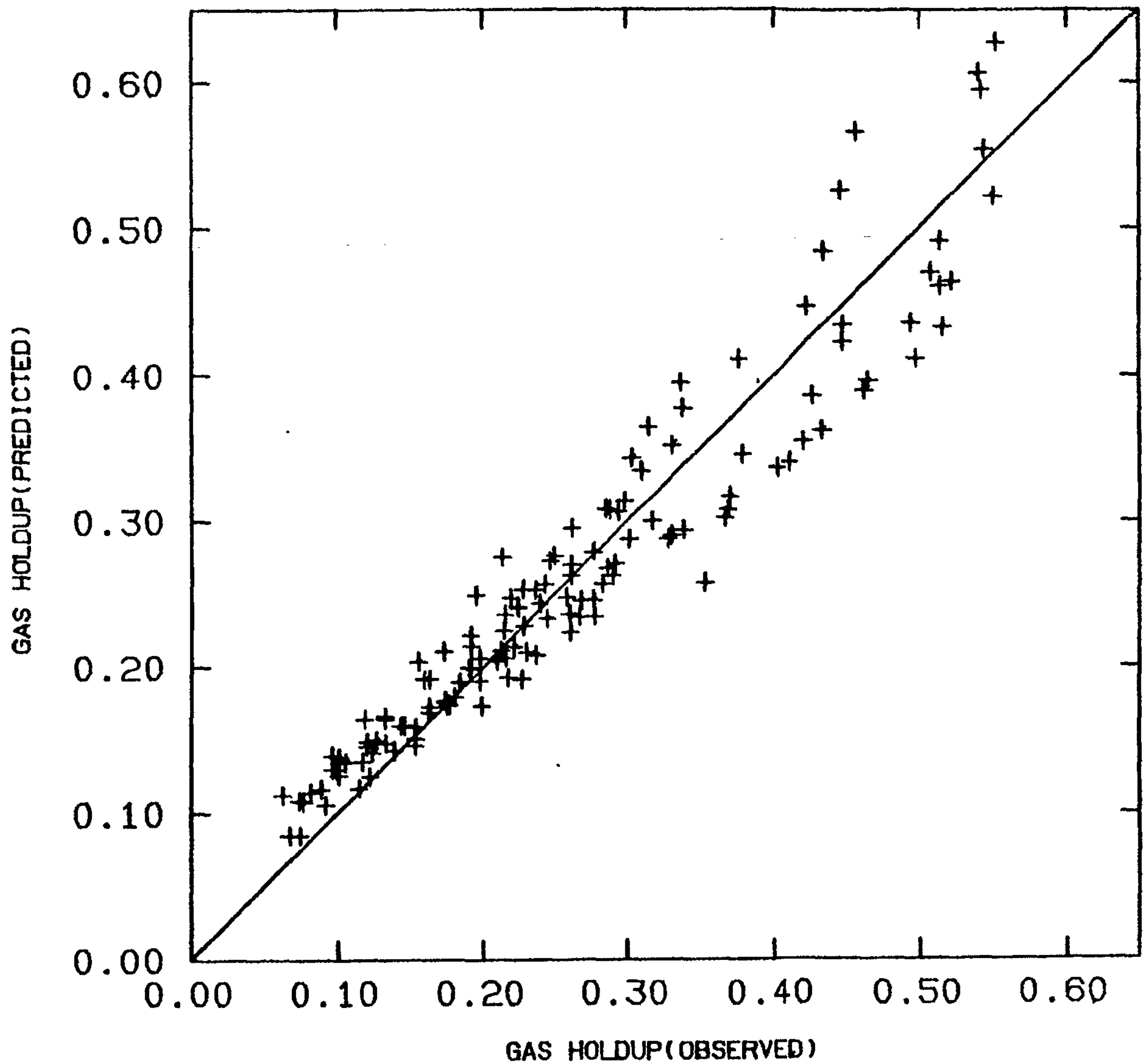


EG(PRED.) VS. EG(OBS.) FOR ALCHOHOL-WATER WITH 3 PARAMETERS.

FIGURE 2.20

20%. The dynamic gas disengagement method confirms the flow regime charts and gives additional information about the fraction of large and small bubbles.

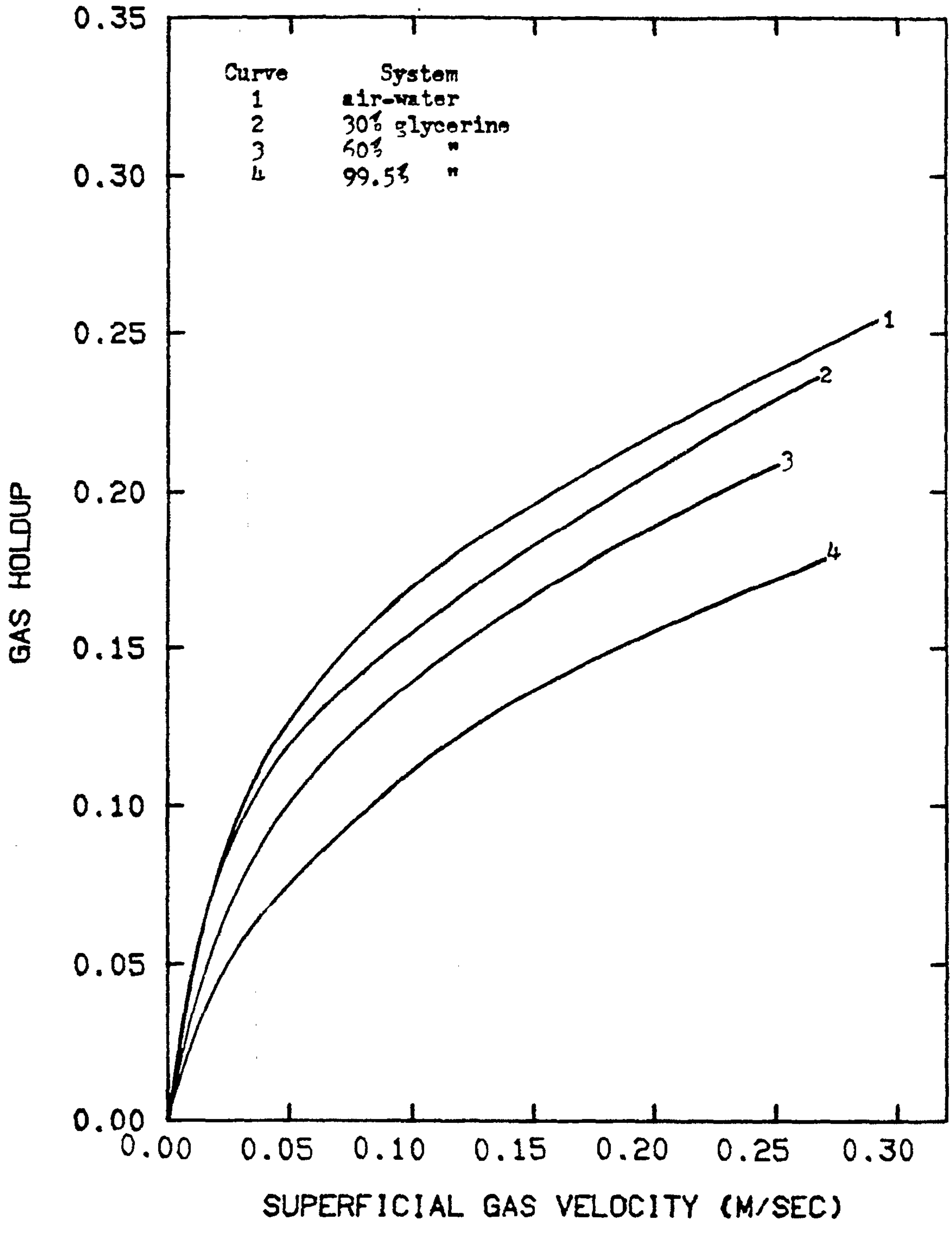
2.4.2 Effect of Viscosity

The effect of viscosity on the hydrodynamics of the bubble column is studied in two separate phases.

2.4.2.1 Newtonian Liquids

For glycerine solutions with a viscosity ranging from 0.246 kg/m·sec to 0.0017 kg/m·sec, the gas holdup increases with gas velocity as shown in Figure 2.21. Gas holdups for these solutions are compared with the widely used existing correlations in Tables A.2.9 to A.2.20. The correlations of Hughmark,[(2.14)] Deckwer[(2.15)] and Kumar[(2.16)] all predict higher gas holdup than the experimental values; the deviations become worse as the viscosity increases. Hughmark[(2.14)] and Kumar[(2.16)] have based their correlations on glycerol data and Deckwer's correlation is for non-Newtonian solutions. The theoretical correlation developed by Mersmann[(2.13)] and correlations developed by Akita and Yoshida[(2.1)] and Hikita et al.[(2.2)] all show a good fit over the entire range of viscosity and gas velocity.

As shown in Figure 2.22 the gas holdup exhibits a maximum with respect to liquid viscosity at 0.003 kg/m·sec. The maximum gas holdup is less than that for air-water; the position of the maximum is independent of the gas velocity. Bach and Pilhofer,[(2.3)] Buchholz et al.,[(2.17)] and Eissa et al.[(2.18)] have studied glycerine solutions in 0.15 m diameter columns and have observed a similar maximum in gas holdup with respect to liuqid viscosity. In the present work, fast rising large bubbles,



EG VS VG COMPARISON PLOT FOR GLYCERINE-WATER SOLUTIONS

Figure 2.21

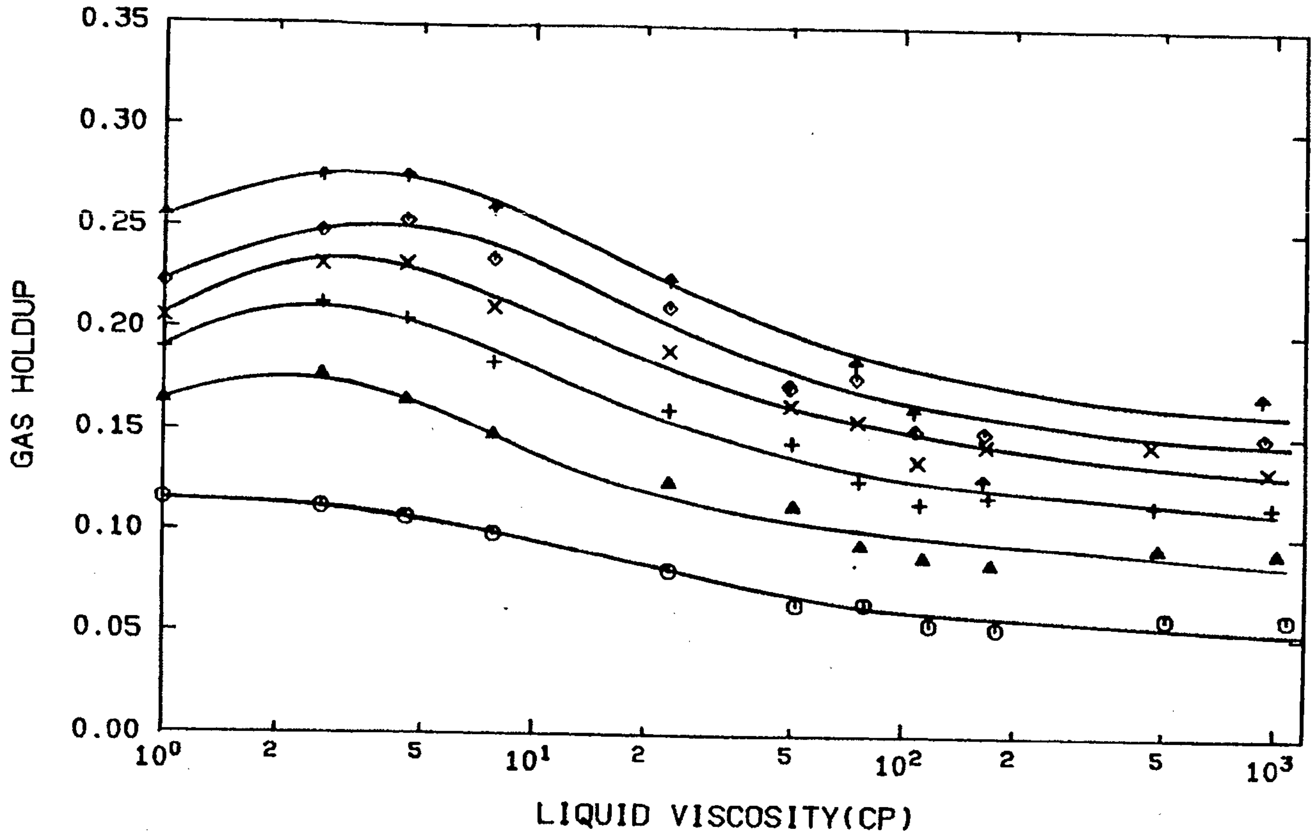


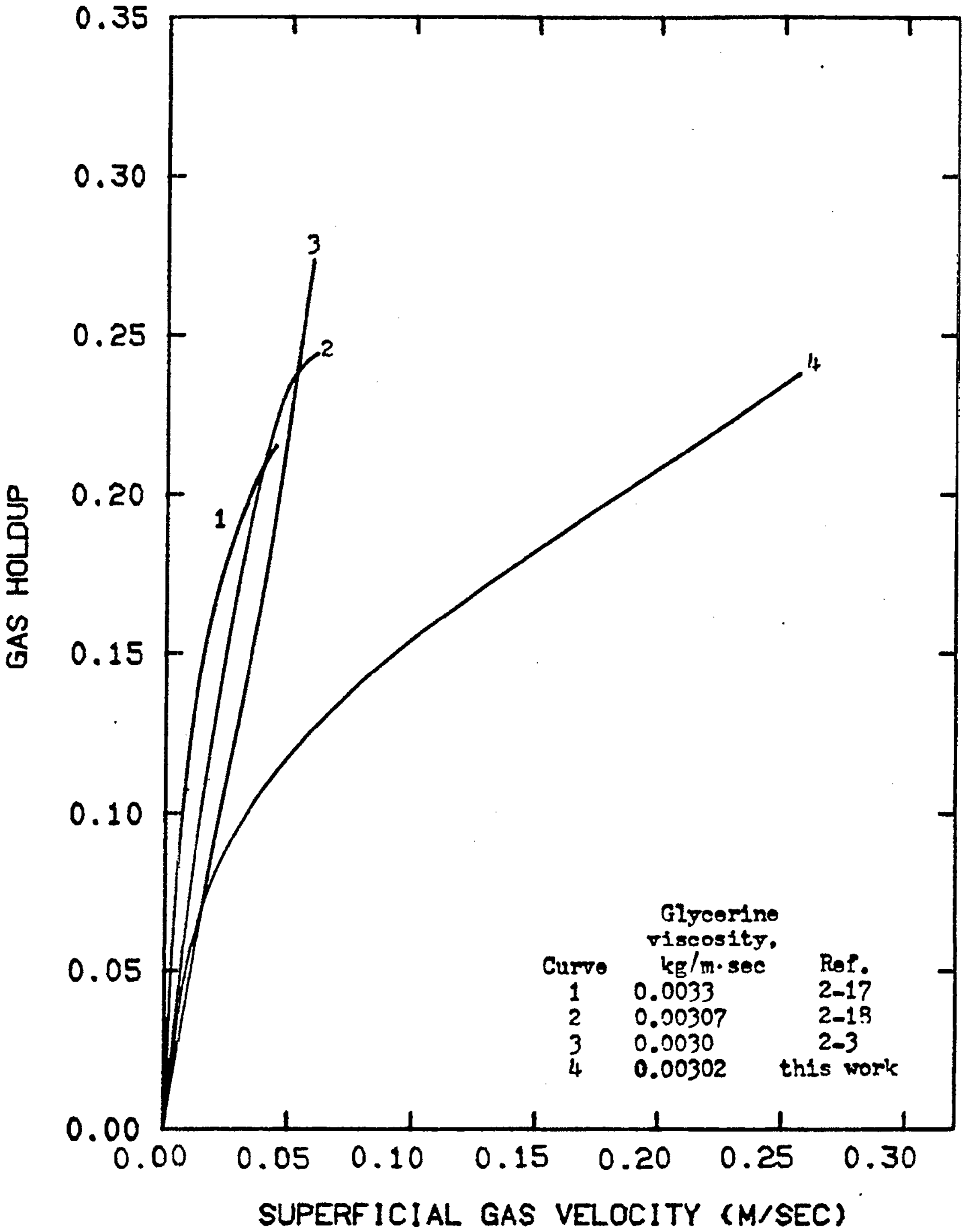
FIGURE 2.22: GAS HOLDUP VS. LIQUID VISCOSITY FOR CMC-WATER.

v_G

- ⊙ 0.045 m/s
- ▲ 0.90 m/s
- + 1.35 m/s
- × 1.8 m/s
- ◇ 2.25 m/s
- ✦ 2.75 m/s

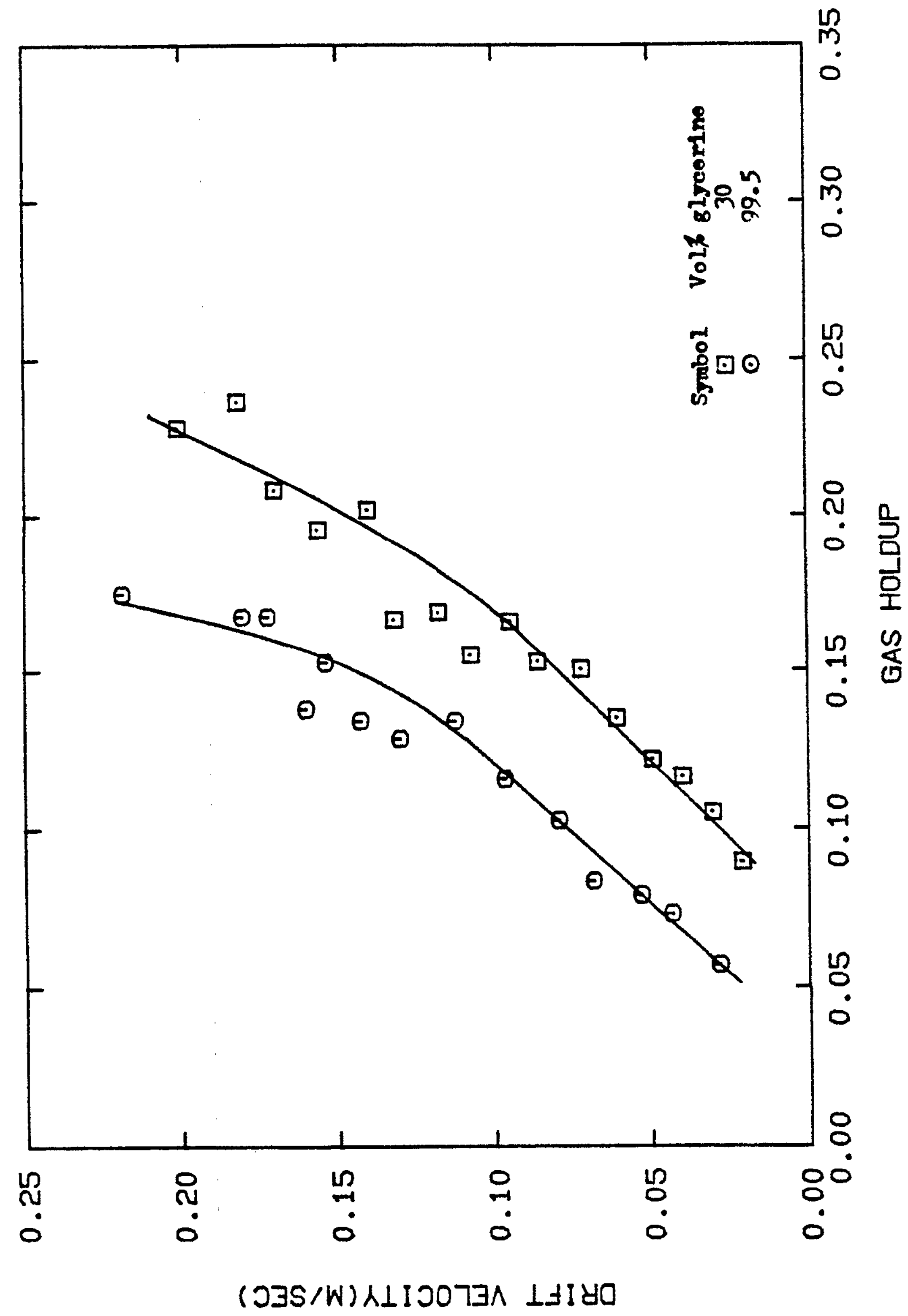
rather than slugs, are observed, still a similar behavior is observed. Figure 2.23 shows the data of Buchholz et al.,[2.17] Bach and Pilhofer,[2.3] and Eissa et al.,[2.18] compared with the present data. For a liquid viscosity of 0.003 kg/m·sec where all the gas holdup data showed a maximum, the comparison shows that the gas holdup obtained in present work is always lower than the previously reported data. The data obtained by Eissa et al.[2.18] and Bach and Pilhofer[2.3] is only up to a gas velocity of 0.06 m/sec; that of Buchholz et al.[2.17] is up to 0.043 m/sec. Upon visual observation the bubbles seemed to be large and irregularly shaped even at a velocity as low as 0.03 m/sec. To analyze the fast rising bubbles, flow regime charts, bubble rise velocity vs. V_G graphs and dynamic disengagement data are used.

Figure 2.24 shows a graph of drift flux against gas holdup for 99.5 and 30% glycerine. For all the concentrations of glycerine greater than 70% (except for 90%), i.e. at a viscosity greater than 0.0020 kg/m·s a point of inflection is present for a gas holdup of 15-20%. It occurs earlier as the liquid viscosity increases and corresponds to a gas velocity of about 0.20 m/sec. Though slugs are never observed for high viscosity solutions, at very high gas velocities the bubbles grow to a size of as much as 0.20 m near the interface. The point of inflection might be an indication of the formation of these very large bubbles. At low viscosities the transition can be taking place from the bubbly flow regime to the churn tuburlent regime but the point of sharp change in slope at higher velocities is absent in these cases. Figure 2.25 shows a graph of V_M against V_G for 99.5 and 30% glycerine. At low gas velocities all the glycerine concentrations show VM increasing linearly with V_G and the curve flattens out at high gas velocities. In the case of high



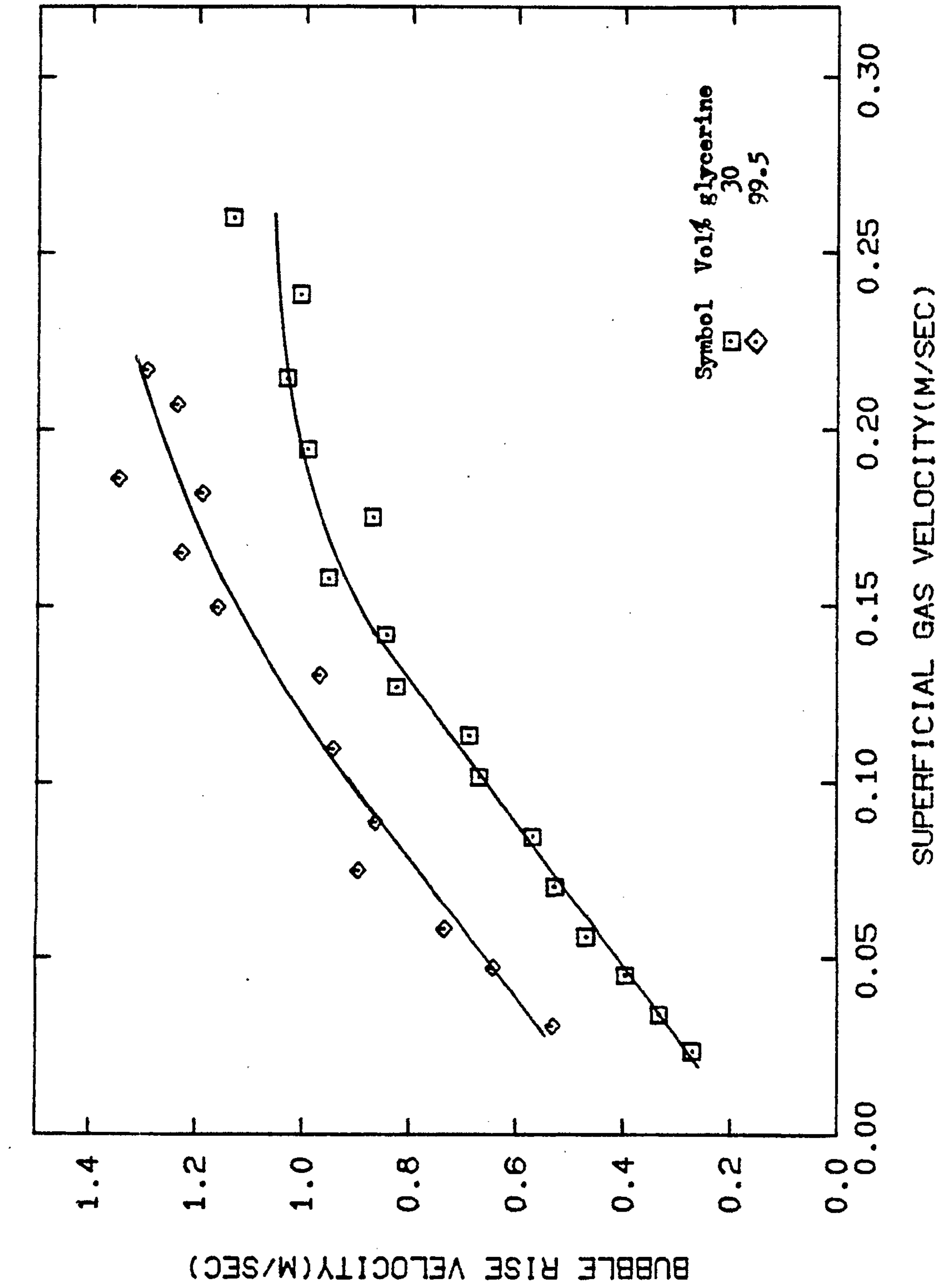
EG VS VG COMPARISON WITH LITERATURE

Figure 2.23



DRIFT FLUX VS GAS HOLDUP FOR GLYCERINE-WATER

Figure 2.24



VM VS. VG FOR GLYCERINE-WATER.

Figure 2.25

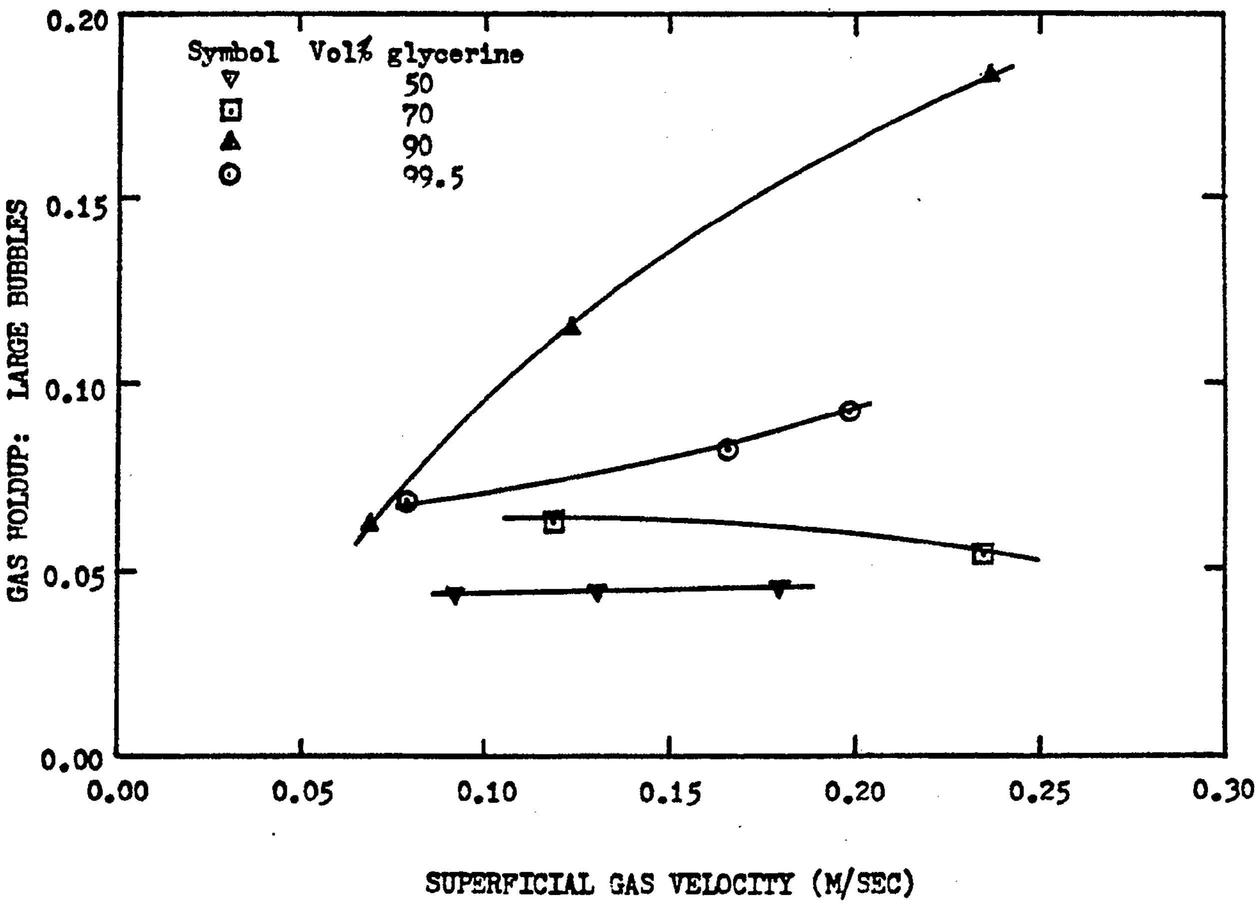
viscosity solutions, the initial flat portion constitutes a small fraction of total curve. For glycerine solutions with large bubbles, the bubble rise velocities are as high as 138 m/sec as seen from Figure 2.25.

Fractional holdup of large bubbles as a function of gas velocity and viscosity is shown in Figure 2.26. Figure 2.27 shows bubble rise velocity as a function of gas velocity as determined by the dynamic gas disengagement method. $\varepsilon_G(t)$ against time data can be fitted with a single straight line suggesting the presence of only one sized bubbles. For 99.5 and 90% glycerine, the calculated bubble rise velocity shows a minimum with respect to V_G at V_G 0.15 m/s. A flattening of the curve is observed in the V_M against V_G graph, and a sharp break is observed in the drift flux graph in this region of gas velocity. This minimum might be an indication at a transition from churn turbulent flow to the flow of large slug-like bubbles.

For 50 and 70% glycerine two classes of bubbles are present at all gas velocities. The rise velocity of the small bubbles is fairly constant, but that of the large bubbles shows a minimum for the 50% solution. Also the rise velocity seems to increase with an increase in viscosity as expected. The minimum in rise velocity for the large bubbles of 50% glycerine concentration is again due to the transition to large bubbles. The disengagement data for glycerine is summarized in Table 2.8.

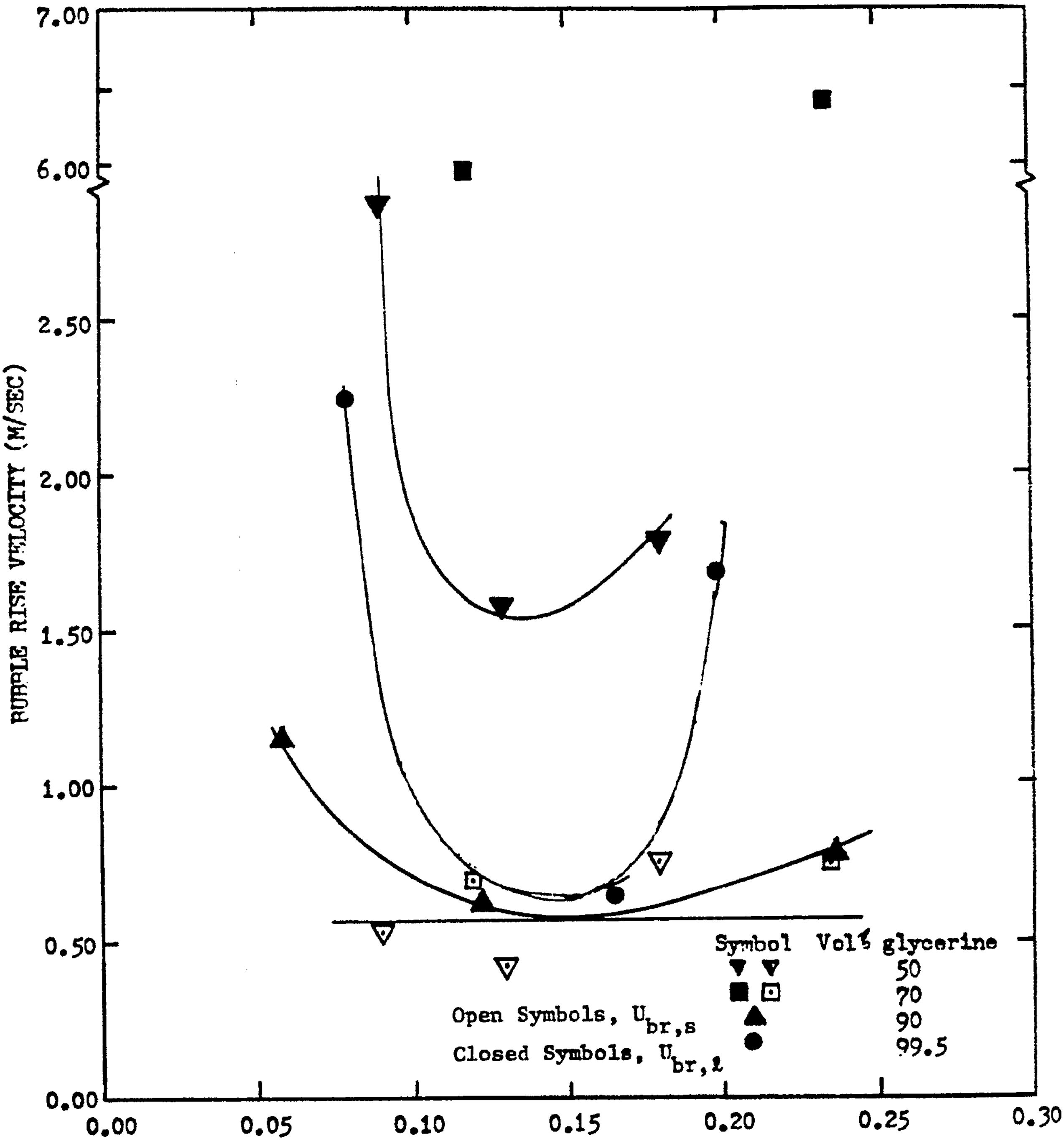
The gas holdup data from the glycerine runs is correlated as a function of gas velocity and liquid viscosity. The following correlation fits the data with an overall percent error of 6.8%.

$$\varepsilon_G = 0.329\ (V_G)^{0.47}\ (\mu)^{-0.045} \qquad (2.4.3)$$



EG,L VS VG FOR GLYCERINE-WATER

Figure 2.26



SUPERFICIAL GAS VELOCITY (M/SEC)

UBR VS VG FOR GLYCERINE-WATER

Figure 2.27

TABLE 2.8

DYNAMIC GAS DISENGAGEMENT RESULTS FOR GLYCERINE SOLUTIONS

	99.5%			90%			70%		50%		
V_G m/sec	0.078	0.164	0.197	0.059	0.122	0.236	0.118	0.234	0.091	0.129	0.179
$\varepsilon_G(O)$	0.069	0.132	0.142	0.064	0.115	0.183	0.125	0.189	0.099	0.143	0.145
$\varepsilon_{G,s}$	0.069	0.132	0.142	0.064	0.115	0.183	0.062	0.135	0.056	0.099	0.099
$\varepsilon_{G,\ell}$							0.063	0.054	0.043	0.044	0.046
$U_{br,s}$ m/sec	2.253	0.656	1.683	1.160	0.615	0.768	0.694	0.755	0.533	0.417	0.757
$U_{br,\ell}$ m/sec							5.945	6.405	2.875	1.576	1.772
$V_G/\varepsilon_G(O)$ m/sec	1.134	1.242	1.387	0.923	1.061	1.290	0.944	1.238	0.913	0.902	1.234

Since the power of the viscosity term is negligible, an empirical equation with ε_G as a function of V_G is fitted to yield an overall percent error of 9.8%.

$$\varepsilon_G = 0.399\ (V_G)^{0.473} \qquad (2.4.4)$$

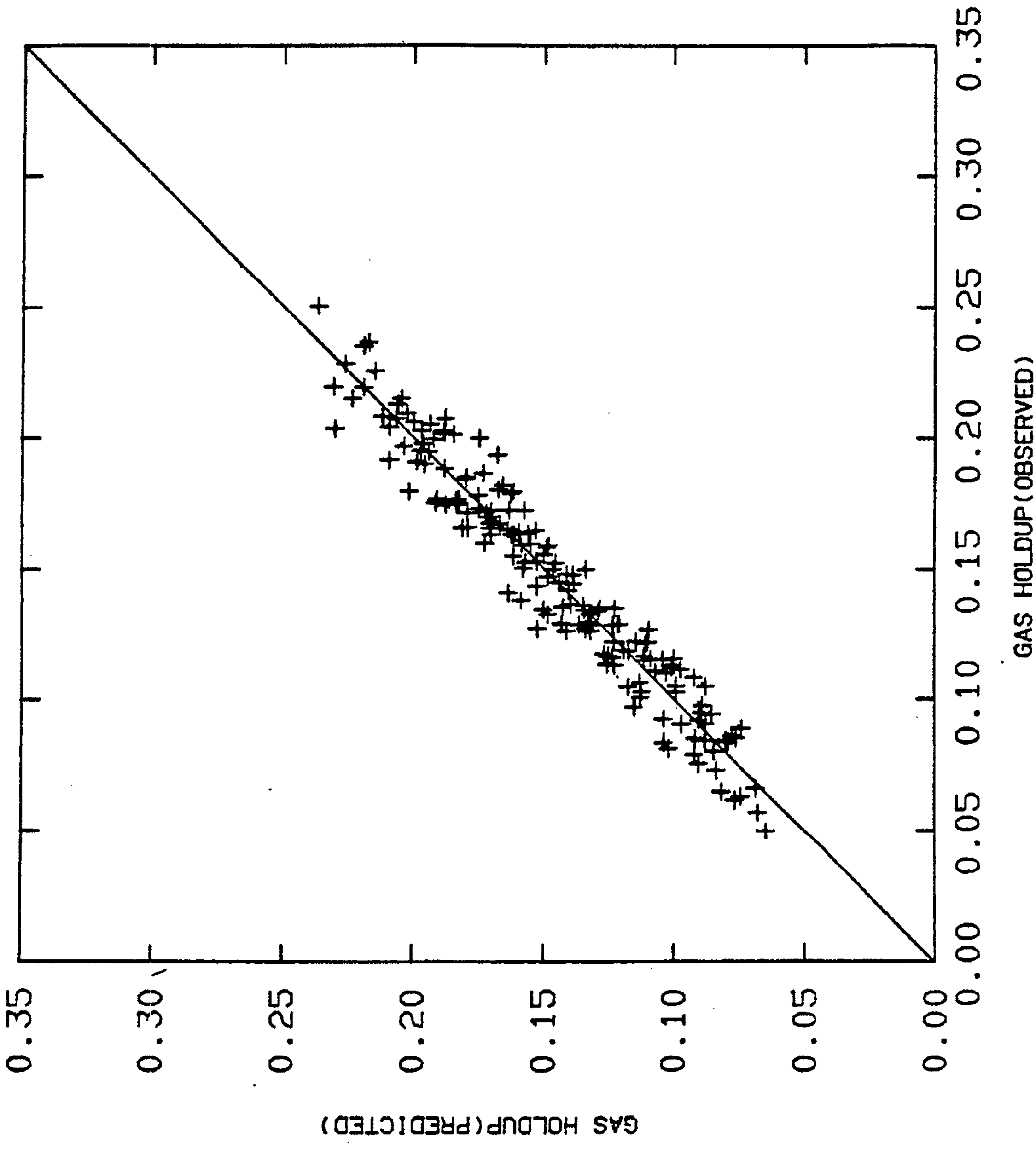
Figures 2.28 and 2.29 show the graphs of predicted vs. observed gas holdup with the use of the three-parameter and two-parameter equations. The power of the viscosity term is very low compared to the power predicted by Akita and Yoshida,(2.1) Hikita et al.(2.2) and Mersmann.(2.13) The reason can be that this equation also considers the maximum holdup shown by the low viscosity glycerine solution. Mersmann's(2.13) correlation usually predicts the gas holdup as good as the empirical correlation based on the present work for high velocity, at low gas velocities it predicts consistently low values.

