Part C:

HYDRODYNAMIC BEHAVIOR OF MULTIPHASE REACTORS

PROGRESS REPORT FOR THE PERIOD
AUGUST 1, 1981 TO SEPTEMBER 30, 1981

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OVERALL SUMMARY

This progress report covers the work done between September 10, 1981, and September 30, 1981. The report is divided into four sections. The first section deals with a cocurrent bubble column. The second section covers data collected on a batch bubble column. The third section deals with a stirred vessel system, while the fourth deals with a downflow bubble column.

1.0 COCURRENT CONTINUOUS BUBBLE COLUMN

As indicated in the last report, the effect of non-Newtonian fluids on the gas holdup and the dispersion coefficient has not been extensively studied yet. Ulbrecht and Baykara[1.1] have recently reported the effect of non-Newtonian medium on the axial dispersion coefficients, but their analysis is restricted to dilute polymer solutions. In the last report, the data collected for CMC (carboxy methyl cellulose) solutions are discussed. This report covers the work done between September 10, 1981 and September 30, 1981. In this period, different PAA (polyacrylamide) solutions have been tested to continue to study the effect of non-Newtonian fluids on the gas holdup and the axial dispersion coefficients. Many investigators[1.2,1.3] have reported the effect of PAA on mass transfer coefficients in a stirred vessel. They have reported that PAA solutions behave differently than CMC solutions because of the viscoelastic behavior present in PAA solutions.

The physical properties of the solutions studied are listed in Table 1.1.

TABLE 1.1

PHYSICAL PROPERTIES OF PAA SOLUTIONS

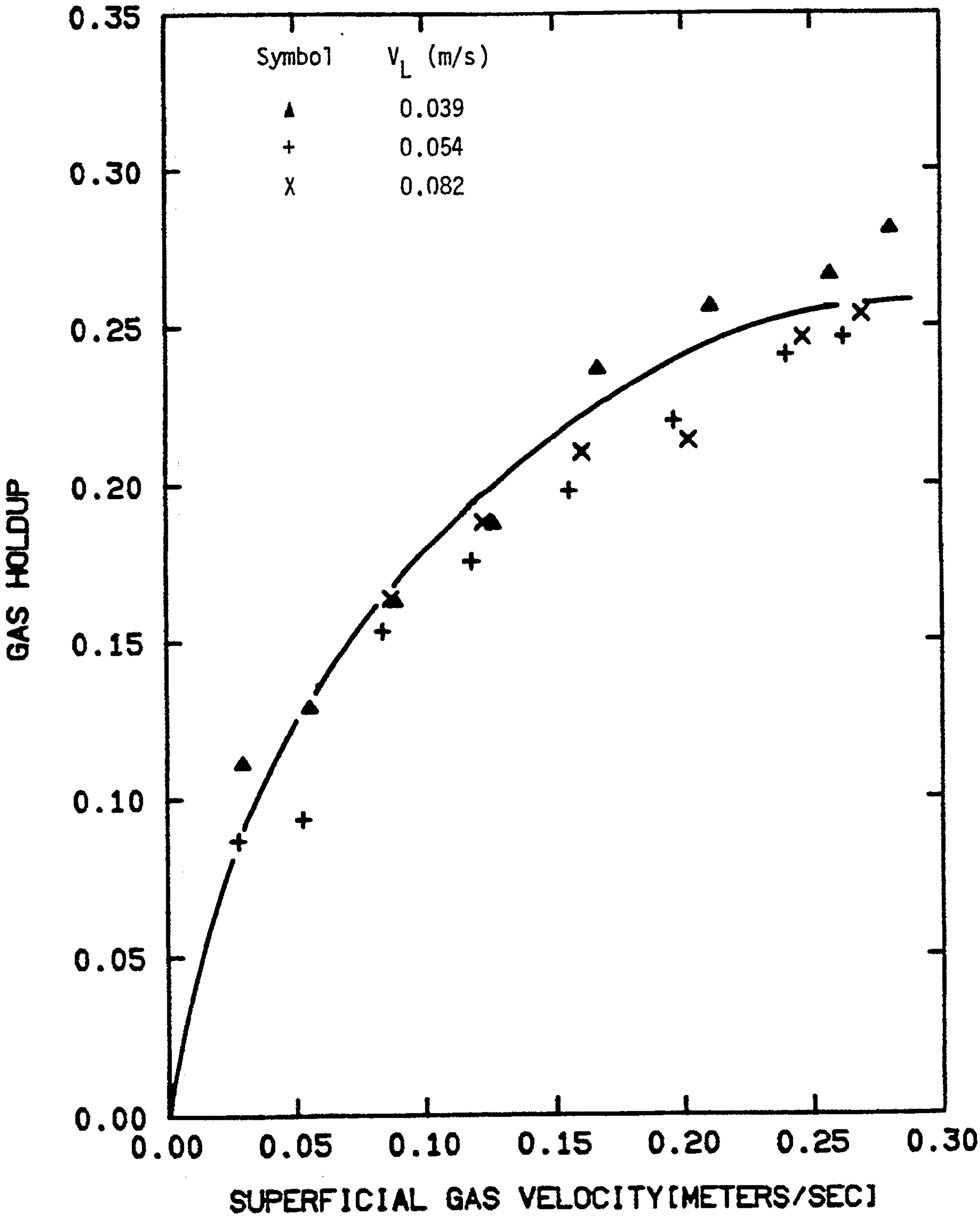
Concentration	ρ_L (g/cc)	σ_L (dynes/cm)	K cP	n	λ sec
50 ppm	.994	72.5	.97	1	0
200 ppm	.994	71.4	1.47	1	0
500 ppm @ 40°C	.994	70.6	1.84	.977	.32
@ 25°C	.996	70.6	2.56	.973	.32
1000 ppm @ 40°C	.994	71.4	3.42	.96	.5
@ 25°C	.998	71.4	3.8	.948	.5
2000 ppm @ 40°C	.994	69.2	4.0	.931	1.1
@ 25°C	.998	69.2	4.42	.923	1.1
3000 ppm @ 40°C	.995	70.4	6.2	.886	.89
@ 25°C	.999	70.4	7.6	.845	.89
4000 ppm @ 40°C	.995	67.3	7.7	.93	.97
@ 25°C	.999	67.3	8.8	.92	.97

The viscoelasticity is manifested in the values of relaxation time or λ. When a viscoelastic liquid flows, only a part of the energy expended will dissipate through viscous friction. The rest will be stored in the liquid and then released as soon as the liquid comes to rest. This process can be characterized with the help of relaxation time. The relaxation time is calculated by the method reported by Yagi and Yoshida.[1.2] The values are approximate and deserve further investigation.

1.1 Results and Discussion

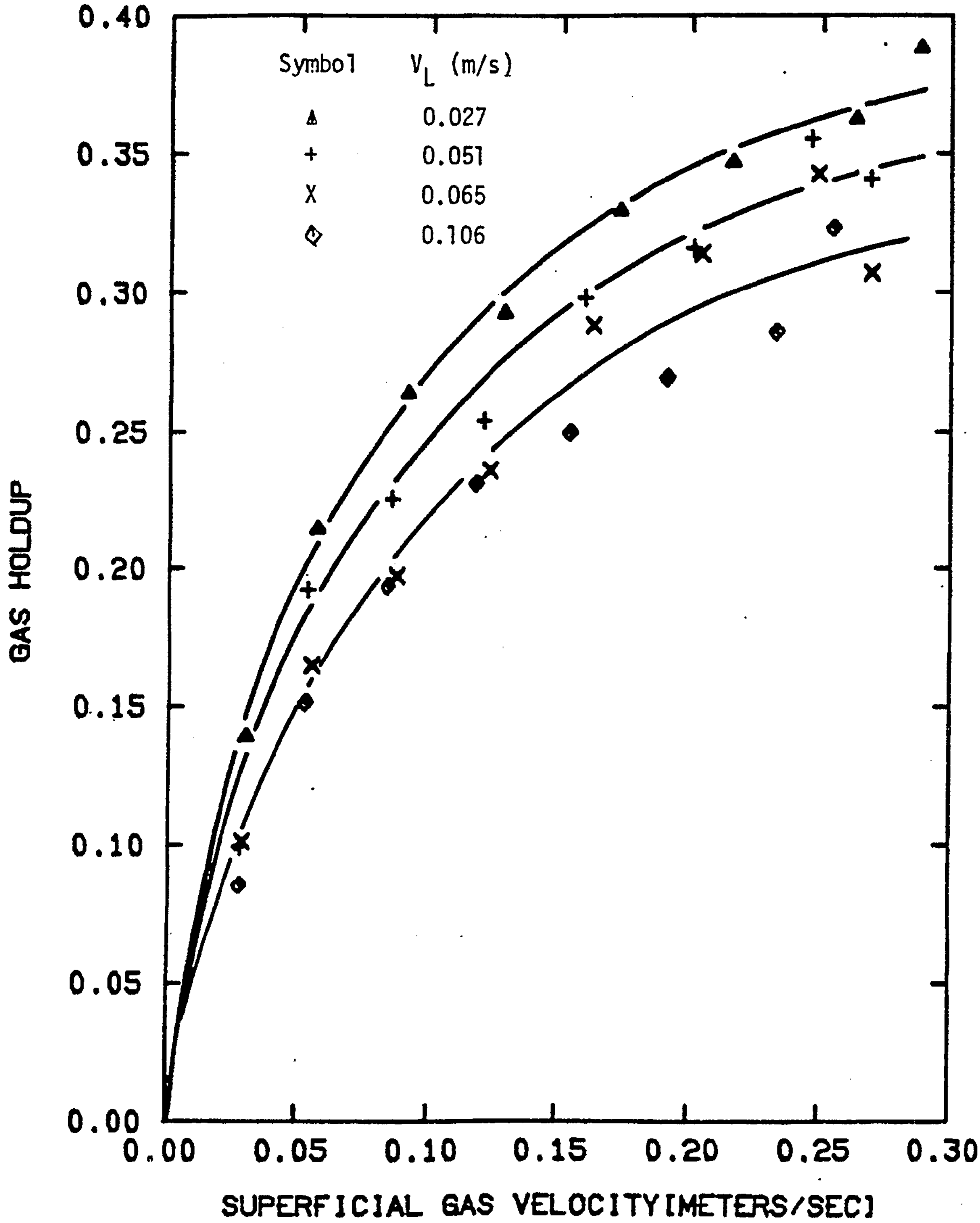
The gas holdup values are calculated with the help of the hydrostatic technique as mentioned in the last report. The gas holdup values showed an increase with an increase in the gas velocity. Figure 1.1 shows the effect of gas velocity on gas holdup for the 50 ppm solution. As can be seen, the effect of liquid velocity is negligible. Figure 1.2 shows the same effect for 2000 ppm solution. It can be seen that the effect of liquid velocity is significant. This is believed to probably be a result of the relaxation time. A rising cloud of bubbles dissipates the energy into the surrounding liquid due to viscous friction. The viscoelastic behavior can show a significant effect only if this process takes place over a time scale comparable to the relaxation time. It is believed that the bubble rise velocity in the churn-turbulent regime is in the range of 60-80 cm/s. Therefore, the average residence time of bubbles would be 4-5 sec. Relaxation time for higher ppm solutions is in the range of 1 sec. and can therefore show some effect.

It should be noted here that the viscosity of the solution did not show any significant effect. On the other hand, holdup increased with an increase in PAA concentration. Visual observations revealed that higher PAA concentrations showed foaming characteristics. As mentioned in the earlier report, surface-active agents can play an important role in determining the values of gas holdup without changing the physico-chemical properties of the solution significantly. The foaming characteristics is an indication of the presence of surface-active agents. Probably the surface agents more than offset the effect of the viscosity. Similar to the alcohol solutions, after



GAS HOLDUP VS SUPERFICIAL GAS VELOCITY[50 PPM PAA SOLUTION]

FIGURE 1.1



GAS HOLDUP VS SUPERFICIAL GAS VELOCITY[2000 PPM PAA]

FIGURE 1.2

certain additions, the effect diminished and further addition of polymer did not cause any additional increase in the holdup values. The holdup values are compared with the values obtained with the help of different available correlations in the literature and attached in the appendix.

To see the flow regime characteristics of the system, drift flux as a function of gas holdup plots are prepared. One of the graphs is shown in Figure 1.3 which is for 1000 ppm solution. The graph reveals that most of the data lie in the churn turbulent regime. Similar observations are made for other concentrations. It was decided to use Zuber-Findley's[1.4] approach for the evaluation of flow regime characteristics. This equation can be written as

$$\frac{V_G}{E_G} = C_1 + C_0 \left(V_G + V_L\right) \quad (1.1)$$

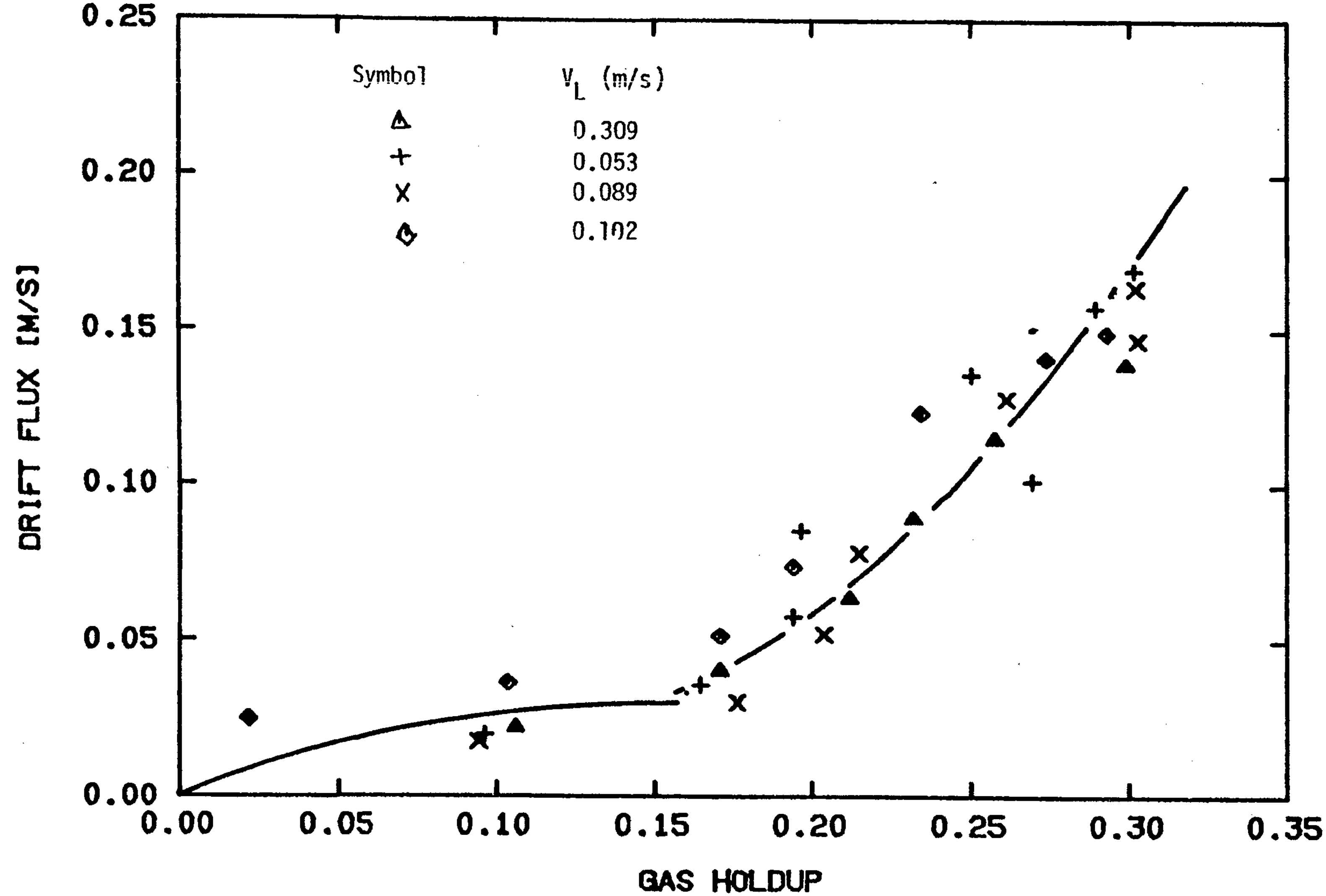
The Zuber-Findley coefficients are listed in Table 1.2.

TABLE 1.2

ZUBER-FINDLEY'S COEFFICIENT FOR PAA SOLUTIONS

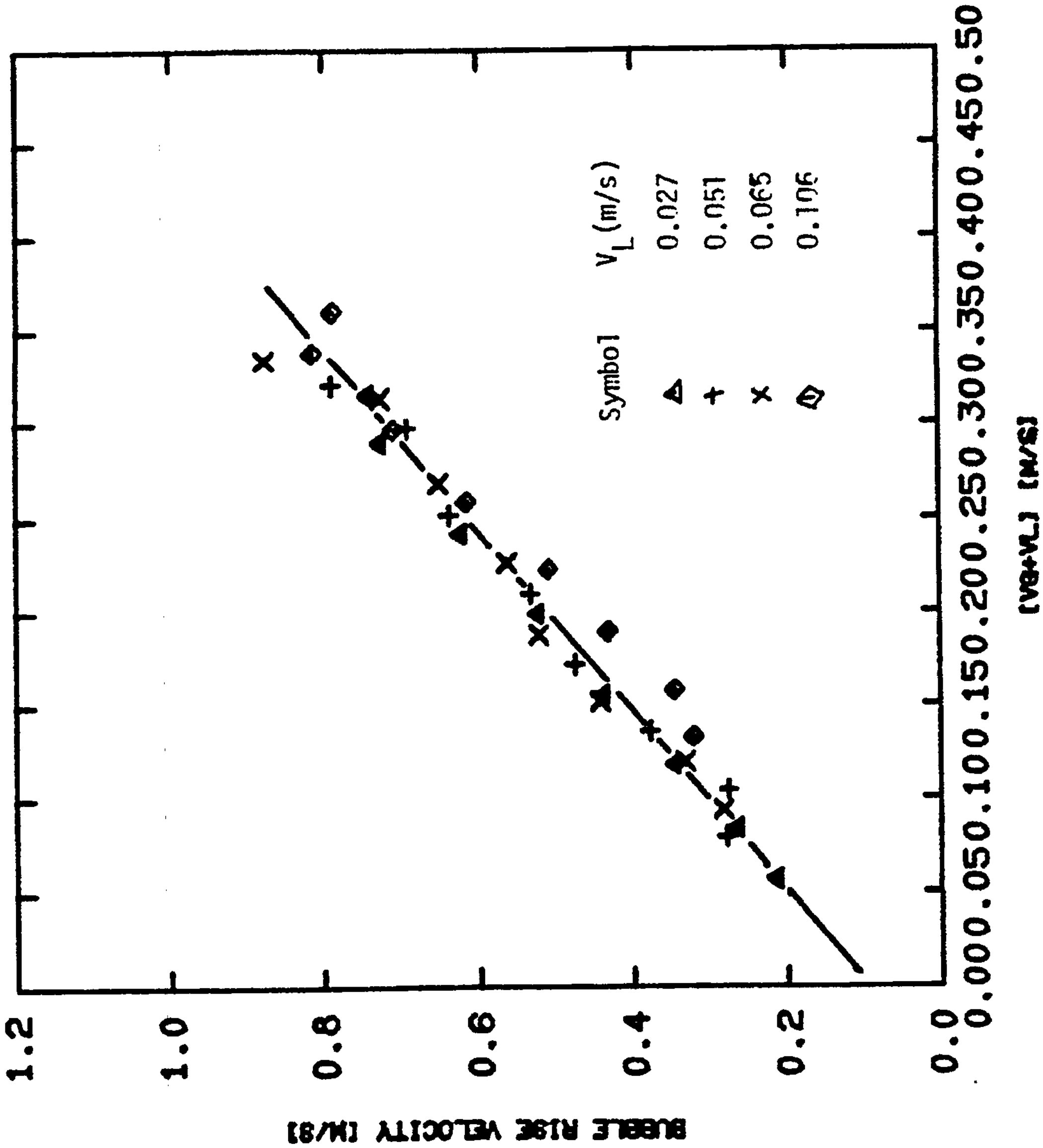
Concentration	C_0	C_1
50 ppm	.105	2.89
200 ppm	.11	2.55
500 ppm	.09	2.60
1000 ppm	.11	2.43
2000 ppm	.083	2.13
3000 ppm	.106	2.04
4000 ppm	.121	1.94

Figure 1.4 shows the graph of $\frac{V_G}{E_A}$ vs $(V_G + V_L)$ for 2000 ppm solution. It can be seen that most of the points lie on a straight line. Zuber-Findley's coefficient shows that C_0 remains fairly constant indicating that bubble size does not change significantly with change in the concentration. The value of C_0 decreases with an increase in the concentration. This is an indication that an increase in holdup value is a direct result of the uniform



DRIFT FLUX VS GAS HOLDUP[1000 PPM PAA SOLUTION]

FIGURE 1.3

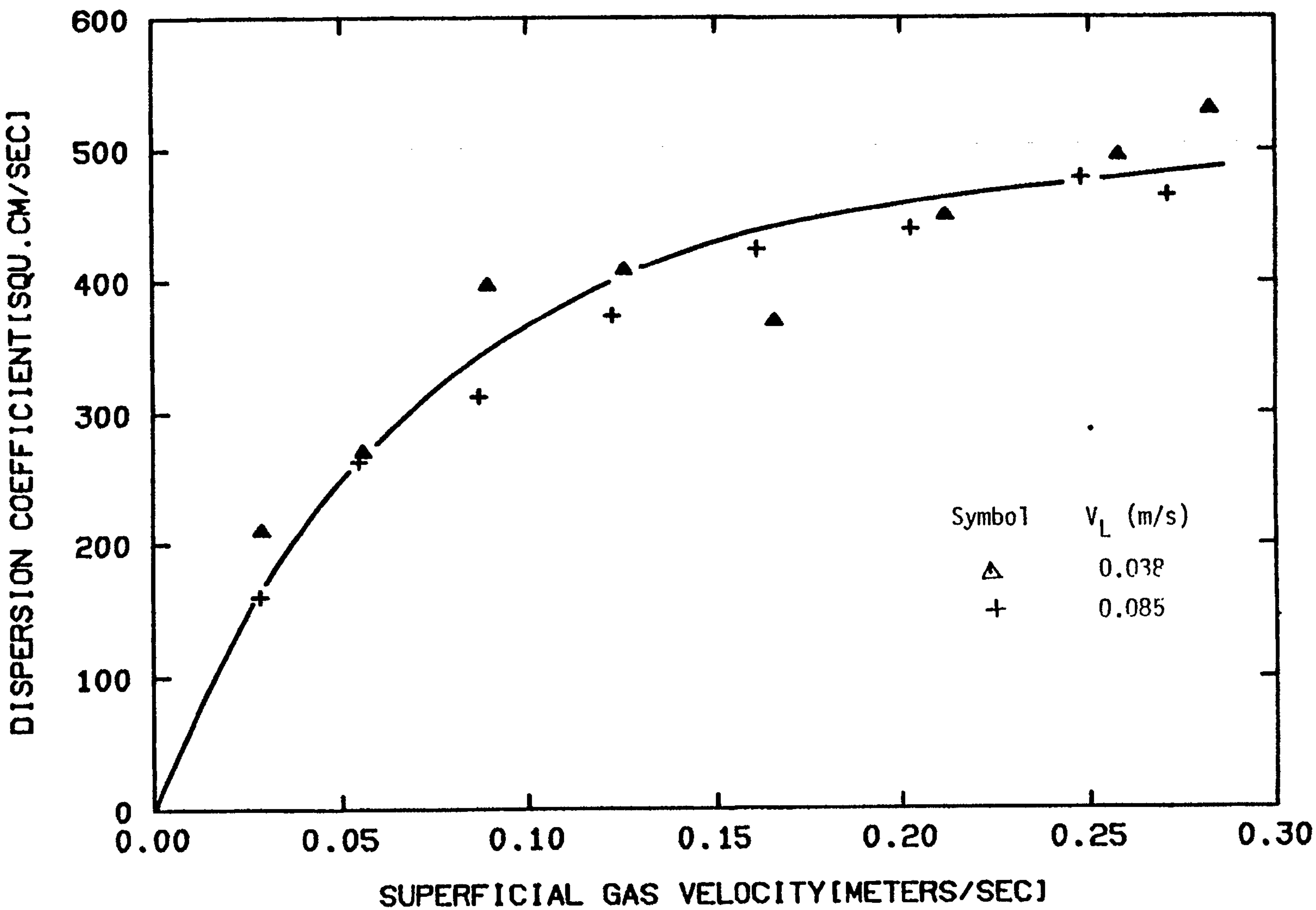


BUBBLE RISE VELOCITY VS [VG+VL] [2000 PPM PAA SOLUTION]

FIGURE 1.4

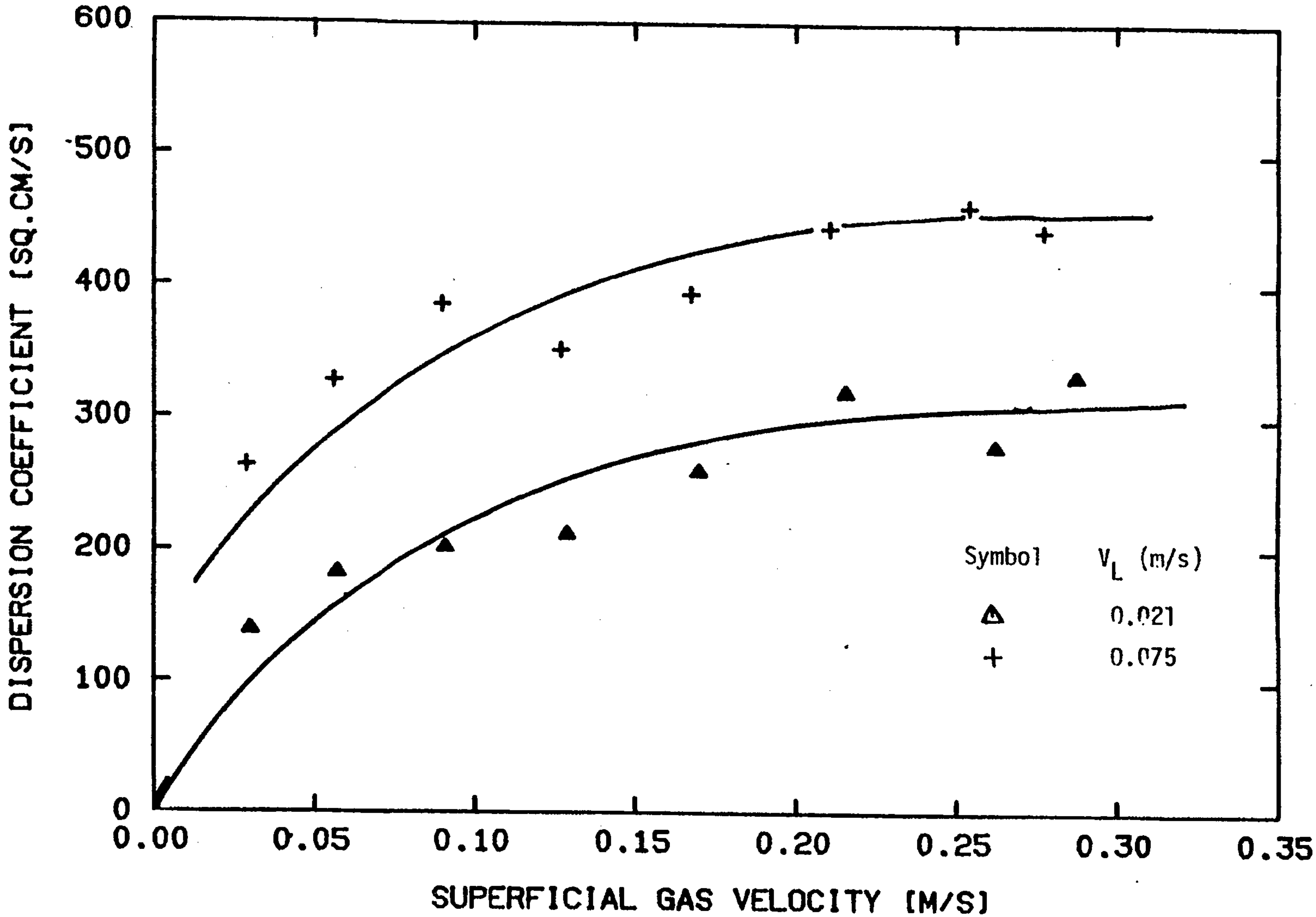
radial distribution, as it is known that C_0 is a nonuniform distribution parameter. It should be noted that for CMC solutions the C_1 values showed considerable increase with increase in concentration, indicating an increase in the bubble sizes. Probably, in the case of PAA solutions, the surface active agents kept the bubble size constant.

The axial dispersion coefficients showed very strange behavior. Figure 1.5 shows the dispersion coefficient values for 200 ppm solution as a function of gas velocity. It can be seen that the effect of liquid velocity is negligible. As the concentration increased further, the dispersion coefficients showed decrease in the value for 2000 ppm solution and the dispersion coefficients showed a minimum. This can be explained on the basis of the relaxation time. It is believed that the energy is dissipated in the form of recoiling of liquid in the case of viscoelastic liquids. This results in less energy dissipation in liquid recirculation which is a main contributing factor for the axial backmixing. Figure 1.6 shows the axial dispersion coefficient values for 4000 ppm solution. It can be seen that the effect of liquid velocity is significant. It reveals that as the liquid velocity is increased, the dispersion coefficient increases. This surprising trend is observed only for 3000 ppm and 4000 ppm solutions. The reasons for this strange behavior cannot be explained yet.



