5.3.4 Continuous-Flow Solids Concentration

Continuous runs were conducted to observe the effect of gas velocity, liquid velocity, feed slurry concentration, particle size , column diameter, and inlet distributor on the behavior of suspended solids in the dissolver. Tables 30 to 32 list the experimental runs in three liquids (water, tetralin, and 50% glycol-50% water solution). In these experiments, solid/liquid slurry was fed continuously to the column at the bottom. Concentrations were then measured from different sample ports at 30-minute intervals in order to determine when steady state had occurred after which it allowed us to average the data points. Experimental data from a typical run are shown in Figure 89 which plots the concentration distribution as a function of time. Usually steady state was achieved 2 hours after the experiment started.

Two types of continuous operations were conducted: once-through and recycle mode which were described in the experimental section. The once-through mode, which required considerable sand and water to make

Table 29

Summary of Liquid Property Effect on V_p/E_{zp} for
Large Particles (60/80 Mesh Sand) in a 12-in. Diameter Column

	Water	Tetralin	70% Glycol	90% Glycol
V_p/E_{zp} (ft^{-1})	0.145-0.195	0.092-0.128	0.069-0.110	0.022-0.037
Viscosity (cp)	1.0	2.7	6.2	13.1

Solids concentration 23-28 lb/ft^3
Gas velocity 0.10-0.43 ft/sec

Table 30

List of Continuous Experiments

(Water System)

Column diameter (in.)	Particle mesh size	Liquid velocity ft/sec	Gas velocity ft/sec	Solids conc. lb/ft^3	Distributor type
12	60/80	0.05	0.43	6.17	II
12	60/80	0.05	0.19	7.27	II
12	60/80	0.05	0.29	7.37	II
12	60/80	0.05	0.33	7.81	II
12	60/80	0.03	0.33	6.84	II
12	60/80	0.01	0.33	8.22	II
12	60/80	0.05	0.43	8.35	II
12	60/80	0.01	0.33	31.16	II
12	60/80	0.05	0.33	23.73	II
12	60/80	0.03	0.37	25.49	II
12	-140	0.05	0.43	12.01	II
12	-140	0.05	0.15	14.84	II
12	-140	0.05	0.33	12.11	II
12	-140	0.03	0.33	12.21	II
12	-140	0.01	0.33	13.15	II

Table 30 (Continued)

List of Continous Experiments

Column diameter (in.)	Particle mesh size	Liquid velocity ft/sec	Gas velocity ft/sec	Solids conc. lb/ft^3	Distributor type
12	60/80	0.05	0.33	23.28	I
12	60/80	0.05	0.15	26.40	I
12	60/80	0.01	0.33	29.42	I
12	60/80	0.03	0.33	29.01	I
12	60/80	0.05	0.43	27.94	I
12	60/80	0.05	0.25	23.35	I
12	-140	0.05	0.43	4.18	I
12	-140	0.05	0.10	4.82	I
12	-140	0.04	0.33	4.44	I
12	-140	0.05	0.19	4.59	I
12	-140	0.02	0.33	4.58	I
5	60/80	0.05	0.40	4.8	
5	60/80	0.05	0.40	4.8	
5	-140	0.05	0.33	4.8	(a)
5	-140	0.05	0.33	4.8	(b)

(a) recycle
(b) continuous feed

Table 31

List of Continous Experiments

(Tetralin System)

Column diameter (in.)	Particle mesh size	Liquid velocity ft/sec	Gas velocity ft/sec	Solids conc. lb/ft^3	Distributor type
12	60/80	0.02	0.39	19.66	I
12	60/80	0.03	0.39	19.19	I
12	60/80	0.04	0.39	20.14	I
12	60/80	0.05	0.39	19.73	I
12	60/80	0.05	0.31	18.64	I
12	60/80	0.05	0.22	18.66	I
12	60/80	0.05	0.13	18.38	I
12	-140	0.02	0.39	15.09	I
12	-140	0.03	0.39	14.15	I
12	-140	0.04	0.39	14.55	I
12	-140	0.05	0.39	13.23	I
12	-140	0.05	0.31	13.63	I
12	-140	0.05	0.22	13.86	I

Table 32

List of Continous Experiments

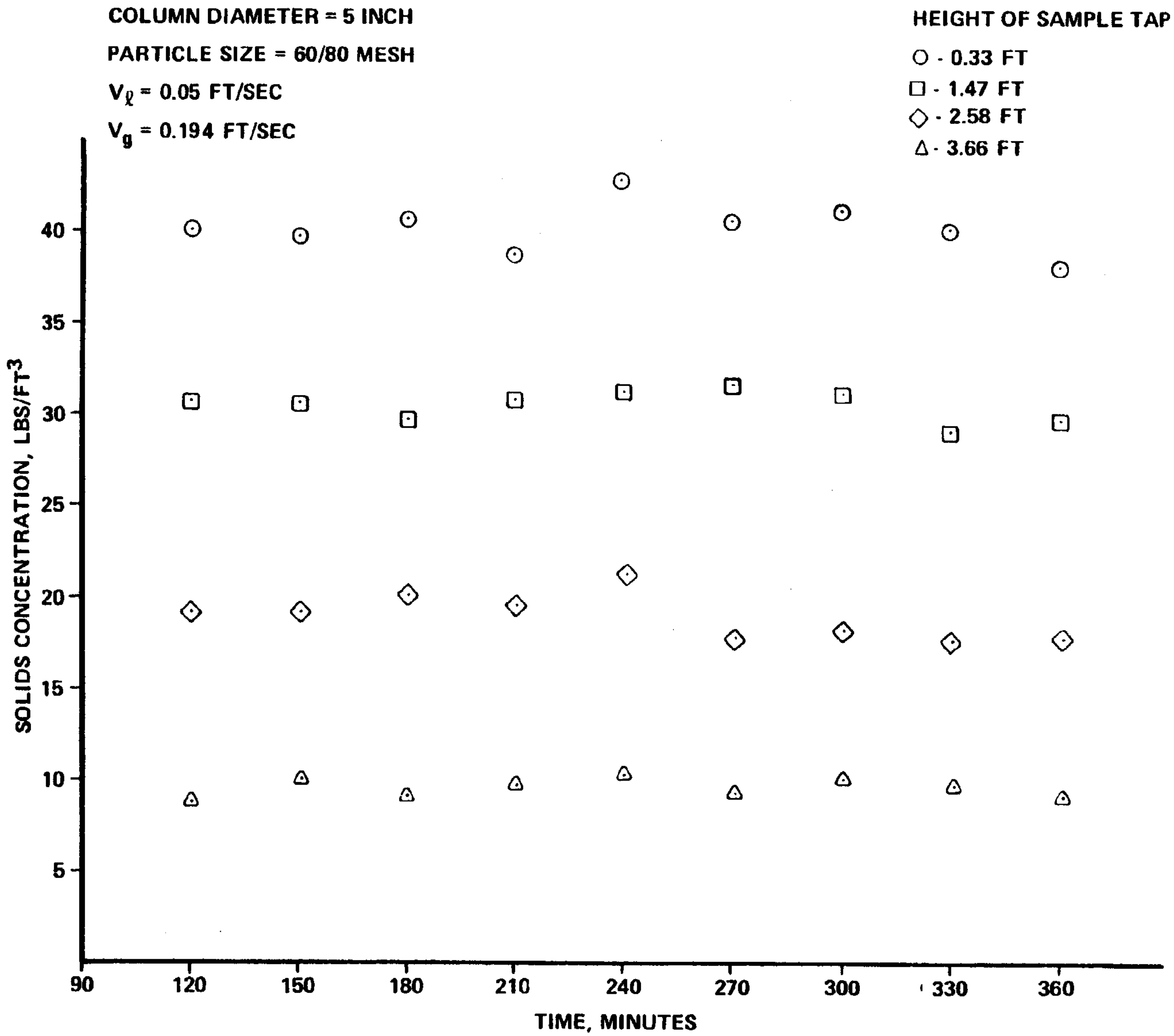
(50% Glycol System)

Column diameter (in.)	Particle mesh size	Liquid velocity ft/sec	Gas velocity ft/sec	Solids conc. lb/ft^3	Distributor type
12	60/80	0.18	0.04	21.99	I
12	60/80	0.03	0.05	21.43	I
12	60/80	0.05	0.05	18.12	I
12	60/80	0.01	0.05	15.84	I
12	-140	0.03	0.05	15.32	I
12	-140	0.05	0.05	11.06	I
12	60/80	0.01	0.02	21.33	I
12	60/80	0.03	0.20	19.56	I
12	60/80	0.05	0.19	16.76	I
12	-140	0.01	0.02	14.18	I
12	-140	0.03	0.02	14.57	I
12	-140	0.05	0.02	13.42	I
12	60/80	0.01	0.40	21.24	I
12	60/80	0.03	0.40	19.05	I
12	60/80	0.05	0.40	16.08	I
12	-140	0.01	0.40	13.77	I
12	-140	0.03	0.40	13.44	I
12	-140	0.05	0.40	12.37	I

I - Distributor plate no. 1 with bubble cap.

II - Distributor plate no. 2 with no bubble cap.

Figure 89. **TYPICAL EXPERIMENTAL DATA FOR AXIAL SOLIDS DISTRIBUTION**



fresh batches of slurry, was very inefficient. The recycle mode, which was used in this work, was more practical. These two modes were compared to determine any appreciable differences.

Figure 90 plots a run from each mode, and Figure 91 plots the non-dimensionalized concentration values, with respect to feed concentration. Although the feed concentrations in both runs are about 10% different, the profile did not seem to vary appreciably. This reinforces the belief that concentration distributions between continuous and recycle runs can be the same if all other run conditions are the same.

The effect of gas velocity on the distribution of fine particles (-140 mesh sand) in all three liquids (water, tetralin, and 50% glycol solution) are displayed in Figures 92-97. Figure 92 shows that at a constant sand/water slurry velocity of 0.05 ft/sec, increasing the gas velocity from 0.10 to 0.43 ft/sec resulted in very little change in solids distribution across the length of the column. A similar result was observed at a higher feed solids concentration as shown in Figure 93. An increase in gas velocity from 0.33 to 0.43 ft/sec resulted in an identical profile. At a gas velocity of 0.15 ft/sec, because of the difference in feed concentration, the profile was different than those at higher gas velocities. But the slopes are identical at all three gas velocities indicating that changes in gas velocity do not appreciably affect the axial solids distribution. Similar results were found in tetralin and 50% glycol solution as shown in Figures 94-97. These results confirm earlier findings from batch experiments (no liquid flow) that gas velocity has practically no effect on the distribution of the fine particles.

The effects of gas velocity on the distribution of large particles (60/80 mesh sand) in all three liquids are shown in Figures 98-104. In general the results are similar to those observed with fine particles; gas velocity has little effect on solid distribution provided that the gas velocity is higher than the critical gas velocity which is defined as the minimum gas velocity necessary to suspend the solid particles. Earlier we had shown that for fine

