Part B:

HYDRODYNAMIC BEHAVIOR OF MULTIPHASE REACTORS

Annual Progress Report
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Overall Summary

This annual report on the hydrodynamic behavior of multiphase reactors is divided into four sections.

Section 1 deals with the measurement of gas holdup and dispersion coefficients in a cocurrent continuous bubble column. Three systems, namely alcohol solutions, carboxy methyl cellulose (CMC) solutions, and electrolytic solutions have been studied. The range of gas velocity covered is 2-30 cm/s while the range of liquid velocity was varied from 0-15 cm/s.

Section 2 deals with the measurement of gas holdup and bubble rise velocity in a batch bubble column. The systems studied were glycerine, CMC and alcohol solutions with and without solids. The range of gas velocity covered is 2-30 cm/s.

Section 3 covers the aspects of mass transfer in a mechanically agitated contactor at high pressure in the presence of solids. The range of variables covered were pressure 400-1400 psig, speed of agitation 400-1000 rpm, solid concentration of 0-30 volume percent and particle size in the range 75-500 microns.

Section 4 deals with the continuous cocurrent downflow column which is a recent addition to the multiphase flow processing laboratory at the University of Pittsburgh. This unit has been erected and is in the process of debugging for minor practical problems.

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1. CONTINUOUS COCURRENT BUBBLE COLUMN

1.1 Introduction

Bubble columns have many important industrial applications, though their scaleup and the design is difficult because of the complexity of the flow pattern characteristics. The aim of these epxeriments was to study the hydrodynamic and mixing characteristics in a .152 m diameter by 3.35 m tall, cocurrent, continuous bubble column. This was done by measuring the phase holdup and the axial heat dispersion coefficient, respectively. The holdup was analyzed using the hydrostatic head techniques, and the dispersion coefficients were analyzed using an axial dispersion model. The effect of a wide range of physical parameters, such as gas velocity, liquid velocity, surface tension, viscosity, and electrolytes concentrations were studied. The data were compared to the existing data wherever possible, and they were analyzed with the help of flow regime characteristics.

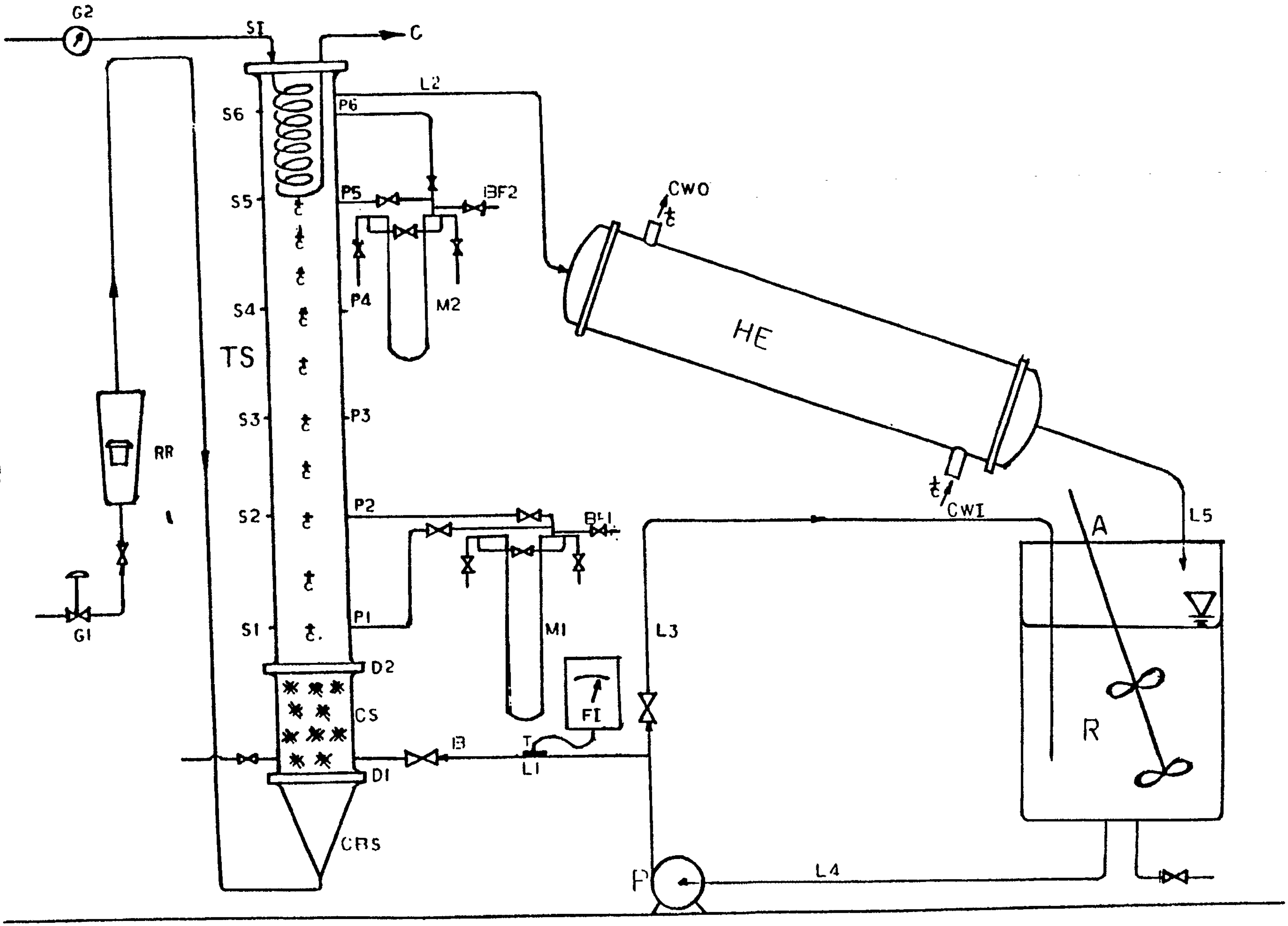
1.2 Experimental Setup and Procedure

1.2.1 Experimental Setup

The experiments are carried out in a .152 meter diameter *3.35 meter tall bubble column. The schematic diagram of the setup is shown in Figure 1.1. The abbreviations of the figure are explained in Table 1.1. The bubble column has four major sections:

1. Conical bottom section for gas inlet and uniform distribution.
2. .3 meter long calming section filled with copper Raschig rings for mixing of gas and slurry.
3. Main test section.
4. Heat source at the top.

FIGURE 1.1: **EXPERIMENTAL SETUP**



DEFINITIONS FOR FIGURE 1.1

A	Agitator
B1, B2	Ball Valves
BF1, BF2	Backflushing System
C	Condensate
CBS	Conical Bottom Section
CS	Calming Section
CWI, CWO	Cooling Water Inlet and Outlet
D1, D2	Distributor Plates
G1, G2	Pressure Gauges
HE	Shell and Tube Heat Exchanger 1" OD SS tubes on the tube (slurry side) Heat transfer area 25 ft^2 14" OD, 6 ft long Black iron shell side (cooling water)
L1-L5	2" OD, Schedule 80, PVC pipes
M1, M2	Manometers
P	Galigher Horizontal Centrifugal Pump
P1-P6	Pressure Taps
R	Reservoir (550 liter, plastic)
RR	Gas Rotameter
SI	Steam Inlet
S1-S6	Sampling Taps
TS	Main Test Section
T, FI	Transducer and Flow Indicator (ultrasonic)
	Thermocouple Holes

Two perforated plate distributors are provided. One having holes of 0.5 mm diameter, is used between the conical bottom section and the calming section, while the one having 1.0 cm holes is fitted between the calming section and the test section.

Four pressure taps, two at the bottom and two at the top; each pair .61 meter (2.0 ft) apart, are provided. Each pair is attached to different mercury manometer to avoid any dynamic lag. To overcome the difficulty of plugging these manometer lines a water backflushing system is used. In addition to the pressure taps, six sampling tubes, .61 meter apart from each other, are inserted to collect solid-liquid samples. Each tube has five holes of 5 mm diameter each, along the length to ensure radially averaged phase concentration at each location. The solid phase concentration will be measured gravimetrically.

For heat tracer experiments, ten iron-constantan thermocouples are connected to the test section. First eight are .3 m (1 ft) apart and the last three are .15 m apart from each other. In addition to the above mentioned thermocouples, the inlet and outlet temperatures of liquid, inlet and outlet temperatures of heat exchanger cooling water are also measured with the help of thermocouples. All the thermocouples are connected to a digital display meter which is capable of reading the temperatures up to first digit. A stainless steel coil heated with steam is used to provide 74 kilowatts of heat into flowing fluid.

The gas phase used is always air. Air inlet pressure is maintained constant with the help of pressure regulator. The gas phase flow rate is measured with the help of calibrated rotameter, while the liquid flow rate is measured with the help of an ultrasonic flow measuring device. Column is insulated with fiberglass insulation material to prevent the heat losses. All the experiments are carried out near atmospheric pressure, in a continuous and steady state manner.

The surface tension is measured by du-Nouy method.[1.31] In this method a platinum-iridium ring of precisely known dimensions is suspended from counter-balanced lever-arm. The arm is held horizontal by torsion applied to a taut stainless steel wire, to which it is clamped. Increasing the torsion in the wire raises the arm and the ring, which carries with it the film of liquid in which it is immersed. The force necessary to pull the test ring free from the surface film is measured directly in dynes/cm. This "apparent" reading is converted to "absolute" value by a correction chart. The viscosity is measured on Brookfield LVT type viscometer. This instrument rotates the spindle in the fluid at a constant speed, and measures the torque necessary to overcome the resultant viscous drag. For given speed and spindle, it produces dial readings proportional to the viscosity.[1.32, 1.33]

1.2.2 Analysis

The analysis of the raw data has been done separately for the holdup and the axial dispersion coefficient as described below.

1.2.2.1 Holdup

To determine the gas holdup, the manometer readings are first converted to absolute pressure by a simple hydrostatic head technique. To get the values of gas holdup in gas-liquid systems, two equations are used.

$$\varepsilon_G + \varepsilon_L = 1.0 \qquad (1.2.1)$$

$$-\frac{dp}{dx} = (\varepsilon_G\rho_G+\varepsilon_L\rho_L+\varepsilon_s\rho_s) + \Delta p_{tp} \qquad (1.2.2)$$

where Δp_{tp} is the frictional pressure drop and dp/dx is the pressure gradient. It is found that the frictional pressure drop is negligible and pressure shows linear dependency with length. To ensure this, gas holdup is calculated in two ways. One is already mentioned above. In the other method, the holdup is calculated in the following manner

$$\varepsilon_G = \frac{HH|_{V_G=0} - HH}{HH|_{V_G=0}} \qquad (1.2.3)$$

where HH is the hydrostatic head. The holdup values calculated by both the methods match well (within ± 1%) indicating a negligible frictional pressure drop and negligible linear variation in holdup values.

To determine the solid and liquid holdup in three phase systems, solid-liquid samples will be collected at several locations along the length of the column. By measuring the weight and the volume of the slurry, density will be obtained. After filtering and drying the samples, it is possible to calculate the relative volume fraction of liquid and the solid. By knowing this quantity, following three equations will be solved simultaneously to get the values of individual phase holdup.

$$\varepsilon_G + \varepsilon_L + \varepsilon_s = 1.0 \qquad (1.2.4)$$

$$-dp/dx = \varepsilon_G\rho_G + \varepsilon_L\rho_L + \varepsilon_s\rho_s \qquad (1.2.5)$$

$$\varepsilon_s/\varepsilon_L = \text{known quantity} \qquad (1.2.6)$$

1.2.2.2 Axial Dispersion Coefficient

The axial dispersion coefficient is analyzed using the axial dispersion model, using heat as a tracer. The method involves a continuous addition of heat as a tracer under steady state conditions. In some cases, significant fluctuations are observed in temperature. These fluctuations are more pronounced in the upper section of the column. To take into account the fluctuations, the average of 25 to 30 values noted at one point, are taken.

The overall energy balance on three phase system, based on the following assumptions can be written as:

1. Heat losses from tube wall are negligible.

2. At any given point, gas, liquid, and solid phase tempratures are the same.

3. Constant physical properties.

4. Steady state flow.

5. The thermal conductivity and the density of the gas phase are small compared to that of liquid and solid, and therefore can be neglected.

6. The molecular thermal conductivity is negligible compared to axial dispersion coefficient of heat.

7. No chemical reaction is occurring.

8. The latent heat of vaporization is negligible.

9. Gas phase backmixing is relatively small.

10. Solid-liquid mixture behaves as a homogeneous slurry.

Based on these assumptions, the following equation is obtained:

$$- (D_{SL}\rho_{SL}C_{PSL}\varepsilon_{SL}) \frac{d^2T}{dx^2} + (\rho_{SL}V_{SL}C_{PSL}) \frac{dT}{dx} = 0 \qquad (1.2.7)$$

For gas-liquid systems, the equation simplifies to:

$$- (D_L\rho_L C_{P_L}\varepsilon_L) \frac{d^2T}{dx^2} + (\rho_L V_L C_{P_L}) \frac{dT}{dx} = 0 \qquad (1.2.8)$$

Solution of this equation is obtained using the boundary conditions,

$$1)\ \text{at } x=x_c,\ T=T_c \qquad 2)\ \text{at } x=x_h,\ T=T_h \qquad (1.2.9)$$

The equation is solved numerically by a pattern grid search method available as a package program on University of Pittsburgh computer library.

1.3 Results and Discussion

As indicated in the last report, the experiments are being carried out in a cocurrent, continuous bubble column, having diameter of .152 m. The phase holdups and the axial heat dispersion coefficients are measured with the help of the hydrostatic head technique, and the axial dispersion model respectively.

The effect of the liquid properties have been studied using different alcohol solutions, carboxy methyl cellulose (CMC) solutions, and electrolyte solutions. The results obtained are summarized in the following sections.

1.3.1 Effect of Surface Tension

The effect of surfactants is not clearly understood. Many investigators have tried different surfactants with entirely opposite conclusions. While Botton et al.[1.1] and Miller[1.2] reported no effect of surface tension, Schügerl et al.,[1.3] Todt et al.[1.4] observed a significant increase in the gas holdup with a decrease in the surface tension. Recently Oels et al.[1.5] carried out experiments with dilute solutions of alcohols and found a significant increase in the values of gas holdup. Bach and Pilhofer[1.6] observed no effect of surface tension on gas holdup for pure liquids but they noted a different behavior for liquid mixtures and electrolyte solutions. The addition of electrolytes increases the gas holdup as noted by Akita and Yoshida,[1.7] Hikita et al.,[1.8] Freedman and Davidson,[1.9] etc. Freedman and Davidson observed that the addition of electrolytes postponed the appearance of large bubbles in the column. Electrolytes and/or alcohol additives probably stabilize the bubble size by formation of an ionic and/or polar double layer at the interface which depresses the coalescence rate.

In SRC-II reaction, where the surface tension of the liquid phase is very low, there is a possibility that the value of the gas holdup and the dispersion coefficient may show entirely different behavior in the presence of long chain carbon molecules. It is assumed that, the surface tension behavior in the SRC-II reactor can be fairly simulated by C_3- C_4 alcohols. In addition, the bubble columns have been recently used as bioreactors for the production of alcoholic beverages, and single cell proteins. The substrate in these reactors can be fairly simulated with the help of alcohol solutions.[1.3]

The alcohol solution studied and their physical properties are tabulated in Table 1.2. All the concentrations of the alcohol solutions mentioned hereafter are in vol %.