2.4.2.2 Non-Newtonian Liquids

Carboxy methyl cellulose solutions are used to study the effect of viscosity on the hydrodynamics of non-Newtonian systems. As explained in Section 1.3, the rheological properties of these solutions are dependent on the mixing technique used to prepare the solution from 7H4 CMC Gum (Manufactured by Hercules Inc.). The rheological properties are listed in Table 2.3. To calculate the apparent viscosity of the liquid in the column, the shear rate expression suggested by Nishikawa et al.(2.19) and the power law model are used. The apparent viscosity is given by

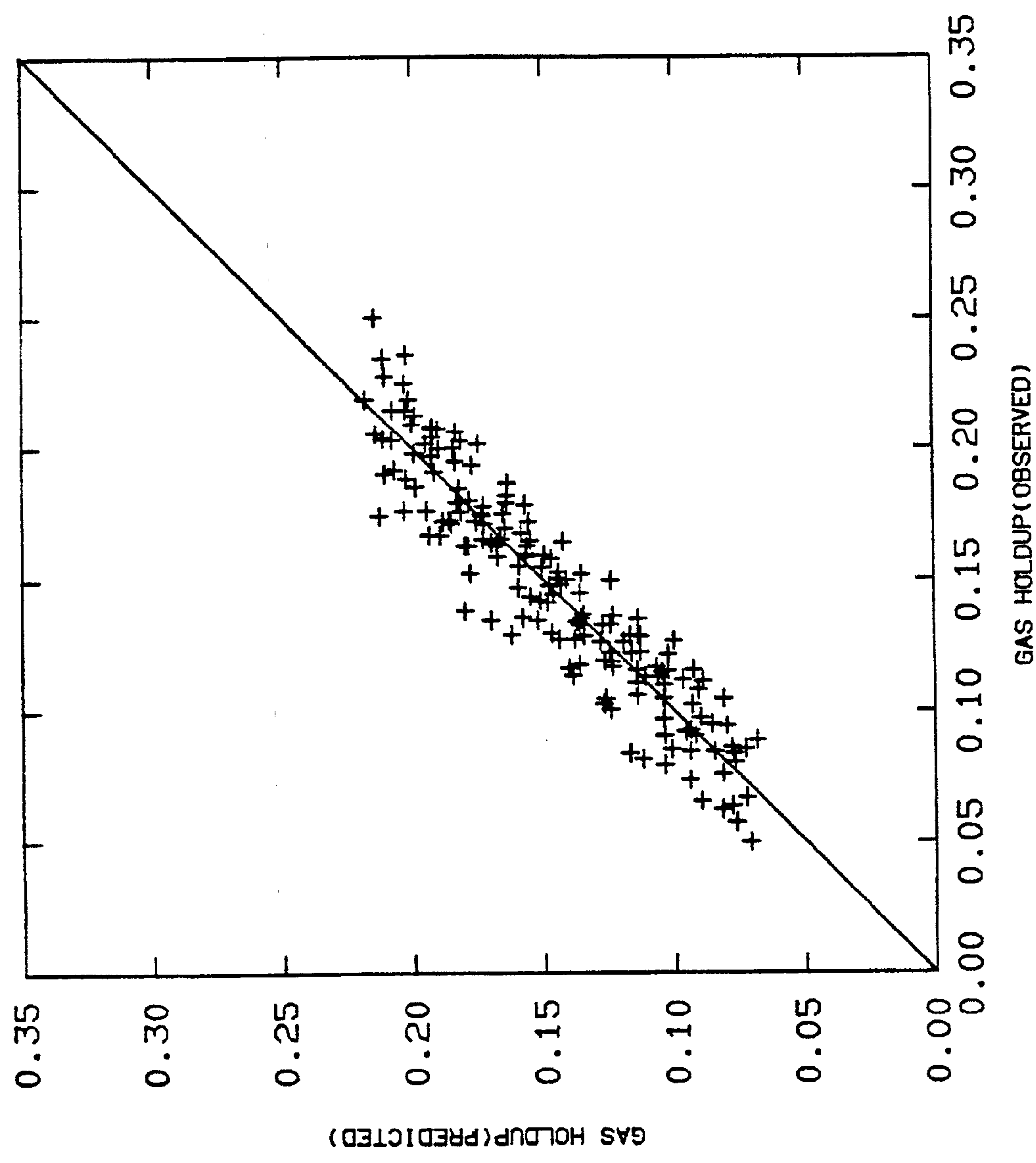
$$\mu = K\ (50\ V_G)^{n-1} \qquad (2.4.5)$$

where V_G is in cm/sec.



EG(PRED.) VS. EG(OBS.) FOR GLYCERINE-WATER WITH 3 PARAMETERS.

FIGURE 2.28

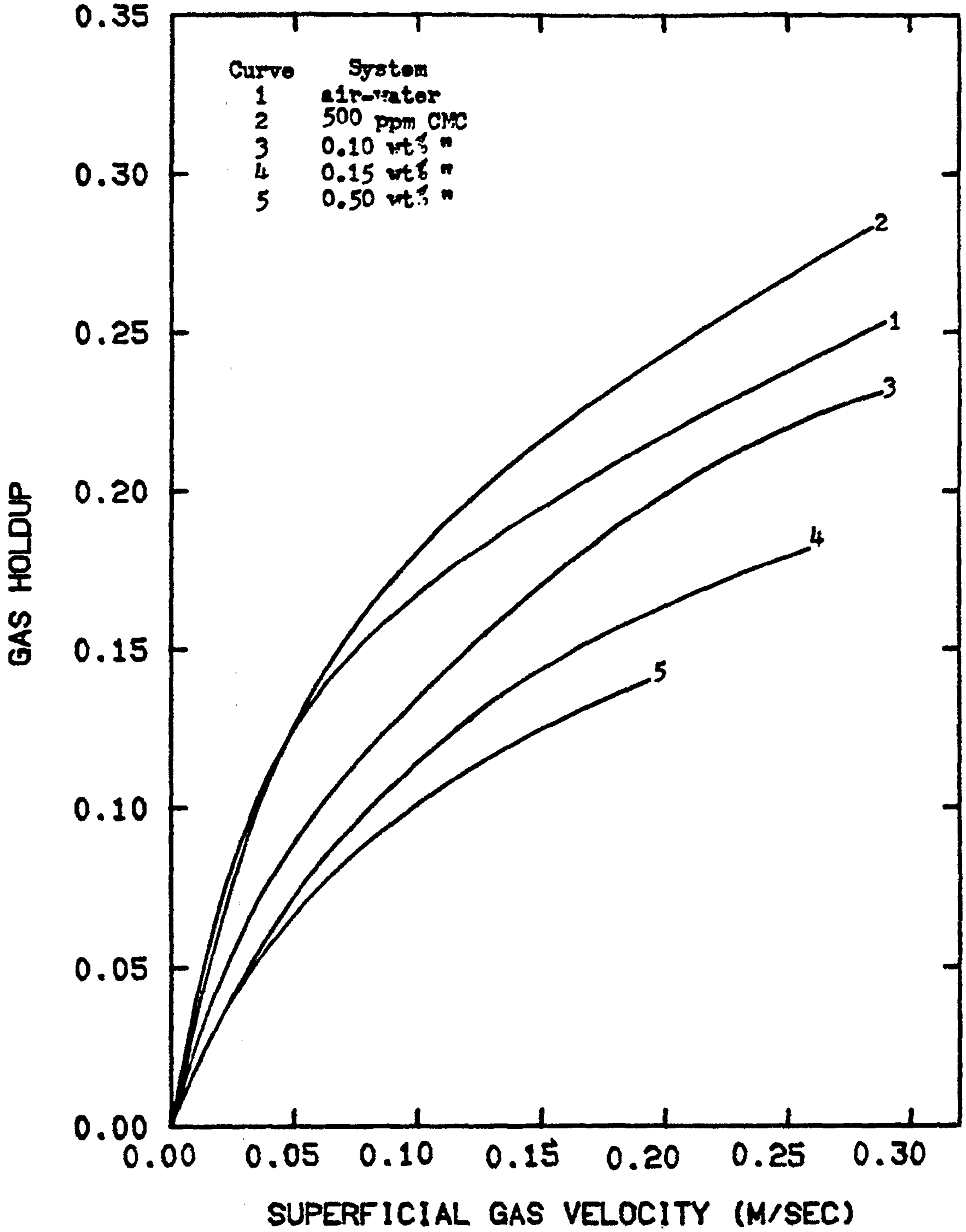


EG(PRED.) VS. EG(OBS.) FOR GLYCERINE-WATER WITH 2 PARAMETERS.

FIGURE 2.29

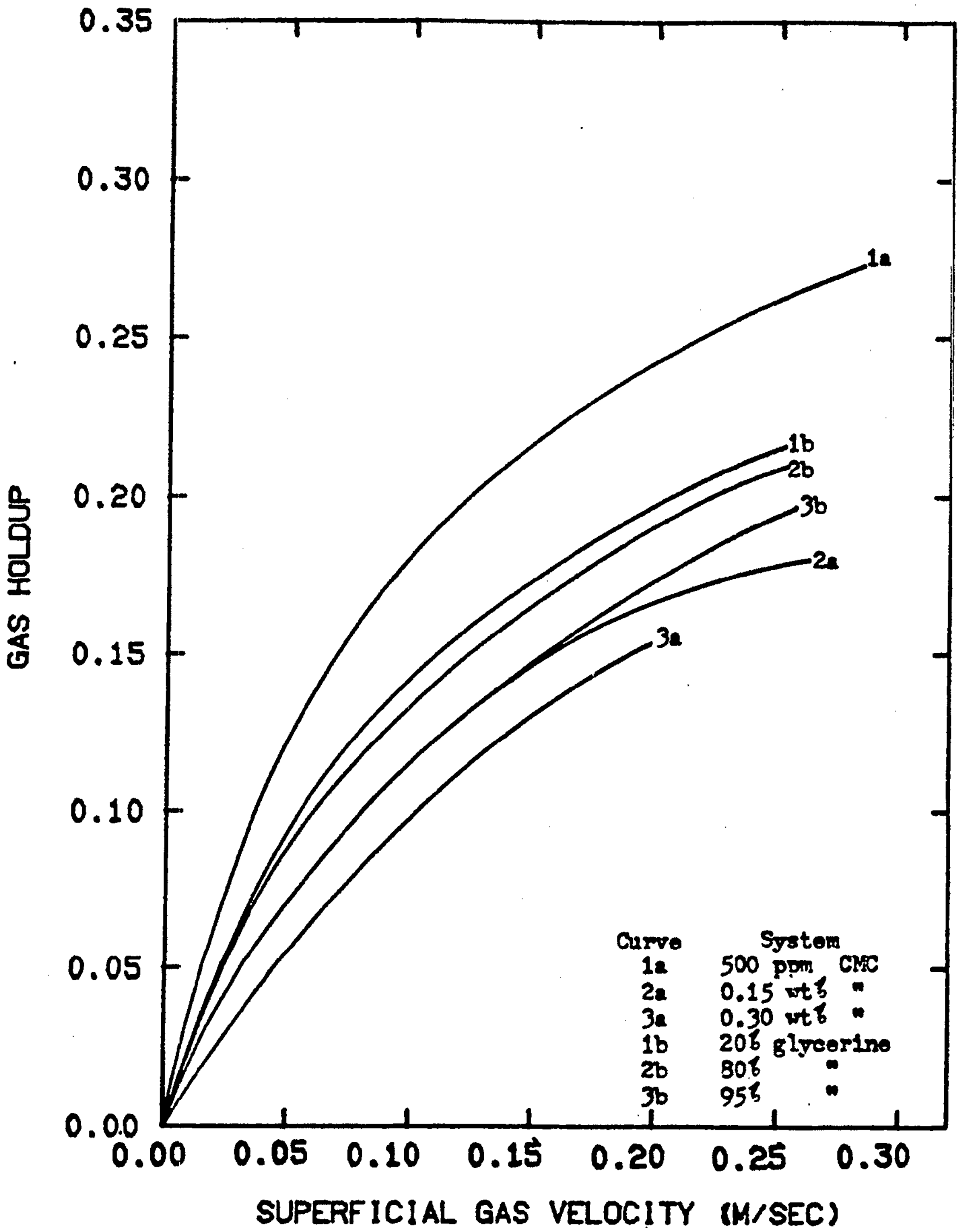
For CMC solutions with a viscosity range of 1.60 to 0.0017 kg/m·sec the gas holdup increases with the gas velocity as shown in Figure 2.30. Tables A.2.21 to A.2.30 include a comparison of experimental gas holdup with some of the widely used correlations. The correlations of Kumar,[(2.16)] Hughmark[(2.14)] and Deckwer[(2.15)] consistently predict much higher gas holdup. Though Deckwer's correlation is specifically developed for pseudoplastic CMC solutions, it predicts very high values after a velocity of 0.06 m/sec. For solutions up to a viscosity of 0.00781 kg/m·sec the correlations of Akita and Yoshida,[(2.1)] Hikita et al.[(2.2)] and Mersmann[(2.13)] fit well. In high viscosity solutions, Akita and Yoshida/s[(2.1)] and Mersmann's[(2.13)] correlations predict low values and Hikita et al.[(2.2)] predicts higher values. Figure 2.31 compares the gas holdup obtained for CMC solutions with glycerine solutions of viscosities around 0.0022, 0.141 and 0.05 kg/m·sec. The gas holdup in the non-Newtonian CMC solutions is less than that in glycerine solutions except at that viscosity for which glycerine solution shows a maximum. The gas holdup again shows a maximum with reference to liquid viscosity (Figure 2.32). Though at a low gas velcoity of 0.045 m/s no maximum is observed, at 0.090 m/sec and higher a maximum in gas holdup with respect to liquid viscosity is present and it shifts to right as velocity increases. In Figure 2.33, the gas holdup data of Buchholz et al.,[(2.17)] and Schumpe and Deckwer[(2.15)] for CMC solutions is shown for comparison. The correlation developed by Schumpe and Deckwer might be predicting very high values as it is based on gas holdup in highly pseudoplastic solutions.

Figure 2.34 shows a flow regime chart for 0.5 wt% and 500 ppm CMC. For 0.5 to 0.3 wt% CMC, no transition occurs in the range of gas velocities studied. For all the concentrations below 0.25 wt% a point of



EG VS VG COMPARISON PLOT FOR CMC-WATER SOLUTIONS

Figure 2.30



EG VS VG COMPARISON OF GLYCERINE AND CMC SOLUTIONS WITH SIMILAR VISCOSITIES

Figure 2.31

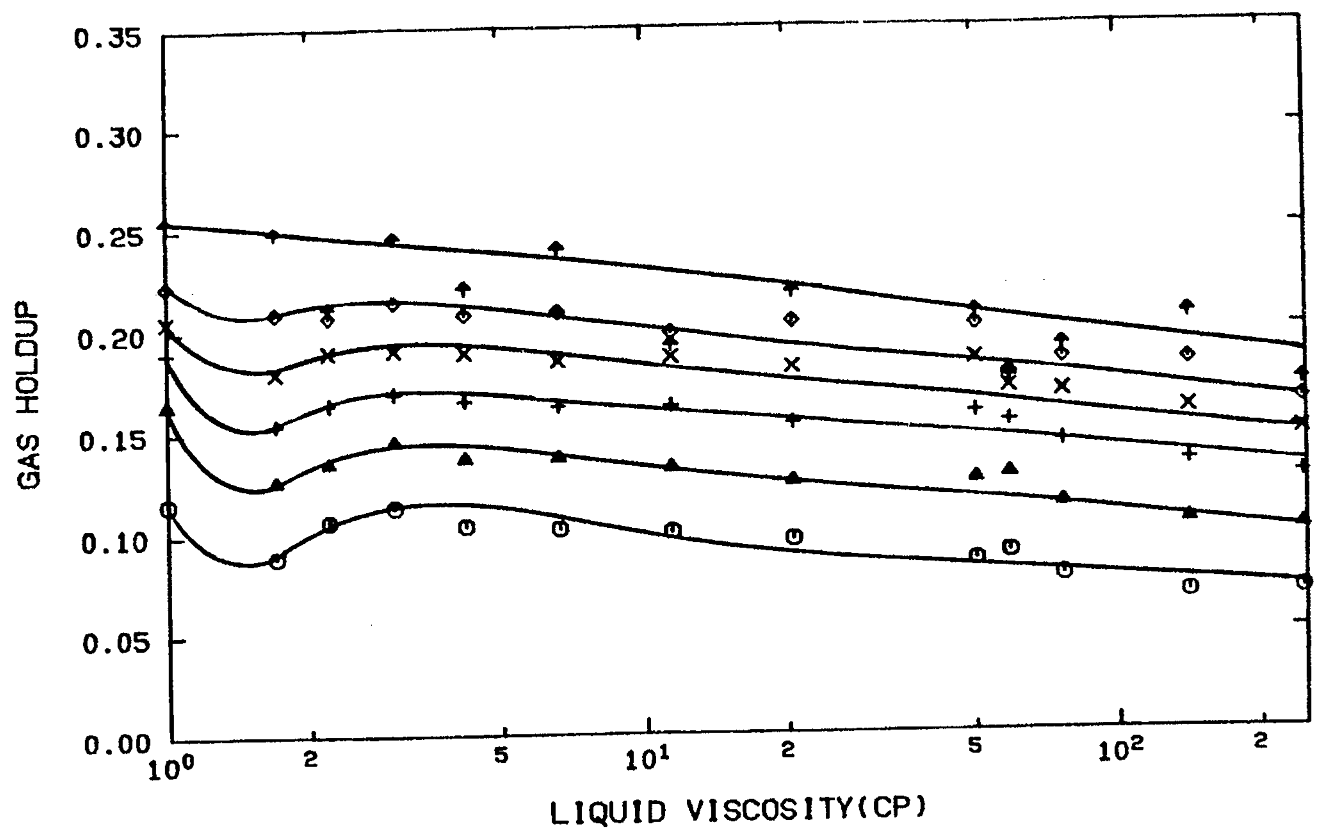
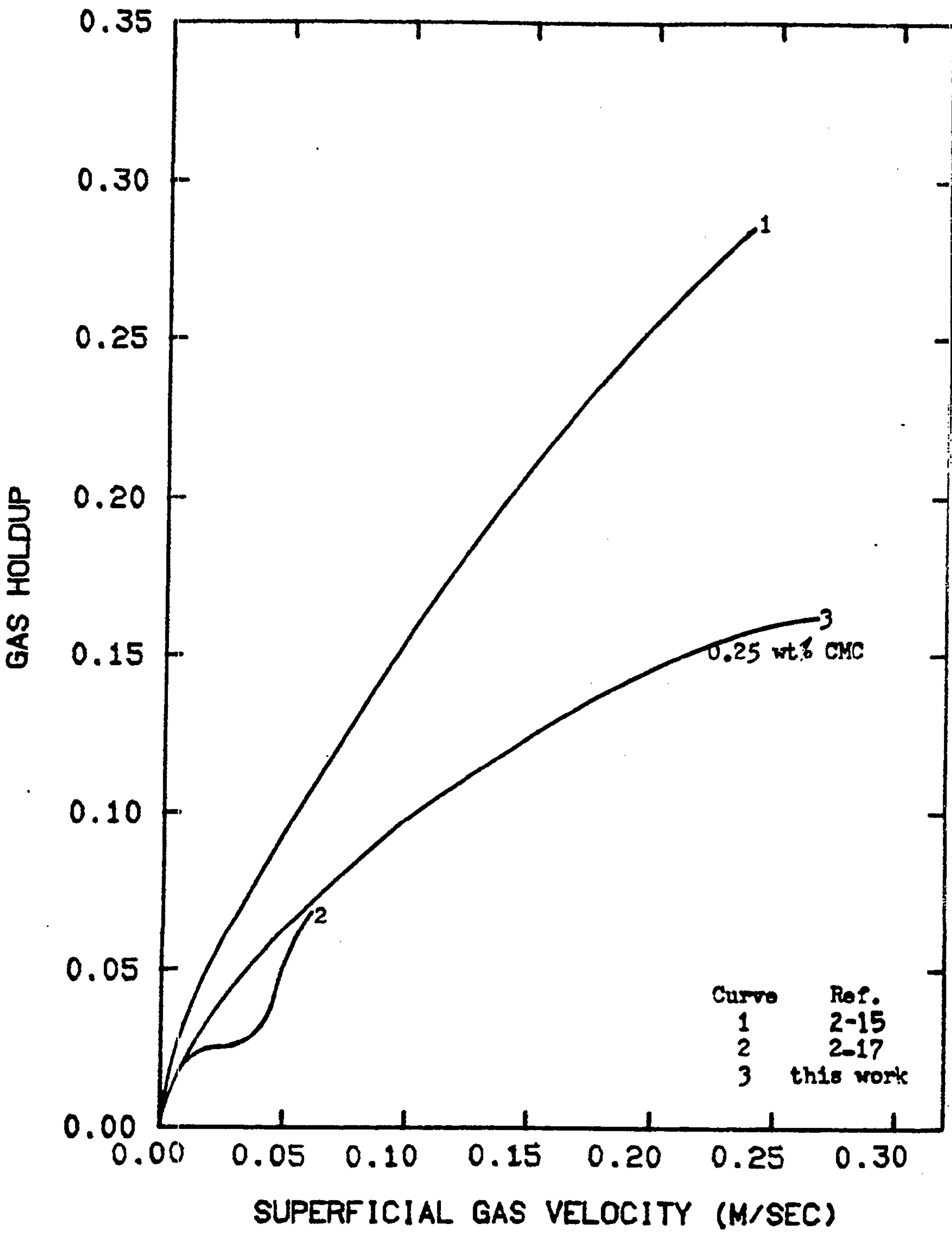


FIGURE 2.32: GAS HOLDUP VS. LIQUID VISCOSITY FOR GLYCERINE-WATER.

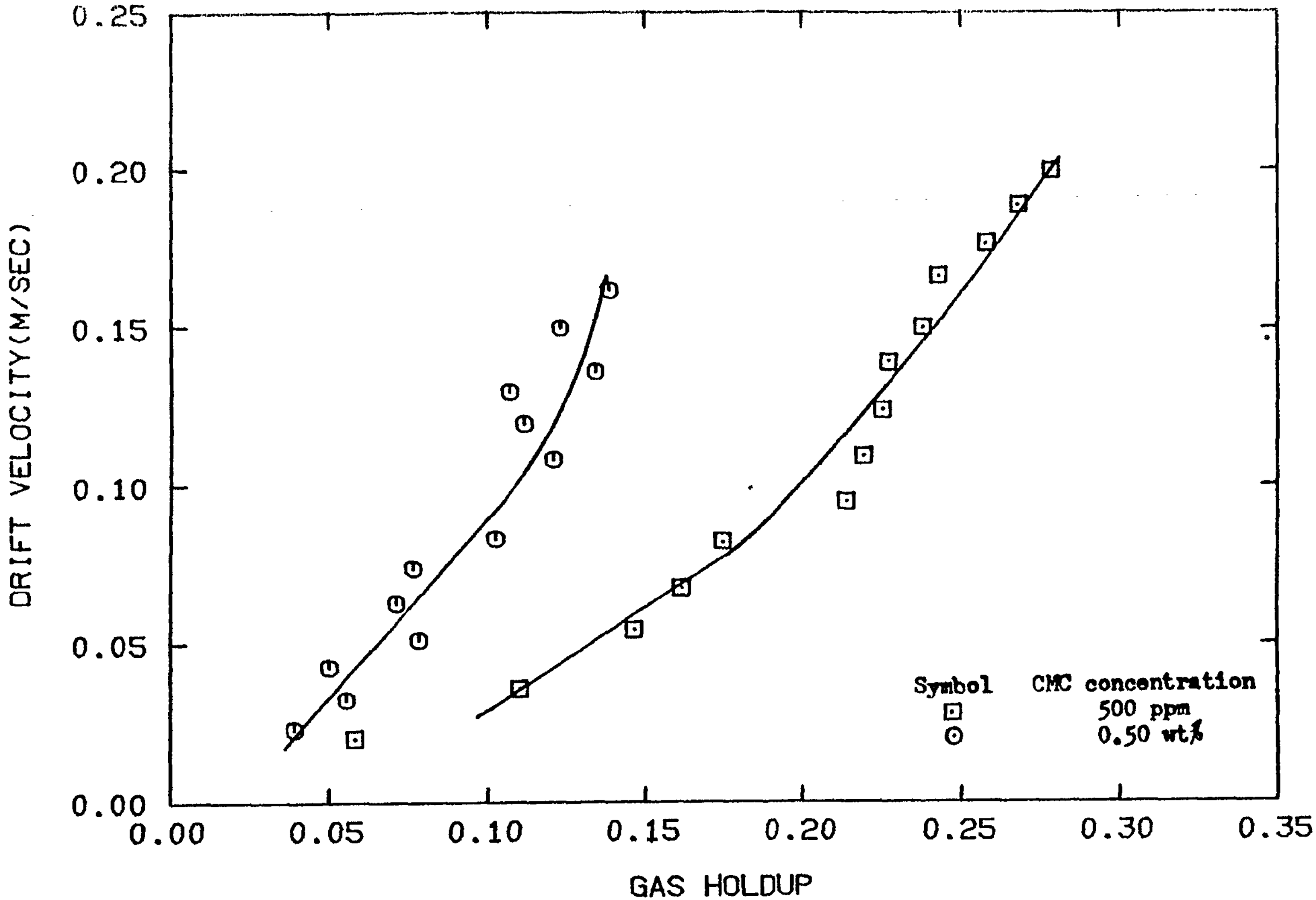
V_G

- ⊙ 0.045 m/s
- ▲ 0.90 m/s
- + 1.35 m/s
- × 1.8 m/s
- ◇ 2.25 m/s
- ♠ 2.75 m/s



EG VS VG COMPARISON WITH LITERATURE
DATA FOR SIMILAR VISCOSITY

Figure 2.33



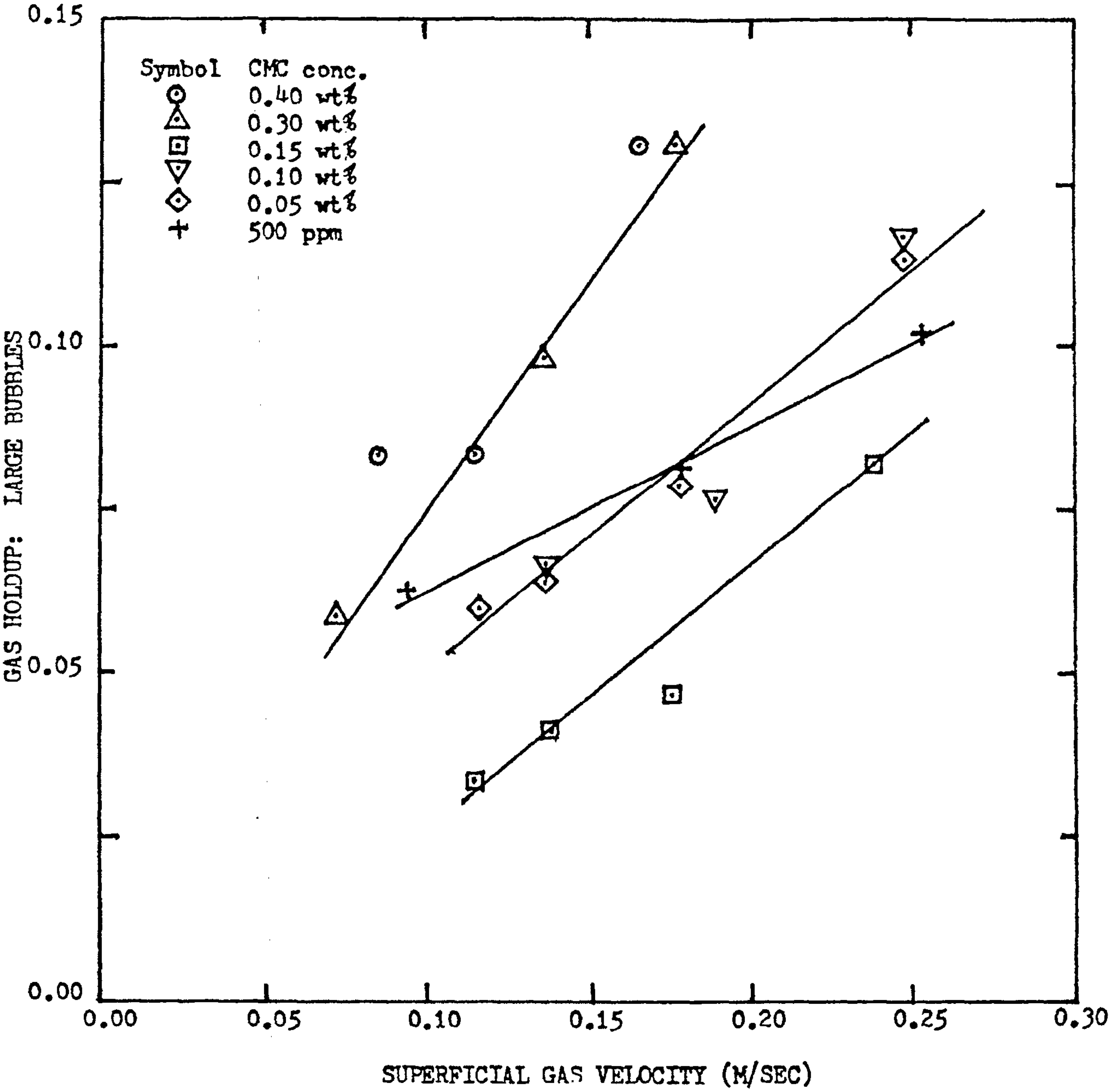
DRIFT FLUX VS GAS HOLDUP FOR CMC-WATER

Figure 2.34

inflection corresponding to a transition in flow regime is observed at holdups of 0.15 to 0.25. The gas holdup at the point of inflection increases as viscosity decreases. This break corresponds to a gas velocity of 0.15-0.20 m/sec. This behavior is similar to that observed for glycerine. From the study of dynamic gas disengagement, the presence of two sizes of bubbles is obserbed below a concentration at 0.15 wt%. Figure 2.35 shows a plot of holdup of large bubbles vs. gas velocity for all the concentrations analyzed. For 0.4 and 0.3 wt%, only large bubbles are present. Since $\varepsilon_{G,s}$ levels off faster than ε_G does, the ratio of $\varepsilon_{G,s}/\varepsilon_G$ passes through a maximum, which for concentrations of 0.15 to 0.05 wt% occurs between 0.15 to 0.20 m/sec. This also corresponds to the point of inflection on the drift flux graph. $\varepsilon_{G,\ell}$ increases with the gas velocity. Table 2.9 shows the summary of dynamic disengagement data for CMC solutions.

Figure 2.36 shows a plot of V_G/ε_G against V_G for 0.5 wt% CMC and 500 ppm CMC. All the concentrations show a linear relationship between V_M and V_G with the intercept increasing with increasing CMC concentration. For the higher concentrations, the lines are identical. If this intercept is an indication of bubble rise velocity of a single bubble then it shows that for all CMC concentrations above 0.25 wt%, the bubble size is the same.