Figure 90

COMPARISON OF CONTINUOUS FEEDING AND RECYCLE RUNS

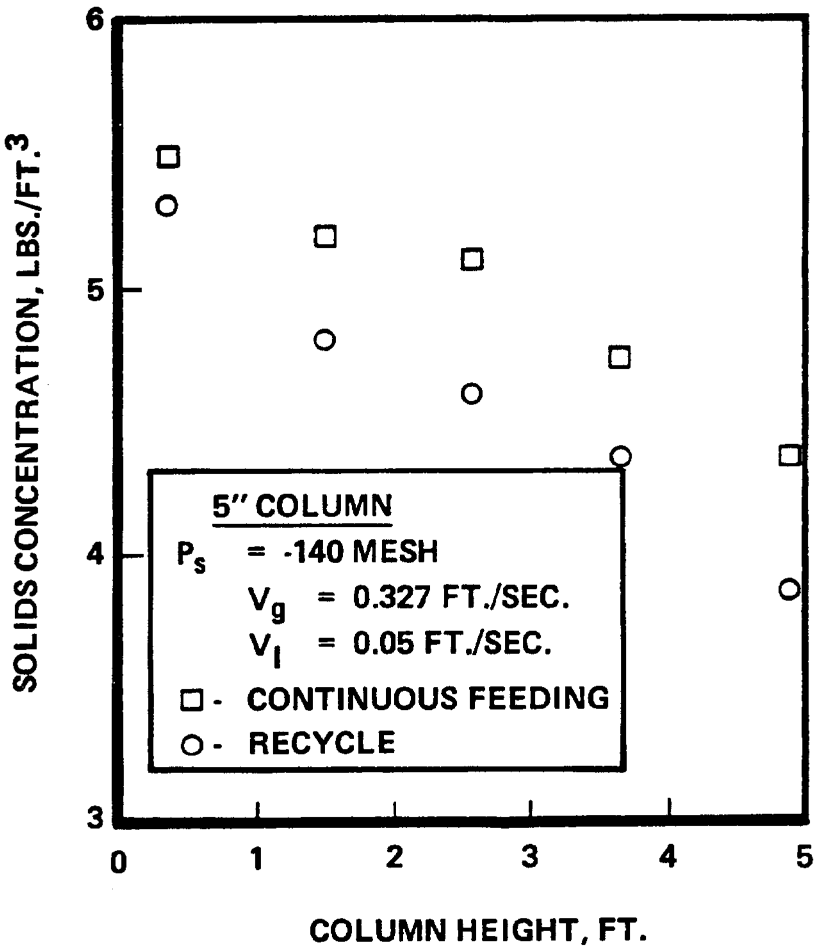


FIGURE 91

COMPARISON OF CONTINUOUS FEEDING AND RECYCLE RUNS USING NORMALIZED SOLIDS CONCENTRATION

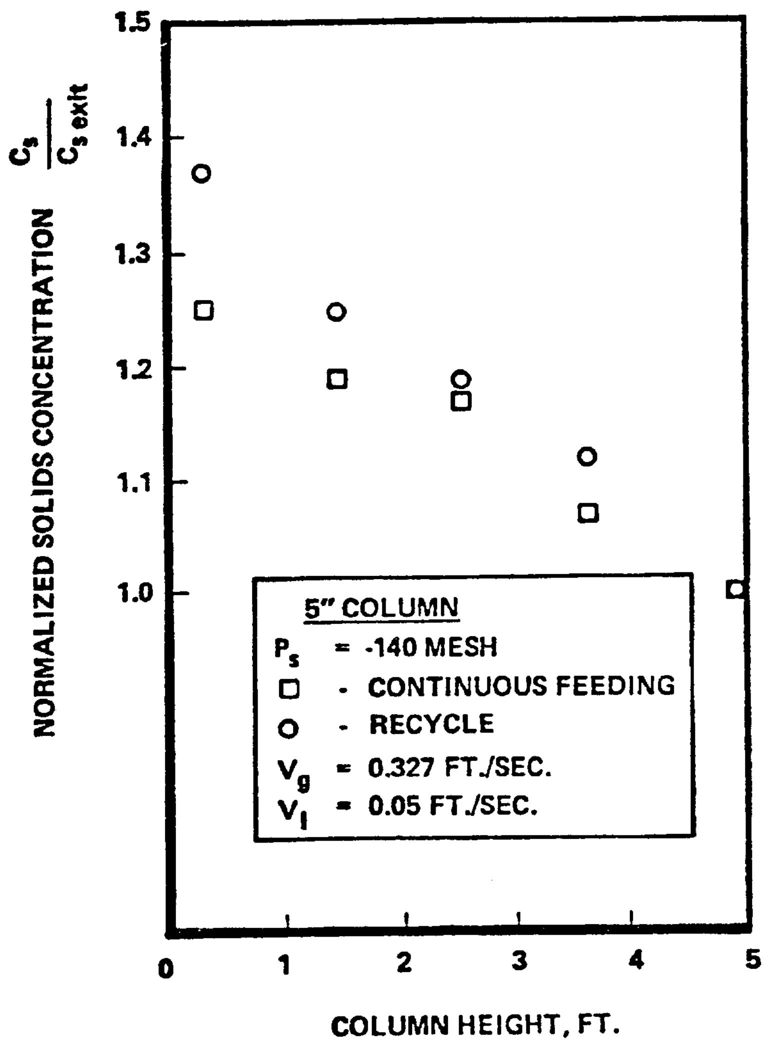


Figure 92

EFFECT OF GAS VELOCITY ON SOLIDS DISTRIBUTION

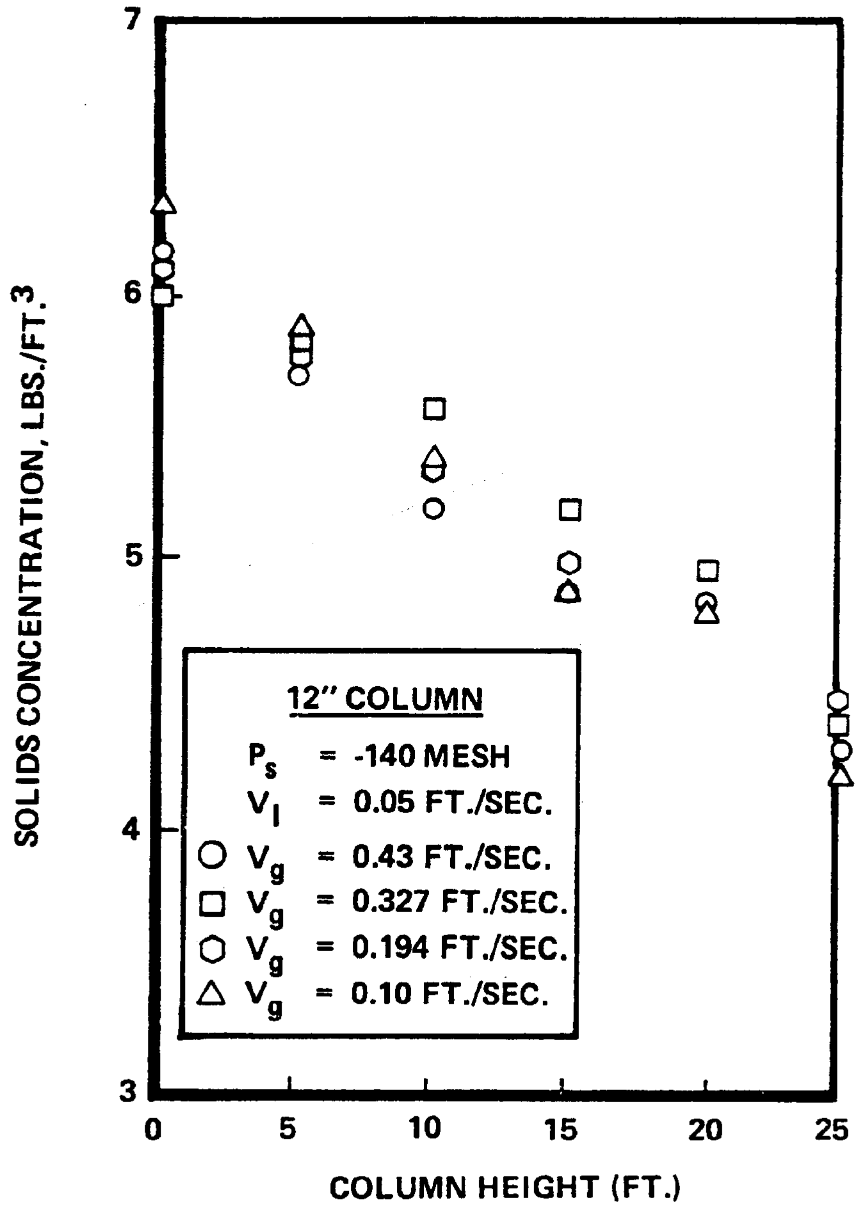


Figure 93. **EFFECT OF GAS VELOCITY ON THE DISTRIBUTION OF FINE PARTICLES**

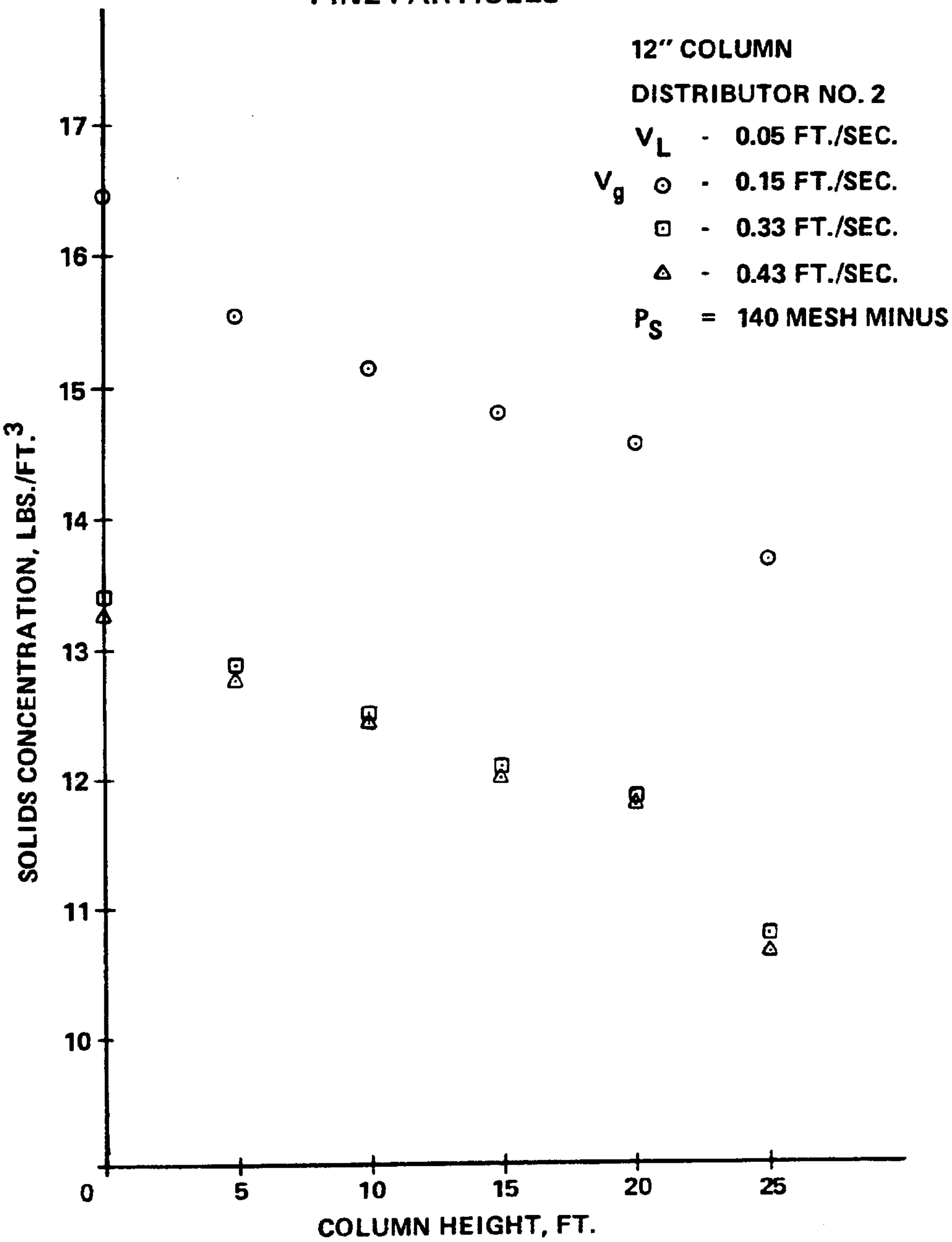


Figure 94

Concentration Versus Length in a 12-Inch Column

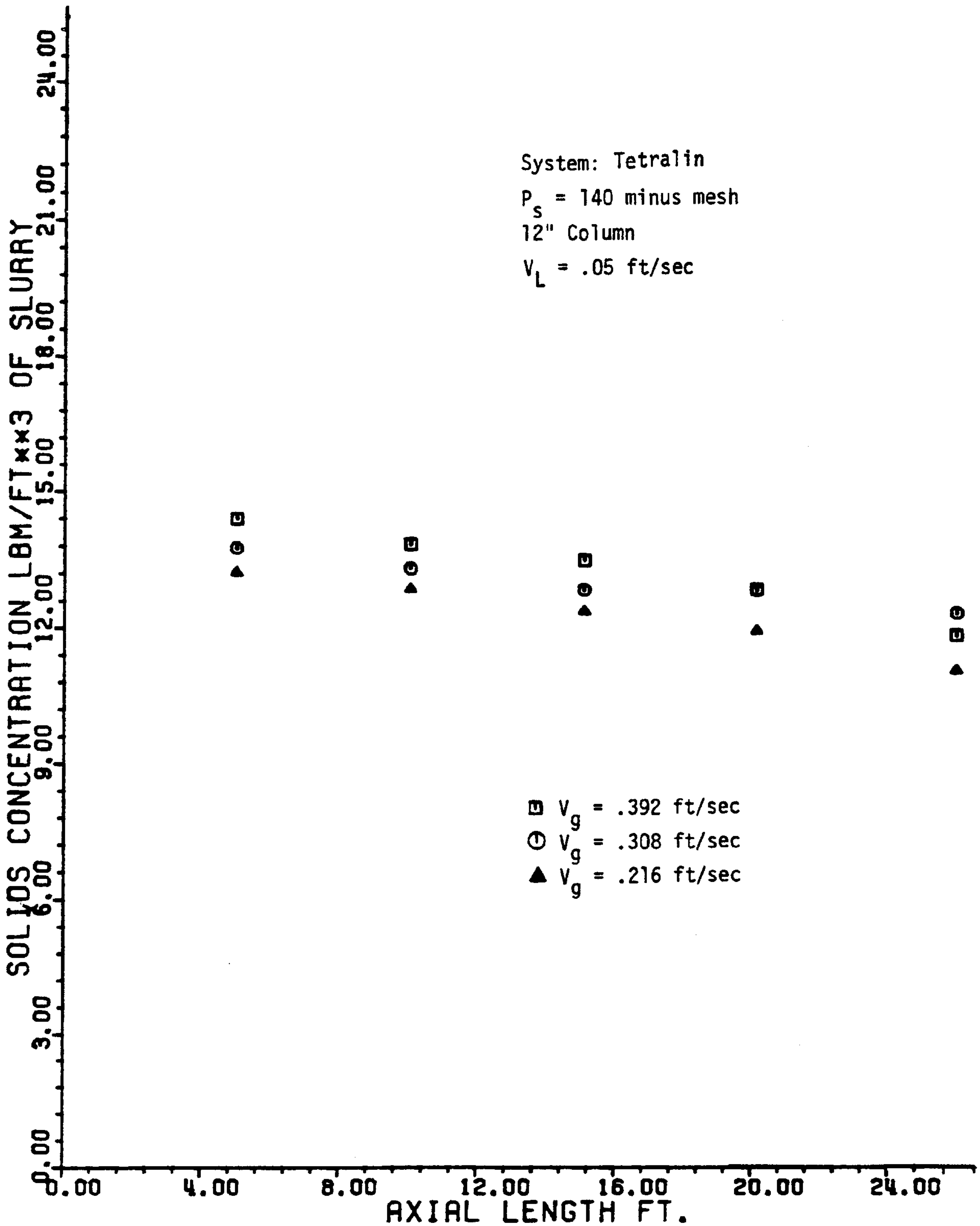


Figure 95

Solids Distribution Profile