TABLE 1.2

PHYSICAL PROPERTIES: ALCOHOL SOLUTIONS

	ρ_L g/cc	σ_L dynes/cm	μ_L cP
.5% Propanol	.9949	65.7	0.85
1% Propanol	.9940	56.3	0.85
3% Propanol	.9908	44.7	0.85
.5% Butanol	.9932	60.8	0.84
2% Butanol	.9912	49.0	0.84
.5% Ethanol	.9931	68.2	0.83
.5% Methanol	.9940	69.7	0.83

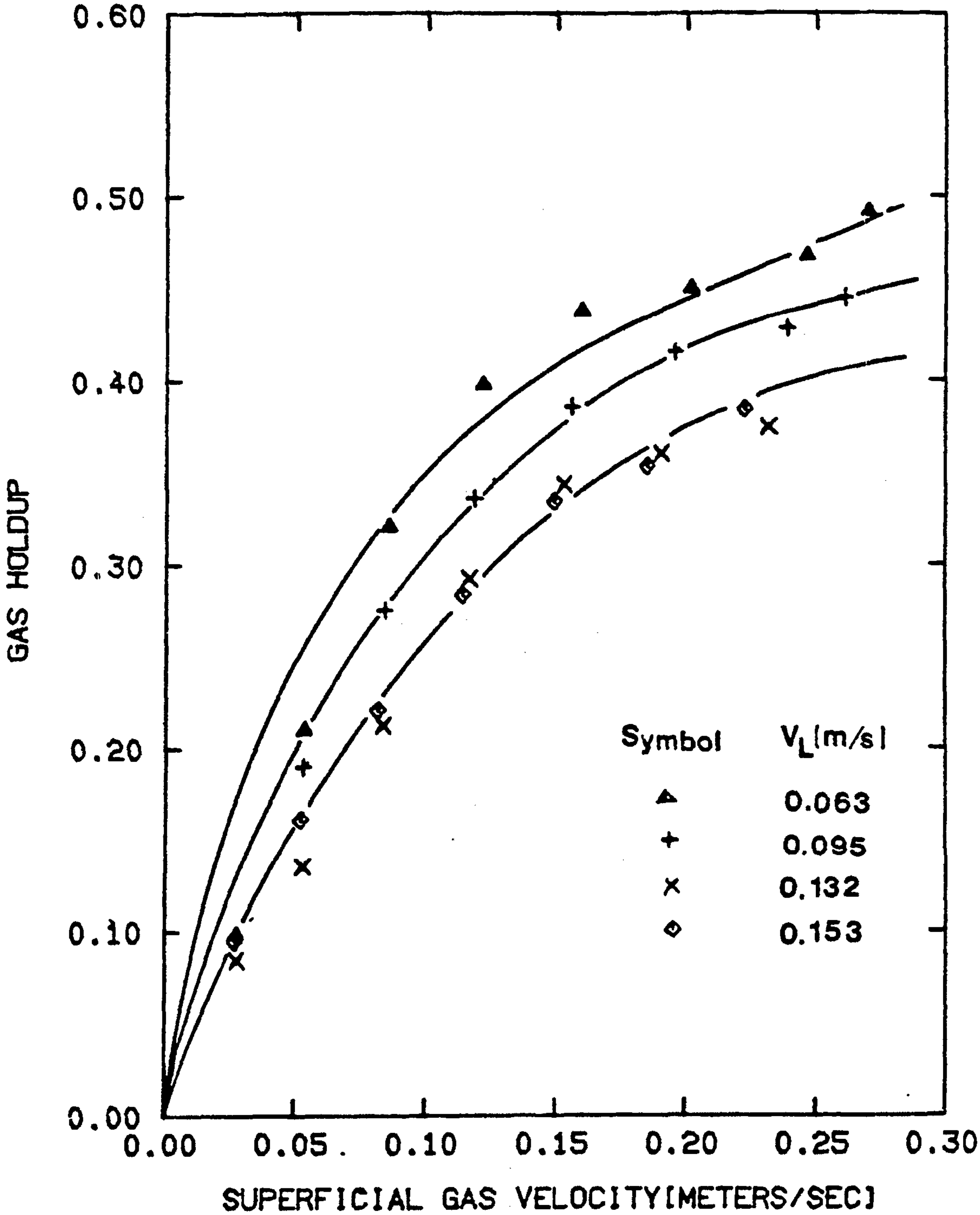
The only work reported on these type of culture media, is by Schügerl and coworkers.(1.3,1.4,1.5) But the relative range of gas and liquid velocities studied is low (V_G < 6.0 cm/s, V_L < 3.0 cm/s).

The experiments were carried out at atmospheric pressure, at gas velocities ranging from 3.0-30.0 cm/s, and the lqiuid velocities ranging from 2.0-15.0 cm/s. Following results are obtained.

1.3.1.1 Gas Holdup

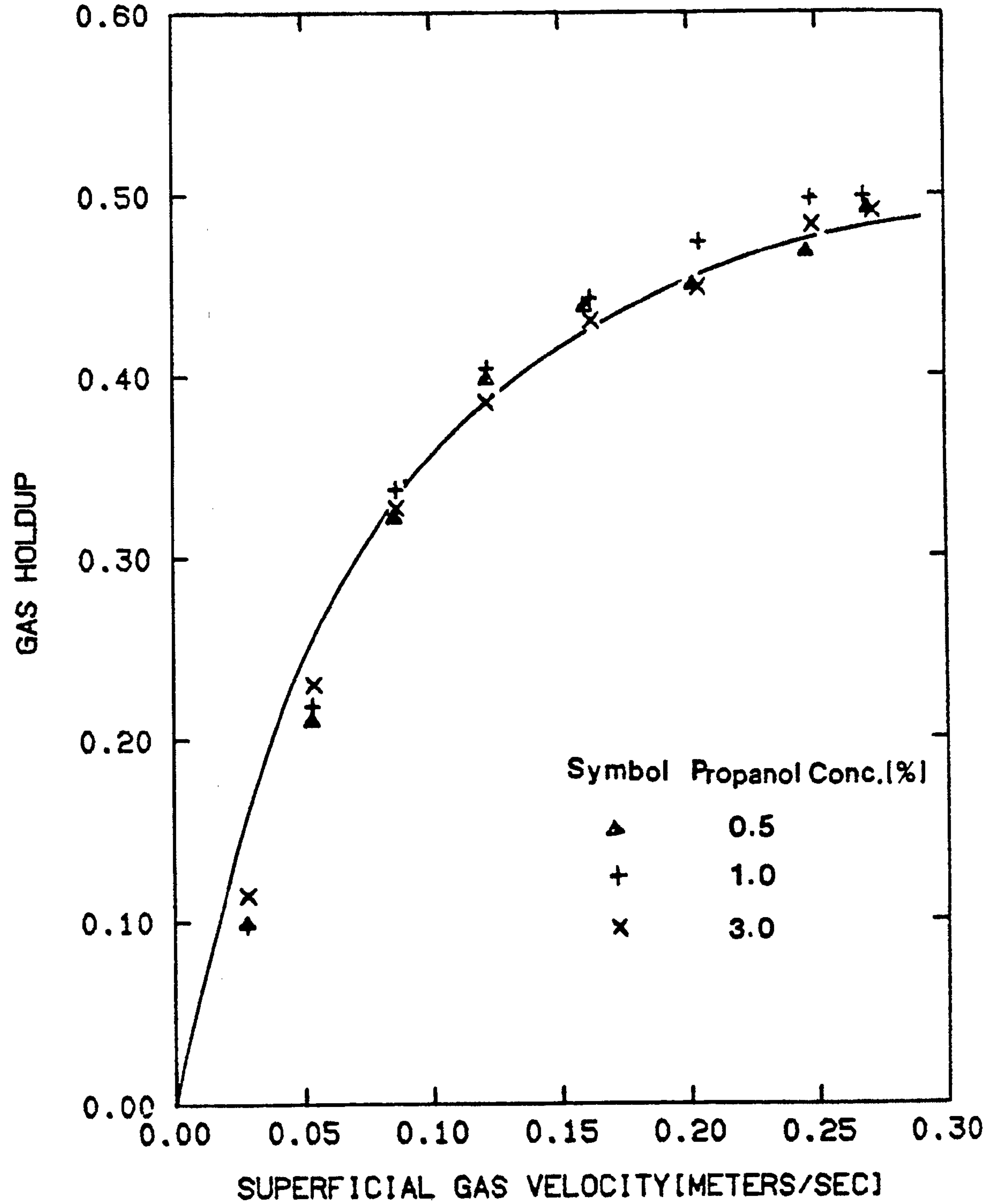
Gas holdup shows an increase with an increase in the gas velocity, but shows a decrease with an increase in the liquid velocity, as illustrated in Figure 1.2, but the effect of liquid velocity becomes insignificant at higher liquid velocities. The effect of alcohol concentration on the gas holdup is observed to be insignificant as shown in Figure 1.3, but the effect of the type of alcohol is predominant as shown in Figure 1.4. The gas holdup increased in the following order,

methanol < ethanol < propanol < butanol



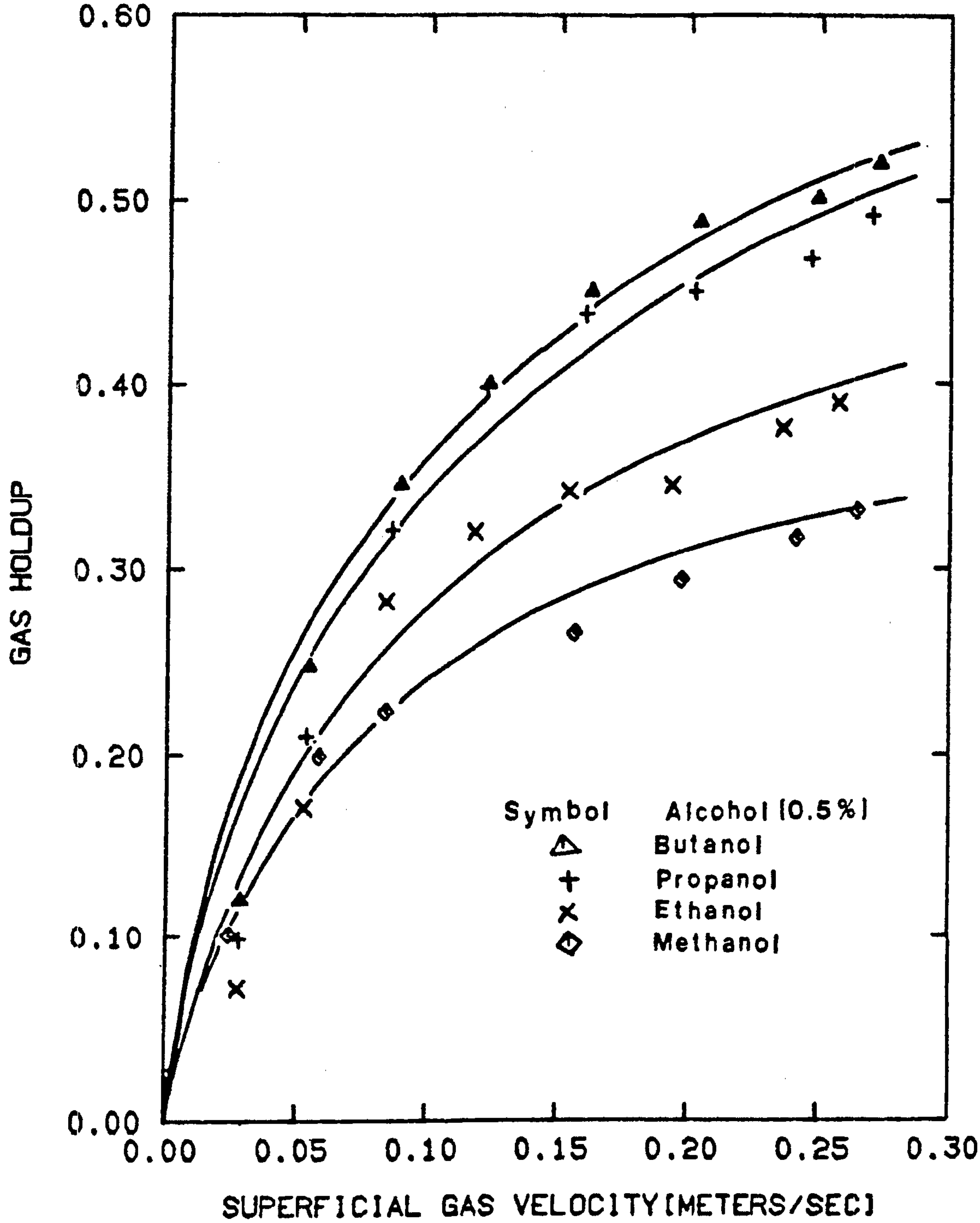
GAS HOLDUP VS SUPERFICIAL GAS VELOCITY[0.5% PROPANOL]

FIGURE 1.2



EFFECT OF CONCENTRATION ON GAS HOLDUP[ALCOHOL SOLUTIONS]

FIGURE 1.3



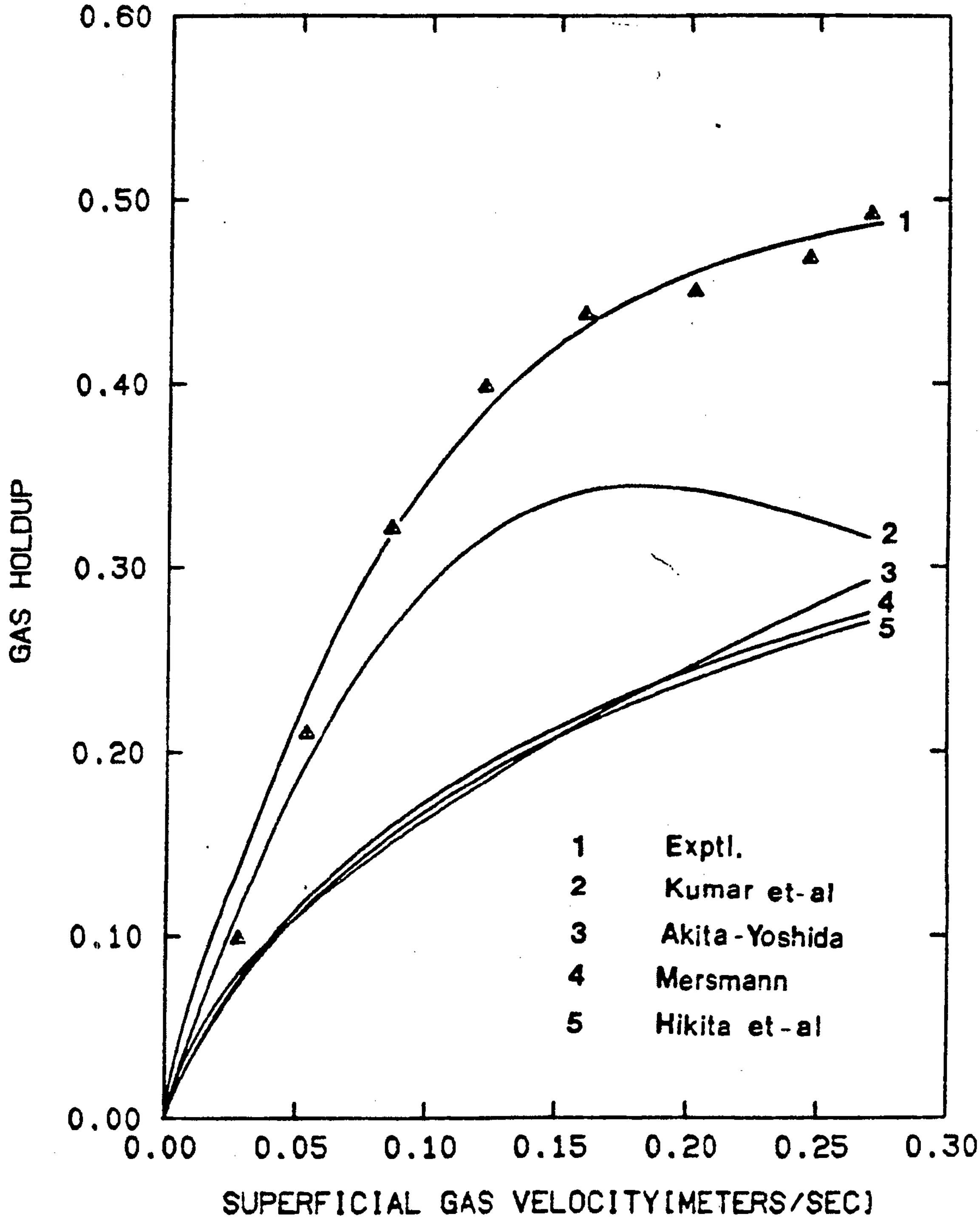
GAS HOLDUP VS SUPERFICIAL GAS VELOCITY[ALCOHOL SOLUTIONS]

FIGURE 1.4

The experimental data are compared with the values calculated with the help of different existing correlations, and all the tabulated results are shown in Appendix 1.1. The values are compared with the values obtained with the correlations by Akita and Yoshida,[1.7] Hikita et al.,[1.8] Kumar et al.,[1.10] Miller,[1.2] and Schügerl et al.[1.3] It is generally observed that none of the correlation was satisfactory in predicting the values of gas holdup. The equation by Schügerl et al.[1.3] predicts reasonable values for low gas velocity range, but is not applicable for high gas velocities. A typical comparison plot is shown in Figure 1.5. To study this strange behavior, flow regimes are tested, and some surprising results are found.