DISPERSION COEFFICIENT VS SUPERFICIAL GAS VELOCITY[200 PPM PAA]

FIGURE 1.5



DISPERSION COEFFICIENT VS GAS VELOCITY[4000 PPM PAA]

FIGURE 1.6

References

1.1 Ulbrecht, J. J., and Z. S. Baykara, Paper presented at ACS Meeting, Las Vegas, August, 1980.

1.2 Yagi, H., and F. Yoshida, Ind. Eng. Chem. Process Des. Dev., 14 (4), 488, 1975.

1.3 Ranade, V. R., and J. L. Vibrecht, AIChE J., 24 (5), 796, 1978.

1.4 Zuber, N., and J. A. Findley, J. of Ht. Transfer (Trans. ASME), ser. C, 87, 453, 1965.

APPENDIX 1.1

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
50 PPM CMA SOLUTION

VC(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	RECKER
0.02923	0.03889	0.11110	0.09637	0.07697	0.07768	0.11521	0.04762	0.06385
0.05560	0.03889	0.12834	0.13316	0.11135	0.12181	0.19535	0.08191	0.10820
0.08666	0.03889	0.16250	0.17476	0.14568	0.16199	0.26808	0.11728	0.15892
0.12680	0.03889	0.18759	0.20975	0.17810	0.19633	0.31839	0.15225	0.21272
0.16708	0.03889	0.23654	0.23941	0.20306	0.22431	0.34152	0.18341	0.26671
0.21091	0.03889	0.25612	0.26335	0.23937	0.24882	0.34132	0.21085	0.32286
0.25746	0.03889	0.26591	0.28517	0.26917	0.27012	0.32441	0.24017	0.38024
0.28053	0.03889	0.28060	0.29460	0.29384	0.27906	0.31375	0.24960	0.40793
0.02765	0.05437	0.08662	0.09285	0.07685	0.07253	0.10566	0.04101	0.06102
0.05289	0.05437	0.09335	0.12898	0.11157	0.11515	0.18793	0.07148	0.10385
0.08393	0.05437	0.15332	0.16931	0.14600	0.15304	0.25697	0.10431	0.15165
0.11647	0.05437	0.17535	0.20277	0.17837	0.18502	0.30586	0.13277	0.20119
0.15584	0.05437	0.19799	0.23095	0.20948	0.21207	0.33765	0.16095	0.25191
0.19654	0.05437	0.22002	0.25563	0.23988	0.23602	0.34366	0.19063	0.30470
0.24002	0.05437	0.24033	0.27734	0.26975	0.25714	0.33204	0.21734	0.35896
0.26251	0.05437	0.24633	0.29716	0.23449	0.26666	0.32223	0.22716	0.38631
0.02888	0.08166	0.12946	0.09562	0.07688	0.07662	0.11401	0.03687	0.06323
0.05465	0.08166	0.17946	0.13204	0.11192	0.11962	0.19337	0.06454	0.10700
0.08730	0.08166	0.16372	0.17312	0.14661	0.15860	0.26533	0.09562	0.15664
0.12289	0.08166	0.18820	0.20658	0.17916	0.19059	0.31462	0.12408	0.20733
0.16082	0.08166	0.21023	0.23436	0.21028	0.21712	0.33563	0.15188	0.25849
0.20231	0.08166	0.21390	0.25888	0.24074	0.24082	0.34294	0.17888	0.31201
0.24667	0.08166	0.24633	0.28046	0.27070	0.26177	0.32918	0.20046	0.36710
0.26953	0.08166	0.25360	0.29020	0.29542	0.27118	0.31685	0.21520	0.39477

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
200 PPM PAA SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSPANN	KUMAR	MILLER	DECKWER
0.02921	0.03791	0.09458	0.08339	0.07599	0.07498	0.11549	0.04464	0.06382
0.05592	0.03791	0.13619	0.12974	0.10997	0.11892	0.19667	0.07724	0.10871
0.08967	0.03791	0.16678	0.17116	0.14391	0.15899	0.27001	0.11116	0.16011
0.12629	0.03791	0.22124	0.20453	0.17566	0.19122	0.31830	0.14453	0.21201
0.16630	0.03791	0.23287	0.23291	0.20623	0.21882	0.34146	0.17291	0.26569
0.21189	0.03791	0.25245	0.25875	0.23631	0.24471	0.34094	0.20125	0.32409
0.25847	0.03791	0.28672	0.28037	0.26568	0.26581	0.32358	0.22537	0.38143
0.28256	0.03791	0.30385	0.29017	0.28023	0.27532	0.31238	0.24017	0.41037
0.02794	0.05996	0.09397	0.07977	0.07548	0.07020	0.11108	0.03665	0.06154
0.05321	0.05996	0.13313	0.12447	0.10965	0.11136	0.18942	0.06447	0.10437
0.08500	0.05996	0.15210	0.16472	0.14363	0.14945	0.26163	0.09472	0.15324
0.11967	0.05996	0.17535	0.19755	0.17550	0.18066	0.31170	0.12255	0.20287
0.15800	0.05996	0.20839	0.22588	0.20627	0.20801	0.33879	0.14838	0.25477
0.19928	0.05996	0.23410	0.25044	0.23628	0.23180	0.34327	0.17544	0.30816
0.24319	0.05996	0.26408	0.27198	0.26577	0.25266	0.33032	0.19948	0.36285
0.26590	0.05996	0.28305	0.29174	0.28033	0.26208	0.32014	0.21174	0.39041
0.02857	0.08528	0.09029	0.08204	0.07581	0.07307	0.11325	0.03329	0.06267
0.05480	0.08528	0.17474	0.12809	0.11055	0.11591	0.19369	0.06059	0.10691
0.08715	0.08528	0.16740	0.16851	0.14481	0.15415	0.26557	0.08851	0.15641
0.12274	0.08528	0.19738	0.20166	0.17698	0.18581	0.31487	0.11666	0.20711
0.16160	0.08528	0.22106	0.22990	0.20798	0.21300	0.34008	0.14240	0.25952
0.20270	0.08528	0.24511	0.25397	0.23801	0.23610	0.34278	0.16647	0.31251
0.24796	0.08528	0.27081	0.27583	0.26782	0.25745	0.32828	0.19083	0.36867
0.27093	0.08528	0.27693	0.28554	0.28243	0.26681	0.31779	0.20054	0.39646
0.02782	0.10965	0.09458	0.07952	0.07556	0.06975	0.11067	0.02890	0.06133
0.05239	0.10965	0.11477	0.12324	0.11016	0.10911	0.18718	0.05199	0.10304
0.08269	0.10965	0.15007	0.16219	0.14415	0.14515	0.25730	0.07719	0.14982
0.11630	0.10965	0.17780	0.19471	0.17611	0.17580	0.30800	0.10096	0.19816
0.15201	0.10965	0.20350	0.22187	0.20657	0.20143	0.33622	0.12437	0.24582
0.19159	0.10965	0.23042	0.24623	0.23658	0.22487	0.34396	0.14873	0.29839
0.23198	0.10965	0.23410	0.26684	0.26544	0.24449	0.33475	0.16934	0.34907
0.25383	0.10965	0.25612	0.27665	0.27990	0.25400	0.32569	0.18165	0.37581

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
500 PPM PAA SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02950	0.03676	0.12273	0.08389	0.07618	0.07577	0.11700	0.04514	0.06435
0.05640	0.03308	0.17290	0.13027	0.11009	0.11993	0.19865	0.08027	0.10947
0.08988	0.03676	0.19922	0.17120	0.14410	0.15923	0.27113	0.11120	0.16041
0.12686	0.03676	0.24083	0.20479	0.17593	0.19181	0.31940	0.14479	0.21280
0.16844	0.03676	0.23165	0.23405	0.20668	0.22078	0.34218	0.17405	0.26850
0.21300	0.03676	0.29427	0.25910	0.23668	0.24547	0.34041	0.20410	0.32548
0.26018	0.03676	0.30324	0.28088	0.26613	0.26682	0.32220	0.23088	0.38351
0.28450	0.03676	0.31487	0.29070	0.28070	0.27637	0.31088	0.24070	0.41267
0.02790	0.05074	0.15087	0.07679	0.07453	0.06749	0.11140	0.03617	0.06146
0.05284	0.05074	0.15149	0.12004	0.10809	0.10711	0.18911	0.06254	0.10377
0.08396	0.05074	0.16923	0.15908	0.14144	0.14375	0.26047	0.09158	0.15170
0.11876	0.05074	0.19310	0.19189	0.17280	0.17513	0.31134	0.11939	0.20159
0.15651	0.05074	0.20839	0.21977	0.20298	0.20193	0.33851	0.14477	0.25280
0.19719	0.05074	0.23348	0.24403	0.23240	0.22536	0.34341	0.16903	0.30552
0.24123	0.05074	0.24266	0.26572	0.26141	0.24650	0.33064	0.19322	0.36044
0.26387	0.05074	0.25490	0.27549	0.27571	0.25596	0.32048	0.20549	0.38796
0.02855	0.07940	0.06704	0.08272	0.07603	0.07411	0.11506	0.03460	0.06335
0.05532	0.07940	0.16678	0.12871	0.11076	0.11697	0.19581	0.06121	0.10775
0.08782	0.07940	0.19371	0.16904	0.14504	0.15515	0.26753	0.09029	0.15740
0.12357	0.07940	0.21329	0.20214	0.17721	0.18677	0.31628	0.11714	0.20826
0.16247	0.07940	0.24511	0.23025	0.20817	0.21382	0.34060	0.14525	0.26066
0.20440	0.07940	0.26102	0.25466	0.23836	0.23742	0.34231	0.16966	0.31466
0.24668	0.07940	0.28121	0.27593	0.26790	0.25795	0.32744	0.19343	0.36955
0.27148	0.07940	0.29773	0.28555	0.28245	0.26719	0.31691	0.20555	0.39711
0.02777	0.08865	0.08295	0.07653	0.07449	0.06711	0.11095	0.02965	0.06123
0.05255	0.08865	0.11416	0.11962	0.10847	0.10619	0.18834	0.05212	0.10331
0.08301	0.08865	0.16923	0.15806	0.14192	0.14181	0.25868	0.07806	0.15029
0.11612	0.08865	0.19248	0.18969	0.17318	0.17142	0.30643	0.10219	0.19791
0.15277	0.08865	0.20839	0.21728	0.20339	0.19772	0.33692	0.12478	0.24784
0.19057	0.08865	0.28672	0.24040	0.23236	0.21955	0.34396	0.14540	0.29709
0.23110	0.08865	0.25123	0.26107	0.26077	0.23928	0.33465	0.16857	0.34799
0.25235	0.08865	0.27938	0.27062	0.27485	0.24844	0.32580	0.17812	0.37401

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
1000 PPM PAA SOLUTION

VC(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	PERSMANN	KUMAR	MILLER	DECKNER
0.02951	0.03906	0.10617	0.07642	0.07302	0.06904	0.11652	0.03767	0.06436
0.05649	0.03906	0.17090	0.12071	0.10584	0.11103	0.19817	0.06571	0.10961
0.09118	0.03906	0.21182	0.16157	0.13877	0.15083	0.27260	0.09657	0.16231
0.12602	0.03906	0.23197	0.19409	0.16942	0.18210	0.31988	0.12409	0.21439
0.16841	0.03906	0.25762	0.22208	0.19900	0.20924	0.34198	0.15208	0.26845
0.21486	0.03906	0.29914	0.24792	0.22815	0.23519	0.34020	0.17792	0.32781
0.26189	0.03906	0.32418	0.26943	0.25664	0.25610	0.32200	0.20193	0.38557
0.20732	0.03906	0.36937	0.27962	0.27078	0.26621	0.31624	0.21462	0.41601
0.02776	0.05296	0.09640	0.07259	0.07277	0.06357	0.11054	0.03196	0.06121
0.05308	0.05296	0.16479	0.11549	0.10581	0.10311	0.18921	0.05674	0.10416
0.08448	0.05296	0.19411	0.15425	0.13067	0.13950	0.26082	0.08425	0.15246
0.11923	0.05296	0.19655	0.18672	0.16957	0.17039	0.31136	0.10922	0.20225
0.15820	0.05296	0.26922	0.21527	0.19949	0.19815	0.33893	0.13527	0.25503
0.19078	0.05296	0.25029	0.23931	0.22053	0.22119	0.34331	0.15931	0.30754
0.24326	0.05296	0.28937	0.26113	0.25724	0.24245	0.33019	0.18113	0.36293
0.26580	0.05296	0.30159	0.27084	0.27137	0.25176	0.32606	0.19334	0.39029
0.02883	0.08878	0.09456	0.07509	0.07285	0.06716	0.11419	0.02822	0.06315
0.05556	0.08878	0.17640	0.11944	0.10648	0.10856	0.19578	0.05069	0.10817
0.08826	0.08878	0.20388	0.15860	0.13961	0.14553	0.26754	0.07610	0.15804
0.12399	0.08878	0.21487	0.19092	0.17076	0.17619	0.31610	0.10092	0.20884
0.16303	0.08878	0.21365	0.21870	0.20076	0.20281	0.34053	0.12370	0.26140
0.20479	0.08878	0.26128	0.24277	0.22996	0.22593	0.34242	0.14777	0.31515
0.24954	0.08878	0.30281	0.26415	0.25870	0.24655	0.32759	0.16915	0.37059
0.27343	0.08878	0.30220	0.27416	0.27300	0.25634	0.31662	0.17916	0.39945
0.02757	0.10186	0.02189	0.07220	0.07260	0.06313	0.10987	0.02533	0.06087
0.05235	0.10186	0.10372	0.11442	0.10610	0.10127	0.18721	0.04567	0.10297
0.08296	0.10186	0.17090	0.15263	0.13922	0.13660	0.25798	0.06888	0.15022
0.11606	0.10186	0.19411	0.18409	0.17010	0.16593	0.30788	0.09159	0.19785
0.15300	0.10186	0.19533	0.21182	0.20008	0.19233	0.33676	0.11432	0.24814
0.19249	0.10186	0.23441	0.23588	0.22921	0.21535	0.34390	0.13588	0.29954
0.23226	0.10186	0.27350	0.25609	0.25718	0.23435	0.33456	0.15609	0.34941
0.25334	0.10186	0.29304	0.26557	0.27114	0.24334	0.32579	0.16557	0.37521

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
2000 PPM PAA SOLUTION

VC(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSMANN	KUMAR	MILLER	DECKWER
0.02986	0.02701	0.13914	0.07723	0.07353	0.07011	0.11855	0.04160	0.06499
0.05666	0.02701	0.21126	0.12137	0.10622	0.11204	0.19983	0.07137	0.10991
0.09136	0.02701	0.26372	0.16243	0.13920	0.15215	0.27412	0.10493	0.16258
0.12836	0.02701	0.29243	0.19527	0.16996	0.18388	0.32110	0.13527	0.21489
0.17221	0.02701	0.32907	0.22550	0.20014	0.21433	0.34300	0.16550	0.27341
0.21560	0.02701	0.34670	0.24953	0.22088	0.23759	0.33954	0.18953	0.32872
0.26306	0.02701	0.36266	0.27129	0.25749	0.25887	0.32049	0.21629	0.38700
0.28819	0.02701	0.38831	0.29137	0.27168	0.26880	0.30885	0.22637	0.41705
0.02776	0.05127	0.09945	0.07255	0.07307	0.06358	0.11131	0.03255	0.06122
0.05330	0.05127	0.19227	0.11595	0.10633	0.10376	0.19094	0.05720	0.10451
0.08526	0.05127	0.22525	0.15544	0.13947	0.14114	0.26350	0.08544	0.15362
0.12053	0.05127	0.25395	0.18831	0.17064	0.17258	0.31371	0.11206	0.20405
0.15886	0.05127	0.29792	0.21637	0.20068	0.19957	0.33962	0.13637	0.25590
0.20087	0.05127	0.31563	0.24122	0.23009	0.22378	0.34278	0.16123	0.31019
0.24595	0.05127	0.35533	0.26324	0.25906	0.24529	0.32621	0.18574	0.36621
0.26903	0.05127	0.34067	0.27312	0.27337	0.25484	0.31756	0.19812	0.39417
0.02872	0.06479	0.10128	0.07496	0.07321	0.06692	0.11456	0.03121	0.06294
0.05486	0.06479	0.16479	0.11880	0.10670	0.10767	0.19500	0.05630	0.10701
0.08725	0.06479	0.19716	0.15820	0.13992	0.14495	0.26697	0.08320	0.15656
0.12295	0.06479	0.23563	0.19096	0.17113	0.17626	0.31603	0.10846	0.20741
0.16217	0.06479	0.29815	0.21920	0.20125	0.20355	0.34066	0.13420	0.26027
0.20394	0.06479	0.31380	0.24353	0.23054	0.22704	0.34228	0.15853	0.31408
0.24869	0.06479	0.34250	0.26510	0.25933	0.24797	0.32711	0.18010	0.36956
0.26939	0.06479	0.30708	0.27391	0.27296	0.25608	0.31752	0.18891	0.39461
0.02753	0.10560	0.08540	0.07208	0.07291	0.06299	0.11048	0.02489	0.06079
0.05249	0.10560	0.15136	0.11478	0.10671	0.10170	0.18674	0.04541	0.10321
0.08378	0.10560	0.19350	0.15386	0.14019	0.13820	0.26076	0.06886	0.15144
0.11752	0.10560	0.23075	0.18582	0.17147	0.16815	0.31051	0.09082	0.19987
0.15345	0.10560	0.24968	0.21278	0.20137	0.19347	0.33750	0.11276	0.24874
0.19095	0.10560	0.26922	0.23580	0.23013	0.21506	0.34390	0.13330	0.29758
0.23264	0.10560	0.28571	0.25715	0.25886	0.23556	0.33372	0.15465	0.34989
0.25465	0.10560	0.32296	0.26706	0.27313	0.24515	0.32429	0.16456	0.37681

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
3000 PPM FAA SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	PERSMANN	KUMAR	MILLER	DECKWER
0.03016	0.02804	0.15221	0.07584	0.07296	0.06910	0.11979	0.03959	0.06552
0.05782	0.02804	0.23701	0.12066	0.10566	0.11215	0.20311	0.06941	0.11173
0.09226	0.02804	0.26202	0.16098	0.13846	0.15120	0.27595	0.10098	0.16389
0.13125	0.02804	0.29802	0.19519	0.16945	0.18491	0.32376	0.13269	0.21882
0.17321	0.02804	0.33462	0.22392	0.19922	0.21311	0.34321	0.15892	0.27471
0.21822	0.02804	0.34743	0.24876	0.22018	0.23750	0.33864	0.18626	0.33201
0.26669	0.02804	0.39014	0.27085	0.25683	0.25921	0.31853	0.21085	0.39136
0.29045	0.02804	0.39868	0.28035	0.27101	0.26816	0.30759	0.22535	0.41973
0.02775	0.05482	0.10462	0.07117	0.07264	0.06230	0.11149	0.03054	0.06120
0.05345	0.05482	0.17783	0.11492	0.10609	0.10282	0.19164	0.05492	0.10475
0.08570	0.05482	0.19491	0.15498	0.13947	0.14082	0.26464	0.08248	0.15427
0.12113	0.05482	0.26690	0.18823	0.17093	0.17258	0.31459	0.11073	0.20489
0.15941	0.05482	0.26446	0.21650	0.20129	0.19964	0.33593	0.13650	0.25663
0.20142	0.05482	0.28460	0.24160	0.23104	0.22402	0.34262	0.16160	0.31090
0.24557	0.05482	0.31693	0.26343	0.26031	0.24505	0.32815	0.18343	0.36575
0.26913	0.05482	0.33899	0.27365	0.27489	0.25502	0.31725	0.19615	0.39429
0.02889	0.07819	0.11194	0.07337	0.07259	0.06565	0.11539	0.02806	0.06326
0.05577	0.07819	0.19918	0.11780	0.10627	0.10723	0.19773	0.05155	0.10846
0.08891	0.07819	0.23457	0.15756	0.13963	0.14497	0.27022	0.07756	0.15899
0.12554	0.07819	0.26019	0.19072	0.17105	0.17675	0.31876	0.10322	0.21098
0.16513	0.07819	0.29802	0.21887	0.20129	0.20382	0.34159	0.12637	0.26416
0.20839	0.07819	0.32059	0.24375	0.23092	0.22799	0.34127	0.14875	0.31968
0.25358	0.07819	0.34377	0.26526	0.25988	0.24873	0.32466	0.17276	0.37551
0.27795	0.07819	0.33645	0.27546	0.27435	0.25873	0.31322	0.18546	0.40491
0.02716	0.08971	0.03629	0.06997	0.07247	0.06066	0.10939	0.02497	0.06014
0.05181	0.08971	0.17539	0.11252	0.10618	0.09910	0.18715	0.04627	0.10211
0.08246	0.08971	0.20346	0.15146	0.13964	0.13525	0.25857	0.07021	0.14947
0.11603	0.08971	0.23030	0.18394	0.17108	0.16575	0.30912	0.09394	0.19779
0.15154	0.08971	0.25836	0.21118	0.20109	0.19131	0.33678	0.11618	0.24619
0.19051	0.08971	0.27422	0.23556	0.23058	0.21459	0.34390	0.13806	0.29702
0.23255	0.08971	0.29619	0.25740	0.25966	0.23566	0.33356	0.15990	0.34982
0.25410	0.08971	0.30839	0.26723	0.27394	0.24509	0.32430	0.17223	0.37614

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
4000 PPM FAA SOLUTION

VC(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSPANN	KUMAR	MILLER	DECKWER
0.03037	0.02056	0.14001	0.07229	0.07159	0.06611	0.12106	0.03854	0.06590
0.05696	0.02056	0.19308	0.11375	0.10303	0.10538	0.20164	0.06625	0.11036
0.09053	0.02056	0.22725	0.15261	0.13482	0.14295	0.27451	0.09511	0.16196
0.12872	0.02056	0.27666	0.18531	0.16467	0.17492	0.32220	0.12281	0.21536
0.16938	0.02056	0.32791	0.21301	0.19340	0.20189	0.34272	0.14801	0.26972
0.21537	0.02056	0.36330	0.23832	0.22148	0.22726	0.33916	0.17332	0.32844
0.26230	0.02056	0.40173	0.25966	0.24898	0.24805	0.31597	0.19966	0.38606
0.28745	0.02056	0.40703	0.26971	0.26272	0.25795	0.30825	0.20971	0.41617
0.02879	0.03863	0.11804	0.06868	0.07088	0.06139	0.11565	0.03055	0.06307
0.05431	0.03863	0.17295	0.10930	0.10278	0.09892	0.19474	0.05430	0.10613
0.08635	0.03863	0.22298	0.14705	0.13473	0.13455	0.26663	0.07955	0.15524
0.12159	0.03863	0.25226	0.17876	0.16481	0.16471	0.31568	0.10376	0.20553
0.15974	0.03863	0.27117	0.20597	0.19383	0.19068	0.34031	0.12597	0.25706
0.20170	0.03863	0.30473	0.23032	0.22217	0.21432	0.34239	0.15032	0.31124
0.24636	0.03863	0.32913	0.25184	0.25008	0.23518	0.32724	0.17184	0.36672
0.26944	0.03863	0.36757	0.26162	0.26393	0.24459	0.31645	0.18162	0.39466
0.02907	0.07476	0.11682	0.06988	0.07122	0.06272	0.11653	0.02613	0.06357
0.05606	0.07476	0.20468	0.11254	0.10406	0.10269	0.19926	0.04754	0.10892
0.08977	0.07476	0.23873	0.15145	0.13664	0.13984	0.27251	0.07145	0.16025
0.12671	0.07476	0.26202	0.18377	0.16725	0.17082	0.32043	0.09377	0.21260
0.16704	0.07476	0.31144	0.21158	0.19676	0.19765	0.34225	0.11658	0.26666
0.21052	0.07476	0.33645	0.23589	0.22557	0.22119	0.34049	0.13839	0.32237
0.25390	0.07476	0.36879	0.25611	0.25334	0.24022	0.32391	0.15611	0.37590
0.27764	0.07476	0.36330	0.26589	0.26726	0.24968	0.31272	0.16839	0.40448
0.02720	0.07819	0.09852	0.06567	0.07065	0.05707	0.11001	0.02348	0.06020
0.05193	0.07819	0.15282	0.10601	0.10315	0.09363	0.18824	0.04288	0.10231
0.08264	0.07819	0.18637	0.14341	0.13542	0.12842	0.26011	0.06466	0.15004
0.11581	0.07819	0.22298	0.17407	0.16542	0.15695	0.30955	0.08532	0.19748
0.15200	0.07819	0.26080	0.20091	0.19438	0.18233	0.33734	0.10591	0.24681
0.19025	0.07819	0.29863	0.22414	0.22242	0.20430	0.34385	0.12414	0.29668
0.23150	0.07819	0.31876	0.24528	0.25015	0.22459	0.33336	0.14528	0.34897
0.25397	0.07819	0.31571	0.25515	0.26393	0.23416	0.32376	0.15515	0.37598

END User: KELKAR [114105,225451] Job: FOR06 Seq: 11890 Finished: 18-Sep-81 16:19 Pages: 2 System: B END

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

50 PPM PAA SOLUTION

VC M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02920	0.03890	181.80000	154.30825	180.45078	103.66197	99.24304	0.00598	0.23736	0.20225
0.05560	0.03890	258.30000	190.54690	229.07942	198.59894	230.21274	0.00553	0.23915	0.19846
0.08900	0.03890	350.00000	223.01631	269.79077	253.57367	293.47004	0.00523	0.24045	0.18998
0.12660	0.03890	593.10000	250.64974	305.07657	299.39639	346.00902	0.00501	0.24142	0.18391
0.16710	0.03890	577.70000	274.54918	334.29037	328.61466	384.13204	0.00485	0.24216	0.17205
0.21100	0.03890	470.50000	296.51804	362.40927	363.93531	474.33648	0.00471	0.24281	0.16784
0.25750	0.03890	572.10000	316.66087	388.46065	397.14701	461.39601	0.00460	0.24335	0.16595
0.28050	0.03890	449.40000	325.72850	399.75996	409.46398	476.40011	0.00456	0.24358	0.16271
0.02900	0.08170	194.30000	154.03849	159.80144	199.27493	162.96161	0.00598	0.23734	0.19696
0.05500	0.08170	259.10000	190.26443	209.78486	127.67028	149.09527	0.00554	0.23912	0.18687
0.08730	0.08170	264.90000	221.60146	258.05951	251.43679	272.02709	0.00524	0.24040	0.18952
0.12300	0.08170	321.80000	248.14561	292.74236	299.51574	325.97711	0.00503	0.24134	0.18374
0.16100	0.08170	330.50000	271.20048	322.56237	337.59818	369.64322	0.00487	0.24208	0.17856
0.20230	0.08170	386.00000	292.42639	351.35577	376.76564	412.54074	0.00474	0.24270	0.17800
0.24670	0.08170	395.10000	312.21490	375.59869	402.72628	444.53356	0.00463	0.24324	0.17044
0.26550	0.08170	472.00000	321.45657	387.56398	417.13910	461.09317	0.00458	0.24348	0.16886

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

500 PPM PAA SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02950	0.03680	177.70000	154.90990	180.44041	134.50417	58.25490	0.00636	0.24002	0.20094
0.05640	0.03680	333.60000	191.84921	227.32590	145.99009	201.34552	0.00588	0.24182	0.18816
0.09000	0.03680	286.40000	223.84013	269.12038	232.64833	281.46316	0.00556	0.24311	0.18213
0.12700	0.03680	370.30000	250.78014	302.90367	276.14685	332.42544	0.00533	0.24406	0.17229
0.16840	0.03680	396.10000	275.29221	335.80586	330.49558	386.67966	0.00516	0.24483	0.17504
0.21300	0.03680	588.60000	297.44261	362.88122	357.13113	421.52373	0.00501	0.24547	0.16323
0.26000	0.03680	483.80000	317.67214	388.76715	389.56682	458.59135	0.00490	0.24601	0.15947
0.28450	0.03680	523.30000	327.25407	400.90089	403.97620	475.32479	0.00484	0.24625	0.15714
0.02500	0.07940	204.40000	154.03849	177.83392	167.17866	164.08541	0.00637	0.23997	0.21808
0.05530	0.07940	262.70000	190.60626	211.84297	102.23881	157.97220	0.00589	0.24177	0.18982
0.08780	0.07940	394.90000	222.01949	254.95094	224.69995	255.34403	0.00556	0.24304	0.18352
0.12360	0.07940	310.90000	248.54442	290.84553	284.95985	316.54637	0.00535	0.24398	0.17912
0.16250	0.07940	374.00000	272.03171	320.58539	322.83306	360.87636	0.00518	0.24473	0.17180
0.20440	0.07940	418.50000	293.42466	348.93583	361.27679	403.14700	0.00504	0.24535	0.16845
0.24870	0.07940	503.00000	313.04799	374.26786	392.78602	439.10595	0.00492	0.24589	0.16424
0.27150	0.07940	486.70000	322.24186	385.45318	404.95945	454.12368	0.00487	0.24612	0.16067

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

2000 PPM PAA SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02990	0.02700	290.10000	155.59993	183.36112	153.54838	111.30010	0.00753	0.24827	0.20302
0.05670	0.02700	266.10000	192.18537	228.32720	120.93557	172.91219	0.00690	0.24955	0.18303
0.09140	0.02700	379.20000	224.58324	270.09697	182.18094	263.63476	0.00646	0.25048	0.17133
0.12840	0.02700	279.10000	251.68908	304.58053	250.85936	325.05035	0.00617	0.25114	0.16518
0.17200	0.02700	326.90000	277.18026	336.93380	298.40855	375.65522	0.00593	0.25171	0.15768
0.21560	0.02700	237.50000	298.63590	364.62138	339.24884	417.58251	0.00575	0.25214	0.15429
0.26300	0.02700	348.30000	318.87709	390.69249	375.21802	456.32016	0.00560	0.25251	0.15142
0.28800	0.02700	372.30000	328.57721	405.56465	408.82680	482.91319	0.00553	0.25268	0.16700
0.02870	0.06500	276.80000	153.51080	172.79997	135.31022	57.24134	0.00757	0.24819	0.21452
0.05500	0.06500	199.00000	190.26443	216.65738	97.40675	170.45798	0.00693	0.24949	0.19640
0.08700	0.06500	213.40000	221.34987	257.79498	218.49556	257.37590	0.00651	0.25039	0.18817
0.12300	0.06500	224.90000	248.14561	291.69125	267.84392	311.99863	0.00621	0.25106	0.17858
0.16200	0.06500	259.30000	271.75521	319.78188	298.59927	352.00293	0.00598	0.25159	0.16646
0.20400	0.06500	223.90000	293.23505	347.54025	337.44550	394.19174	0.00579	0.25203	0.16104
0.24870	0.06500	252.50000	313.04799	372.64146	369.54681	430.58730	0.00564	0.25241	0.15536
0.26940	0.06500	320.50000	321.41721	386.96418	397.50239	454.66064	0.00558	0.25256	0.16289

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

1000 PPM PAA SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02950	0.03900	240.00000	154.50990	181.75667	96.63060	104.22412	0.00764	0.24927	0.21396
0.05650	0.03900	391.50000	191.96140	226.94218	130.31984	196.45012	0.00702	0.25080	0.19571
0.09100	0.03900	535.00000	224.65784	268.74481	221.22615	274.37246	0.00660	0.25190	0.18528
0.12600	0.03900	440.50000	251.43006	303.69200	278.78311	333.18634	0.00632	0.25269	0.18066
0.16840	0.03900	470.50000	275.25221	334.15911	319.83383	379.07067	0.00610	0.25332	0.17474
0.21500	0.03900	592.20000	298.36139	362.87110	352.65909	419.06851	0.00591	0.25387	0.16550
0.26200	0.03900	621.40000	318.47647	388.40631	384.27213	455.25032	0.00576	0.25432	0.16037
0.28730	0.03900	643.40000	328.31345	399.33654	391.30009	468.37297	0.00565	0.25452	0.15132
0.02900	0.08900	229.00000	154.03849	168.17455	147.01875	77.02875	0.00766	0.24923	0.21754
0.05560	0.08900	333.50000	190.94690	206.58069	174.26827	105.67598	0.00704	0.25076	0.19415
0.08830	0.08900	308.10000	222.43593	250.89081	204.08386	239.34125	0.00663	0.25183	0.18736
0.12400	0.08900	458.50000	248.80957	288.50403	281.22189	310.22108	0.00634	0.25262	0.18501
0.16300	0.08900	443.90000	272.30764	322.19901	336.58125	366.40147	0.00612	0.25324	0.18581
0.20480	0.08900	475.40000	293.61403	346.92163	360.39869	398.49107	0.00594	0.25376	0.17415
0.24550	0.08900	534.40000	313.37994	370.32003	384.99521	429.96323	0.00579	0.25421	0.16488
0.27340	0.08900	595.70000	322.90431	383.86058	404.37940	450.16989	0.00573	0.25441	0.16514

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

2000 PPM PAA SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.03000	0.02800	352.20000	155.77147	182.01250	173.37662	142.61427	0.00796	0.25141	0.20171
0.05800	0.02800	389.90000	193.62844	228.25615	161.59705	151.64515	0.00724	0.25236	0.17917
0.09230	0.02800	442.60000	225.71191	270.78790	183.99948	264.40072	0.00676	0.25304	0.17348
0.13130	0.02800	416.50000	253.55097	306.44725	251.40104	326.83156	0.00642	0.25353	0.16550
0.17320	0.02800	428.90000	277.81694	337.19696	296.60943	374.95929	0.00617	0.25392	0.15791
0.21800	0.02800	411.10000	299.72887	365.72951	340.65476	419.25164	0.00596	0.25423	0.15549
0.26670	0.02800	433.70000	320.35058	391.30338	370.59680	455.22471	0.00579	0.25450	0.14739
0.29050	0.02800	443.30000	329.51572	403.05144	386.30451	472.18458	0.00571	0.25462	0.14579
0.02900	0.07800	135.40000	154.03849	166.62893	176.43848	134.83436	0.00802	0.25136	0.21387
0.05600	0.07800	328.00000	191.39913	206.73852	197.12606	80.54716	0.00728	0.25233	0.18908
0.08900	0.07800	245.60000	223.01631	250.38147	156.96083	225.66656	0.00680	0.25299	0.18021
0.12550	0.07800	283.00000	249.79880	287.02134	250.55041	297.63364	0.00647	0.25347	0.17426
0.16500	0.07800	291.80000	273.40574	316.75663	294.15860	344.69890	0.00621	0.25385	0.16571
0.20840	0.07800	483.30000	295.30725	345.76783	337.79930	390.25730	0.00600	0.25417	0.16100
0.25360	0.07800	433.70000	315.07008	371.39948	372.51052	428.19940	0.00583	0.25444	0.15630
0.27600	0.07800	432.40000	324.76760	385.80210	395.46902	450.45396	0.00575	0.25456	0.15791

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

4000 PPM PAA SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.03040	0.02060	138.70000	156.45383	186.89145	149.06647	102.86412	0.00865	0.25505	0.20826
0.05700	0.02060	181.90000	192.52034	232.44990	103.33469	195.12639	0.00794	0.25629	0.19372
0.09100	0.02060	201.20000	224.65784	273.58429	211.44434	277.87132	0.00745	0.25720	0.18511
0.12870	0.02060	211.70000	251.88299	307.64362	257.77052	331.05999	0.00710	0.25787	0.17326
0.16940	0.02060	259.20000	275.79052	337.34579	293.85313	374.84023	0.00684	0.25839	0.16208
0.21540	0.02060	319.80000	298.54445	366.05961	332.40160	417.59522	0.00662	0.25884	0.15509
0.26230	0.02080	278.10000	318.59676	391.06046	363.11880	453.33622	0.00644	0.25920	0.14791
0.28750	0.02060	331.60000	328.38886	403.73724	380.93139	471.93222	0.00636	0.25937	0.14683
0.02910	0.07500	263.10000	154.21358	166.62929	183.32415	145.48731	0.00870	0.25496	0.21534
0.05600	0.07500	328.20000	191.39913	206.87798	203.91362	105.71052	0.00796	0.25626	0.19046
0.09000	0.07500	386.20000	223.84013	252.23330	152.35227	226.69525	0.00746	0.25718	0.18227
0.12670	0.07500	351.70000	250.58450	288.93712	249.93461	299.43237	0.00712	0.25784	0.17677
0.16700	0.07500	394.50000	274.49494	317.70905	287.20082	343.49916	0.00685	0.25836	0.16566
0.21050	0.07500	443.80000	296.28599	346.35079	331.11933	388.60164	0.00664	0.25879	0.16054
0.25400	0.07500	461.30000	315.23399	369.90696	361.40138	423.09764	0.00647	0.25914	0.15415
0.37760	0.07500	442.50000	324.61332	383.83273	384.37315	444.80970	0.00639	0.25931	0.15538

2.0 BATCH BUBBLE COLUMN

The holdup characteristics of three-phase systems are studied in highly viscous non-Newtonian medium. Kim et al. (1975, 1977) have analyzed phase holdup and bubble characteristics in three-phase fluidized beds with various non-Newtonian (carboxymethylcellulose solutions) and Newtonian solutions. For particles of sizes in the range of 1-6 mm, and gas velocity between 0-0.1 m/s, Kim et al. (1975) found a slight decrease in $\varepsilon_\ell + \varepsilon_G$ with respect to gas velocity. Kim et al. (1975) have reported that bubble sizes are relatively insensitive to viscosity and surface tension for similar systems with a U_G<0.06 m/s. To study the effect of viscosity on the bubble size distribution in three-phase systems, slurries of sand and polystyrene are studied. Properties of the sand and polystyrene slurries are given in Table 2.1. Phase holdups are measured by a hydrostatic head method, and relative bubble sizes and rise velocities are determined using the dynamic gas-disengagement method.

For the three-phase experiments with water as a liquid medium, a distribution of solids along the column is observed. For polystyrene runs, gas holdup varied axially with a deviation of less than 3%. Tables A2.1 to A2.4 indicate the comparison of phase holdups for 10 wt% sand/10, 20, and 30 wt% polystyrene in water. For the run of air-water-sand, a significant solid distribution is observed, with part of the sand settling into the conical section of the column. For CMC solution-solid runs, no axial variation of phase holdups is observed. Tables A2.5-A2.8 indicate that correlation of Kito et al. (1976) is applicable to air-water-solid runs. Begovich and Watson's (1978) correlation predicts very low gas holdup for air-water-solid systems; whereas, for air-CMC solution/solid runs it predicts values of gas holdup within a reasonable agreement.