Figure 2.37 shows bubble rise velocities as determined by dynamic gas disengagement method plotted against V_G. The bubble rise velocity of small bubbles is independent of V_G and increases with an increase in



EG,L VS VG FOR CMC-WATER

Figure 2.35

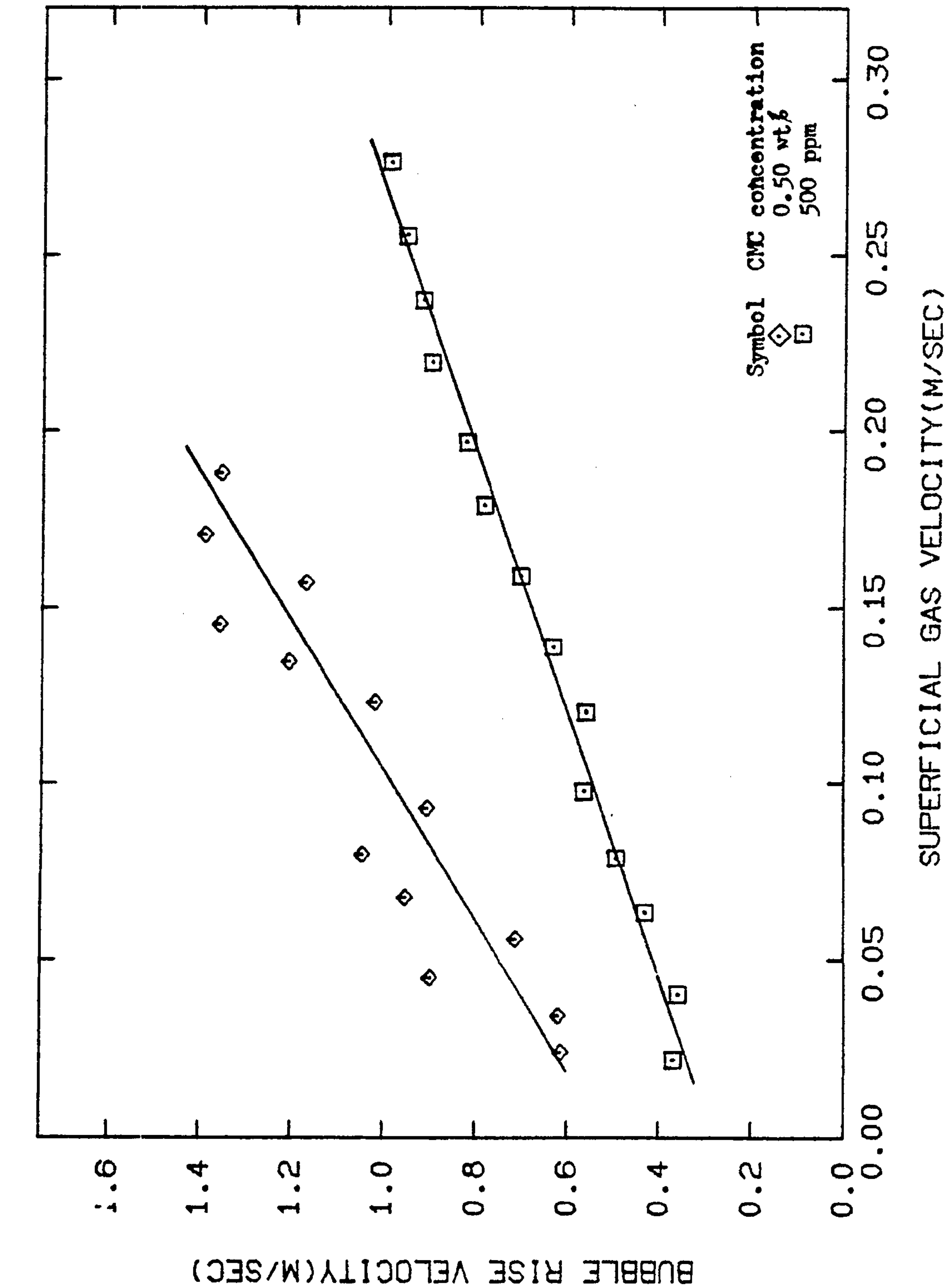
TABLE 2.9

DYNAMIC GAS DISENGAGEMENT RESULTS FOR CMC SOLUTIONS

	0.40 wt%			0.30 wt%			0.15 wt%			
V_G m/sec	0.084	0.116	0.165	0.072	0.136	0.176	0.114	0.138	0.176	0.238
$\varepsilon_G(0)$	0.083	0.083	0.131	0.058	0.098	0.131	0.102	0.136	0.162	0.203
$\varepsilon_{G,s}$	0.083	0.083	0.131	0.058	0.098	0.131	0.069	0.095	0.115	0.121
$\varepsilon_{G,\ell}$							0.033	0.041	0.047	0.082
$U_{br,s}$ m/sec	1.968	1.330	1.270	1.341	0.911	0.823	0.998	0.579	0.911	0.475
$U_{br,\ell}$ m/sec							2.739	2.970	2.998	1.469
$V_G/\varepsilon_G(0)$ m/sec	1.012	1.393	1.260	1.226	1.382	1.344	1.118	1.015	1.086	1.172

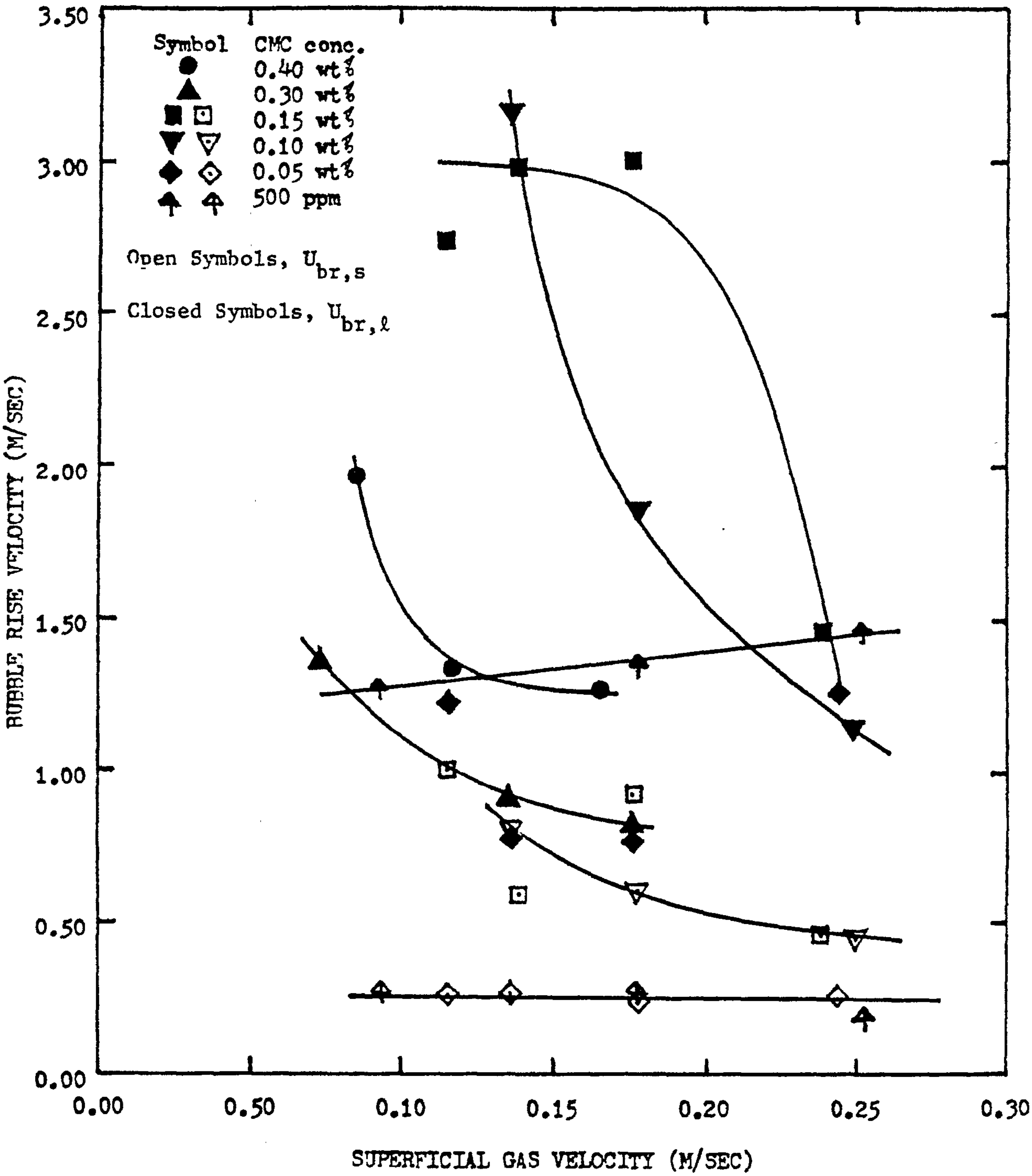
TABLE 2.9
(Continued)

	0.10 wt%				0.05 wt%				500 ppm		
V_G m/sec	0.118	0.136	0.178	0.248	0.115	0.136	0.178	0.243	0.094	0.178	0.252
$\varepsilon_G(0)$	0.120	0.125	0.176	0.218	0.165	0.182	0.222	0.282	0.191	0.268	0.301
$\varepsilon_{G,s}$	0.120	0.059	0.100	0.101	0.106	0.119	0.143	0.169	0.129	0.187	0.199
$\varepsilon_{G,\ell}$	0.120	0.066	0.076	0.117	0.059	0.063	0.079	0.113	0.062	0.081	0.102
$U_{br,s}$ m/sec	0.912	0.786	0.602	0.466	0.245	0.256	0.235	0.252	0.261	0.256	0.198
$U_{br,\ell}$ m/sec	0.912	3.152	1.863	1.134	1.221	0.786	0.774	1.267	1.272	1.351	1.459
$V_G/\ _G(0)$ m/sec	0.983	1.088	1.011	1.138	0.697	0.747	0.802	0.862	0.490	0.664	0.837



VM VS. VG FOR CMC-WATER.

Figure 2.36



UBR VS VG FOR CMC-WATER

Figure 2.37

viscosity. For bubbles in highly viscous solutions, the bubble rise velocity decreases with an increase in V_G and levels off at high gas velocities. The initial large bubble rise velocity might be due to large bubbles formed as a result channeling and coalescence. As gas velocity increases less channeling occurs and, hence, comparatively small bubbles are formed.

When the holdup data for CMC are correlated with an empirical equation the following is found to fit the data with an average overall percent error of 10.3%

$$\varepsilon_G = 0.287\ V_G^{0.536}\ (\mu_{eff})^{-0.121} \qquad (2.4.6)$$

If we neglect the effect of viscosity, the resulting equation can predict gas holdup with an average percent error of 22.3%.

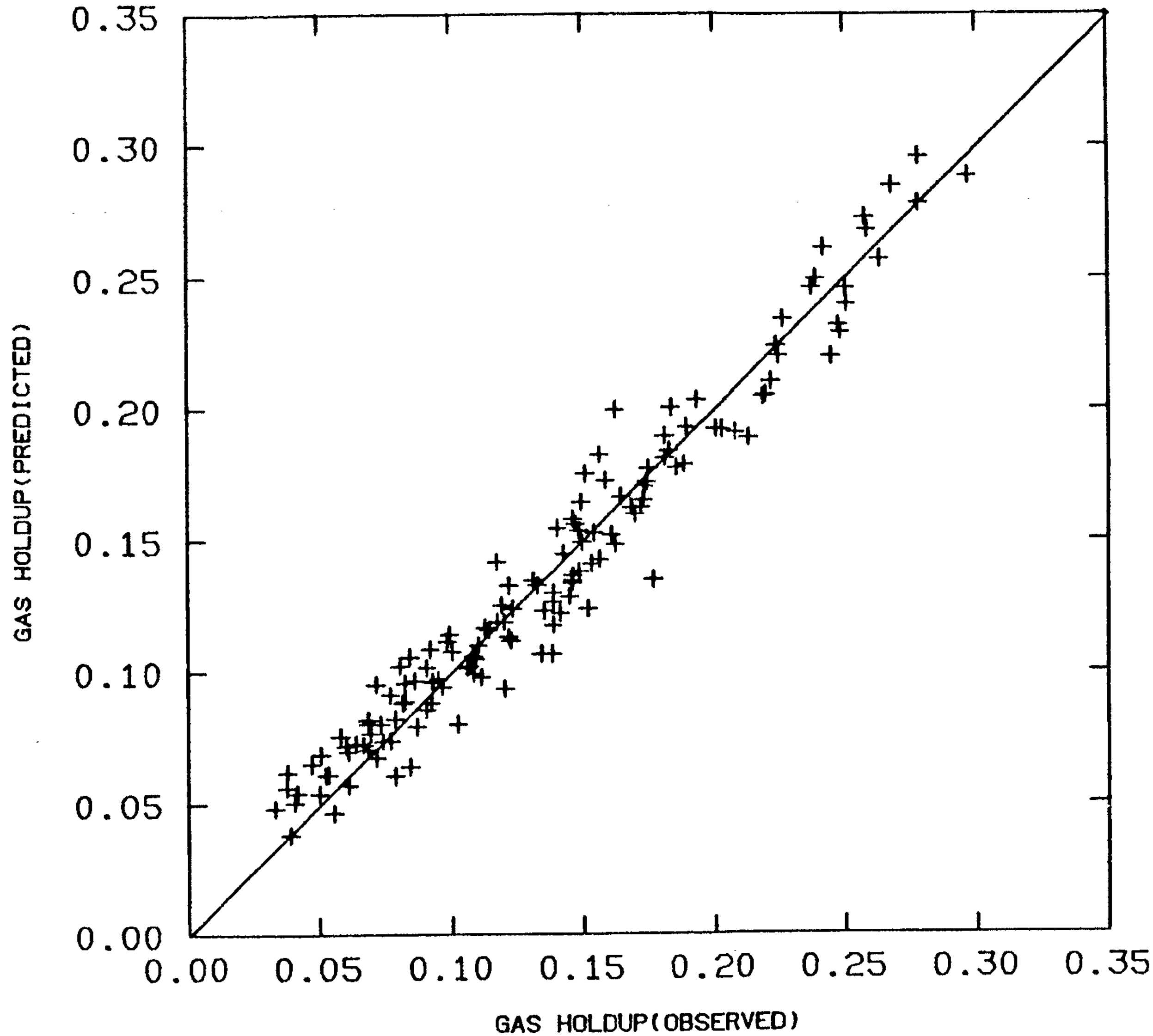
$$\varepsilon_G = 0.536\ V_G^{0.646} \qquad (2.4.7)$$

Figures 2.38 and 2.39 show the predicted vs. observed gas holdup for the above three- and two-parameter equations.

2.4.3 Effect of Solids

The effect of the addition of solids is studied by using air-water-coal and air-water-sand systems. The physical properties of the coal and sand particles are listed in Tables 2.5 and 2.6, respectively.

The addition of coal particles (average size = 33×10^{-6} m) causes a significant reduction in the gas holdup as compared to the air-water and, with increasing coal concentration, the gas holdup is decreased further. These effects can be seen in Figure 2.40.



GAS HOLDUP(PRED.) VS. GAS HOLDUP(OBS.) FOR CMC-WATER WITH 3 PARAMETERS

FIGURE 2.38

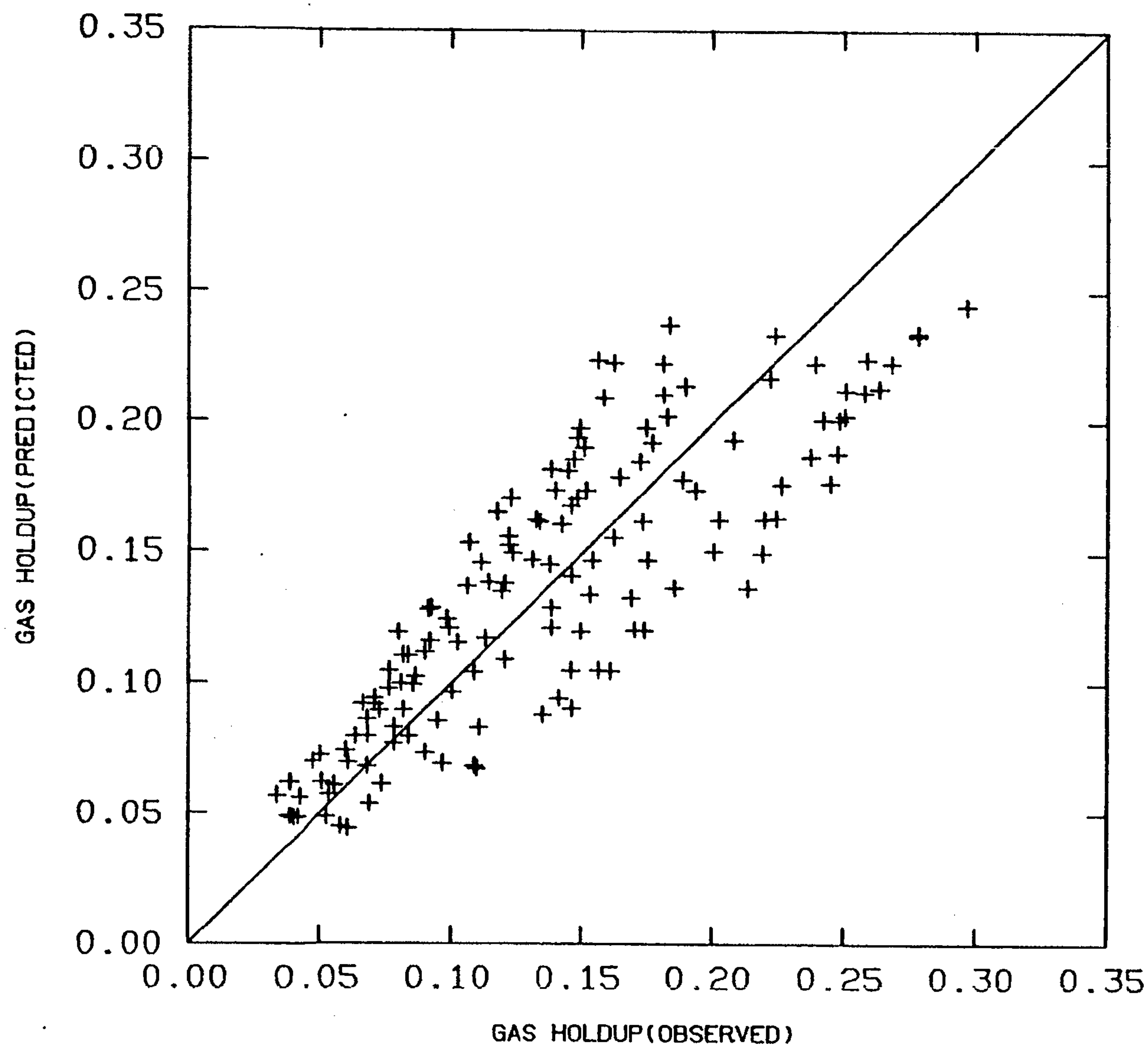
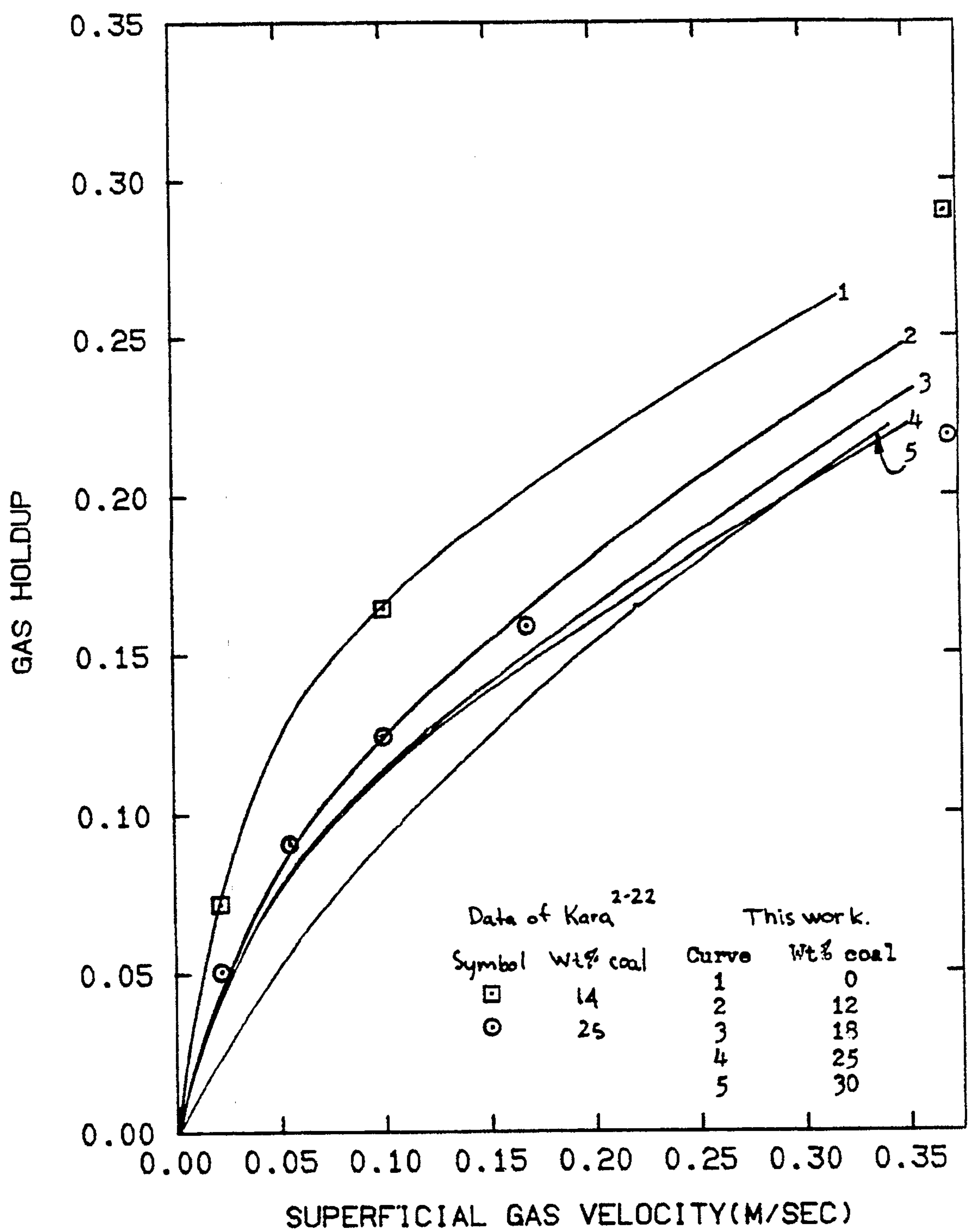


FIGURE 2.39: GAS HOLDUP(PRED.) VS. GAS HOLDUP(OBS.) FOR CMC-WATER WITH 2 PARAMETERS



GAS HOLDUP VS.SUPERFICIAL GAS VELOCITY FOR AIR-WATER-COAL.

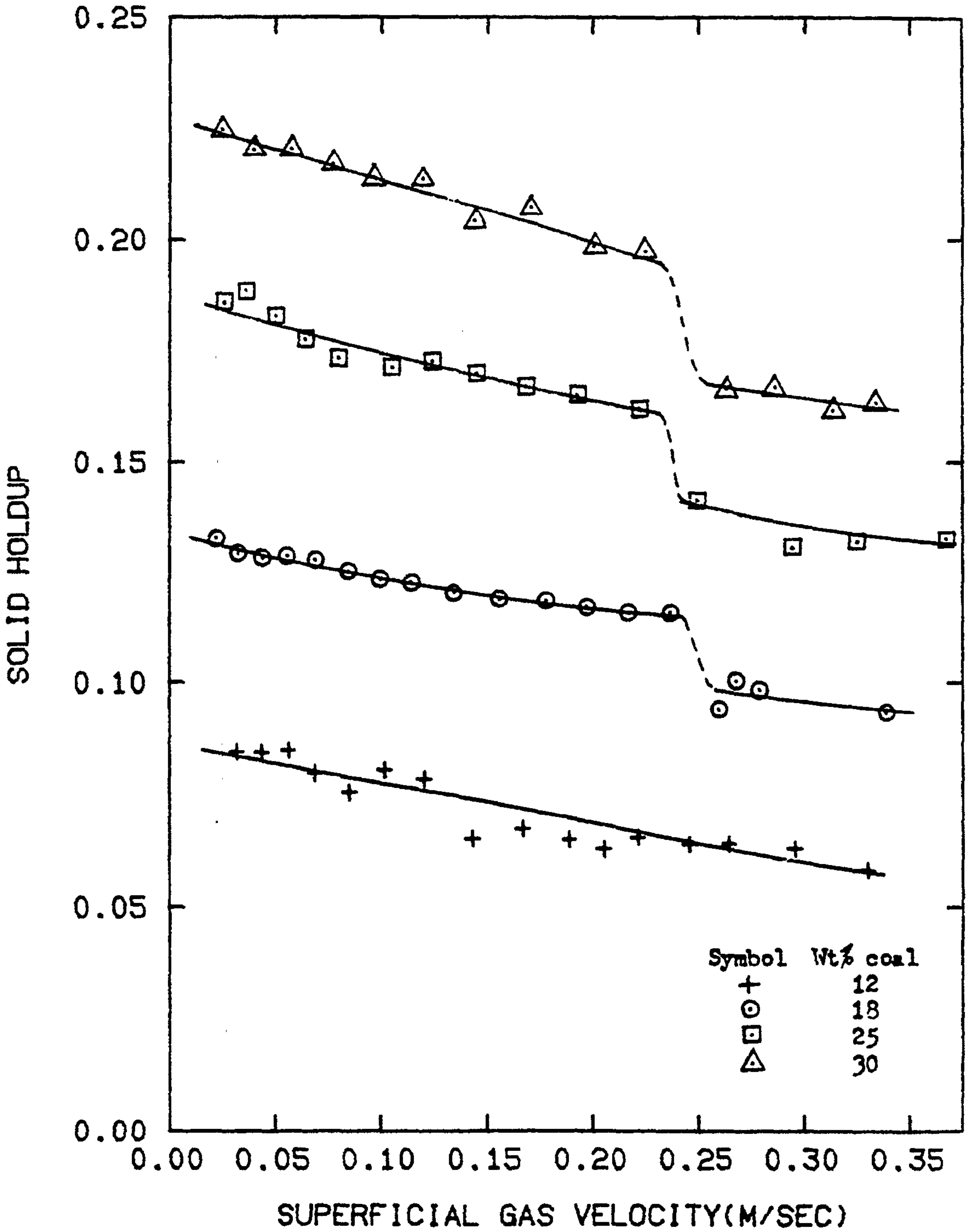
Figure 2.40

Solid holdup as a function of gas velocity and coal concentration is shown in Figure 2.41. The solid holdup is found to be independent of height indicating that the coal particles are completely suspended, even at a superficial gas velocity of 0.022 m/sec. As shown in the figure, the solid holdup decreases with an increase in gas velocity, with the rate of decrease being the same for all concentrations. However, at a gas velocity of 0.24 m/sec there is a sharp decrease in solid holdup for coal concentrations of 18, 25, and 30 wt%.

In Figure 2.42 liquid holdup is plotted as a function of gas velocity and coal concentration. As expected, ε_ℓ decreases with increasing coal concentration and gas velocity.

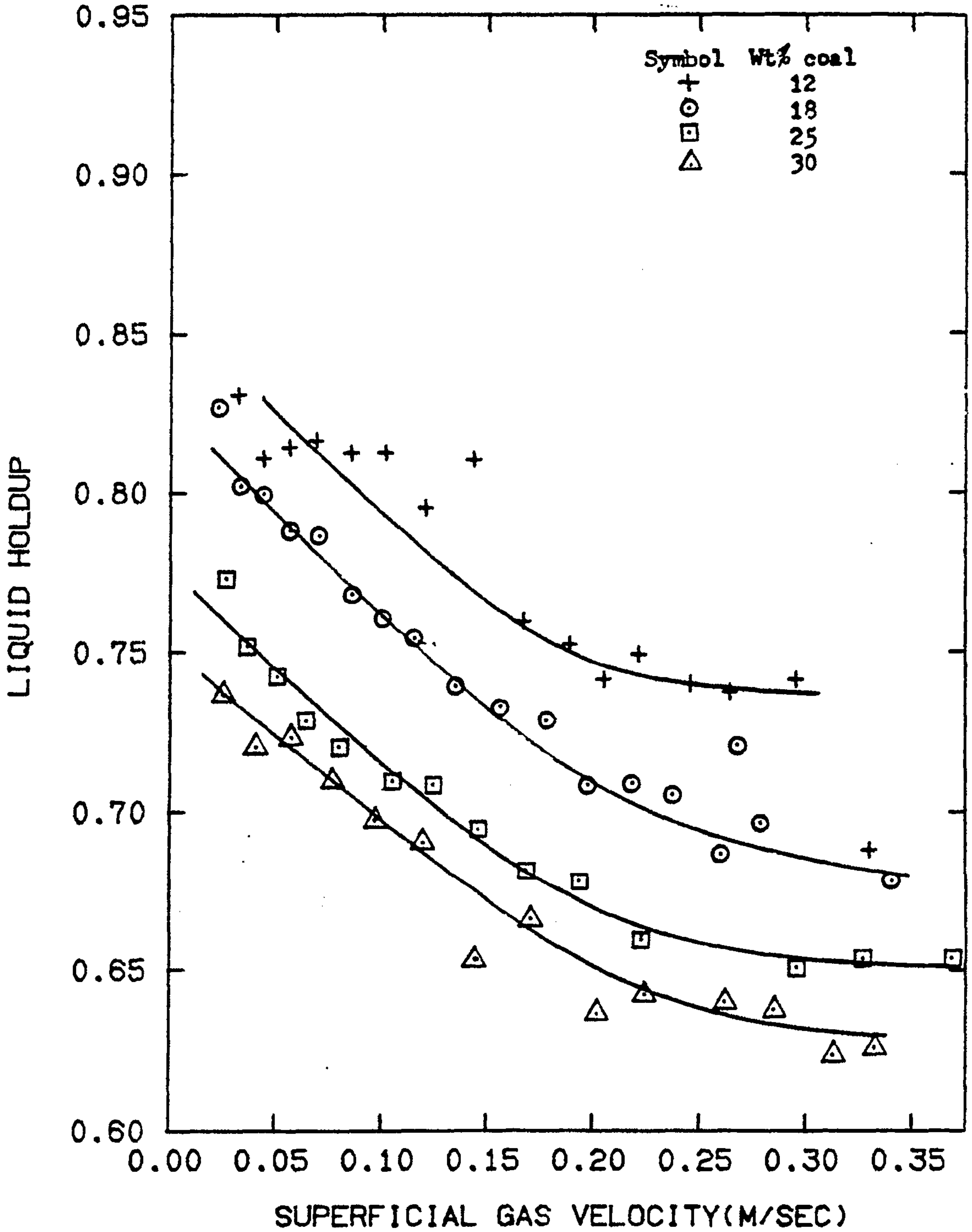
Gas holdup values are compared with two literature correlations in Tables A.2.39 to A.2.42 for the air-water-coal systems studied. The correlation of Begovich and Watson(2.20) predicts values which are at least 30% lower than the experimental holdups. The correlation proposed by Kito et al.(2.21) is somewhat better, predicting the gas holdup within an error of 20%. Kara(2.22) has performed experiments in an 0.152 m diameter bubble column using 30×10^{-6} m diameter coal particles. Her data for 14 and 25 wt% coal is shown in Figure 2.40 along with the present data. For both concentrations, this work shows lower gas holdup.

The addition of the denser sand particles results in gas holdup which decreases along the length of the column as shown in Figure 2.43. In contrast to the air-water-coal system, the gas holdup does not vary much from the air-water data. The effect of sand particle size for 10 wt% sand is shown in Figure 2.44. Gas holdup is seen to be relatively independent of particle size and, again, is not much different from the air-water system. Gas holdup is found to decrease slightly with increasing



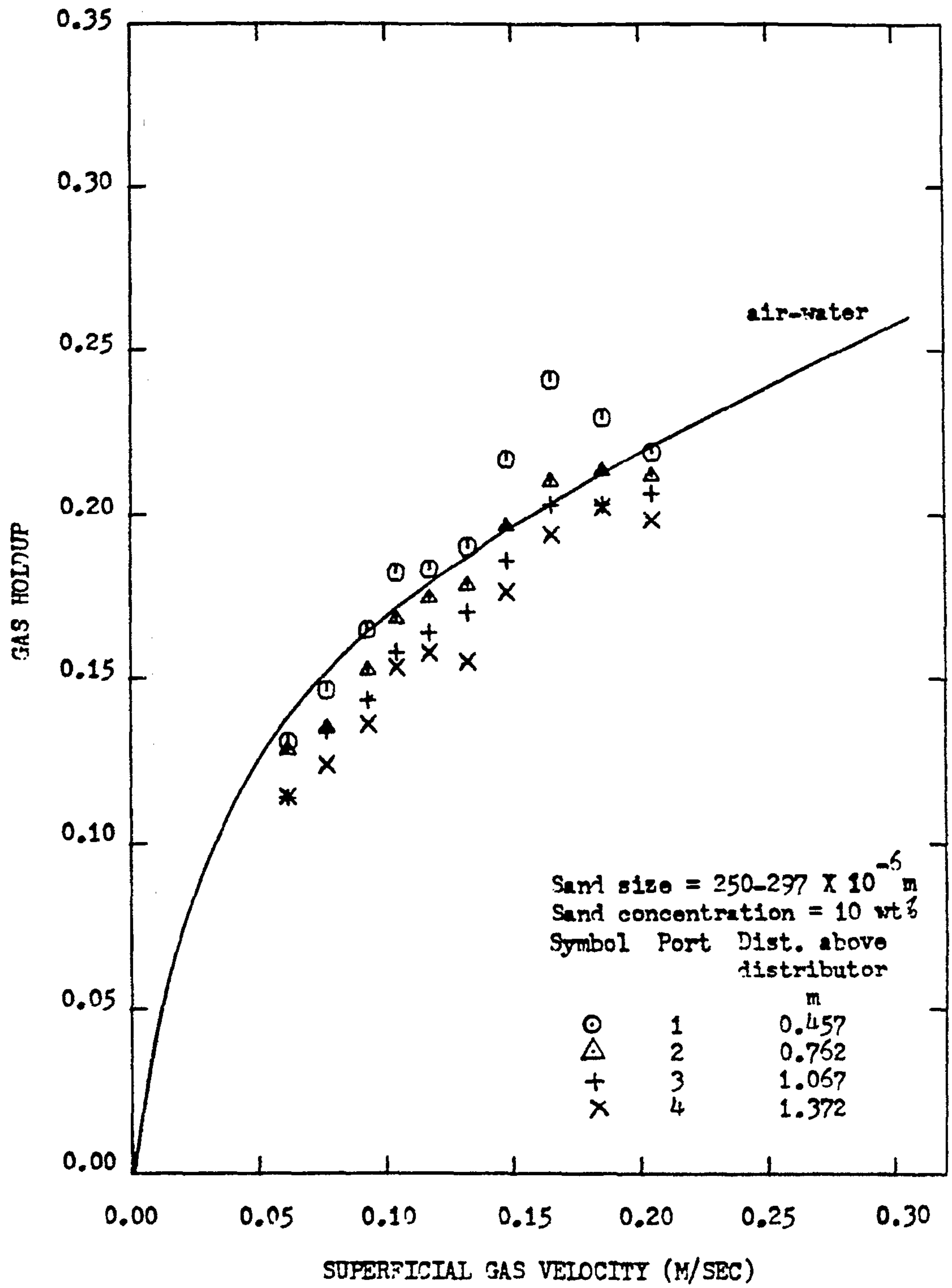
SOLID HOLDUP VS.SUPERFICIAL GAS VELOCITY FOR AIR-WATER-COAL.

Figure 2.41



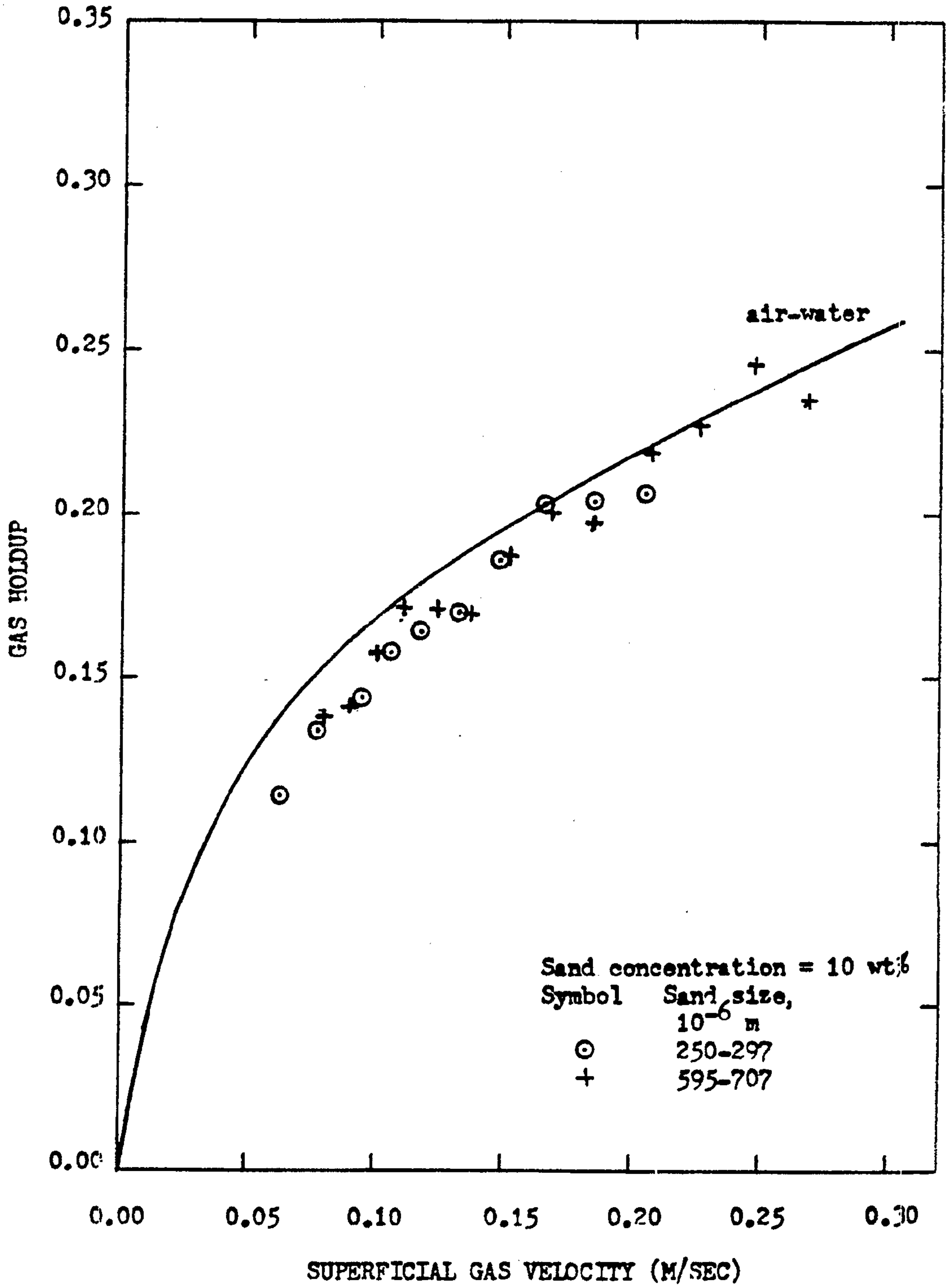
LIQUID HOLDUP VS.SUPERFICIAL GAS VELOCITY FOR AIR-WATER-COAL.