1.3.1.2 Flow Regimes

The gas holdup depends on the physical properties of the liquid phase, bubble density, bubble size and the coalescence rate. Schügerl et al.[1.3] observed that in the presence of alcohol solutions, the effect of distributor plate is also important. Present experiments are carried out with perforated plates having holes of 0.5 mm diameter. Berghmans[1.11] has derived a criterion for the stability of the bubbles for small viscosity liquids. He based his criterion on relative magnitude of buoyancy, interfacial and gravitational forces. For this perforated plate, it is observed that the bubbles are below the boundary of stable and unstable region indicating that the bubble size is not solely governed by the dynamic equilibrium. Therefore, the bubble size depends essentially on the type of system being used. This observation is also supported by Schügerl et al.,[1.3] who indicated that for perforated plate distributors having holes of diameter greater than 0.5 mm, will be on the boundary of the stable and unstable region.

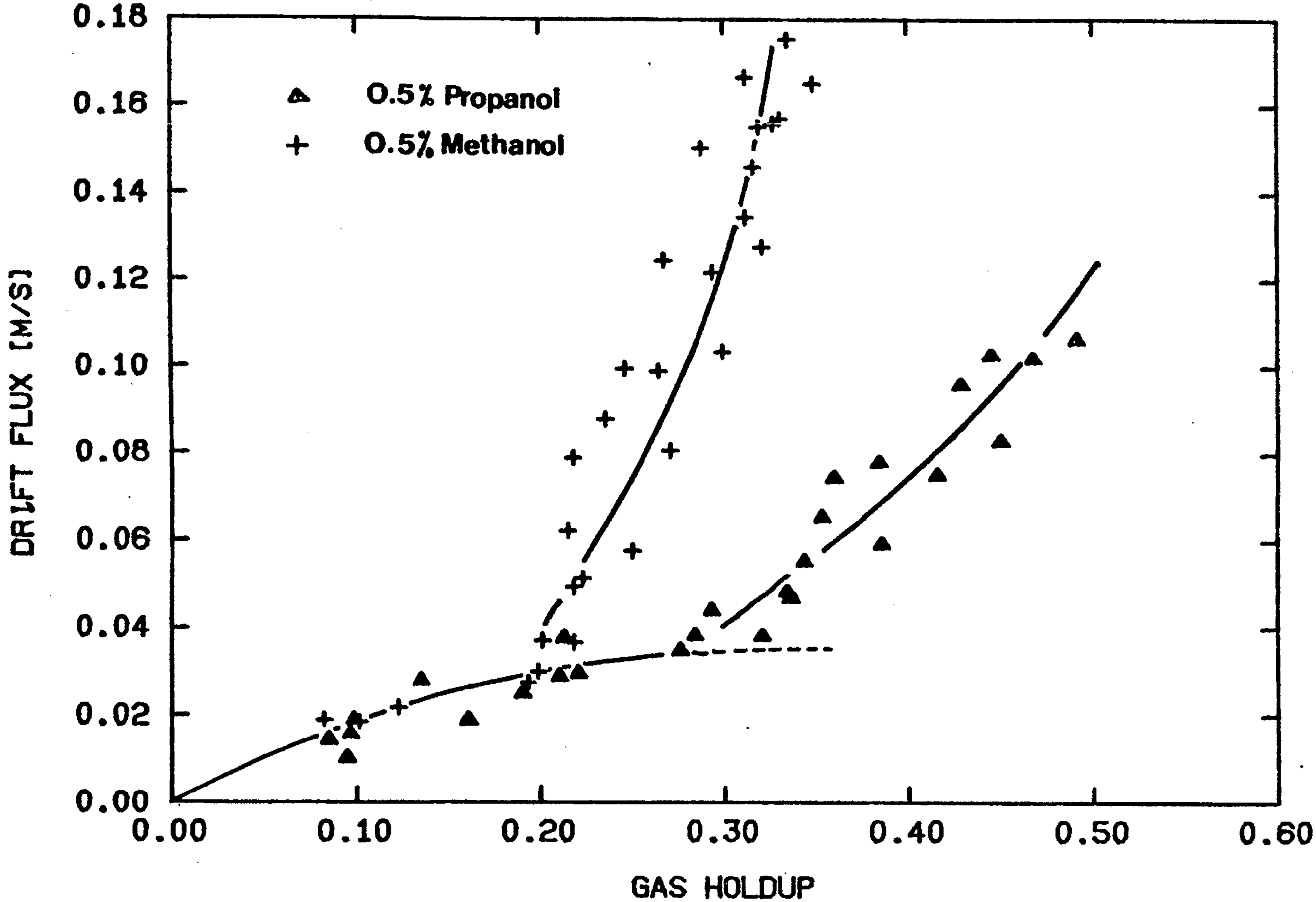


COMPARISON OF DIFFERENT CORRELATIONS WITH EXPTL RESULTS

FIGURE 1.5

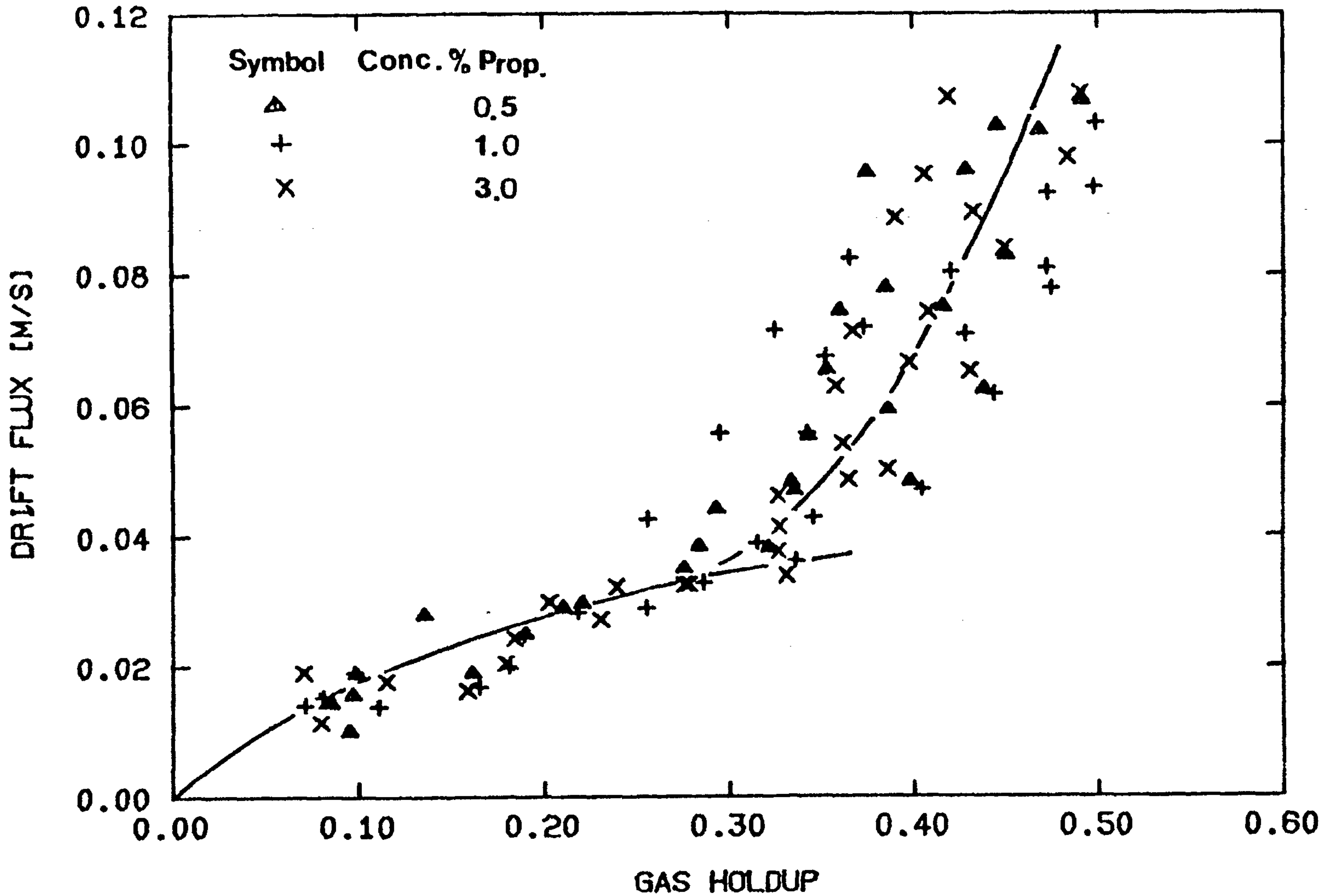
To see the regime in which most of the data lie, the flow regime diagrams are prepared, where drift flux as a function of gas holdup is plotted. As shown in Figure 1.6, the drift flux diagram clearly shows the transition. For methanol solution, the transition from the bubbly flow is much earlier than the propanol solution. The dotted line indicates the direction of the probable points, if flooding is avoided and the bubbly flow regime can be maintained. It should be noted that both the alochols are hardly distinguishable from each other in the bubbly flow regime but their behavior is drastically different in the churn turbulent regime. Also, it is interesting to note that the surface tension for both the solutions is almost equal to each other. When the same drift flux graph is plotted for three different solutions of propanol, as shown in Figure 1.7, it can be easily seen that they cannot be distinguished from each other. The surface tension for these three solutions varies from 44 to 68 dynes/cm. Therefore, it can be concluded that the surface tension is not the deciding criterion in these solutions.

In alcohol solutions it is generally believed that the coalescence rate is reduced due to a layer of oriented dipole molecules at the surface of the bubble. The rise velocity of the same diameter bubble may not be the same in the presence of surfactants. The interface of the bubble is mobile, and an internal circulation movement exists in a bubble which always reduces the drag on the bubble. Therefore, the velocity predicted by Stoke's law may not be a correct indication of true value. Oels et al.[1.5] have explained the behavior of bubbles in water containing surfactants. They reported that the surfactants are absorbed at the top of the bubble and are being transported to the rear by an interfacial flow. Therefore, surfactant gets enriched at the rear and a surface tension



DRIFT FLUX VS GAS HOLDUP [0.5% METHANOL, 0.5%PROPANOL]

FIGURE 1.6



DRIFT FLUX VS GAS HOLDUP [PROPANOL SOLUTIONS]

FIGURE 1.7

gradient is formed. They categorized the bubbles in three regions depending upon their circulation. The surface tension gradient of the bubble essentially depends on the type of the alcohol, and as the chain length of the alcohol increases, the rigidity of bubble will increase, causing a reduction in the bubble rise velocity, and hence an increase in the gas holdup.

From the flow regime charts, it is observed that most of the data lie in the churn turbulent regime. To analyze these data, a theory by Zuber and Findley[1.12] is used which is designed for the churn turbulent regime.

The drift flux of the gas is defined as the volumetric flux of gas relative to the surface moving at an average velocity. If the total phase velocity V_T, is defined as

$$V_T = V_G + V_L \qquad (1.3.1)$$

Drift flux can be defined as,

$$\nu_{CD} = V_G \pm \varepsilon_G V_G \qquad (1.3.2)$$

or,

$$\nu_{CD} = V_G (1-\varepsilon_G) \pm V_L \varepsilon_G \qquad (1.3.3)$$

where + ve sign corresponds to the countercurrent flow and the - ve sign corresponds to the cocurrent flow. Zuber and Findley[1.12] modified this approach for the churn turbulent flow. For cocurrent flow, equation (1.3.2) can be written as,

$$\frac{V_G}{\varepsilon_G} = V_T + \nu_{CD} \tag{1.3.4}$$

or,

$$\frac{\langle V_G \rangle}{\langle \varepsilon_G \rangle} = \frac{\langle V_T \varepsilon_G \rangle}{\langle \varepsilon_G \rangle} + \frac{\langle \nu_{CD} \varepsilon_G \rangle}{\langle \varepsilon_G \rangle} \tag{1.3.5}$$

where < > bracket indicates the average value along the cross section. If we define

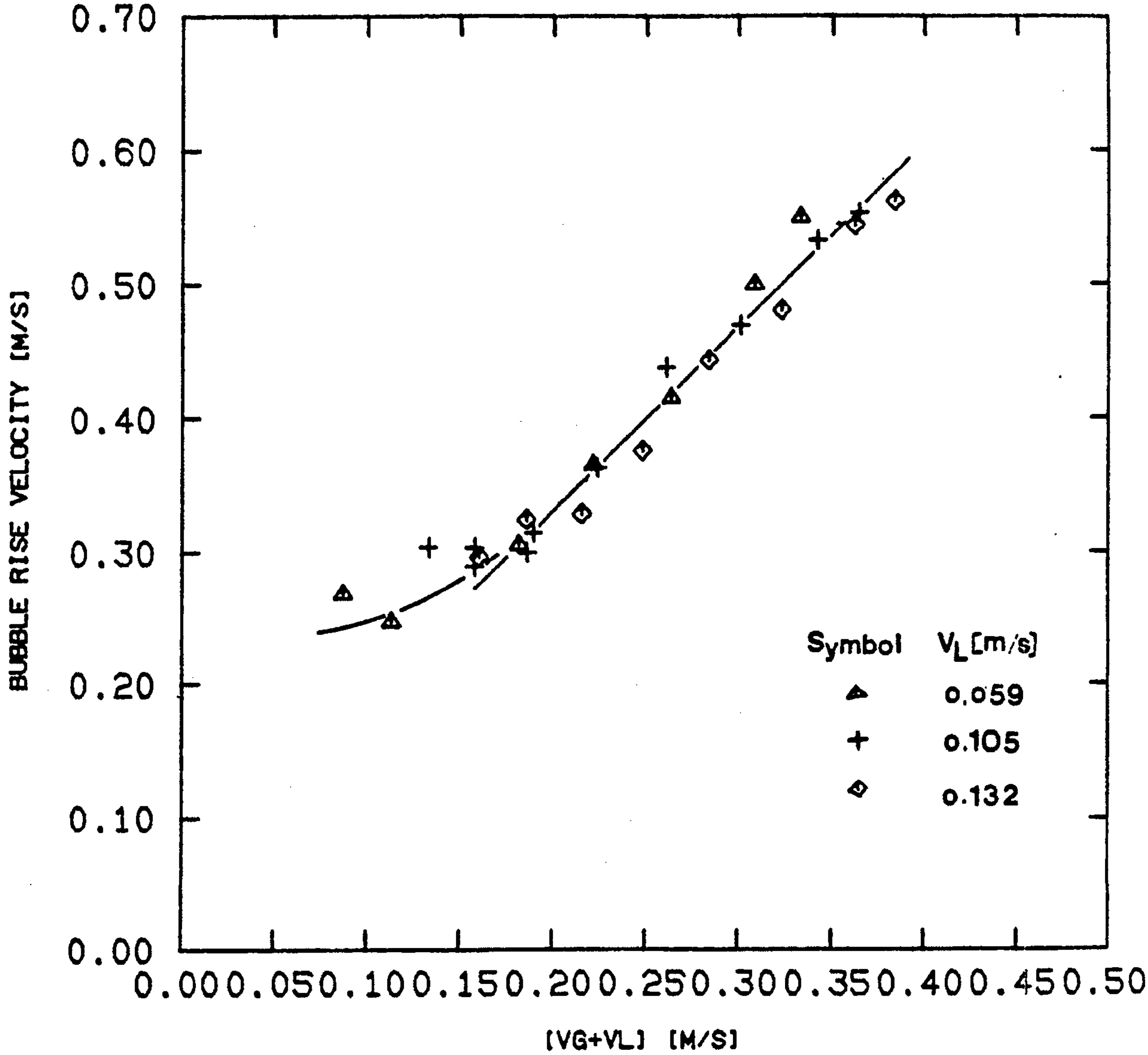
$$C_o = \frac{\langle \varepsilon_G V_T \rangle}{\langle \varepsilon_G V_T \rangle} \tag{1.3.6}$$

as a distribution parameter, which is a rough indication of nonuniform radial distribution, equation (1.3.5) can be written as,

$$\frac{\langle V_G \rangle}{\langle \varepsilon_G \rangle} = C_o \langle V_T \rangle + \frac{\langle \varepsilon_G \nu_{CD} \rangle}{\langle \varepsilon_G \rangle} \tag{1.3.7}$$