From Figure 2.1, it is clear that the gas holdup is virtually unaffected by the concentration of polystyrene and there is negligible effect of the presence of solids on the gas holdup. It should be noted that the

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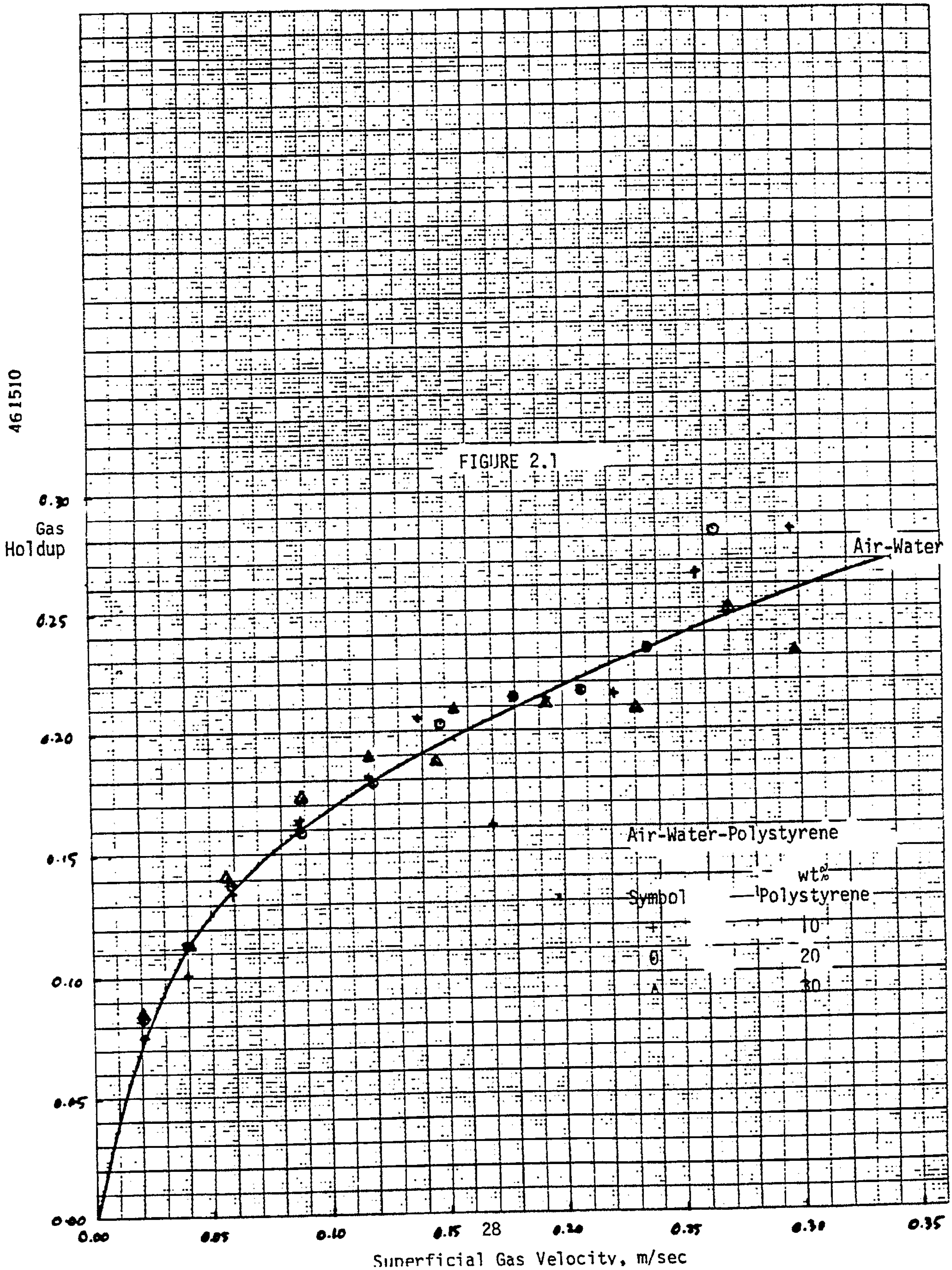

FIGURE 2.1

TABLE 2.1

PHYSICAL PROPERTIES OF THE SLURRIES

Solid	Wt% of Solid	ρ_L gm/cc	σ_L Dynes/cm	Consistency Index CP(sec)$^{n-1}$	Flow Behavior Index (n)
Sand*	10%	1.0	72.0	1.0	1.0
Polystyrene**	10%	1.0	72.0	1.0	1.0
Polystyrene	20%	1.0	72.0	1.0	1.0
Polystyrene	30%	1.0	72.0	1.0	1.0
Polystyrene***	10%	0.9997	68.2	311	0.968
Polystyrene***	20%	0.9997	67.5	438	0.946
Sand***	10%	0.9997	69.2	169	0.914
Sand***	20%	0.9997	69.1	119	0.952

* All sand used has an average size (120 µm) and a density of 2.65 gm/cc.
** All polystyrene used has an average size (320 µm) and a density of 1.2 gm/cc.
*** These slurries contain 0.5 wt% CMC solution as liquid phase.

calculation of gas holdup is based on the assumption of no axial variation of gas holdup. The gas holdup in a highly viscous, non-Newtonian solution has been correlated by

$$\varepsilon_G = 0.287\ V_G^{0.536}\ (\mu_{eff})^{-0.121}$$

Where, $\mu_{eff} = k(5000.0 \times V_G)^{n-1}$ (V_G in m/s). Figures 2.2 and 2.3 indicate the gas holdup data for 10 and 20 wt% polystyrene and sand in CMC solutions. The air-CMC solution curve is based on the equation reported above. For polystyrene-CMC solution mixtures, the gas holdup tends to lie above the air-CMC solution line; whereas for sand, it lies below. The effect of the addition of solids on gas holdup in CMC solutions is more than air-water-solid runs.

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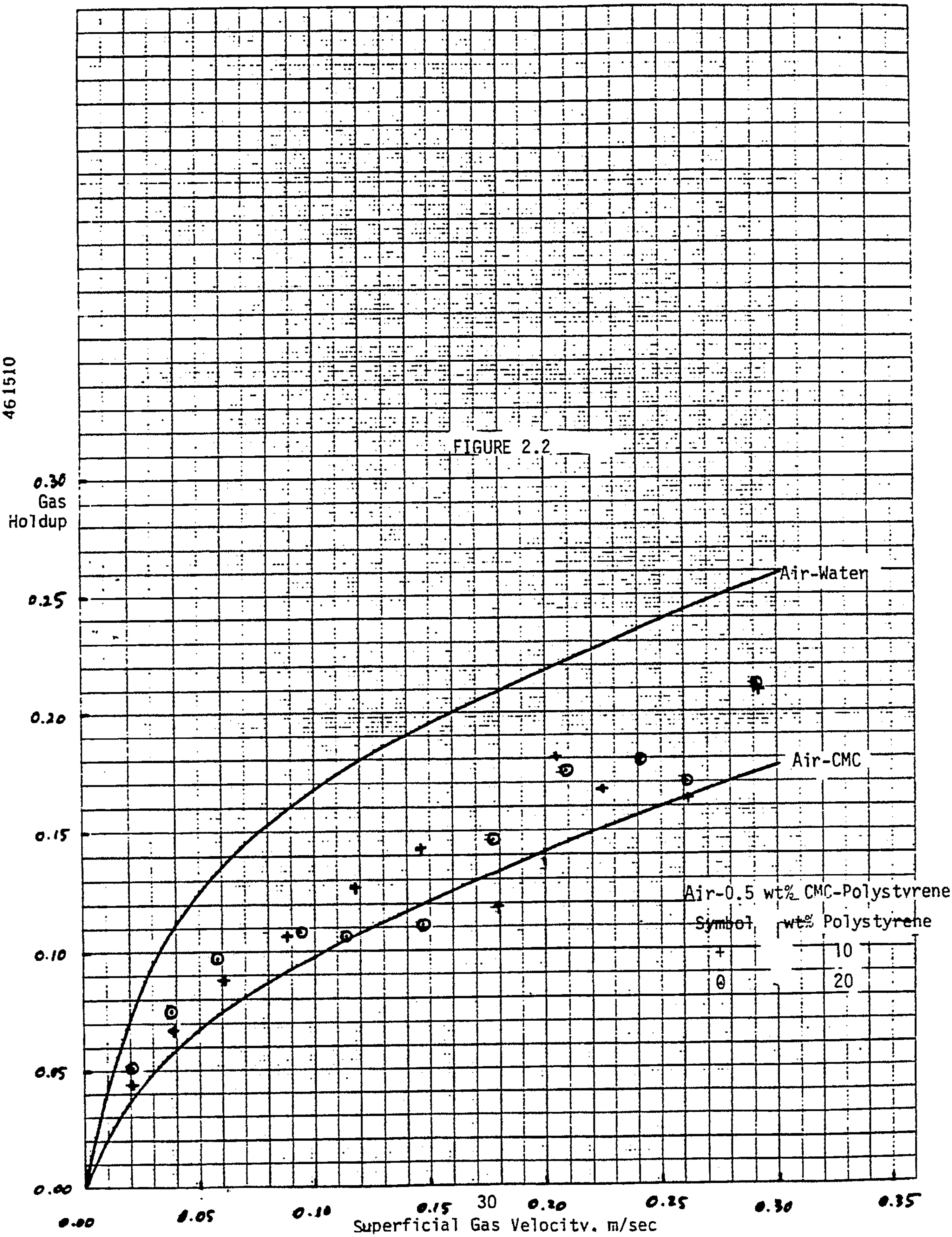
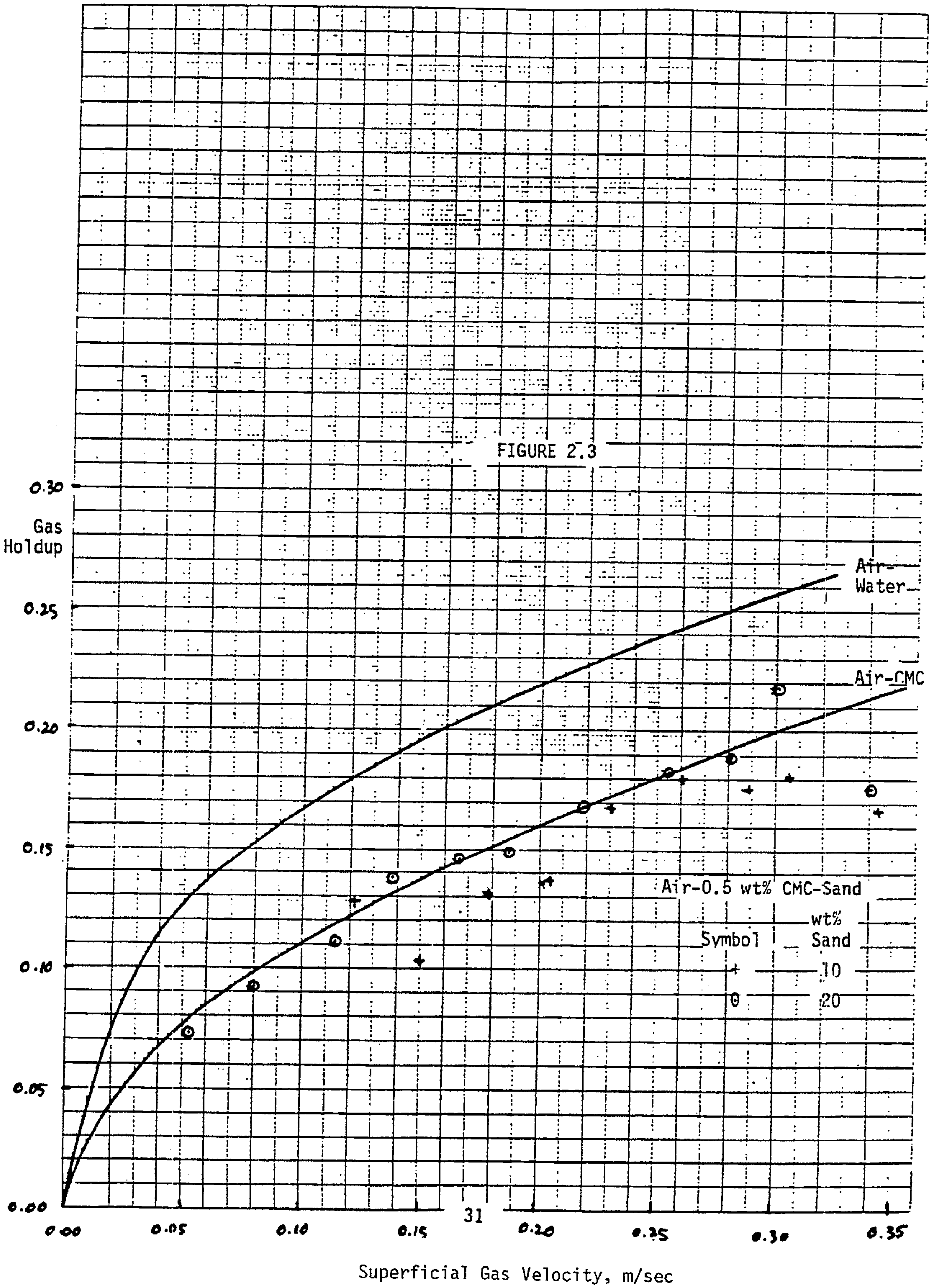


FIGURE 2.2
Gas Holdup
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Air-Water
Air-CMC
Air-0.5 wt% CMC-Polystyrene
Symbol
wt% Polystyrene
+
10
Θ
20
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Superficial Gas Velocity, m/sec

30



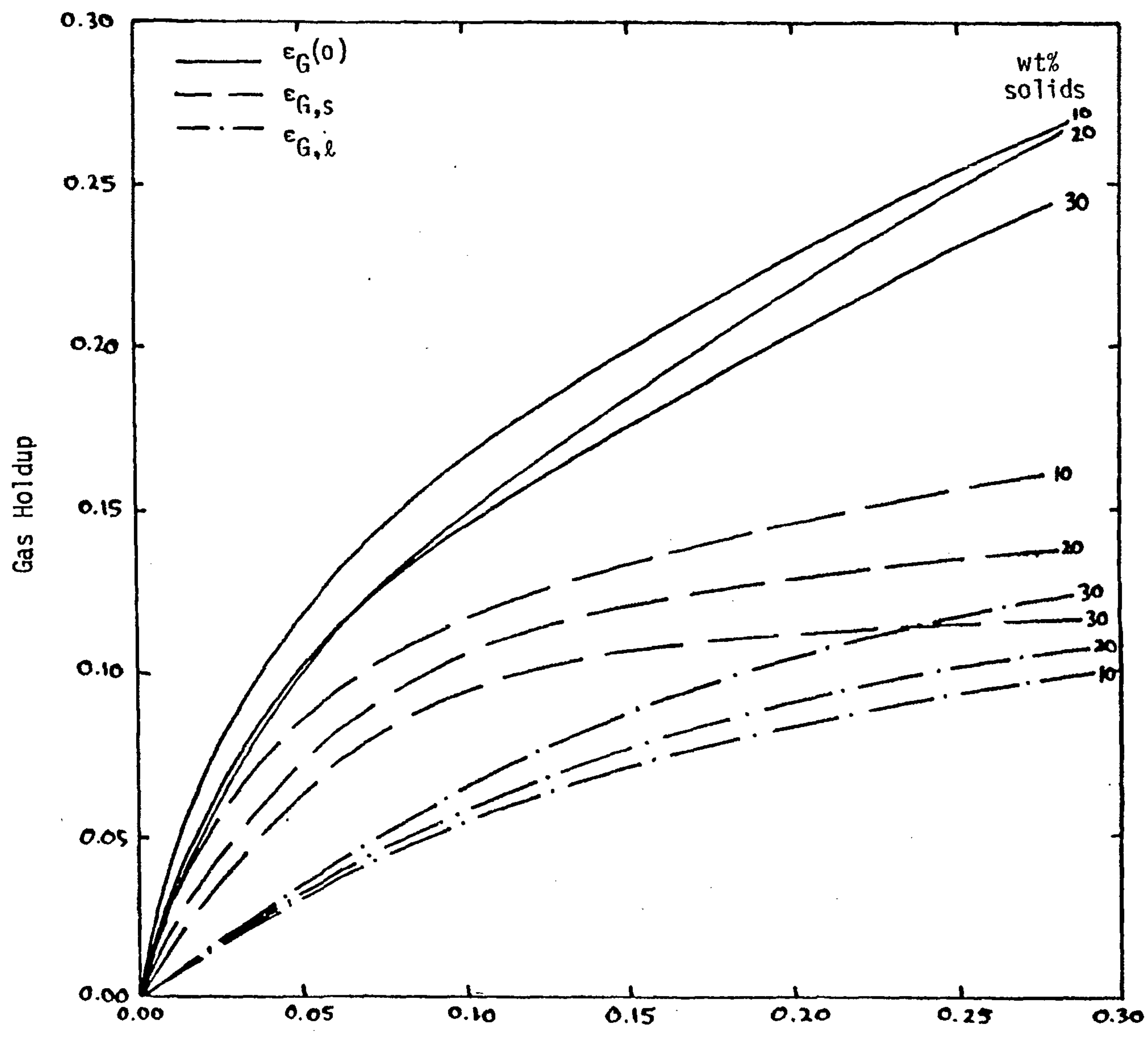
Gas Holdup
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Air-Water
Air-CMC
Air-0.5 wt% CMC-Sand
Symbol
wt% Sand
+ 10
⊙ 20
Superficial Gas Velocity, m/sec

FIGURE 2.3

Figure 2.4 shows gas holdup data obtained from dynamic gas the disengagement method for air-water-polystyrene ε_G as well as $\varepsilon_{G,s}$ (gas holdup due to small bubbles) decreases with an increase in concentration of solids. $\varepsilon_{G,\ell}$ (gas holdup due to large bubbles) shows a pronounced increase with the concentration of solids. Figure 2.5 shows bubble rise velocities as a function of superficial gas velocity. $U_{br,s}$ (the bubble rise velocity of small bubbles) is virtually independent of gas velocity, although it shows a definite increase with solid concentration.

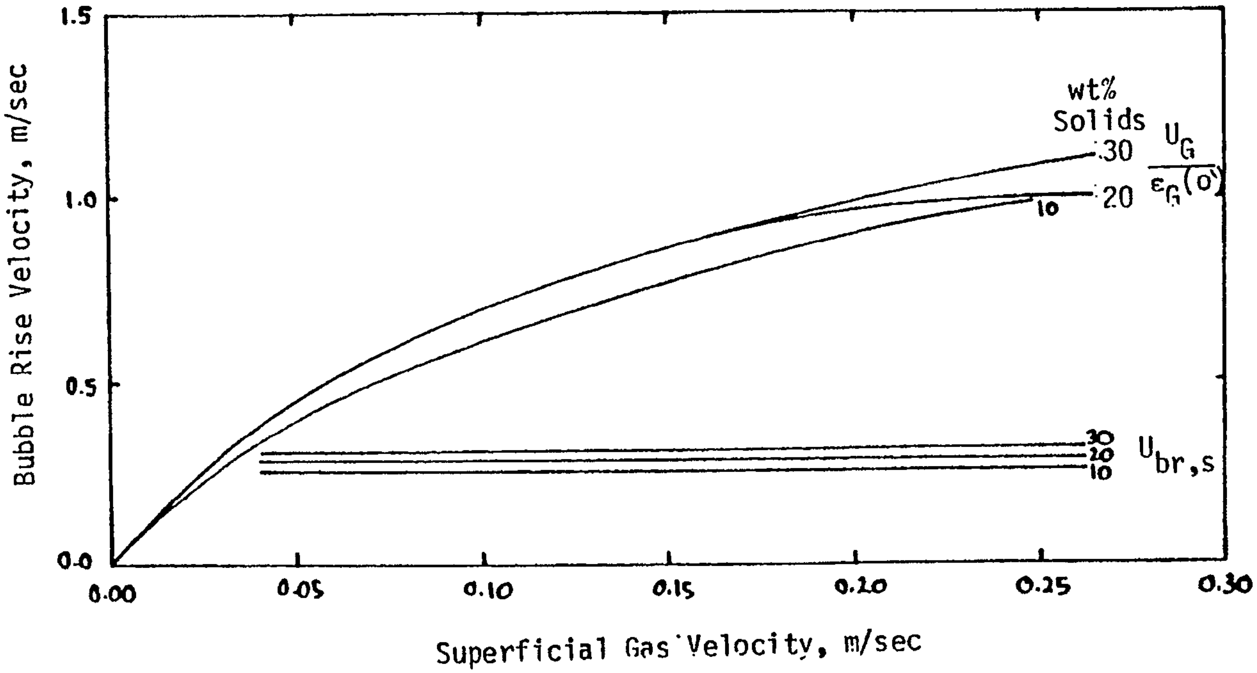
Figures 2.6 and 2.7 shows ε_G V_s V_G and U_{br}-V_G for air-CMC solution-polystyrene system. With the addition of solids, $\varepsilon_{G,s}$ increases; whereas $\varepsilon_{G,\ell}$ shows a significant decrease. This indicates that with the addition of solids, smaller bubbles are formed. On the other hand, in the air-water-polystyrene system, $\varepsilon_{G,s}$ shows a decrease with $\varepsilon_{G,\ell}$ increasing when polystyrene concentration is increased from 10% to 30%. Since interfacial area is mostly determined by small bubbles, with the addition of polystyrene "a" should increase in the mixture of air-CMC solution-polystyrene. From Figure 2.7, it can be seen that $U_{br,s}$ increases with the addition of solids. It seems strange that $U_{br,s}$ as well as $\varepsilon_{G,s}$ increases with the addition of solids, but it is possible as the bubble size distribution itself is greatly altered. The bubble rise velocities of large bubbles are not shown in the figure, as a small error in the slope of plot of $\varepsilon_{G,}$ (t) vs time can produce large errors in the predicted value of $U_{br,\ell}$. This is especially true for three-phase systems or highly viscous solutions. $U_{br,\ell}$ is generally greater than 1.0 m/s.

More data are needed before any conclusions can be drawn about bubble size distribution, "a" and K_La in three-phase systems. The dynamic gas disengagement method in conjunction with the knowledge of "a" and K_La can be a great tool in the explanation of observed trends.



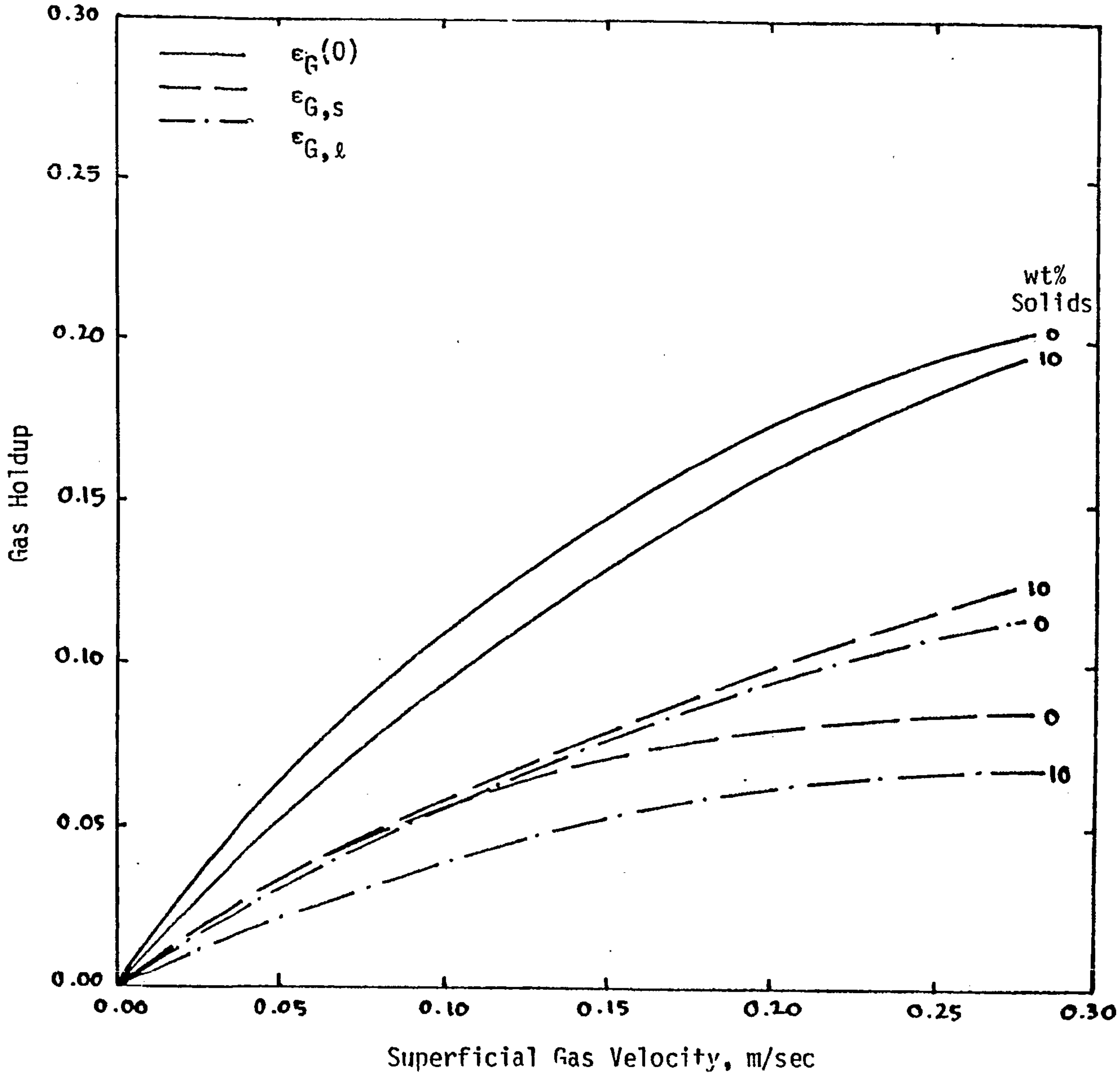
ε_G vs. U_G for Air-Water-Polystyrene

FIGURE 2.4



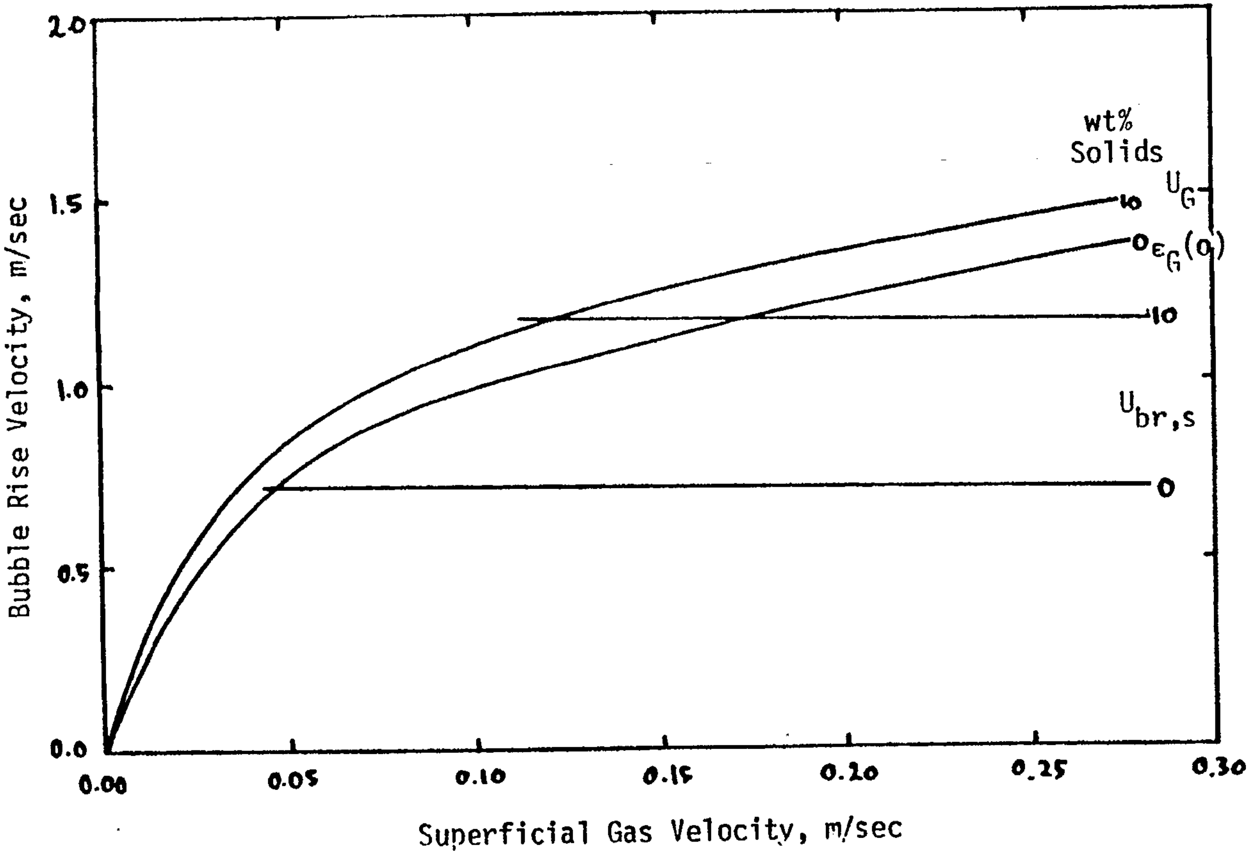
U_{br} vs. U_G for Air-Water-Polystyrene

FIGURE 2.5



ε_G vs. U_G for Air-0.5 wt% CMC-Polystyrene

FIGURE 2.6



U_{br} vs. U_G for Air-0.5 wt% CMC-Polystyrene

FIGURE 2.7

References

2.1 Kim, S. D., C. G. J. Baker, and M. A. Bergougnou, "Phase Holdup Characteristics of Three-Phase Fluidized Beds," The Canadian Journal of Chem. Eng., 53, 134 (1975).

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2.3 Begovich, J. M., and J. S. Watson, "Hydrodynamic Characteristics of Three-Phase Fluidized Beds," Fluidization, Proceedings of the Second Engineering Conference, Trinity College, Cambridge, England, April 2-6, 1978, edited by Davidson, J. F., and D. L. Keairns, 190-195 (1978).

2.4 Kito, M., T. Shimida, T. Sakai, S. Sugiyama, and C. Y. Wen, Fluidization Technology, edited by Keairns, D. L., Volume 1, Washington Hemisphere Publishing Company (1976).