Figure 2.42



EG VS VG FOR AIR-SAND-WATER

Figure 2.43



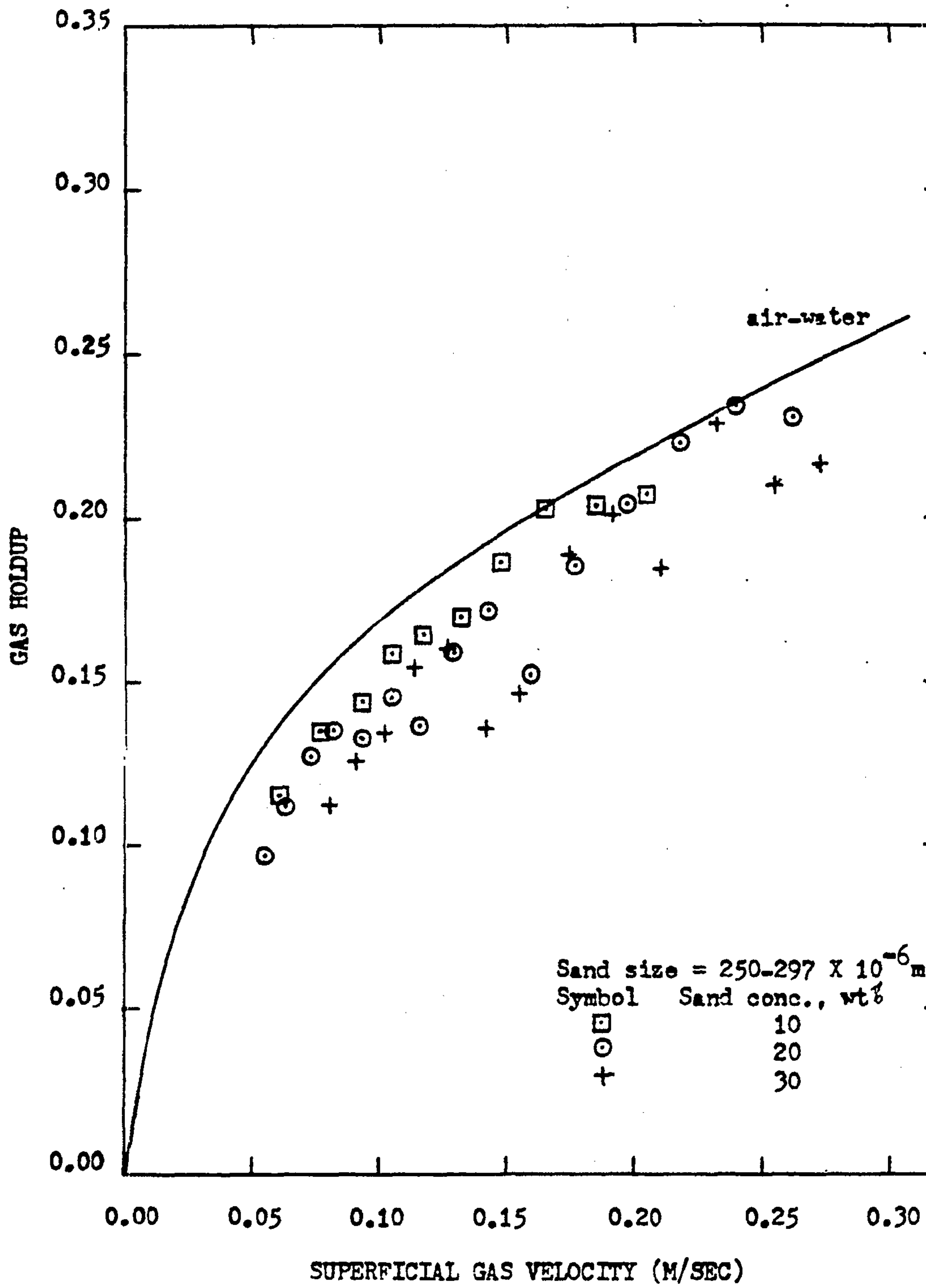
EG(PORT 3) VS VG FOR AIR-SAND-WATER

Figure 2.44

sand concentration as shown in Figure 2.45 for the 250-297 x 10^{-6} m sand. The gas holdup shown in Figures 2.44 and 2.45 is measured at port 3.

A comparison of the experimental gas holdups for the air-water-sand systems with some reported correlations is made in Tables A.2.31 to A.2.38. Neither the correlation of Begovich and Watson[2.20] nor that of Kito et al.[2.21] is able to predict the axial variation of gas holdup. Good agreement is obtained between the experimental results and Kito et al's[2.21] correlation for sand concentrations $\leq$ 20 wt% and gas velocities $\leq$ 0.20 m/sec. The correlation of Begovich and Watson[2.20] does not agree with the experimental data even for the lowest concentrations.

A detailed analysis of solid concentration profiles, ratio of suspended to unsuspended material, etc. will be included in the next report.



EG(PORT 3) VS VG FOR AIR-SAND-WATER

Figure 2.45

APPENDIX 2.1

TABLE A.2.1

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
1.0 WT% METHANOL SOLUTION

SURFACE TENSION= 0.06674 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1006.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	SCHUGERL
0.17436	0.09638	0.38985	0.44724	0.22037	0.23660	0.21930	1.75415
0.14064	0.09640	0.44711	0.31456	0.19853	0.20872	0.19763	1.47878
0.10937	0.07718	0.37153	0.29438	0.17409	0.18045	0.17326	1.05947
0.08272	0.06389	0.36337	0.22764	0.14865	0.15360	0.14785	0.78531
0.05878	0.04757	0.30874	0.19032	0.12035	0.12602	0.11966	0.51644
0.03751	0.03177	0.24521	0.15297	0.08856	0.09720	0.08801	0.29605
0.01715	0.01587	0.23109	0.07420	0.04815	0.06186	0.04778	0.12806
0.02722	0.02410	0.23734	0.11470	0.06974	0.08074	0.06929	0.20937
0.04807	0.03964	0.27426	0.17527	0.10535	0.11219	0.10473	0.40026
0.06972	0.05473	0.32440	0.21491	0.13409	0.13912	0.13334	0.62901
0.09534	0.06892	0.34414	0.27702	0.16134	0.16664	0.16056	0.89148
0.12398	0.08555	0.39997	0.30998	0.18611	0.19405	0.18524	1.24218
0.15782	0.10472	0.46907	0.33646	0.21014	0.22313	0.20921	1.69855

TABLE A.2.2

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
5.0 WTZ METHANOL SOLUTION

SURFACE TENSION= 0.06143 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	SCHUGERL
0.09993	0.06715	0.30466	0.32799	0.16645	0.17392	0.16558	0.91796
0.08722	0.06191	0.30055	0.29021	0.15410	0.16076	0.15327	0.79262
0.07490	0.05543	0.28823	0.25985	0.14082	0.14715	0.14007	0.66548
0.06161	0.04832	0.28566	0.21567	0.12475	0.13150	0.12401	0.54114
0.04898	0.04044	0.28083	0.17442	0.10732	0.11515	0.10666	0.42337
0.03626	0.03123	0.26143	0.13869	0.08695	0.09676	0.08639	0.30108
0.02347	0.02131	0.25519	0.09195	0.06254	0.07522	0.06211	0.18961
0.01704	0.01589	0.25356	0.06720	0.04825	0.06251	0.04791	0.13555
0.02989	0.02624	0.24459	0.12220	0.07538	0.08652	0.07488	0.23996
0.04268	0.03645	0.29234	0.14601	0.09765	0.10633	0.09704	0.37260
0.05547	0.04641	0.33939	0.16344	0.11658	0.12373	0.11589	0.51857
0.06819	0.05511	0.35547	0.19184	0.13297	0.13943	0.13222	0.65456
0.08086	0.06505	0.41355	0.19553	0.14742	0.15387	0.14661	0.82874
0.09349	0.07350	0.43725	0.21382	0.16035	0.16736	0.15949	0.98493

TABLE A.2.3

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
1.0 WT% ETHANOL SOLUTION

SURFACE TENSION= 0.06608 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY= 995.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	SCHUGERL
0.02123	0.01949	0.25933	0.08186	0.05726	0.06986	0.05694	0.16719
0.03133	0.02735	0.24672	0.12698	0.07747	0.08749	0.07707	0.24591
0.03985	0.03292	0.22906	0.17396	0.09234	0.10056	0.09188	0.30698
0.05037	0.03845	0.21283	0.23668	0.10859	0.11510	0.10811	0.38083
0.05588	0.04131	0.21433	0.26070	0.11633	0.12222	0.11582	0.42540
0.05984	0.04324	0.21571	0.27740	0.12162	0.12718	0.12107	0.45799
0.04510	0.03530	0.20759	0.21726	0.10071	0.10797	0.10026	0.33618
0.03417	0.02892	0.22235	0.15370	0.08264	0.09202	0.08221	0.25861
0.02556	0.02302	0.25719	0.09938	0.06632	0.07779	0.06596	0.20219
0.03076	0.02667	0.23097	0.13319	0.07642	0.08646	0.07611	0.23522
0.05114	0.03937	0.22224	0.23010	0.10970	0.11601	0.10928	0.39340
0.05970	0.04376	0.22359	0.26700	0.12144	0.12689	0.12098	0.46326

TABLE A.2.4

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.5 WT% PROPANOL SOLUTION

SURFACE TENSION= 0.06416 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY= 998.99990 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VR(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	SCHUGERL
0.03950	0.03054	0.17421	0.22674	0.09209	0.10134	0.09113	0.27692
0.07337	0.04854	0.21680	0.33841	0.13859	0.14490	0.13739	0.57422
0.02796	0.02367	0.18239	0.15327	0.07134	0.08306	0.07049	0.19667
0.05647	0.04133	0.21061	0.26814	0.11751	0.12468	0.11634	0.43236
0.07654	0.04852	0.20909	0.36606	0.14219	0.14860	0.14090	0.59176
0.05580	0.04244	0.23306	0.23942	0.11659	0.12384	0.11541	0.44406
0.07858	0.04965	0.21342	0.36822	0.14445	0.15092	0.14313	0.61306
0.09079	0.05344	0.22069	0.41140	0.15718	0.16408	0.15578	0.72183

TABLE A.2.5

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
1.0 WT% PROPANOL SOLUTION

SURFACE TENSION= 0.06091 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY= 998.04000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	SCHUGERL
0.01722	0.01590	0.22451	0.07672	0.04870	0.06340	0.04807	0.13108
0.02378	0.02127	0.22506	0.10565	0.06322	0.07640	0.06243	0.18355
0.03295	0.02759	0.20264	0.16259	0.08110	0.09228	0.08012	0.24754
0.03883	0.03169	0.21101	0.18404	0.09138	0.10150	0.09031	0.29838
0.04549	0.03581	0.21369	0.21288	0.10209	0.11123	0.10092	0.35352
0.05717	0.04241	0.22138	0.25826	0.11894	0.12698	0.11763	0.45469
0.06031	0.04323	0.21301	0.28314	0.12311	0.13098	0.12176	0.47360
0.01925	0.01754	0.21601	0.08912	0.05337	0.06763	0.05267	0.14500
0.02456	0.02208	0.24317	0.10101	0.06485	0.07781	0.06407	0.19563
0.04169	0.03371	0.21779	0.19143	0.09608	0.10558	0.09509	0.32521
0.05069	0.03911	0.22192	0.22842	0.10986	0.11822	0.10877	0.40151
0.06219	0.04594	0.23800	0.26130	0.12554	0.13307	0.12435	0.51041
0.06508	0.04607	0.22277	0.29214	0.12919	0.13663	0.12797	0.52162
0.07205	0.04824	0.21805	0.33042	0.13759	0.14483	0.13636	0.57511
0.08186	0.05160	0.22146	0.36963	0.14854	0.15594	0.14724	0.66084
0.08935	0.05337	0.22188	0.40268	0.15630	0.16408	0.15495	0.72444
0.09633	0.05575	0.22868	0.42125	0.16312	0.17138	0.16174	0.79267
0.10893	0.06236	0.25481	0.42750	0.17457	0.18404	0.17312	0.93942
0.03172	0.02751	0.23874	0.13287	0.07885	0.09011	0.07801	0.25352
0.04533	0.03749	0.26192	0.17308	0.10184	0.11070	0.10090	0.38110
0.06398	0.04566	0.22344	0.28633	0.12781	0.13512	0.12670	0.51303
0.07570	0.05169	0.23866	0.31719	0.14178	0.14894	0.14059	0.62701
0.09929	0.05621	0.22884	0.43388	0.16591	0.17419	0.16464	0.81826
0.11305	0.06052	0.24327	0.46472	0.17810	0.18779	0.17677	0.95911
0.12980	0.06575	0.26304	0.49346	0.19148	0.20344	0.19010	1.14144
0.14090	0.06848	0.27412	0.51401	0.19962	0.21334	0.19820	1.26325
0.15454	0.07511	0.30067	0.51401	0.20893	0.22505	0.20749	1.44152
0.20958	0.09626	0.38760	0.54070	0.24061	0.26841	0.23908	2.18388

TABLE A.2.6

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
1.5 WT% PROPANOL SOLUTION

SURFACE TENSION= 0.05615 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY= 997.06000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	SCHUGERL
0.01740	0.01612	0.23579	0.07380	0.04952	0.06461	0.04898	0.13896
0.02390	0.02110	0.20398	0.11715	0.06396	0.07763	0.06328	0.18279
0.03419	0.02828	0.19783	0.17284	0.08395	0.09554	0.08309	0.26233
0.04386	0.03519	0.22191	0.19765	0.10023	0.11035	0.09924	0.35542
0.05479	0.04248	0.24401	0.22452	0.11642	0.12551	0.11531	0.46477
0.05881	0.04488	0.24833	0.23681	0.12190	0.13077	0.12075	0.50377
0.06485	0.04788	0.24782	0.26170	0.12971	0.13839	0.12852	0.55737
0.02737	0.02406	0.22663	0.12077	0.07106	0.08392	0.07036	0.21929
0.05703	0.04451	0.25987	0.21945	0.11951	0.12822	0.11854	0.49655
0.07875	0.05629	0.27610	0.28525	0.14603	0.15456	0.14492	0.71139
0.09507	0.06365	0.28768	0.33048	0.16283	0.17237	0.16163	0.87937
0.11952	0.06015	0.24062	0.49671	0.18440	0.19671	0.18316	1.04149
0.12927	0.07143	0.28889	0.44746	0.19205	0.20584	0.19079	1.21286
0.07114	0.04968	0.23581	0.30171	0.13736	0.14575	0.13628	0.60209
0.02156	0.01938	0.21355	0.10095	0.05894	0.07302	0.05839	0.16713
0.03403	0.02848	0.20868	0.16309	0.08366	0.09509	0.08293	0.26649
0.05236	0.03956	0.21421	0.24441	0.11300	0.12191	0.11215	0.42156
0.09272	0.05764	0.24506	0.37834	0.16053	0.16971	0.15945	0.80517
0.11033	0.05935	0.23876	0.46212	0.17672	0.18762	0.17562	0.95539
0.12865	0.06232	0.24952	0.51560	0.19158	0.20507	0.19042	1.14035
0.14219	0.06800	0.27251	0.52178	0.20152	0.21730	0.20033	1.30943
0.14505	0.07146	0.28591	0.50733	0.20352	0.21982	0.20232	1.36193
0.16850	0.07574	0.30607	0.55053	0.21880	0.23974	0.21756	1.63449
0.18386	0.08378	0.33778	0.54434	0.22786	0.25216	0.22659	1.85944
0.20361	0.09320	0.37548	0.54228	0.23860	0.26749	0.23730	2.15425
0.21978	0.09834	0.39774	0.55256	0.24672	0.27958	0.24541	2.38518

TABLE A.2.7

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.5 WT% BUTANOL SOLUTION

SURFACE TENSION= 0.06319 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY= 999.02000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	SCHUGERL
0.01673	0.01569	0.26733	0.06260	0.04737	0.06203	0.04668	0.13436
0.02276	0.02056	0.23576	0.09654	0.06086	0.07410	0.06001	0.17629
0.02897	0.02552	0.24343	0.11902	0.07341	0.08520	0.07243	0.22948
0.03608	0.03032	0.22602	0.15965	0.08641	0.09667	0.08534	0.28025
0.04242	0.03428	0.22109	0.19184	0.09696	0.10614	0.09580	0.32880
0.04874	0.03822	0.22583	0.21581	0.10668	0.11503	0.10544	0.38310
0.05504	0.04166	0.22647	0.24302	0.11569	0.12342	0.11438	0.43530
0.06130	0.04598	0.24526	0.24994	0.12405	0.13137	0.12267	0.50224
0.06764	0.04993	0.25830	0.26185	0.13198	0.13905	0.13055	0.56764
0.07378	0.05174	0.24694	0.29878	0.13923	0.14625	0.13773	0.61073
0.02945	0.02555	0.22211	0.13261	0.07434	0.08585	0.07346	0.22532
0.03950	0.03335	0.25364	0.15571	0.09220	0.10173	0.09117	0.32192
0.05035	0.03907	0.22475	0.22403	0.10905	0.11698	0.10796	0.39558
0.06013	0.04528	0.24345	0.24698	0.12253	0.12963	0.12134	0.49082
0.07177	0.05108	0.24890	0.28837	0.13691	0.14362	0.13563	0.59525
0.08389	0.05844	0.27657	0.30331	0.15031	0.15717	0.14895	0.72933
0.09641	0.06384	0.28542	0.33777	0.16280	0.17035	0.16139	0.85336
0.10924	0.06820	0.29078	0.37570	0.17444	0.18314	0.17296	0.97899
0.12348	0.07116	0.29145	0.42367	0.18618	0.19650	0.18470	1.11314
0.13866	0.07832	0.31866	0.43512	0.19759	0.21014	0.19606	1.30009
0.15589	0.08635	0.34945	0.44610	0.20938	0.22488	0.20781	1.52213
0.17366	0.09436	0.38029	0.45666	0.22045	0.23938	0.21885	1.75983

TABLE A.2.8

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
1.6 WT% BUTANOL SOLUTION

SURFACE TENSION= 0.04823 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY= 996.40000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIRITA	MERSMANN	SCHUGERL
0.02431	0.02138	0.20177	0.12048	0.06579	0.08060	0.06515	0.19559
0.03152	0.02595	0.17826	0.17685	0.08017	0.09371	0.07940	0.24437
0.03953	0.03123	0.18815	0.21011	0.09444	0.10683	0.09356	0.31584
0.03573	0.02866	0.18043	0.19805	0.08788	0.10075	0.08705	0.27975
0.02787	0.02387	0.19407	0.14360	0.07308	0.08724	0.07237	0.22211
0.02064	0.01864	0.21291	0.09695	0.05779	0.07334	0.05721	0.16842
0.02331	0.02042	0.18794	0.12404	0.06366	0.07855	0.06313	0.18218
0.03282	0.02690	0.18185	0.18047	0.08259	0.09574	0.08192	0.25680
0.04234	0.03294	0.19075	0.22195	0.09909	0.11093	0.09832	0.34104
0.05177	0.03742	0.18673	0.27722	0.11356	0.12462	0.11271	0.41700
0.05540	0.03586	0.15705	0.35274	0.11872	0.12954	0.11789	0.41854
0.04905	0.03292	0.14918	0.32883	0.10956	0.12073	0.10878	0.36149

TABLE A.2.9

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
10.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.05860 NEWTON/M
LIQUID VISCOSITY= 0.00170 KG/(M*SEC)
LIQUID DENSITY=1039.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VN(M/S)	EXPTL	AKITAAYOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	DECKWER
0.03481	0.03217	0.45944	0.07577	0.08009	0.09294	0.07988	0.14139	0.09522	0.07370
0.04684	0.04250	0.50621	0.09253	0.09912	0.11032	0.09888	0.17987	0.12021	0.09400
0.05853	0.05286	0.60395	0.09692	0.11524	0.12550	0.11498	0.21262	0.14172	0.11285
0.06712	0.05955	0.59508	0.11280	0.12590	0.13585	0.12561	0.23389	0.15602	0.12626
0.07828	0.06841	0.62111	0.12603	0.13852	0.14848	0.13821	0.25818	0.17298	0.14323
0.09065	0.07922	0.71926	0.12603	0.15119	0.16163	0.15085	0.28098	0.18993	0.16154
0.10628	0.09279	0.83743	0.12692	0.16556	0.17721	0.16521	0.30403	0.20900	0.18405
0.12363	0.10619	0.87663	0.14103	0.17978	0.19340	0.17941	0.32276	0.22758	0.20834
0.13845	0.11630	0.86556	0.15995	0.19076	0.20646	0.19040	0.33367	0.24167	0.22861
0.15593	0.12859	0.88913	0.17538	0.20258	0.22119	0.20218	0.34129	0.25654	0.25203
0.17263	0.14235	0.98433	0.17538	0.21289	0.23459	0.21249	0.34400	0.26921	0.27395
0.19268	0.15804	1.07153	0.17982	0.22423	0.24999	0.22381	0.34244	0.28280	0.29979
0.21441	0.16971	1.02847	0.20847	0.23542	0.26593	0.23499	0.33625	0.29582	0.32724
0.23972	0.18815	1.11434	0.21512	0.24727	0.28368	0.24682	0.32531	0.30915	0.35859
0.27034	0.20265	1.07975	0.25037	0.26019	0.30411	0.25973	0.31030	0.32312	0.39574

TABLE A.2.10

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
20.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.05800 NEWTON/M
LIQUID VISCOSITY= 0.00221 KG/(M*SEC)
LIQUID DENSITY=1071.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	KUMAR	HUGHMARK	DECKWER
0.03084	0.02837	0.38424	0.08026	0.07128	0.08586	0.07123	0.12869	0.08481	0.06673
0.04188	0.03723	0.37700	0.11110	0.08945	0.10248	0.08940	0.16598	0.10859	0.08577
0.05392	0.04710	0.42629	0.12648	0.10668	0.11859	0.10661	0.20174	0.13157	0.10550
0.06949	0.06059	0.54220	0.12817	0.12599	0.13735	0.12590	0.24097	0.15760	0.12991
0.08380	0.07242	0.61674	0.13588	0.14146	0.15305	0.14136	0.27047	0.17847	0.15147
0.10292	0.08929	0.77708	0.13245	0.15955	0.17238	0.15943	0.30101	0.20268	0.17927
0.11733	0.09968	0.77996	0.15043	0.17164	0.18595	0.17151	0.31795	0.21665	0.19960
0.13786	0.11535	0.84432	0.16328	0.18706	0.20412	0.18692	0.33415	0.23864	0.22781
0.15733	0.13124	0.94861	0.16585	0.20011	0.22035	0.19995	0.34208	0.25515	0.25388
0.19395	0.15391	0.93949	0.20644	0.22142	0.24868	0.22126	0.34177	0.28114	0.30140
0.21419	0.17042	1.04817	0.20435	0.23178	0.26340	0.23160	0.33552	0.29327	0.32697
0.23615	0.18435	1.07654	0.21936	0.24209	0.27871	0.24190	0.32587	0.30500	0.35421
0.26170	0.20839	1.28463	0.20371	0.25307	0.29556	0.25296	0.31318	0.31707	0.38534

TABLE A.2.11

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
30.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.05760 NEWTON/M
LIQUID VISCOSITY= 0.00302 KG/(M*SEC)
LIQUID DENSITY=1096.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSHMANN	KUMAR	HUGHMARK	BECKNER
0.02410	0.02196	0.27169	0.08871	0.05671	0.07358	0.05672	0.10443	0.06788	0.05452
0.03450	0.03089	0.32979	0.10461	0.07504	0.09053	0.07506	0.14242	0.09178	0.07318
0.04566	0.04038	0.39537	0.11548	0.09216	0.10645	0.09218	0.17877	0.11466	0.09205
0.05654	0.04969	0.46608	0.12131	0.10690	0.12046	0.10691	0.21003	0.13463	0.10969
0.07079	0.06125	0.52558	0.13469	0.12393	0.13718	0.12393	0.24507	0.15785	0.13189
0.08504	0.07230	0.56785	0.14975	0.13893	0.15253	0.13893	0.27390	0.17829	0.15329
0.10178	0.08626	0.66833	0.15225	0.15452	0.16923	0.15451	0.30047	0.19937	0.17760
0.11337	0.09469	0.68798	0.16478	0.16432	0.18015	0.16429	0.31470	0.21245	0.19405
0.12737	0.10766	0.82305	0.15476	0.17519	0.19271	0.17516	0.32772	0.22679	0.21351
0.14188	0.11803	0.84388	0.16813	0.18554	0.20511	0.18551	0.33687	0.24022	0.23325
0.15804	0.13181	0.95215	0.16598	0.19613	0.21830	0.19610	0.34252	0.25369	0.25482
0.17539	0.14003	0.87009	0.20157	0.20657	0.23186	0.20653	0.34403	0.26669	0.27754
0.19441	0.15644	0.99548	0.19529	0.21708	0.24609	0.21703	0.34133	0.27945	0.30199
0.21493	0.17027	1.03436	0.20779	0.22748	0.26090	0.22743	0.33460	0.29173	0.32789
0.23860	0.18217	1.00886	0.23651	0.23848	0.27685	0.23850	0.32380	0.30431	0.35723
0.25993	0.20061	1.13909	0.22819	0.24758	0.29094	0.24759	0.31309	0.31440	0.38320

TABLE A.2.12

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
40.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.05790 NEWTON/M
LIQUID VISCOSITY= 0.00423 KG/(M*SEC)
LIQUID DENSITY=1124.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	DECKWER
0.03351	0.03035	0.35540	0.09429	0.07069	0.08722	0.07110	0.13957	0.08741	0.07143
0.04623	0.04150	0.45136	0.10243	0.08977	0.10504	0.09025	0.18122	0.11308	0.09300
0.05933	0.05253	0.51744	0.11467	0.10681	0.12134	0.10735	0.21818	0.13639	0.11412
0.07090	0.06179	0.55158	0.12855	0.12018	0.13451	0.12075	0.24612	0.15476	0.13207
0.08530	0.07399	0.64339	0.13258	0.13505	0.14969	0.13565	0.27515	0.17517	0.15369
0.10294	0.08803	0.71076	0.14483	0.15116	0.16688	0.15180	0.30276	0.19711	0.17929
0.11649	0.09867	0.76154	0.15296	0.16227	0.17927	0.16292	0.31858	0.21205	0.19843
0.13518	0.11285	0.81826	0.16520	0.17615	0.19538	0.17681	0.33357	0.23040	0.22418
0.15226	0.12382	0.81501	0.18682	0.18760	0.20929	0.18829	0.34124	0.24523	0.24715
0.17175	0.14177	0.98391	0.17455	0.19949	0.22439	0.20018	0.34407	0.26028	0.27280
0.19406	0.15623	0.99541	0.19496	0.21183	0.24083	0.21253	0.34117	0.27547	0.30155
0.21471	0.17241	1.08972	0.19703	0.22224	0.25536	0.22293	0.33425	0.28790	0.32762
0.24068	0.18640	1.06715	0.22553	0.23417	0.27279	0.23487	0.32217	0.30171	0.35977
0.27967	0.21830	1.27442	0.21945	0.25013	0.29755	0.25083	0.30323	0.31937	0.40691

TABLE A.2.13

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
50.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.05890 NEWTON/M
LIQUID VISCOSITY= 0.00666 KG/(M*SEC)
LIQUID DENSITY=1147.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSHANN	KUMAR	HUGHMARK	DECKWER
0.02755	0.02520	0.32308	0.08528	0.05728	0.07593	0.05777	0.11809	0.07184	0.06084
0.03861	0.03495	0.40699	0.09487	0.07456	0.09227	0.07516	0.15708	0.09519	0.08023
0.05007	0.04448	0.44839	0.11167	0.09028	0.10723	0.09097	0.19277	0.11684	0.09929
0.06193	0.05471	0.53182	0.11644	0.10472	0.12125	0.10549	0.22494	0.13692	0.11819
0.07497	0.06534	0.58376	0.12842	0.11893	0.13543	0.11974	0.25507	0.15673	0.13825
0.08949	0.07764	0.67577	0.13243	0.13307	0.15003	0.13393	0.28259	0.17637	0.15985
0.10072	0.08698	0.73832	0.13641	0.14301	0.16066	0.14389	0.29984	0.19009	0.17611
0.11134	0.09465	0.74245	0.14997	0.15175	0.17027	0.15265	0.31319	0.20204	0.19121
0.12562	0.10557	0.78714	0.15959	0.16260	0.18255	0.16354	0.32691	0.21671	0.21109
0.13915	0.11428	0.77833	0.17879	0.17210	0.19369	0.17305	0.33590	0.22936	0.22957
0.15420	0.12799	0.90736	0.16994	0.18186	0.20554	0.18284	0.34182	0.24214	0.24973
0.17077	0.14147	0.99536	0.17157	0.19180	0.21805	0.19279	0.34406	0.25490	0.27154
0.18979	0.15132	0.93625	0.20271	0.20230	0.23178	0.20330	0.34212	0.26807	0.29610
0.21263	0.17200	1.11273	0.19109	0.21382	0.24752	0.21484	0.33502	0.28213	0.32501
0.23060	0.18147	1.08236	0.21305	0.22219	0.25943	0.22321	0.32704	0.29204	0.34737
0.26184	0.20029	1.11394	0.23506	0.23548	0.27924	0.23650	0.31139	0.30729	0.38551

TABLE A.2.14

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
60.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.05920 NEWTON/M
LIQUID VISCOSITY= 0.01140 KG/(M*SEC)
LIQUID DENSITY=1168.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	DECKWER
0.03128	0.02866	0.37370	0.08369	0.05924	0.07949	0.05989	0.13210	0.07845	0.06750
0.04364	0.03893	0.40406	0.10801	0.07669	0.09637	0.07749	0.17377	0.10307	0.08871
0.05665	0.05013	0.49224	0.11508	0.09279	0.11206	0.09369	0.21170	0.12605	0.10987
0.06957	0.06108	0.56970	0.12212	0.10699	0.12620	0.10797	0.24376	0.14639	0.13003
0.08400	0.07421	0.72023	0.11663	0.12117	0.14073	0.12223	0.27341	0.16663	0.15176
0.10075	0.08782	0.78470	0.12839	0.13586	0.15635	0.13697	0.30035	0.18740	0.17616
0.12112	0.10195	0.76545	0.15823	0.15168	0.17392	0.15285	0.32343	0.20941	0.20487
0.13654	0.11301	0.79222	0.17235	0.16247	0.18639	0.16368	0.33470	0.22413	0.22603
0.17109	0.14060	0.96006	0.17821	0.18370	0.21238	0.18497	0.34407	0.25223	0.27195
0.18968	0.15624	1.07594	0.17629	0.19378	0.22544	0.19507	0.34201	0.26511	0.29595
0.20878	0.16707	1.04516	0.19976	0.20335	0.23830	0.20466	0.33625	0.27701	0.32018
0.23317	0.18430	1.11243	0.20961	0.21458	0.25404	0.21590	0.32543	0.29057	0.35054
0.25019	0.20218	1.30370	0.19191	0.22184	0.26459	0.22318	0.31683	0.29909	0.37139
0.15278	0.12495	0.83878	0.18214	0.17290	0.19893	0.17413	0.34157	0.23809	0.24784

TABLE A.2.15

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
70.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.06720 NEWTON/M
LIQUID VISCOSITY= 0.02060 KG/(M*SEC)
LIQUID DENSITY=1194.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSHANN	KUMAR	HUGHMARK	DECKWER
0.03193	0.02919	0.37143	0.08598	0.05523	0.07623	0.05605	0.13150	0.07035	0.06867
0.04284	0.03866	0.43928	0.09751	0.06966	0.09034	0.07064	0.16769	0.09004	0.08736
0.05820	0.05181	0.53016	0.10977	0.08756	0.10785	0.08872	0.21182	0.11492	0.11232
0.07114	0.06360	0.67146	0.10594	0.10090	0.12113	0.10217	0.24314	0.13364	0.13242
0.08549	0.07505	0.70031	0.12207	0.11423	0.13471	0.11560	0.27206	0.15238	0.15396
0.09991	0.08710	0.77934	0.12820	0.12635	0.14742	0.12780	0.29546	0.16938	0.17496
0.11488	0.09786	0.77534	0.14817	0.13780	0.15983	0.13931	0.31423	0.18535	0.19618
0.13525	0.11584	0.94230	0.14353	0.15189	0.17566	0.15347	0.33173	0.20475	0.22427
0.15302	0.12554	0.85185	0.17964	0.16301	0.18866	0.16465	0.34041	0.21983	0.24817
0.17130	0.14291	1.03341	0.16576	0.17350	0.20139	0.17518	0.34393	0.23381	0.27223
0.19128	0.15597	1.03613	0.18461	0.18405	0.21467	0.18575	0.34268	0.24758	0.29800
0.20997	0.16636	1.01096	0.20769	0.19315	0.22655	0.19489	0.33778	0.25923	0.32167
0.23077	0.18507	1.16540	0.19802	0.20256	0.23929	0.20432	0.32944	0.27099	0.34757
0.25247	0.19811	1.17269	0.21529	0.21166	0.25206	0.21344	0.31900	0.28209	0.37416

TABLE A.2.16

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
80.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.06530 NEWTON/M
LIQUID VISCOSITY= 0.05040 KG/(M*SEC)
LIQUID DENSITY=1216.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	BECKNER
0.03178	0.02977	0.50163	0.06335	0.04904	0.07305	0.04998	0.13227	0.07069	0.06839
0.04493	0.04087	0.49656	0.09049	0.06484	0.08924	0.06601	0.17580	0.09442	0.09085
0.05857	0.05244	0.55913	0.10476	0.07939	0.10402	0.08075	0.21460	0.11642	0.11292
0.07155	0.06330	0.62046	0.11532	0.09183	0.11678	0.09334	0.24591	0.13523	0.13306
0.08440	0.07441	0.71318	0.11834	0.10306	0.12848	0.10468	0.27189	0.15212	0.15234
0.10191	0.08816	0.75536	0.13492	0.11693	0.14330	0.11868	0.29993	0.17279	0.17783
0.11978	0.10249	0.82981	0.14435	0.12967	0.15733	0.13152	0.32060	0.19148	0.20301
0.13829	0.11630	0.86953	0.15904	0.14164	0.17098	0.14357	0.33457	0.20872	0.22840
0.15974	0.13434	1.00442	0.15904	0.15423	0.18586	0.15623	0.34269	0.22643	0.25707
0.18026	0.14534	0.93057	0.19371	0.16519	0.19931	0.16726	0.34382	0.24147	0.28384
0.19624	0.15697	0.98063	0.20011	0.17310	0.20935	0.17521	0.34114	0.25208	0.30432
0.22061	0.17613	1.09422	0.20161	0.18429	0.22403	0.18644	0.33273	0.26669	0.33498
0.25282	0.20147	1.24476	0.20310	0.19767	0.24240	0.19988	0.31734	0.28354	0.37458

TABLE A.2.17

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
85.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.06450 NEWTON/M
LIQUID VISCOSITY= 0.05900 KG/(M*SEC)
LIQUID DENSITY=1227.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	BECKNER
0.02732	0.02551	0.41093	0.06649	0.04240	0.06667	0.04323	0.11664	0.06219	0.06042
0.03765	0.03448	0.44597	0.08443	0.05534	0.08026	0.05637	0.15315	0.08185	0.07860
0.04885	0.04437	0.53164	0.09189	0.06802	0.09330	0.06923	0.18836	0.10127	0.09731
0.06123	0.05433	0.54286	0.11279	0.08071	0.10631	0.08207	0.22227	0.12073	0.11710
0.07418	0.06515	0.60905	0.12180	0.09275	0.11878	0.09425	0.25247	0.13916	0.13705
0.08852	0.07801	0.74529	0.11877	0.10488	0.13157	0.10650	0.28005	0.15758	0.15842
0.10455	0.09057	0.78181	0.13373	0.11720	0.14486	0.11893	0.30419	0.17607	0.18159
0.12234	0.10425	0.82708	0.14792	0.12960	0.15865	0.13142	0.32354	0.19438	0.20657
0.14387	0.12151	0.92584	0.15539	0.14313	0.17424	0.14505	0.33781	0.21395	0.23593
0.16472	0.13765	1.00232	0.16434	0.15499	0.18844	0.15698	0.34361	0.23065	0.26362
0.18243	0.14953	1.01150	0.18036	0.16426	0.19991	0.16630	0.34351	0.24338	0.28665
0.19957	0.16506	1.15421	0.17291	0.17261	0.21058	0.17469	0.33996	0.25460	0.30855
0.21938	0.18060	1.24160	0.17667	0.18161	0.22242	0.18372	0.33277	0.26639	0.33342
0.24078	0.19823	1.36276	0.17667	0.19066	0.23472	0.19281	0.32273	0.27794	0.35987