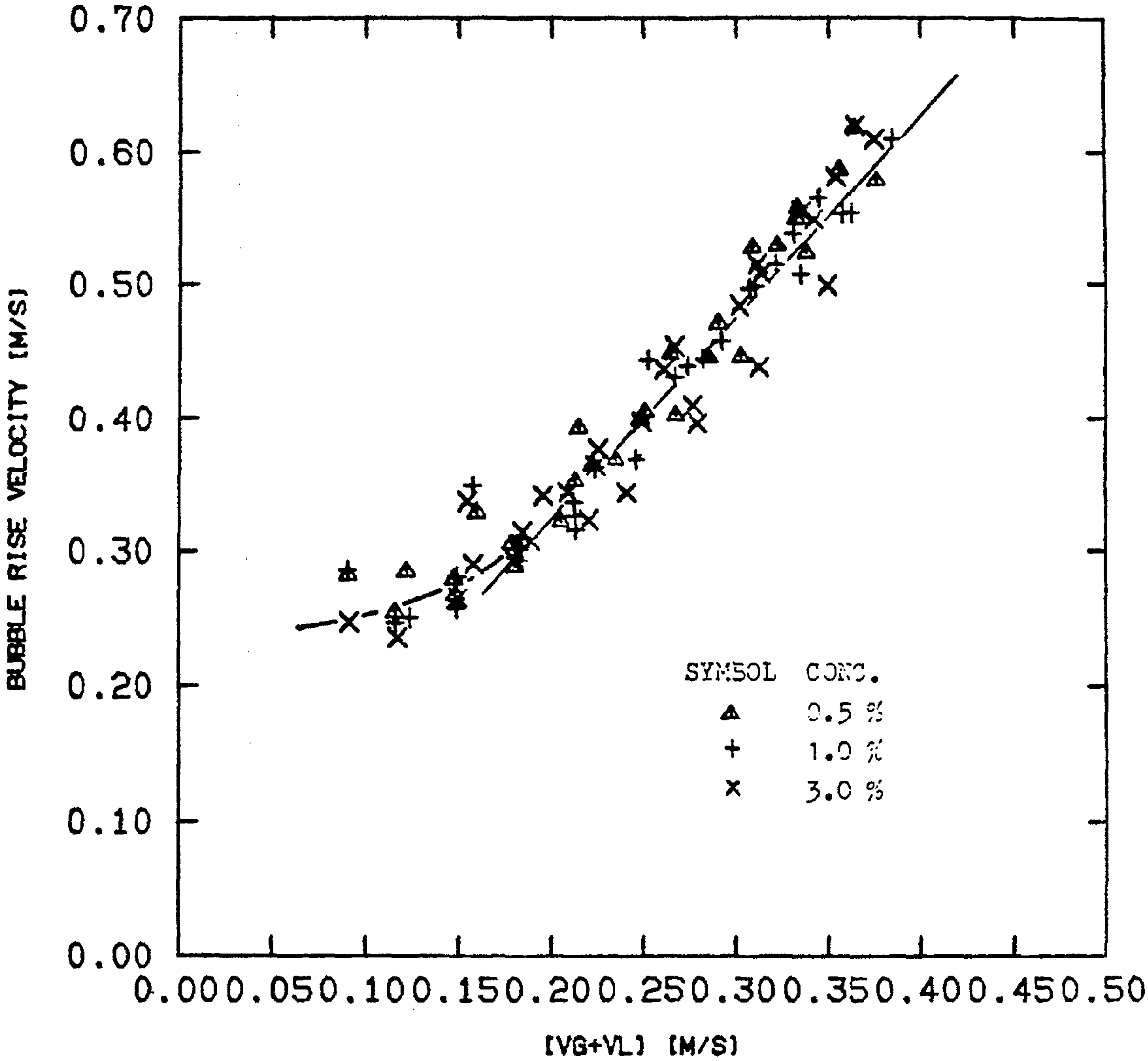
If the value of drift flux velocity is constant, or very small compared to the value of $\langle V_T \rangle$, by plotting the graph of V_G/ε_G versus V_T, the value of C_o can be obtained.

Figure 1.8 shows the graph of bubble rise velocity as a function of total velocity for 0.5% butanol. It can be easily seen that most of the data can be linearly correlated. At low gas velocity, it shows a maximum with respect to the bubble rise velocity indicating a transition from bubble flow to the churn turbulent flow. Figure 1.9 shows the same graph for all the propanol solutions. It can be easily seen that just one line can be drawn through all the data. When the data for all the four alcohols are fitted with the following equation,



BUBBLE RISE VELOCITY VS [VG+VL] [0.5% BUTANOL]

FIGURE 1.8



BUBBLE RISE VELOCITY VS [VG+VL] [PROPANOL SOLUTIONS]

FIGURE 1.9

$$V_G/\varepsilon_G = C_1 + C_o\ (V_G + V_L) \qquad (1.3.8)$$

where C_1 is a constant, the following values as indicated in Table 1.3 are obtained. From this table it can be clearly seen that the values of the distribution parameter increase significantly with a decrease in the chain length.

TABLE 1.3

COEFFICIENTS OF ZUBER-FINDLEY'S EQUATION

	C_o	C_1
Butanol	1.23	.095
Propanol	1.28	.095
Ethanol	1.66	.086
Methanol	2.41	.071

It can, therefore, be concluded that the increase in the nonuniformity of the distribution causes a decrease in the holdup value. Though it cannot be proved at the moment, it is believed that the value of C_1 is some indication of the bubble size. It is interesting to note that the value of C_1 essentially remains independent of the type of the alcohol. Zuber and Findley[1.12] have reported that if the value of C_1 is much less than $(V_G + V_L)$, gas holdup can be calculated by a simple relationship as follows,

$$\varepsilon_G = \frac{V_G}{C_o(V_G+V_L)} \qquad (1.3.9)$$

It is observed that for this set of experiments, the value of C_1 is significantly less than (V_G+V_L). The holdup values calculated, based on the above correlation, reasonably (± 10%) matched with the experimental data.

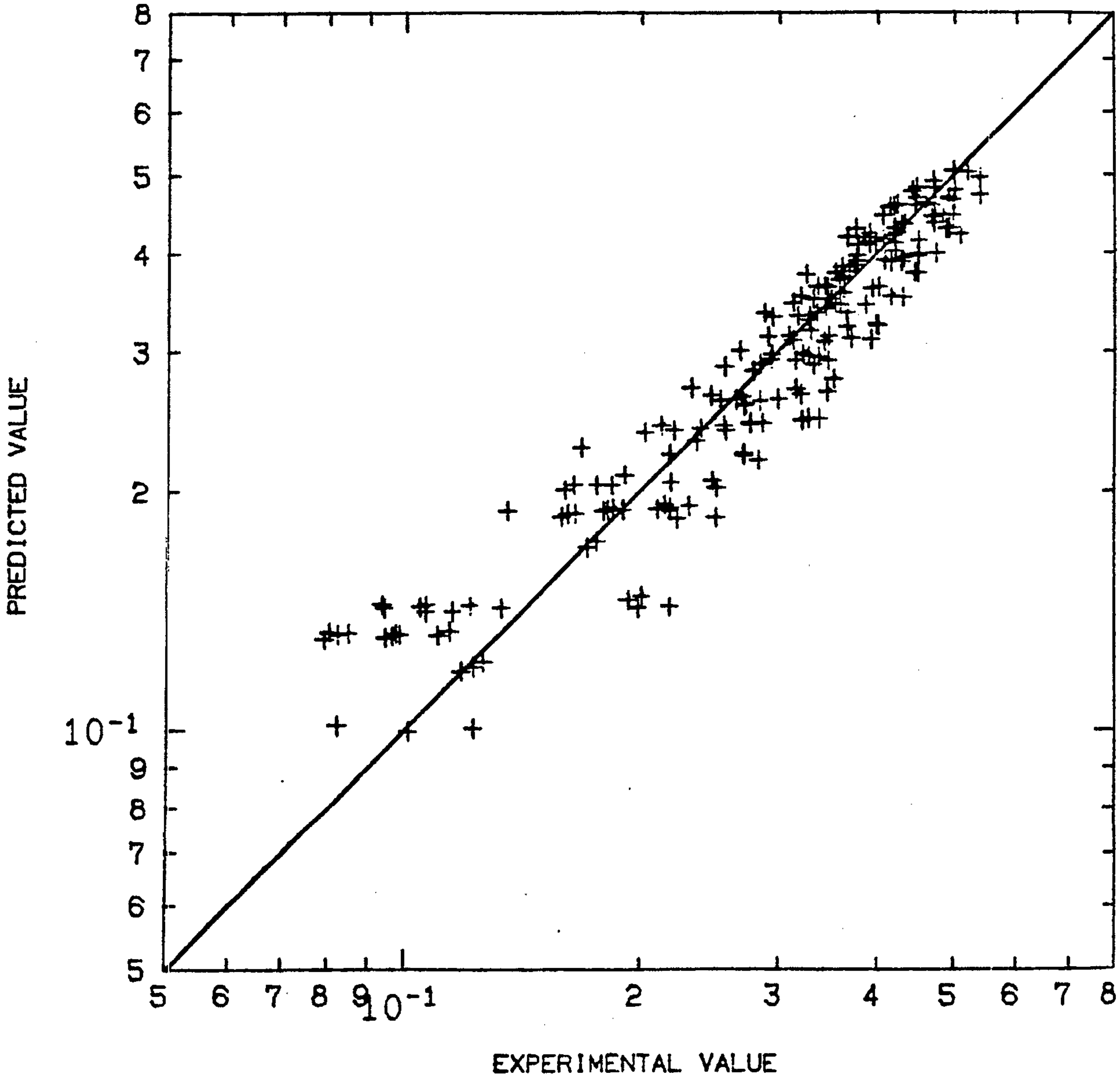
Since the effect of surface tension on the holdup has been found to be negligible, the gas holdup is empirically correlated with the superficial gas velocity and the carbon number, which is the number of carbon atoms in the alcohol. The following equation is obtained.

$$\varepsilon_G = .75\ (V_G)^{.557}\ (C_N)^{.26} \qquad (1.3.10)$$

The parity plot for this correlation is shown in Figure 1.10. The data fits reasonably well with the equation. After application of the statistical F test, it is found that 90% of the data fit within the range of ± 5%. When the data by Schügerl et al.(1.3) for perforated plates is tested, it is found that their data fit within ± 10% range.

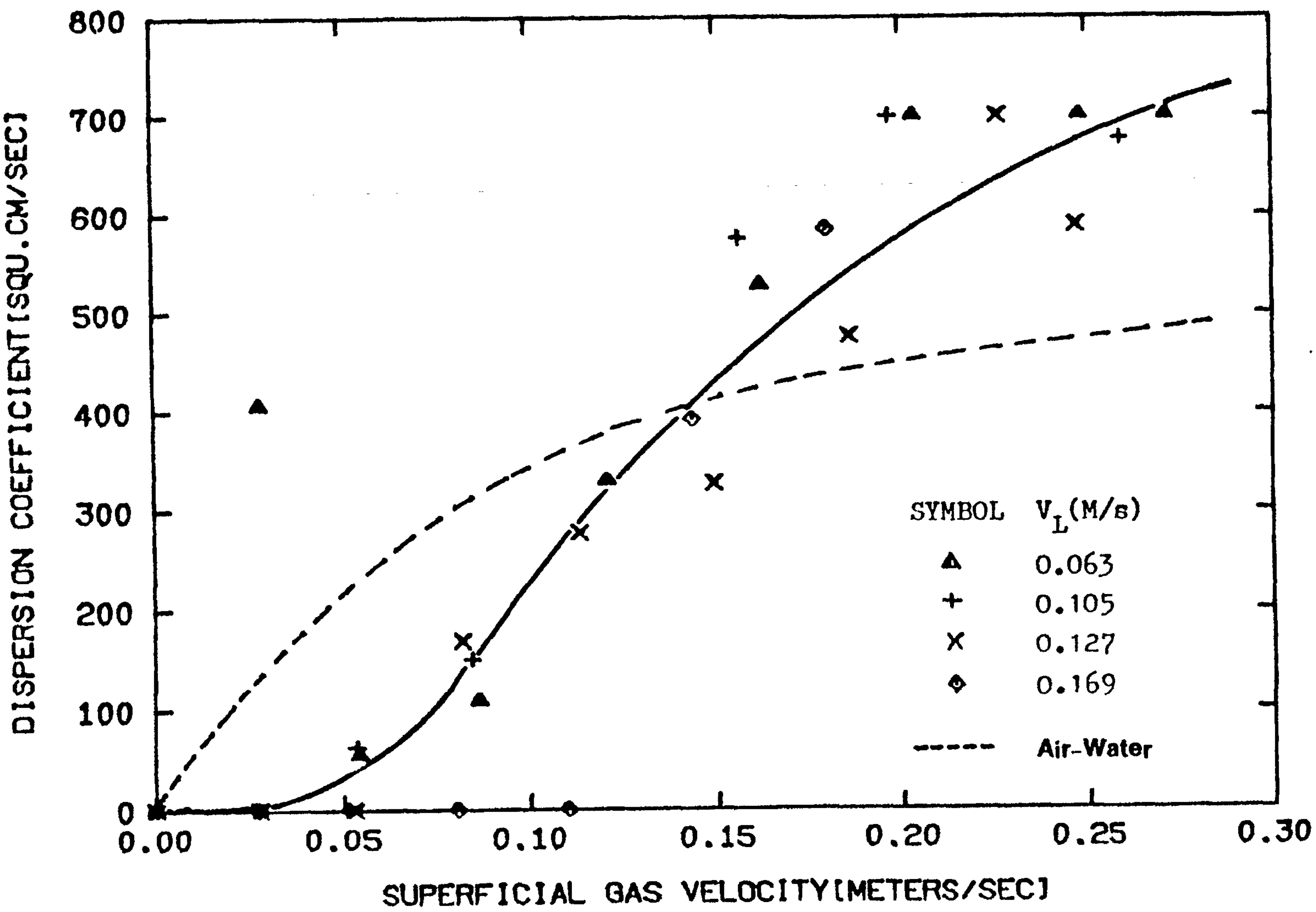
1.3.1.3 Dispersion Coefficient

The heat dispersion coefficients are obtained using a steady state method. The dispersion coefficients showed a very strange behavior. The dispersion coefficients for 3.0% propanol solution are shown in Figure 1.11. The dispersion coefficients are shown as a function of superficial gas velocity. It can be easily seen that the value of dispersion is negligible at low gas velocities, and can be approximated as zero. The value is very low at very low gas velocities due to the suppression of coalescence. But once the flow enters in the heterogeneous or churn turbulent regime, the value of dispersion coefficient suddenly shoots up. Though it should be noted that the behavior of dispersion coefficient in bubbly flow regime is unpredictable. Especially at low liquid velocities, dispersion coefficient shows a maximum with respect to gas velocity. The