TABLE A2.1

AIR-WATER-120 MICRON SAND(10.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 1.00000 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
SOLID DENSITY=2650.00000 KG/(M**3)
DIAMETER OF PARTICLES=120.0000*10**-06 M

POINT #	VG(M/S)	VDRIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGOVICH-WATSON	GAS HOLDUP KITO ET AL.
1	0.02121	0.01992	0.34786	0.06099	0.92651	0.01250	0.02560	0.05348
2	0.02121	0.02000	0.37060	0.05721	0.93257	0.01021	0.02560	0.05348
3	0.02121	0.01995	0.35562	0.05966	0.92865	0.01169	0.02560	0.05348
4	0.02121	0.02016	0.42858	0.04950	0.94496	0.00554	0.02560	0.05348
1	0.04094	0.03660	0.36625	0.10600	0.87532	0.01869	0.04110	0.08510
2	0.04094	0.03649	0.37668	0.10869	0.87099	0.02032	0.04110	0.08510
3	0.04094	0.03697	0.42216	0.09698	0.88980	0.01322	0.04110	0.08510
4	0.04094	0.03718	0.44576	0.09184	0.89804	0.01011	0.04110	0.08510
1	0.05960	0.05137	0.43153	0.13610	0.83818	0.02371	0.05385	0.10958
2	0.05960	0.05135	0.43069	0.13837	0.83775	0.02388	0.05385	0.10958
3	0.05960	0.05151	0.43905	0.13574	0.84198	0.02228	0.05385	0.10958
4	0.05960	0.05257	0.50566	0.11786	0.87070	0.01144	0.05385	0.10958
1	0.08975	0.07515	0.55189	0.16262	0.81156	0.02582	0.07231	0.14250
2	0.08975	0.07562	0.57017	0.15741	0.81994	0.02265	0.07231	0.14250
3	0.08975	0.07503	0.54712	0.16404	0.80929	0.02667	0.07231	0.14250
4	0.08975	0.07619	0.59406	0.15108	0.83011	0.01882	0.07231	0.14250
1	0.12353	0.10119	0.68288	0.18090	0.79384	0.02525	0.09102	0.17304
2	0.12353	0.10182	0.70269	0.17580	0.80204	0.02216	0.09102	0.17304
3	0.12353	0.10102	0.67769	0.18229	0.79162	0.02609	0.09102	0.17304
4	0.12353	0.10258	0.72834	0.16961	0.81198	0.01841	0.09102	0.17304
1	0.15027	0.11907	0.72376	0.20762	0.77259	0.01979	0.10481	0.19389
2	0.15027	0.11937	0.73089	0.20560	0.77585	0.01856	0.10481	0.19389
3	0.15027	0.12029	0.75322	0.19950	0.78564	0.01486	0.10481	0.19389
4	0.15027	0.12138	0.78169	0.19223	0.79731	0.01046	0.10481	0.19389
1	0.17987	0.13710	0.75638	0.23781	0.74742	0.01478	0.11929	0.21310
2	0.17987	0.13802	0.77298	0.23270	0.75562	0.01168	0.11929	0.21310
3	0.17987	0.13873	0.78640	0.22873	0.76200	0.00927	0.11929	0.21310
4	0.17987	0.13875	0.78674	0.22863	0.76216	0.00921	0.11929	0.21310
1	0.20965	0.15318	0.77840	0.26934	0.71953	0.01113	0.13320	0.23307
2	0.20965	0.15422	0.79296	0.26439	0.72748	0.00813	0.13320	0.23307
3	0.20965	0.15437	0.79511	0.26368	0.72862	0.00770	0.13320	0.23307
4	0.20965	0.15491	0.80291	0.26111	0.73274	0.00615	0.13320	0.23307
1	0.24115	0.17217	0.84309	0.28603	0.70507	0.00890	0.14733	0.25234
2	0.24115	0.17227	0.84432	0.28561	0.70574	0.00865	0.14733	0.25234
3	0.24115	0.17323	0.85619	0.28165	0.71210	0.00625	0.14733	0.25234
4	0.24115	0.17354	0.86016	0.28035	0.71419	0.00546	0.14733	0.25234
5	0.24115	0.17386	0.86420	0.27904	0.71629	0.00467	0.14733	0.25234
1	0.26804	0.19039	0.92530	0.28968	0.70144	0.00888	0.15898	0.26452
2	0.26804	0.19059	0.92764	0.28895	0.70261	0.00844	0.15898	0.26452
3	0.26804	0.19111	0.93391	0.28701	0.70573	0.00726	0.15898	0.26452
4	0.26804	0.19204	0.94531	0.28354	0.71129	0.00516	0.15898	0.26452
5	0.26804	0.19237	0.94949	0.28230	0.71329	0.00441	0.15898	0.26452
1	0.30100	0.21098	1.00646	0.29906	0.69139	0.00954	0.17282	0.28015
2	0.30100	0.21137	1.01086	0.29776	0.69349	0.00875	0.17282	0.28015
3	0.30100	0.21254	1.02428	0.29386	0.69975	0.00639	0.17282	0.28015
4	0.30100	0.21300	1.02959	0.29235	0.70218	0.00547	0.17282	0.28015
5	0.30100	0.21360	1.03666	0.29035	0.70539	0.00426	0.17282	0.28015
1	0.36234	0.24515	1.12029	0.32344	0.66790	0.00866	0.19752	0.30604
2	0.36234	0.24607	1.12920	0.32088	0.67200	0.00712	0.19752	0.30604
3	0.36234	0.24717	1.13953	0.31786	0.67685	0.00529	0.19752	0.30604
4	0.36234	0.24772	1.14543	0.31634	0.67930	0.00436	0.19752	0.30604
5	0.36234	0.24824	1.15078	0.31489	0.68163	0.00348	0.19752	0.30604
1	0.34563	0.23773	1.10717	0.31217	0.68038	0.00744	0.19091	0.29935
2	0.34563	0.23790	1.10891	0.31168	0.68117	0.00715	0.19091	0.29935
3	0.34563	0.23871	1.11731	0.30534	0.68493	0.00573	0.19091	0.29935
4	0.34563	0.23904	1.12076	0.30839	0.68647	0.00515	0.19091	0.29935
5	0.34563	0.23974	1.12819	0.30636	0.68973	0.00392	0.19091	0.29935

TABLE A2.2

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-300 MICRON POLYSTYRENE(10.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 1.00000 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
SOLID DENSITY=1200.00000 KG/(M**3)
DIAMETER OF PARTICLES=300.0000*10**-06 M

PORT #	VG(M/S)	VDRIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGOVICH-WATSON	GAS HOLDUP KITO ET AL.
1	0.02100	0.01941	0.27747	0.07568	0.84362	0.08070	0.02964	0.05308
2	0.02100	0.01941	0.27819	0.07548	0.84479	0.07973	0.02964	0.05308
3	0.02100	0.01943	0.28072	0.07480	0.84888	0.07632	0.02964	0.05308
4	0.02100	0.01943	0.28080	0.07478	0.84900	0.07622	0.02964	0.05308
1	0.04026	0.03576	0.36008	0.11181	0.81013	0.07806	0.04736	0.08412
2	0.04026	0.03576	0.36041	0.11171	0.81073	0.07756	0.04736	0.08412
3	0.04026	0.03577	0.36099	0.11153	0.81180	0.07667	0.04736	0.08412
4	0.04026	0.03583	0.36573	0.11008	0.82049	0.06943	0.04736	0.08412
1	0.05870	0.05077	0.43475	0.13502	0.78993	0.07505	0.06213	0.10849
2	0.05870	0.05080	0.43556	0.13464	0.79218	0.07317	0.06213	0.10849
3	0.05870	0.05081	0.43655	0.13446	0.79328	0.07226	0.06213	0.10849
4	0.05870	0.05085	0.43880	0.13377	0.79742	0.06881	0.06213	0.10849
1	0.08826	0.07372	0.53545	0.16483	0.76205	0.07313	0.08334	0.14103
2	0.08826	0.07376	0.53723	0.16429	0.76525	0.07046	0.08334	0.14103
3	0.08826	0.07377	0.53748	0.16422	0.76570	0.07008	0.08334	0.14103
4	0.08826	0.07377	0.53734	0.16426	0.76546	0.07028	0.08334	0.14103
1	0.11778	0.09629	0.64542	0.18249	0.74775	0.06976	0.10258	0.16821
2	0.11778	0.09632	0.64631	0.18224	0.74927	0.06849	0.10258	0.16821
3	0.11778	0.09654	0.65295	0.18039	0.76038	0.05923	0.10258	0.16821
4	0.11778	0.09643	0.64959	0.18132	0.75479	0.06389	0.10258	0.16821
1	0.13800	0.10965	0.67176	0.20543	0.72899	0.06558	0.11497	0.18462
2	0.13800	0.10969	0.67273	0.20513	0.73078	0.06410	0.11497	0.18462
3	0.13800	0.10968	0.67242	0.20523	0.73020	0.06458	0.11497	0.18462
4	0.13800	0.10974	0.67403	0.20473	0.73314	0.06213	0.11497	0.18462
1	0.17060	0.14257	1.03849	0.16428	0.76499	0.07074	0.13394	0.20647
2	0.17060	0.14269	1.04291	0.16358	0.76917	0.06726	0.13394	0.20647
3	0.17060	0.14265	1.04855	0.16264	0.77481	0.06255	0.13394	0.20647
4	0.17060	0.14277	1.04581	0.16312	0.77189	0.06499	0.13394	0.20647
5	0.17060	0.14289	1.05042	0.16241	0.77618	0.06141	0.13394	0.20647
1	0.19275	0.15102	0.89033	0.21649	0.71581	0.06769	0.14625	0.22197
2	0.19275	0.15112	0.89244	0.21598	0.71887	0.06514	0.14625	0.22197
3	0.19275	0.15120	0.89427	0.21554	0.72153	0.06293	0.14625	0.22197
4	0.19275	0.15124	0.89502	0.21536	0.72261	0.06203	0.14625	0.22197
5	0.19275	0.15139	0.89834	0.21456	0.72739	0.05805	0.14625	0.22197
1	0.22204	0.17360	1.01770	0.21818	0.71691	0.06491	0.16193	0.24086
2	0.22204	0.17368	1.01950	0.21780	0.71922	0.06298	0.16193	0.24086
3	0.22204	0.17363	1.01831	0.21805	0.71769	0.06426	0.16193	0.24086
4	0.22204	0.17375	1.02052	0.21749	0.72104	0.06147	0.16193	0.24086
5	0.22204	0.17386	1.02329	0.21699	0.72406	0.05895	0.16193	0.24086
1	0.25729	0.18852	0.96265	0.26727	0.67505	0.05768	0.18005	0.26158
2	0.25729	0.18842	0.96121	0.26767	0.67264	0.05969	0.18005	0.26158
3	0.25729	0.18843	0.96139	0.26762	0.67294	0.05944	0.18005	0.26158
4	0.25729	0.18859	0.96364	0.26700	0.67670	0.05631	0.18005	0.26158
5	0.25729	0.18974	0.96572	0.26642	0.68014	0.05344	0.18005	0.26158
1	0.29687	0.21194	1.03771	0.28608	0.65449	0.05943	0.19959	0.27827
2	0.29687	0.21205	1.03904	0.28571	0.65568	0.05761	0.19959	0.27827
3	0.29687	0.21166	1.03670	0.28636	0.65281	0.06083	0.19959	0.27827
4	0.29687	0.21209	1.03956	0.28557	0.65754	0.05689	0.19959	0.27827
5	0.29687	0.21241	1.04344	0.28451	0.66391	0.05155	0.19959	0.27827

TABLE A2.3

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-300 MICRON POLYSTYRENE(20.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 1.00000 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
SOLID DENSITY=1200.00000 KG/(M**3)
DIAMETER OF PARTICLES=300.0000*10**-06 M

PORT #	VG(M/S)	VDRIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGOVICH-WATSON	GAS HOLDUP KITU ET AL.
1	0.02149	0.01965	0.25194	0.08528	0.77689	0.13782	0.03013	0.05397
2	0.02149	0.01968	0.25554	0.08395	0.78489	0.13116	0.03013	0.05397
3	0.02149	0.01971	0.25940	0.08283	0.79162	0.12555	0.03013	0.05397
4	0.02149	0.01970	0.25857	0.08310	0.79003	0.12688	0.03013	0.05397
1	0.04013	0.03546	0.34473	0.11640	0.74603	0.13757	0.04725	0.08393
2	0.04013	0.03554	0.35083	0.11438	0.75817	0.12745	0.04725	0.08393
3	0.04013	0.03552	0.34986	0.11469	0.75629	0.12902	0.04725	0.08393
4	0.04013	0.03570	0.36344	0.11041	0.78199	0.10760	0.04725	0.08393
1	0.05916	0.05091	0.42410	0.13550	0.73091	0.12959	0.06248	0.10905
2	0.05916	0.05096	0.42670	0.13665	0.73601	0.12534	0.06248	0.10905
3	0.05916	0.05101	0.42956	0.13773	0.74155	0.12072	0.06248	0.10905
4	0.05916	0.05107	0.43231	0.13685	0.74680	0.11635	0.06248	0.10905
1	0.08881	0.07459	0.55474	0.16009	0.71738	0.12253	0.08371	0.14157
2	0.08881	0.07463	0.55611	0.15969	0.71975	0.12056	0.08371	0.14157
3	0.08881	0.07473	0.56010	0.15856	0.72657	0.11487	0.08371	0.14157
4	0.08881	0.07468	0.55813	0.15511	0.72322	0.11767	0.08371	0.14157
1	0.11947	0.09784	0.66010	0.18098	0.69722	0.12180	0.10364	0.16963
2	0.11947	0.09793	0.66261	0.18030	0.70132	0.11838	0.10364	0.16963
3	0.11947	0.09810	0.66785	0.17888	0.70982	0.11130	0.10364	0.16963
4	0.11947	0.09819	0.67069	0.17812	0.71437	0.10751	0.10364	0.16963
1	0.14820	0.11731	0.71109	0.20841	0.67426	0.11732	0.12103	0.19236
2	0.14820	0.11741	0.71339	0.20774	0.67830	0.11396	0.12103	0.19236
3	0.14820	0.11750	0.71531	0.20718	0.68164	0.11118	0.12103	0.19236
4	0.14820	0.11762	0.71829	0.20632	0.68681	0.10687	0.12103	0.19236
5	0.14820	0.11772	0.72065	0.20565	0.69086	0.10349	0.12103	0.19236
1	0.17945	0.14013	0.81898	0.21911	0.66509	0.11579	0.13891	0.21280
2	0.17945	0.14034	0.82341	0.21793	0.67217	0.10990	0.13891	0.21280
3	0.17945	0.14036	0.82379	0.21783	0.67277	0.10935	0.13891	0.21280
4	0.17945	0.14026	0.82177	0.21838	0.66948	0.11214	0.13891	0.21280
5	0.17945	0.14048	0.82642	0.21714	0.67692	0.10594	0.13891	0.21280
1	0.20719	0.16130	0.93548	0.22148	0.66234	0.11617	0.15406	0.23149
2	0.20719	0.16159	0.94137	0.22010	0.67065	0.10925	0.15406	0.23149
3	0.20719	0.16155	0.94050	0.22030	0.66944	0.11026	0.15406	0.23149
4	0.20719	0.16168	0.94330	0.21965	0.67336	0.10700	0.15406	0.23149
5	0.20719	0.16196	0.94908	0.21831	0.68139	0.10030	0.15406	0.23149
1	0.23589	0.17942	0.98549	0.23536	0.64752	0.11312	0.16914	0.24924
2	0.23589	0.18022	0.99965	0.23597	0.66786	0.09617	0.16914	0.24924
3	0.23589	0.17975	0.95124	0.23797	0.65585	0.10618	0.16914	0.24924
4	0.23589	0.17987	0.95331	0.23747	0.65883	0.10370	0.16914	0.24924
5	0.23589	0.18020	0.99921	0.23607	0.66725	0.09468	0.16914	0.24924
1	0.26438	0.18015	0.91690	0.28834	0.60608	0.10556	0.18361	0.26270
2	0.26438	0.18032	0.91899	0.28768	0.61002	0.10230	0.18361	0.26270
3	0.26438	0.18937	0.92180	0.28373	0.63376	0.08252	0.18361	0.26270
4	0.26438	0.18860	0.92238	0.28663	0.61636	0.09701	0.18361	0.26270
5	0.26438	0.18872	0.92382	0.28618	0.61905	0.09478	0.18361	0.26270
1	0.29172	0.21385	1.05250	0.26692	0.63126	0.10182	0.19709	0.27589
2	0.29172	0.21379	1.05204	0.26713	0.62999	0.10288	0.19709	0.27589
3	0.29172	0.21391	1.05373	0.26672	0.63247	0.10082	0.19709	0.27589
4	0.29172	0.21417	1.05743	0.26582	0.63786	0.09632	0.19709	0.27589

TABLE A2.4

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-300 MICRON POLYSTYRENE(30.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 1.00000 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
SOLID DENSITY=1200.00000 KG/(M**3)
DIAMETER OF PARTICLES=300.0000*10**-06 M

PORT #	VG(M/S)	VDRIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGOVICH-WATSON	GAS HOLDUP KITO ET AL.
1	0.02098	0.01913	0.23843	0.08799	0.69196	0.22004	0.02962	0.05305
2	0.02098	0.01920	0.24743	0.08479	0.71117	0.20404	0.02962	0.05305
3	0.02098	0.01919	0.24639	0.08515	0.70902	0.20583	0.02962	0.05305
4	0.02098	0.01920	0.24734	0.08492	0.71098	0.20419	0.02962	0.05305
1	0.04159	0.03654	0.34240	0.12146	0.68347	0.19506	0.04848	0.08602
2	0.04159	0.03710	0.38524	0.10796	0.76452	0.12752	0.04848	0.08602
3	0.04159	0.03732	0.40483	0.10273	0.79587	0.10139	0.04848	0.08602
4	0.04159	0.03659	0.34624	0.12011	0.69157	0.18831	0.04848	0.08602
1	0.05743	0.04910	0.39554	0.14506	0.63802	0.21693	0.06116	0.10693
2	0.05743	0.04913	0.35724	0.14458	0.64086	0.21456	0.06116	0.10693
3	0.05743	0.04949	0.41544	0.13825	0.67886	0.18289	0.06116	0.10693
4	0.05743	0.04953	0.41737	0.13761	0.68270	0.17969	0.06116	0.10693
1	0.08882	0.07319	0.50487	0.17592	0.63148	0.19260	0.08372	0.14158
2	0.08882	0.07326	0.50702	0.17517	0.63595	0.18888	0.08372	0.14158
3	0.08882	0.07352	0.51576	0.17221	0.65376	0.17403	0.08372	0.14158
4	0.08882	0.07354	0.51641	0.17199	0.65507	0.17294	0.08372	0.14158
1	0.11775	0.09534	0.61888	0.19026	0.62761	0.18213	0.10256	0.16818
2	0.11775	0.09536	0.61919	0.19016	0.62817	0.18167	0.10256	0.16818
3	0.11775	0.09538	0.61989	0.18995	0.62946	0.18059	0.10256	0.16818
4	0.11775	0.09547	0.62242	0.18918	0.63410	0.17672	0.10256	0.16818
1	0.14649	0.11833	0.76205	0.19223	0.62405	0.18372	0.12003	0.19109
2	0.14649	0.11749	0.73995	0.19797	0.58960	0.21243	0.12003	0.19109
3	0.14649	0.11849	0.76655	0.19110	0.63082	0.17808	0.12003	0.19109
4	0.14649	0.11868	0.77163	0.18984	0.63837	0.17179	0.12003	0.19109
5	0.14649	0.11875	0.77353	0.18938	0.64116	0.16946	0.12003	0.19109
1	0.15369	0.12042	0.71003	0.21645	0.60083	0.18271	0.12424	0.19639
2	0.15369	0.12060	0.71379	0.21531	0.60767	0.17701	0.12424	0.19639
3	0.15369	0.12121	0.72729	0.21132	0.63165	0.15703	0.12424	0.19639
4	0.15369	0.12078	0.71771	0.21414	0.61472	0.17114	0.12424	0.19639
1	0.19326	0.15140	0.85221	0.21661	0.61126	0.17213	0.14653	0.22231
2	0.19326	0.15102	0.88413	0.21859	0.59938	0.18203	0.14653	0.22231
3	0.19326	0.15134	0.85054	0.21692	0.60940	0.17366	0.14653	0.22231
4	0.19326	0.15161	0.85665	0.21554	0.61768	0.16677	0.14653	0.22231
5	0.19326	0.15186	0.90214	0.21423	0.62556	0.16021	0.14653	0.22231
1	0.23141	0.18190	1.08165	0.21394	0.61570	0.17036	0.16682	0.24656
2	0.23141	0.18169	1.07704	0.21485	0.61020	0.17494	0.16682	0.24656
3	0.23141	0.18179	1.07919	0.21442	0.61277	0.17280	0.16682	0.24656
4	0.23141	0.18230	1.05042	0.21222	0.62602	0.16176	0.16682	0.24656
5	0.23141	0.18232	1.05096	0.21211	0.62665	0.16124	0.16682	0.24656
1	0.26993	0.20072	1.05283	0.25638	0.56860	0.17502	0.18638	0.26545
2	0.26993	0.20092	1.05586	0.25565	0.57302	0.17133	0.18638	0.26545
3	0.26993	0.20138	1.06253	0.25395	0.58322	0.16283	0.18638	0.26545
4	0.26993	0.20161	1.06652	0.25309	0.58835	0.15856	0.18638	0.26545
5	0.26993	0.20168	1.06753	0.25285	0.58979	0.15736	0.18638	0.26545
1	0.29816	0.22718	1.25240	0.23807	0.58619	0.17574	0.20021	0.27886
2	0.29816	0.22717	1.25226	0.23809	0.58604	0.17587	0.20021	0.27886
3	0.29816	0.22916	1.27004	0.23476	0.60603	0.15921	0.20021	0.27886
4	0.29816	0.22766	1.26094	0.23646	0.59587	0.16768	0.20021	0.27886
5	0.29816	0.22834	1.27331	0.23416	0.60965	0.15619	0.20021	0.27886

TABLE A2.5

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-0.5WTXCMC-300 MICRON POLYSTYRENE(10.0 WT X)

SURFACE TENSION= 0.06820 NEWTON/M
LIQUID CONSISTENCY INDEX= 0.31100 KG/(M*SEC**(2-N))
FLOW BEHAVIOR INDEX= 0.96800
LIQUID DENSITY= 999.70000 KG/(M**3)
SOLID DENSITY=1200.00000 KG/(M**3)
DIAMETER OF PARTICLES=300.0000*10**-06 M

VG(M/S)	VDRIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGOVICH-WATSON	GAS HOLDUP KITO ET AL.
0.02077	0.01985	0.46895	0.04429	0.86267	0.09304	0.02940	0.05323
0.03893	0.03631	0.57824	0.06732	0.83914	0.09354	0.04623	0.08300
0.06121	0.05579	0.69180	0.08848	0.81755	0.09398	0.06403	0.11253
0.08656	0.07911	0.83051	0.10663	0.80500	0.08837	0.08354	0.14252
0.11805	0.10308	0.93077	0.12683	0.78902	0.08415	0.10275	0.16979
0.14663	0.12573	1.02874	0.14254	0.77261	0.08485	0.12011	0.19163
0.17941	0.15815	1.51417	0.11848	0.79136	0.09016	0.13889	0.21578
0.20488	0.16803	1.13914	0.17985	0.73897	0.08118	0.15282	0.23271
0.22462	0.18717	1.34746	0.16670	0.74943	0.08388	0.16328	0.24492
0.26214	0.21950	1.61149	0.16267	0.75062	0.08672	0.18249	0.26336
0.29193	0.23080	1.39406	0.20941	0.71085	0.07974	0.19720	0.27782

TABLE A2.6

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-0.5%ISOPROPANOL-300 MICRON POLYSTYRENE(20.0 WT %)

SURFACE TENSION= 0.06750 NEWTON/M
LIQUID CONSISTENCY INDEX= 0.43900 KG/(M*SEC**(2-N))
FLOW BEHAVIOR INDEX= 0.54000
LIQUID DENSITY= 999.70000 KG/(M**3)
SOLID DENSITY=1200.00000 KG/(M**3)
DIAMETER OF PARTICLES=300.0000*10**-06 M

VG(M/S)	VETIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGOVICH-WATSON	GAS HOLDUP KITO ET AL.
0.02073	0.01906	0.40811	0.05000	0.75963	0.18957	0.02937	0.05326
0.03794	0.03508	0.59378	0.07529	0.74567	0.17904	0.04538	0.08168
0.05633	0.05268	0.60211	0.09697	0.72618	0.17695	0.06185	0.10920
0.09433	0.08407	0.86757	0.10073	0.71476	0.17651	0.08743	0.14845
0.11302	0.10155	1.07241	0.10555	0.72432	0.16973	0.09996	0.16622
0.14673	0.13044	1.32161	0.11102	0.71664	0.17233	0.12017	0.19180
0.17705	0.15116	1.21637	0.14622	0.68902	0.16476	0.13757	0.21432
0.20893	0.17235	1.19457	0.17468	0.66590	0.15922	0.15499	0.23555
0.24065	0.19774	1.34493	0.17912	0.66334	0.15754	0.17171	0.25482
0.26051	0.21644	1.53090	0.17042	0.67010	0.15947	0.18187	0.26308
0.29072	0.22920	1.37375	0.21163	0.63725	0.15112	0.19661	0.27760

TABLE A2.7

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-0.5% CMC-120 MICRON SAND(10.0 WT %)

SURFACE TENSION= 0.06920 NEWTON/M
LIQUID CONSISTENCY INDEX= 0.16900 KG/(M*SEC**(2-N))
FLOW BEHAVIOR INDEX= 0.94600
LIQUID DENSITY= 999.70000 KG/(M**3)
SOLID DENSITY=2650.00000 KG/(M**3)
DIAMETER OF PARTICLES=120.0000*10**-06 M

VG(M/S)	VDRIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGGVICH-WATSON	GAS HOLDUP KITO ET AL.
0.34423	0.28691	2.06723	0.16652	0.80259	0.03090	0.19036	0.30015
0.30555	0.25025	1.68835	0.18097	0.78214	0.03688	0.17470	0.28355
0.28892	0.23816	1.64471	0.17566	0.78647	0.03786	0.16780	0.27591
0.26142	0.21440	1.45352	0.17985	0.78255	0.03760	0.15614	0.26509
0.23122	0.19244	1.37861	0.16772	0.79565	0.03663	0.14294	0.24829
0.20454	0.17656	1.49531	0.13679	0.82312	0.04010	0.13086	0.23216
0.17880	0.15540	1.36638	0.13086	0.82930	0.03984	0.11878	0.21526
0.14995	0.13450	1.45232	0.10328	0.85916	0.03756	0.10467	0.19441
0.12174	0.10615	0.95052	0.12807	0.83209	0.03984	0.09006	0.17148
0.08895	0.06931	0.40290	0.22077	0.66993	0.10930	0.07185	0.14259

TABLE A2.8

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-0.5WT%CMC-120 MICRON SAND(20.0 WT %)

SURFACE TENSION= 0.06710 NEWTON/M
LIQUID CONSISTENCY INDEX= 0.11900 KG/(M*SEC**(2-N))
FLOW BEHAVIOR INDEX= 0.95200
LIQUID DENSITY= 999.70000 KG/(M**3)
SOLID DENSITY=2650.00000 KG/(M**3)
DIAMETER OF PARTICLES=120.0000*10**-06 M

VG(M/S)	VDRIFT(M/S)	VM(M/S)	GAS HOLDUP EXPTL	LIQUID HOLDUP EXPTL	SOLID HOLDUP EXPTL	GAS HOLDUP BEGOVICH-WATSON	GAS HOLDUP KITO ET AL.
0.34131	0.23142	1.91518	0.17546	0.75984	0.06470	0.18919	0.29900
0.30136	0.21565	1.39312	0.21764	0.70994	0.07222	0.17295	0.28168
0.29066	0.22795	1.43771	0.18860	0.73239	0.07901	0.16447	0.27219
0.25466	0.20810	1.39275	0.18785	0.74525	0.07190	0.15323	0.26135
0.21929	0.19237	1.30253	0.16836	0.75630	0.07534	0.13759	0.24124
0.18698	0.15907	1.25276	0.14925	0.78029	0.07046	0.12267	0.22088
0.16555	0.14136	1.13293	0.14614	0.77690	0.07687	0.11238	0.20611
0.13840	0.11931	1.09333	0.13794	0.77960	0.08246	0.09878	0.18557
0.11271	0.10199	1.02492	0.11054	0.80187	0.08719	0.08574	0.16473
0.07998	0.07260	0.96665	0.09728	0.82626	0.08145	0.06656	0.13341
0.05330	0.04942	0.73317	0.07269	0.83831	0.08900	0.04969	0.10247

3.0 MECHANICALLY AGITATED VESSEL

3.1 Introduction

Liquid phase viscosity is a very important parameter which affects the mass transfer coefficient significantly in gas-liquid and gas-liquid-solid agitated reactors. However, no systematic studies are reported in literature in this area. Only one work reported is by Elstner and Onken,[3.1] who have obtained a mass transfer coefficient, k_ℓ, for glycerin solutions of various concentrations. However, their viscosity range studied is very narrow, and they have not measured or estimated the power consumption per unit liquid volume. Hence, in this work data of mass transfer coefficients and power/volume in an agitated reactor system for glycerin solutions of various viscosities were obtained.

The advantage of using glycerin solutions is that glycerin is a Newtonian fluid, and it can provide a wide range of liquid phase viscosity, but its surface tension remains almost constant. For these experiments, oxygen was absorbed in glycerin solutions of various concentrations. The viscosity of the solution was measured by Brookfield LVT type viscometer.

3.2 Results and Discussion

Since the geometry of our system is peculiar and does not conform to the standard configuration (for example, we utilize two impellers having the ratio of impeller diameter-to-vessel diameter of 0.57), it was decided to initially obtain some data in a standard vessel arrangement (only one impeller, ratio of liquid height-to-vessel diameter equal to 1, and impeller diameter-to-vessel diameter = 0.45) so as to give a good comparison of our data with that of Elstner and Onken.[3.1] Data for 10 wt% and 40 wt% glycerin solutions were obtained in standard vessel configuration and are reported in Table 3.1. They are plotted in Figure 3.1. In these measurements, $k_\ell a$ was first evaluated. To evaluate "a", the surface area was taken to be the cross-section of the vessel. Knowing $k_\ell a$ and "a", k_ℓ was evaluated. The figure

TABLE 3.1

MASS TRANSFER COEFFICIENT k_ℓ FOR STANDARD VESSEL ARRANGEMENT

Temperature - 24°C (average)

	$k_\ell \times 10^{-3}$ (cm/sec)		
rpm	Water	10 wt% Glycerin	40 wt% Glycerin
400	5.3	2.7	1.4
600	8.5	4.0	1.7
800	11.5	6.8	2.3

also shows the data of Elstner and Onken under similar conditions. Even though our data values are slightly higher than those of Elstner and Onken, considering the fact that the two methods of measurement are entirely different (we employ measurement of change in total pressure of the gas phase with respect to time for a batch system, whereas Elstner and Onken employ an oxygen concentration measurement cell), the difference in values of k_ℓ is within acceptable limits. To compare the order of magnitude of values, data of k_ℓ obtained for water in our system for a standard vessel arrangement are also shown in Figure 3.1.

Table 3.2 summarizes the data of $k_\ell a$ for various concentrations of glycerin solutions at three values of rpm. Figures 3.2, 3.3, and 3.4 show the nature of these data on log-log plots. It can be seen that the liquid phase viscosity has a very significant effect on $k_\ell a$. With an increase in viscosity, the $k_\ell a$ value decreases several-fold for all three values of rpm. In Figure 3.4, data for the oxygen-water system are also shown to give a comparison about the order of magnitude of $k_\ell a$ values.

The data of power consumed per unit liquid volume for the above experiments are summarized in Table 3.3 and are plotted in Figures 3.5 and 3.6. From Figure 3.5, the slopes of the lines for various values of viscosity indicate that for higher values of viscosity, increase in power input increases the value of $k_\ell a$ significantly as compared to lower values of viscosity. Figure 3.6 indicates that as compared to higher values of rpm, for lower values of rpm, the increase in power consumed is much higher with increase in viscosity.

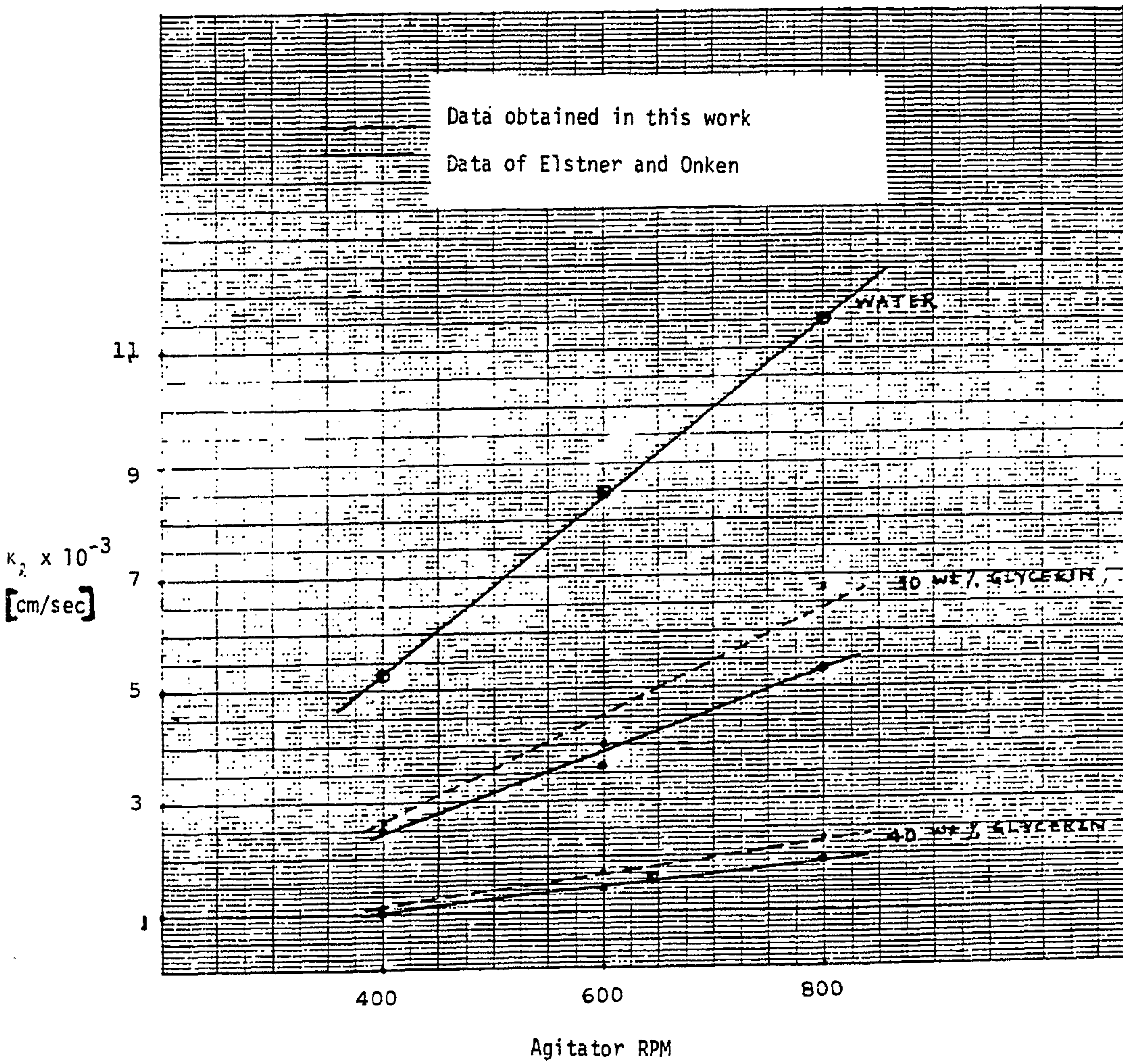


FIGURE 3.1 Values of Mass Transfer Coefficient 'k_ℓ' for Various Values of Agitator RPM in Standard Vessel Arrangement

TABLE 3.2

VALUES OF $k_{\ell}a$ FOR GLYCERIN SOLUTIONS

Temperature - 24°C (average)

Glycerin Concentration Volume %	Viscosity cP	$k_{\ell}a$ (sec^{-1}) 1000 rpm	800 rpm	600 rpm
51	7.0	0.08627	0.0296	0.0042
58	10.6	0.04624	0.0103	0.0020
70	20.0	0.02598	0.00675	0.000832
86	66.0	0.01835	0.0051	0.00050
92	92.0	0.0087	0.0030	0.00040
94	115.0	0.00845	0.0017	0.00032