TABLE A.2.18

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
90.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.06380 NEWTON/M
LIQUID VISCOSITY= 0.07620 KG/(M*SEC)
LIQUID DENSITY=1228.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	DECKWER
0.03503	0.03286	0.56471	0.06204	0.05045	0.07596	0.05155	0.14461	0.07770	0.07408
0.04704	0.04307	0.55698	0.08446	0.06397	0.09007	0.06529	0.18338	0.09905	0.09434
0.05813	0.05288	0.64300	0.09041	0.07529	0.10180	0.07679	0.21471	0.11694	0.11222
0.07172	0.06380	0.64891	0.11053	0.08792	0.11496	0.08958	0.24760	0.13680	0.13332
0.08783	0.07864	0.83988	0.10457	0.10143	0.12924	0.10325	0.27930	0.15782	0.15741
0.10316	0.09106	0.87971	0.11726	0.11307	0.14184	0.11502	0.30276	0.17569	0.17960
0.11584	0.10113	0.91241	0.12696	0.12196	0.15168	0.12400	0.31766	0.18912	0.19752
0.12867	0.11041	0.90681	0.14189	0.13036	0.16121	0.13246	0.32898	0.20162	0.21529
0.14446	0.12320	0.98180	0.14714	0.13998	0.17235	0.14217	0.33826	0.21568	0.23672
0.16046	0.13422	0.98129	0.16352	0.14904	0.18316	0.15129	0.34307	0.22865	0.25802
0.17707	0.14653	1.02657	0.17249	0.15780	0.19389	0.16012	0.34394	0.24091	0.27972
0.19761	0.16367	1.15066	0.17174	0.16785	0.20658	0.17024	0.34035	0.25463	0.30606
0.23857	0.19359	1.26538	0.18853	0.18576	0.23041	0.18822	0.32348	0.27805	0.35718
0.25999	0.21049	1.36554	0.19039	0.19418	0.24216	0.19668	0.31268	0.28861	0.38328

TABLE A.2.19

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
95.0%GLYCERINE SOLUTION

SURFACE TENSION= 0.06410 NEWTON/M
LIQUID VISCOSITY= 0.14100 KG/(M*SEC)
LIQUID DENSITY=1243.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VR(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSHANN	KUMAR	HUGHMARK	DECKWER
0.02612	0.02482	0.52462	0.04978	0.03615	0.06211	0.03706	0.11259	0.05942	0.05823
0.04252	0.03975	0.65171	0.06524	0.05449	0.08233	0.05578	0.16964	0.09002	0.08683
0.05498	0.05030	0.64558	0.08517	0.06685	0.09552	0.06835	0.20651	0.11056	0.10721
0.06853	0.06295	0.84105	0.08148	0.07905	0.10849	0.08075	0.24069	0.13069	0.12843
0.08520	0.07663	0.84650	0.10066	0.09262	0.12305	0.09451	0.27493	0.15277	0.15354
0.10714	0.09502	0.94655	0.11319	0.10852	0.14048	0.11061	0.30811	0.17810	0.18528
0.12083	0.10520	0.93402	0.12936	0.11751	0.15060	0.11971	0.32270	0.19210	0.20447
0.14085	0.12180	1.04113	0.13529	0.12962	0.16457	0.13194	0.33669	0.21053	0.23186
0.18331	0.15338	1.12254	0.16330	0.15200	0.19165	0.15452	0.34328	0.24314	0.28778
0.18562	0.15530	1.13652	0.16332	0.15311	0.19304	0.15564	0.34294	0.24470	0.29075
0.20488	0.16954	1.18785	0.17248	0.16201	0.20441	0.16459	0.33797	0.25704	0.31527
0.22972	0.18713	1.23910	0.18539	0.17262	0.21838	0.17528	0.32758	0.27129	0.34628
0.26910	0.21375	1.30831	0.20568	0.18779	0.23933	0.19052	0.30802	0.29076	0.39425

TABLE A.2.20

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
99.5%GLYCERINE SOLUTION

SURFACE TENSION= 0.06450 NEWTON/M
LIQUID VISCOSITY= 0.24600 KG/(M*SEC)
LIQUID DENSITY=1249.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VW(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	KUMAR	HUGHMARK	DECKWER
0.03040	0.02866	0.53094	0.05726	0.03807	0.06572	0.03917	0.12842	0.06720	0.06595
0.04724	0.04377	0.64339	0.07342	0.05507	0.08479	0.05656	0.18417	0.09718	0.09466
0.05818	0.05357	0.73400	0.07926	0.06502	0.09564	0.06671	0.21506	0.11453	0.11229
0.07508	0.06880	0.89722	0.08368	0.07900	0.11085	0.08095	0.25508	0.13858	0.13841
0.08877	0.07966	0.86424	0.10272	0.08930	0.12212	0.09142	0.28116	0.15597	0.15880
0.10964	0.09693	0.94541	0.11597	0.10355	0.13798	0.10589	0.31106	0.17948	0.18881
0.13040	0.11289	0.97113	0.13428	0.11630	0.15250	0.11892	0.33038	0.19987	0.21766
0.14957	0.13031	1.16138	0.12879	0.12703	0.16509	0.12969	0.34035	0.21653	0.24357
0.16518	0.14299	1.22963	0.13434	0.13515	0.17486	0.13789	0.34374	0.22879	0.26423
0.18187	0.15411	1.19164	0.15262	0.14328	0.18486	0.14611	0.34348	0.24077	0.28592
0.20731	0.17262	1.23897	0.16732	0.15475	0.19942	0.15768	0.33715	0.25713	0.31832
0.18610	0.16042	1.34895	0.13796	0.14526	0.18734	0.14810	0.34287	0.24364	0.29136
0.21705	0.18073	1.29692	0.16736	0.15888	0.20478	0.16185	0.33333	0.26287	0.33054
0.26510	0.21879	1.51763	0.17468	0.17746	0.22987	0.18058	0.30998	0.28759	0.38944

TABLE A.2.21

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
500PPM CMC-WATER

SURFACE TENSION= 0.07090 NEWTON/M
CONSISTENCY INDEX= 0.00266 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 1.00000
LIQUID DENSITY= 996.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	KUMAR	HUGHMARK	BECKNER
0.02170	0.02045	0.37458	0.05794	0.05059	0.06643	0.05053	0.08878	0.05813	0.05002
0.04009	0.03570	0.36626	0.10946	0.08192	0.09472	0.08167	0.15150	0.09468	0.08275
0.06354	0.05425	0.43444	0.14626	0.11309	0.12362	0.11278	0.21628	0.13509	0.12071
0.07980	0.06696	0.49573	0.16098	0.13093	0.14104	0.13058	0.25204	0.15869	0.14551
0.09886	0.08167	0.56858	0.17387	0.14907	0.15963	0.14869	0.28528	0.18273	0.17344
0.12030	0.09463	0.56362	0.21345	0.16678	0.17872	0.16643	0.31265	0.20604	0.20374
0.13925	0.10875	0.63584	0.21900	0.18057	0.19450	0.18020	0.32901	0.22396	0.22970
0.15920	0.12346	0.70902	0.22454	0.19362	0.21017	0.19323	0.33937	0.24061	0.25636
0.17899	0.13846	0.79057	0.22640	0.20531	0.22491	0.20491	0.34374	0.25524	0.28220
0.19644	0.14979	0.82725	0.23746	0.21478	0.23735	0.21437	0.34355	0.26685	0.30457
0.21946	0.16633	0.90657	0.24207	0.22625	0.25307	0.22581	0.33877	0.28057	0.33354
0.23772	0.17644	0.92209	0.25781	0.23463	0.26506	0.23418	0.33233	0.29036	0.35614
0.25743	0.18846	0.96077	0.26794	0.24306	0.27757	0.24260	0.32379	0.29999	0.38018
0.27648	0.19957	0.99391	0.27817	0.25069	0.28927	0.25022	0.31491	0.30849	0.40310

TABLE A.2.22

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
1000PPM CMC-WATER

SURFACE TENSION= 0.06990 NEWTON/M
CONSISTENCY INDEX= 0.00455 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 1.00000
LIQUID DENSITY= 996.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	KUMAR	HUGHMARK	DECKWER
0.02110	0.01982	0.34769	0.06069	0.04605	0.06372	0.04598	0.08682	0.05544	0.04889
0.04093	0.03649	0.37715	0.10853	0.07795	0.09346	0.07785	0.15457	0.09739	0.08417
0.06091	0.05267	0.45040	0.13524	0.10361	0.11760	0.10349	0.21035	0.13234	0.11660
0.08023	0.06769	0.51308	0.15637	0.12431	0.13791	0.12416	0.25345	0.16082	0.14615
0.09911	0.08224	0.58230	0.17020	0.14171	0.15585	0.14153	0.28619	0.18468	0.17380
0.12047	0.09808	0.64829	0.18583	0.15888	0.17447	0.15869	0.31327	0.20793	0.20397
0.14032	0.11218	0.69973	0.20054	0.17297	0.19057	0.17276	0.33007	0.22667	0.23115
0.15835	0.12354	0.72022	0.21987	0.18452	0.20437	0.18430	0.33927	0.24171	0.25524
0.17968	0.13569	0.73394	0.24482	0.19692	0.21975	0.19675	0.34385	0.25750	0.28310
0.19837	0.14926	0.80125	0.24758	0.20685	0.23268	0.20667	0.34324	0.26983	0.30703
0.22172	0.16621	0.88563	0.25036	0.21822	0.24816	0.21804	0.33783	0.28358	0.33636
0.24030	0.17702	0.91252	0.26334	0.22657	0.25999	0.22638	0.33094	0.29340	0.35931
0.26005	0.19277	1.00518	0.25871	0.23485	0.27216	0.23464	0.32215	0.30290	0.38334
0.27828	0.20088	1.00045	0.27818	0.24202	0.28304	0.24181	0.31361	0.31093	0.40525
0.29770	0.20940	1.00365	0.29662	0.24922	0.29431	0.24900	0.30502	0.31879	0.42830

TABLE A.2.23

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.05 WT% CMC-WATER

SURFACE TENSION= 0.07030 NEWTON/M
CONSISTENCY INDEX= 0.00781 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 1.00000
LIQUID DENSITY=1000.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	KUMAR	HUGHMARK	BECKNER
0.02851	0.02655	0.41295	0.06905	0.05482	0.07355	0.05493	0.11361	0.07151	0.06257
0.04191	0.03787	0.43428	0.09650	0.07418	0.09189	0.07432	0.15752	0.09848	0.08581
0.05580	0.04964	0.50595	0.11028	0.09155	0.10842	0.09171	0.19714	0.12308	0.10851
0.06789	0.05829	0.48008	0.14142	0.10496	0.12146	0.10513	0.22704	0.14218	0.12745
0.08010	0.06841	0.54869	0.14599	0.11721	0.13365	0.11738	0.25313	0.15959	0.14596
0.09841	0.08368	0.65754	0.14966	0.13359	0.15054	0.13377	0.28507	0.18273	0.17279
0.11530	0.09582	0.68255	0.16892	0.14703	0.16499	0.14721	0.30756	0.20145	0.19676
0.13567	0.11189	0.77391	0.17530	0.16154	0.18128	0.16171	0.32675	0.22129	0.22484
0.15819	0.12610	0.77992	0.20282	0.17583	0.19811	0.17601	0.33918	0.24036	0.25501
0.17553	0.14151	0.90583	0.19377	0.18582	0.21040	0.18600	0.34342	0.25336	0.27772
0.21920	0.16477	0.88271	0.24832	0.20789	0.23908	0.20815	0.33865	0.28097	0.33322
0.23897	0.17906	0.95327	0.25069	0.21671	0.25135	0.21696	0.33153	0.29154	0.35767
0.25706	0.19558	1.07484	0.23916	0.22426	0.26220	0.22450	0.32359	0.30035	0.37973

TABLE A.2.24

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.10 WT% CMC-WATER

SURFACE TENSION= 0.06670 NEWTON/M
CONSISTENCY INDEX= 0.02660 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 1.00000
LIQUID DENSITY=1001.00000 KG/(M**3)

VB(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	DECKWER
0.02440	0.02312	0.46407	0.05258	0.04084	0.06366	0.04112	0.10014	0.06535	0.05507
0.03486	0.03230	0.47340	0.07365	0.05499	0.07825	0.05534	0.13668	0.08842	0.07379
0.04612	0.04196	0.51189	0.09009	0.06863	0.09199	0.06905	0.17196	0.11064	0.09281
0.05853	0.05299	0.61813	0.09469	0.08215	0.10557	0.08263	0.20627	0.13253	0.11285
0.07077	0.06368	0.70638	0.10019	0.09421	0.11783	0.09473	0.23565	0.15183	0.13186
0.08513	0.07489	0.70755	0.12032	0.10705	0.13112	0.10761	0.26484	0.17205	0.15344
0.10036	0.08645	0.72395	0.13863	0.11937	0.14420	0.11997	0.28998	0.19106	0.17560
0.11715	0.09920	0.76440	0.15326	0.13170	0.15770	0.13233	0.31138	0.20962	0.19935
0.13567	0.11475	0.87977	0.15421	0.14404	0.17168	0.14468	0.32809	0.22767	0.22484
0.15746	0.13015	0.90788	0.17343	0.15715	0.18712	0.15783	0.33968	0.24623	0.25405
0.18205	0.14765	0.96348	0.18896	0.17048	0.20352	0.17117	0.34406	0.26436	0.28616
0.20665	0.16362	0.99251	0.20821	0.18252	0.21901	0.18322	0.34125	0.28007	0.31750
0.24711	0.19228	1.11367	0.22189	0.20009	0.24286	0.20081	0.32660	0.30180	0.36764
0.27700	0.21499	1.23745	0.22384	0.21163	0.25927	0.21243	0.31254	0.31529	0.40371

TABLE A.2.25

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS

0.15 WT% CMC-WATER

SURFACE TENSION= 0.06800 NEWTON/M
CONSISTENCY INDEX= 0.05900 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 0.97500
LIQUID DENSITY=1001.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSHMANN	KUMAR	HUGHMARK	BECKWER
0.02450	0.02357	0.84614	0.03791	0.03712	0.06128	0.03752	0.10006	0.06448	0.05525
0.03545	0.03365	0.69872	0.05073	0.05080	0.07591	0.05131	0.13805	0.08822	0.07480
0.04956	0.04569	0.63385	0.07819	0.06653	0.09219	0.06716	0.18128	0.11526	0.09846
0.06516	0.06054	0.91891	0.07091	0.08193	0.10804	0.08266	0.22198	0.14129	0.12323
0.07945	0.07084	0.73272	0.10844	0.09458	0.12119	0.09538	0.25319	0.16222	0.14499
0.09531	0.08454	0.84373	0.11296	0.10730	0.13467	0.10816	0.28153	0.18275	0.16832
0.11042	0.09511	0.79642	0.13864	0.11834	0.14665	0.11926	0.30289	0.20013	0.18990
0.12719	0.10858	0.86919	0.14633	0.12958	0.15918	0.13054	0.32074	0.21732	0.21325
0.14818	0.12411	0.91224	0.16244	0.14237	0.17393	0.14337	0.33537	0.23624	0.24171
0.16668	0.14229	1.13888	0.14635	0.15267	0.18620	0.15370	0.34212	0.25093	0.26619
0.18345	0.15323	1.11339	0.16477	0.16133	0.19685	0.16238	0.34407	0.26290	0.28796
0.20178	0.17130	1.33574	0.15108	0.17016	0.20803	0.17123	0.34245	0.27474	0.31135
0.22148	0.18094	1.21002	0.18304	0.17900	0.21958	0.18009	0.33732	0.28621	0.33606
0.24186	0.19594	1.27385	0.18987	0.18754	0.23107	0.18864	0.32944	0.29691	0.36122
0.25736	0.21555	1.38436	0.16244	0.19366	0.23953	0.19478	0.32243	0.30435	0.38009

TABLE A.2.26

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.20 WT% CMC-WATER

SURFACE TENSION= 0.07030 NEWTON/M
CONSISTENCY INDEX= 0.09430 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 0.96700
LIQUID DENSITY=1002.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	DECKWER
0.03151	0.02983	0.58912	0.05349	0.04322	0.06902	0.04368	0.12400	0.07773	0.06792
0.04084	0.03806	0.59942	0.06813	0.05368	0.08022	0.05422	0.15429	0.09630	0.08401
0.05236	0.04879	0.76838	0.06814	0.06553	0.09265	0.06615	0.18795	0.11710	0.10300
0.06294	0.05778	0.76847	0.08190	0.07552	0.10308	0.07622	0.21537	0.13440	0.11977
0.07393	0.06760	0.86433	0.08553	0.08515	0.11317	0.08591	0.24051	0.15079	0.13667
0.08690	0.07963	1.03839	0.08369	0.09566	0.12429	0.09647	0.26603	0.16834	0.15604
0.10039	0.09043	1.01163	0.09924	0.10575	0.13515	0.10661	0.28812	0.18482	0.17565
0.11906	0.10485	0.99742	0.11937	0.11851	0.14920	0.11943	0.31179	0.20508	0.20201
0.13607	0.11822	1.03706	0.13121	0.12913	0.16121	0.13010	0.32711	0.22141	0.22539
0.15576	0.13353	1.09174	0.14267	0.14041	0.17436	0.14141	0.33827	0.23818	0.25180
0.17553	0.15089	1.25056	0.14036	0.15081	0.18687	0.15185	0.34344	0.25312	0.27773
0.19297	0.15971	1.11949	0.17238	0.15933	0.19744	0.16038	0.34380	0.26494	0.30018
0.21430	0.17687	1.22697	0.17466	0.16902	0.20980	0.17010	0.34001	0.27794	0.32710
0.23591	0.19309	1.29961	0.18153	0.17813	0.22184	0.17923	0.33271	0.28973	0.35392
0.25688	0.21028	1.41603	0.18141	0.18638	0.23309	0.18748	0.32361	0.30003	0.37951
0.28406	0.23185	1.54544	0.18381	0.19632	0.24712	0.19743	0.31095	0.31197	0.41214

TABLE A.2.27

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.25 WT% CMC-WATER

SURFACE TENSION= 0.07130 NEWTON/M
CONSISTENCY INDEX= 0.16100 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 0.94300
LIQUID DENSITY=1002.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	KUMAR	HUGHMARK	HECKNER
0.02435	0.02336	0.59827	0.04070	0.03246	0.05796	0.03288	0.09849	0.06149	0.05497
0.03526	0.03392	0.92932	0.03794	0.04481	0.07188	0.04536	0.13609	0.08439	0.07447
0.04663	0.04384	0.77847	0.05990	0.05655	0.08456	0.05721	0.17124	0.10585	0.09366
0.05912	0.05509	0.86765	0.06813	0.06833	0.09706	0.06909	0.20530	0.12699	0.11377
0.07221	0.06669	0.94544	0.07638	0.07964	0.10903	0.08048	0.23624	0.14685	0.13406
0.08849	0.08052	0.98213	0.09010	0.09245	0.12270	0.09339	0.26832	0.16879	0.15838
0.10478	0.09448	1.06556	0.09834	0.10412	0.13536	0.10512	0.29387	0.18817	0.18192
0.14397	0.12640	1.17929	0.12208	0.12850	0.16282	0.12962	0.33207	0.22664	0.23607
0.16311	0.14395	1.38821	0.11750	0.13891	0.17507	0.14008	0.34067	0.24218	0.26151
0.19448	0.16584	1.32069	0.14726	0.15433	0.19390	0.15556	0.34373	0.26415	0.30208
0.21397	0.18197	1.43091	0.14954	0.16305	0.20500	0.16430	0.34030	0.27601	0.32669
0.23386	0.19675	1.47393	0.15866	0.17137	0.21589	0.17263	0.33384	0.28694	0.35139
0.25918	0.21864	1.65708	0.15640	0.18122	0.22917	0.18252	0.32297	0.29940	0.38229

TABLE A.2.28

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.3 WT% CMC-WATER

SURFACE TENSION= 0.07000 NEWTON/M
CONSISTENCY INDEX= 0.23200 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 0.95200
LIQUID DENSITY=1001.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VW(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSMANN	KUMAR	HUGHMARK	DECKWER
0.03039	0.02913	0.73081	0.04158	0.03725	0.06460	0.03786	0.12025	0.07571	0.06593
0.04255	0.04055	0.90355	0.04709	0.04965	0.07854	0.05043	0.15966	0.09995	0.08689
0.05217	0.04885	0.82083	0.06356	0.05868	0.08841	0.05957	0.18754	0.11725	0.10269
0.06269	0.05814	0.86245	0.07269	0.06790	0.09837	0.06888	0.21490	0.13453	0.11939
0.07437	0.06835	0.91890	0.08094	0.07742	0.10862	0.07849	0.24159	0.15198	0.13734
0.08696	0.07985	1.06263	0.08184	0.08695	0.11897	0.08810	0.26628	0.16901	0.15613
0.09818	0.09032	1.22680	0.08003	0.09489	0.12765	0.09611	0.28492	0.18284	0.17247
0.10972	0.09968	1.19896	0.09152	0.10258	0.13615	0.10387	0.30102	0.19591	0.18893
0.12379	0.10963	1.08228	0.11438	0.11137	0.14601	0.11274	0.31672	0.21046	0.20857
0.13980	0.12253	1.13166	0.12354	0.12069	0.15670	0.12212	0.32981	0.22541	0.23045
0.15855	0.13752	1.19505	0.13267	0.13081	0.16859	0.13231	0.33939	0.24106	0.25550
0.17087	0.14547	1.14958	0.14864	0.13705	0.17611	0.13857	0.34274	0.25041	0.27167
0.20782	0.17694	1.39840	0.14861	0.15413	0.19733	0.15572	0.34154	0.27480	0.31897

TABLE A.2.29

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.4 WT% CMC-WATER

SURFACE TENSION= 0.06500 NEWTON/M
CONSISTENCY INDEX= 0.73800 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 0.93100
LIQUID DENSITY=1002.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	MERSMANN	KUMAR	HUGHMARK	BECKNER
0.03096	0.02992	0.92754	0.03338	0.03278	0.06284	0.03335	0.12419	0.08179	0.06694
0.04229	0.03972	0.69563	0.06079	0.04303	0.07535	0.04378	0.16130	0.10541	0.08645
0.05218	0.04782	0.62335	0.08372	0.05139	0.08516	0.05225	0.19029	0.12396	0.10271
0.06536	0.06103	0.98534	0.06634	0.06177	0.09707	0.06275	0.22425	0.14612	0.12354
0.07749	0.07079	0.89668	0.08641	0.07063	0.10717	0.07172	0.25105	0.16431	0.14204
0.09373	0.08511	1.01959	0.09193	0.08164	0.11972	0.08284	0.28075	0.18595	0.16603
0.11047	0.10026	1.19559	0.09240	0.09209	0.13171	0.09340	0.30453	0.20551	0.18998
0.12174	0.10883	1.14780	0.10607	0.09868	0.13938	0.10005	0.31697	0.21736	0.20574
0.13348	0.11504	0.96631	0.13813	0.10520	0.14704	0.10663	0.32714	0.22873	0.22186
0.14883	0.13067	1.21975	0.12201	0.11327	0.15668	0.11474	0.33653	0.24229	0.24257
0.16263	0.14351	1.38328	0.11757	0.12012	0.16498	0.12164	0.34160	0.25337	0.26087
0.17542	0.14878	1.15529	0.15184	0.12616	0.17240	0.12772	0.34379	0.26282	0.27758
0.18737	0.16020	1.29224	0.14500	0.13155	0.17914	0.13316	0.34392	0.27102	0.29299
0.20511	0.16880	1.15875	0.17701	0.13917	0.18882	0.14081	0.34128	0.28220	0.31556

TABLE A.2.30

COMPARISON OF HOLDUP DATA WITH THE EXISTING CORRELATIONS
0.5 WT% CMC-WATER

SURFACE TENSION= 0.07210 NEWTON/M
CONSISTENCY INDEX= 1.72800 KG/(M*SEC)
FLOW BEHAVIOUR INDEX= 0.91300
LIQUID DENSITY=1008.00000 KG/(M**3)

VG(M/S)	VDRIFT(M/S)	VM(M/S)	EXPTL	AKITA&YOSHIDA	HIKITA	HERSHMANN	KUMAR	HUGHMARK	BECKNER
0.02403	0.02309	0.61398	0.03914	0.02298	0.05110	0.02350	0.09723	0.05988	0.05439
0.03439	0.03249	0.61954	0.05552	0.03188	0.06298	0.03257	0.13311	0.08149	0.07297
0.04498	0.04273	0.89826	0.05007	0.04039	0.07363	0.04124	0.16620	0.10147	0.09093
0.05579	0.05142	0.71290	0.07825	0.04857	0.08348	0.04954	0.19648	0.12001	0.10849
0.06767	0.06287	0.95364	0.07096	0.05701	0.09343	0.05811	0.22585	0.13849	0.12710
0.08006	0.07395	1.04755	0.07643	0.06527	0.10304	0.06650	0.25236	0.15594	0.14590
0.09297	0.08346	0.90847	0.10234	0.07336	0.11241	0.07470	0.27577	0.17241	0.16493
0.12319	0.10834	1.02225	0.12051	0.09056	0.13245	0.09210	0.31544	0.20543	0.20774
0.13455	0.11956	1.20773	0.11141	0.09648	0.13945	0.09809	0.32546	0.21619	0.22333
0.14519	0.12967	1.35852	0.10687	0.10180	0.14576	0.10346	0.33269	0.22557	0.23770
0.15725	0.13618	1.17211	0.13416	0.10757	0.15270	0.10928	0.33857	0.23548	0.25378
0.17090	0.14992	1.39202	0.12277	0.11381	0.16030	0.11558	0.34256	0.24587	0.27171
0.18811	0.16202	1.35646	0.13867	0.12127	0.16951	0.12310	0.34406	0.25786	0.29394

TABLE A.2.31

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-120 MICRON SAND(17.7 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 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.	PORT#
0.06860	0.05973	0.53046	0.12932	0.83009	0.04059	0.05959	0.12010	2
0.06860	0.06030	0.56721	0.12094	0.84354	0.03551	0.05959	0.12010	3
0.06860	0.06180	0.69178	0.09917	0.87852	0.02231	0.05959	0.12010	4
0.07893	0.06575	0.47260	0.16702	0.77451	0.05848	0.06593	0.13142	2
0.07893	0.06859	0.60213	0.13109	0.83221	0.03670	0.06593	0.13142	3
0.07893	0.06864	0.60554	0.13035	0.83340	0.03625	0.06593	0.13142	4
0.08855	0.07200	0.47367	0.18696	0.75415	0.05890	0.07162	0.14131	2
0.08855	0.07440	0.55416	0.15980	0.79776	0.04244	0.07162	0.14131	3
0.08855	0.07395	0.53690	0.16494	0.78951	0.04555	0.07162	0.14131	4
0.09829	0.08059	0.54582	0.18008	0.76685	0.05307	0.07721	0.15076	2
0.09829	0.08069	0.54876	0.17912	0.76840	0.05248	0.07721	0.15076	3
0.09629	0.08339	0.64817	0.15165	0.81252	0.03583	0.07721	0.15076	4
0.10946	0.08894	0.58386	0.18749	0.75830	0.05422	0.08343	0.16099	2
0.10946	0.09222	0.69499	0.15751	0.80645	0.03605	0.08343	0.16099	3
0.10946	0.09276	0.71743	0.15258	0.81436	0.03306	0.08343	0.16099	4
0.11934	0.09667	0.62841	0.18990	0.76108	0.04901	0.08878	0.16954	2
0.11934	0.09764	0.65631	0.18183	0.77405	0.04412	0.08878	0.16954	3
0.11934	0.09988	0.73195	0.16304	0.80423	0.03273	0.08878	0.16954	4
0.13147	0.10364	0.62120	0.21164	0.73838	0.04999	0.09519	0.17951	2
0.13147	0.10619	0.68381	0.19226	0.76950	0.03824	0.09519	0.17951	3
0.13147	0.10729	0.71479	0.18393	0.78288	0.03319	0.09519	0.17951	4
0.14009	0.11248	0.71080	0.19709	0.76592	0.03699	0.09964	0.18626	2
0.14009	0.11302	0.72493	0.19324	0.77209	0.03467	0.09964	0.18626	3
0.14009	0.11517	0.78766	0.17785	0.79681	0.02534	0.09964	0.18626	4

TABLE A.2.31
(Continued)

VS(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.	PORT#
0.15073	0.12206	0.79248	0.19020	0.77948	0.03032	0.10504	0.19426	2
0.15073	0.12286	0.81521	0.18490	0.78800	0.02711	0.10504	0.19426	3
0.15073	0.12419	0.85622	0.17604	0.80222	0.02174	0.10504	0.19426	4
0.16103	0.13043	0.84734	0.19004	0.77971	0.03025	0.11016	0.20166	2
0.16103	0.12877	0.80387	0.20032	0.76320	0.03648	0.11016	0.20166	3
0.16103	0.13149	0.87793	0.18342	0.79034	0.02624	0.11016	0.20166	4
0.17697	0.13966	0.83932	0.21085	0.76018	0.02896	0.11791	0.21255	2
0.17697	0.14010	0.84947	0.20833	0.76423	0.02744	0.11791	0.21255	3
0.17697	0.14258	0.91060	0.19435	0.78669	0.01896	0.11791	0.21255	4
0.19222	0.14764	0.82880	0.23193	0.74296	0.02511	0.12513	0.22237	2
0.19222	0.14783	0.83244	0.23091	0.74459	0.02450	0.12513	0.22237	3
0.19222	0.14977	0.87030	0.22087	0.76072	0.01841	0.12513	0.22237	4
0.20961	0.15806	0.85229	0.24594	0.72548	0.02858	0.13319	0.23295	2
0.20961	0.16221	0.92691	0.22614	0.75728	0.01658	0.13319	0.23295	3
0.20961	0.16091	0.90226	0.23231	0.74736	0.02033	0.13319	0.23295	4
0.25136	0.19630	1.14763	0.21902	0.76536	0.01561	0.15179	0.25712	2
0.25136	0.19294	1.08150	0.23242	0.74386	0.02373	0.15179	0.25712	3
0.25136	0.19706	1.16364	0.21601	0.77020	0.01379	0.15179	0.25712	4
0.27481	0.21013	1.16758	0.23536	0.74301	0.02162	0.16186	0.26677	2
0.27481	0.21025	1.16985	0.23491	0.74375	0.02135	0.16186	0.26677	3
0.27481	0.21190	1.20055	0.22890	0.75339	0.01770	0.16186	0.26677	4

TABLE A.2.32

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-120 MICRON SAND(38.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 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.	PORT#
0.06909	0.06031	0.54412	0.12697	0.77225	0.10078	0.05990	0.12065	2
0.06909	0.06253	0.72837	0.09485	0.82364	0.08131	0.05990	0.12065	3
0.06909	0.06401	0.93961	0.07353	0.85808	0.06839	0.05990	0.12065	4
0.07955	0.06968	0.64094	0.12411	0.78016	0.09573	0.06630	0.13208	2
0.07955	0.07044	0.69473	0.11451	0.79559	0.08990	0.06630	0.13208	3
0.07955	0.07301	0.96748	0.08222	0.84744	0.07034	0.06630	0.13208	4
0.09109	0.07839	0.65346	0.13940	0.75784	0.10276	0.07309	0.14382	2
0.09109	0.08242	0.95647	0.09524	0.82876	0.07600	0.07309	0.14382	3
0.09109	0.05525	0.23151	0.39347	0.34979	0.25674	0.07309	0.14382	4
0.09962	0.08730	0.80550	0.12367	0.78588	0.09045	0.07795	0.15200	2
0.09962	0.08974	1.00471	0.09915	0.82526	0.07559	0.07795	0.15200	3
0.09962	0.09471	2.02210	0.04926	0.90538	0.04536	0.07795	0.15200	4
0.11159	0.09872	0.96762	0.11532	0.79593	0.08875	0.08459	0.16286	2
0.11159	0.09992	1.06732	0.10455	0.81323	0.08222	0.08459	0.16286	3
0.11159	0.10181	1.27388	0.08760	0.84046	0.07194	0.08459	0.16286	4
0.12286	0.11145	1.32331	0.09284	0.82431	0.08284	0.09066	0.17250	2
0.12286	0.10952	1.13167	0.10857	0.79906	0.09237	0.09066	0.17250	3
0.12286	0.11340	1.59537	0.07701	0.84974	0.07325	0.09066	0.17250	4
0.13632	0.11250	0.78009	0.17475	0.71773	0.10752	0.09771	0.18335	2
0.13632	0.12053	1.17683	0.11584	0.81235	0.07181	0.09771	0.18335	3
0.13632	0.11945	1.10160	0.12375	0.79964	0.07661	0.09771	0.18335	4
0.14745	0.12402	0.92793	0.15890	0.73485	0.10626	0.10338	0.19183	2
0.14745	0.12281	0.88251	0.16707	0.72171	0.11122	0.10338	0.19183	3
0.14745	0.13185	1.39401	0.10577	0.82017	0.07406	0.10338	0.19183	4

TABLE A.2.32
(Continued)

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.	PORT#
0.16152	0.13689	1.05925	0.15249	0.74789	0.09962	0.11040	0.20201	2
0.16152	0.14038	1.23374	0.13092	0.78253	0.08655	0.11040	0.20201	3
0.16152	0.13969	1.19490	0.13518	0.77570	0.08913	0.11040	0.20201	4
0.10728	0.09359	0.84087	0.12758	0.76154	0.11088	0.08223	0.15903	2
0.10728	0.09532	0.96252	0.11146	0.78743	0.10111	0.08223	0.15903	3
0.10728	0.09879	1.35603	0.07911	0.83938	0.08150	0.08223	0.15903	4
0.12587	0.10718	0.84758	0.14851	0.74036	0.11113	0.09226	0.17499	2
0.12587	0.11300	1.23099	0.10225	0.81465	0.08309	0.09226	0.17499	3
0.12587	0.11284	1.21593	0.10352	0.81262	0.08386	0.09226	0.17499	4
0.15367	0.12756	0.90435	0.16992	0.71435	0.11573	0.10651	0.19640	2
0.15367	0.12894	0.95494	0.16092	0.72881	0.11027	0.10651	0.19640	3
0.15367	0.13510	1.27163	0.12084	0.79318	0.08598	0.10651	0.19640	4
0.17910	0.14657	0.98609	0.18162	0.71499	0.10339	0.11892	0.21395	2
0.17910	0.14686	1.06092	0.16881	0.73556	0.09562	0.11892	0.21395	3
0.17910	0.15439	1.29797	0.13798	0.78508	0.07694	0.11892	0.21395	4
0.20871	0.17067	1.14516	0.18225	0.71121	0.10654	0.13277	0.23242	2
0.20871	0.17336	1.23224	0.16937	0.73189	0.09873	0.13277	0.23242	3
0.20871	0.17736	1.38970	0.15018	0.76271	0.08710	0.13277	0.23242	4
0.26320	0.20031	1.10153	0.23894	0.65836	0.10270	0.15691	0.26209	2
0.26320	0.20517	1.19383	0.22046	0.68803	0.09151	0.15691	0.26209	3
0.26320	0.20288	1.14842	0.22918	0.67403	0.09679	0.15691	0.26209	4
0.26320	0.21549	1.45213	0.18125	0.75101	0.06774	0.15691	0.26209	5
0.26320	0.24491	3.78833	0.06948	0.93052	0.00000	0.15691	0.26209	6

TABLE A.2.33

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-120 MICRON SAND(47.3 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 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.	PORT#
0.08335	0.07344	0.70074	0.11895	0.70910	0.17196	0.06856	0.13604	2
0.08335	0.07437	0.77339	0.10777	0.72704	0.16518	0.06856	0.13604	3
0.09689	0.08502	0.79087	0.12251	0.70897	0.16852	0.07641	0.14942	2
0.09689	0.08567	0.83718	0.11573	0.71986	0.16442	0.07641	0.14942	3
0.11231	0.09719	0.83434	0.13461	0.69448	0.17091	0.08499	0.16350	2
0.11231	0.10020	1.04110	0.10788	0.73741	0.15471	0.08499	0.16350	3
0.11231	0.10329	1.39761	0.08036	0.78161	0.13803	0.08499	0.16350	4
0.12364	0.10730	0.93557	0.13215	0.70396	0.16388	0.09107	0.17314	2
0.12364	0.10806	0.98156	0.12596	0.71391	0.16013	0.09107	0.17314	3
0.12364	0.11378	1.55107	0.07971	0.78819	0.13210	0.09107	0.17314	4
0.13674	0.11856	1.02841	0.13297	0.71822	0.14882	0.09792	0.18367	2
0.13674	0.11537	0.87480	0.15631	0.68072	0.16296	0.09792	0.18367	3
0.13674	0.12060	1.15860	0.11802	0.74222	0.13976	0.09792	0.18367	4
0.17310	0.14461	1.05166	0.16460	0.66045	0.17495	0.11604	0.20997	2
0.17310	0.14822	1.20425	0.14374	0.69394	0.16231	0.11604	0.20997	3
0.17310	0.15110	1.36217	0.12708	0.72071	0.15221	0.11604	0.20997	4
0.08359	0.08147	3.28499	0.02545	0.79251	0.18204	0.06871	0.13629	2
0.10846	0.09521	0.88799	0.12214	0.69281	0.18505	0.08288	0.16009	2
0.10846	0.09810	1.13583	0.09549	0.73561	0.16890	0.08288	0.16009	3
0.10846	0.10031	1.44313	0.07516	0.76827	0.15657	0.08288	0.16009	4
0.13703	0.11103	0.72227	0.18973	0.62983	0.18045	0.09807	0.18390	2
0.13703	0.12073	1.15207	0.11894	0.74351	0.13755	0.09807	0.18390	3
0.13703	0.12027	1.12051	0.12230	0.73813	0.13958	0.09807	0.18390	4
0.16714	0.14339	1.17604	0.14212	0.70491	0.15297	0.11315	0.20592	2
0.16714	0.14927	1.56285	0.10695	0.76141	0.13165	0.11315	0.20592	3
0.16714	0.14108	1.07192	0.15593	0.68274	0.16133	0.11315	0.20592	4
0.20943	0.17542	1.28958	0.16240	0.68342	0.15418	0.13310	0.23284	2
0.20943	0.17499	1.27361	0.16444	0.68015	0.15541	0.13310	0.23284	3
0.20943	0.17216	1.17676	0.17797	0.65841	0.16362	0.13310	0.23284	4
0.24397	0.19449	1.20288	0.20282	0.63098	0.16620	0.14857	0.25391	2
0.24397	0.20969	1.73616	0.14052	0.73103	0.12844	0.14857	0.25391	3
0.24397	0.21327	1.93896	0.12583	0.75464	0.11953	0.14857	0.25391	4
0.28328	0.21876	1.24385	0.22774	0.61038	0.16187	0.16544	0.27007	2
0.28328	0.22697	1.42508	0.19878	0.65690	0.14432	0.16544	0.27007	3
0.28328	0.23823	1.78141	0.15902	0.72076	0.12022	0.16544	0.27007	4