COMPARISON OF EXPERIMENTAL AND PREDICTED GAS HOLDUP[ALCOHOL SOLUTIONS]

FIGURE 1.10



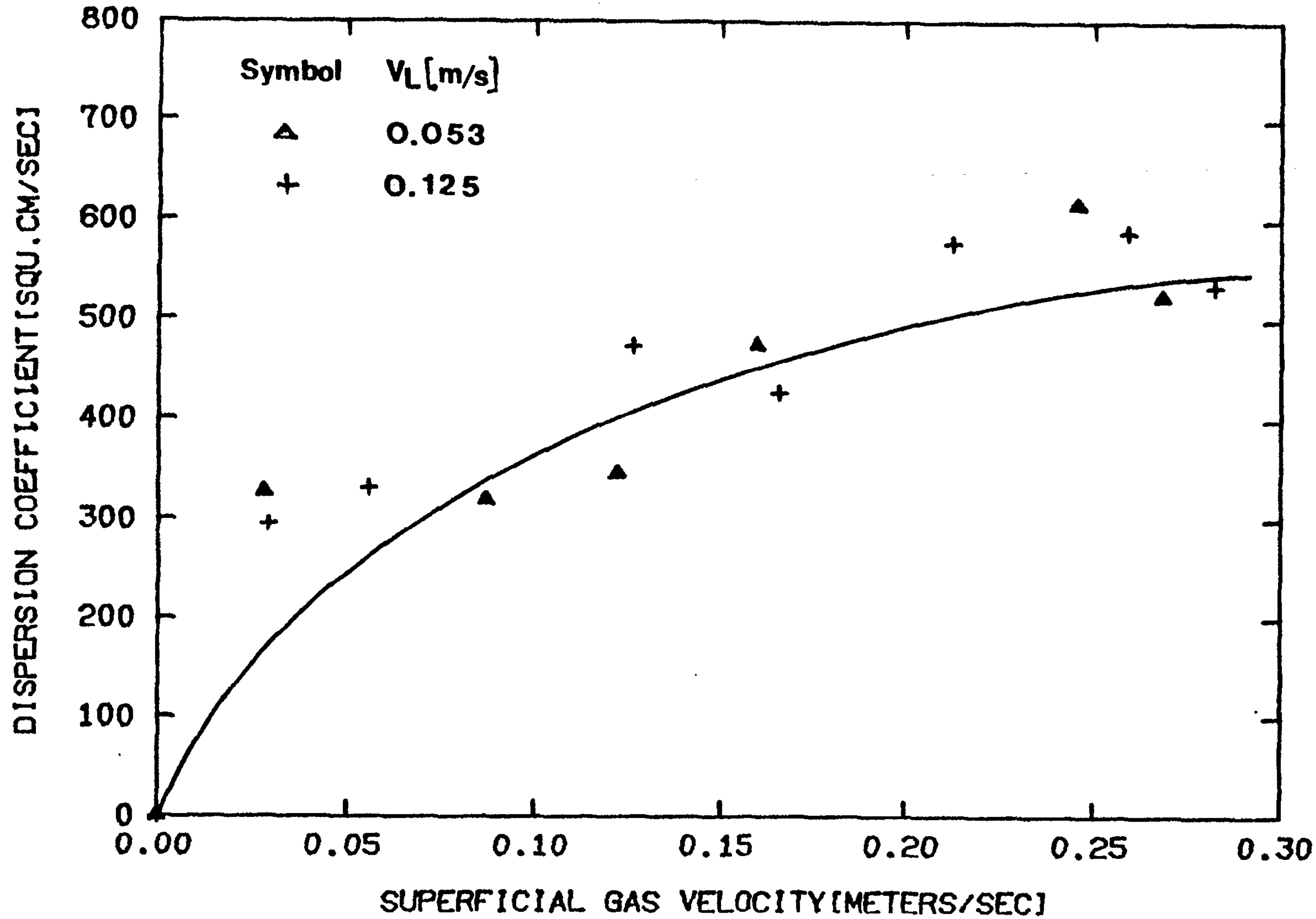
DISPERSION COEFFICIENT VS SUPERFICIAL GAS VELOCITY[3.0% PROPANOL]

FIGURE 1.11

effect of liquid velocity at high gas flow rates, however, is insignificant. In the case of homogeneous flow, where very high values of gas holdup exist, and the distribution of bubbles is almost uniform (as in the case of butanol or propanol as explained in the previous section), there is hardly any liquid recirculation due to the lack of nonuniform radial distribution. Therefore the value of the dispersion remains low. Still, the existence of a maximum at low liquid velocity cannot be explained satisfactorily. Recently Konig et al.[1.13] explained the maximum based on the fact that at low gas velocities, the bubble density in the swarm is low, therefore eddies due to single bubbles can propagate for longer distances and may overlap. Hence, the intensity of backmixing is higher than that at higher bubble density. Probably, at high liquid velocities, the bubbles do not have an opportunity to form eddies and propagate, and therefore, they just rise in uniform fashion.

The effect of concentration on the backmixing is negligible. The data for methanol solution is shown in Figure 1.12. The behavior is similar to water, indicating an absence of radial uniformity throughout the range of gas velocity under consideration. The effect of liquid velocity is also negligible. The values for the methanol solution are lower than the propanol solutions at high gas velocities. It should be noted that the dispersion coefficient values are based on the overall cross sectional area. When the values of dispersion coefficients are calculated based on the available liquid area ($D_L X \varepsilon_L$), and compared with each other, it is found that the effect of the type of alcohol is also insignificant, at higher gas velocities.

The values of the experimental data have been compared with the values predicted by the correlations of Baird and Rice,[1.14] Joshi,[1.15]



DISPERSION COEFFICIENT VS SUPERFICIAL GAS VELOCITY[0.5% METHANOL]

FIGURE 1.12

Deckwer et al.,[1.16] and Field and Davidson.[1.17] The values do not match with any of the correlations at low gas velocities, but at high gas velocities, the values based on the total cross sectional area match reasonably well with correlation by Baird and Rice. An empirical correlation, similar to Baird and Rice is fitted, and the following equation is obtained

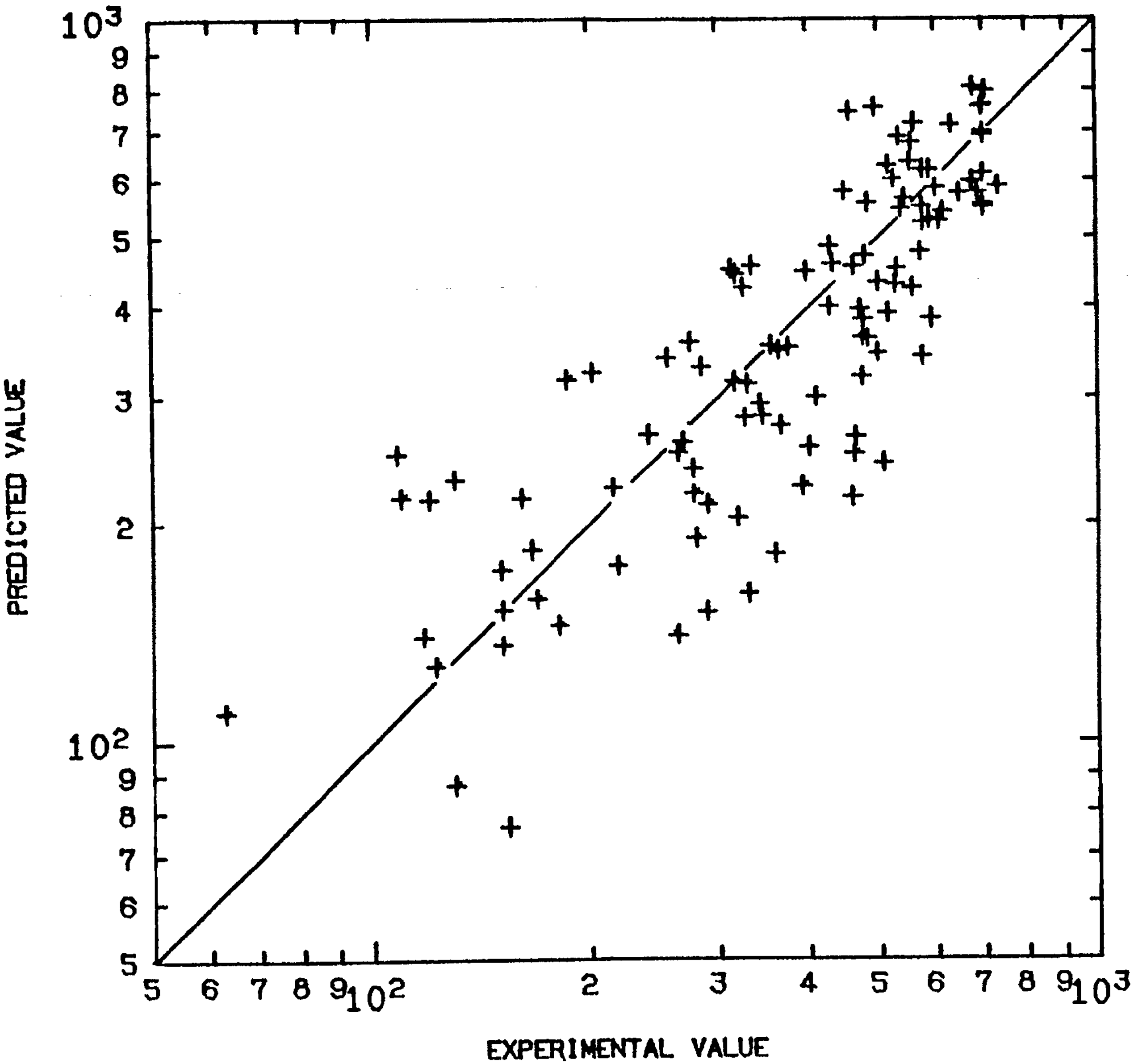
$$D_L \varepsilon_L = 1.42\ d_c^{1.33} \left(V_G - \frac{\varepsilon_G V_L}{(1-\varepsilon_G)}\right)^{0.73} \qquad (1.3.11)$$

The parity plot is shown in Figure 1.13. The data fit reasonably well. The statistical F test shows that 90% of the data fits within ± 14% region.

It is interesting to note that when the data for the gas velocity greater than 8.0 cm/s are correlated with a similar type of equation, the error is reduced to ± 9%, indicating a relative uncertainty in the bubbly flow regime in alcohol solutions.

1.3.2 Effect of Viscosity

An increase in the viscosity for Newtonian liquids, normally decreases the gas holdup. Most of the work has been carried out with glycerol solutions or sugar solutions. Many investigators have reported a maximum with respect to viscosity near the vicinity of three centipoise (Eissa and Schügerl,[1.18] Bach and Pilhofer,[1.6] Buchholz et al.[1.20] This is explained on the basis of hindered gas bubble motion in the viscous fluids, in which at relatively low viscosities, drag forces are not large enough to cuase bubble coalescence. These moderate forces contribute to more uniform distribution of bubbles and hence higher holdup. Nishikawa



COMPARISON OF EXPTL AND CALC DISPERSION COEFFICIENT[ALCOHOL SOLUTIONS]

FIGURE 1.13

et al.,[1.21] and Nakanoh and Yoshida[1.22] have reported the holdup values in the non-Newtonian medium. They observed higher values of gas holdup with respect to the values predicted by Akita and Yoshida's[1.7] correlation. No explanation is given.

Cova[1.23] and Aoyama et al.[1.24] reported that the axial dispersion coefficient is independent of the viscosity, while Pilhofer et al.[1.25] noted a dependency of dispersion coefficient on the liquid viscosity in the two phase systems. Towell and Ackerman[1.26] also indicated that an increase in the liquid viscosity reduces the dispersion. The effect of non-Newtonian medium has been recently studied by Ulbrecht and Baykara,[1.27] but their analysis is restricted to dilute polymer solutions. They concluded that the terminal mixing time is a function of the liquid rheological properties.

To study the effect of viscosity, present experiments were carried out with carboxy methyl cellulose (CMC) solutions in water, ranging from 50 ppm to 2300 ppm. The solutions behave as non-Newtonian liquids, and their flow behavior index and the consistency index were calculated with the help of Brookfield LVT type viscometer as explained in the experimental section. The values of the consistency index and flow behavior index are given in Table 1.4

The rheological properties of the solutions are sensitive to the mixing techniques and therefore the same ppm solution can give different viscosity values. The type of CMC used was 7H4 (high molecular weight). The densities and surface tensions of the solutions are similar to water and therefore are not mentioned. The apparent viscosity is calculated with the help of the equation derived by Nashikawa et al.[1.21] They reported

TABLE 1.4

RHEOLOGICAL PROPERTIES OF CMC SOLUTIONS

Solution	Consistency Index K (Nt sec/m²)	Flow Behavior Index (n)
50 ppm	.002	1.000
500 ppm	.0045	1.000
1000 ppm	.0076	1.000
1200 ppm @ 25°C	.0116	1.000
@ 35°C	.0147	1.000
1800 ppm @ 25°C	.0324	0.964
@ 35°C	.0262	0.966
2300 ppm @ 25°C	.0598	0.952
@ 35°C	.038	0.946

that the average shear rate in the bubble column is calculated by

$$\dot{\nu} = 50\ V_G \qquad (1.3.12)$$

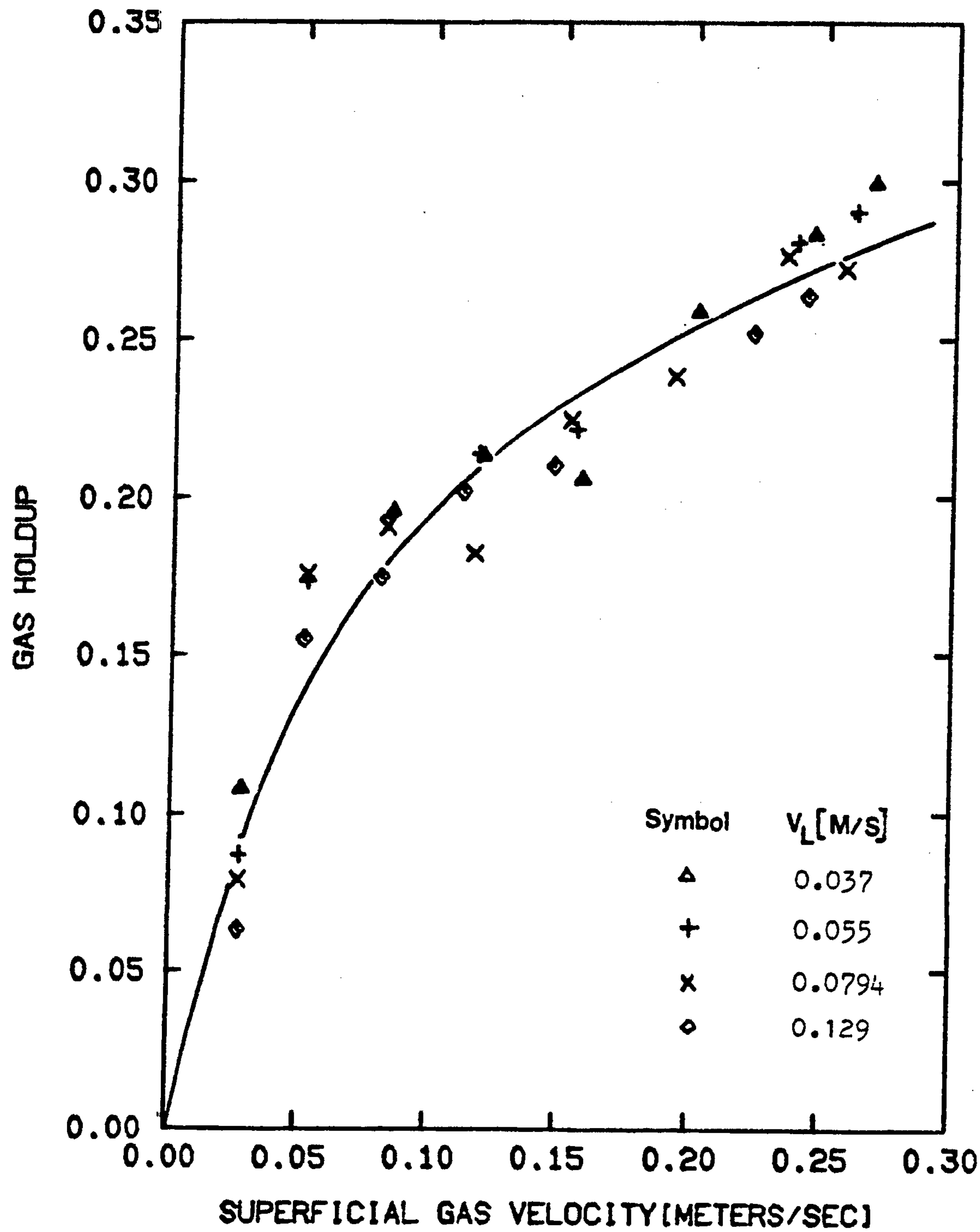
where V_G is in cm/s. The apparent viscosity is calculated by the equation,

$$\mu = K(\dot{\nu})^{n-1} \qquad (1.3.13)$$

The following results are obtained.