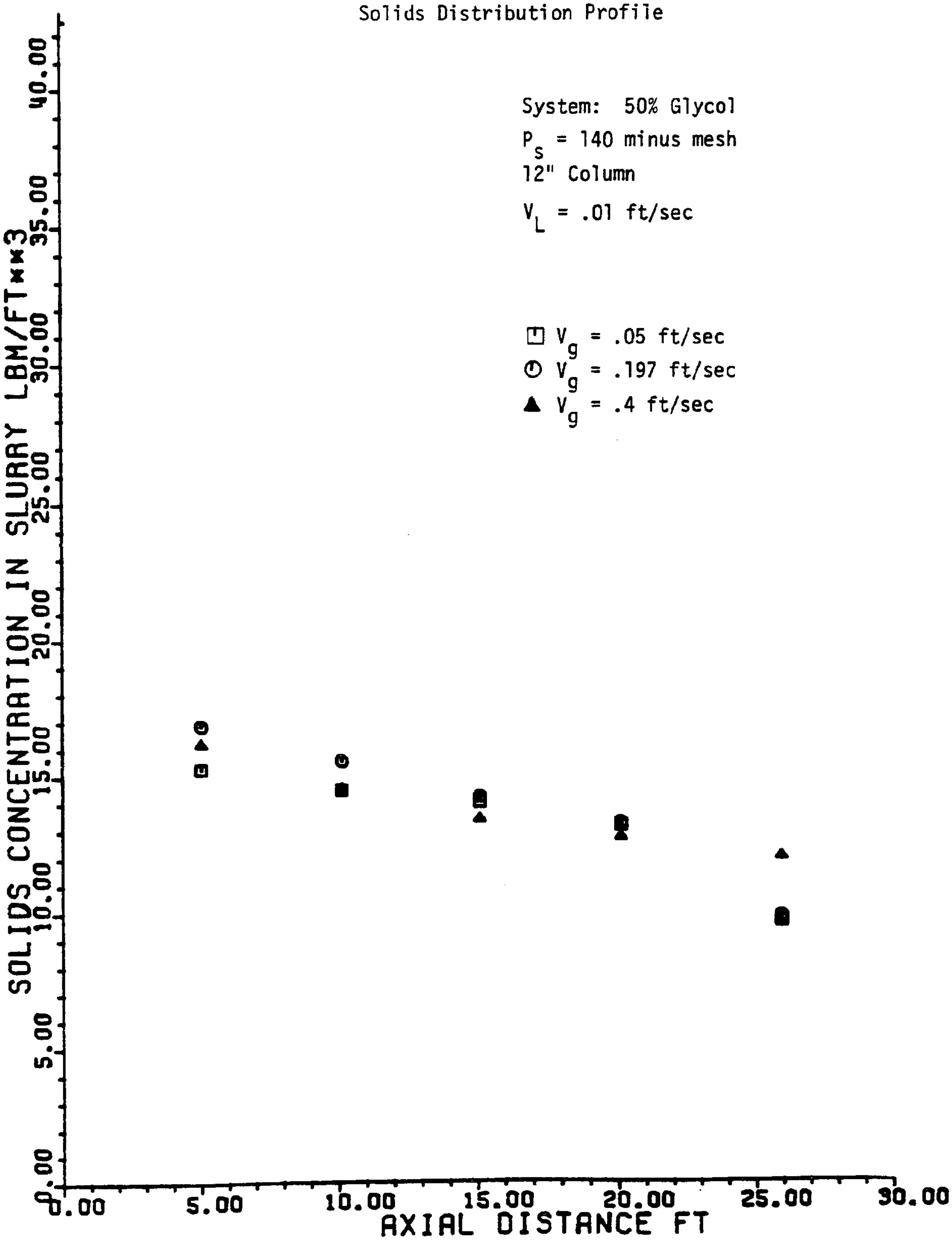


Figure 96

Solids Distribution Profile

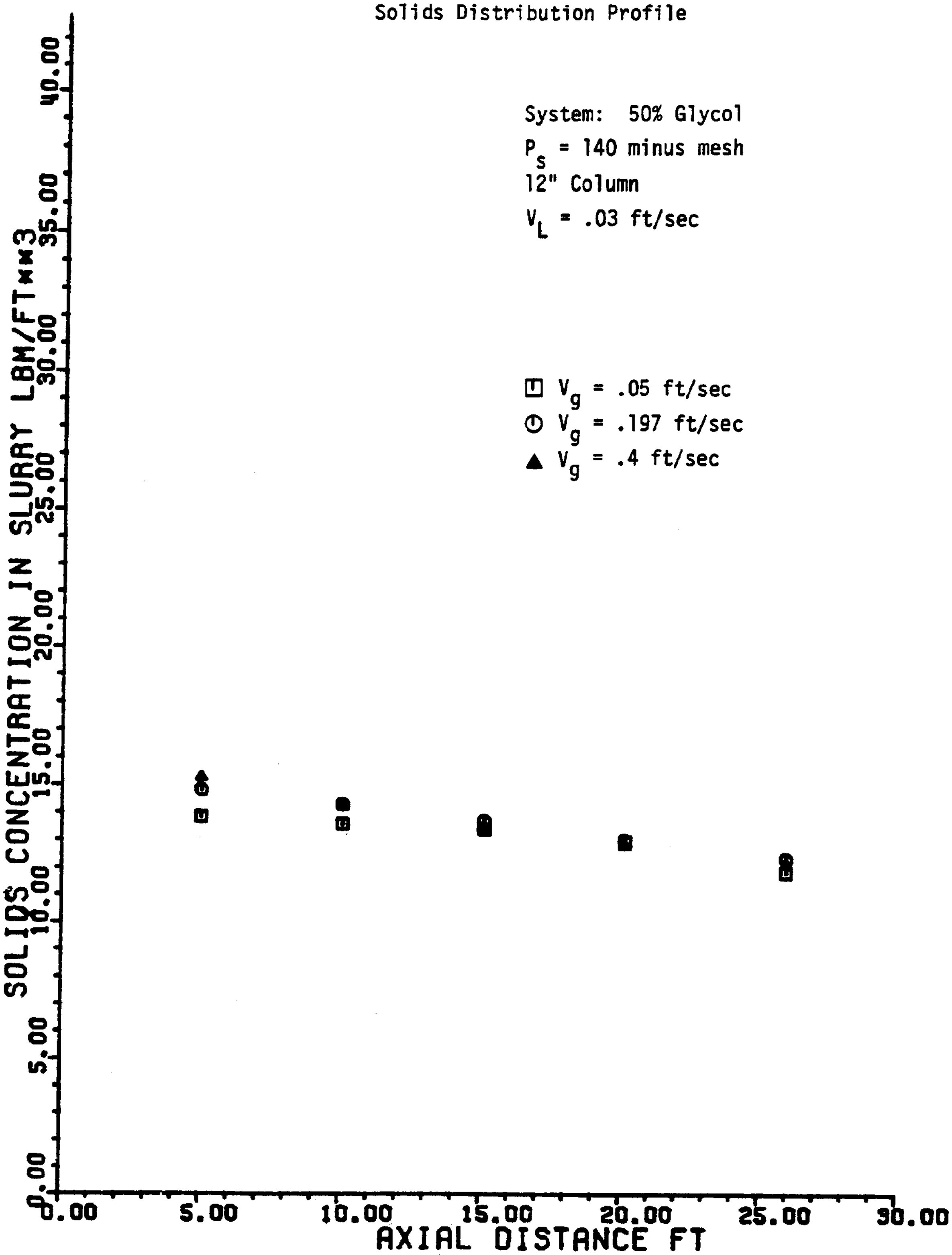


Figure 97

Solids Distribution Profile

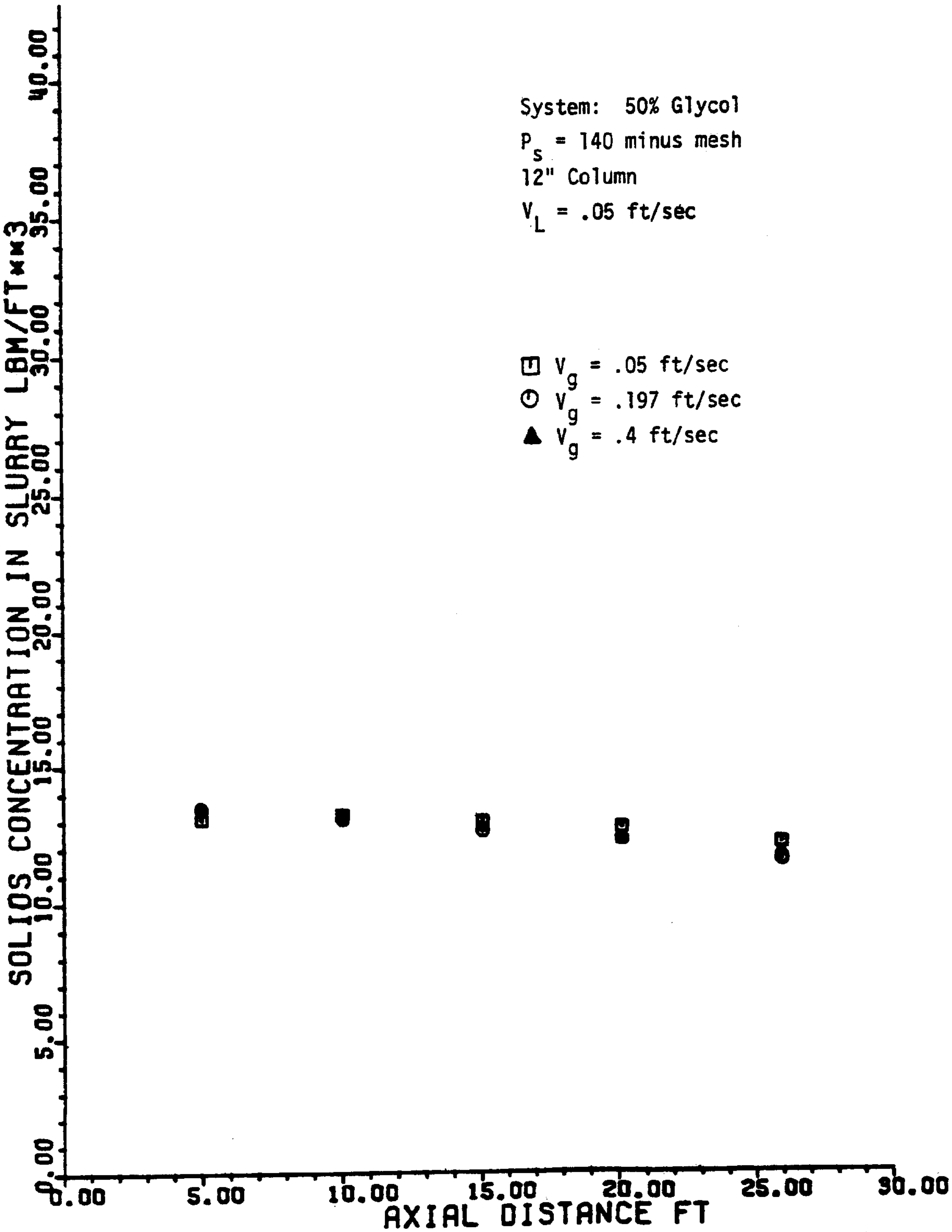


Figure 98. **EFFECT OF GAS VELOCITY ON SOLIDS DISTRIBUTION**

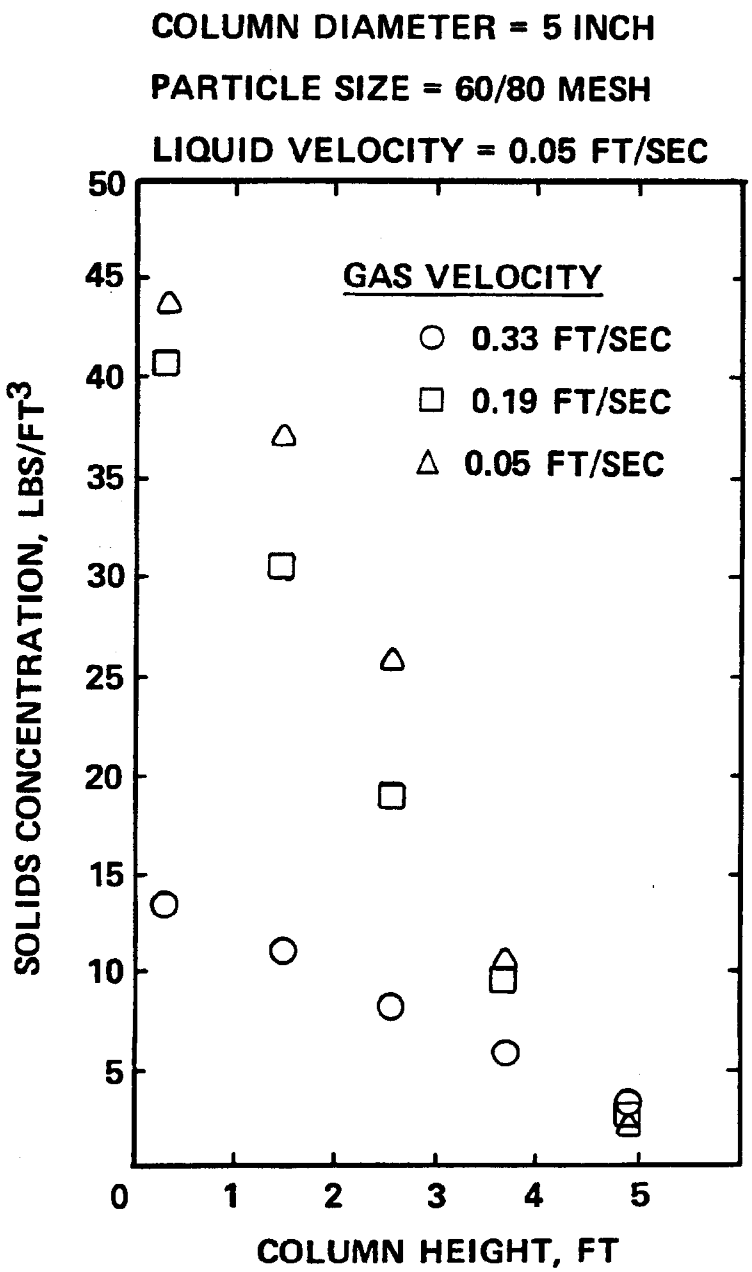


Figure 99. **EFFECT OF GAS VELOCITY ON THE DISTRIBUTION OF LARGE PARTICLES**

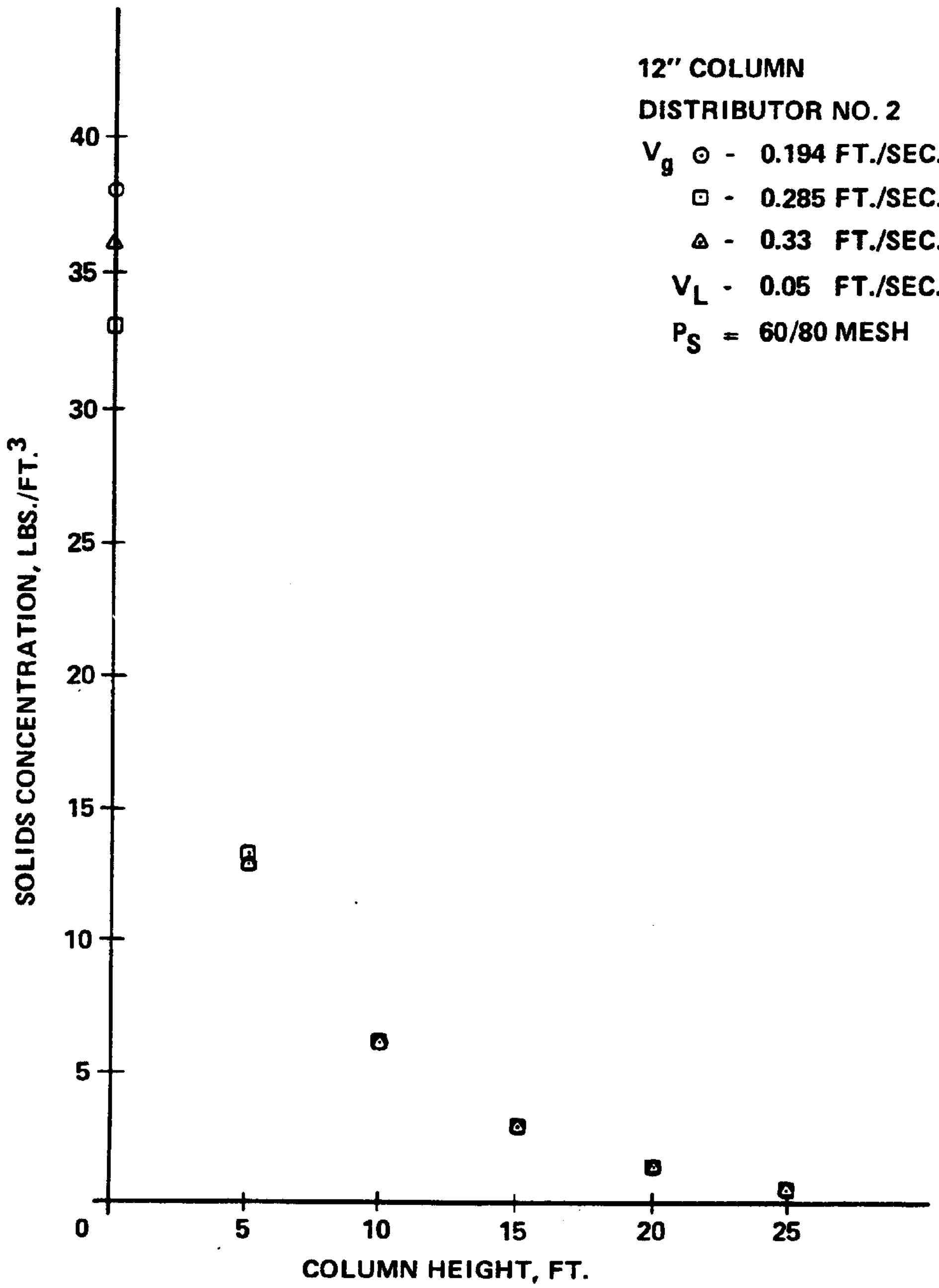


Figure 100. **EFFECT OF GAS VELOCITY ON AXIAL SOLIDS DISTRIBUTION**

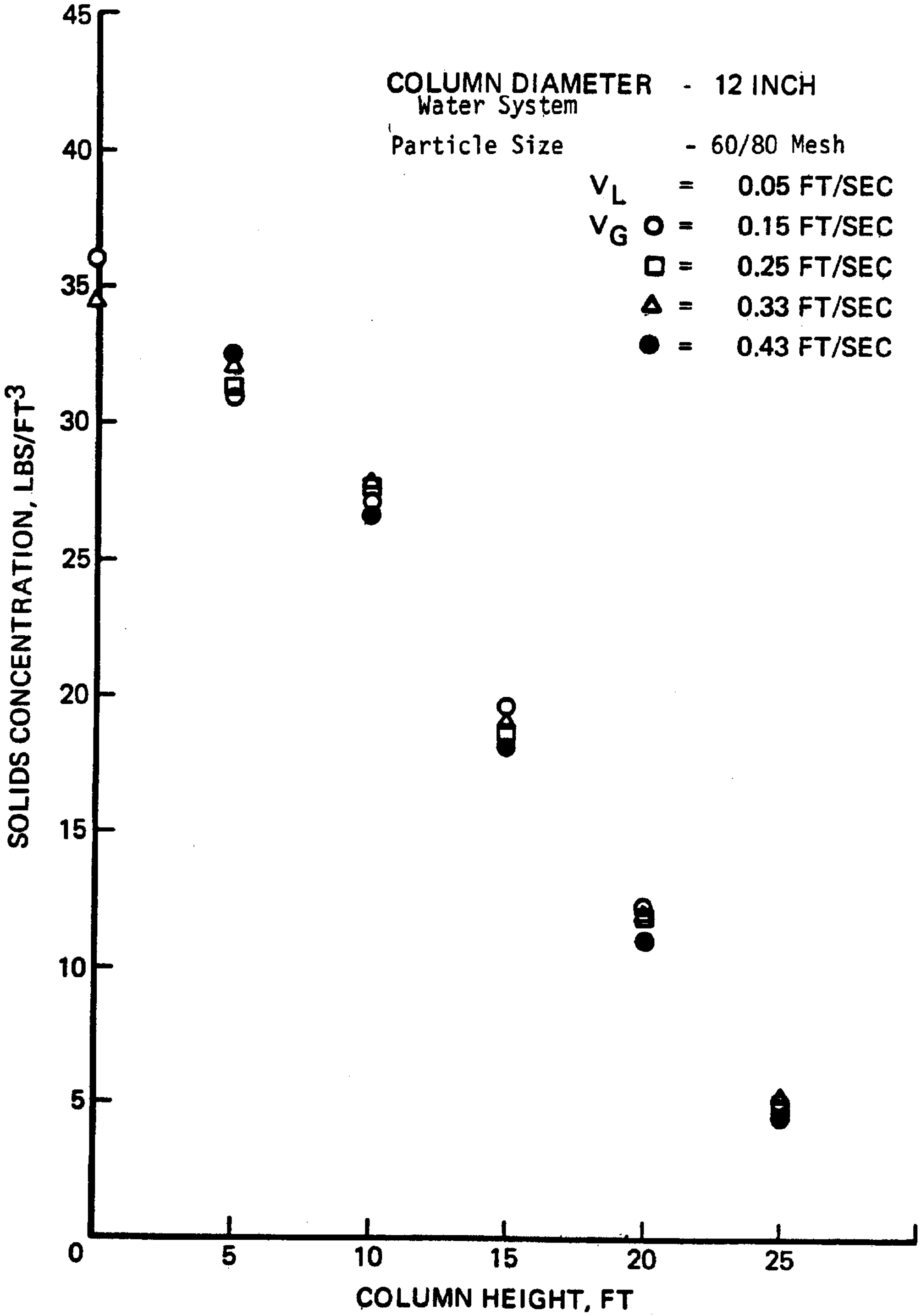


Figure 101

Concentration Versus Length in a 12-Inch Column