TABLE A.2.34

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-275 MICRON SAND(10.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES=275.0000*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.	PORT#
0.06184	0.05377	0.47349	0.13061	0.85241	0.01698	0.06357	0.11225	1
0.06184	0.05393	0.48336	0.12795	0.85669	0.01536	0.06357	0.11225	2
0.06184	0.05480	0.54315	0.11386	0.87931	0.00683	0.06357	0.11225	3
0.06184	0.05478	0.54110	0.11429	0.87862	0.00709	0.06357	0.11225	4
0.07669	0.06550	0.52536	0.14598	0.83108	0.02295	0.07423	0.12903	1
0.07669	0.06637	0.56364	0.13463	0.84930	0.01607	0.07423	0.12903	2
0.07669	0.06641	0.57185	0.13411	0.85014	0.01575	0.07423	0.12903	3
0.07669	0.06720	0.61945	0.12380	0.86669	0.00951	0.07423	0.12903	4
0.09319	0.07789	0.56748	0.16422	0.81065	0.02513	0.08541	0.14588	1
0.09319	0.07902	0.61287	0.15206	0.83018	0.01775	0.08541	0.14588	2
0.09319	0.07985	0.65098	0.14316	0.84448	0.01236	0.08541	0.14588	3
0.09319	0.08051	0.68456	0.13613	0.85576	0.00811	0.08541	0.14588	4
0.10468	0.08565	0.57602	0.18173	0.79420	0.02407	0.09286	0.15668	1
0.10468	0.08711	0.62369	0.16784	0.81651	0.01565	0.09286	0.15668	2
0.10468	0.08818	0.66406	0.15763	0.83290	0.00947	0.09286	0.15668	3
0.10468	0.08863	0.68294	0.15327	0.83990	0.00683	0.09286	0.15668	4
0.11754	0.09605	0.64294	0.18292	0.79356	0.02362	0.10095	0.16802	1
0.11754	0.09708	0.67519	0.17409	0.80759	0.01832	0.10095	0.16802	2
0.11754	0.09831	0.71851	0.16359	0.82445	0.01196	0.10095	0.16802	3
0.11754	0.09902	0.74575	0.15761	0.83404	0.00834	0.10095	0.16802	4

TABLE A.2.34
(Continued)

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.	PORT#
0.13256	0.10745	0.69990	0.18939	0.78078	0.02983	0.11007	0.18038	1
0.13256	0.10898	0.74518	0.17788	0.79927	0.02285	0.11007	0.18038	2
0.13256	0.11006	0.78102	0.16972	0.81237	0.01790	0.11007	0.18038	3
0.13256	0.11201	0.85515	0.15501	0.83600	0.00899	0.11007	0.18038	4
0.14797	0.11597	0.68410	0.21631	0.74809	0.03560	0.11915	0.19222	1
0.14797	0.11900	0.75580	0.19579	0.78105	0.023[illegible]7	0.11915	0.19222	2
0.14797	0.12053	0.79786	0.18546	0.79763	0.01691	0.11915	0.19222	3
0.14797	0.12192	0.84050	0.17605	0.81274	0.01121	0.11915	0.19222	4
0.16528	0.12555	0.69759	0.24038	0.72054	0.03909	0.12902	0.20463	1
0.16528	0.13061	0.78784	0.20979	0.76966	0.02055	0.12902	0.20463	2
0.16528	0.13176	0.81496	0.20281	0.78087	0.01632	0.12902	0.20463	3
0.16528	0.13332	0.85483	0.19335	0.79606	0.01059	0.12902	0.20463	4
0.18552	0.14301	0.80971	0.22912	0.74195	0.02894	0.14021	0.21812	1
0.18552	0.14599	0.87080	0.21304	0.76776	0.01919	0.14021	0.21812	2
0.18552	0.14784	0.91344	0.20310	0.78374	0.01317	0.14021	0.21812	3
0.18552	0.14800	0.91736	0.20223	0.78513	0.01264	0.14021	0.21812	4
0.20495	0.16011	0.93674	0.21879	0.75964	0.02157	0.15064	0.23017	1
0.20495	0.16159	0.96870	0.21157	0.77123	0.01720	0.15064	0.23017	2
0.20495	0.16266	0.99322	0.20634	0.77962	0.01403	0.15064	0.23017	3
0.20495	0.16432	1.03388	0.19823	0.79265	0.00912	0.15064	0.23017	4

TABLE A.2.35

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-275 MICRON SAND(20.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES=275.0000*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.	PORT#
0.05415	0.04858	0.52631	0.10289	0.87532	0.02180	0.05777	0.10280	1
0.05415	0.04840	0.50363	0.10625	0.86991	0.02384	0.05777	0.10280	2
0.05415	0.04890	0.55826	0.09700	0.88478	0.01823	0.05777	0.10280	3
0.05415	0.04957	0.64052	0.08454	0.90478	0.01068	0.05777	0.10280	4
0.06253	0.05449	0.48657	0.12851	0.84414	0.02735	0.06408	0.11306	1
0.06253	0.05459	0.49248	0.12697	0.84662	0.02641	0.06408	0.11306	2
0.06253	0.05555	0.56048	0.11156	0.87136	0.01708	0.06408	0.11306	3
0.06253	0.05600	0.59936	0.10450	0.88270	0.01280	0.06408	0.11306	4
0.07197	0.06300	0.57742	0.12464	0.85036	0.02500	0.07091	0.12388	1
0.07197	0.06190	0.51430	0.13993	0.82580	0.03427	0.07091	0.12388	2
0.07197	0.06276	0.56281	0.12787	0.84517	0.02696	0.07091	0.12388	3
0.07197	0.06407	0.65555	0.10978	0.87422	0.01600	0.07091	0.12389	4
0.08175	0.06864	0.50983	0.16035	0.79913	0.04052	0.07772	0.13438	1
0.08175	0.06905	0.52600	0.15542	0.80705	0.03753	0.07772	0.13438	2
0.08175	0.07067	0.60297	0.13558	0.83891	0.02550	0.07772	0.13438	3
0.08175	0.07249	0.72171	0.11328	0.87474	0.01198	0.07772	0.13438	4
0.09276	0.07851	0.60391	0.15361	0.81439	0.03201	0.08513	0.14546	1
0.09276	0.07826	0.59316	0.15639	0.80992	0.03369	0.08513	0.14546	2
0.09276	0.08045	0.69906	0.13270	0.84797	0.01933	0.08513	0.14546	3
0.09276	0.08153	0.76600	0.12110	0.86659	0.01231	0.08513	0.14546	4
0.10411	0.08655	0.61711	0.16871	0.79292	0.03838	0.09250	0.15616	1
0.10411	0.08866	0.70143	0.14843	0.82549	0.02609	0.09250	0.15616	2
0.10411	0.08893	0.71419	0.14577	0.82975	0.02448	0.09250	0.15616	3
0.10411	0.08989	0.76217	0.13660	0.84449	0.01892	0.09250	0.15616	4
0.11500	0.09619	0.70289	0.16362	0.79663	0.03975	0.09937	0.16584	1
0.11500	0.09646	0.71306	0.16128	0.80038	0.03834	0.09937	0.16584	2
0.11500	0.09931	0.84295	0.13643	0.84029	0.02328	0.09937	0.16584	3
0.11500	0.10096	0.94190	0.12210	0.86331	0.01459	0.09937	0.16584	4
0.12832	0.10385	0.67294	0.19069	0.76372	0.04559	0.10753	0.17698	1
0.12832	0.10617	0.74338	0.17262	0.79274	0.03464	0.10753	0.17698	2
0.12832	0.10789	0.80577	0.15925	0.81420	0.02654	0.10753	0.17698	3
0.12832	0.11017	0.90711	0.14145	0.84278	0.01576	0.10753	0.17698	4
0.14282	0.11188	0.65923	0.21665	0.72978	0.05357	0.11615	0.18835	1
0.14282	0.11651	0.77514	0.18426	0.78181	0.03393	0.11615	0.18835	2
0.14282	0.11829	0.83136	0.17180	0.80182	0.02638	0.11615	0.18835	3
0.14282	0.12086	0.92884	0.15377	0.83078	0.01545	0.11615	0.18835	4

TABLE A.2.35
(Continued)

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.	PORT#
0.15894	0.12772	0.80920	0.19642	0.75560	0.04798	0.12544	0.20019	1
0.15894	0.13069	0.89403	0.17778	0.78553	0.03668	0.12544	0.20019	2
0.15894	0.13478	1.04538	0.15205	0.82687	0.02109	0.12544	0.20019	3
0.15894	0.13581	1.09184	0.14558	0.83726	0.01716	0.12544	0.20019	4
0.17676	0.13515	0.75091	0.23540	0.71411	0.05049	0.13542	0.21241	1
0.17676	0.13982	0.84570	0.20902	0.75649	0.03450	0.13542	0.21241	2
0.17676	0.14410	0.95664	0.18478	0.79542	0.01981	0.13542	0.21241	3
0.17676	0.14565	1.00431	0.17601	0.80950	0.01449	0.13542	0.21241	4
0.19708	0.15058	0.83526	0.23596	0.72531	0.03873	0.14645	0.22539	1
0.19708	0.15125	0.84740	0.23258	0.73074	0.03668	0.14645	0.22539	2
0.19708	0.15689	0.96630	0.20396	0.77670	0.01934	0.14645	0.22539	3
0.19708	0.15855	1.00801	0.19552	0.79026	0.01422	0.14645	0.22539	4
0.19708	0.15967	1.03809	0.18985	0.79936	0.01079	0.14645	0.22539	5
0.19708	0.16318	1.14552	0.17205	0.82795	0.00000	0.14645	0.22539	6
0.21795	0.16076	0.83051	0.26243	0.69392	0.04365	0.15746	0.23781	1
0.21795	0.16693	0.93106	0.23409	0.73943	0.02647	0.15746	0.23781	2
0.21795	0.16947	0.97984	0.22244	0.75815	0.01941	0.15746	0.23781	3
0.21795	0.17241	1.04312	0.20894	0.77983	0.01123	0.15746	0.23781	4
0.21795	0.17364	1.07187	0.20334	0.78883	0.00783	0.15746	0.23781	5
0.21795	0.17645	1.14463	0.19042	0.80958	0.00000	0.15746	0.23781	6
0.23947	0.17965	0.95873	0.24977	0.72542	0.02481	0.16850	0.25190	1
0.23947	0.17997	0.96383	0.24845	0.72754	0.02401	0.16850	0.25190	2
0.23947	0.18343	1.02342	0.23399	0.75077	0.01524	0.16850	0.25190	3
0.23947	0.18550	1.06257	0.22537	0.76462	0.01002	0.16850	0.25190	4
0.23947	0.18675	1.08779	0.22014	0.77301	0.00685	0.16850	0.25190	5
0.23947	0.18946	1.14666	0.20884	0.79116	0.00000	0.16850	0.25190	6
0.26166	0.19661	1.05258	0.24859	0.72453	0.02688	0.17960	0.26146	1
0.26166	0.19926	1.09728	0.23846	0.74080	0.02074	0.17960	0.26146	2
0.26166	0.20141	1.13647	0.23024	0.75400	0.01576	0.17960	0.26146	3
0.26166	0.20461	1.20015	0.21802	0.77362	0.00836	0.17960	0.26146	4
0.26166	0.20494	1.20711	0.21676	0.77564	0.00759	0.17960	0.26146	5
0.26166	0.20822	1.28116	0.20424	0.79576	0.00000	0.17960	0.26146	6

TABLE A.2.36

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-275 MICRON SAND(30.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES=275.0000*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.	PORT#
0.08030	0.06648	0.46667	0.17207	0.78306	0.04487	0.07673	0.13286	1
0.08030	0.06842	0.54280	0.14794	0.82182	0.03024	0.07673	0.13286	2
0.08030	0.07131	0.71716	0.11197	0.87959	0.00844	0.07673	0.13286	3
0.08030	0.07184	0.76221	0.10535	0.89022	0.00443	0.07673	0.13286	4
0.09054	0.07350	0.48095	0.18825	0.76206	0.04969	0.08365	0.14329	1
0.09054	0.07806	0.65682	0.13785	0.84302	0.01914	0.08365	0.14329	2
0.09054	0.07919	0.72228	0.12535	0.86308	0.01157	0.08365	0.14328	3
0.09054	0.07993	0.77281	0.11716	0.87625	0.00660	0.08365	0.14328	4
0.10195	0.08507	0.61585	0.16554	0.79578	0.03863	0.09111	0.15417	1
0.10195	0.08698	0.69433	0.14683	0.82583	0.02734	0.09111	0.15417	2
0.10195	0.08830	0.76162	0.13386	0.84667	0.01947	0.09111	0.15417	3
0.10195	0.09019	0.88350	0.11539	0.87633	0.00828	0.09111	0.15417	4
0.11356	0.08904	0.52597	0.21591	0.70379	0.08030	0.09847	0.16459	1
0.11356	0.09592	0.72684	0.15624	0.79962	0.04414	0.09847	0.16459	2
0.11356	0.09615	0.74056	0.15335	0.80427	0.04238	0.09847	0.16459	3
0.11356	0.09963	0.92551	0.12270	0.85349	0.02381	0.09847	0.16459	4
0.12658	0.09963	0.59454	0.21290	0.70195	0.08515	0.10647	0.17556	1
0.12658	0.10570	0.76738	0.16495	0.77897	0.05609	0.10647	0.17556	2
0.12658	0.10646	0.79640	0.15894	0.78852	0.05244	0.10647	0.17556	3
0.12658	0.11045	0.99366	0.12739	0.83929	0.03332	0.10647	0.17556	4
0.14189	0.11040	0.63928	0.22195	0.68964	0.08841	0.11560	0.18764	1
0.14189	0.11698	0.80824	0.17555	0.76415	0.06029	0.11560	0.18764	2
0.14189	0.12275	1.05166	0.13492	0.82942	0.03566	0.11560	0.18764	3
0.14189	0.12604	1.27048	0.11168	0.86674	0.02158	0.11560	0.18764	4
0.15492	0.12046	0.69640	0.22246	0.69435	0.08318	0.12315	0.19731	1
0.15492	0.12837	0.90377	0.17142	0.77633	0.05225	0.12315	0.19731	2
0.15492	0.13240	1.06539	0.14542	0.81810	0.03649	0.12315	0.19731	3
0.15492	0.13739	1.36860	0.11320	0.86984	0.01696	0.12315	0.19731	4
0.17463	0.12792	0.65283	0.26750	0.64898	0.08352	0.13424	0.21099	1
0.17463	0.13754	0.82208	0.21242	0.73743	0.05015	0.13424	0.21099	2
0.17463	0.14180	0.92892	0.18799	0.77667	0.03534	0.13424	0.21099	3
0.17463	0.14519	1.03574	0.16861	0.80781	0.02359	0.13424	0.21099	4
0.17463	0.14832	1.15905	0.15067	0.83662	0.01272	0.13424	0.21099	5
0.17463	0.15198	1.34658	0.12969	0.87031	0.00000	0.13424	0.21099	6

TABLE A.2.36
(Continued)

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.	PORT#
0.19165	0.13663	0.66753	0.28710	0.61749	0.09540	0.14353	0.22201	1
0.19165	0.15196	0.92536	0.20711	0.74597	0.04692	0.14353	0.22201	2
0.19165	0.15327	0.95702	0.20026	0.75697	0.04277	0.14353	0.22201	3
0.19165	0.15714	1.06417	0.18009	0.76936	0.03055	0.14353	0.22201	4
0.19165	0.16149	1.21797	0.15735	0.82588	0.01677	0.14353	0.22201	5
0.19165	0.16680	1.47777	0.12969	0.87031	0.00000	0.14353	0.22201	6
0.21071	0.16448	0.96032	0.21942	0.71508	0.06550	0.15368	0.23360	1
0.21071	0.16574	0.98715	0.21346	0.72466	0.06189	0.15368	0.23360	2
0.21071	0.17207	1.14893	0.18340	0.77293	0.04367	0.15368	0.23360	3
0.21071	0.17578	1.27083	0.16581	0.80118	0.03301	0.15368	0.23360	4
0.21071	0.17788	1.35211	0.15584	0.81719	0.02697	0.15368	0.23360	5
0.21071	0.18725	1.89246	0.11134	0.88866	0.00000	0.15368	0.23360	6
0.23220	0.17107	0.88200	0.26326	0.65857	0.07817	0.16480	0.24582	1
0.23220	0.17830	1.00027	0.23213	0.70856	0.05931	0.16480	0.24582	2
0.23220	0.17935	1.02024	0.22759	0.71586	0.05655	0.16480	0.24582	3
0.23220	0.18854	1.23488	0.18603	0.77939	0.03258	0.16480	0.24582	4
0.23220	0.19191	1.33843	0.17348	0.80275	0.02376	0.16480	0.24582	5
0.23220	0.20102	1.72923	0.13428	0.86572	0.00000	0.16480	0.24582	6
0.25504	0.19256	1.04110	0.24497	0.67960	0.07544	0.17632	0.25868	1
0.25504	0.19686	1.11799	0.22812	0.70666	0.06522	0.17632	0.25868	2
0.25504	0.20177	1.22111	0.20886	0.73759	0.05355	0.17632	0.25868	3
0.25504	0.21107	1.47942	0.17239	0.79616	0.03145	0.17632	0.25868	4
0.25504	0.21491	1.62116	0.15732	0.82037	0.02231	0.17632	0.25868	5
0.25504	0.22430	2.11650	0.12050	0.87950	0.00000	0.17632	0.25868	6
0.27290	0.19567	0.96434	0.28299	0.62692	0.09009	0.18513	0.26602	1
0.27290	0.20431	1.08585	0.25133	0.67778	0.07090	0.18513	0.26602	2
0.27290	0.21412	1.26689	0.21541	0.73546	0.04913	0.18513	0.26602	3
0.27290	0.22113	1.43849	0.18971	0.77673	0.03355	0.18513	0.26602	4
0.27290	0.22693	1.61993	0.16847	0.81086	0.02068	0.18513	0.26602	5
0.27290	0.23624	2.03130	0.13435	0.86565	0.00000	0.18513	0.26602	6

TABLE A.2.37

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-650 MICRON SAND(10.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES=650.0000*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.	PORT#
0.07977	0.06783	0.53321	0.14960	0.83858	0.01182	0.08823	0.13230	1
0.07977	0.06849	0.56434	0.14135	0.85183	0.00682	0.08823	0.13230	2
0.07977	0.06874	0.57723	0.13819	0.85690	0.00491	0.08823	0.13230	3
0.07977	0.06924	0.60460	0.13193	0.86695	0.00112	0.08823	0.13230	4
0.08983	0.07430	0.51971	0.17285	0.80345	0.02370	0.09611	0.14258	1
0.08983	0.07674	0.61618	0.14579	0.84691	0.00730	0.09611	0.14258	2
0.08983	0.07717	0.63733	0.14095	0.85468	0.00437	0.09611	0.14258	3
0.08983	0.07750	0.65431	0.13729	0.86055	0.00215	0.09611	0.14258	4
0.10028	0.08356	0.60150	0.16671	0.81944	0.01385	0.10403	0.15262	1
0.10028	0.08414	0.62302	0.16095	0.82869	0.01036	0.10403	0.15262	2
0.10029	0.08447	0.63619	0.15762	0.83404	0.00834	0.10403	0.15262	3
0.10028	0.08551	0.68109	0.14723	0.85073	0.00204	0.10403	0.15262	4
0.11093	0.08993	0.58584	0.18935	0.79584	0.01460	0.11188	0.16228	1
0.11093	0.09135	0.62841	0.17653	0.81644	0.00703	0.11188	0.16228	2
0.11093	0.09194	0.64810	0.17117	0.82506	0.00378	0.11188	0.16228	3
0.11093	0.09225	0.65887	0.16837	0.82955	0.00208	0.11188	0.16228	4
0.12393	0.10003	0.64260	0.19285	0.78908	0.01807	0.12117	0.17338	1
0.12393	0.10194	0.69855	0.17741	0.81389	0.00871	0.12117	0.17338	2
0.12393	0.10277	0.72583	0.17074	0.82460	0.00467	0.12117	0.17338	3
0.12393	0.10337	0.74708	0.16588	0.83240	0.00172	0.12117	0.17338	4
0.13739	0.11175	0.73603	0.18666	0.79903	0.01430	0.13051	0.18418	1
0.13739	0.11296	0.77262	0.17782	0.81323	0.00895	0.13051	0.18418	2
0.13739	0.11415	0.81204	0.16919	0.82709	0.00371	0.13051	0.18418	3
0.13739	0.11460	0.82825	0.16588	0.83241	0.00171	0.13051	0.18418	4
0.15242	0.12050	0.72761	0.20942	0.77138	0.01921	0.14063	0.19549	1
0.15242	0.12393	0.81558	0.18688	0.80757	0.00555	0.14063	0.19549	2
0.15242	0.12390	0.81456	0.18711	0.80720	0.00569	0.14063	0.19549	3
0.15242	0.12491	0.84470	0.18044	0.81792	0.00164	0.14063	0.19549	4
0.16864	0.13091	0.75386	0.22370	0.75729	0.01901	0.15126	0.20694	1
0.16864	0.13495	0.84417	0.19977	0.79573	0.00450	0.15126	0.20694	2
0.16864	0.13481	0.84075	0.20058	0.79442	0.00500	0.15126	0.20694	3
0.16864	0.13564	0.86190	0.19566	0.80233	0.00201	0.15126	0.20694	4

TABLE A.2.37
(Continued)

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.	PORT#
0.18506	0.14725	0.90576	0.20431	0.78899	0.00670	0.16172	0.21782	1
0.18506	0.14788	0.92113	0.20090	0.79446	0.00463	0.16172	0.21782	2
0.18506	0.14852	0.93733	0.19743	0.80004	0.00253	0.16172	0.21782	3
0.18506	0.14894	0.94806	0.19520	0.80363	0.00117	0.16172	0.21782	4
0.20756	0.15943	0.89510	0.23186	0.75804	0.01008	0.17565	0.23173	1
0.20756	0.16130	0.93125	0.22288	0.77249	0.00463	0.17565	0.23173	2
0.20756	0.16210	0.94765	0.21902	0.77869	0.00229	0.17565	0.23173	3
0.20756	0.16199	0.94551	0.21952	0.77789	0.00259	0.17565	0.23173	4
0.20756	0.16242	0.95451	0.21745	0.78121	0.00134	0.17565	0.23173	5
0.20756	0.16288	0.96428	0.21525	0.78475	0.00000	0.17565	0.23173	6
0.22588	0.17178	0.94316	0.23949	0.74691	0.01359	0.18668	0.24231	1
0.22588	0.17412	0.98570	0.22916	0.76351	0.00733	0.18668	0.24231	2
0.22588	0.17439	0.99098	0.22794	0.76547	0.00659	0.18668	0.24231	3
0.22588	0.17602	1.02340	0.22072	0.77707	0.00221	0.18668	0.24231	4
0.22588	0.17616	1.02624	0.22010	0.77805	0.00184	0.18668	0.24231	5
0.22588	0.17685	1.04062	0.21706	0.78294	0.00000	0.18668	0.24231	6
0.24737	0.18151	0.92916	0.26623	0.70678	0.02700	0.19930	0.25539	1
0.24737	0.18548	0.98867	0.25020	0.73251	0.01729	0.19930	0.25539	2
0.24737	0.18664	1.00765	0.24549	0.74008	0.01443	0.19930	0.25539	3
0.24737	0.19088	1.08321	0.22836	0.76758	0.00405	0.19930	0.25539	4
0.24737	0.19137	1.09269	0.22638	0.77077	0.00285	0.19930	0.25539	5
0.24737	0.19253	1.11589	0.22168	0.77832	0.00000	0.19930	0.25539	6
0.26878	0.20035	1.05577	0.25458	0.72434	0.02108	0.21158	0.26436	1
0.26878	0.20205	1.08256	0.24828	0.73446	0.01726	0.21158	0.26436	2
0.26878	0.20564	1.14426	0.23489	0.75596	0.00915	0.21158	0.26436	3
0.26878	0.20765	1.18188	0.22742	0.76797	0.00462	0.21158	0.26436	4
0.26878	0.20751	1.17910	0.22795	0.76711	0.00494	0.21158	0.26436	5
0.26878	0.20970	1.22283	0.21980	0.78020	0.00000	0.21158	0.26436	6
0.33650	0.24518	1.24001	0.27137	0.70021	0.02843	0.24873	0.29559	1
0.33650	0.25225	1.34397	0.25037	0.73392	0.01571	0.24873	0.29559	2
0.33650	0.25475	1.38521	0.24292	0.74589	0.01119	0.24873	0.29559	3
0.33650	0.26040	1.48798	0.22614	0.77284	0.00102	0.24873	0.29559	4
0.33650	0.25883	1.45788	0.23081	0.76534	0.00385	0.24873	0.29559	5
0.33650	0.26097	1.49914	0.22446	0.77554	0.00000	0.24873	0.29559	6

TABLE A.2.38

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-650 MICRON SAND(20.0 WT %)

SURFACE TENSION= 0.07200 NEWTON/M
LIQUID VISCOSITY= 0.00100 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES=650.0000*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.	PORT#
0.10713	0.08875	0.62421	0.17163	0.82040	0.00797	0.10911	0.15890	1
0.10713	0.08983	0.66338	0.16150	0.83668	0.00182	0.10911	0.15890	2
0.10713	0.08995	0.66781	0.16042	0.83840	0.00117	0.10911	0.15890	3
0.10713	0.09001	0.67016	0.15986	0.83931	0.00083	0.10911	0.15890	4
0.12821	0.10556	0.72559	0.17670	0.81281	0.01049	0.12417	0.17689	1
0.12821	0.10679	0.76743	0.16707	0.82829	0.00465	0.12417	0.17689	2
0.12821	0.10736	0.78838	0.16263	0.83542	0.00195	0.12417	0.17689	3
0.12821	0.10752	0.79463	0.16135	0.83747	0.00118	0.12417	0.17689	4
0.15380	0.12265	0.75948	0.20251	0.77857	0.01892	0.14155	0.19650	1
0.15380	0.12592	0.84859	0.18124	0.81273	0.00603	0.14155	0.19650	2
0.15380	0.12681	0.87638	0.17549	0.82196	0.00255	0.14155	0.19650	3
0.15380	0.12707	0.88509	0.17377	0.82473	0.00150	0.14155	0.19650	4
0.17004	0.13535	0.83338	0.20404	0.78166	0.01430	0.15216	0.20790	1
0.17004	0.13759	0.89098	0.19085	0.80284	0.00631	0.15216	0.20790	2
0.17004	0.13821	0.90827	0.18722	0.80868	0.00411	0.15216	0.20790	3
0.17004	0.13698	0.92794	0.18325	0.81505	0.00170	0.15216	0.20790	4
0.19141	0.14591	0.80513	0.23774	0.73912	0.02313	0.16570	0.22186	1
0.19141	0.15147	0.91724	0.20668	0.78579	0.00552	0.16570	0.22186	2
0.19141	0.15202	0.93002	0.20582	0.79040	0.00379	0.16570	0.22186	3
0.19141	0.15242	0.93971	0.20370	0.79380	0.00250	0.16570	0.22186	4
0.19141	0.15284	0.94980	0.20153	0.79728	0.00119	0.16570	0.22186	5
0.19141	0.15321	0.95913	0.19957	0.80043	0.00000	0.16570	0.22186	6
0.21098	0.15832	0.84526	0.24961	0.73124	0.01916	0.17773	0.23376	1
0.21098	0.16180	0.90502	0.23312	0.75771	0.00917	0.17773	0.23376	2
0.21098	0.16286	0.92459	0.22809	0.76579	0.00612	0.17773	0.23376	3
0.21098	0.16338	0.93508	0.22563	0.76975	0.00463	0.17773	0.23376	4
0.21098	0.16442	0.95601	0.22069	0.77758	0.00153	0.17773	0.23376	5
0.21098	0.16499	0.96783	0.21799	0.78201	0.00000	0.17773	0.23376	6
0.23273	0.17690	0.97022	0.23987	0.73294	0.02719	0.19074	0.24611	1
0.23273	0.18203	1.06842	0.21782	0.76835	0.01383	0.19074	0.24611	2
0.23273	0.18502	1.13525	0.20500	0.78894	0.00606	0.19074	0.24611	3
0.23273	0.18560	1.14919	0.20251	0.79293	0.00455	0.19074	0.24611	4
0.23273	0.18625	1.16523	0.19973	0.79741	0.00286	0.19074	0.24611	5
0.23273	0.18734	1.19345	0.19500	0.80500	0.00000	0.19074	0.24611	6

TABLE A.2.38
(Continued)

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.	PORT#
0.25427	0.19611	1.11163	0.22874	0.73580	0.03547	0.20329	0.25836	1
0.25427	0.20363	1.27665	0.19917	0.78328	0.01755	0.20329	0.25836	2
0.25427	0.20632	1.34838	0.18859	0.80030	0.01112	0.20329	0.25836	3
0.25427	0.20894	1.42614	0.17829	0.81681	0.00489	0.20329	0.25836	4
0.25427	0.20988	1.45638	0.17459	0.82276	0.00265	0.20329	0.25836	5
0.25427	0.21099	1.49378	0.17022	0.82978	0.00000	0.20329	0.25836	6
0.28804	0.21333	1.11050	0.25938	0.70075	0.03987	0.22239	0.27189	1
0.28804	0.22104	1.23828	0.23261	0.74374	0.02365	0.22239	0.27189	2
0.28804	0.22597	1.33576	0.21547	0.77126	0.01327	0.22239	0.27189	3
0.28804	0.22675	1.35367	0.21278	0.77556	0.01163	0.22239	0.27189	4
0.28804	0.23029	1.43639	0.20053	0.79527	0.00421	0.22239	0.27189	5
0.28804	0.23228	1.48790	0.19359	0.80641	0.00000	0.22239	0.27189	6
0.30592	0.21688	1.05111	0.29105	0.67500	0.03395	0.23225	0.28237	1
0.30592	0.22172	1.11147	0.27524	0.70039	0.02437	0.23225	0.28237	2
0.30592	0.22534	1.16146	0.26340	0.71941	0.01719	0.23225	0.28237	3
0.30592	0.22968	1.22747	0.24923	0.74216	0.00861	0.23225	0.28237	4
0.30592	0.23195	1.26516	0.24181	0.75408	0.00411	0.23225	0.28237	5
0.30592	0.23402	1.30166	0.23503	0.76497	0.00000	0.23225	0.28237	6
0.33691	0.23779	1.14512	0.29422	0.65875	0.04703	0.24895	0.29576	1
0.33691	0.25010	1.30746	0.25768	0.71742	0.02489	0.24895	0.29576	2
0.33691	0.25594	1.40181	0.24034	0.74528	0.01438	0.24895	0.29576	3
0.33691	0.25907	1.45828	0.23103	0.76022	0.00874	0.24895	0.29576	4
0.33691	0.26077	1.49075	0.22600	0.76831	0.00569	0.24895	0.29576	5
0.33691	0.26393	1.55540	0.21661	0.78339	0.00000	0.24895	0.29576	6
0.35115	0.25406	1.26994	0.27651	0.68858	0.03491	0.25649	0.30160	1
0.35115	0.26036	1.35809	0.25857	0.71740	0.02403	0.25649	0.30160	2
0.35115	0.26705	1.46607	0.23952	0.74799	0.01249	0.25649	0.30160	3
0.35115	0.26966	1.51310	0.23208	0.75994	0.00798	0.25649	0.30160	4

TABLE A.2.39

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-33 MICRON COAL(12.0 WT %)

SURFACE TENSION= 0.07095 NEWTON/M
LIQUID VISCOSITY= 0.00170 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES= 33.0000*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.
0.03192	0.02922	0.37737	0.08459	0.83078	0.08463	0.02766	0.07184
0.04381	0.03923	0.41848	0.10470	0.81081	0.08449	0.03474	0.08941
0.05630	0.05063	0.55896	0.10073	0.81433	0.08493	0.04161	0.10582
0.06873	0.06160	0.66286	0.10368	0.81643	0.07989	0.04804	0.12057
0.08531	0.07576	0.76254	0.11187	0.81247	0.07565	0.05613	0.13837
0.10174	0.09087	0.95207	0.10686	0.81260	0.08054	0.06371	0.15432
0.12053	0.10529	0.95296	0.12648	0.79503	0.07849	0.07198	0.17090
0.14333	0.12549	1.15119	0.12451	0.81027	0.06522	0.08155	0.19002
0.16718	0.13825	0.96615	0.17303	0.75948	0.06749	0.09110	0.20534
0.18904	0.15446	1.03336	0.18294	0.75201	0.06505	0.09953	0.22079
0.20540	0.16516	1.04842	0.19591	0.74115	0.06294	0.10566	0.23089
0.22154	0.18045	1.19457	0.18545	0.74903	0.06552	0.11158	0.24033
0.24574	0.19751	1.25207	0.19626	0.73985	0.06389	0.12022	0.25363
0.26461	0.21205	1.33207	0.19865	0.73735	0.06400	0.12680	0.26336
0.29564	0.23769	1.50840	0.19599	0.74104	0.06297	0.13734	0.27831
0.33009	0.24625	1.29962	0.25399	0.68781	0.05820	0.14868	0.29358

TABLE A.2.40

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-33 MICRON COAL(18.0 WT %)

SURFACE TENSION= 0.07069 NEWTON/M
LIQUID VISCOSITY= 0.00202 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES= 33.0000*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.
0.02148	0.02062	0.53477	0.04017	0.82685	0.13298	0.02079	0.05423
0.03199	0.02979	0.46523	0.06875	0.80180	0.12945	0.02770	0.07199
0.04332	0.04016	0.59351	0.07299	0.79855	0.12847	0.03446	0.08924
0.05509	0.05051	0.66216	0.08320	0.78791	0.12888	0.04097	0.10437
0.06877	0.06288	0.80246	0.08570	0.78611	0.12819	0.04806	0.12070
0.08481	0.07569	0.78865	0.10753	0.76715	0.12531	0.05589	0.13933
0.09919	0.08768	0.85464	0.11607	0.76029	0.12364	0.06256	0.15292
0.11435	0.10027	0.92860	0.12315	0.75389	0.12296	0.06931	0.16581
0.13395	0.11512	0.95255	0.14063	0.73874	0.12064	0.07767	0.18071
0.15555	0.13235	1.04311	0.14912	0.73194	0.11894	0.08650	0.19825
0.17813	0.15092	1.16628	0.15273	0.72856	0.11870	0.09536	0.21384
0.19743	0.16289	1.12846	0.17495	0.70811	0.11694	0.10269	0.22617
0.21756	0.17939	1.24018	0.17543	0.70868	0.11569	0.11013	0.23819
0.23715	0.19468	1.32433	0.17907	0.70533	0.11560	0.11718	0.24917
0.26009	0.20325	1.19011	0.21855	0.68708	0.09437	0.12524	0.26124
0.27887	0.22167	1.35954	0.20512	0.69634	0.09854	0.13169	0.27056
0.26828	0.22038	1.50259	0.17855	0.72067	0.10079	0.12807	0.26536
0.33957	0.26212	1.48886	0.22808	0.67807	0.09386	0.15175	0.29780

TABLE A.2.41

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-33 MICRON COAL(25.0 WT %)

SURFACE TENSION= 0.07084 NEWTON/M
LIQUID VISCOSITY= 0.00270 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES= 33.0000*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.
0.02541	0.02438	0.62877	0.04042	0.77544	0.18615	0.02347	0.06113
0.03577	0.03364	0.60134	0.05548	0.75237	0.18815	0.03002	0.07778
0.04997	0.04623	0.66790	0.07482	0.74261	0.16257	0.03819	0.09775
0.06363	0.05765	0.67736	0.09353	0.72867	0.17739	0.04544	0.11472
0.07535	0.07032	0.74748	0.10615	0.72066	0.17319	0.05327	0.13223
0.10509	0.09257	0.88243	0.11509	0.70985	0.17106	0.06522	0.15743
0.12407	0.10934	1.04481	0.11875	0.70870	0.17255	0.07350	0.17350
0.14513	0.12552	1.07377	0.13516	0.69464	0.16999	0.08223	0.19052
0.16520	0.14273	1.11046	0.15147	0.68143	0.16703	0.09151	0.20711
0.19354	0.16320	1.23453	0.15677	0.67804	0.16519	0.10123	0.22372
0.22279	0.18304	1.24873	0.17841	0.65567	0.16192	0.11203	0.24118
0.24974	0.21115	1.61633	0.15451	0.70469	0.14080	0.12163	0.25551
0.28532	0.23057	1.34911	0.21890	0.65025	0.13085	0.13723	0.27841
0.32656	0.25644	1.52077	0.21474	0.65342	0.13184	0.14754	0.29239
0.36612	0.28902	1.71331	0.21486	0.65285	0.13249	0.16083	0.30946

TABLE A.2.42

EXPERIMENTAL GAS-LIQUID-SOLID HOLDUPS COMPARED WITH EXISTING CORRELATIONS
AIR-WATER-33 MICRON COAL(30.0 WT %)

SURFACE TENSION= 0.07089 NEWTON/M
LIQUID VISCOSITY= 0.00367 KG/(M*SEC)
LIQUID DENSITY=1000.00000 KG/(M**3)
DIAMETER OF PARTICLES= 33.0000*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.
0.02477	0.02362	0.64621	0.03633	0.73884	0.22483	0.02304	0.05995
0.03939	0.03755	0.67878	0.05877	0.72060	0.22063	0.03247	0.08363
0.05649	0.05333	1.00754	0.05605	0.72332	0.22063	0.04172	0.10605
0.07650	0.07057	1.05544	0.07221	0.71050	0.21729	0.05189	0.12516
0.09631	0.08780	1.09031	0.08833	0.69751	0.21366	0.06125	0.14923
0.11923	0.10752	1.25739	0.09482	0.69098	0.21420	0.07142	0.16963
0.14377	0.12340	1.01461	0.14170	0.65360	0.20471	0.09173	0.18949
0.17062	0.14902	1.34759	0.12661	0.66615	0.20724	0.09245	0.20678
0.20097	0.16737	1.22014	0.16471	0.63636	0.19893	0.10402	0.22836
0.22404	0.18825	1.40253	0.15974	0.64240	0.19763	0.11248	0.24155
0.26293	0.21215	1.36140	0.19313	0.64015	0.16672	0.12622	0.26282
0.28573	0.22587	1.46137	0.19553	0.63761	0.16686	0.13401	0.27404
0.31349	0.24628	1.48223	0.21439	0.62389	0.16172	0.14326	0.28563
0.33328	0.26315	1.58394	0.21041	0.62608	0.16351	0.14972	0.29545

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3. MECHANICALLY AGITATED VESSEL

3.1 Introduction

Many industrial processes like hydrogenation of fatty oils, oxy-desulfurization, fermentation etc. involve three phase agitated reactor system. Many of them operate at high pressure and high temperature. Knowledge of values of gas-liquid-solid mass transfer coefficients is important in these reactors to have an order of magnitude estimates of the transport rates and relative mass transfer resistances. Hence in this project work, measurements of mass transfer coefficients are being carried out for a three phase agitated reactor system under high pressure, high temperature conditions.

