarized as a function of gas velocity in Tables 26-28. V_p/E_{zp} increases markedly in comparison with the case of fine particles primarily because the particle terminal velocity increases due to an increase in particle size.

In most of these experiments, complete suspension was achieved only at higher gas velocities. The critical gas velocity, which is defined as the velocity above which all particles are in complete suspension, for the 60/80 mesh sand particles in water was determined to be between 0.193 and 0.217 ft/sec. The results shown in Table 26 indicated that above the critical gas velocity, all the V_p/E_{zp} values showed no systematic change with gas velocity. With the limited amount of data available, the V_p/E_{zp} values seemed to be independent of gas velocity which is consistent with the behavior observed with the fine particles.

The results with water (Table 26) and tetralin (Table 27) as the liquid phase show that increasing the column diameter resulted in a decrease in V_p/E_{zp} values. This means an increase in solid dispersion coefficient with increasing column diameter, and is consistent with the observation using fine particles. Furthermore, the results also indicated that the V_p/E_{zp} values for the sand particles are slightly less than that for the glass beads, although the same size range of particles, namely 60/70 mesh, were used. This slight difference in

Table 26

Summary of V_p/E_{zp} for Fine Particles as a Function of Gas Velocity

Particle Size = 60/70 Mesh for 5-in.-Column Experiments

Particle Size = 60/80 Mesh 12-in.-Column Experiments

Gas velocity ft/sec	Vp/E_{zp}					
	C_s = 7.5 lb/ft^3			C_s = 28.6 lb/ft^3		
	5-in. Column		12-in. Column	5-in. Column		12-in. Column
	Glass beads	Sand	Sand	Glass Beads	Sand	Sand
0.10						
0.15	0.959		0.174	0.117		
0.20	0.916	0.757	0.175	1.115	0.789	0.193
0.24			0.181			0.179
0.28			0.205			0.152
0.30		0.740		0.828		
0.33	0.864	0.662	0.204	0.982	0.979	0.154
0.37						0.154
0.43	0.846	0.729		0.940		0.946

Table 27

Summary of V_p/E_{zp} for Fine Particles as a Function of Column Diameter and Gas Velocity

Particle Size = 60/80 Mesh for Glass Beads
Particle Size = 60/80 for Sand (Tetralin)

Gas Velocity ft/sec	V_p/E_{zp}					
	C_2 = 6.65 - 8.295 lb/ft^3			C_s 23.66 - 26.4 lb/ft^3		
	5" Column		12" Column	5" Column		12" Column
	Glass Beads	Sand	Sand	Glass Beads	Sand	Sand
0.100	0.541	0.369		0.77	0.216	
0.133			0.128			0.120
0.150	0.573	0.455		0.468	0.466	
0.200	0.604	0.479		0.431	0.605	
0.216			0.118			0.104
0.250	0.641	0.488		0.514	0.584	
0.308			0.115			0.109
0.330	0.652	0.484		0.634	0.580	
0.365			0.131			0.0956
0.392			0.127			
0.400	0.691	0.484		0.465	0.497	0.9961

Table 28a

V_p/E_{zp} for 90% and 70% Glycol in 12-in.
Column Using 60/80-Mesh Sand

Gas velocity (ft/sec)	90% glycol	70% glycol
0.216	0.0216	0.0690
0.392	0.0220	0.0699
0.043	0.0373	0.1100
Viscosity (cp)	13.08	6.2

Table 28b

Summary of V_p/E_{zp} for Large Particles as a Function of Gas Velocity

Particle Size = 60/80 Mesh
Liquid = Glycol Mixture, 50% by wt.

12" Column		
Gas velocity (ft/sec)	C_s (lb/ft^3)	V_p/E_{zp} 12-in. column
0.05	1.41	
	11.81	0.077
0.20	6.64	0.113
	18.05	0.101
0.40	6.64	0.118
	18.05	0.080

V_p/E_{zp} values for sand and glass beads possibly reflected some intrinsic difference in the distribution of these particles within the 60/70 mesh range and effect of particle shape.

V_p/E_{zp} ratio decreases as the liquid viscosity increases. The results from Table 26-28 are summarized in Table 29 to illustrate the effect of viscosity. Within the range of gas velocity and solids concentration in this study, the V_p/E_{zp} decreases with increasing liquid viscosity. This decrease in V_p/E_{zp} is primarily due to the reduction of solid terminal velocity with increasing viscosity. This finding agrees with the observation of the fine particles.

The straight line plots shown in Figures 59-88 and the good agreement in the V_p/E_{zp} behavior with the wide range of parameters strongly support the validity of this one-dimensional mass-balance model (Equation 4) to describe the behavior of solids in a three-phase upflow column in a batch mode.