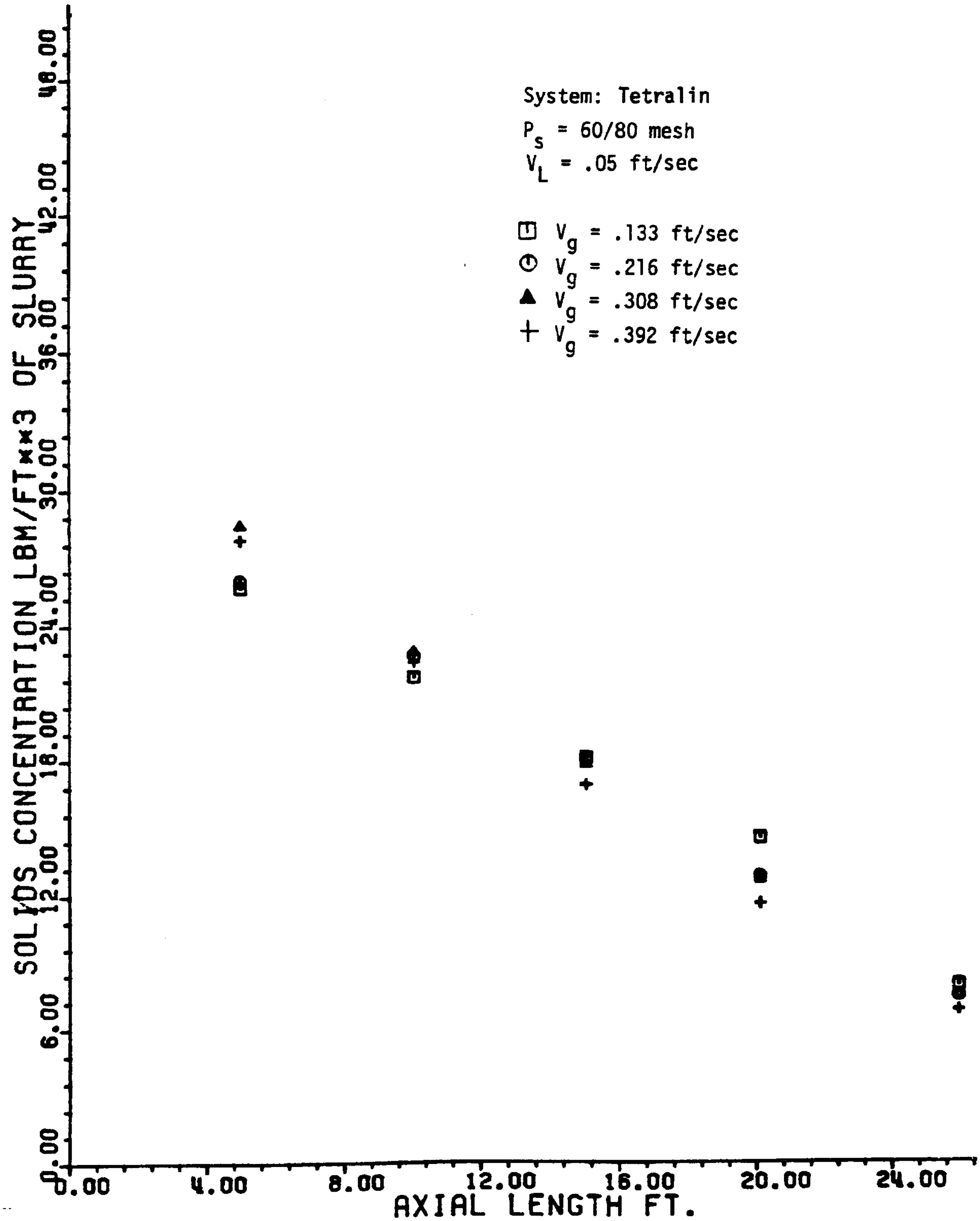


Figure 102

Solids Distribution Concentration Versus Axial Length

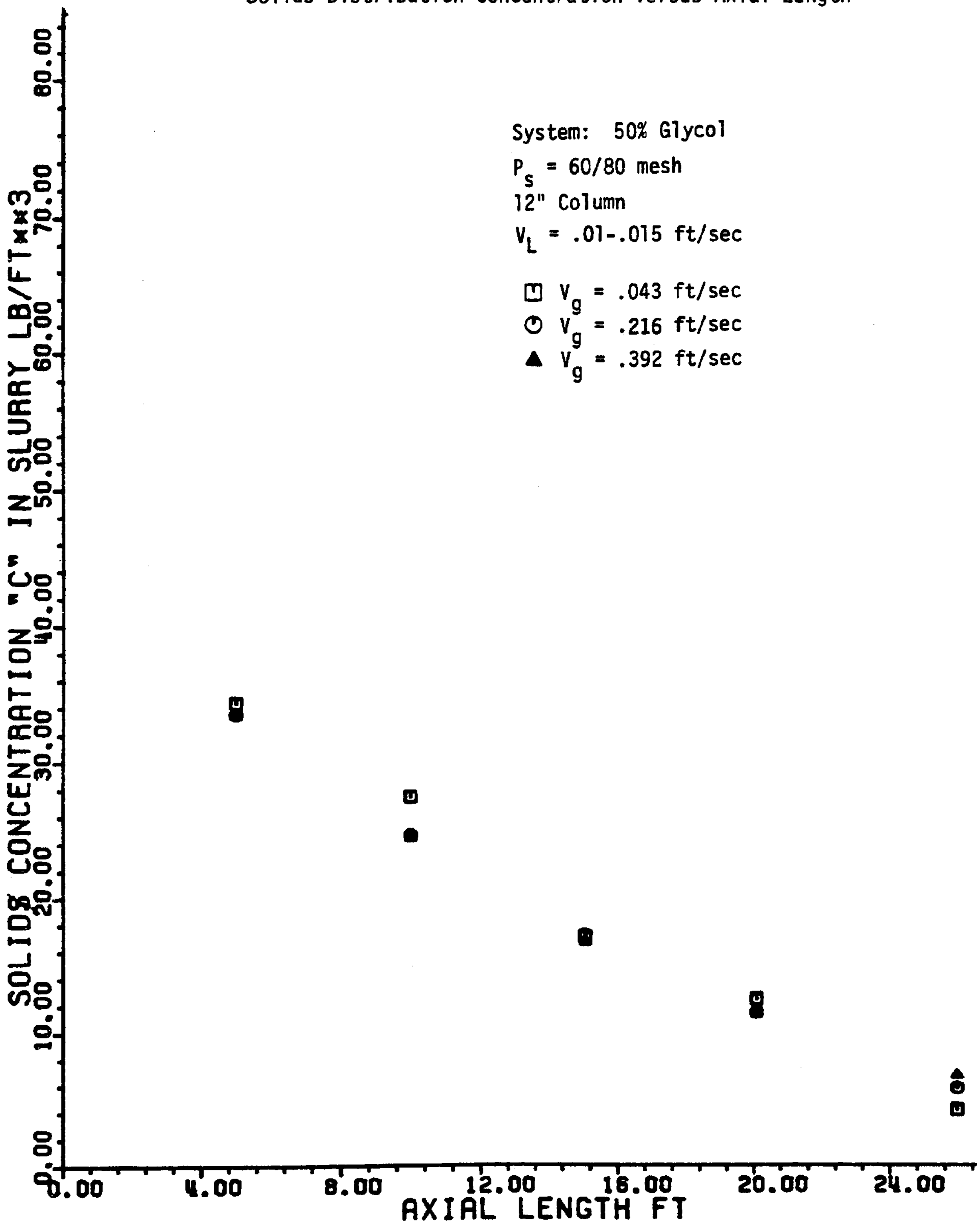


Figure 103

Solids Distribution Concentration Versus Axial Length

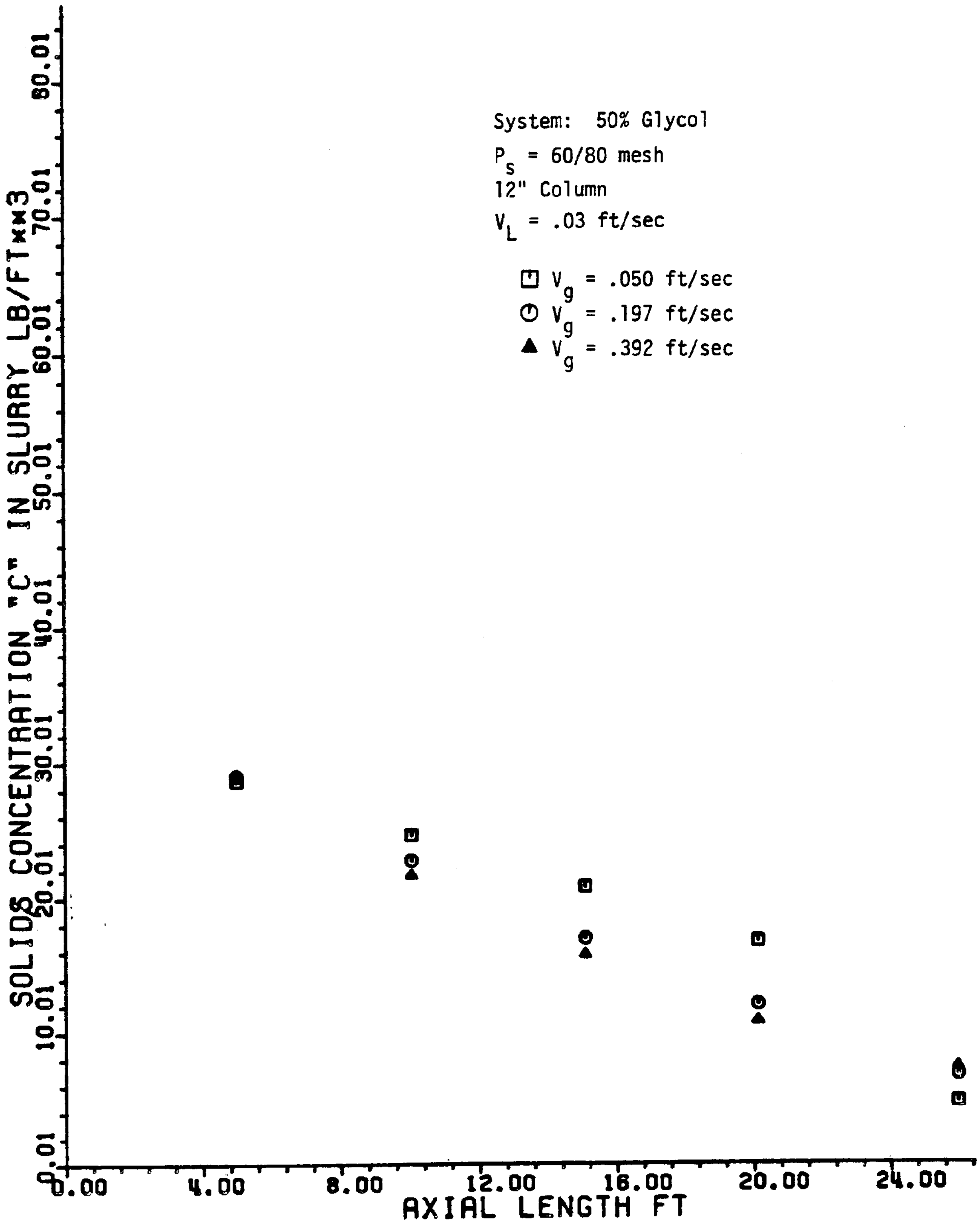
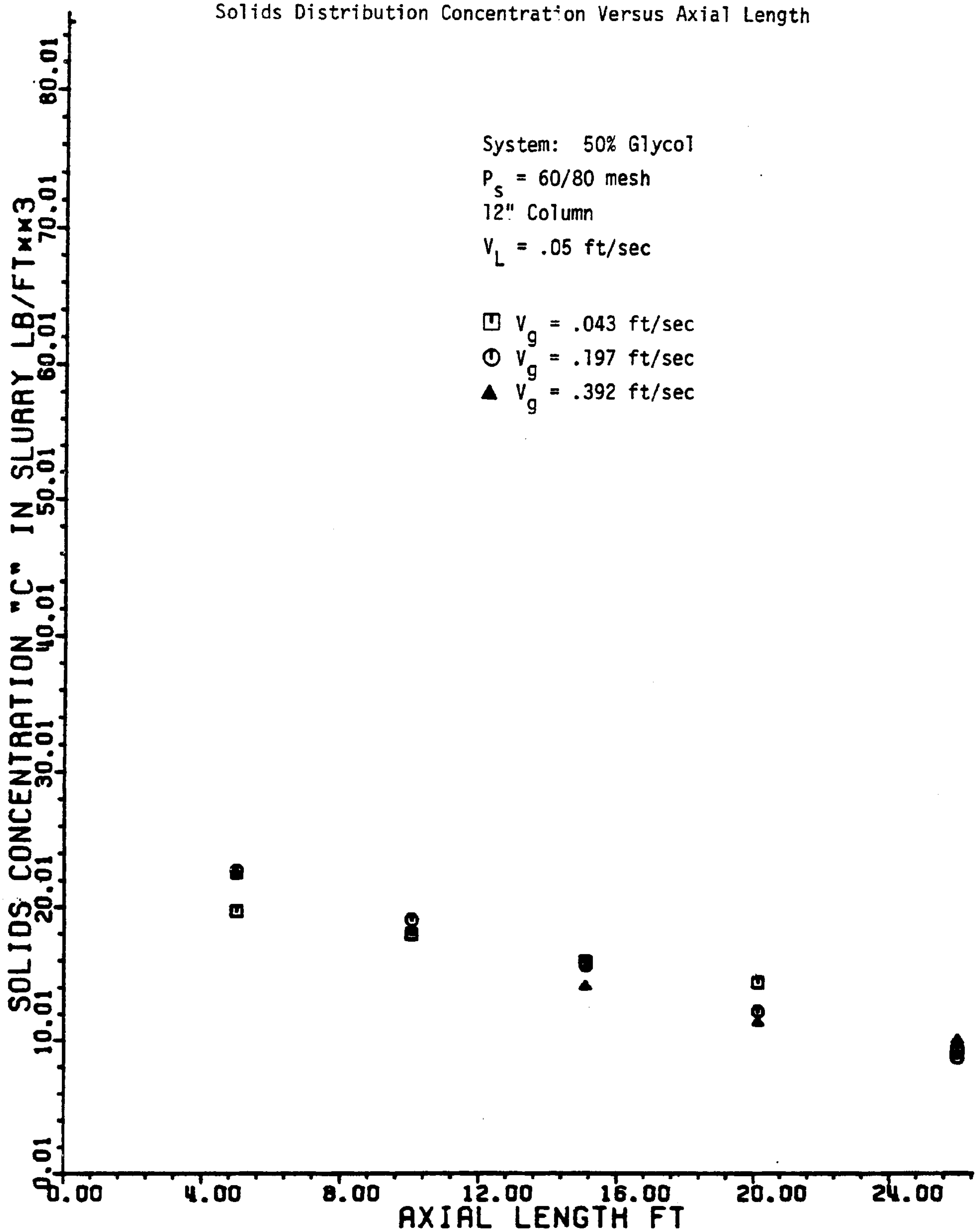


Figure 104

Solids Distribution Concentration Versus Axial Length



particles (-140 mesh) changes in the gas velocity did not significantly affect the solids concentration profiles. All the velocities with the -140 mesh solids were above the critical gas velocities for these solids.