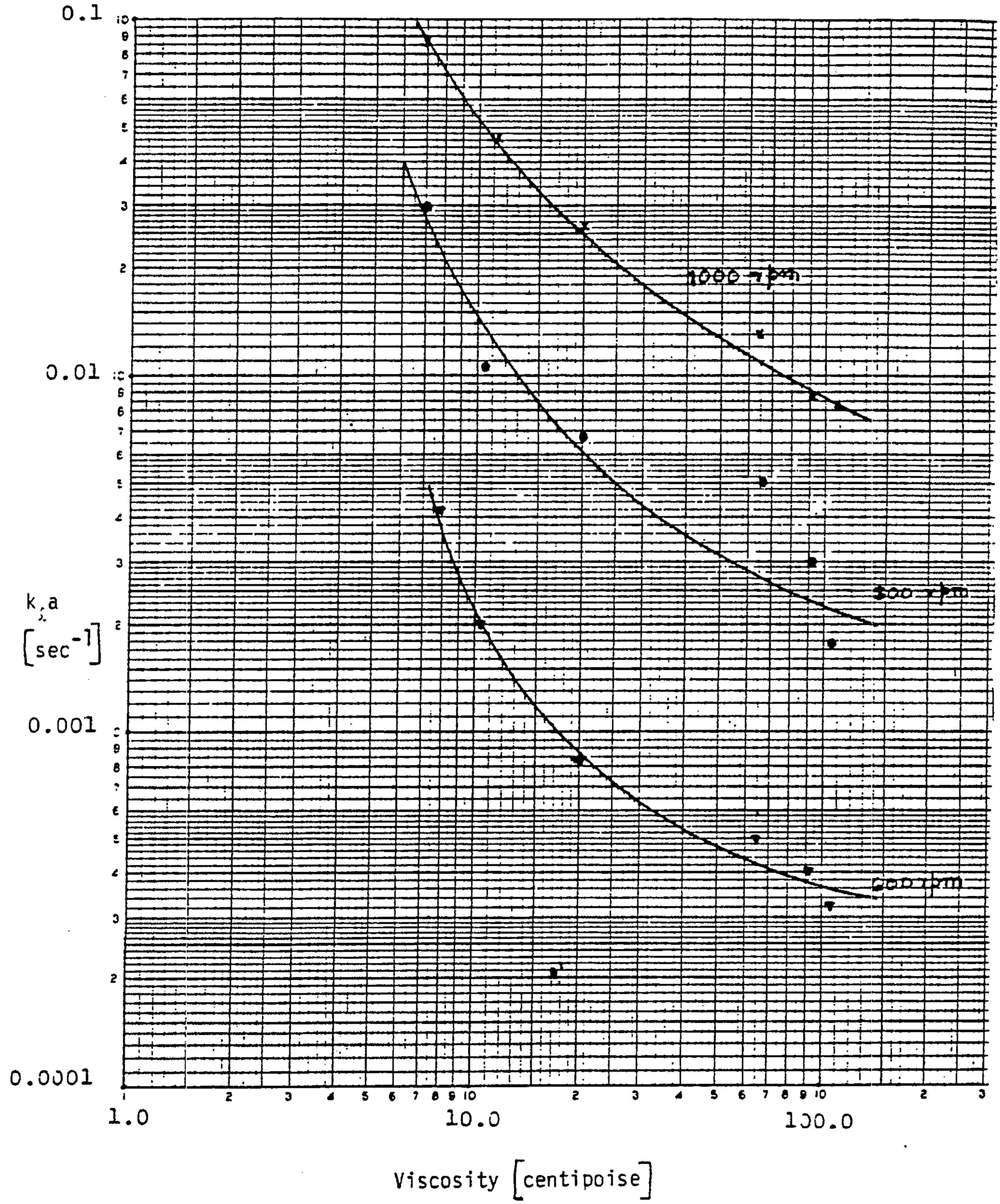


FIGURE 3.2 '$k_\ell a$' as a Function of Liquid Phase Viscosity

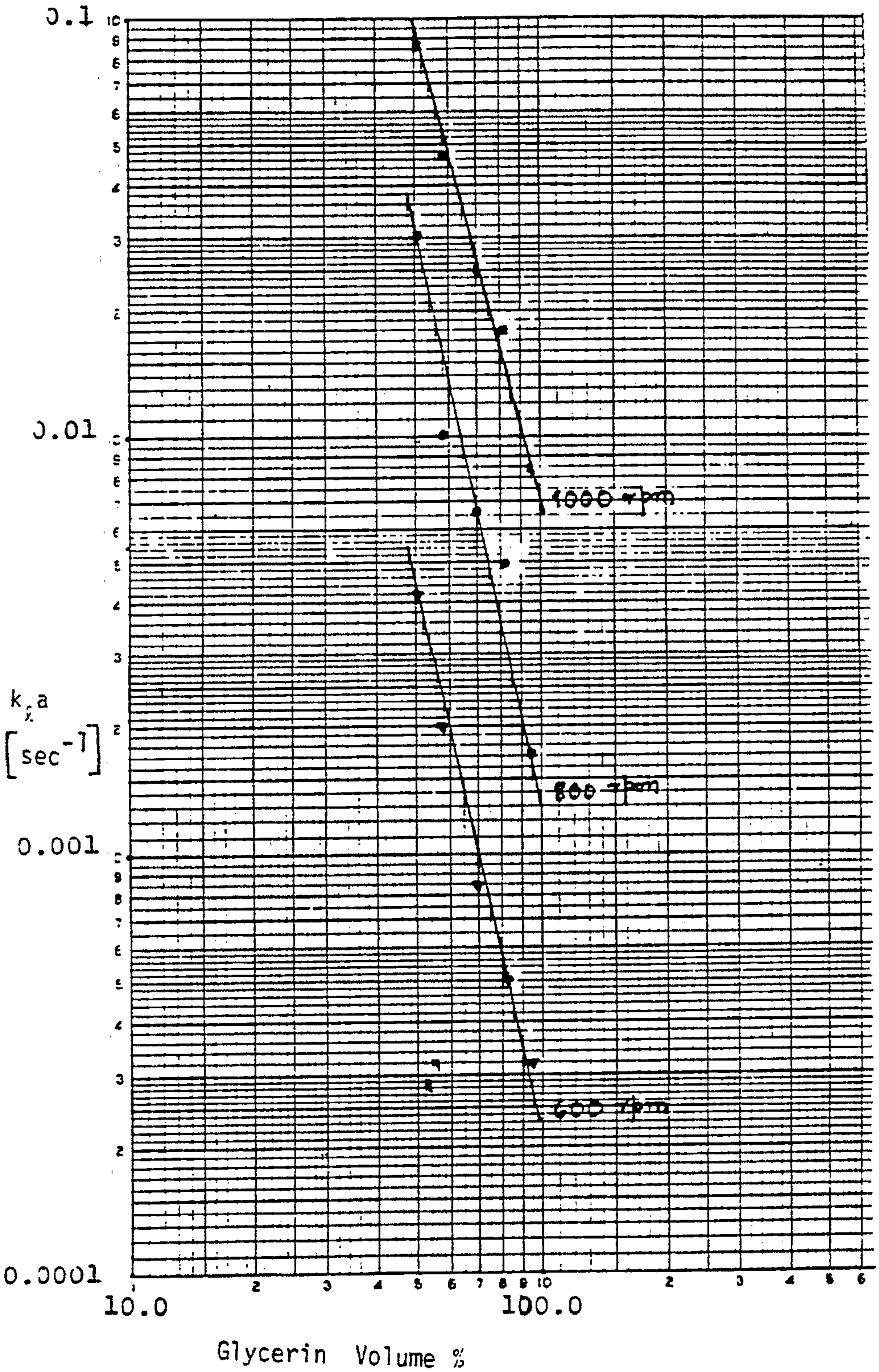


FIGURE 3.3 '$k_\ell a$' as a Function of Glycerin Concentration

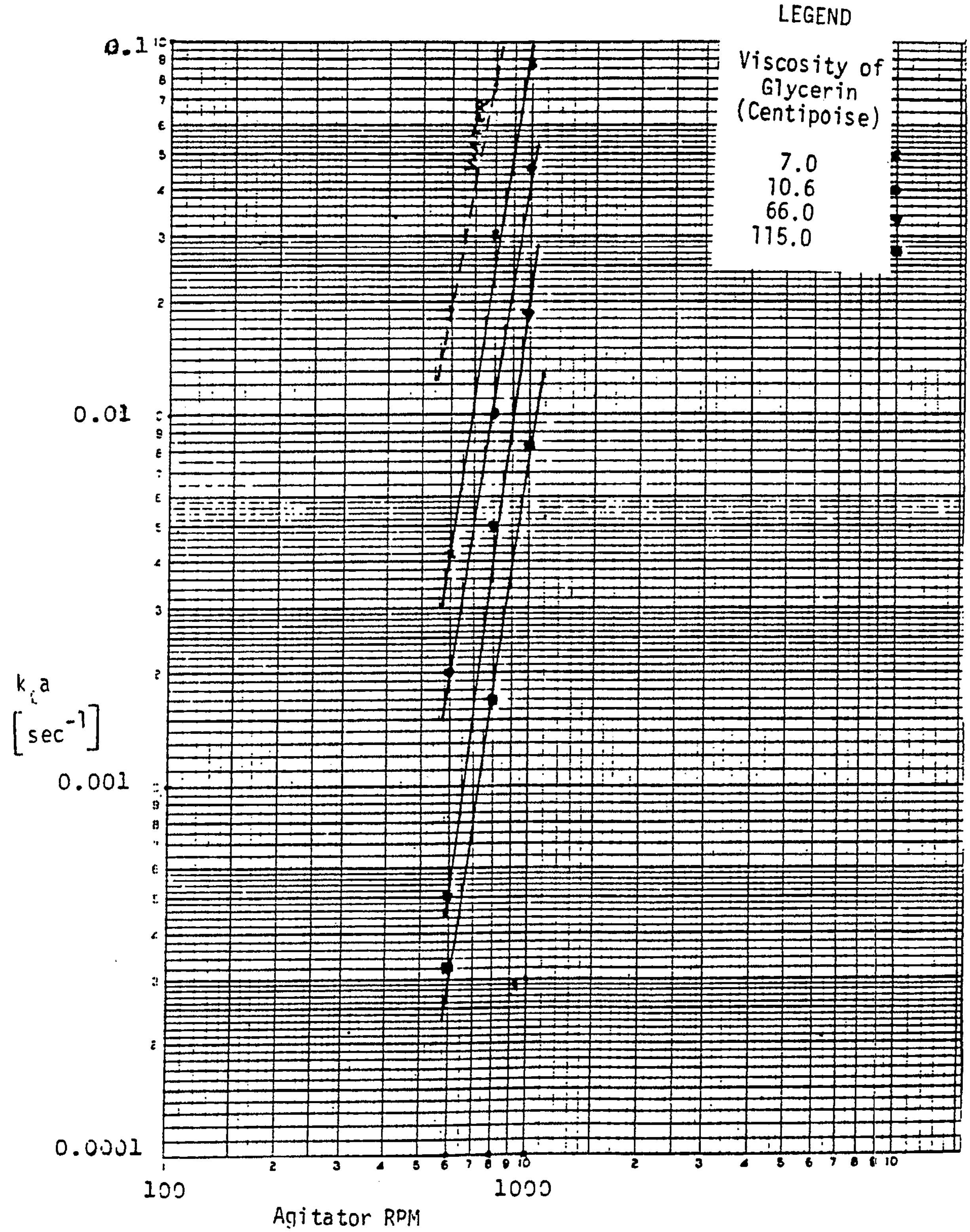


FIGURE 3.4 Variation of '$k_\ell a$' with Agitator RPM

Table 3.3

POWER CONSUMPTION FOR GLYCERIN SOLUTIONS

Glycerin Concentration Volume %	Viscosity cP	Power/Volume (W/m^3)		
		1000 rpm	800 rpm	600 rpm
51	7.0	6.8	3.6	1.1
70	20.0	8.6	5.0	1.8
86	66.0	9.6	6.4	2.7
92	92.0	11.4	7.3	3.2
94	115.0	13.6	8.2	4.1

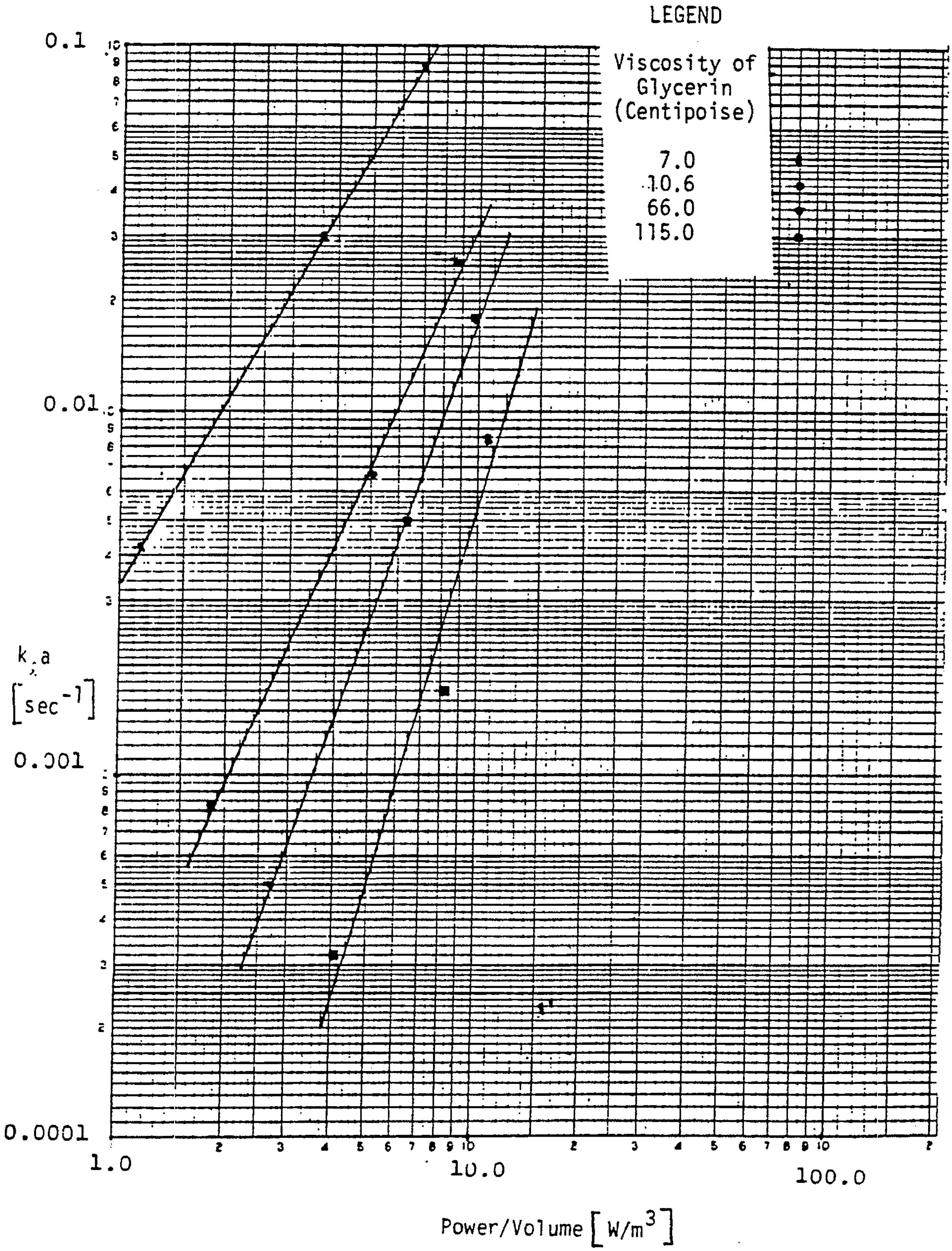


FIGURE 3.5 Variation of '$k_\ell a$' with Power/Volume

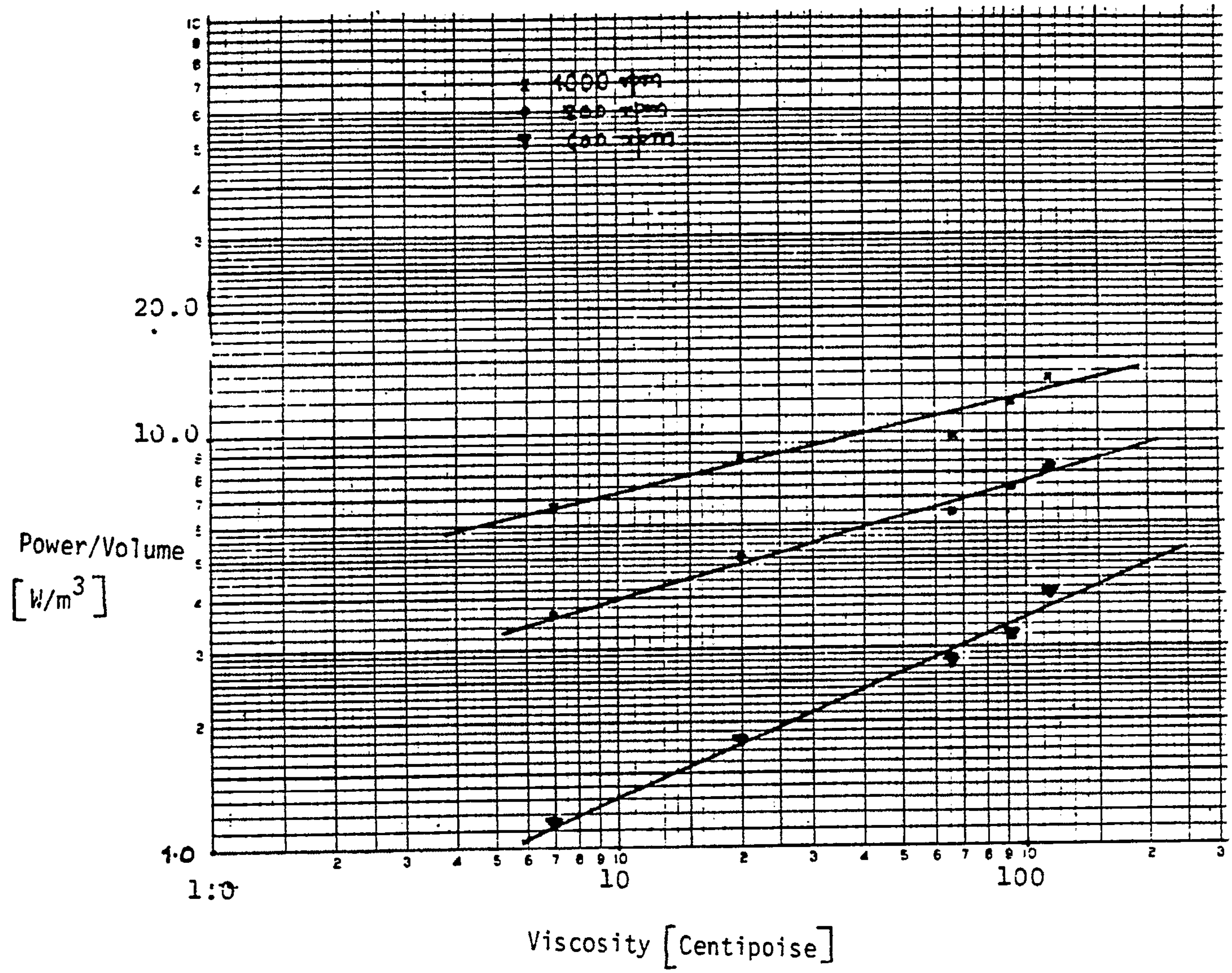


FIGURE 3.6 Variation of Power/Volume with Viscosity

References

3.1 Elstner, F., and U. Onken, Ger. Chem. Eng., 4, 84-89 (1981).

4.0 CONTINUOUS COCURRENT DOWNFLOW BUBBLE COLUMN

4.1 Introduction

The use of bubble columns has been widely employed in gas-liquid systems and recently to gas-liquid-solid systems in Fischer-Tropsch synthesis, oxidation of organic compounds, and in coal liquefaction. The reported work is exclusively concentration on systems in which gas is introduced at the bottom of the column and liquid may be either in batch mode or flows cocurrently upward along with the gas phase. However, the gas phase residence time is limited due to the rise in velocity of the bubbles, which can be overcome provided the gas is dispersed from the top of the column in a liquid flowing vertically downward, so that the gas bubbles are forced down by the liquid flow in a direction opposite to that imposed by the bouyancy. Under these conditions, the mean residence time of the gas phase can be extended to the point of a state of suspension by variation of the liquid velocity.

The above premise has been substantiated by experimental measurements of phase holdup in a glass column 0.075 m ID and 2.45 m in height. The gas phase holdup was measured using the hydrostatic head technique. The effect of a wide range of physical parameters, such as superficial gas velocity, superficial liquid velocity, surface tension, and electrolyte concentrations, were studied.

The experimental data reported is the progress made during the period mentioned. The results obtained can be explained qualitatively, and a detailed analysis of this data will be provided at a later stage.

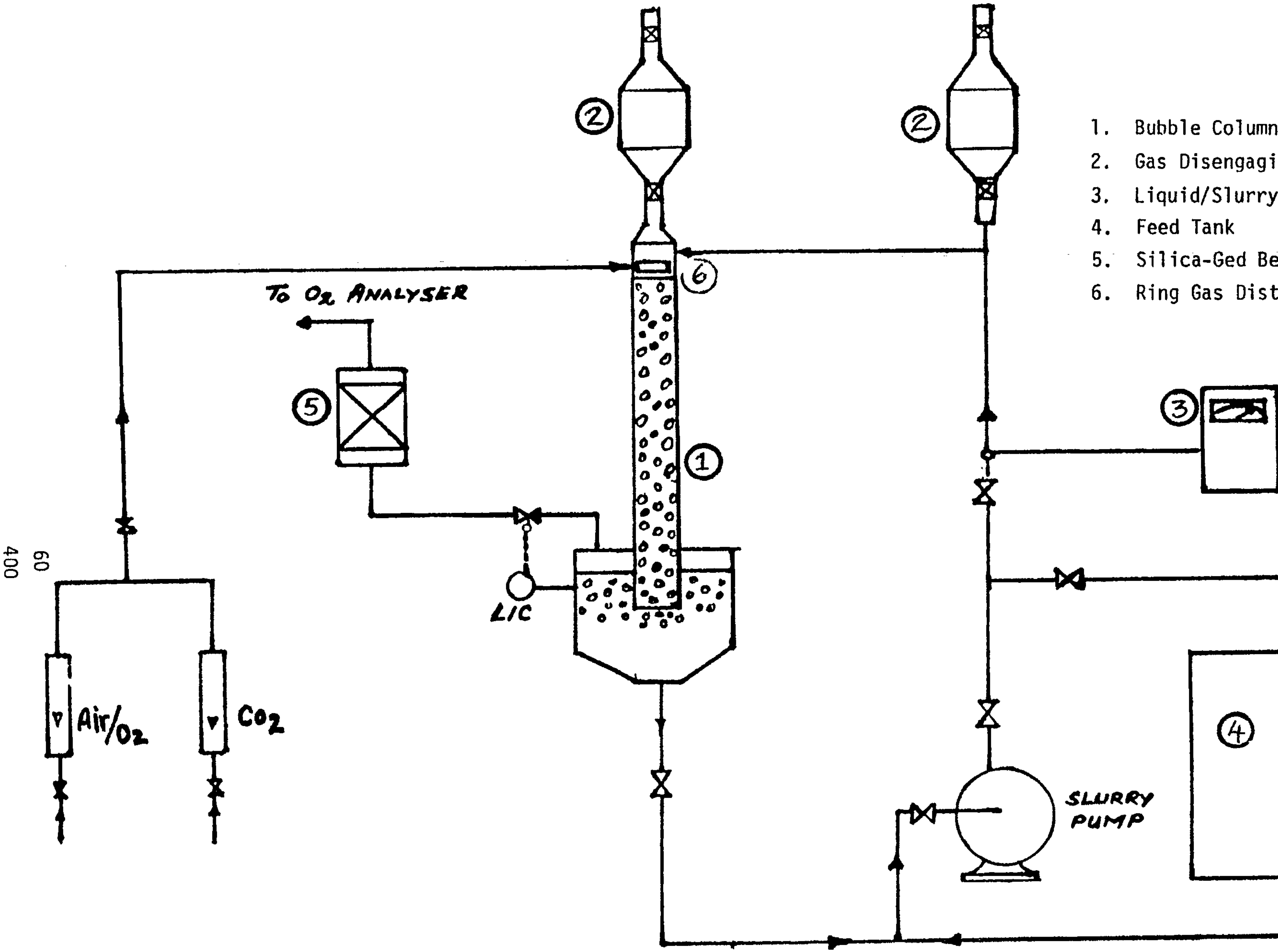
4.2 Experimental Setup and Procedure

4.2.1 Experimental Setup

The downflow bubble column consisted of a glass column with an internal diameter of 0.075 m and height of 2.45 m. The gas phase is introduced through the top of the column. The downflowing gas-liquid or gas-liquid-solid mixture is discharged into a cylindrical disengaging tank made of plexiglass with an internal diameter of 0.30 m and height of 0.30 m. The bottom of the disengaging tank is fitted with a conical stainless steel flat circular plate, 0.075 m in diameter, which acts as a baffle. The baffle is located 0.10 m from the bottom section of the cone which prevents any containment of the gas phase in the recycle liquid. The degassed liquid is recycled by means of a slurry pump having a capacity of 40 gpm, while the gas phase is drawn off at the top of the disengaging tank. Two glass bulbs, 0.152 m in diameter, are mounted at the top of the column and the liquid line and serve to disengage any gas which may be entrained in the recycle liquid.

The gas phase used is always air. The air inlet pressure is maintained constant with the help of a pressure regulator. The gas flow rate is monitored with the help of two rotometers of different ranges mounted in parallel. The liquid flow rate is metered using a calibrated elbow meter in the liquid line which is connected to a liquid indicator. The slurries to be used were metered by using an ultrasonic measuring device.

The column is fitted with six ports along the length; the distance between two consecutive ports is 0.035 m. Four of these ports are used as pressure taps to measure the pressure along the length of the column. The distance between the two pressure taps is 0.61 m. The pressure taps are connected to a mercury manometer, one end open to atmosphere. A back-flushing system is incorporated to ensure that no air bubbles are entrained in the lines connecting the ports to the liquid level indicator. The two other ports were provided for conductivity probes. These probes were at a distance of 1.22 m apart. The conductivity of a two-phase or three-phase mixture depends on the relative amount of each phase present in the mixture. This principle was employed to measure the gas holdup with these probes. The method has been used previously by Stepanek et al.[4.1] However, during the course of the experiments it was found that the gas phase would accummulate in the region directly below the probe at higher gas velocities since the probes resulted in the formation of a "wake" region. The entrapped gas bubbles would coalesce and eventually very large bubbles or slugs would discharge, rising through the column. Hence, the probes have been eliminated and the ports closed.



1. Bubble Column
2. Gas Disengaging Bulbs
3. Liquid/Slurry Flowmeter
4. Feed Tank
5. Silica-Ged Bed
6. Ring Gas Distributer

Figure 4.1

The system is devoid of any problems such as leaks which prevailed previously in the disengaging section or entrainment of large amounts of the gas phase in the recycle liquid. Figure 4.1 is the process diagram of the cocurrent downflow bubble column. All the experiments were carried out at near-atmospheric conditions and under steady-state conditions.

The surface tension is measured with a Fisher Surface Tensiomat (Model 21) using the du-Nouy method.[4.21] In this method, a platinum ring of precisely known dimensions is suspended from a counterbalanced lever arm. The arm is held horizontal by torsion applied to a taut stainless steel wire to which it is clamped. Increasing the torsion in the wire raises the arm and the ring which carries with it the film of liquid in which it is immersed. The force necessary to pull the test ring free from the surface film is measured directly in dynes/cm. This apparent reading is converted to the absolute value by use of a correction chart.

The viscosity is measured using a Brookfield LVT type viscometer. The spindle is rotated in a given fluid at a constant speed. The torque necessary to overcome the resultant viscous drag is measured. For a given spindle and speed, it produces dial readings proportional to the viscosity.[4.2,4.3]

4.2.2 Procedure and Measurement of Holdup

In the case of bubble columns with negligible liquid, the variation of pressure with height is entirely due to the hydrostatic head in gas liquid systems

$$\frac{dp}{dx} = \varepsilon_L \rho_L + \varepsilon_g \ell_g \tag{4.1}$$

$$\varepsilon_L + \varepsilon_g = 1.0 \tag{4.2}$$

The above two equations are employed to obtain the gas phase holdup. To use these equations, the manometer readings were first corrected to absolute pressure. However, in the presence of liquid flow, there are two additional terms on the right hand side of Equation (4.1) to account for wall friction and acceleration due to voidage changes along the length of the column. Hence a momentum balance on a control volume changes Equation (4.1) to

$$\frac{dp}{dx} = (\varepsilon_g \ell_g + \varepsilon_L \ell_L) + \rho_L V_L^2 \frac{d}{dx}\left(\frac{1}{1-\varepsilon_g}\right) + \frac{4\ Tw}{dc} \tag{4.3}$$

The acceleration term is normally small and is neglected; however, in wider columns it can become appreciable. At high flow rates the viscous drag term can account for about as high as 25% of the first two terms. Hence, the effect of these two terms was first determined. The hydrostatic head was measured in the absence of gas flow through the column for the entire range of liquid velocities covered in this work. It was found that the manometric readings of the liquid hydrostatic head between any two tappings on the column was in very close agreement (within ±2%) to the height of liquid between these ports. Also, the axial variation of holdup was found to be negligible since the holdup calculated in the following manner

$$\varepsilon_G = \frac{HH/_{VG\,=\,0} - HH}{HH/_{VG\,=\,0}} \tag{4.4}$$

between two consecutive tappings was found to be in close agreement along the length of the column. Hence, Equations (4.1) and (4.2) were used to obtain integral values of holdup.

To determine the solid and liquid holdups in three-phase systems, solid-liquid samples will be selected at the differing tappings along the length of the column. By measuring the weight and volume of the slurry, density will be obtained. After filtering and drying the samples, it is possible to calculate the relative volume fraction of liquid and the solid. Using this information, the following time equations will be solved simultaneously to get the values of individual phase holdup as

$$\varepsilon_G + \varepsilon_L + \varepsilon_S = 1.0 \qquad (4.5)$$

$$\frac{dp}{dx} = \varepsilon_G \rho_G + \varepsilon_L \rho_L + \varepsilon_S \rho_S \qquad (4.6)$$

$$\varepsilon_S/\varepsilon_L = \text{Known quantity} \qquad (4.7)$$

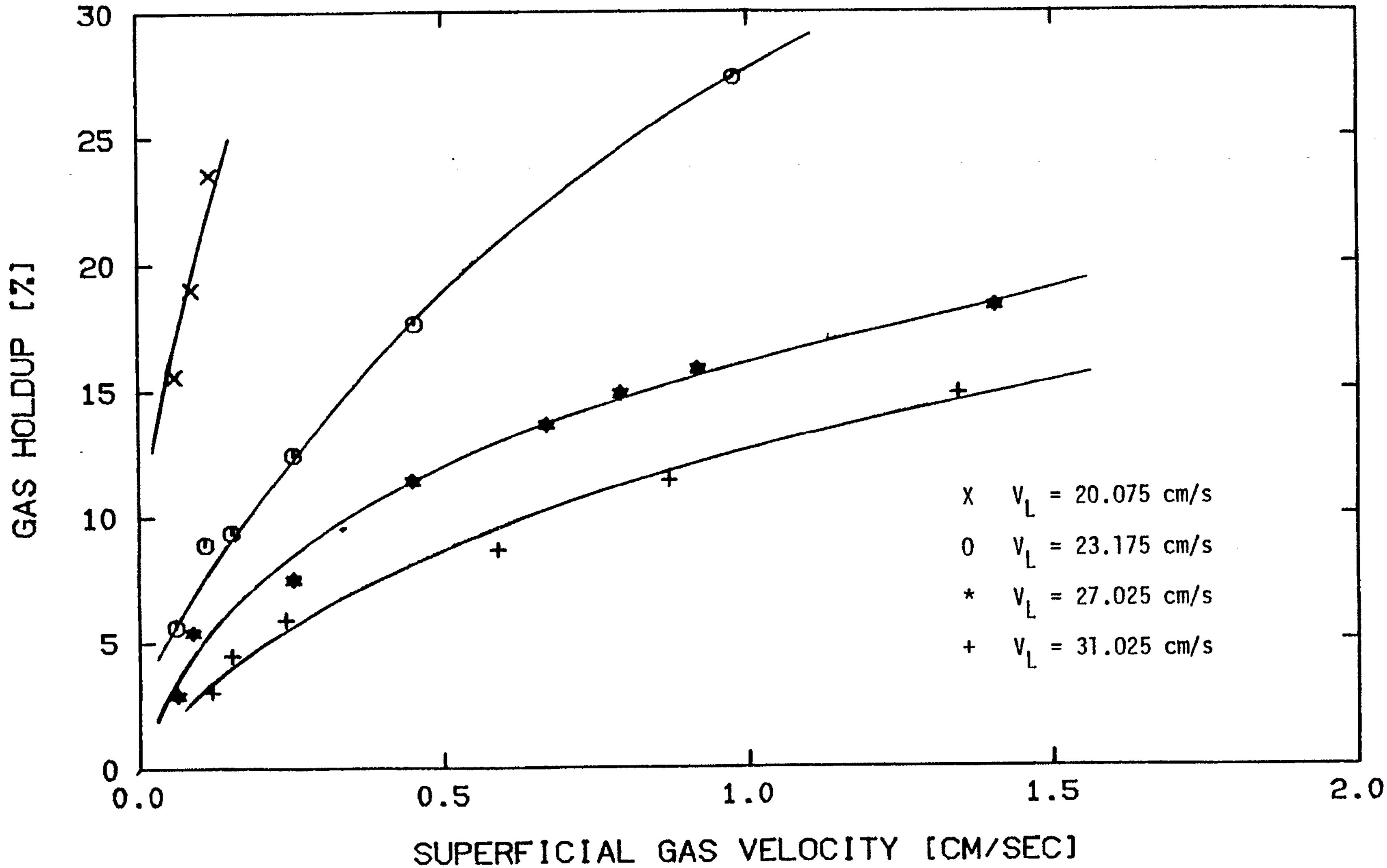
4.3 Results and Discussion

4.3.1 Gas Holdup

Gas holdup shows an increase with an increase in the gas velocity but shows a decrease with an increase in liquid velocity (as can be seen clearly in Figure 4.2 for air-water data). The experiments were carried out at near-atmospheric pressure at gas velocities ranging from 0.06-2.2 cm/s and liquid velocities ranging from 20.0-32.0 cm/s. The range of gas velocities is extremely low; however, the gas holdup is nearly an order of magnitude greater than in conventional bubble columns operated cocurrently. Hills[4.5] has reported holdup measurements in a bubble column at high liquid throughputs. At the highest gas velocity, his correlation gives values of gas holdup in a cocurrently operated upward bubble column of less than 1% for all the liquid velocities employed in this work. The termination points on the curves in the direction of increasing gas holdup represents the limits of the mode of downflow operation within 10% of the maximum gas velocity which can be employed. This results from the formation of bubble agglomeration at the top of the column due to the migration of large bubbles or slugs formed due to coalescence at the bottom of the column.