1.3.2.1 Gas Holdup

The gas holdup shows an increase with an increase in the gas velocity, but remains essentially independent of the liquid velocity as shown in Figure 1.14. For all the solutions, from 50 ppm to 2300 ppm, the gas holdup shows the same behavior. When gas holdup is plotted as a function apparent viscosity, it is observed that the gas holdup shows a maximum with respect to the viscosity in the vicinity of 3 cP. The value is close to the one observed by other investigators[1.18, 1.19, 1.20] for Newtonian



GAS HOLDUP VS SUPERFICIAL GAS VELOCITY[50 PPM CMC GUM]

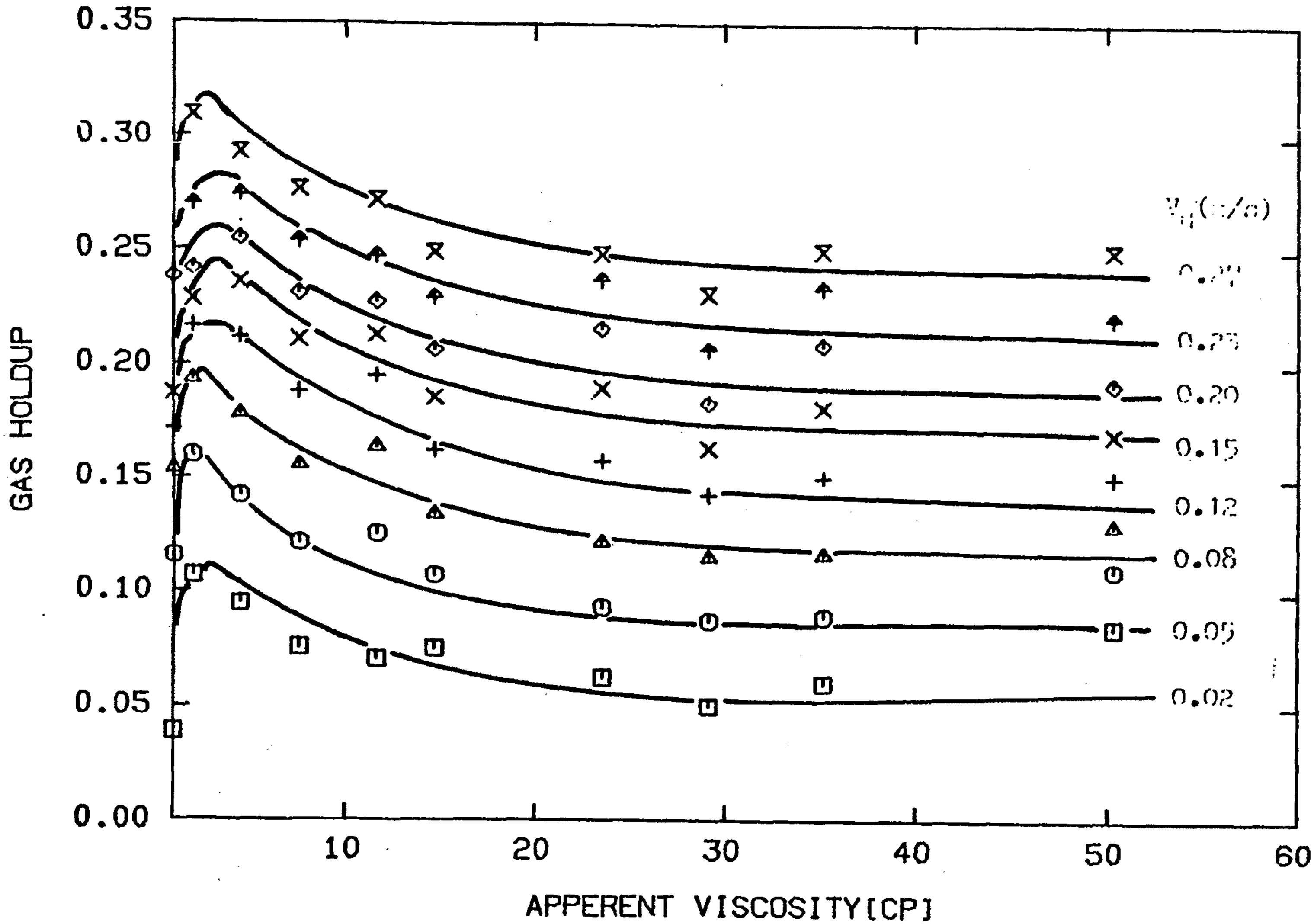
FIGURE 1.14

liquids. The similar observation is probably a result of Newtonian liquid-like behavior of CMC solution at low concentrations. From Figure 1.15, it can be seen that the maximum shifts on the right side as the gas velocity increases. The gas holdup data are compared with the values obtained with the help of different correlations. A typical comparison is shown in Figure 1.16. It can be seen that the values observed for 50 ppm solutions are higher than predicted by Akita and Yoshida,[1.7] and Hikita et al.,[1.8] as reported earlier.[1.21, 1.22] The correlation proposed by Schumpe and Deckwer[1.28] is strictly applicable for the CMC solutions, but it is limited to gas velocity of 15 cm/s. They observed a negligible effect of the viscosity on the gas holdup. The values predicted by their equation, match reasonably well at low gas velocities, but predict much higher values at high gas velocities. The comparison of the holdup values with different correlated values is shown in Appendix 1.1, in tabulated form.

1.3.2.2 Flow Regimes

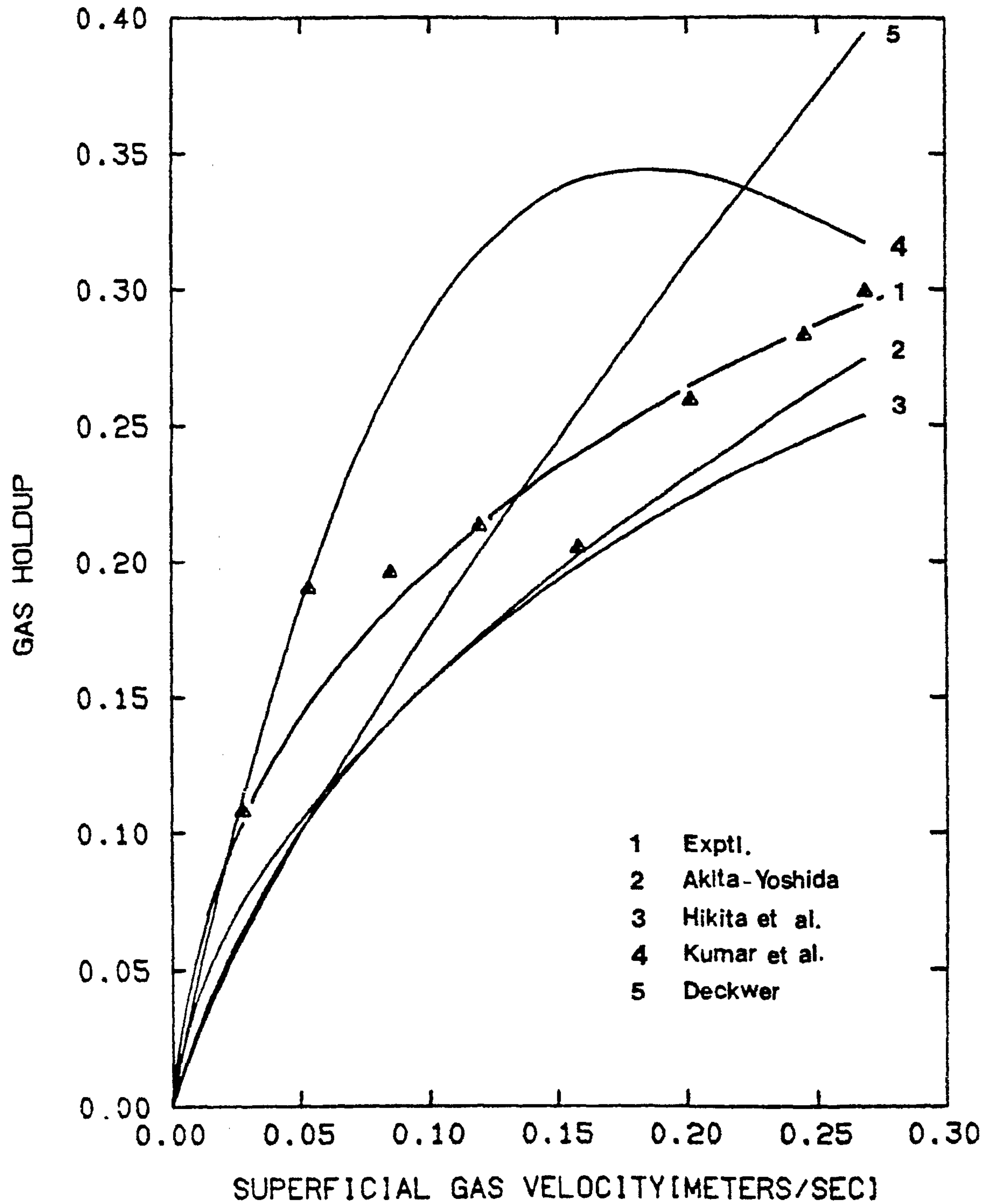
To analyze the data, flow regime maps are prepared as shown in Figure 1.17. In this figure, the drift flux is plotted as a function of the gas holdup. It can be easily seen that the transition from homogeneous to heterogeneous flow drastically changes the value of drift flux. There is a point of inflection where this transition takes place. For the 2300 ppm solution, the transition is earlier than the 50 ppm solution. It should be noted that the data points for both solutions cannot be distinguished from each other in the homogeneous flow regime. The transition is within the range of 7 to 15% holdup value.

Since most of the data lie in the churn turbulent regime, it was decided to use the theory developed by Zuber and Findley.[1.12] The



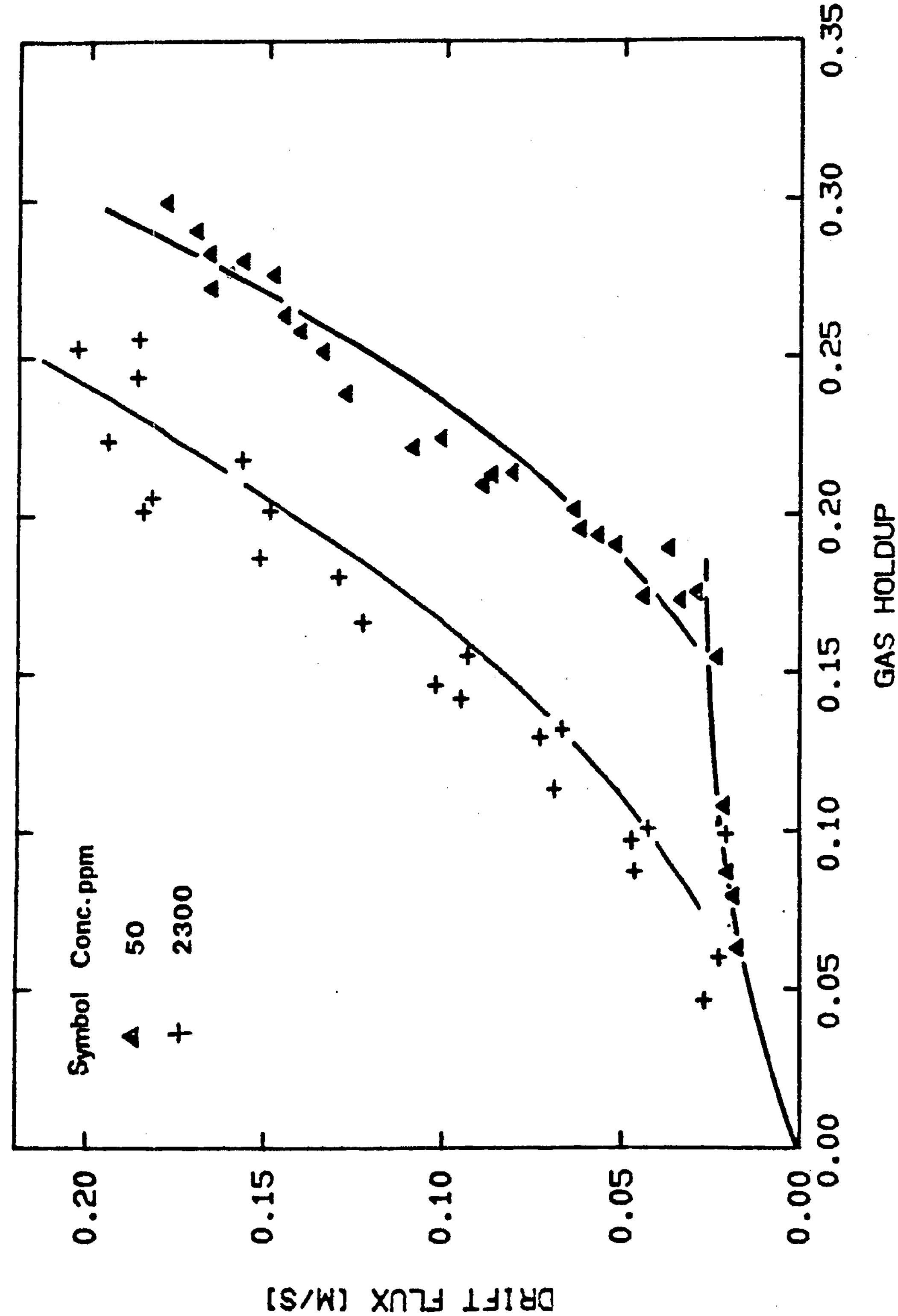
GAS HOLDUP VS APPERENT VISCOSITY[CMC SOLUTIONS]

FIGURE 1.15



COMPARISON OF EXPTL VALUES WITH CORRELATIONS[50 PPM CMC]

FIGURE 1.16



DRIFT FLUX VS GAS HOLDUP [50 AND 2300 PPM CMC GUM]