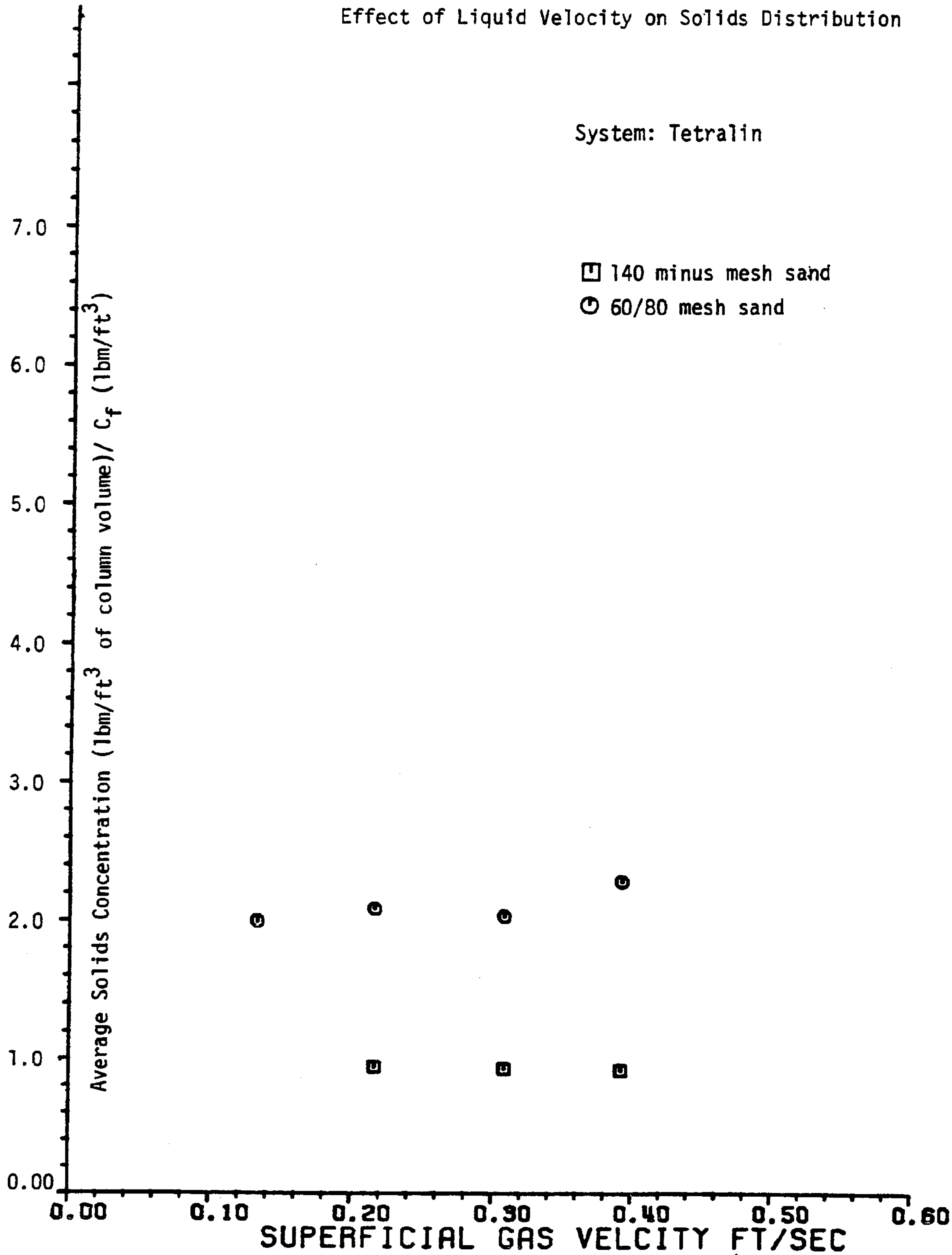
Figure 98 plots the data on 60/80 mesh particles in a 5-in. diameter column. Although increasing gas velocity from 0.05 to 0.194 ft/sec did not change the solids accumulation, increasing up to 0.327 ft/sec resulted in a dramatic decrease. Since the critical gas velocity for 60/80 mesh particles is around 0.2 ft/sec, at the higher 0.327 ft/sec velocity no settled solids will be present in the column thereby sharply decreasing the solids concentration profile.

The lack of independence on gas velocity can be clearly illustrated in Figure 99 and 100. Figure 99 plots the distribution of the 60/80 mesh particles in a 12-in. diameter column. Although the critical gas velocity of these particles in the 12-in. diameter column was not measured, it is believed to be less than that determined in the 5-in. diameter column (0.2 ft/sec) because of the increased turbulence in the larger diameter column as discussed earlier in the liquid dispersion section. Therefore Figure 99 shows that for 60/80 mesh particles, increasing gas velocity from 0.194 to 0.33 ft/sec did not change the solids concentration in the bulk of the column though a slight difference at the bottom of the column was observed. This slight difference at the column bottom could be due to sampling erros at this very high solids concentration region. Nevertheless, the results shown in Figure 99 illustrate the independence of gas velocity on solid accumulation beyond the critical gas velocity. Likewise gas velocity does not affect the distribution of the 60/80 mesh particles in tetralin and 50% glycol solution as shown in Figures 101-104.

In addition, Figure 105 graphs the ratio of average column solids concentration/feed concentration as a function of gas velocity. The invariance found over a four-fold increase in gas velocity for the fine particles (-140 mesh) strongly indicates the lack of any

Figure 105

Effect of Liquid Velocity on Solids Distribution



dependence on gas velocity. One may note the slightly higher value at 0.4 ft/sec for the 60/80 mesh particles. However, the difference is so small that the effect of gas velocity on the 60/80 mesh particle concentration will be minimal.

Liquid velocity has a more pronounced effect on the solids distribution profiles. The steepness of the profile decreases with an increase in liquid velocity. As liquid velocity increases, the convective force increases and ultimately creates a homogeneous mixture. This also means that net solids accumulation in the column will decrease.

Figures 106-109 show the effect of liquid velocity on the distribution of large particles (60/80 mesh sand). A general trend was observed: more solids were retained in the column as liquid velocity decreased. The concentration profile in the 5-in. diameter column rose dramatically as the liquid velocity was reduced from 0.05 to 0.01 ft/sec as shown in Figure 106. The effect of liquid flow was less dramatic though persistent in the 12-in. diameter column as illustrated in Figures 107-109 because of the enhanced turbulence in a larger diameter column.

It is interesting to note that the exit concentrations (Figures 106-109) varied only slightly with liquid velocity. This slight variation in exit concentration was due to the experimental technique employed in this study. The exit concentration should be identical to feed concentrations at steady-state conditions. For all the recycle experiments a known amount of material was used to make up the slurry inventory which was circulated through the column until steady state was achieved. Hence, the steady state feed concentration would be higher for those experiments with lower solids accumulation in the column. The direction of variation in exit concentration supports the effect of liquid velocity discussed above; the lowest liquid flow rate having the least feed concentration had the highest retained solid concentration which strongly supported the results of increasing solid accumulation with decreasing liquid velocity.