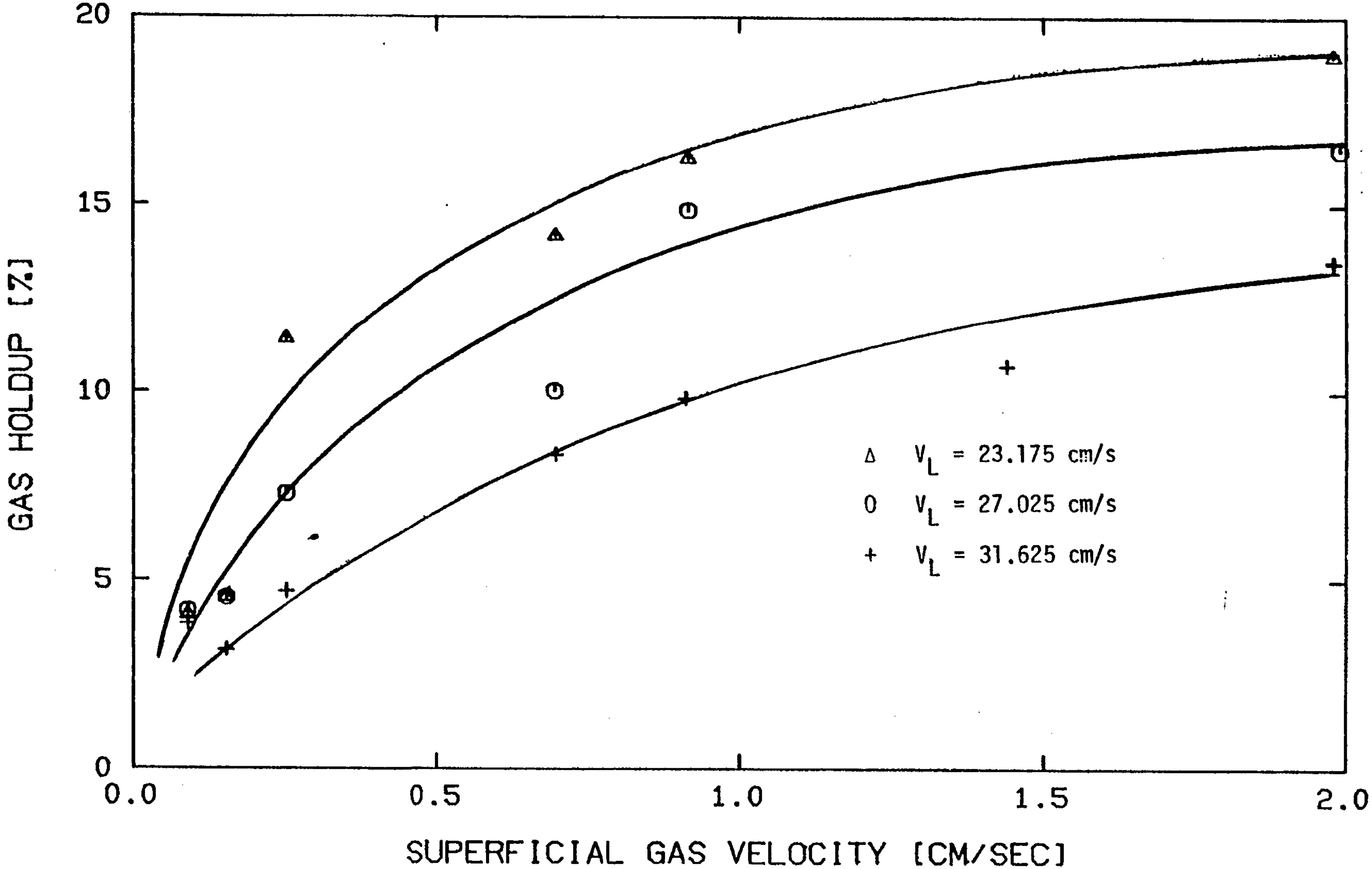
4.3.2 Effects of Surface Tension and Alcohol Property

The gas holdup decreases with the addition of surfactants such as alcohols (C_1-C_4) as compared to the gas holdup obtained in an air-water system as can be seen from Figures 4.3-4.8. However, the effect of alcohol concentration (or surface tension) on the gas holdup is observed to be insignificant (Figures 4.9-4.11); but the effect of the type of alcohol is predominant



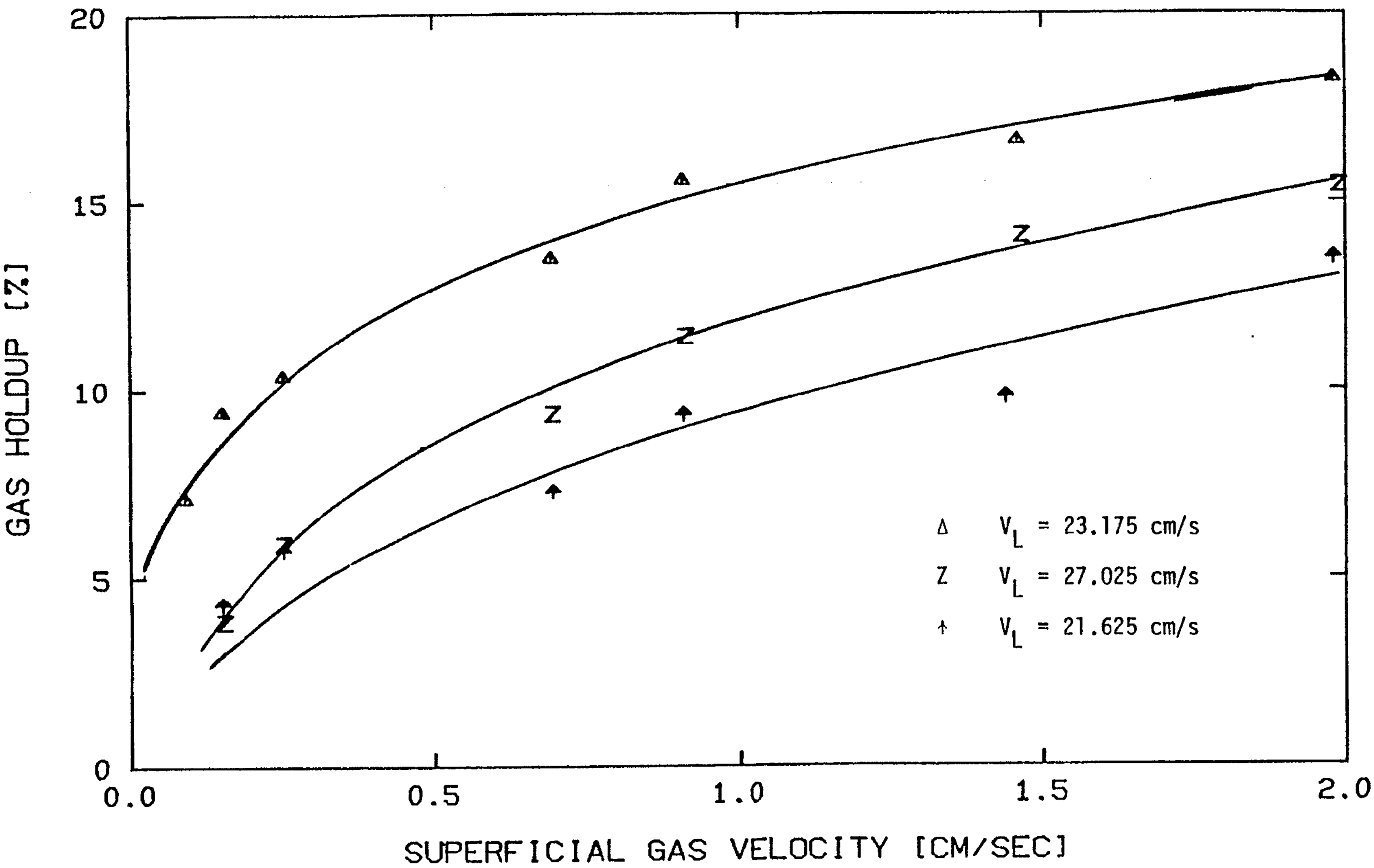
GAS HOLD UP FOR AIR WATER SYSTEM

FIGURE 4.2



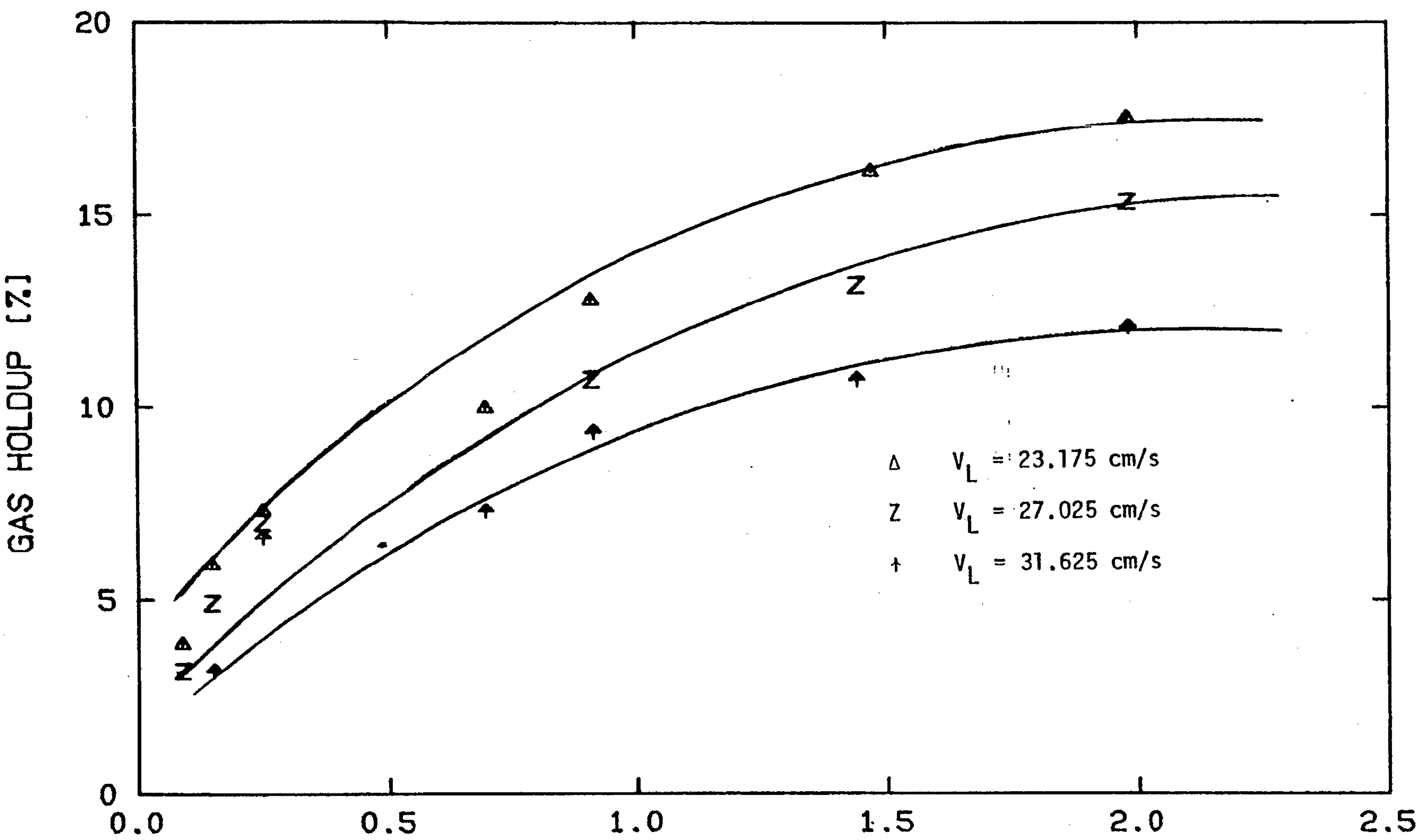
GAS HOLDUP FOR AIR-0.5%METHANOL SYSTEM

FIGURE 4.3



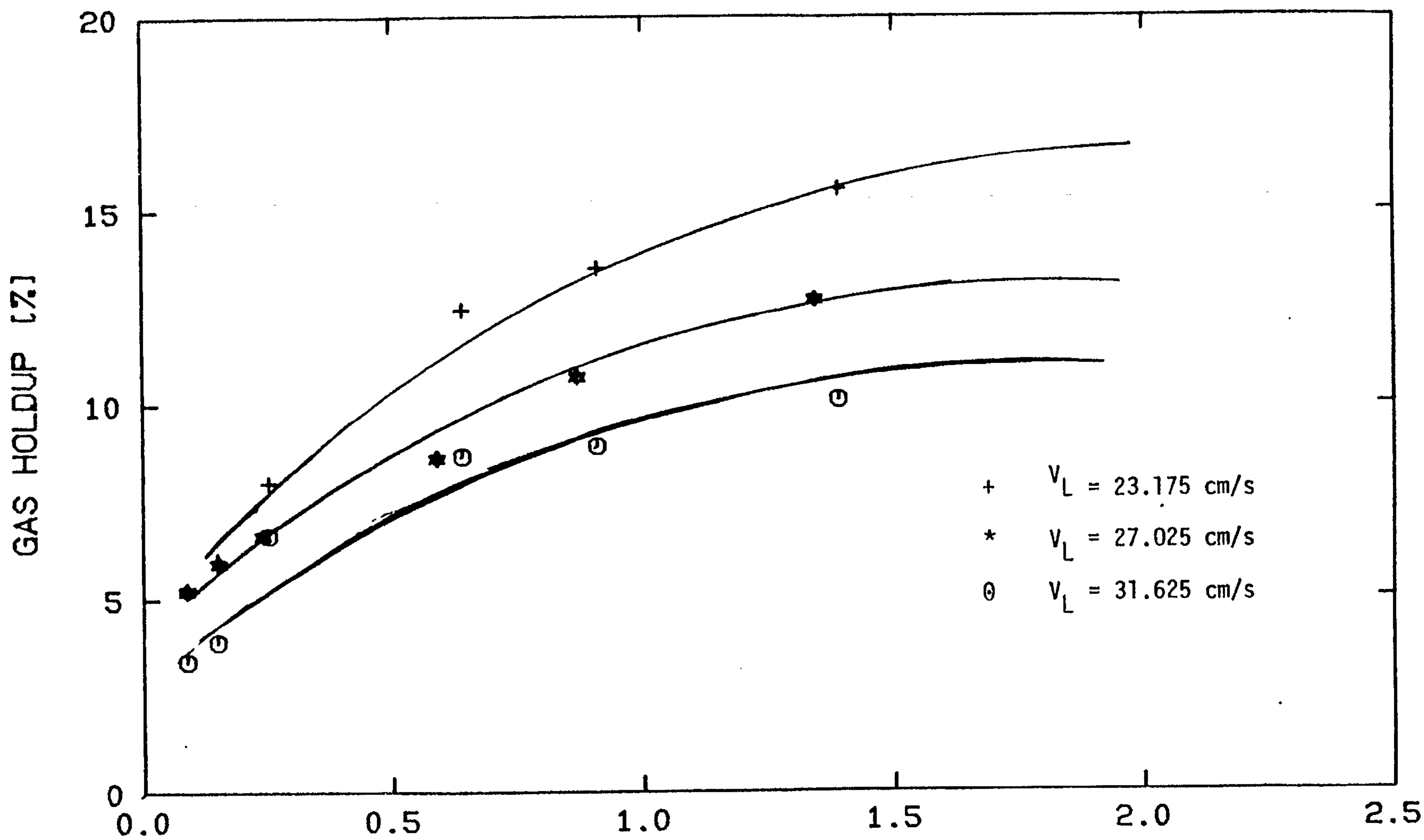
GAS HOLD UP FOR AIR-0.5% ETHANOL SYSTEM

FIGURE 4.4



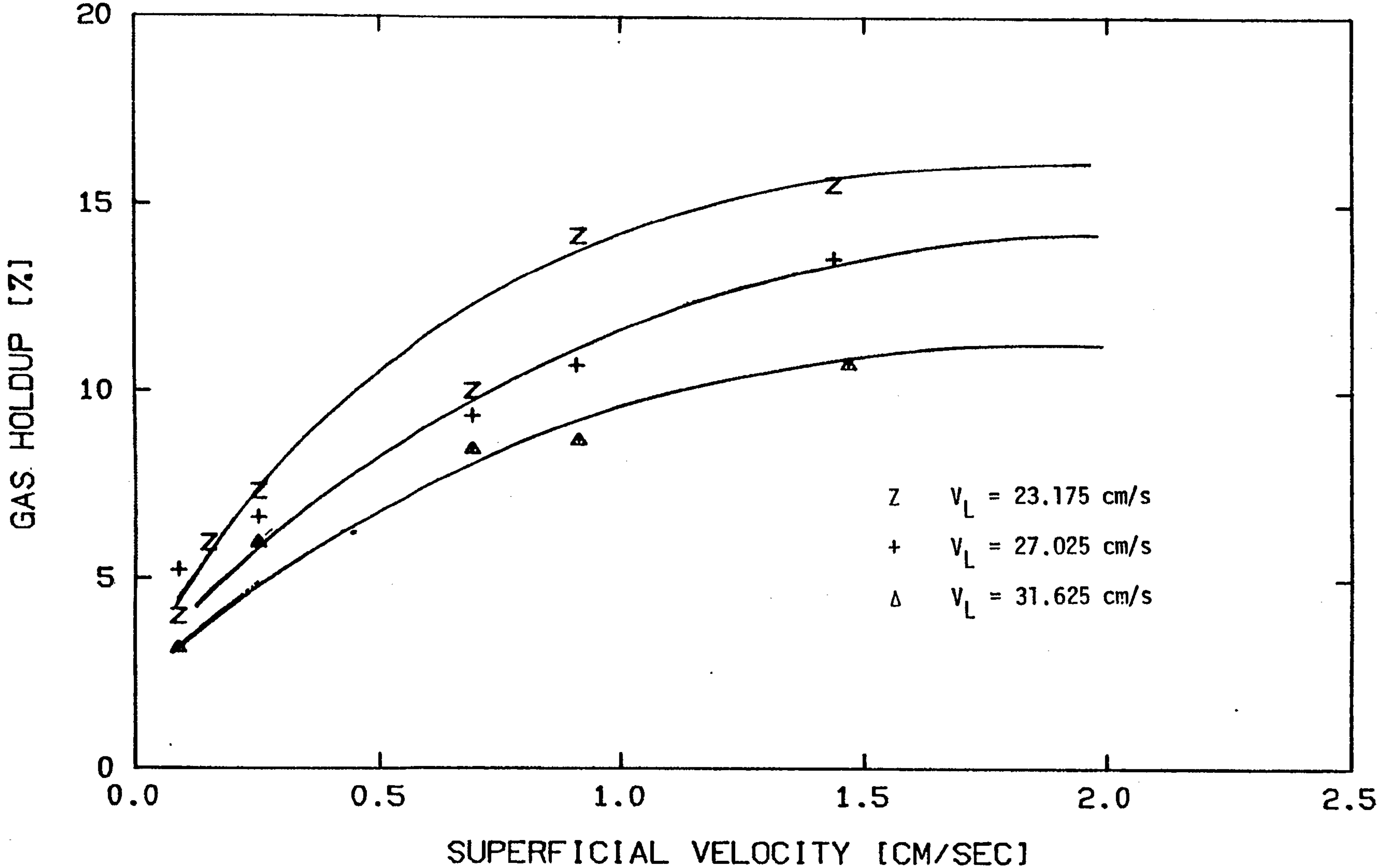
GAS HOLD UP FOR AIR-0.5% PROPANOL SYSTEM

FIGURE 4.5



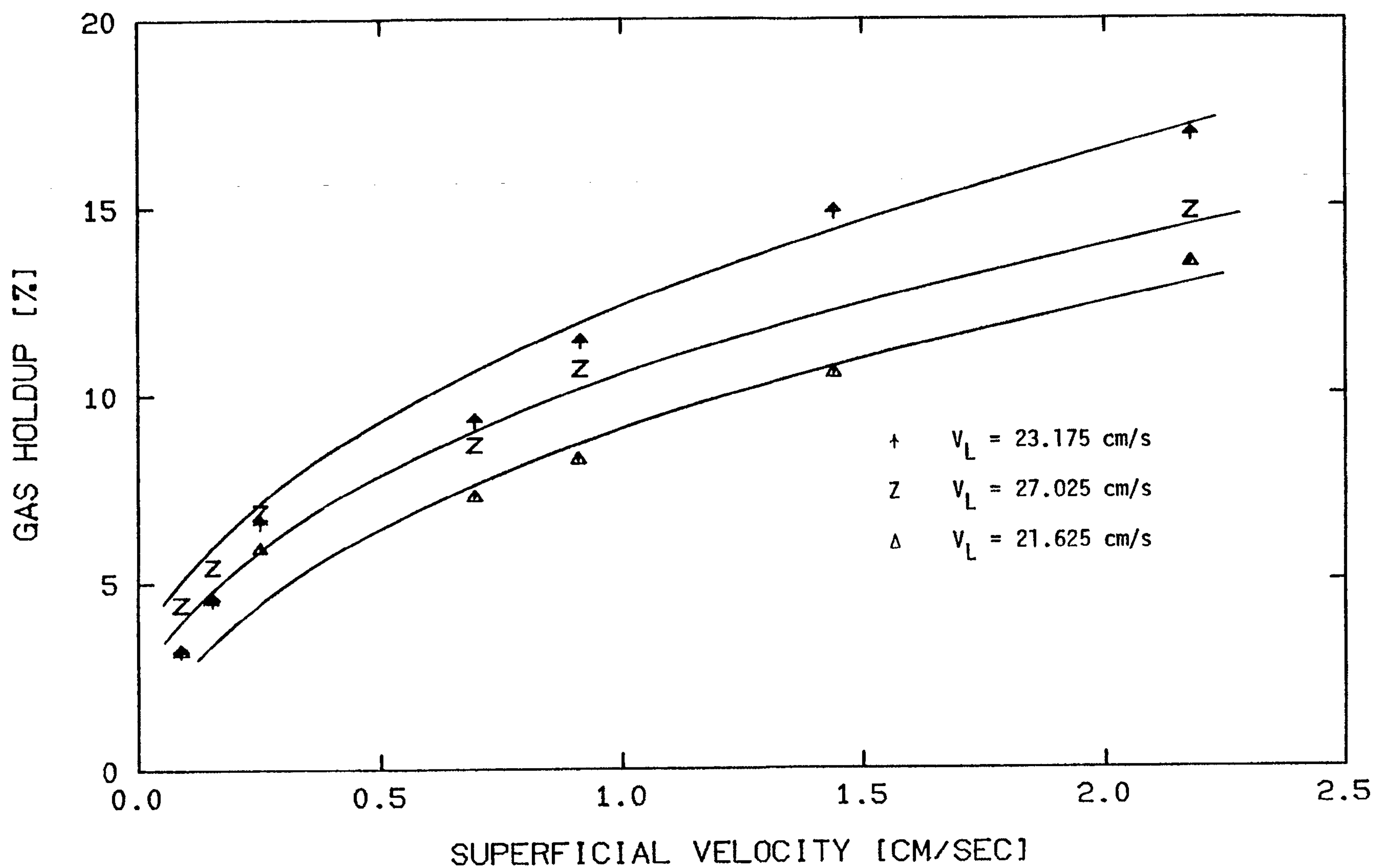
GAS HOLD UP FOR AIR-0.5% BUTANOL SYSTEM

FIGURE 4.6



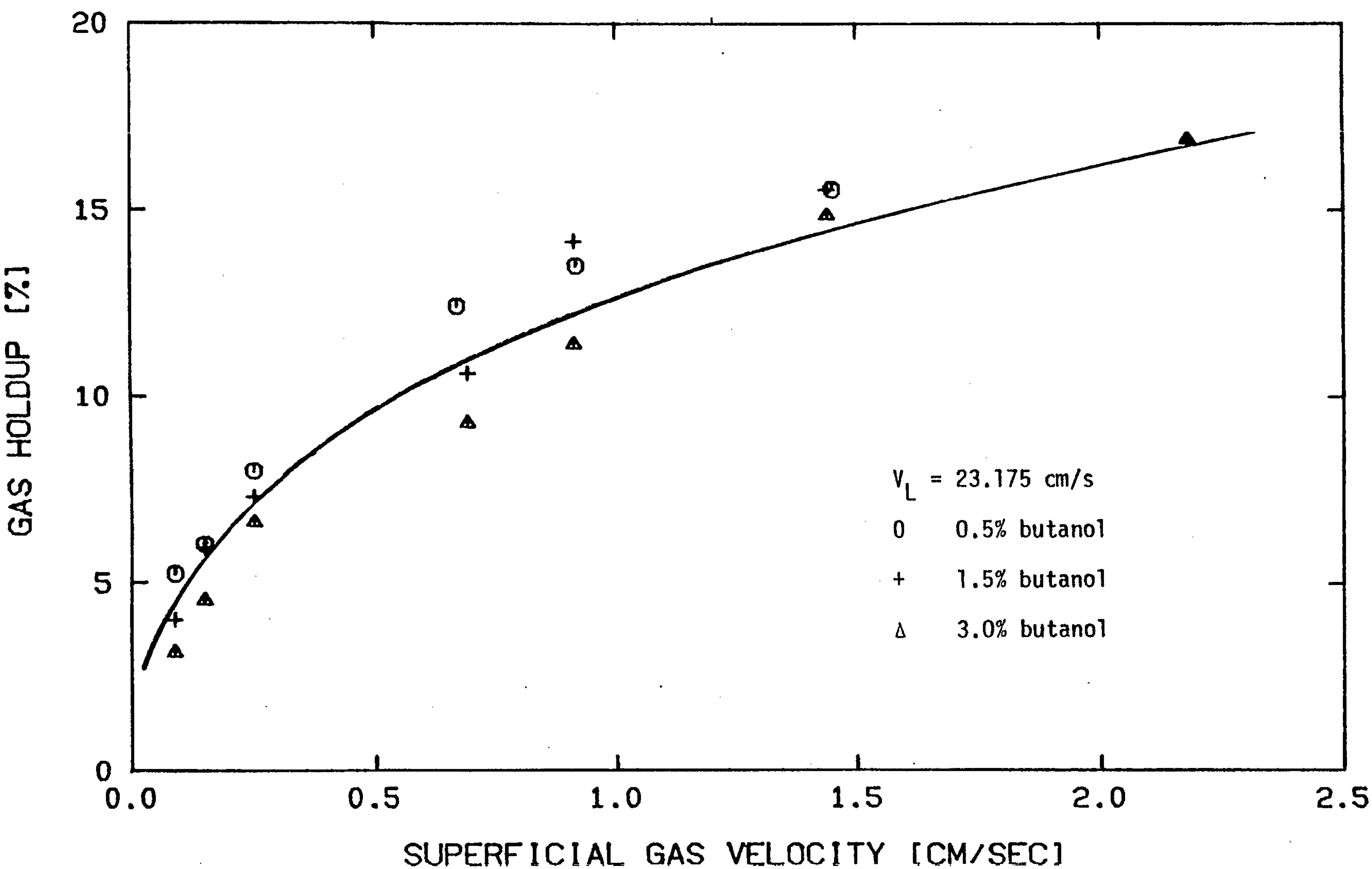
GAS HOLDUP FOR AIR-1.5% BUTANOL SYSTEM

FIGURE 4.7



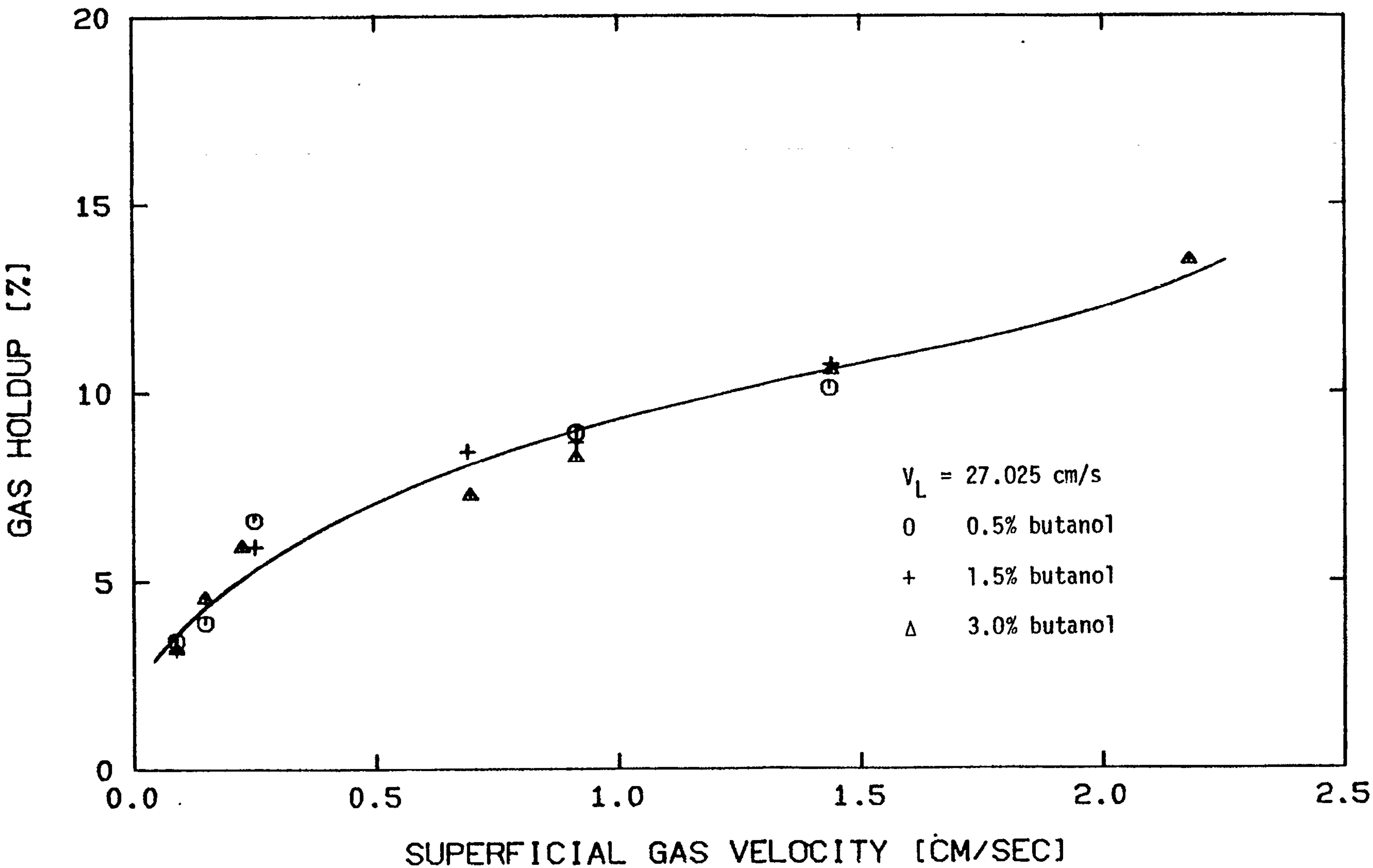
GAS HOLDUP FOR AIR-3.0% BUTANOL SYSTEM

FIGURE 4.8



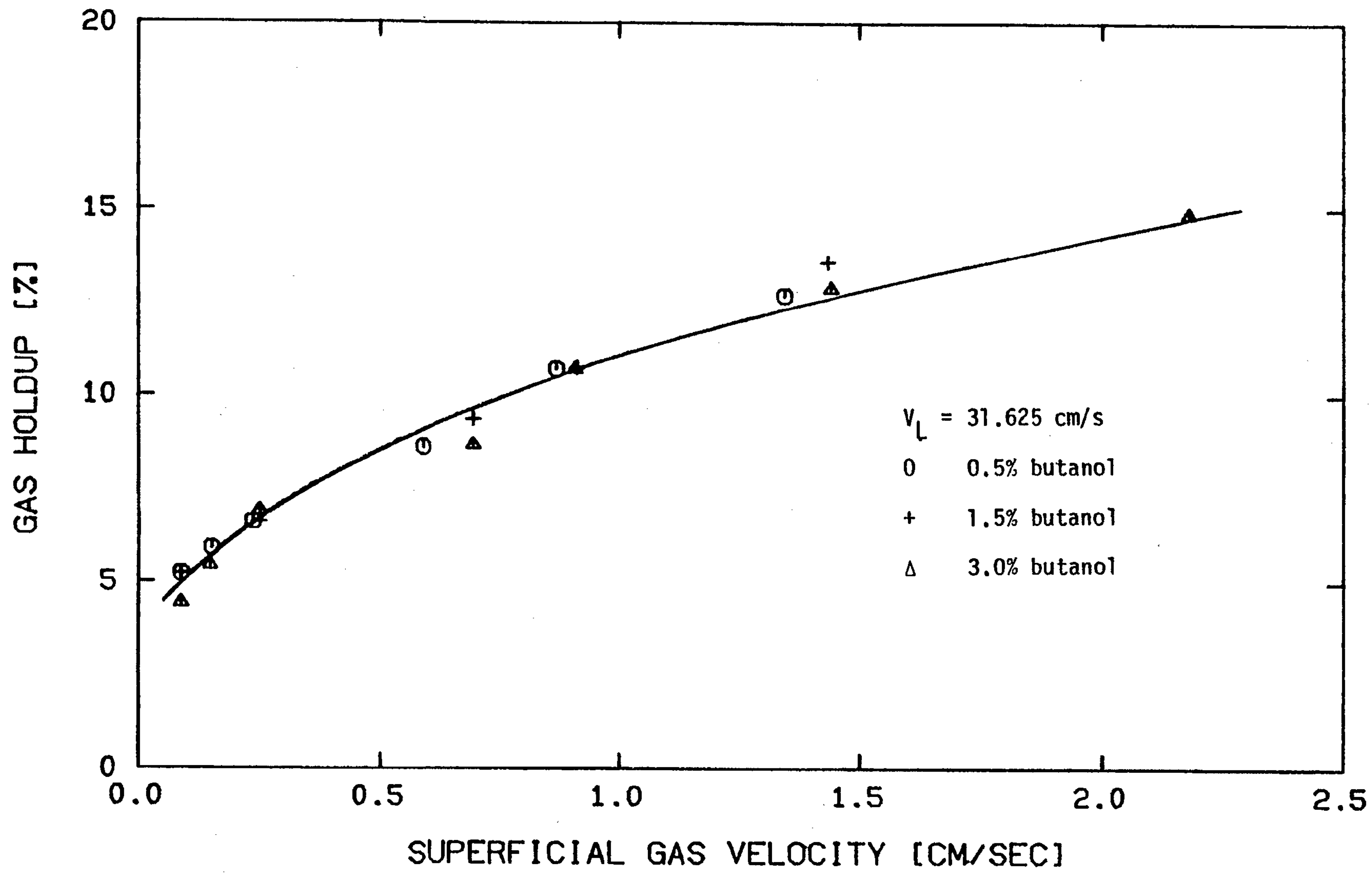
EFFECT OF CONCENTRATION AIR-BUTANOL SYSTEM

FIGURE 4.9



EFFECT OF CONCENTRATION AIR-BUTANOL SYSTEM

FIGURE 4.10



EFFECT OF CONCENTRATION AIR-BUTANOL SYSTEM

FIGURE 4.11

especially at low liquid velocities (Figure 4.9) as compared to the higher liquid velocities (Figures 4.10 and 4.11). The gas holdup decreased in the following order:

Methanol < Ethanol < Propanol < Butanol

The effect of surfactants is still ambiguous. The reported literature is at times in complete agreement. Bolton et al.(4.6) and Miller(4.7) reported no effect of surface tension; Schugerl et al., Todt et al.,(4.9) and recently Oels(4.8) observed a significant increase in gas holdup with decrease in the surface tension; Sharma et al.(4.10) found only a slight increase in the gas holdup with a decrease in surface tension. Bach and Pilhofer(4.11) made a detailed study on gas holdup characteristics using pure liquids and liquids mixtures. They found that pure liquids and mixtures behaved differently and also that surface tension was found to have no effect on gas holdup in the case of pure liquids. However, Schugerl et al.(4.8) do report a variation in the coalescence behavior of the gas phase in the presence of surfactants. Friedel et al.(4.12) also report a decrease in bubble size from changing from distilled water to tap water to aqueous ethanol. The same behavior was observed during experiments with air-water and air-alcohol systems. However, with different concentrations of butanol, or for different alcohols, significant bubble size variation could not be observed visually.