Data for oxygen-water and oxygen-water-glass beads systems are collected to determine the product of mass transfer coefficient 'k_ℓ' and interfacial area per unit slurry volume 'a'. The product '$k_\ell a$' is called as volumetric mass transfer coefficient. In these measurements, the gas side resistance to mass transfer is assumed to be negligible.

3.2 Experimental Set-Up and Procedure

The flow diagram of the apparatus is shown in Figure 3.1. The basic technique involves batch absorption of the solute gas in initially solute free liquid containing solids. Measurement of total pressure of the gas phase with respect to time, as the absorption proceeds, is utilized to calculate the mass transfer coefficients. A pressure transducer is utilized to carry out these measurements with good accuracy. This technique is previously utilized by Teramoto, et al.[3.1] and Nam, N.D.[3.2]

This batch absorption technique presents some drawbacks as suggested by Kozinsky and King.[3.3] Under conditions of high agitation, the liquid tends to approach saturation very quickly, thus reducing the time available for measurement. Also, there is a possibility of significant error due to small temperature change or leaks.

However, in this study, transducer read-out was employed with high efficiency to measure the fast absorption rate of the solute gas. The prevention of leaks was undertaken by pressurizing the vessel overnight to detect any possible leak. Since with increase in pressure, for a closed volume of the gas, the temperature of the gas increases; after pressurizing the vessel, agitation was not started until the entire system reached a thermal equilibrium.

The reactor utilized was a two liter vessel made of stainless steel. It contained two impellers in the liquid phase and one impeller in the gas phase. The impellers were turbines with six blades pitched at 45° angle. The vessel also contained four vertical baffles attached to the wall having width 1/8 of the vessel diameter. A thermowell was utilized to measure the temperature of the gas and liquid phase, and the temperature was measured by chromel-alumel thermocouple.

3.2.1 Procedure

The steps involved in the operating procedure were as follows:

1. Take requisite amount of liquid in the vessel and add to that predetermined quantity of solids.

2. Degas the liquid by applying vacuum and agitation.

3. Pressurize the reactor slowly to the desired pressure.

4. As soon as the desired pressure reaches, close the inlet valve and wait until the entire system reaches a thermal equilibrium indicated by constant temperature in the gas and liquid phases.

5. Start agitation and measure the total pressure of the gas phase as a function of time.

6. Utilize this knowledge of pressure versus time to calculate the volumetric mass transfer coefficient '$k_\ell a$'.

The pressure was measured by a pressure transducer, output of which was supplied to a high speed recorder. The calibration of the transducer was carried out by pressurizing the reactor to various pressure levels and noting the corresponding output voltages on the recorder.

To measure the power input to the agitator, following procedure was employed. A power meter was connected between the main supply and the agitator motor. First, power was measured to run the agitator in empty vessel without any liquid in it. Let this power be 'x' watts. Then the power meter reading was taken when agitating the liquid. Let this reading be 'y' watts. Then (y-x) was the power input to the liquid by the agitator. Power input was measured this way for different values of rpm.

3.2.2 Method of Calculations

The rate of solute gas uptake is related to the rate of change in pressure as

$$\frac{dN}{dt} = \frac{V_g}{RT}\frac{dP}{dt} \qquad (3.2.1)$$

where N = number of moles of the gas

V_g = volume of the gas phase

P = pressure of the gas phase

t = time

Also,

$$-\frac{dN}{dt} = V_\ell\ k_\ell a\ (C^*-C_b) \qquad (3.2.2)$$

where V_ℓ = volume of (liquid + solid) phase

$k_\ell a$ = volumetric mass transfer coefficient

C^* = equilibrium concentration of the solute gas

C_b = bulk concentration of the solute gas

Expressing all the concentrations in terms of pressure using Henry's law and integrating between the limits of initial and final pressure, we get

$$-\frac{P_f}{P_i}\ \ell n\ \frac{P-P_f}{P_i-P_f} = k_\ell a\ t \qquad (3.2.3)$$

where P_f and P_i are values of final and initial pressure and P is the value of pressure at time t. Hence, a plot of $-\frac{P_f}{P_i}\ \ell n\ \frac{P-P_f}{P_i-P_f}$ versus time will be a straight line and $k_\ell a$ will be the slope of the line.

The linearity of this plot was excellent in all the runs. The detailed derivation of the batch absorption equation 3.2.3 is given in Appendix 3.1 following this section. A sample recorder output showing voltage (which actually represents pressure) versus time is shown in Figure 3.2.

3.3 Results and Discussion

Data for oxygen-water and oxygen-water-glass beads systems are collected for the following four variable parameters:

1. Total pressure (400-1400 psig)
2. Agitator rpm (400, 600, 800, 1000)
3. Solids concentration (0-30 volume percent)
4. Solids particle size (75-500 microns)

The details of the results along with their interpretation are as follows.

3.3.1 Effect of Total Pressure

Various dependencies of $k_\ell a$ on pressure are reported in the literature. Yoshida and Arakawa(3.4) and Phillips, et al.(3.5) observed a decrease in $k_\ell a$ with increase in pressure. The dependency was much more pronounced at lower values of rpm. They interpreted it on the basis of change in surface renewal rate or interfacial turbulence which in turn they accounted for by change in surface tension due to the gas pressure. Teramoto et al.(3.1) observed no dependency of $k_\ell a$ on pressure for various gas-liquid systems.

In this work, the effect of total pressure on $k_\ell a$ was studied for four different values of rpm (400, 600, 800 and 1000) in the pressure range 400-1400 psig for oxygen-water and oxygen-water-glass beads systems. The results are shown in Tables 3.1 and 3.2, and are plotted in Figures 3.3 and 3.4. It can be observed that the $k_\ell a$ values are independent of pressure over the range of pressure studied for all four values of rpm. Also, addition of solids even though changed value of $k_\ell a$, it remained independent of the total pressure. This supports the observations made by Teramoto, et al.[3.1] The results can be explained on the basis that the pressure does not change the physical properties of water significantly and also the change in the liquid phase diffusivity of the dissolved gas must be negligible. As reported by Sridhar and Potter,[3.6] the effect of pressure on 'a' is negligible above about 150 psig, hence it may be concluded that the 'k_ℓ' does not depend on pressure.

It is important in all these measurements to check the amount of oxygen absorbed as compared to the equilibrium solubility. Frolich[3.7] has reported that between 0-70 atmospheres pressure, the solubility of oxygen in water is given by

$$y = 0.028\ (x) \qquad (3.3.1)$$

where y = volume of gas at 25°C and 1 atm. pressure per unit volume of liquid

x = absolute pressure in atmospheres.

Knowing the total change in pressure due to absorption and volume of the gas phase in the vessel, amount of gas absorbed in the liquid was calculated and it was compared with the value of solubility given by equation 3.3.1. The percentage error was calculated as

$$\%\ \text{error} = \frac{\text{Solubility observed} - \text{Solubility reported}}{\text{Solubility reported}} \times 100 \qquad (3.3.2)$$

Values of these percentage error are also tabulated in Table 3.1 for those runs. It can be seen that the observed solubility values are about 1-7% lower than the reported solubility values. This is probably because of some absorption of the gas during the time the reactor is pressurized and waiting for thermal equilibrium. However, these quantities are negligible.

3.3.2 Effect of Agitator RPM or Power/Volume

The average values of $k_\ell a$ for various values of rpm and power/volume are summarized in Table 3.3. The plot of $k_\ell a$ versus rpm is shown in Figure 3.5 for oxygen-water system and the logarithmic plot of $k_\ell a$ versus power/volume is shown in Figure 3.6. The values of $k_\ell a$ increase with increase in power/volume. However, the value of $k_\ell a$ obtained at 400 rpm is much lower as compared to the values at other rpm. This is probably due to the fact that at 400 rpm, there is no surface breakage and hence no gas entrainment and the interface remains calm. At 400 rpm, the time required to obtain the equilibrium was also found to be very high as compared to other values of rpm. It is indicated by Perez and Sandall[3.8] that there is a certain value of rpm above which only, the rpm shows effect on $k_\ell a$, and in this case, the value of that critical rpm appears to lie between 400 and 600 rpm. Hence on the plots of $k_\ell a$ versus rpm and power/volume, only those values corresponding to 600, 800 and 1000 rpm are plotted. To compare the values with other literature values, data of Robinson and Wilke[3.9] and Van't Riet[3.10] for oxygen-water system are also shown on the same plot. It can be seen that the slope of the curve obtained in this work and the other works differs. At high values of power/volume, we have obtained higher values of $k_\ell a$, and at lower values of power/volume, we have obtained much lower values of $k_\ell a$ as compared to the other reported data. This discrepancy is probably because of different geometrical parameters of the agitator and hence different hydrodynamics in our system. The ratio of impeller diameter/vessel diameter is 0.57 in our system as compared to 0.33-0.4 used by other workers, and as reported by Koetsier, et al.,[2.11] this ratio has a significant effect on the values of $k_\ell a$. Also, we employ two impellers (which help to mix the solids thoroughly when gas-liquid-solid system is under consideration) as compared to only one used by other workers. Experiments are being carried out under standard conditions of geometrical arrangement of the agitator, and the data will be then compared with other workers. Also, as reported by Van't Riet(3.10) in his review article, the values of $k_{\ell}a$ reported in the literature under similar conditions vary so much (for example, for k_{ℓ}, the values vary between 1 and 6×10^{-4} cm/s) that, it is difficult at this stage to conclude anything regarding the order of magnitude of obtained values.

3.3.3 Effect of Solids Concentration

Very few data are reported in the literature on the effect of solids concentration on $k_{\ell}a$. Joosten et al.(3.12) observed an initial increase followed by decrease in $k_{\ell}a$ with increase in solids concentration for various solids with varying densities. However, Slesser et al.(3.13) and Mehta and Sharma(3.14) observed no particular trend in value of $k_{\ell}a$ with increase in solids concentration. Sometimes the values decreased continuously, sometimes increased and sometimes first decreased and then increased. Mehta and Sharma interpreted their results based on opposing effect of presence of solids on k_{ℓ} and a.

In this work, glass beads of 500 microns average size were added to water to study the effect of solids concentration. The solids concentration was varied from 0-30 volume percent. Total volume of the slurry (liquid + solid) was kept constant for all concentrations. The results at two values of rpm and at two different values of initial pressure are summarized in Tables 3.4 and 3.5, and are plotted in Figures 3.7 and 3.8. It can be seen that for low values of solids concentration (2-3 volume %), the value of $k_\ell a$ increases about 20-40 percent, and then it decreases with further increase in the solids concentration. The probable reason for this peculiar behavior may be that very small concentrations of solids do not change the viscosity of water significantly and help surface mobility and renewal increasing the value of $k_\ell a$. However, higher concentrations increase the viscosity of the slurry significantly, decreasing the surface renewal rate and hence $k_\ell a$. However, these conclusions and reasoning are tentative and more data for different sized solids and solids with different density are required to reach any firm conclusion.

3.3.4 Effect of Solids Particle Size

Solids particle size is a very important parameter since for a given mass concentration of particles, as the particle size increases, the number of particles in the slurry decreases. Data for four different sized glass beads 63-88, 105-177, 212-300 and 425-600 microns were obtained at two values of rpm at 600 psi initial pressure. The solids concentration in the slurry was kept constant at 10 volume percent. The data are summarized in Table 3.6 and are plotted in Figures 3.9 and 3.10. It can be seen that as the particle size increases, under similar operating conditions, the value of $k_\ell a$ decreases, indicating that smaller particles have a better effect on transfer coefficient than large ones. As indicated by Slesser et al.,[3.13] probably the value of k_ℓ increases with particle concentration, increasing the value of $k_\ell a$.

One more important observation which stems out when studying the effect of solids concentration and solids particle size is that pressure does not have any effect on $k_\ell a$ in the presence of various amounts and various sizes of solids.

TABLE 3.1

EFFECT OF TOTAL PRESSURE ON '$k_{\ell}a$'

System - Oxygen-Water

Temperature - 22°C (average)

Agitator rpm	Initial Pressure (psig)	Average Pressure (psig)	$k_{\ell}a$ (sec^{-1})	% Error in Solubility
1000	391.3	385.6	0.176	-2.04
	587.3	578.9	0.177	-3.5
	793.9	782.5	0.177	-4.5
	975.5	961.7	0.181	-1.6
	1212.3	1195.0	0.178	-2.1
	1385.0	1365.0	0.176	-3.5
800	441.5	434.9	0.0733	-4.7
	599.6	590.8	0.072	-7.1
	781.4	769.9	0.0737	-4.4
	977.6	963.1	0.0771	-7.4
	1207.1	1190.0	0.076	-5.2
600	392.3	386.4	0.0197	-1.65
	578.7	570.3	0.0183	-3.1
	782.1	770.9	0.0214	-5.2
	980.7	966.5	0.0214	-3.8
	1227.3	1210.1	0.0205	-4.2
400	578.4	570.1	0.000850	-4.1
	730.8	720.3	0.000845	-5.0
	997.6	983.4	0.000853	-4.5

TABLE 3.2

EFFECT OF TOTAL PRESSURE ON '$k_\ell a$'

System - Oxygen-Water-Glass Beads

Solids Concentration - 3 volume percent

Solids Particle Size - 75 Microns

Temperature - 22°C (average)

Agitator rpm	Initial Pressure (psig)	Average Pressure (psig)	$k_\ell a$ (sec^{-1})
	967.0	954.1	0.211
1000	591.5	583.6	0.215
	386.9	381.6	0.220
	977.0	964.9	0.100
800	586.4	578.9	0.095
	391.3	386.2	0.093
	1003.8	991.5	0.031
600	780.7	770.4	0.029
	592.9	585.0	0.028

TABLE 3.3

EFFECT OF AGITATOR RPM OR POWER/VOLUME ON '$k_\ell a$'

System - Oxygen-Water

Tempearature - 22°C (average)

Agitator rpm	Power/Volume (kw/m^3)	$k_\ell a$ (sec^{-1})
1000	7.0	0.178
800	4.1	0.075
600	2.3	0.021

TABLE 3.4

EFFECT OF SOLIDS CONCENTRATION ON '$k_\ell a$'

Agitator rpm - 1000

System - Oxygen-Water-Glass Beads

Solids Particle Size - 500 microns

Temperature - 22°C (average)

Solids Concentration Volume %	$k_\ell a$ (sec^{-1}) 600 psig*	$k_\ell a$ (sec^{-1}) 1000 psig*
0	0.177	0.181
3.0	0.188	0.190
6.7	0.154	0.151
10.0	0.139	0.138
25.5	0.128	0.1285
29.8	0.115	0.119

*Values of initial pressures.

TABLE 3.5

EFFECT OF SOLIDS CONCENTRATION ON '$k_\ell a$'

Agitator rpm - 800

System - Oxygen-Water-Glass Beads

Solids Particle Size - 500 microns

Temperature - 22°C (average)

Solids Concentration Volume %	$k_\ell a$ (sec^{-1}) 600 psig*	1000 psig*
0	0.072	0.0771
3.0	0.093	0.106
6.7	0.065	0.061
10.0	0.04	0.39
25.45	0.0283	0.026

*Values of initial pressures.

TABLE 3.6

EFFECT OF SOLIDS PARTICLE SIZE ON '$k_\ell a$'

System - Oxygen-Water-Glass Beads

Initial Pressure - 600 psig

Solids Concentration - 10 Volume %

Temperature - 22°C (average)

Size Range (microns)	Average Representative Size (microns)	$k_\ell a$ (sec^{-1}) 800 rpm	1000 rpm
63-88	75	0.060	0.161
105-177	150	0.054	0.156
212-300	250	0.042	0.142
425-600	500	0.040	0.138

APPENDIX 3.1

Derivation of Equation of Batch Absorption

Henry's law constant can be expressed as:

$$H = \frac{P}{C^*}$$

where P is the instantaneous pressure of the gas and C* is the corresponding value of the equilibrium concentration of the solute gas in the liquid.

The bulk concentration C_b of the solute gas in the liquid:

$$C_b = \frac{V_g}{V_1 \cdot RT} (P_i - P)$$

Where P_i is the initial pressure, V_g is the volume of the gas space and V_1 is the volume of the liquid. Then:

$$C^* - C_b = (\frac{1}{H} + \frac{V_g}{V_1 \cdot RT}) P - \frac{V_g}{V_1 \cdot RT} P_i \qquad (3.1.1)$$

The rate of the solute uptake is related to the rate of change in pressure by means of the ideal gas law:

$$\frac{dN}{dt} = \frac{V_g}{RT} \times \frac{dP}{dt} \qquad (3.1.2)$$

also:

$$-\frac{dN}{dt} = V_1 k_\ell a \quad (C^* - C_b) \qquad (3.1.3)$$

Hence from equations (3.1.1), (3.1.2), and (3.1.3)

$$- \frac{1}{RT} \frac{dP}{dt} = \frac{V_g}{V_1} k_\ell a \ \frac{V_1}{V_g} \left[\left(\frac{V_1}{HV_g} + \frac{1}{RT}\right) P - \frac{1}{RT} P_i \right] \qquad (3.1.4)$$

Let $\alpha = \frac{V_1}{HV_g} RT$, then equation (3.1.4) becomes

$$- \frac{dP}{dt} = k_\ell a \ \left[(\alpha+1) \ P-P_i \right] \qquad (3.1.5)$$

Integrate equation (3.1.5)

$$- \int_{P_i}^{P} \frac{dP}{(\alpha+1) \ P-P_i} = k_\ell a$$

$$- \ln \frac{(\alpha+1) \ P-P_i}{\alpha P_i} = (\alpha+1) k_\ell a \ t \qquad (3.1.6)$$

At equilibrium, the final pressure is P_f and the final concentration of the solute is C* where C* is equal:

$$C^* = \frac{V_g}{V_1 RT} (P_i - P_f)$$

and

$$C^* = \frac{P_f}{H}$$

Hence

$$\frac{P_f}{H} = \frac{V_g}{V_1 RT} (P_i - P_f)$$

or

$$\frac{P_i - P_f}{P_f} = \frac{V_1 RT}{H \cdot V_g} = \alpha$$

Therefore equation (3.1.6) becomes

$$-\frac{P_f}{P_i}\ln\frac{P-P_f}{P_i-P_f} = k_\ell a\ t \qquad (3.1.7)$$

A plot of $-\frac{P_f}{P_i}\ln\frac{P-P_f}{P_i-P_f}$ versus t is a straight line and $k_\ell a$ is equal to the slope of the curve.

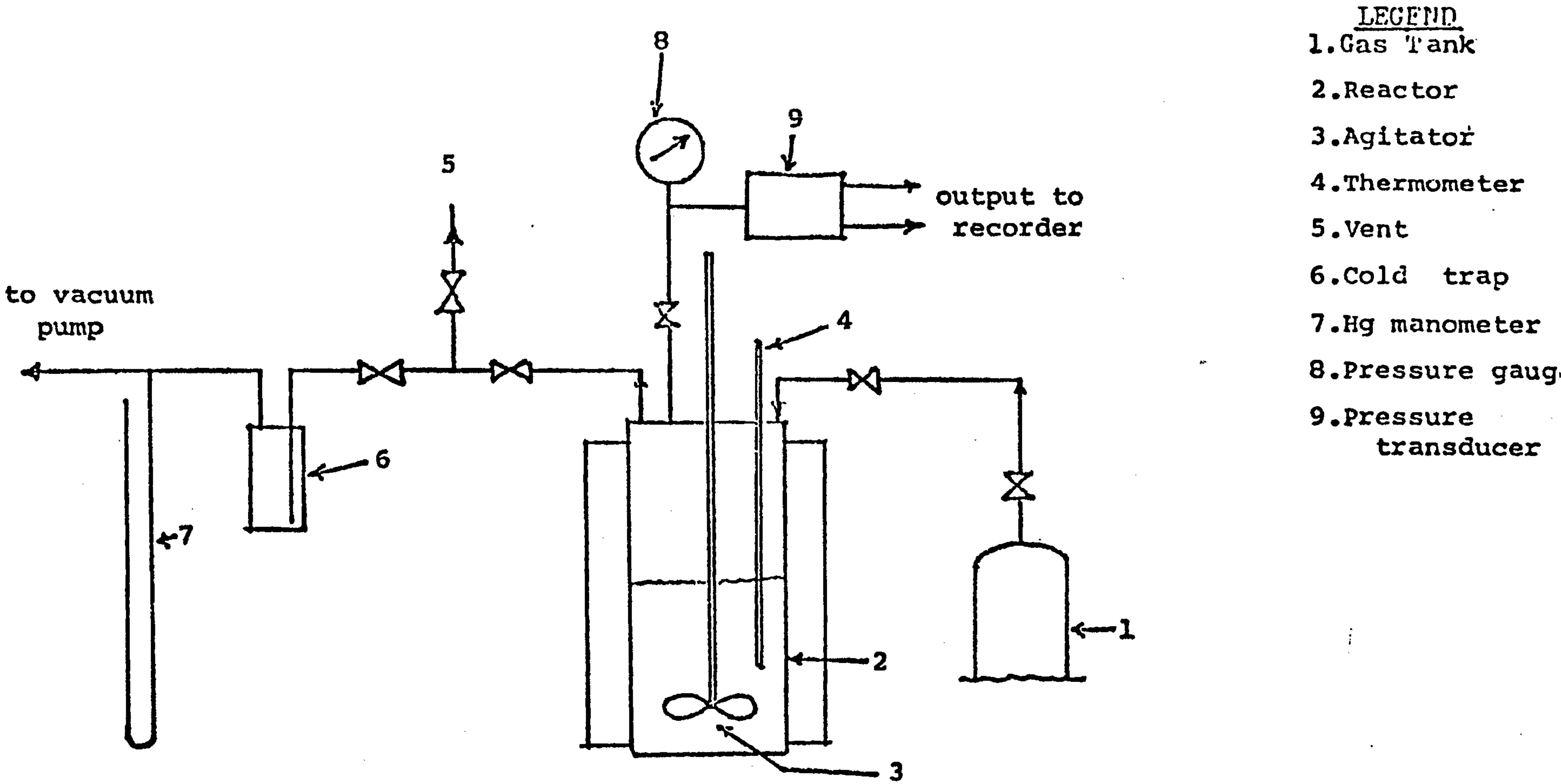

FIGURE 3.1: SCHAMATIC FLOW DIAGRAM OF THE APPARATUS FOR MEASUREMENT OF MASS TRANSFER COEFFICIENTS

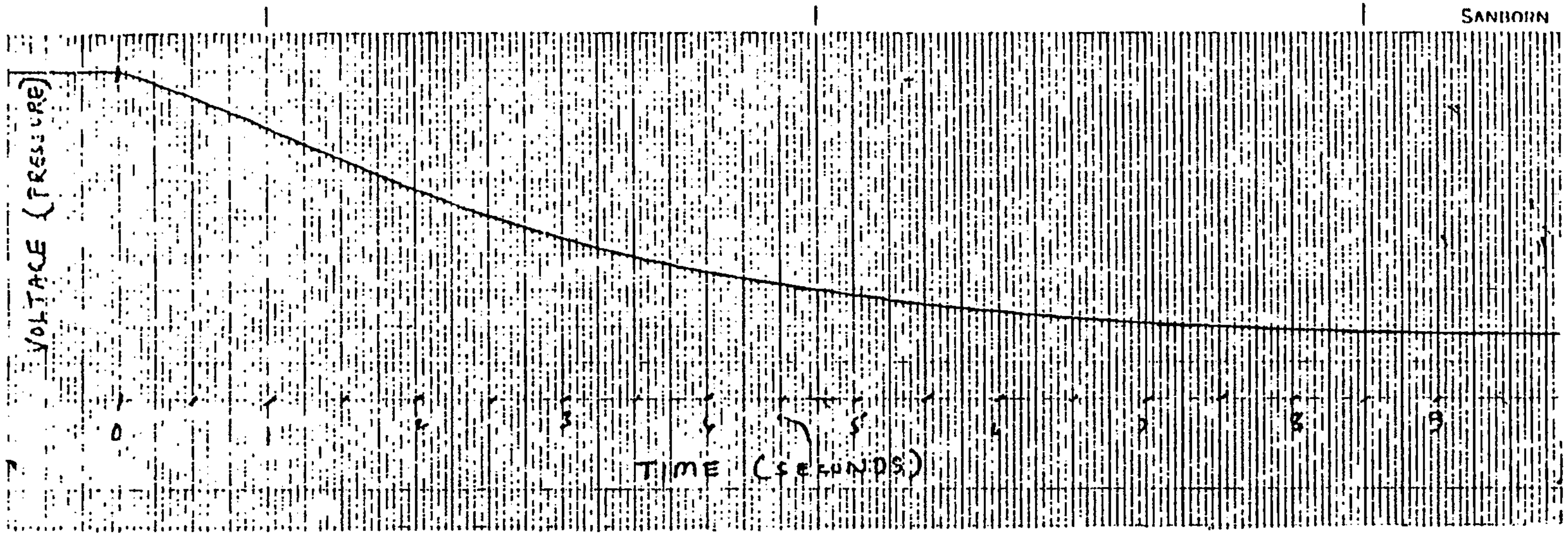

FIGURE 3.2 - Absorption Plot Showing Pressure as a Function of Time

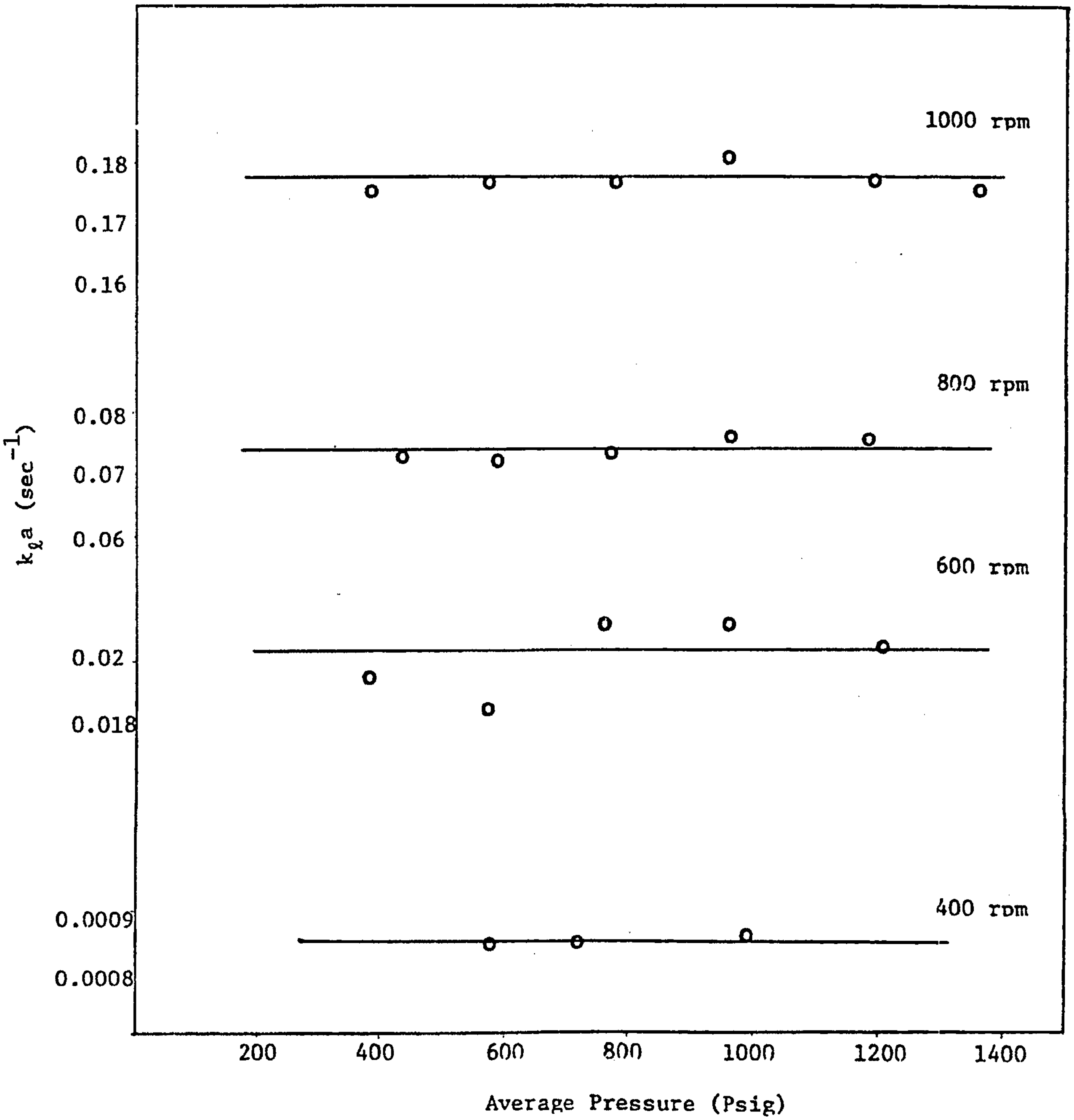

FIGURE 3.3 - Effect of Total Pressure on '$k_\ell a$' for Oxygen-Water System

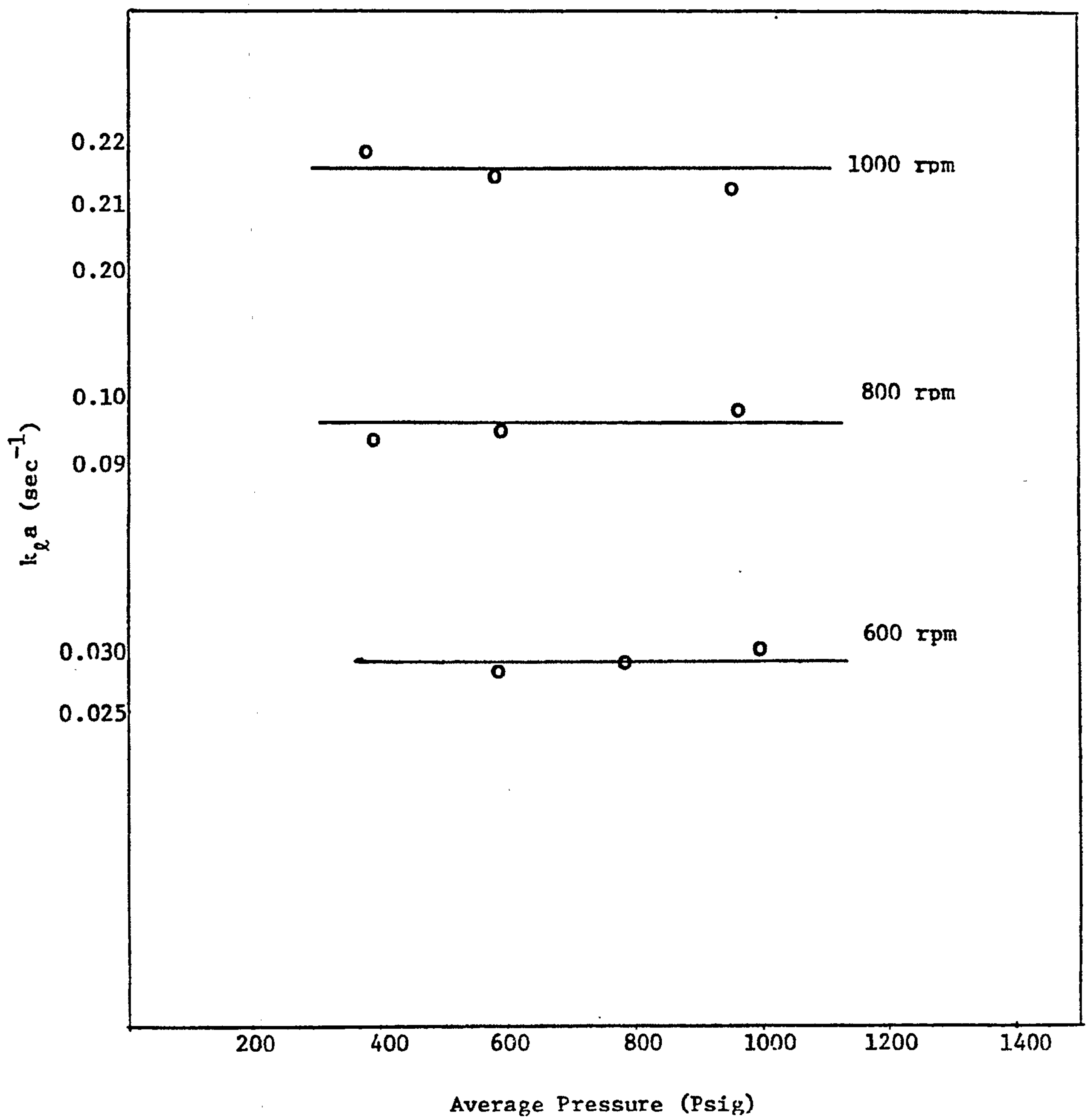

FIGURE 3.4 - Effect of Total Pressure on '$k_\ell a$' for Oxygen-water Glass Beads (3 volume %) System.