Figure 106. **EFFECT OF LIQUID VELOCITY ON SOLIDS DISTRIBUTION**

COLUMN DIAMETER = 5 INCH

PARTICLE SIZE = 60/80 MESH

GAS VELOCITY = 0.327 FT/SEC

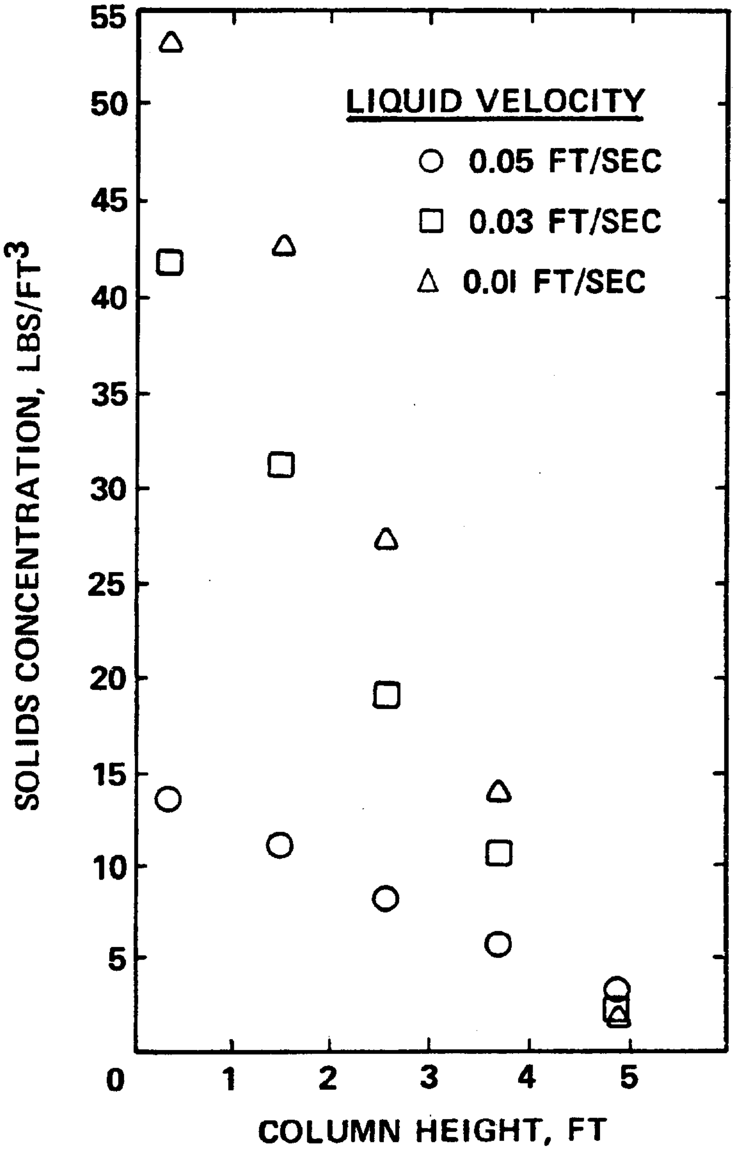


Figure 107. **EFFECT OF LIQUID VELOCITY ON AXIAL SOLIDS DISTRIBUTION**

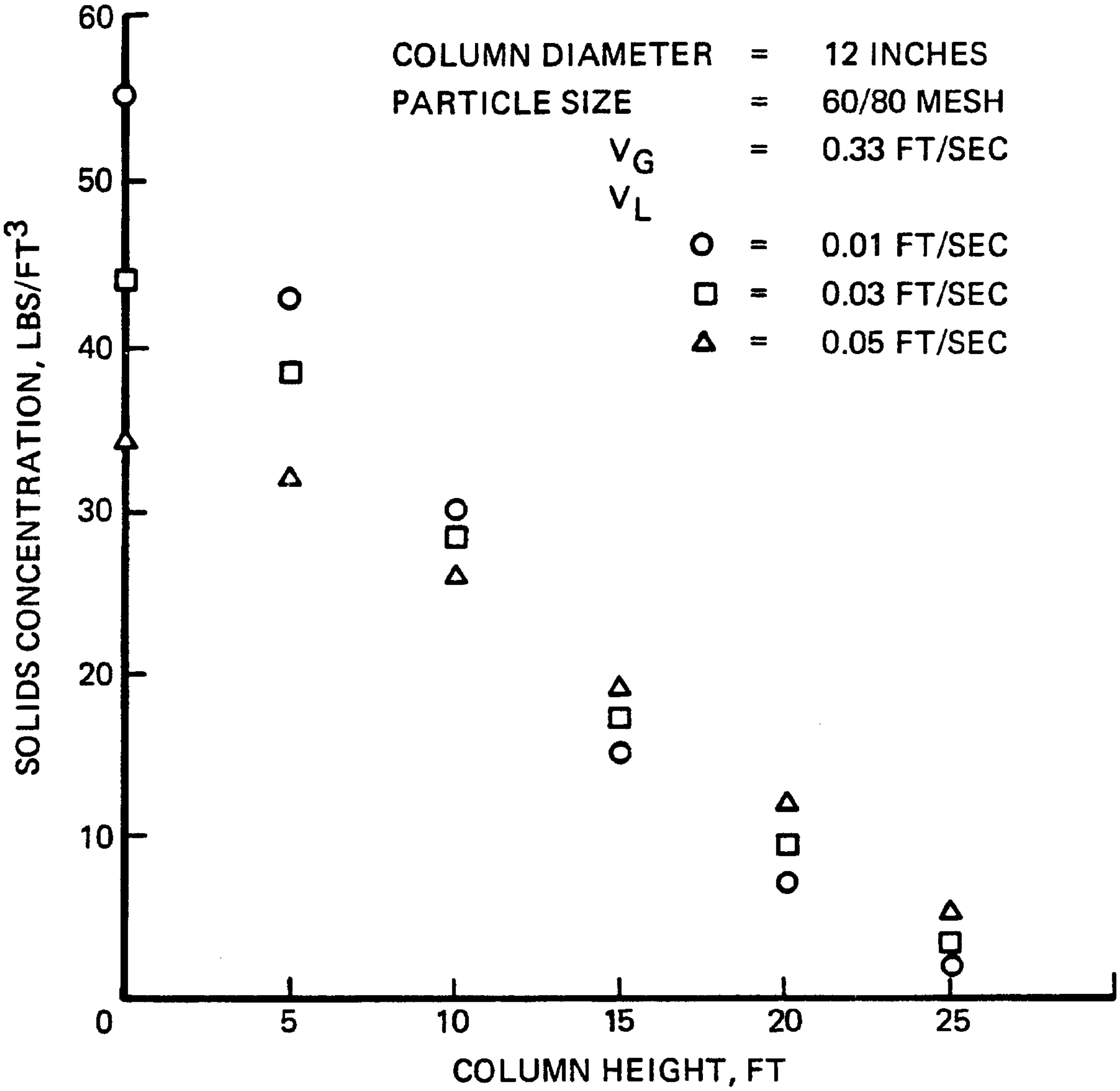


Figure 108. **EFFECT OF LIQUID VELOCITY ON THE DISTRIBUTION OF LARGE PARTICLES**

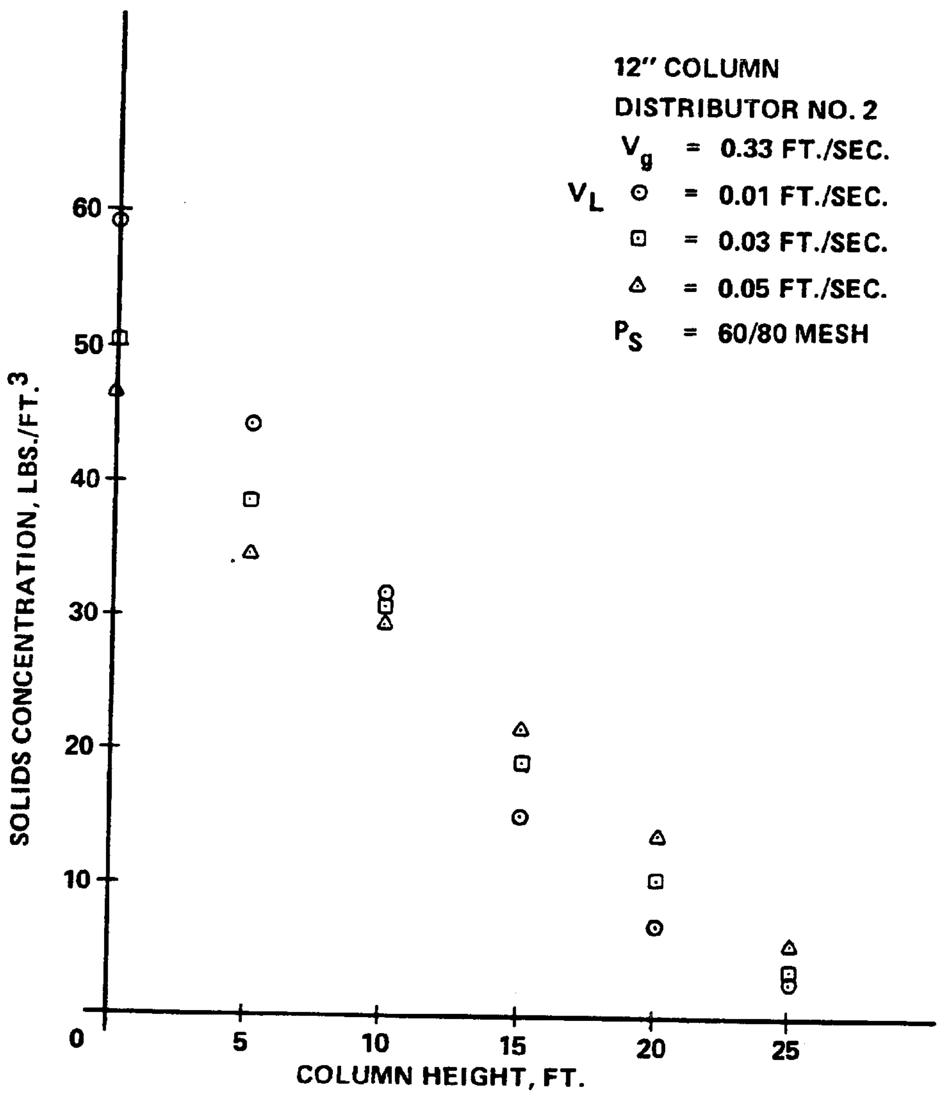
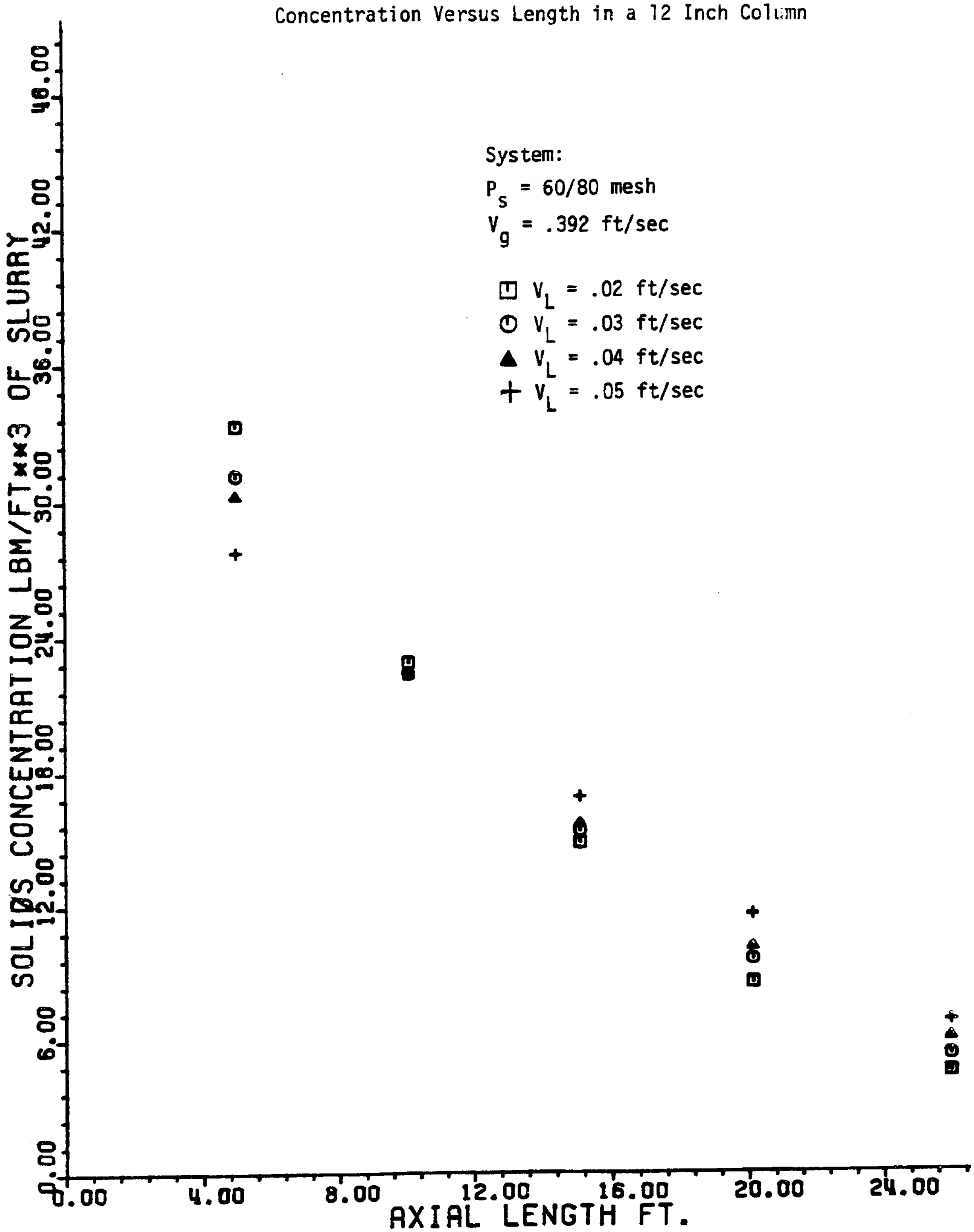


Figure 109

Concentration Versus Length in a 12 Inch Column



Under the conditions tested in this study, a linear relationship exists between liquid velocity and solids accumulation as shown in Figures 110-112. To eliminate the slight varations in exit concentration, Figures 110-112 plot the ratio of average column solids concentration/exit concentration as a function of liquid velocity. The average column solids concentration was determined by integrating the concentration profiles shown in Figures 106-109. These graphs clearly illustrate the effect of liquid velocity on solids accumulation. Less solids accumulation was found in tetralin (Figure 112) than in water primarily because of the viscosity effect. Particle terminal velocity is lower in a more viscuous liquid (tetralin vs. water) and can be carried through the column easier by the bulk flow. Therefore, less accumulation was found in tetralin.

A similar effect of liquid velocity was found on the distribution and accumulation of fine particles (-140 mesh) as shown in Figures 113-115. As liquid velocity increases, the accumulation of the fine particles decreased. But the effect was much less dramatic than that observed with the 60/80 mesh particles because the fine particles were more homogeneously mixed. In addition, a linear relationship between liquid velocity and solids accumulation was also observed as shown in Figure 116.

Following the above discussion, the effect of particle size on solids distribution is quite obvious. Figures 117 and 118 graph the comparison of the concentration profiles between -140 mesh and 60/80 mesh sand. With the larger particles at identical flow conditions, more solids accumulate. This effect is expected because the terminal velocity of larger particles would make the profile steeper assuming that the particle size does not have a strong effect on the axial solids dispersion coefficient.

The hydrodynamic effect in the absence of a distributor was evaluated using air/water/-140 mesh sand in a 12-in. diameter column. For fine particles at low concentrations the solids concentration decreases almost linearly with column height as shown in Figure 119 for both