In alcohol solutions, the coalescence rate is reduced and the bubble size decreases. The decrease in the bubble size results in a decrease in the bouyancy force and a corresponding decrease in the bubble rise velocity. The bouyancy force and the drag force being in opposite directions, for the same liquid velocity, there is a decrease in the gas holdup as bubbles are entrained from the column. A comparison of the data for alcohol solutions and air-water systems reveals this conclusion as can be seen from Figures 4.2 and Figure 4.12. This phenomena is directly opposite to the case of cocurrently-operated upflow systems, where the presence of surfactants does increase the gas holdup since the bubble-rise velocity decreases.

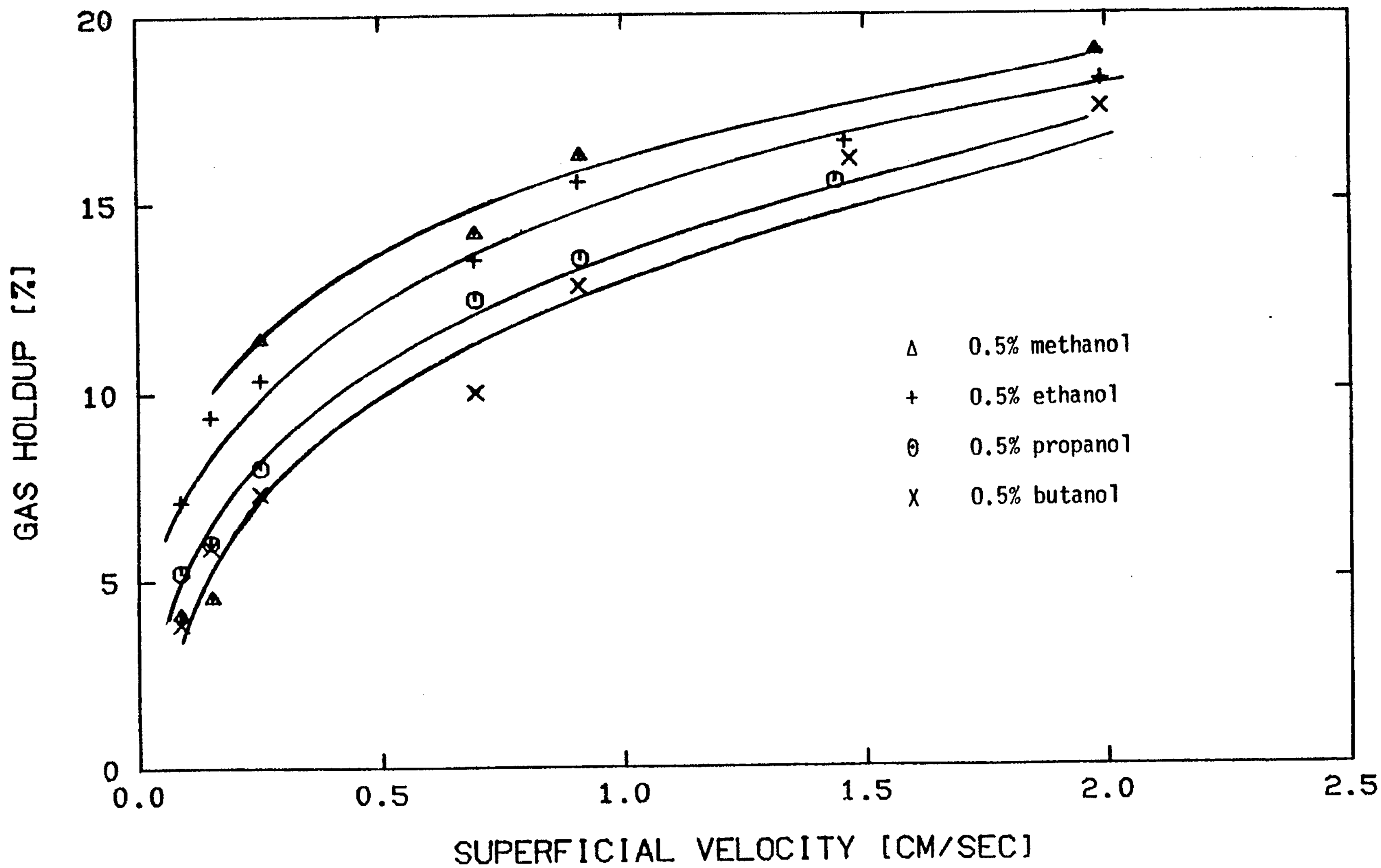
In the presence of surfactants, the rise velocity of the same diameter bubble need not be the same. The interface of the bubble is mobile and an internal circulation movement exists in the bubble which reduces the drag on the bubble. Oels et al.[4.13] report that the surfactants are absorbed at the top of the bubble and are transported to the rear, and a surface tension gradient is formed. The surface tension gradient across the bubble depends essentially on the type of alcohol. As the chain length of the alcohol increases, the rigidity of the bubble increases causing a reduction in the bubble rise velocity and hence an increase in gas holdup. For a downflow system, an increase in the chain length of the alcohol should decrease the gas holdup. This behavior is clearly seen in Figure 4.12 at low liquid velocities. However, at higher liquid velocity, the holdup becomes progressively independent of the type of alcohol; since the relative velocity between the two phases is dominated by the liquid velocity (Figures 4.13 and 4.14).

Visual observation indicates the bubble size to be uniform indicating that the flow regime encountered in the range of gas and liquid velocities studied is essentially the bubbly-flow regime. The drift flux diagram in Figures 4.22 and 4.23 clearly shows the absence of any transition from this regime.

The physical properties of the solutions are reported in Table 4.1.

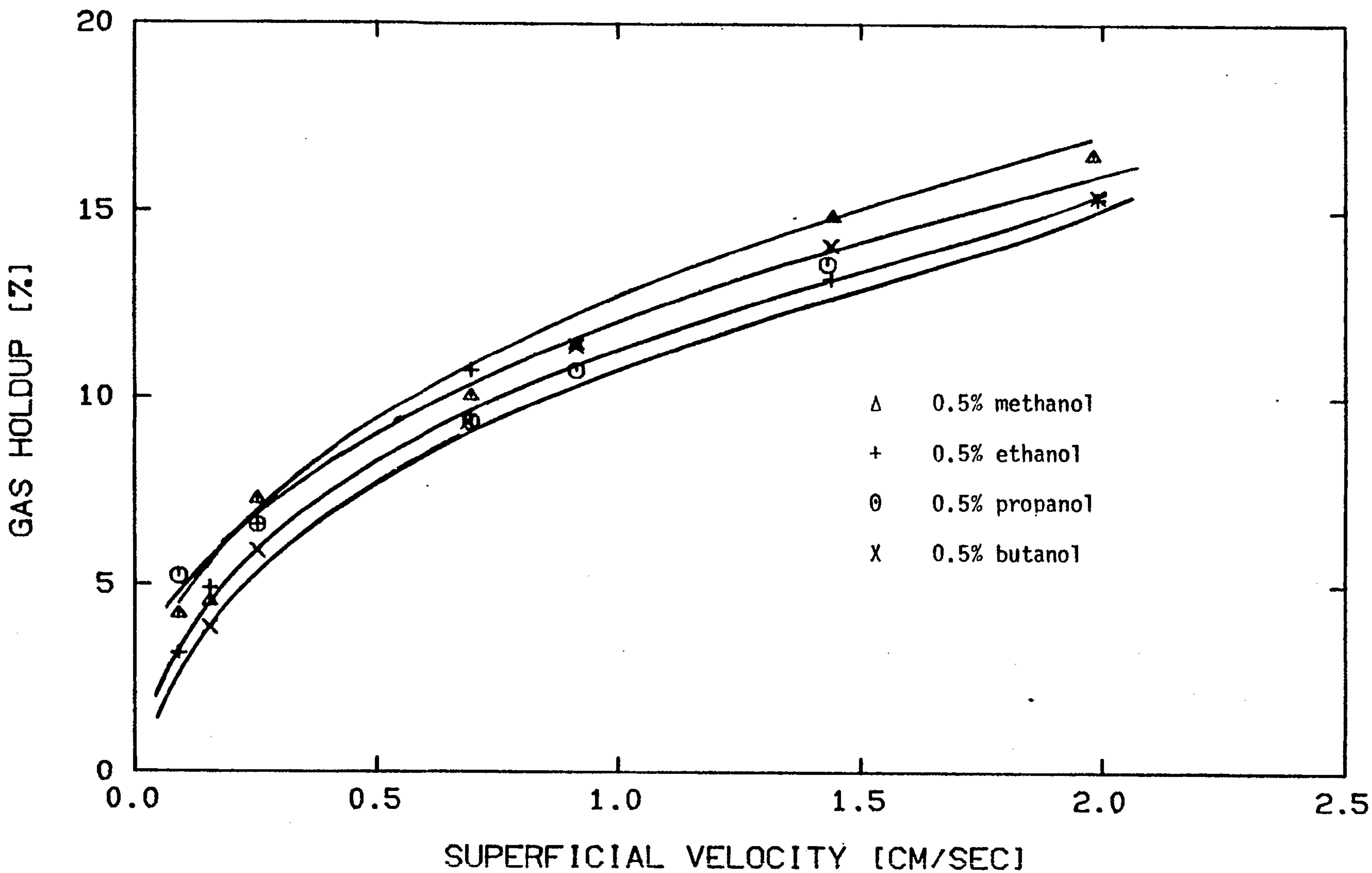
4.3.3 Effect of Electrolytes Solution

The effect of electrolyte solutions on the gas holdup has been studied using NaCl in the range of concentrations of 0.05 m to 1.25 m. The gas holdup decreases with an increase in ionic strength up to 0.5 m and is independent of the ionic strength beyond 0.5 m. In upflow systems, Akita and Yoshida[4.14] have reported an overall increase of about 25% in the holdup on addition of an electrolyte. This increase in voidage is primarily due to the postponement of the appearance of large bubbles, since the addition of an electrolyte induces a non-coalescing behavior due to the presence of an ionic double-polar layer between the gas and liquid phases. Braulich et al.[4.] report that the holdup is a function of both the concentration and the gas



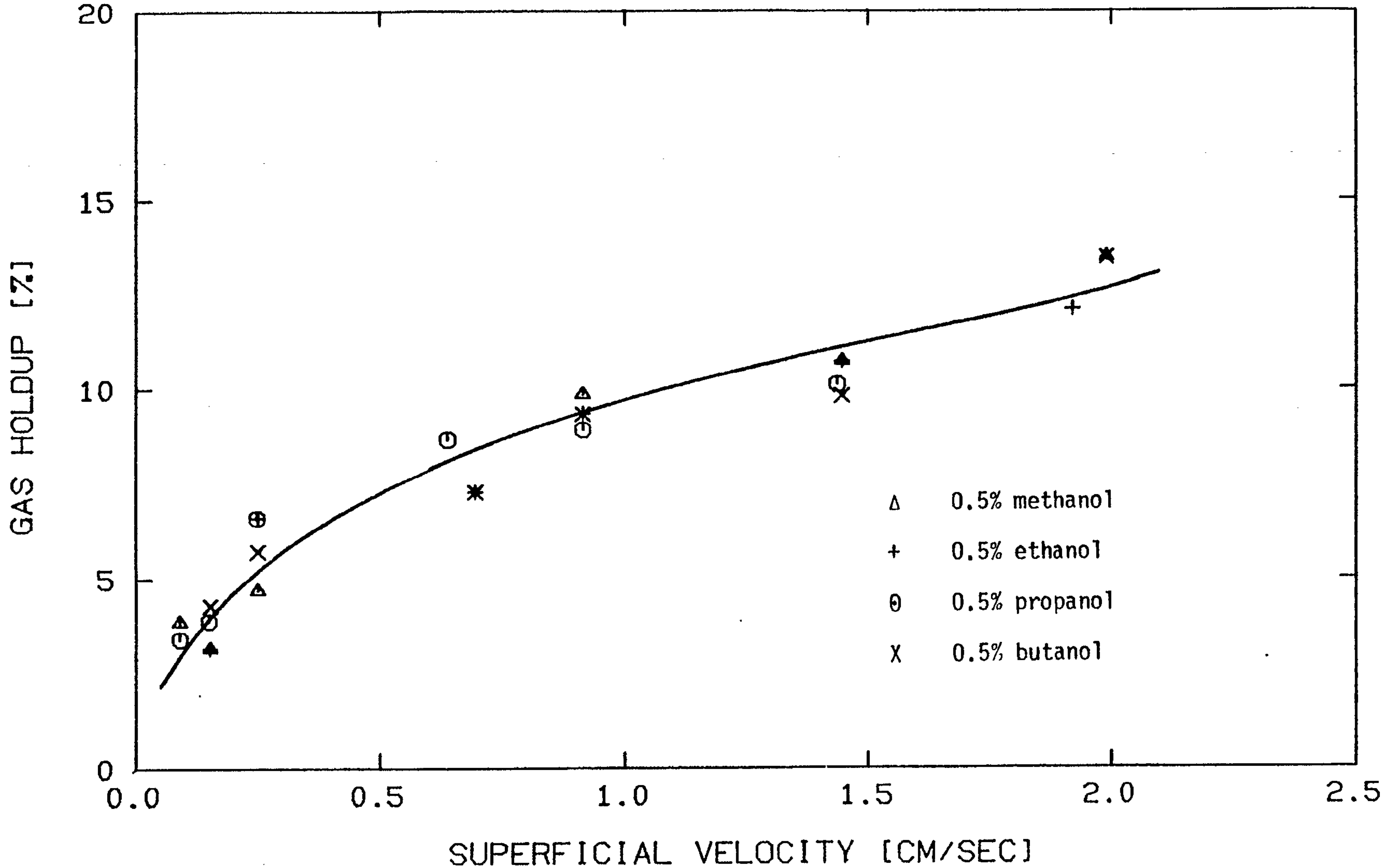
EFFECT OF ALCOHOL PROPERTY ON GAS HOLDUP, VL=23.175

FIGURE 4.12



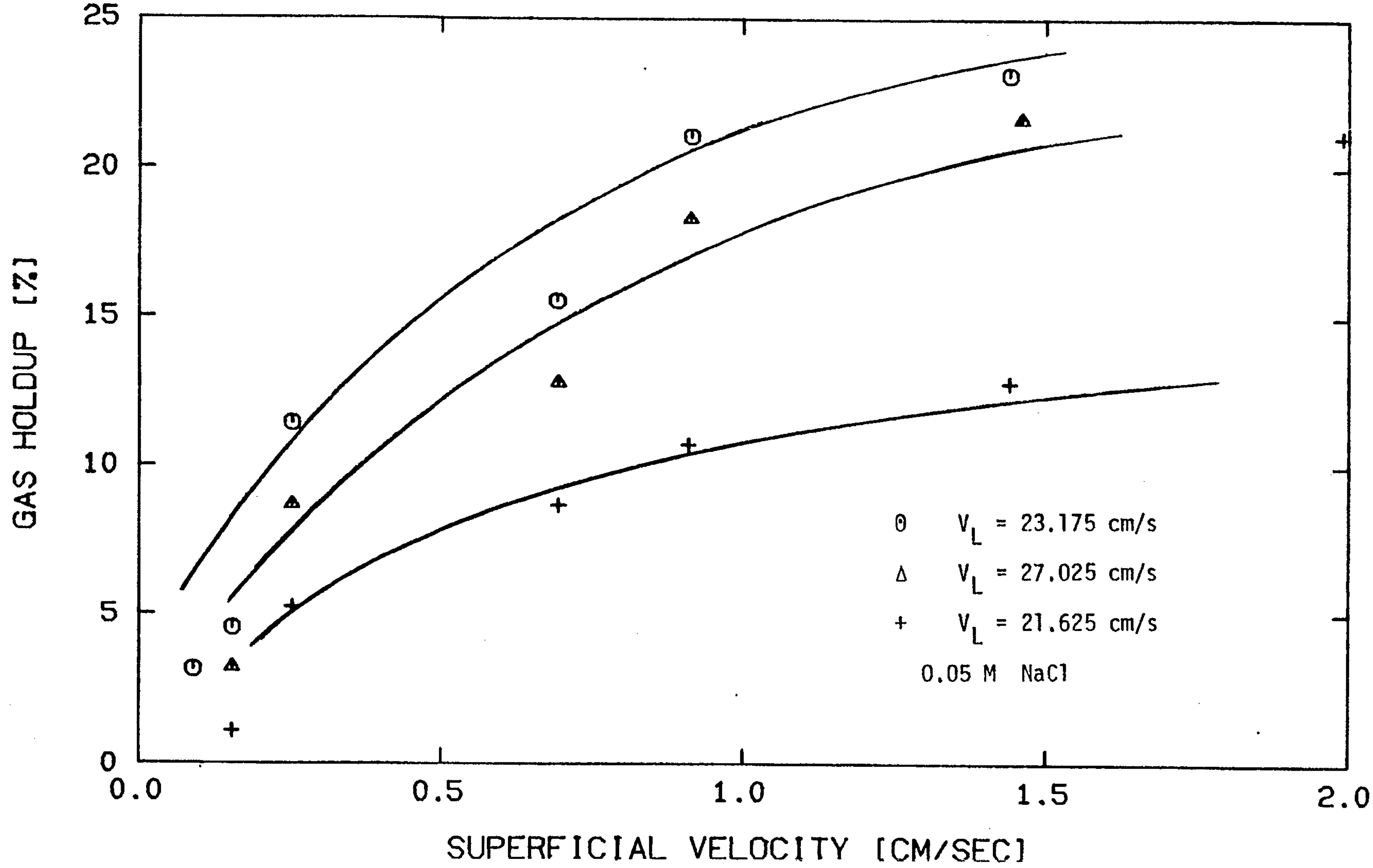
EFFECT OF ALCOHOL PROPERTY ON GAS HOLDUP, VL=27.025

FIGURE 4.13



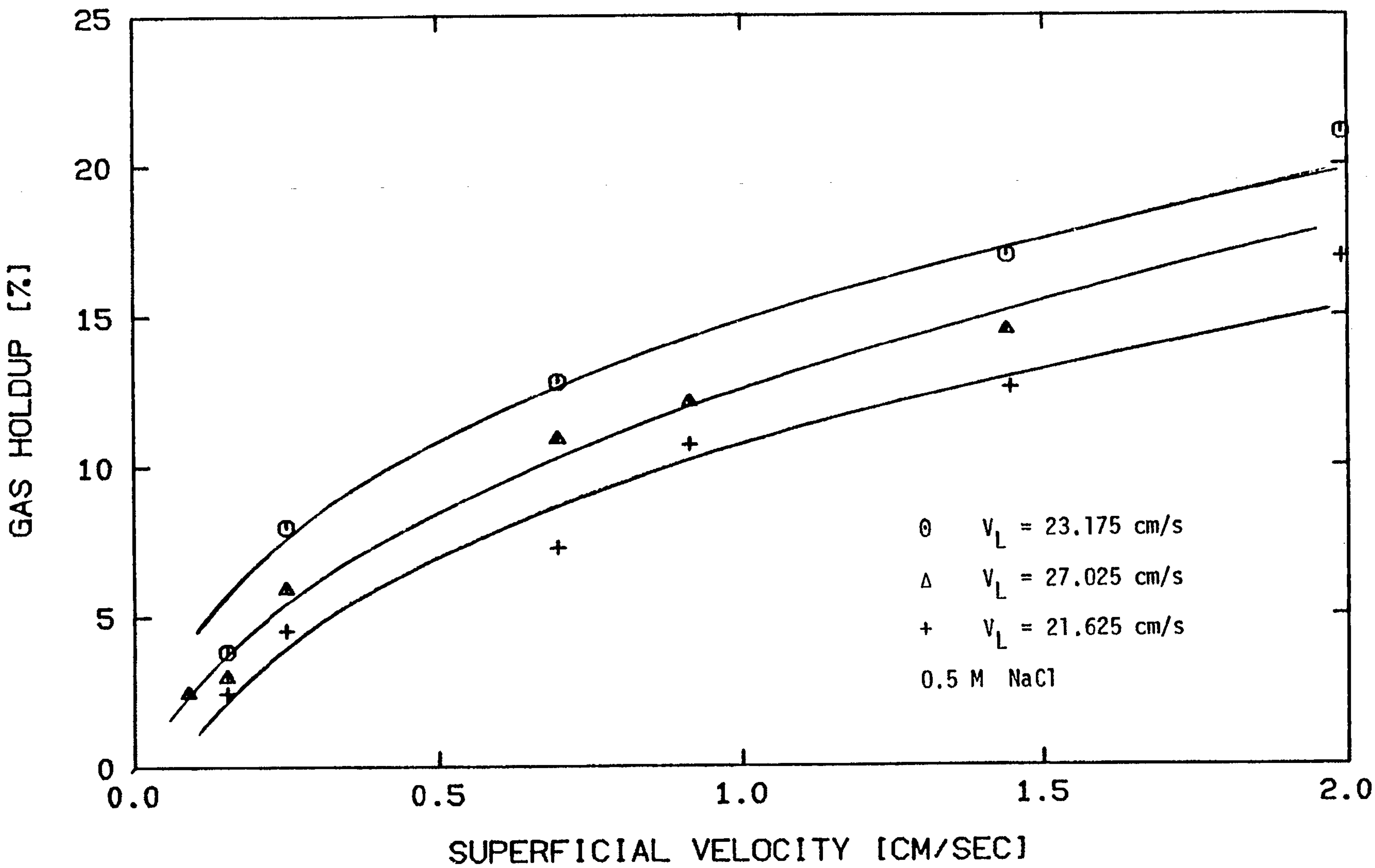
EFFECT OF ALCOHOL PROPERTY ON GAS HOLDUP, VL=31.625