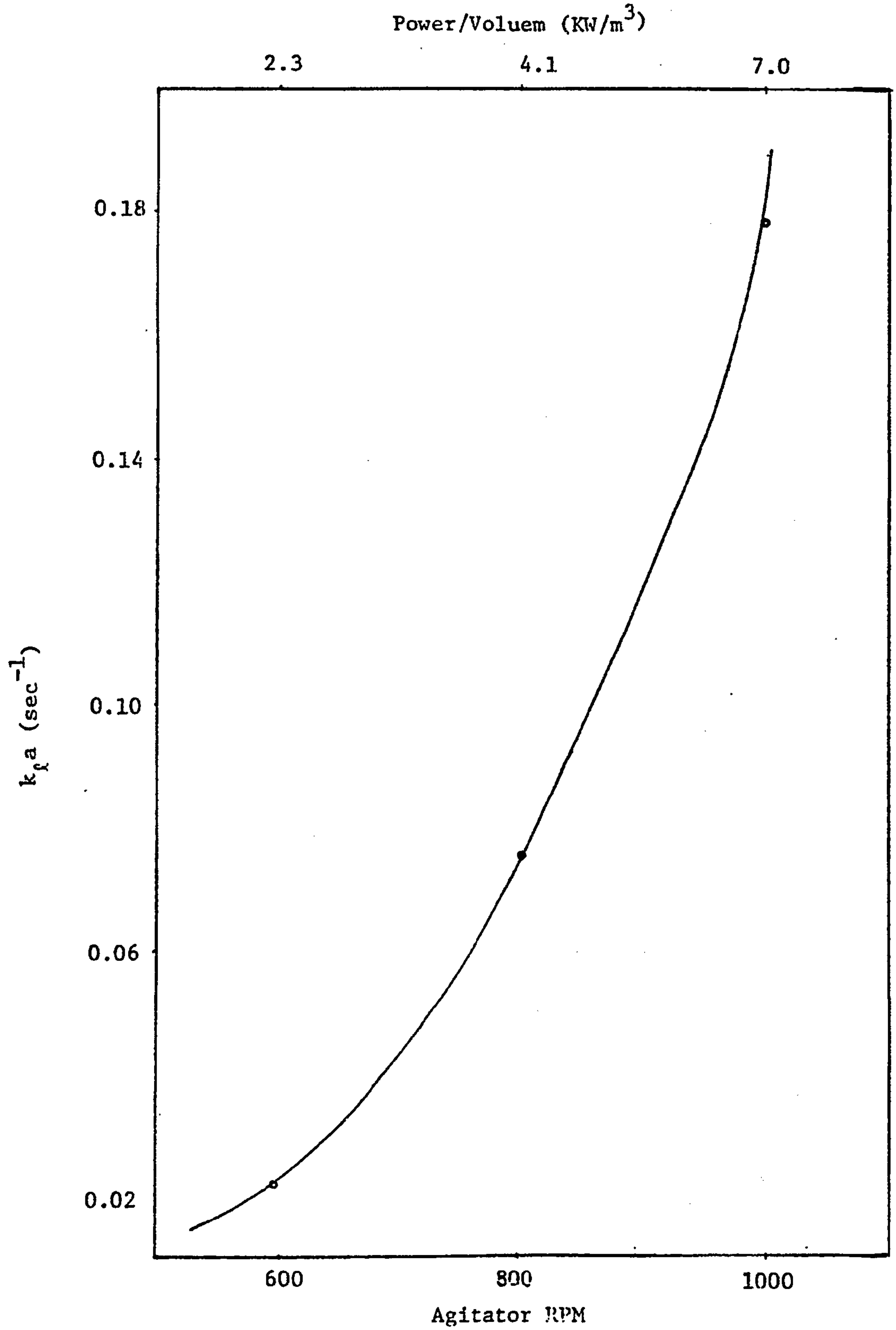

FIGURE 3.5 - Dependency of '$k_{\ell}a$' on Agitator RPM or Power/Volume

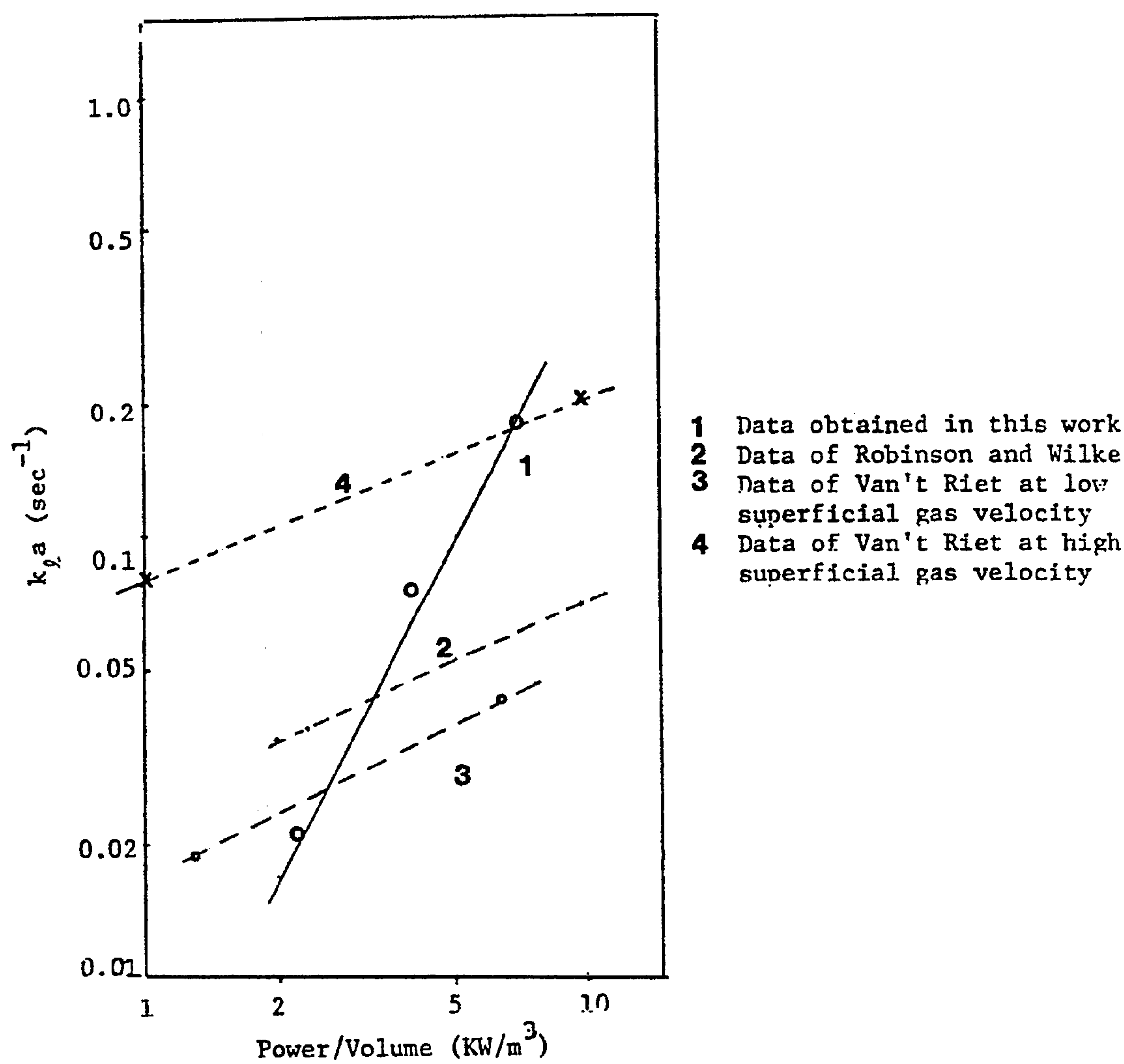

FIGURE 3.6 - Logarithmic Plot of '$k_\ell a$' versus Power/Volume

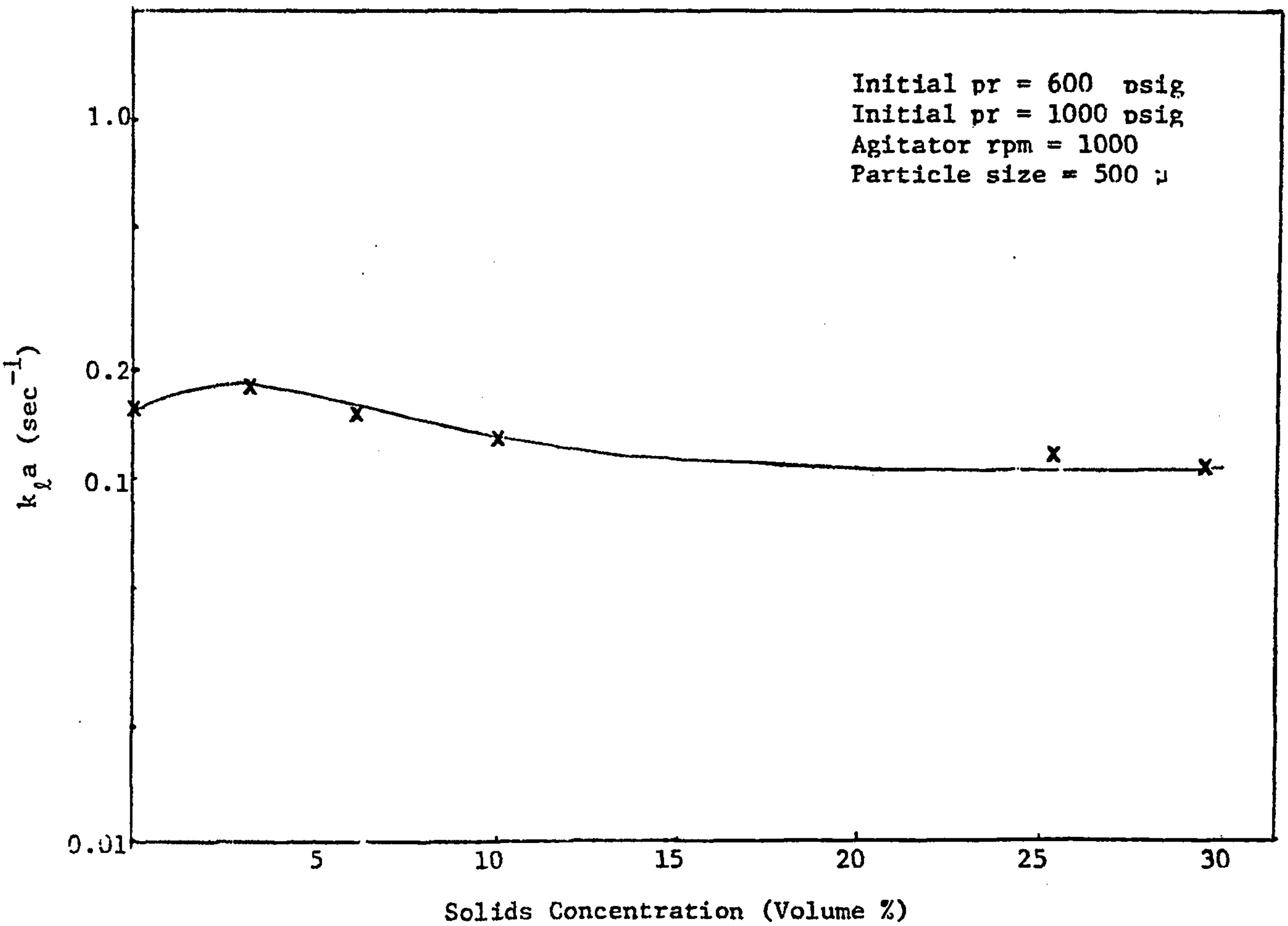

FIGURE 3.7 - Effect of Solids Concentration on '$k_\ell a$'

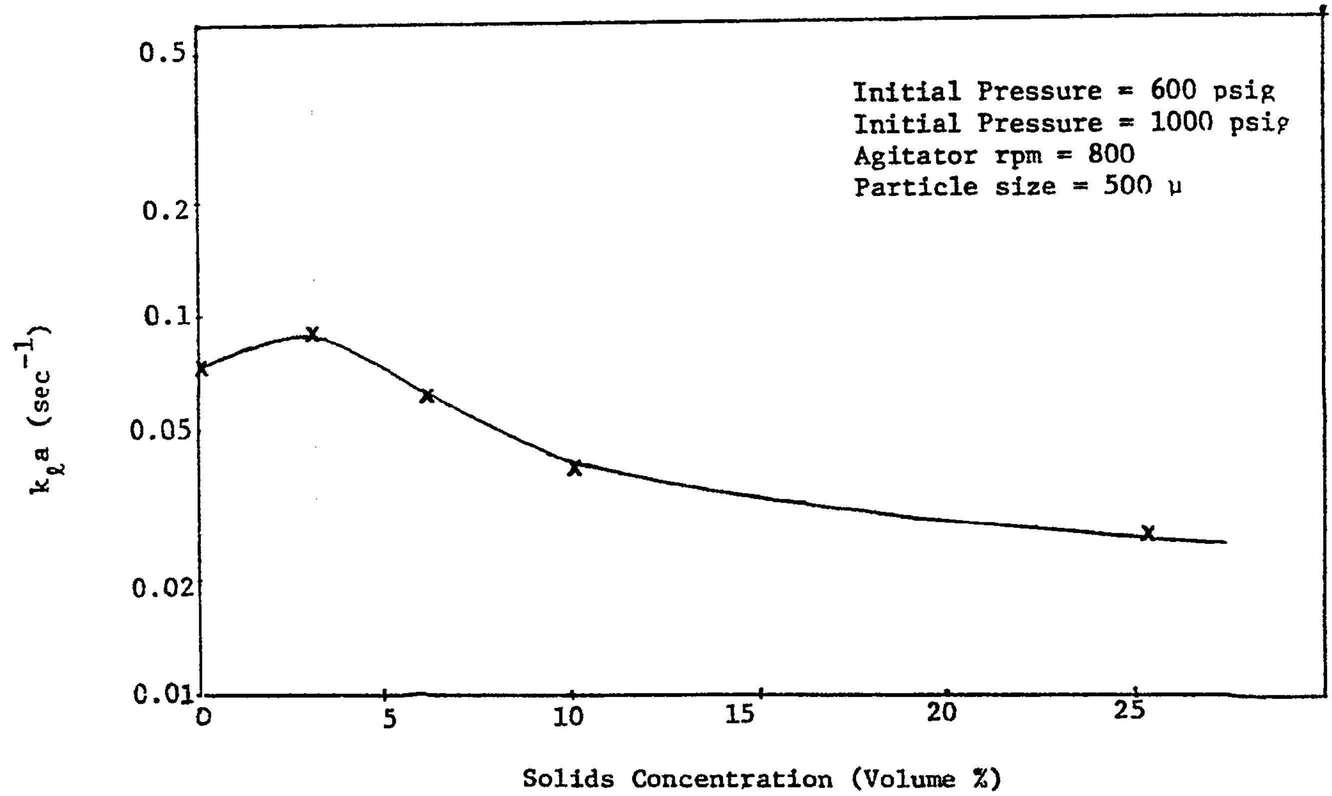

FIGURE 3.8 - Effect of Solids Concentration on '$k_\ell a$'

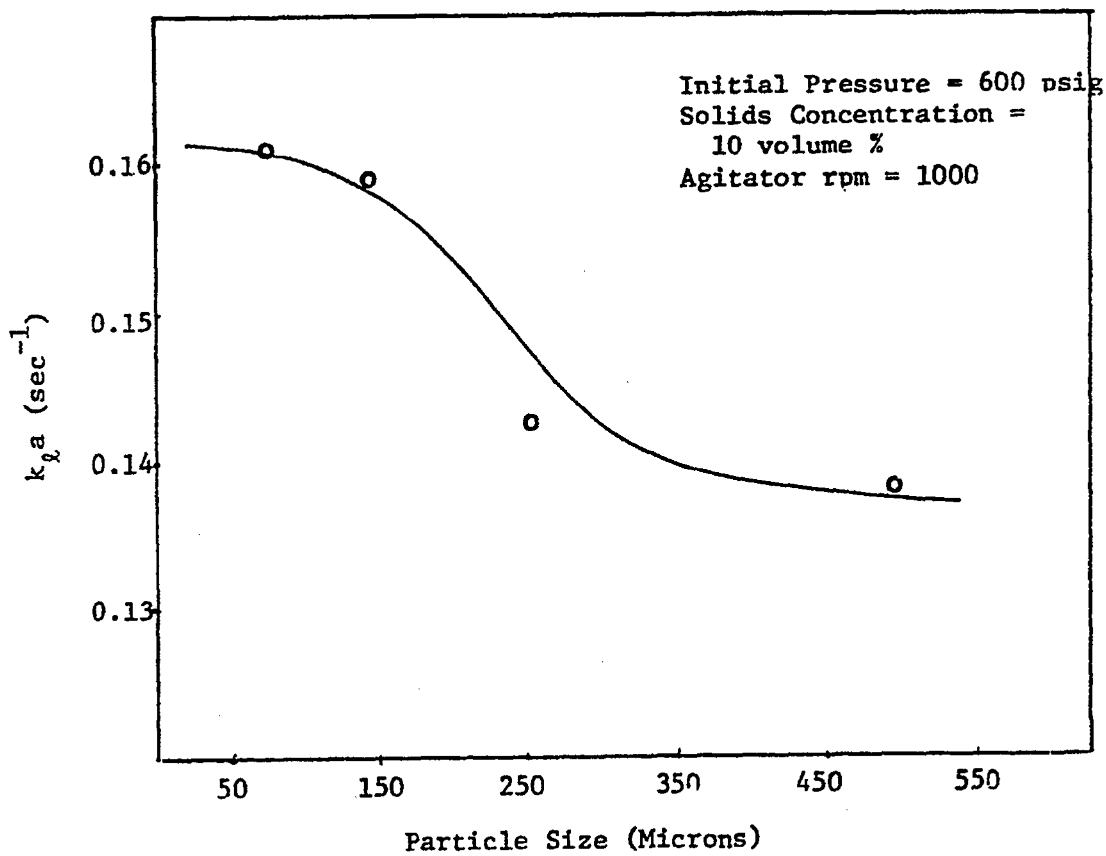

FIGURE 3.9 - Effect of Solids Particle Size on '$k_\ell a$'

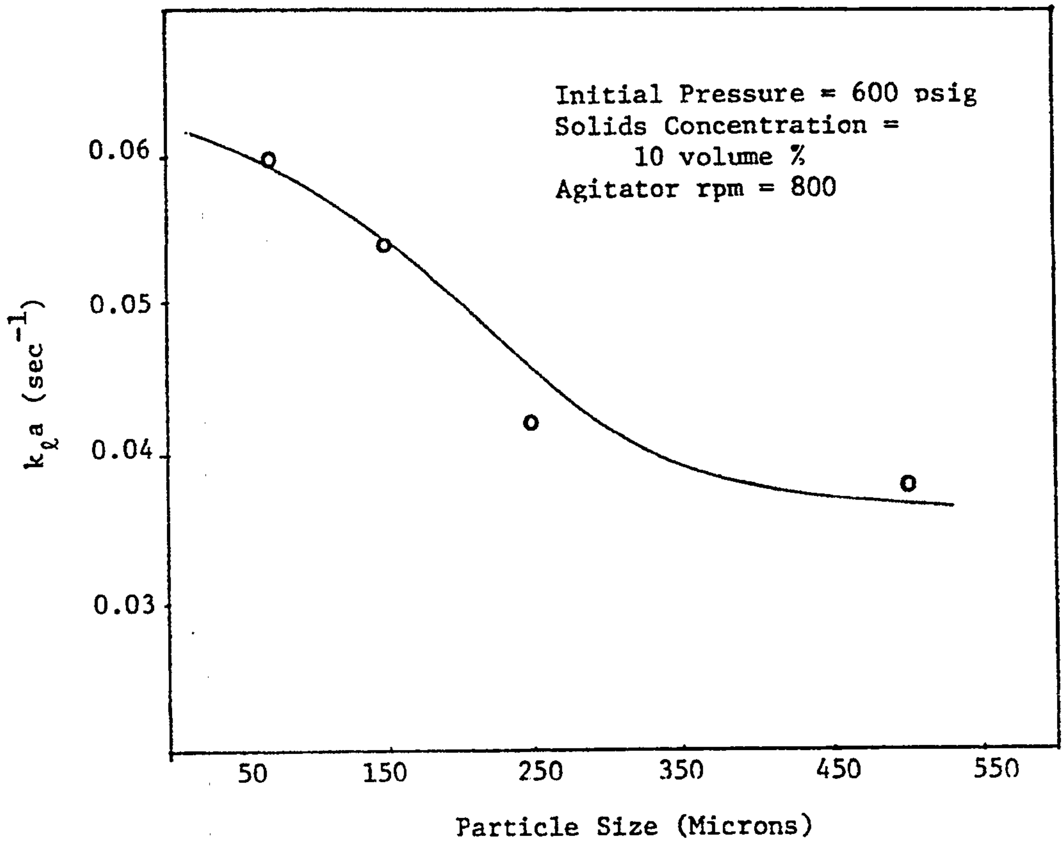

FIGURE 3.10 - Effect of Particle Size on '$k_\ell a$'

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4. CONTINUOUS COCURRENT DOWNFLOW BUBBLE COLUMN

4.1 Introduction

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

4.2 Experimental Set-Up and Procedure

The downflow reactor consisting of a glass column with an internal diameter of .075 m, and 2.45 m in height has been erected. The gas is introduced through a ring distributor with holes 1 mm in diameter radially into the liquid phase which is also introduced through the top of the column. The downflowing gas-liquid mixture is discharged into a disengaging tank with a rectangular cross-section .09 sq meter in area and .61 meter in height. 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 .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 flowrate is monitored by means of a rotameter in the line. The pressure at the upstream end of the rotameter is maintained constant by means of an air regulator. The liquid flow rate is metered using a calibrated eblow meter in the liquid line which is connected to a liquid level indicator. The slurries to be used will be metered by using an ultrasonics measuring device.

The pressure in the disengaging tank is maintained using a back pressure regulator provided with a pressure gauge. The column is fitted with six ports along the length, the distance between two consecutive ports is 0.305 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 are inserted with conductivity probes. These probes are at a distance of 1.22 m apart. The conductivity of a two phase or three phase mixture depends upon the relative amount of each phase present in the mixture. This principle will be employed to measure the gas holdup with the use of these probes. The method has been used previously by Stepanek et al.[4.1]

The Figure 4.1 is the process diagram of the cocurrent downflow bubble column.

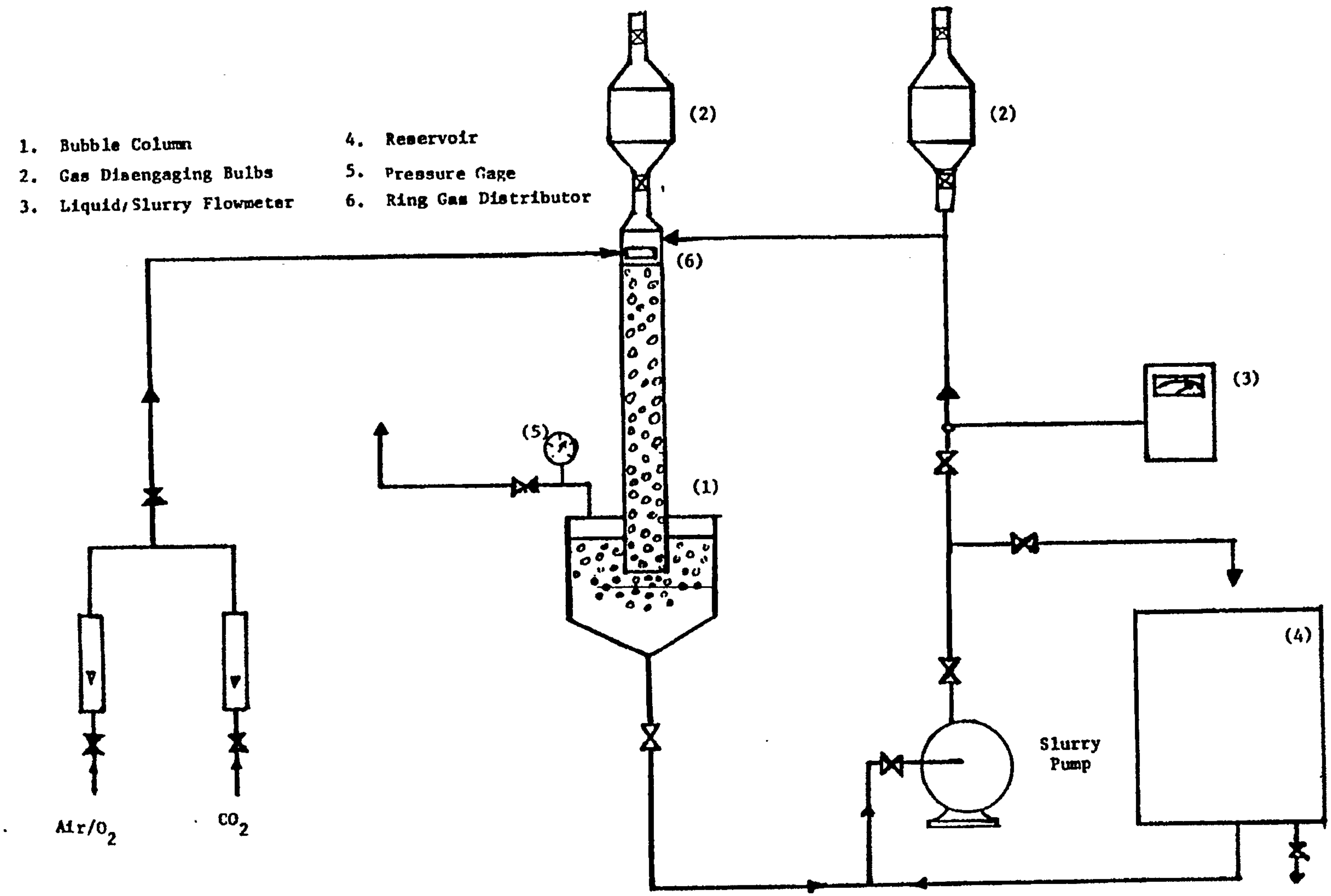


FIGURE 4.1: Experimental Set-Up

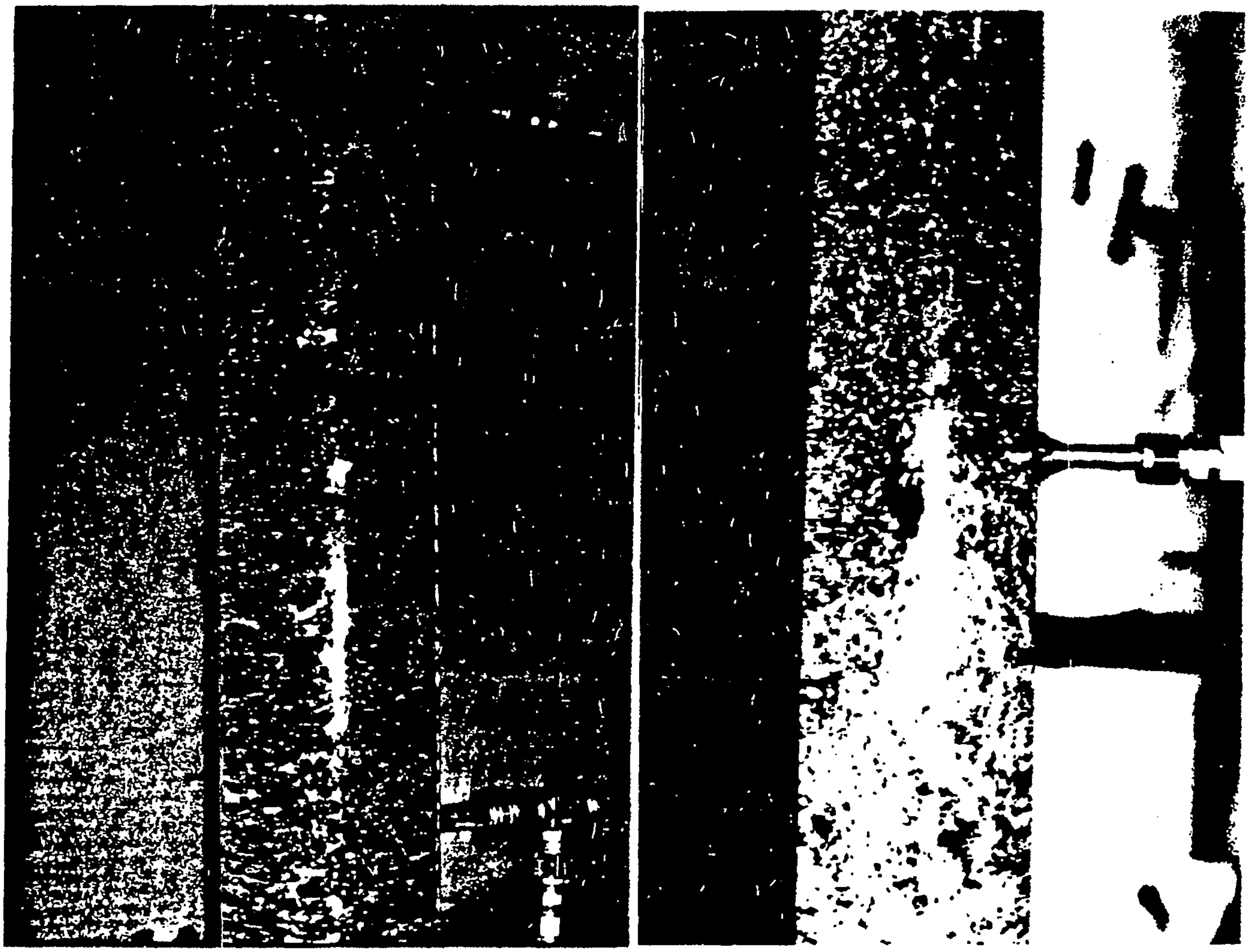
4.3 Results and Discussion

Some experimental measurements were made to determine the gas phase holdup in a air-water mixture. The gas phase holdup was determined by measuring the hydrostatic pressure along the length of the column of the two phase mixture. The following were the values of gas holdup obtained at the three liquid velocities and two gas velocities.

V_L(cm/s)	V_G (cm/s)	ε_G%
31	0.15	11.9
38	0.15	11.4
36	0.1	5.4

The gas holdup increases by more than two fold for an increase in gas velocity of only 50 percent. However, it is not significantly affected by the increase in liquid velocity. A comparison of this preliminary data in the downflow bubble column to a cocurrently operated upflow bubble column using the correlation reported by Hills[4.2] at high liquid throughputs shows that at a liquid velocity of 31 cm/s and gas velocity of .15 cm/s, the holdup is only 0.2%. Thus, the holdup in a downflow bubble column is nearly two orders of magnitude larger than in conventional bubble columns. Besides, the use of pressure taps, conductivity probes will be employed to measure the local holdup, since at higher gas velocities there seems to be an axial variation of the holdup, with the gas holdup decreasing progressively downwards.

Of course, these results are premature to make any in depth comments at this point, as the system is still in the process of debugging, for minor problems such as leaks through the disengaging section at the bottom and trace entrainment of the gas phase in the recycle liquid. Once these problems are overcome interesting data on holdup measurements would accrue. Moreso, as can be seen from Figure 4.2, and 4.3 which provide some pictures of gas dispersed in the liquid phase, for air-water system, the bubble flow regime is encountered. The pictures also show the uniform and fine dispersion of the gas phase, which suggests that high interfacial areas would be obtained in such a downflow column.

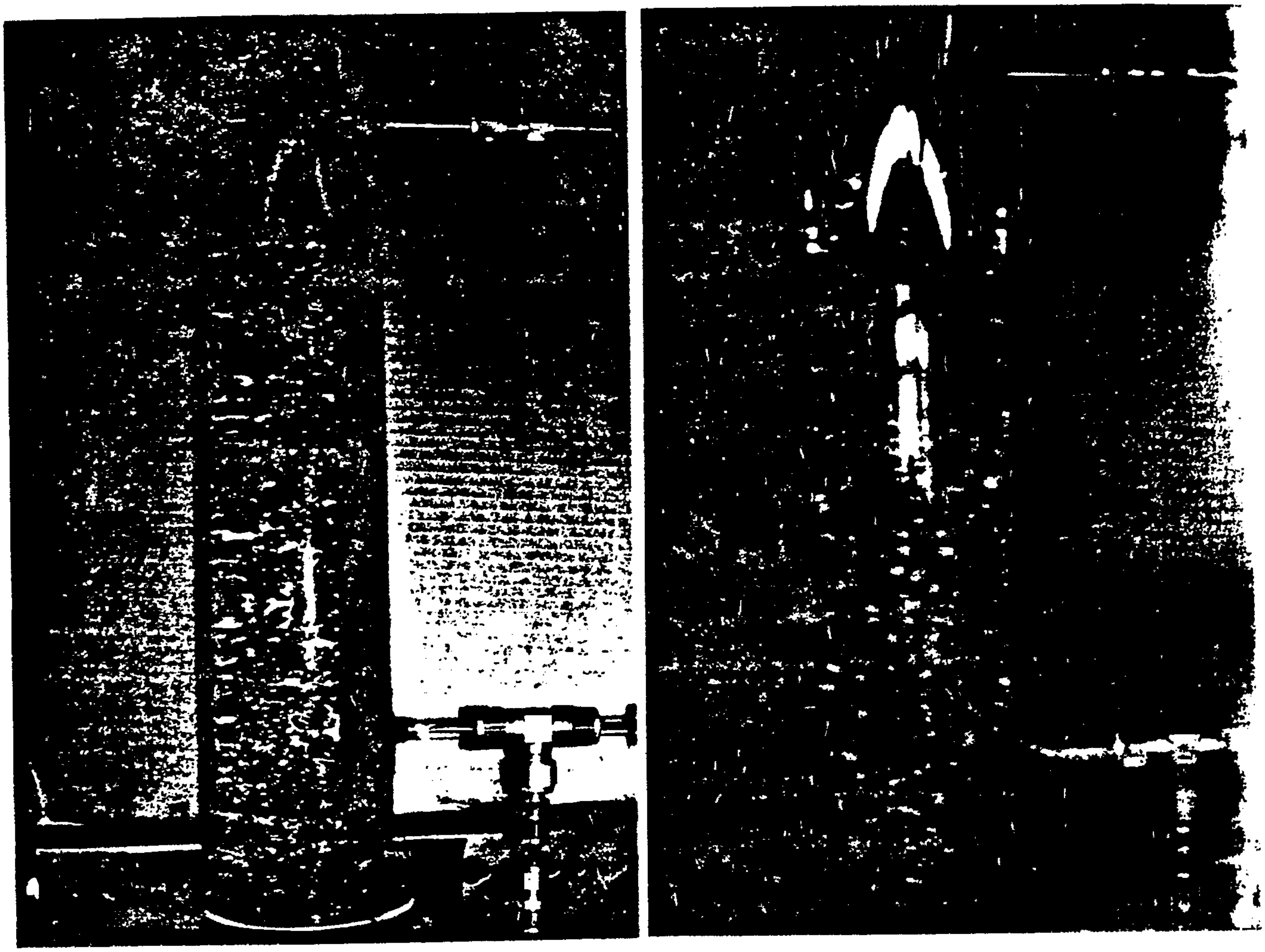


4.2(a) 4.2(b)

FIGURE 4.2: Gas Dispersion in Air-Water System

4.2(a): Photograph of gas bubbles at V_G=0.1 cm/s and V_L=31 cm/s

4.2(b): Photograph of gas bubbles at V_G=0.1 cm/s and V_L=20.5 cm/s



4.3(a) 4.3(b)

FIGURE 4.3: Gas Dispersion in Air-Water System

4.3(a): Photograph of gas bubbles at V_G=0.1 cm/s and V_L=31 cm/s

4.3(b): Photograph of gas bubbles at V_G=0.15 cm/s and V_L=31 cm/s

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Conclusions

The gas holdup and dispersion coefficient data in the cocurrent continuous column were analyzed using flow regime maps. A theory by Zuber and Findley has been successfully applied to rationalize all the data with the help of nonuniform radial distribution.

The gas holdup and bubble rise velocities data have been analyzed using flow regime maps and gas disengagement technique in batch bubble column.

The results obtained in a mechanically agitated contactor reveal that pressure has no effect on $k_\ell a$, an increase in rpm increases $k_\ell a$ and that an increase in solid concentration decreases $k_\ell a$, though particles of smaller size gave better values of $k_\ell a$ than particles of larger size.

The downflow bubble column is in operation and some preliminary data were obtained.

Nomenclature

a	interfacial area, cm^2/cm^3
c	ratio of solid to liquid holdup ($\varepsilon_s/\varepsilon_L$)
C_b	bulk concentration of the gas in the liquid
C_N	carbon number
Cp	specific heat
Co	distribution parameter
C_1	constant in equation (1.3.8)
C*	equilibrium concentration of the gas in the liquid
D	axial dispersion coefficient
d_b	bubble diameter
d_c	diameter of the column, m
g	gravitational acceleration, m^2/s
H	Henry's law constant
HH	hydrostatic head
k_ℓ	mass transfer coefficient, cm/s
k_L	mass transfer coefficient, m/s
L	length of column
n	flow behavior index
N	number of moles of gas
P	pressure
hi	unaerated liquid height, m
h(t)	aerated liquid height, m
K	consistency index, kg/m·s
ΔP_{tp}	two phase functional pressure drop
R	gas constant
T	temperature, C

T_c, T_h boundary values of axial temperature

t_{max} (d_b) maximum time required for bubbles of size d_b to disengage, s

u_{br} (d_b) bubble rise velocity of bubbles of size, d_b, m/s

$U_{b\infty}$ single bubble rise velocity, m/s

U_s slip velocity, m/s

V superficial fluid velocity, m/s

V_c circulation velocity, m/s

V_G volume of gas phase

V_ℓ or V_1 volume of liquid phase

VM bubble rise velocity defined as V_G/ε_G, m/s

V_T total phase velocity, m/s

x axial distance, m; absolute pressure, atm in equation (3.3.1)

x_c, x_h boundary values of axial distance

y volume of gas at 25°C and 1 atm per unit volume of liquid

Subscripts

G gas phase

L liquid phase

S solid phase

SL slurry phase

Greek Letters

α $\frac{V_1}{HV_g} RT$

ε phase holdup

ν_{CD} drift flux, m/s

$\dot{\nu}$ shear rate, s^{-1}

ρ phase density, kg/m^3

σ	interfacial tension, N/m
μ	viscosity, kg/m·s
$\varepsilon_G(t)$	gas holdup as a function of time
$\varepsilon_{G,i}$	gas holdup of bubbles of size i
ε_{Go}	observed gas holdup
ε_{GP}	predicted gas holdup

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