Figure 110. **EFFECT OF LIQUID VELOCITY ON SOLIDS ACCUMULATION**

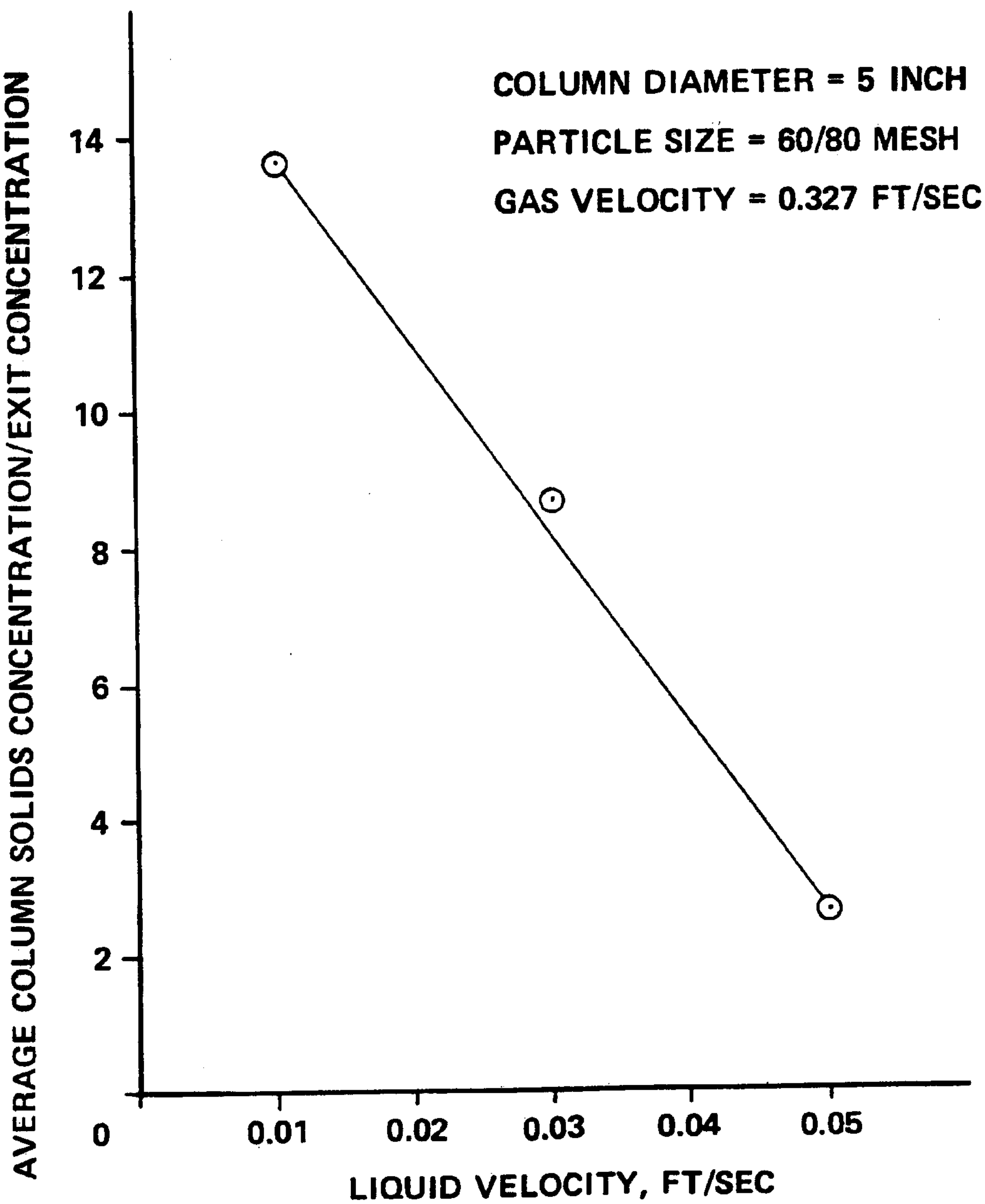


Figure 111. **EFFECT OF LIQUID VELOCITY ON SOLIDS RETENTION**

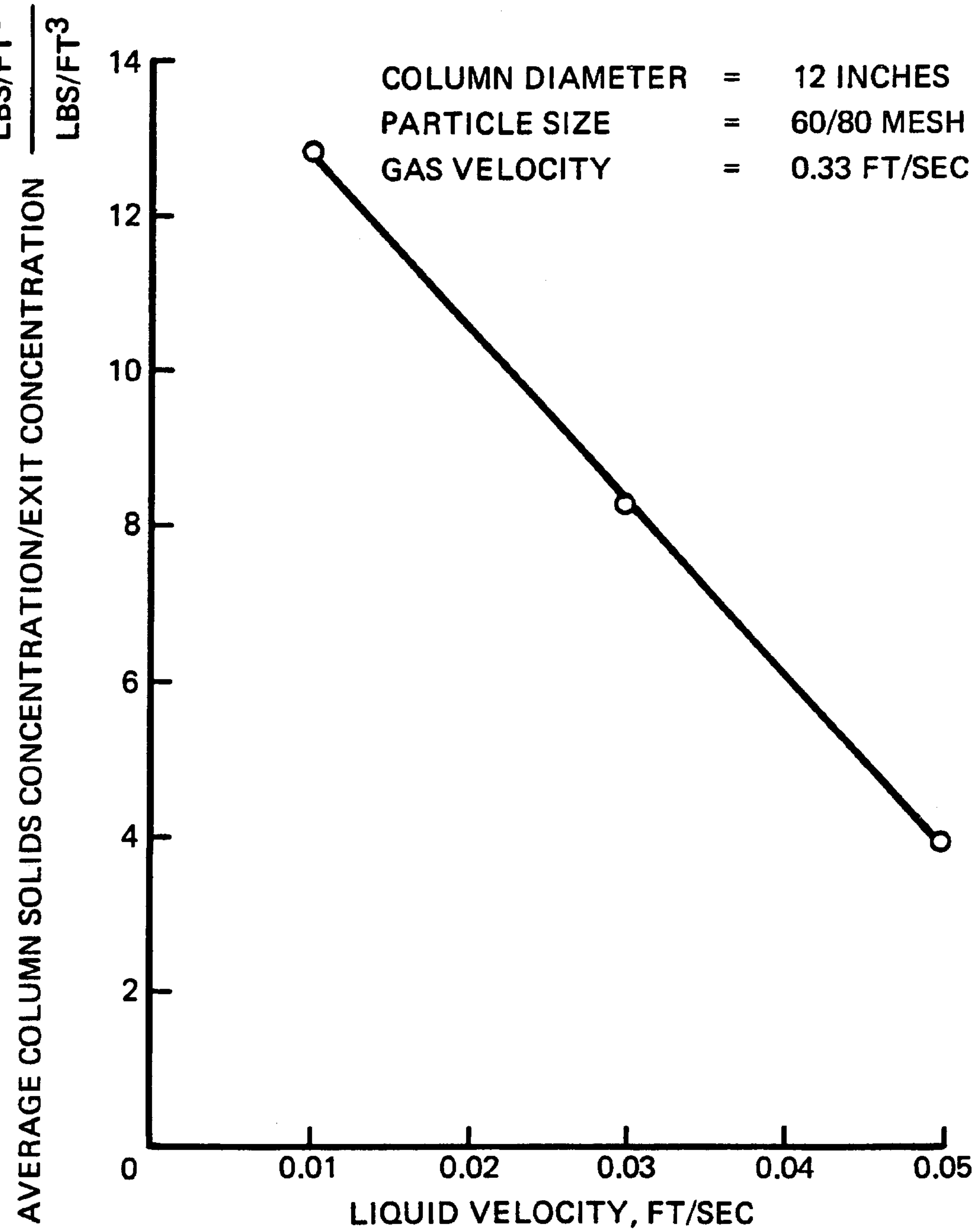


Figure 112

Effect of Liquid Velocity on Solids Accumulation

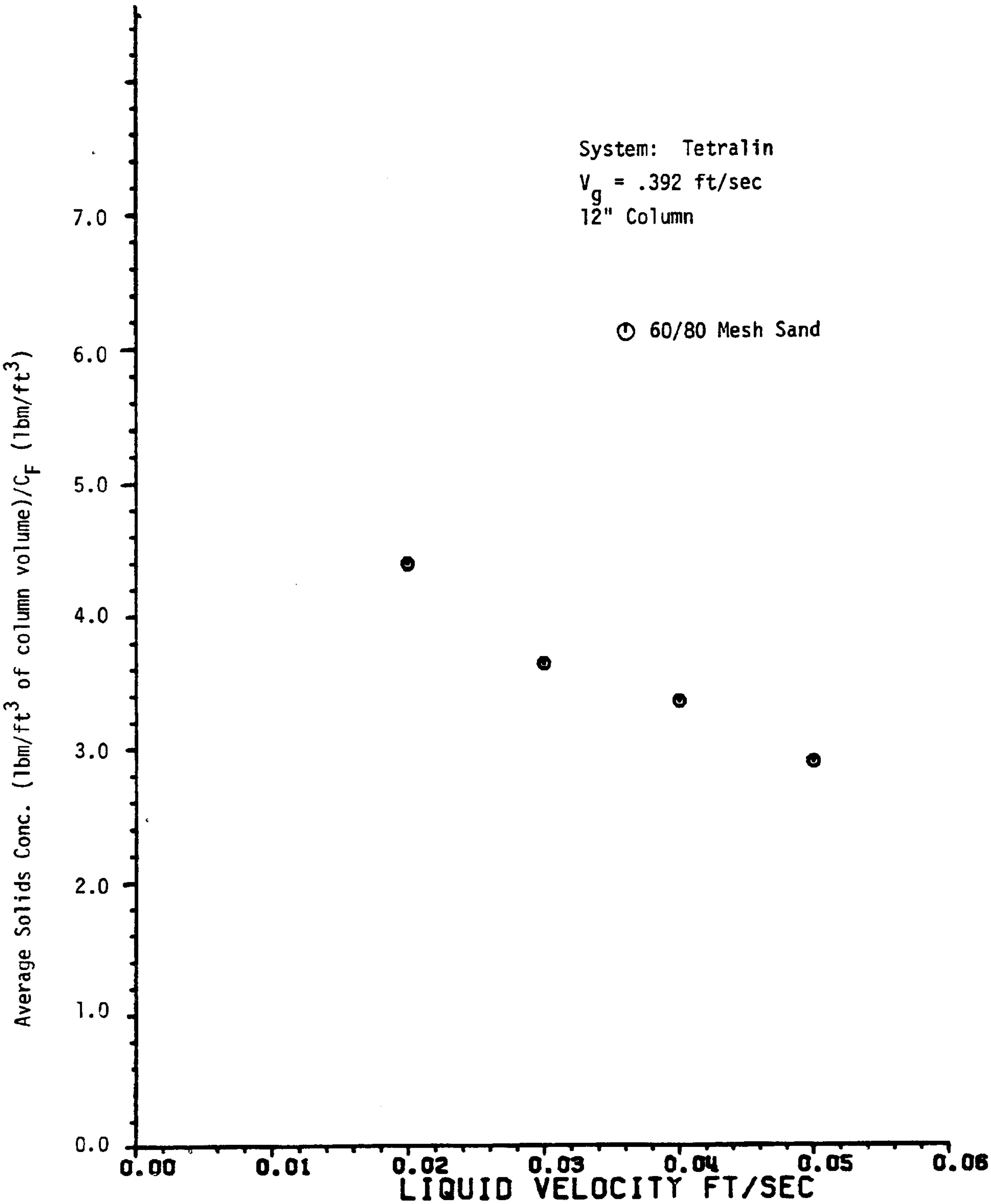


Figure 113. **EFFECT OF LIQUID VELOCITY ON THE DISTRIBUTION OF FINE PARTICLES**

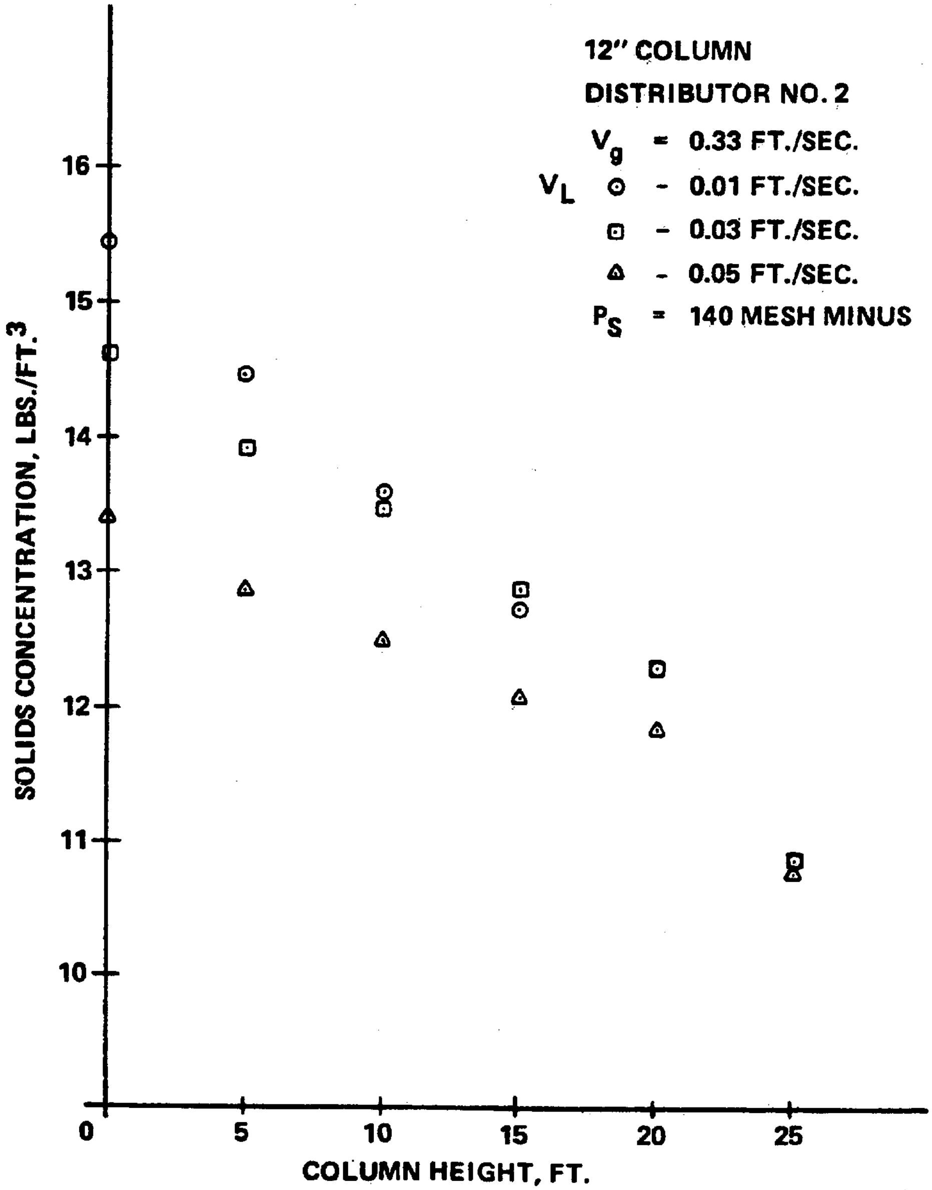


Figure 114

EFFECT OF LIQUID VELOCITY ON SOLID CONC.