FIGURE 1.17

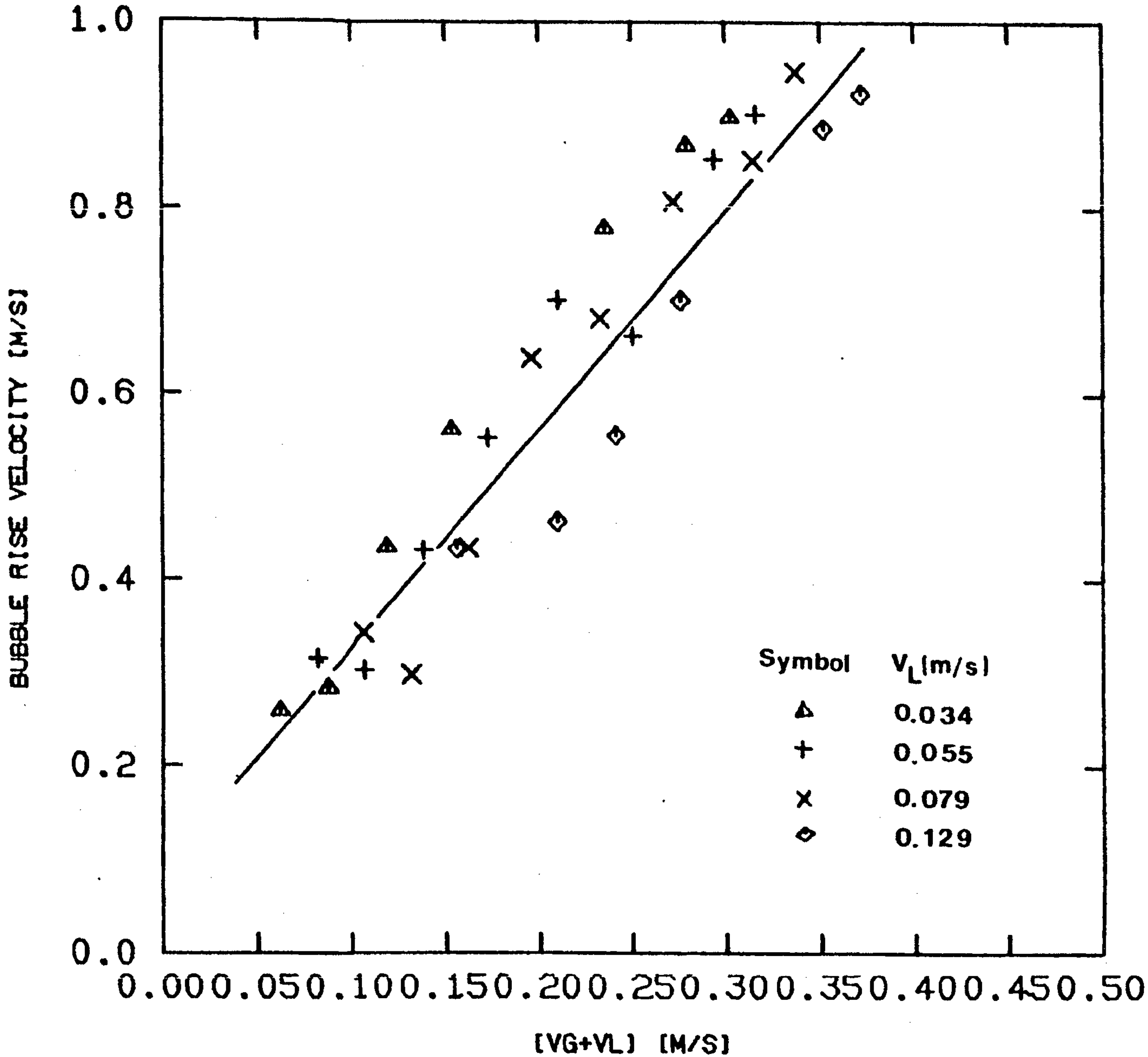
bubble rise velocity (u_G/ε_G) is plotted as a function of the total phase velocity, V_T, as shown in Figures 1.18 and 1.19, for 50 ppm solution and 2300 ppm solution respectively. It can be seen that the data show fairly linear relationship, but the fluctuation along the line are much more compared to the alcohol solutions for 2300 ppm solution, the fluctuations are comparatively less. When the data for all the solutions are fitted with a linear relationship, with the help of least squart fit, following coefficients are obtained as shown in Table 1.6. It is observed that the value of the distribution parameter C_o remains essentially independent of the concentration of the CMC. This indicates that the radial distribution does not change with the change in the CMC concentration. However, the value of C_1, which is an indication of the bubble size, increases significantly with an increase in the concentration. The value of C_1 changes from .104 for 50 ppm to 0.328 for 2300 ppm. This is in agreement with the

TABLE 1.5

ZUBER-FINDLEY'S COEFFICIENTS FOR CMC SOLUTIONS

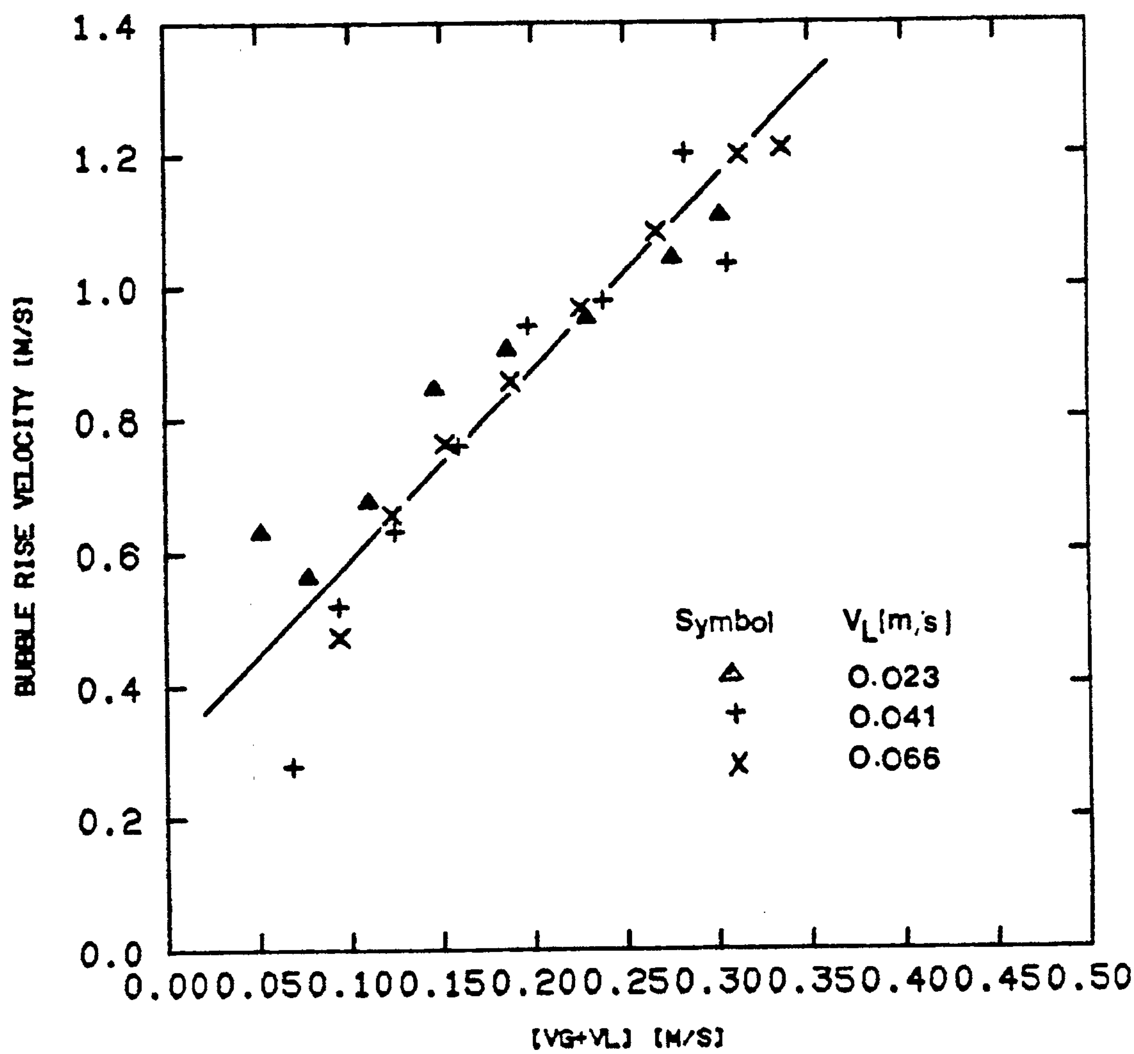
Concentration (ppm)	C_o	C_1
50	.104	2.36
500	.116	2.93
1000	.138	2.76
1200	.260	2.64
1800	.288	2.75
2300	.328	2.72

work reported earlier by Bach and Pilhofer,[1.19] that the bubble size shows an increase with an increase in the viscosity of the solution.



BUBBLE RISE VELOCITY VS [VG+VL] [50 PPM CMC GUM]

FIGURE 1.18

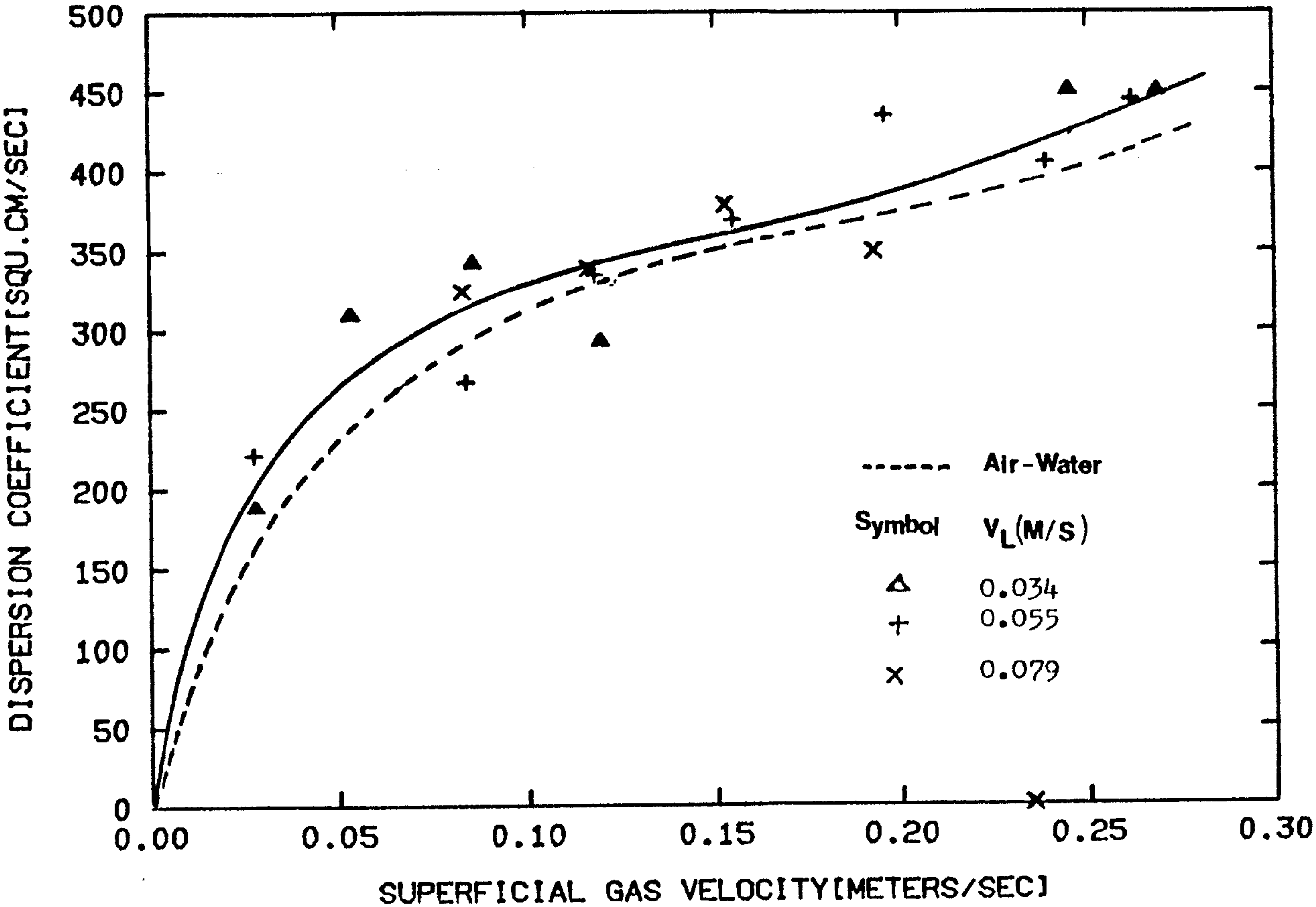


BUBBLE RISE VELOCITY VS [VG+VL] [2300 PPM CMC GUM]

FIGURE 1.19

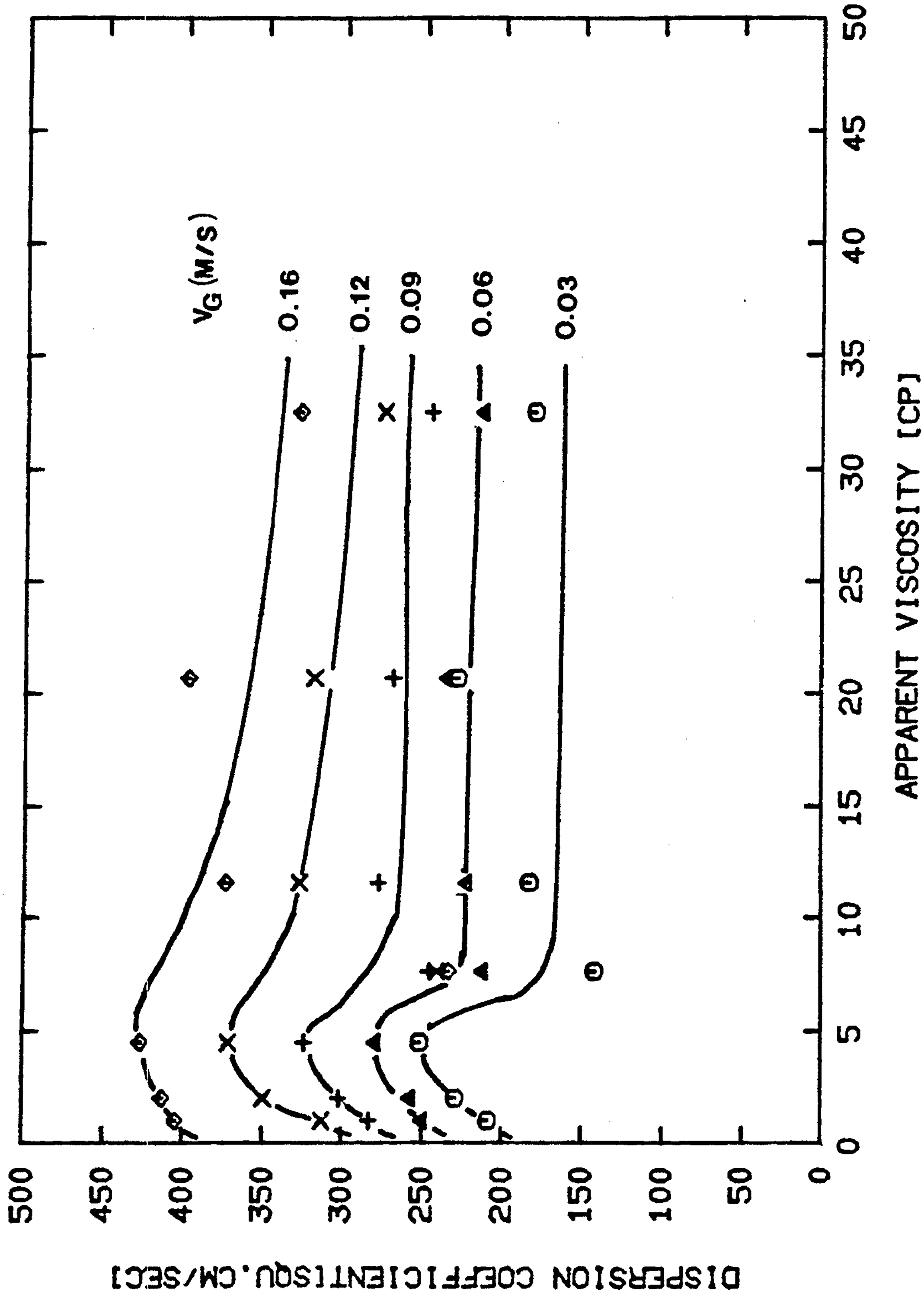
1.3.2.3 Dispersion Coefficient

The dispersion coefficient values for 50 ppm solution are plotted as a function of the gas velocity in Figure 1.20. The values show an increase with an increase in the gas velocity, but show no effect of the liquid velocity. The values of dispersion coefficient are slightly higher than the values of air-water. When the values of dispersion coefficient are plotted as a function of the apparent viscosity, it is observed that a maximum exists with respect to the apparent viscosity in the vicinity of 4.5 cP (Figure 1.21). This can be qualitatively explained with the help of distribution parameters. The axial backmixing in the bubble columns is caused by two phenomena. One, the bubbles carry large amounts of dead water in their wakes, and when the bubbles leave the top surface, that liquid is recirculated. Second, nonuniform radial distribution of the gas holdup causes recirculation eddies in the liquid phase and hence causes a backmixing. As the bubble size increases, the amount of water carried in the form of wakes decreases, causing a reduction in the value of the dispersion coefficient. If Table 1.6 is observed carefully, it can be seen that the value of C_1 increases with an increase in the concentration, indicating an increase in the bubble size, but the value of C_o shows a maximum for 500 ppm solution, after which the value essentially remains constant. An increase in the value of C_o, is a direct indication of the nonuniform distribution. Comparative increase in the value of C_o is much more than the increase in the value of C_1, when the concentration is increased from 50 ppm to 500 ppm, indicating that the increase in the viscosity (or increase in the bubble diameter) is more than compensated by an increase in the nonuniform distribution causing a maximum with respect to the apparent viscosity. It can be seen that the peak is much more



DISPERSION COEFFICIENT VS SUPERFICIAL GAS VELOCITY[50 PPM CMC GUM]

FIGURE 1.2D



EFFECT OF APPARENT VISCOSITY ON DISPERSION[CMC SOLUTIONS]

FIGURE 1.21

sharp at the low gas velocity after which it tends to flatten out.