FIGURE 4.14



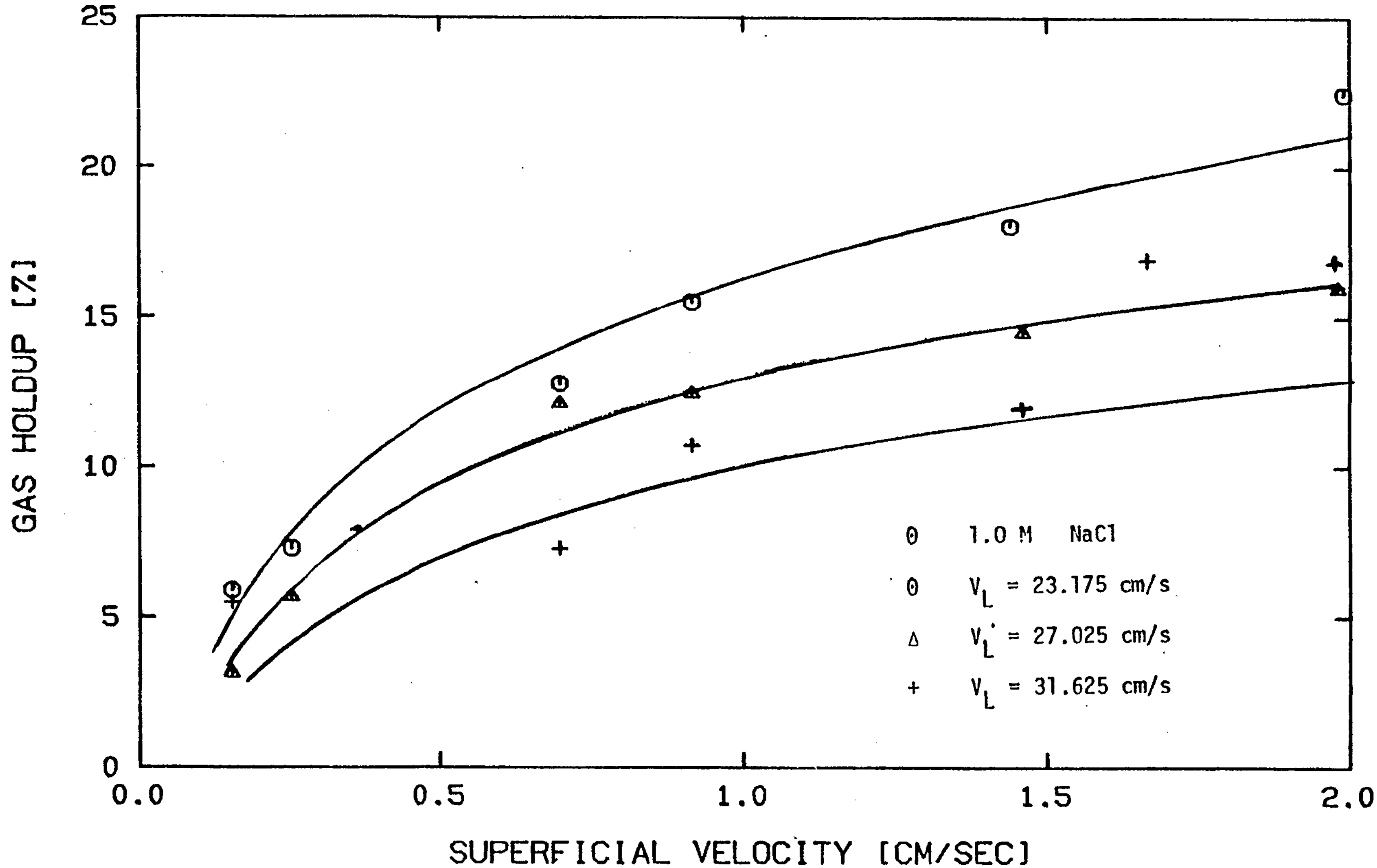
EFFECT OF IONIC STRENGTH ON GAS HOLDUP

FIGURE 4.15



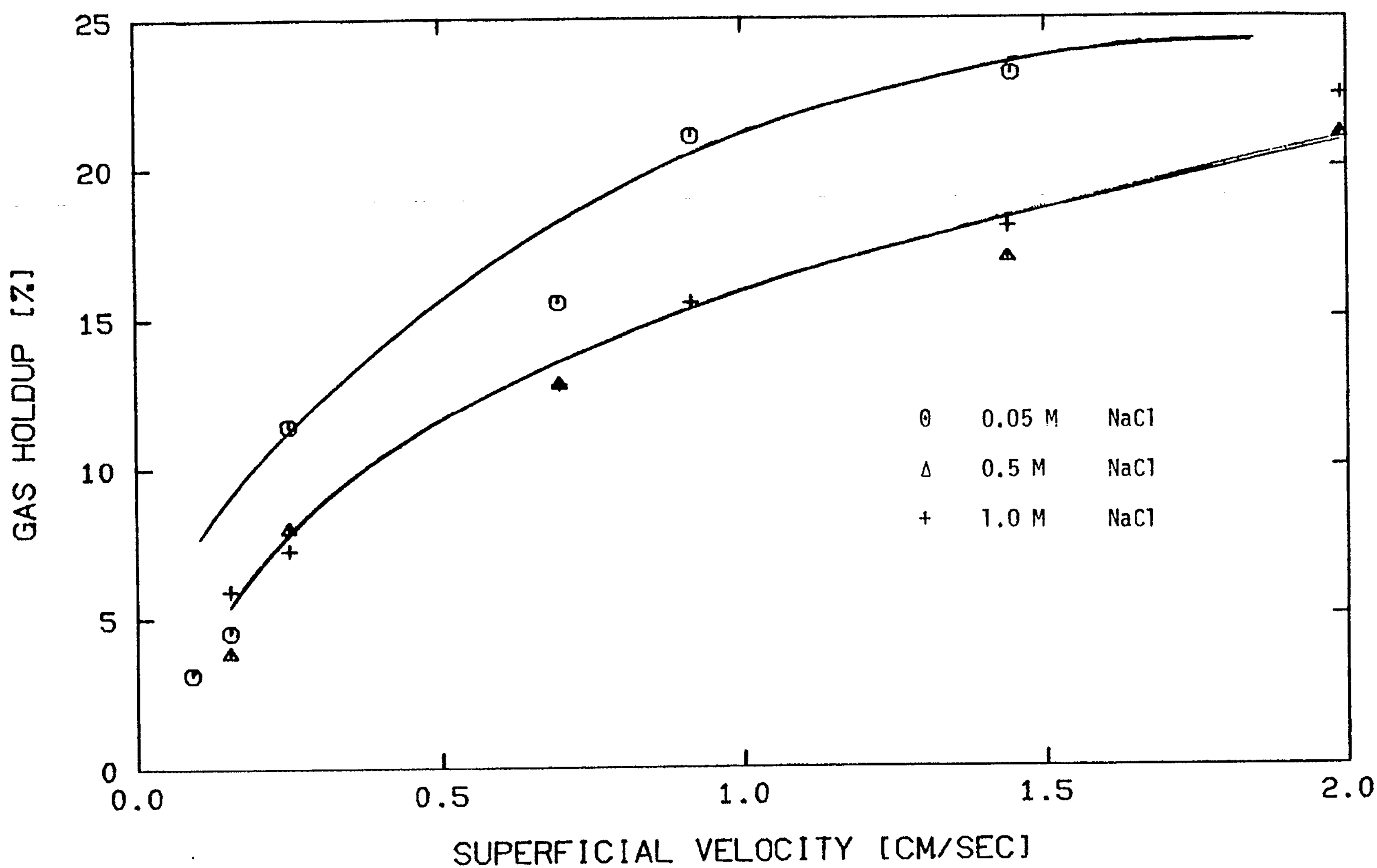
EFFECT OF IONIC STRENGTH ON GAS HOLDUP

FIGURE 4.16



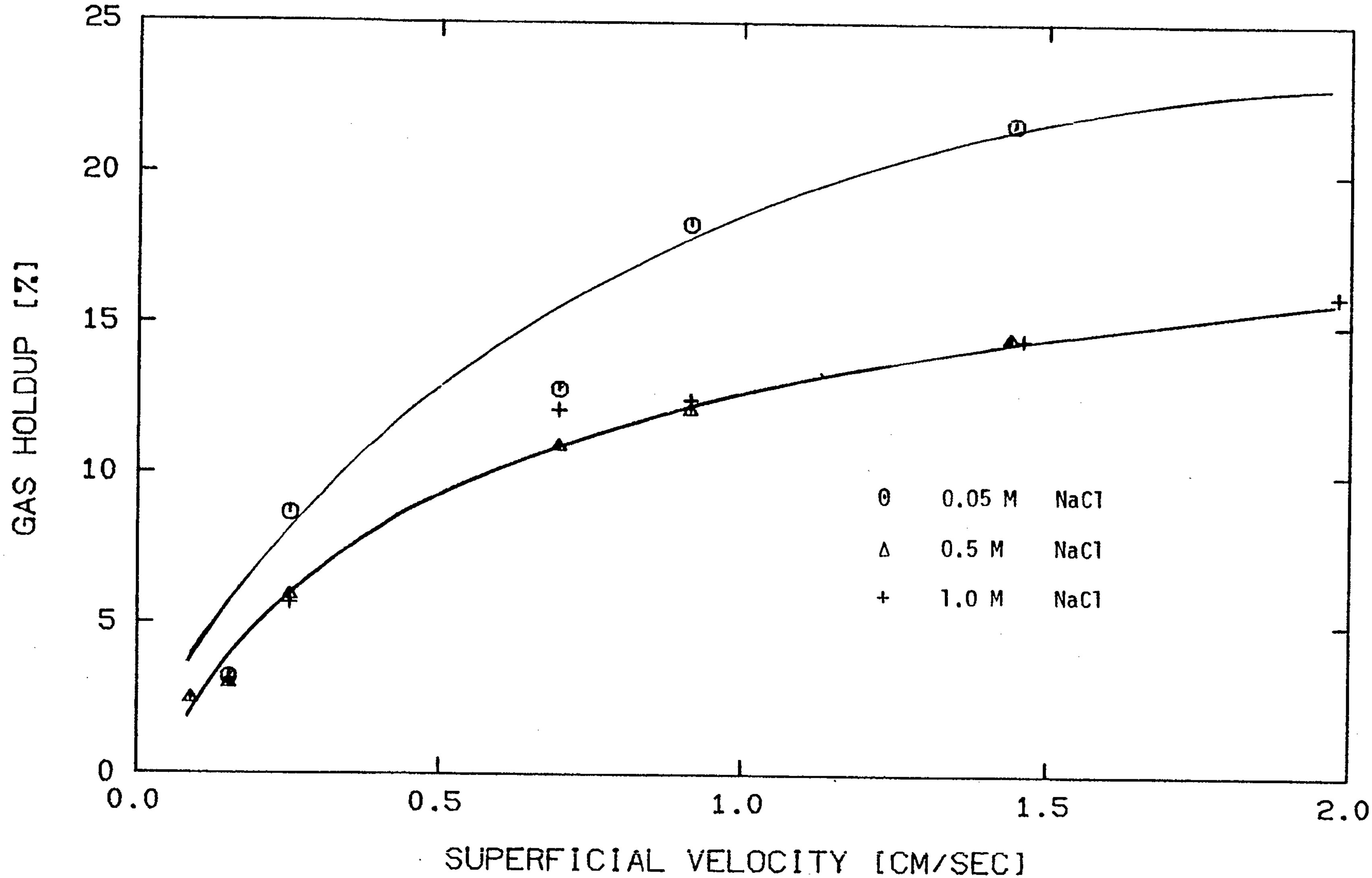
EFFECT OF IONIC STRENGTH ON GAS HOLDUP

FIGURE 4.17



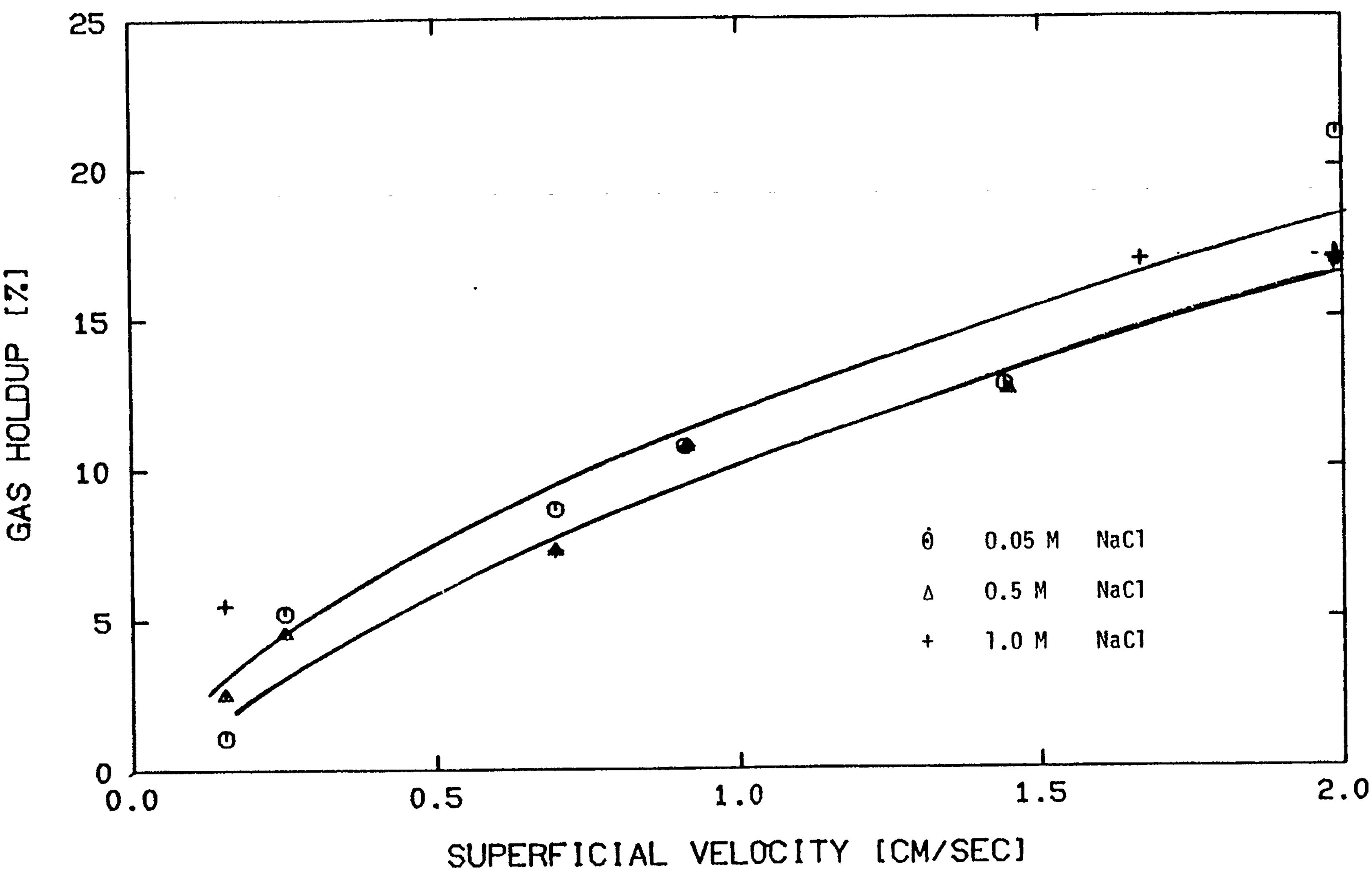
EFFECT OF IONIC STRENGTH ON GAS HOLDUP, VL=23.175

FIGURE 4.18



EFFECT OF IONIC STRENGTH ON GAS HOLDUP, VL=27.175

FIGURE 4.19



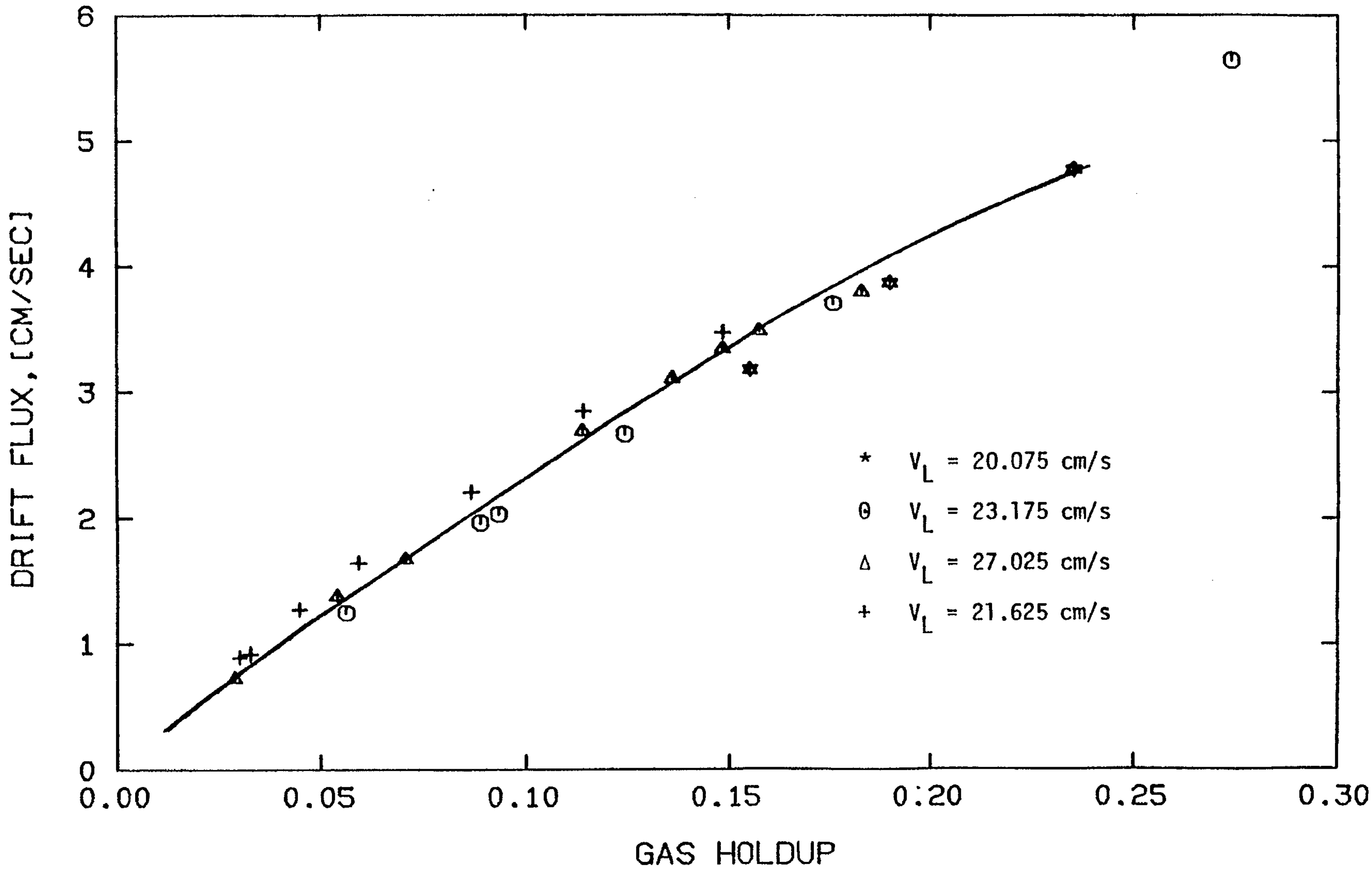
EFFECT OF IONIC STRENGTH ON GAS HOLDUP, VL=31.625

FIGURE 4.20

TABLE 4.1

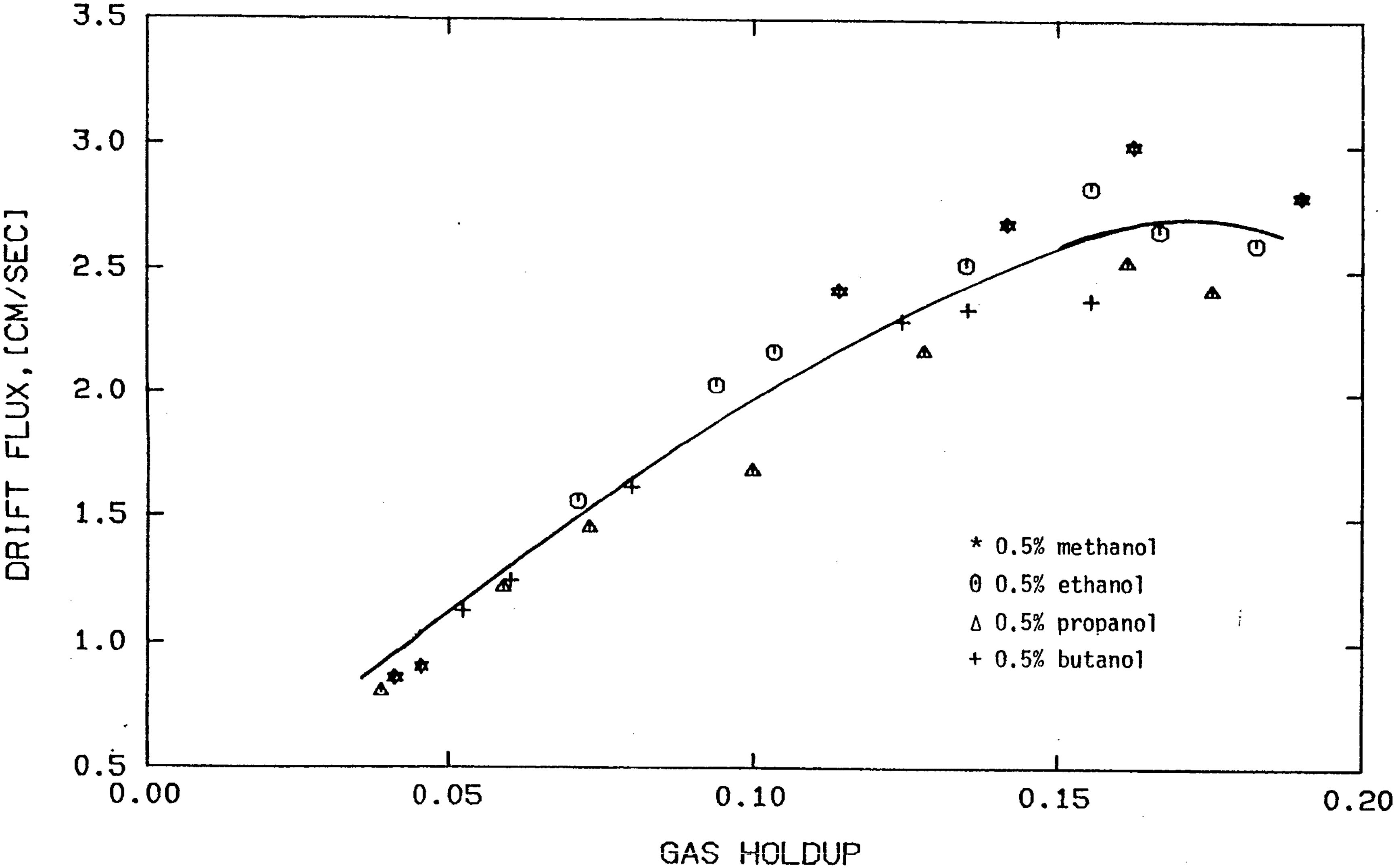
PHYSICAL PROPERTIES: ALCOHOL SOLUTIONS

	ρ_L (g/cm^3)	σ_L (dynes/cm)	μ_L (cp)
0.5% Methanol	0.994	67.96	0.83
0.5% Ethanol	0.9931	66.96	0.83
0.5% n-Propanol	0.9008	64.85	0.85
0.5% n-Butanol	0.9932	60.18	0.84
1.5% n-Butanol	0.9912	49.316	0.85
3.0% n-Butanol	0.9900	40.26	0.85



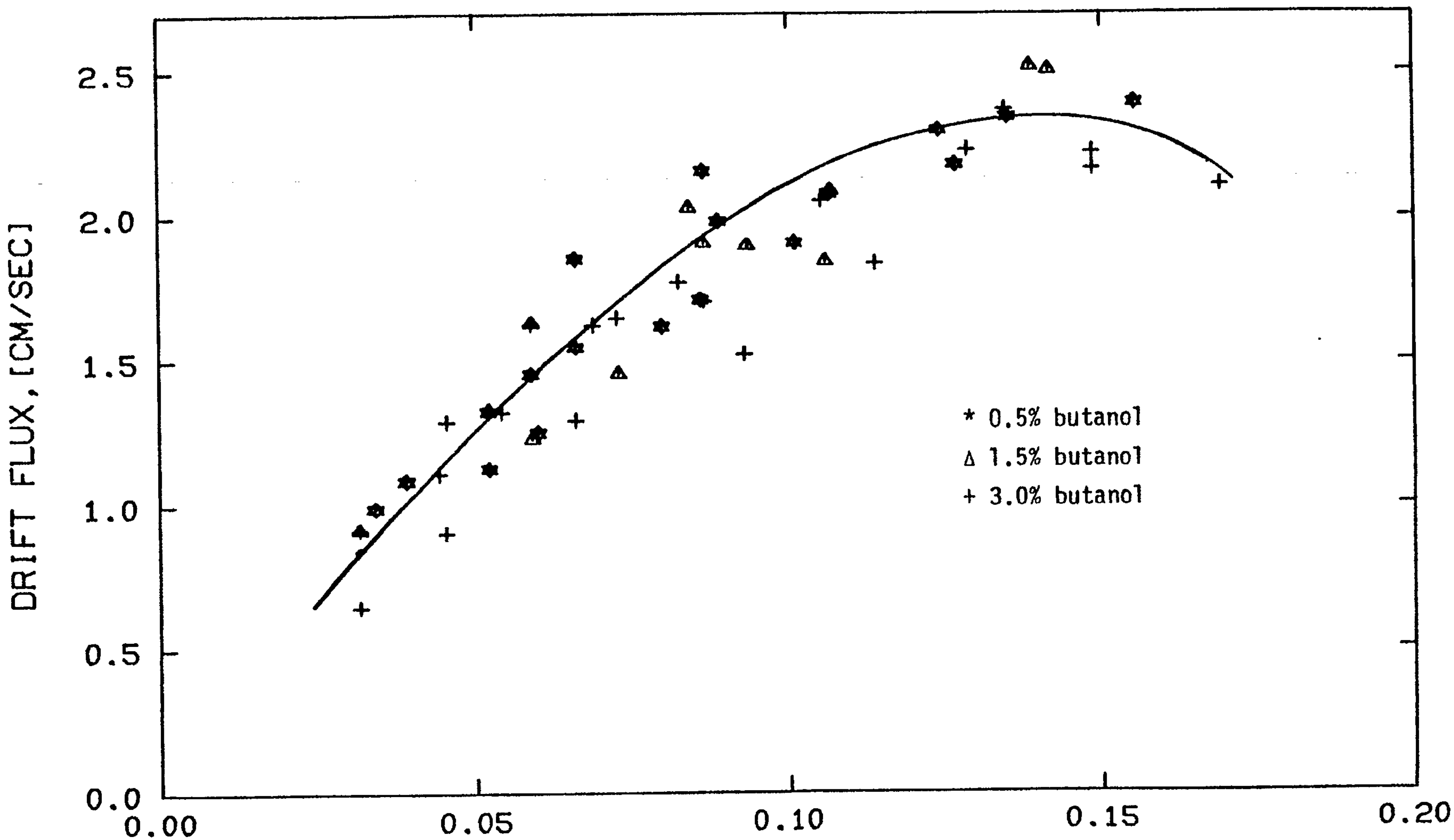
GAS HOLDUP FOR AIR-WATER SYSTEM

FIGURE 4.21



GAS HOLDUP FOR AIR-ALCOHOL SYSTEMS

FIGURE 4.22



GAS HOLDUP FOR AIR-BUTANOL SYSTEM

FIGURE 4.23

velocity. In the present study the holdup decreases with the addition of an electrolyte; however, the decrease in holdup is relatively small. Table 4.2 shows the concentration ranges of NaCl solutions employed and the physical properties of the system.

A visual observation of the systems shows a very uniform bubble size distribution indicating that the bubbly-flow regime is encountered.

Figures 4.15 to 4.20 show the effect of electrolyte concentration.

The experimental data is compared with the correlation for gas holdup provided by Freidal et al.[4.12] Their correlation predicts the holdup to be much higher than the experimental values obtained for the air-water system in our work. The predicted and experimental values are in error by 15-40% for air-water data. For alcohols and electrolytes, the disagreement is much too large and use of this correlation seems inappropriate. Friedel et al.[4.12] report that their correlation predicts their own experimental data within 28% standard deviation. The results are presented in Appendix 1. This disagreement may be due to the diameter of the column and nature of the sparger(?) used especially for the air-water system. The holdup is known to be a function of the column diameter up to 0.015 m ID (Akita and Yoshida).[4.14] There is consistent diameter effect where the values of gas holdup in our work (D_c = 0.075 m), Freidel et al.[4.12] (D_c = 0.015 m) and Fujie et al.[4.16] (D_c = 0.45 m) are compared. The holdup decreases with increase in column diameter in the range of gas and liquid velocities studied.

4.3.4 Effect of Viscosity

CMC solutions of 50 ppm and 1000 ppm were employed to determine the effect of viscosity. However, at gas velocities as low as 0.06 cm/s, large gas bubbles and slugs were observed, resulting in a gas cushion at the top of the downflow bubble column at the highest liquid velocity (31.625 cm/s) employed. The appearance of the gas cushion is a sensitive indicator of the heterogeneous flow conditions which prevail and limit the mode of operation of the downflow system. The range of gas velocities were so small that no

TABLE 4.2

PHYSICAL PROPERTIES: NaCl SOLUTIONS

	σ_L (dynes/cm)	μ_L (cp)	ρ_L (g/cm^3)
0.05 m	70.50	1.0	0.998
0.5 m	70.15	1.22	1.0415
1.0 m	73.50	1.23	1.065
1.25 m	74.25	1.29	1.074

conclusive data could be obtained, although Freidel et al.[4.12] do report measurements of gas holdup in which they varied the liquid velocity from 1-11.4 cp. They report a decrease in holdup with an increase in viscosity.

4.4 Proposed Future Work

1. Measurements of gas holdup using solids,

2. Measurement of interfacial areas in gas-liquid and gas-liquid-solid systems,

3. Analysis and correlation for the data obtained in holdup measurements.

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COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-WATER SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01 (X) ABS
0.0613	20.7500	0.1556	0.1387	0.1221
0.0889	20.7500	0.1899	0.1576	0.2047
0.1530	20.7500	0.2353	0.1895	0.2416
0.0615	23.1750	0.0562	0.1121	0.4988
0.1100	23.1750	0.0889	0.1378	0.3547
0.1530	23.1750	0.0935	0.1547	0.3954
0.2530	23.1750	0.1244	0.1842	0.3246
0.4540	23.1750	0.1760	0.2255	0.2194
0.9779	23.1750	0.2738	0.2949	0.0717
0.0613	27.0250	0.0289	0.0824	0.6497
0.0889	27.0250	0.0540	0.0945	0.4284
0.2520	27.0250	0.0706	0.1380	0.4885
0.4500	27.0250	0.1140	0.1703	0.3305
0.6710	27.0250	0.1362	0.1972	0.3092
0.7920	27.0250	0.1486	0.2097	0.2913
0.9280	27.0250	0.1580	0.2225	0.2900
1.4050	27.0250	0.1830	0.2609	0.2986
0.0613	31.6250	0.0300	0.0597	0.4967
0.1201	31.6250	0.0327	0.0768	0.5745
0.1530	31.6250	0.0448	0.0841	0.4675
0.2390	31.6250	0.0591	0.0994	0.4051
0.5900	31.6250	0.0867	0.1398	0.3796
0.8700	31.6250	0.1142	0.1624	0.2968
1.4400	31.6250	0.1486	0.1987	0.2523

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-.5% METHANOL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01 (%) ABS
0.0889	23.1750	0.0408	0.1250	0.6735
0.1500	23.1750	0.0453	0.1503	0.6985
0.2520	23.1750	0.1140	0.1801	0.3670
0.6910	23.1750	0.1417	0.2560	0.4464
0.9100	23.1750	0.1624	0.2822	0.4246
1.9900	23.1750	0.1899	0.3763	0.4954
0.0889	27.0250	0.0419	0.0923	0.5460
0.1530	27.0250	0.0453	0.1125	0.5974
0.2520	27.0250	0.0728	0.1349	0.4604
0.6970	27.0250	0.1004	0.1958	0.4874
0.9140	27.0250	0.1142	0.2168	0.4733
1.4340	27.0250	0.1486	0.2580	0.4241
1.9900	27.0250	0.1648	0.2944	0.4401
0.0889	31.6250	0.0386	0.0670	0.4241
0.1530	31.6250	0.0316	0.0822	0.6154
0.2520	31.6250	0.0470	0.0990	0.5255
0.6940	31.6250	0.0834	0.1455	0.4268
0.9140	31.6250	0.0985	0.1620	0.3921
1.4500	31.6250	0.1073	0.1952	0.4503
1.9800	31.6250	0.1348	0.2227	0.3944

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-0.5% ETHANOL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.02(X) ABS
0.0889	23.1750	0.0710	0.1170	0.3933
0.1500	23.1750	0.0938	0.1410	0.3347
0.2520	23.1750	0.1034	0.1693	0.3893
0.6940	23.1750	0.1349	0.2424	0.4435
0.9100	23.1750	0.1555	0.2674	0.4184
1.4600	23.1750	0.1824	0.3186	0.4276
0.1530	27.0250	0.0385	0.1053	0.6343
0.2520	27.0250	0.0591	0.1264	0.5326
0.6960	27.0250	0.0935	0.1843	0.4926
0.9140	27.0250	0.1140	0.2044	0.4424
1.4600	27.0250	0.1410	0.2458	0.4263
1.9900	27.0250	0.1541	0.2791	0.4479
0.1500	31.6250	0.0430	0.0761	0.4352
0.2520	31.6250	0.0572	0.0926	0.3822
0.6960	31.6250	0.0729	0.1366	0.4664
0.9100	31.6250	0.0933	0.1519	0.3858
1.4400	31.6250	0.0981	0.1832	0.4646
1.9800	31.6250	0.1348	0.2100	0.3581

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-.5% PROPANOL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01 (%) ABS
0.0889	23.1750	0.0385	0.1214	0.6828
0.1520	23.1750	0.0589	0.1467	0.5986
0.2520	23.1750	0.0729	0.1752	0.5839
0.6940	23.1750	0.0998	0.2501	0.6009
0.9140	23.1750	0.1280	0.2760	0.5362
1.4400	23.1750	0.1614	0.3260	0.5049
1.9970	23.1750	0.1752	0.3690	0.5252
0.0889	27.0250	0.0316	0.0895	0.6470
0.1530	27.0250	0.0491	0.1092	0.5505
0.2520	27.0250	0.0660	0.1311	0.4964
0.9140	27.0250	0.1073	0.2112	0.4920
1.4400	27.0250	0.1320	0.2521	0.4764
1.9780	27.0250	0.1535	0.2868	0.4647
0.1530	31.6250	0.0316	0.0797	0.6034
0.2520	31.6250	0.0660	0.0961	0.3133
0.6940	31.6250	0.0729	0.1414	0.4845
0.9140	31.6250	0.0935	0.1576	0.4066
1.4400	31.6250	0.1079	0.1895	0.4306
1.9200	31.6250	0.1211	0.2141	0.4343

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-0.5% BUTANOL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01 (%) ABS
0.0889	23.1750	0.0523	0.0479	0.0904
0.1500	23.1750	0.0601	0.0587	0.0242
0.2520	23.1750	0.0799	0.0719	0.1119
0.6740	23.1750	0.1244	0.1070	0.1622
0.9180	23.1750	0.1352	0.1222	0.1063
1.4400	23.1750	0.1555	0.1499	0.0376
0.0889	27.0250	0.0521	0.0346	0.5058
0.1500	27.0250	0.0590	0.0425	0.3898
0.2530	27.0250	0.0660	0.0522	0.2646
0.6740	27.0250	0.0861	0.0779	0.1046
0.9144	27.0250	0.1070	0.0889	0.2031
1.4370	27.0250	0.1269	0.1093	0.1609
0.0889	31.6250	0.0340	0.0247	0.3766
0.1500	31.6250	0.0389	0.0304	0.2817
0.2510	31.6250	0.0660	0.0372	0.7719
0.6410	31.6250	0.0866	0.0547	0.5819
0.9140	31.6250	0.0890	0.0638	0.3946
1.4360	31.6250	0.1011	0.0784	0.2894

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-1.5% BUTANOL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01(%) ABS
0.0889	23.1750	0.0401	0.1106	0.6374
0.1500	23.1750	0.0592	0.1334	0.5563
0.2530	23.1750	0.0729	0.1608	0.5463
0.6960	23.1750	0.1064	0.2311	0.5397
0.9140	23.1750	0.1418	0.2555	0.4451
1.4400	23.1750	0.1555	0.3034	0.4874
0.0889	27.0250	0.0522	0.0813	0.3582
0.2520	27.0250	0.0660	0.1196	0.4480
0.6760	27.0250	0.0936	0.1729	0.4589
0.9100	27.0250	0.1073	0.1939	0.4467
1.4330	27.0250	0.1359	0.2324	0.4152
0.0889	31.6250	0.0316	0.0589	0.4633
0.2520	31.6250	0.0591	0.0874	0.3236
0.6940	31.6250	0.0843	0.1291	0.3472
0.9140	31.6250	0.0867	0.1441	0.3985
1.4440	31.6250	0.1073	0.1741	0.3838

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-3.0% BUTANOL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01(%) ABS
0.0889	23.1750	0.0316	0.1008	0.6864
0.1530	23.1750	0.0453	0.1227	0.6309
0.2520	23.1750	0.0660	0.1470	0.5511
0.6910	23.1750	0.0930	0.2126	0.5626
0.9140	23.1750	0.1142	0.2362	0.5165
1.4400	23.1750	0.1486	0.2816	0.4727
2.1800	23.1750	0.1690	0.3338	0.4937
0.0889	27.0250	0.0442	0.0739	0.4018
0.1520	27.0250	0.0543	0.0903	0.3985
0.2520	27.0250	0.0688	0.1090	0.3690
0.6910	27.0250	0.0867	0.1599	0.4579
0.9140	27.0250	0.1070	0.1785	0.4005
1.4400	27.0250	0.1288	0.2148	0.4003
2.1800	27.0250	0.1487	0.2568	0.4210
0.0889	31.6250	0.0316	0.0534	0.4079
0.1530	31.6250	0.0454	0.0656	0.3083
0.2520	31.6250	0.0590	0.0794	0.2572
0.6970	31.6250	0.0726	0.1181	0.3852
0.9140	31.6250	0.0826	0.1318	0.3731
1.4400	31.6250	0.1057	0.1594	0.3371
2.1800	31.6250	0.1348	0.1918	0.2971

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-0.05M NACL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01(X) ABS
0.0889	23.1750	0.0316	0.1242	0.7455
0.1500	23.1750	0.0453	0.1493	0.6967
0.2530	23.1750	0.1142	0.1793	0.3630
0.6960	23.1750	0.1555	0.2553	0.3908
0.9140	23.1750	0.2106	0.2812	0.2511
1.4400	23.1750	0.2313	0.3318	0.3029
0.1530	27.0250	0.0321	0.1118	0.7129
0.2520	27.0250	0.0866	0.1341	0.3541
0.6760	27.0250	0.1280	0.1925	0.3351
0.9100	27.0250	0.1830	0.2153	0.1499
1.4330	27.0250	0.2164	0.2566	0.1566
0.1530	31.6250	0.0190	0.0816	0.7672
0.2520	31.6250	0.0522	0.0984	0.4696
0.6940	31.6250	0.0866	0.1446	0.4012
0.9140	31.6250	0.1073	0.1611	0.3338
1.4440	31.6250	0.1280	0.1938	0.3394
1.9700	31.6250	0.2106	0.2209	0.0467

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-0.5M NACL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01(%) ABS
0.0889	23.1750	0.0316	0.1242	0.7455
0.1500	23.1750	0.0384	0.1493	0.7429
0.2530	23.1750	0.0798	0.1793	0.5549
0.6940	23.1750	0.1280	0.2550	0.4980
1.4400	23.1750	0.1699	0.3318	0.4879
1.9800	23.1750	0.2106	0.3739	0.4367
0.1530	27.0250	0.0299	0.1118	0.7326
0.2520	27.0250	0.0591	0.1341	0.5592
0.6760	27.0250	0.1090	0.1925	0.4338
0.9100	27.0250	0.1211	0.2153	0.4374
1.4330	27.0250	0.1422	0.2566	0.4458
0.1530	31.6250	0.0247	0.0816	0.6974
0.2520	31.6250	0.0453	0.0984	0.5397
0.6940	31.6250	0.0729	0.1446	0.4959
0.9140	31.6250	0.1071	0.1611	0.3351
1.4440	31.6250	0.1261	0.1938	0.3492
1.9700	31.6250	0.1693	0.2209	0.2337

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR-1.0M NACL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01 (X) ABS
0.1500	23.1750	0.0591	0.1493	0.6043
0.2530	23.1750	0.0729	0.1793	0.5933
0.6940	23.1750	0.1280	0.2550	0.4980
0.9100	23.1750	0.1553	0.2808	0.4469
1.4400	23.1750	0.1806	0.3318	0.4556
1.9800	23.1750	0.2242	0.3739	0.4004
0.1530	27.0250	0.0313	0.1118	0.7201
0.2520	27.0250	0.0567	0.1341	0.5771
0.6760	27.0250	0.1211	0.1925	0.3709
0.9100	27.0250	0.1245	0.2153	0.4216
1.4330	27.0250	0.1450	0.2566	0.4349
1.9700	27.0250	0.1598	0.2917	0.4521
0.2520	31.6250	0.0550	0.0984	0.4411
0.6940	31.6250	0.0729	0.1446	0.4959
0.9310	31.6250	0.1073	0.1622	0.3387
1.4440	31.6250	0.1693	0.1938	0.1262
1.9700	31.6250	0.1908	0.2209	0.1364

COMPARISON OF EXPERIMENTAL VALUES AND EXISTING CORRELATION
FOR AIR=1.25M NACL SYSTEM

VG (CM/S)	VL (CM/S)	EG EXPTL	EG FREIDEL	ERROR*0.01(X) ABS
0.1500	23.1750	0.0522	0.1493	0.6505
0.2530	23.1750	0.0660	0.1793	0.6318
0.6940	23.1750	0.1280	0.2550	0.4980
0.9100	23.1750	0.1555	0.2808	0.4462
1.4400	23.1750	0.1693	0.3318	0.4897
1.9800	23.1750	0.2037	0.3739	0.4552
0.1530	27.0250	0.0372	0.1118	0.6673
0.2520	27.0250	0.0522	0.1341	0.6107
0.6760	27.0250	0.0809	0.1925	0.5798
0.9100	27.0250	0.1107	0.2153	0.4857
1.4330	27.0250	0.1350	0.2566	0.4739
1.9700	27.0250	0.1652	0.2917	0.4336
0.1530	31.6250	0.0113	0.0816	0.8615
0.2520	31.6250	0.0453	0.0984	0.5397
0.6940	31.6250	0.0660	0.1446	0.5436
0.9310	31.6250	0.1004	0.1622	0.3812
1.4440	31.6250	0.1142	0.1938	0.4106
1.9700	31.6250	0.1625	0.2209	0.2645

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