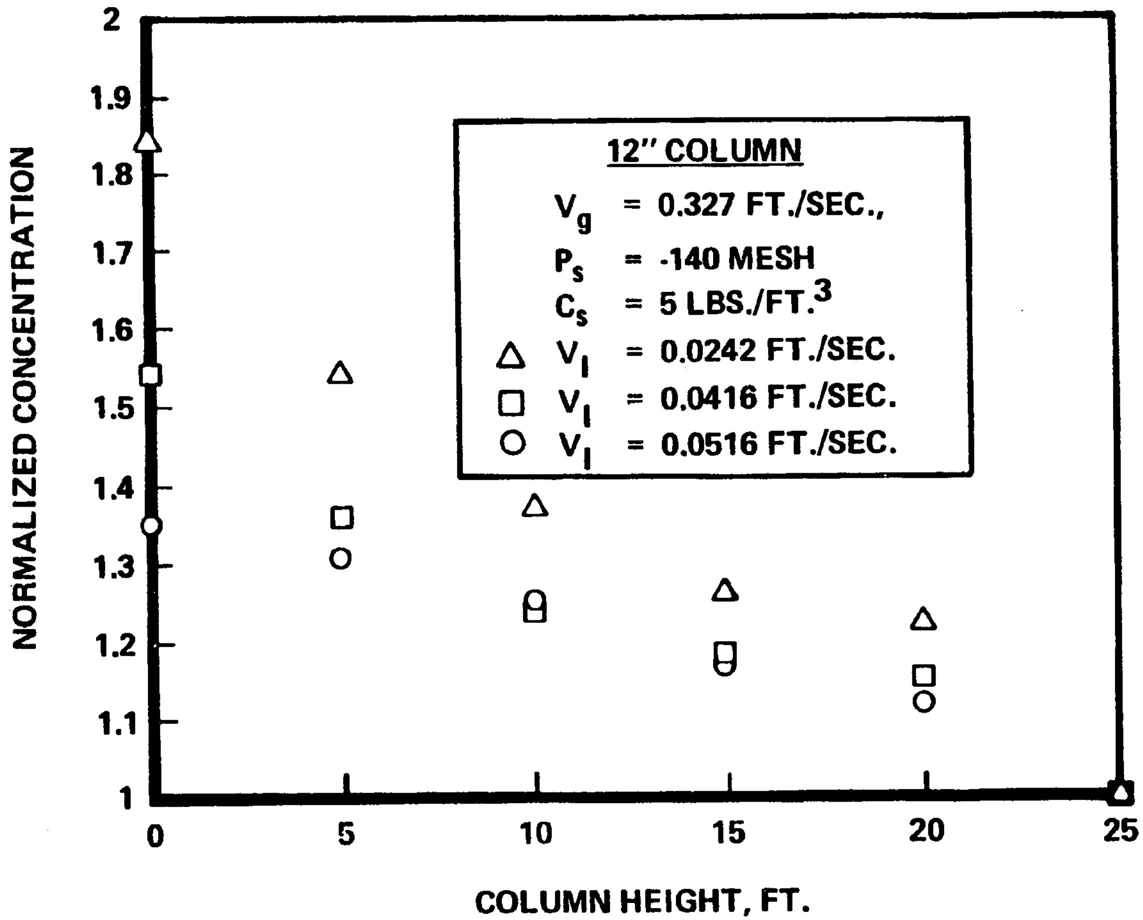


Figure 115

Concentration Versus Length in a 12 Inch Column

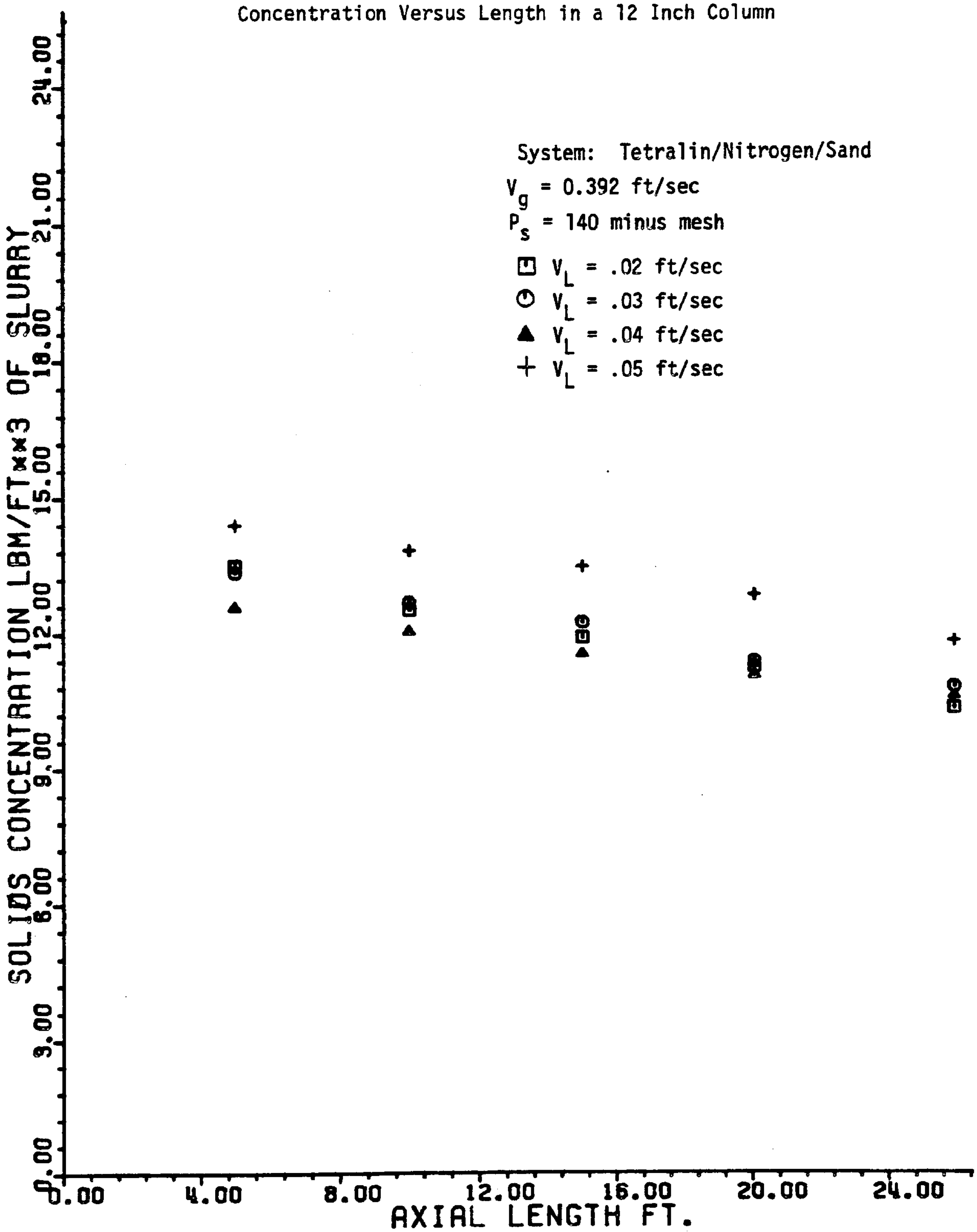


Figure 116. **EFFECT OF LIQUID VELOCITY ON SOLIDS ACCUMULATION**

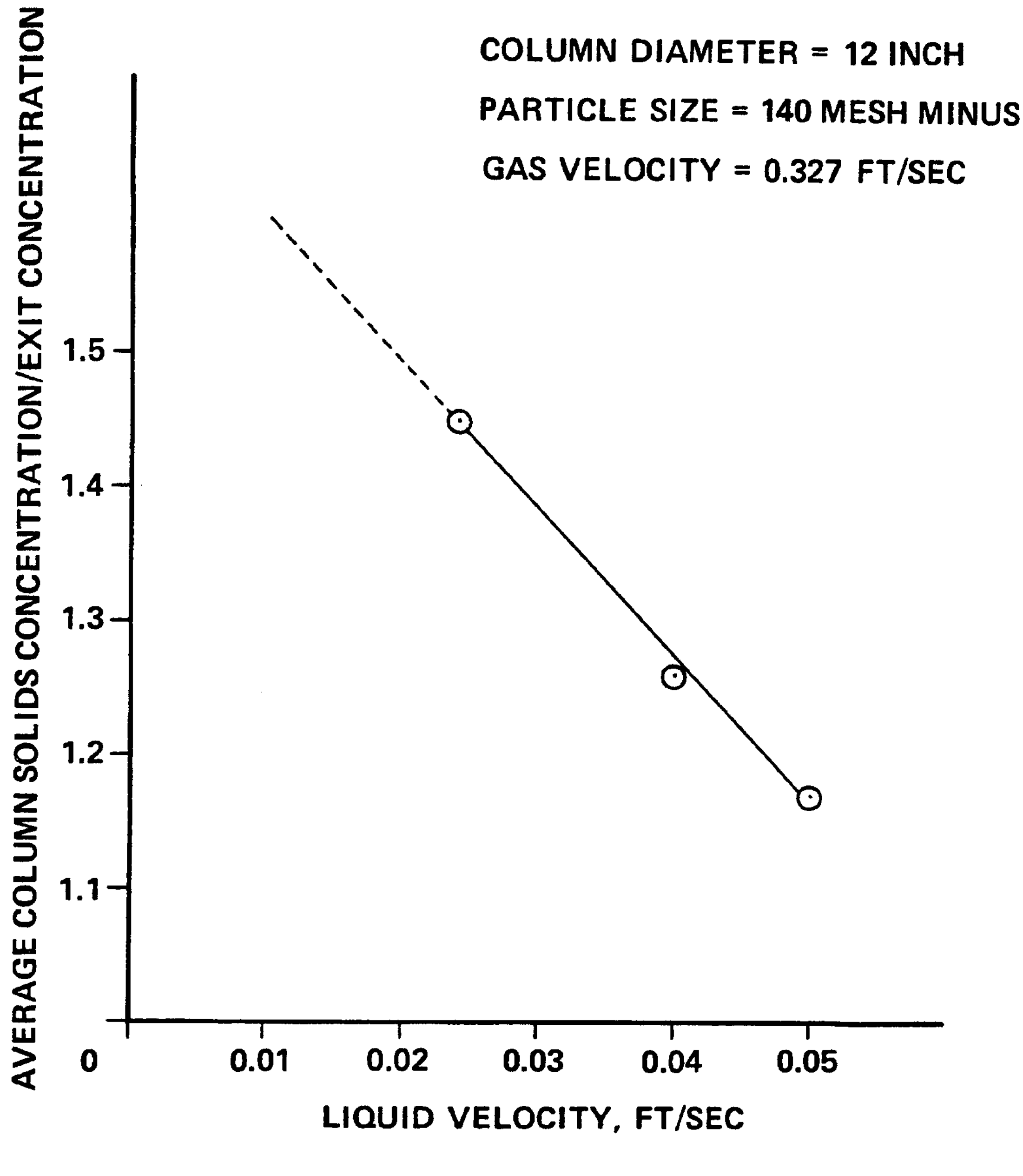


Figure 117. **EFFECT OF PARTICLE SIZE ON SOLIDS DISTRIBUTION**

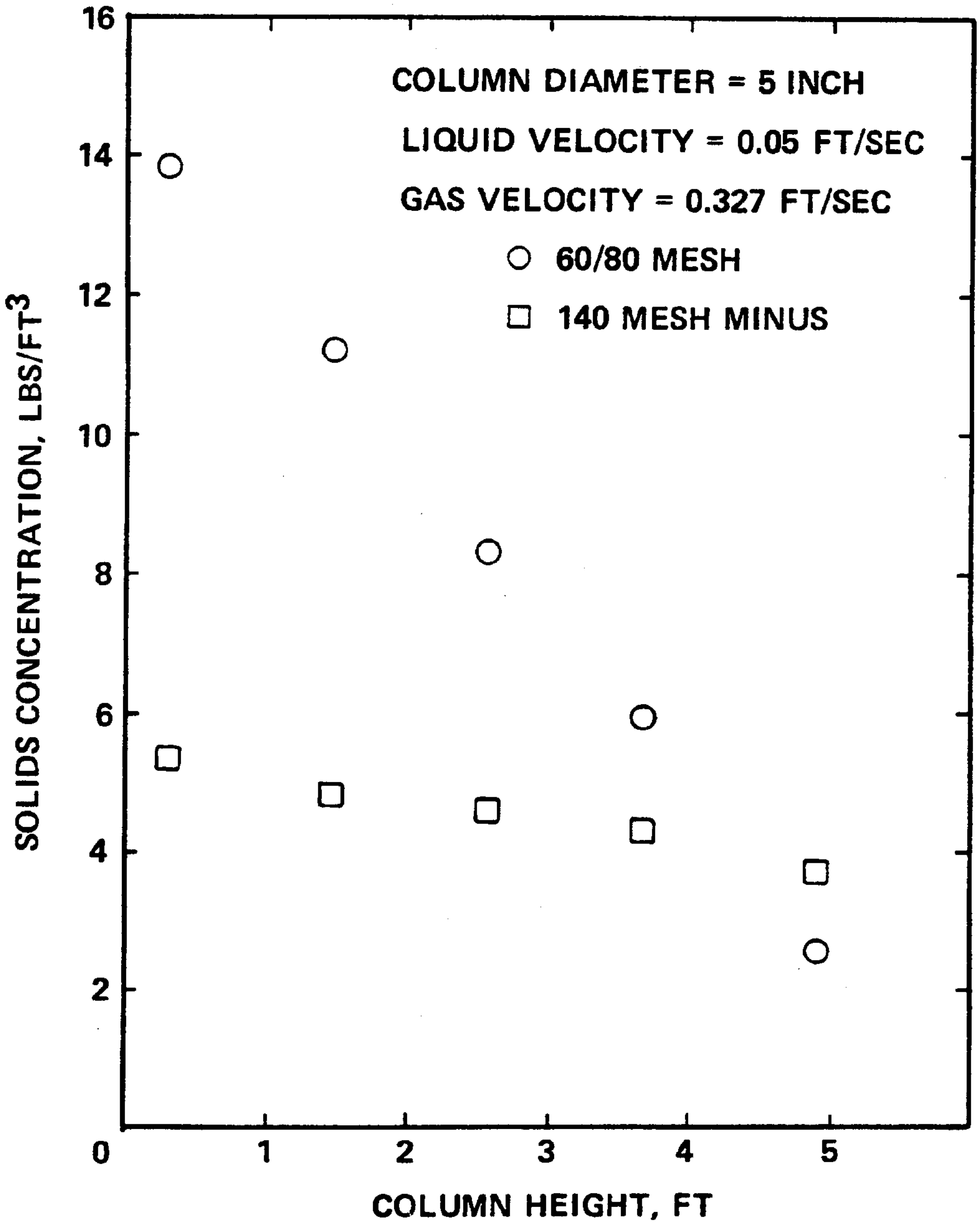


Figure 118

Effect of Particle Size

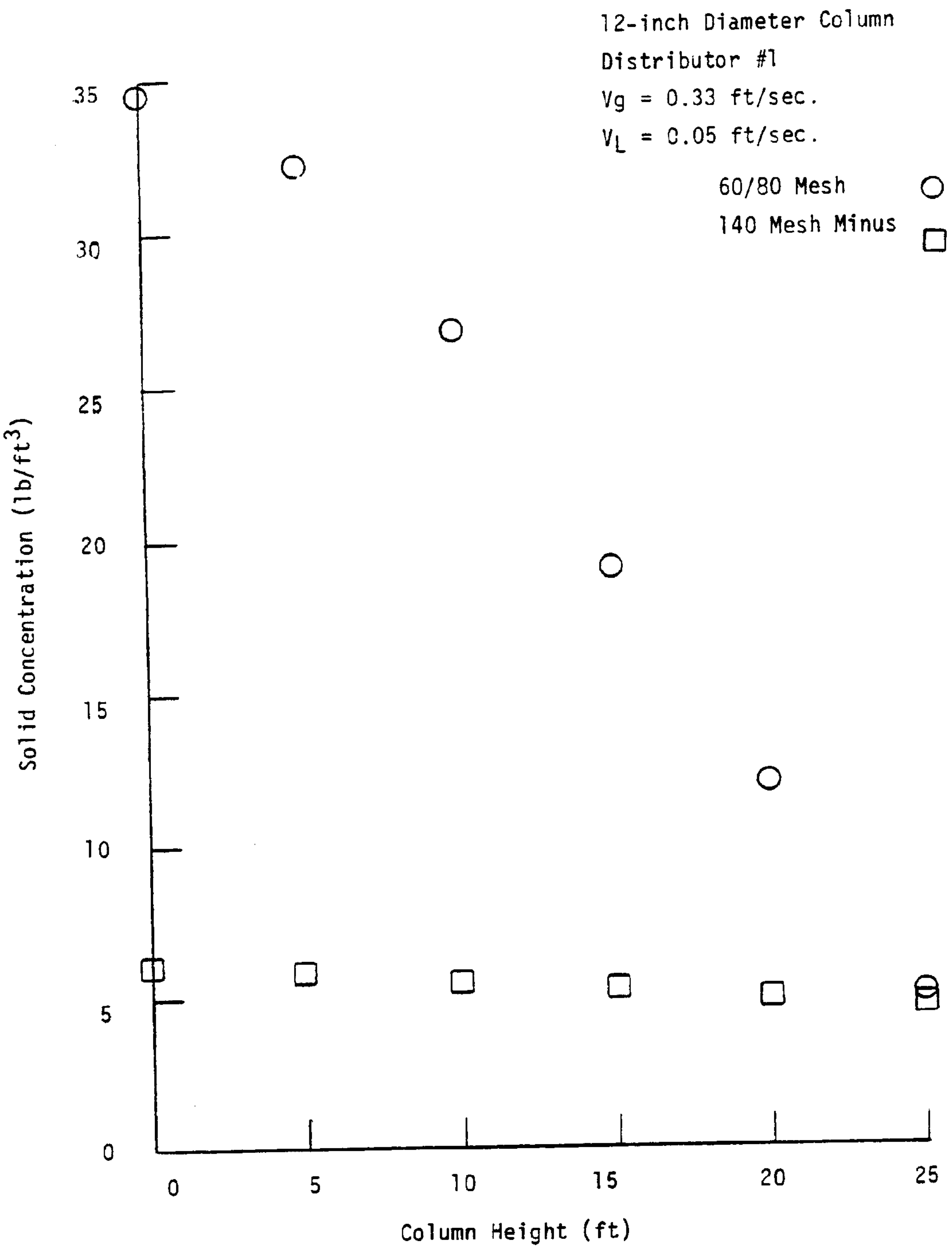
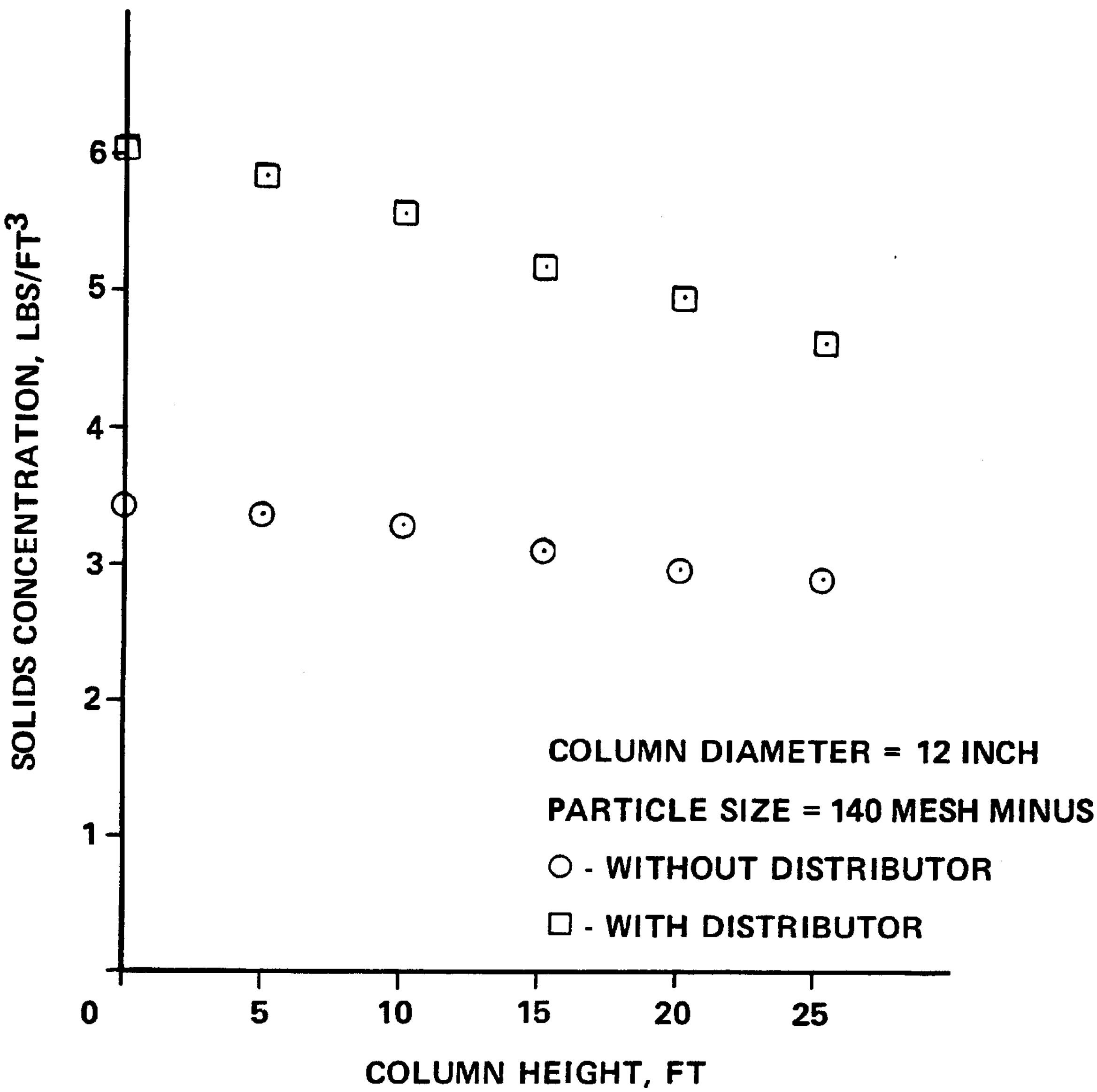


Figure 119. **EFFECT OF DISTRIBUTOR ON SOLIDS DISTRIBUTION**



cases (presence or absence of a distributor). The differences in solid concentrations between the top and bottom of the column are fairly small in both cases. The normalized solid concentrations with respect to exit concentration, plotted as a function of column height in Figure 120, show that solids accumulation increases slightly in the presence of a distributor. This small difference could possibly be due to the unusual surging behavior in the absence of an inlet distributor (see gas holdup discussion). Nevertheless, the effect of inlet distribution is small.

The average retained solids concentration decreases with increasing column diameter as shown in Figures 121 and 122. Experiments were conducted using -140 mesh sand in a 5-in. and 12-in. diameter column in both the absence and presence of an inlet distributor at identical operating conditions. In order to compare the effect of column diameter, the solids concentration was normalized by dividing by exit concentration whereas the column height was normalized by dividing by the total depth of the column (since the 12-in. diameter column is about 5 times taller than the 5-in. diameter column). Figures 121 and 122 show that solids per unit volume accumulate more in the smaller column than in the larger one. This effect is mainly due to the increased dispersion expected in the larger column, which tends to make the solids distribution more homogeneous. Again this finding agrees with the earlier batch experimental runs which showed that increasing column diameter resulted in an increase in the solid dispersion coefficient leading to a less steep distribution profile.