The values of the dispersion coefficients are compared with the values obtained by different correlations that have been reported earlier. The values show slightly higher values than the ones predicted by Deckwer et al.[1.16] and Baird and Rice.[1.14] The comparisons of the values are tabulated along with the slip velocity and the single bubble rise velocity (calculated with the help of the method proposed by Clift et al.)[1.29] and shown in the Appendix 1.2.

1.3.3 Effect of Electrolyte Solutions

The effect of the electrolyte solutions on the gas holdup has been studied by many investigators. Akita and Yoshida[1.7] have reported overall 25% increase in the holdup values after the addition of an electrolyte, for otherwise identical physical properties. Hikita et al.[1.8] have correlated their holdup data with the ionic strength of the electrolyte solution. Freedman and Davidson[1.9] reported that an addition of electrolyte postponed the appearance of large bubbles in the column and is reflected by the increased voidage at the values of V_G between 5 and 10 cm/s. This is supported by Braulick et al.[1.30] who observed swarms of minute or 'ionic' bubbles in the presence of electrolytes, whose extent of the formation is function of both concentration and gas velocity. It is generally believed that the addition of the electrolyte into a solution induces a non-coalescing behavior, by virtue of an ionic double polar layer between the gas phase and the liquid phase. Schügerl et al.[1.3] measured the values of dispersion coefficients in the presence of Na_2SO_4 solutions, but the results are inconclusive.

Present experiments are carried out to see the effect of electrolyte solutions as a non-coalescing medium on the gas holdup and axial dispersion coefficient. The study is done with the help of four different solutions of sodium chloride. The concentration ranges from .05 molar to 1.0 molar solution. The physical properties of the solutions are given in Table 1.6.

TABLE 1.6

PHYSICAL PROPERTIES OF NaCl SOLUTIONS

Concentration	ρ_L (g/cc)	σ_L (dynes/cm)	μ_L (cP)
0.05 M	0.998	70.50	1.00
0.2 M	1.018	72.15	1.22
0.5 M	1.045	71.25	1.23
1.0 M	1.065	73.50	1.29

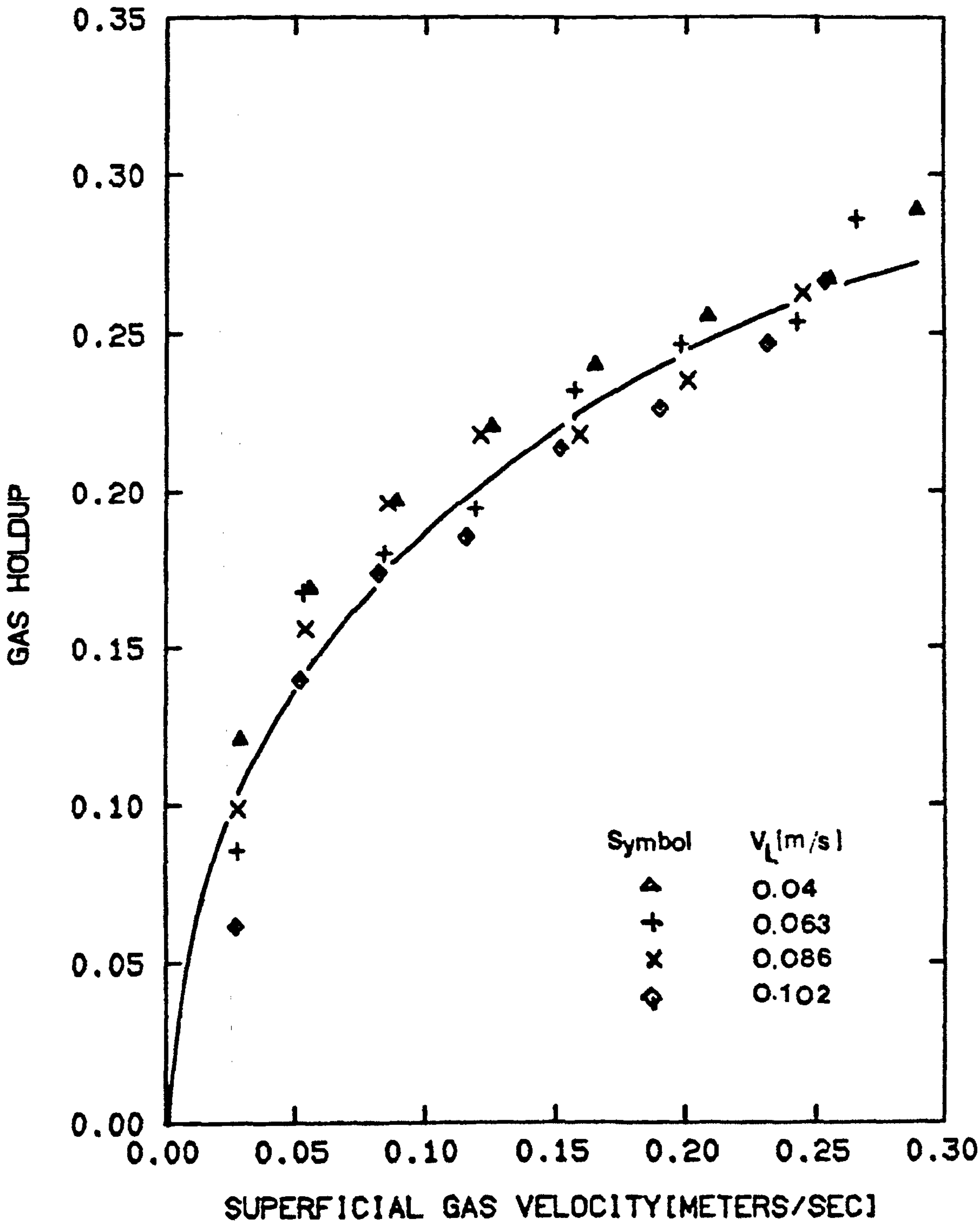
The following results are obtained.

1.3.3.1 Gas Holdup

Gas holdup shows an increase with an increase in the gas velocity, but shows an independence with respect to the liquid velocity. The values of the gas holdup for .05 M solution are shown in Figure 1.22. The gas holdup values also remain independent of the concentration. The experimental values are compared with different correlations in Figure 1.23. The values reasonably match with the correlations by Akita and Yoshida(1.6) and Hikita et al.(1.7)

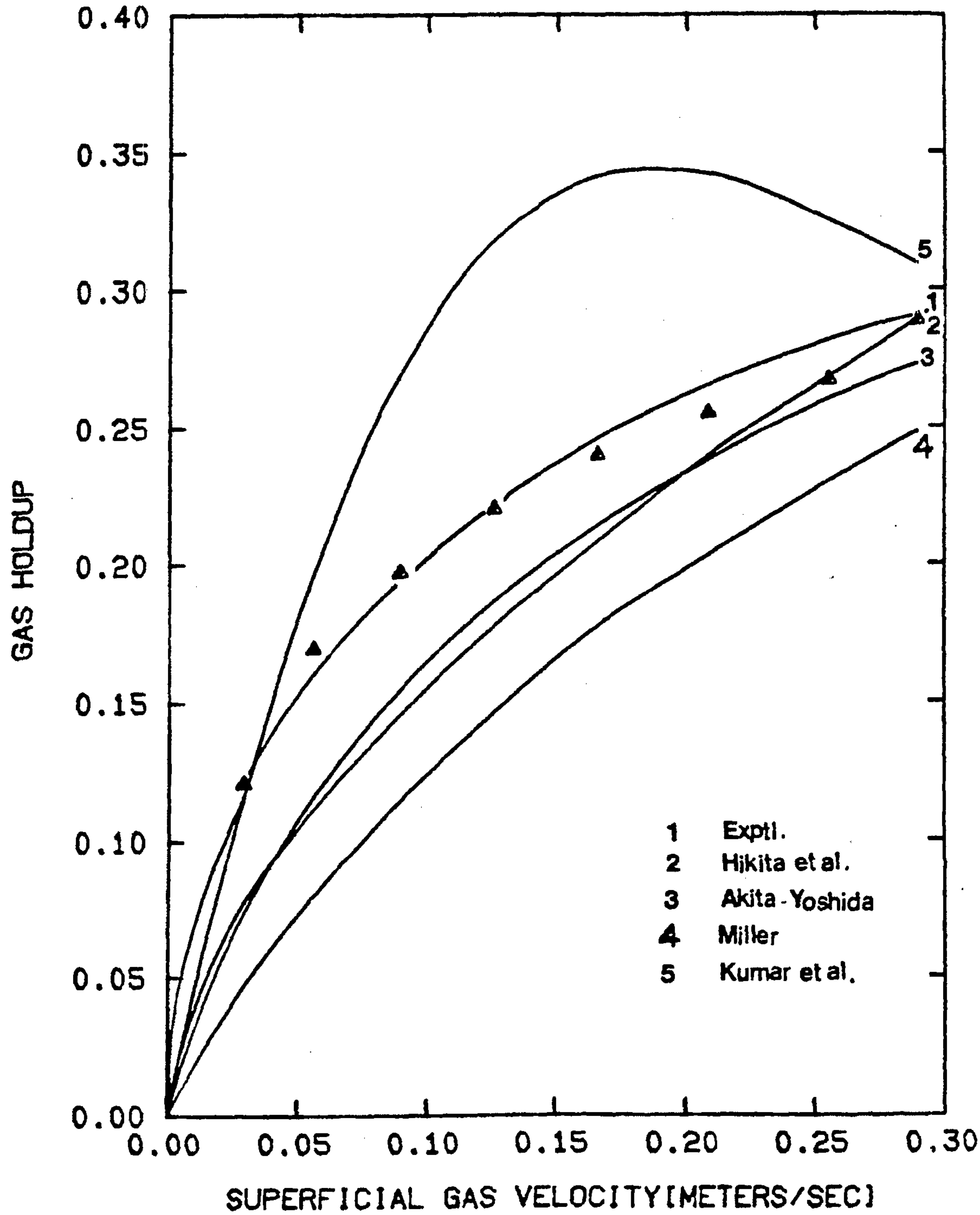
1.3.3.2 Flow Regimes

The flow regime maps are prepared with the help of drift flux thoery. The drift flux plotted as a function of the gas holdup is shown in Figure 1.24. The transition from the bubbly flow regime to the churn



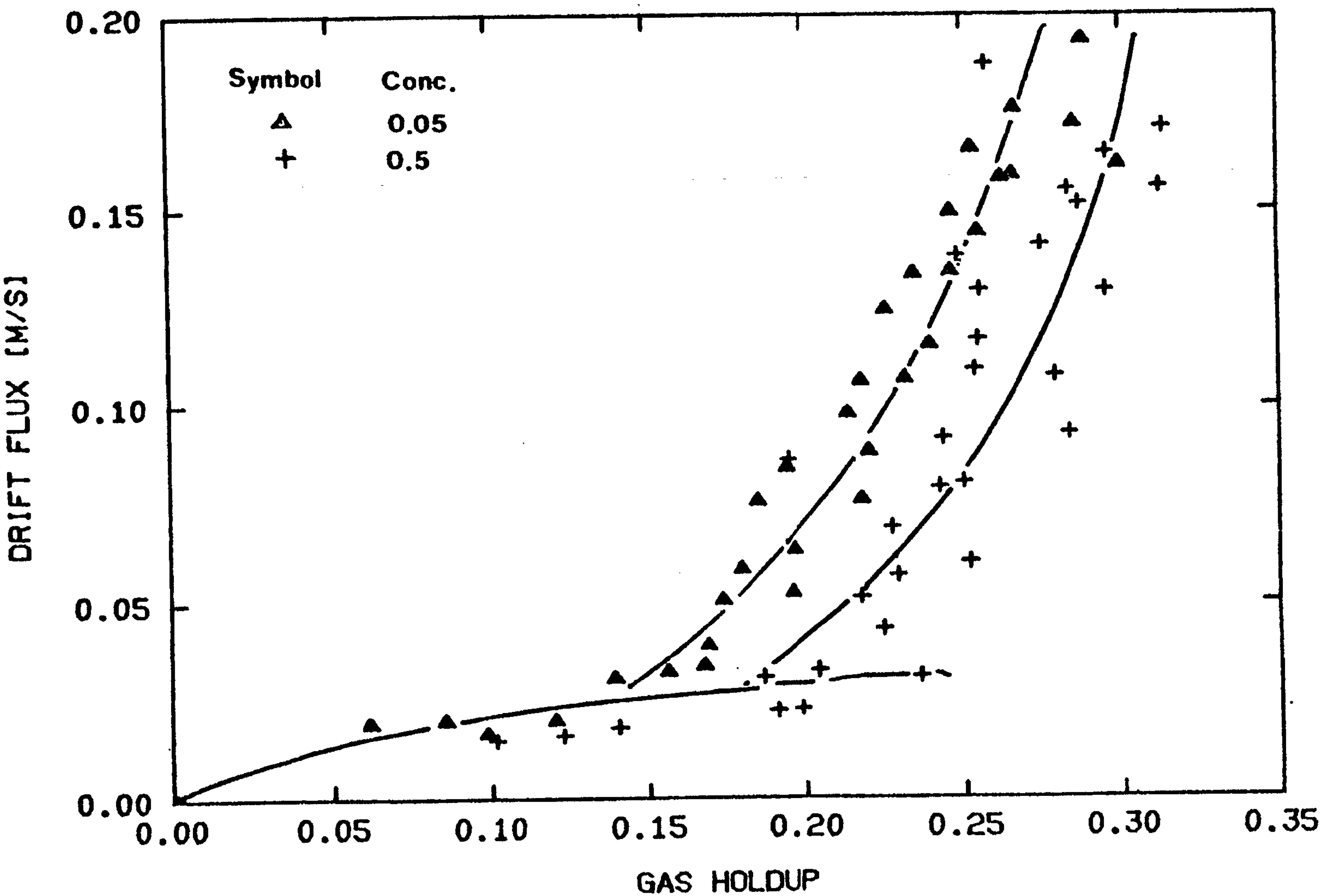
GAS HOLDUP VS SUPERFICIAL GAS VELOCITY[0.05 M NACL SOLN]

FIGURE 1.22



COMPARISON OF EXPTL VALUES WITH CORRELATIONS[.05M NACL]

FIGURE 1.23



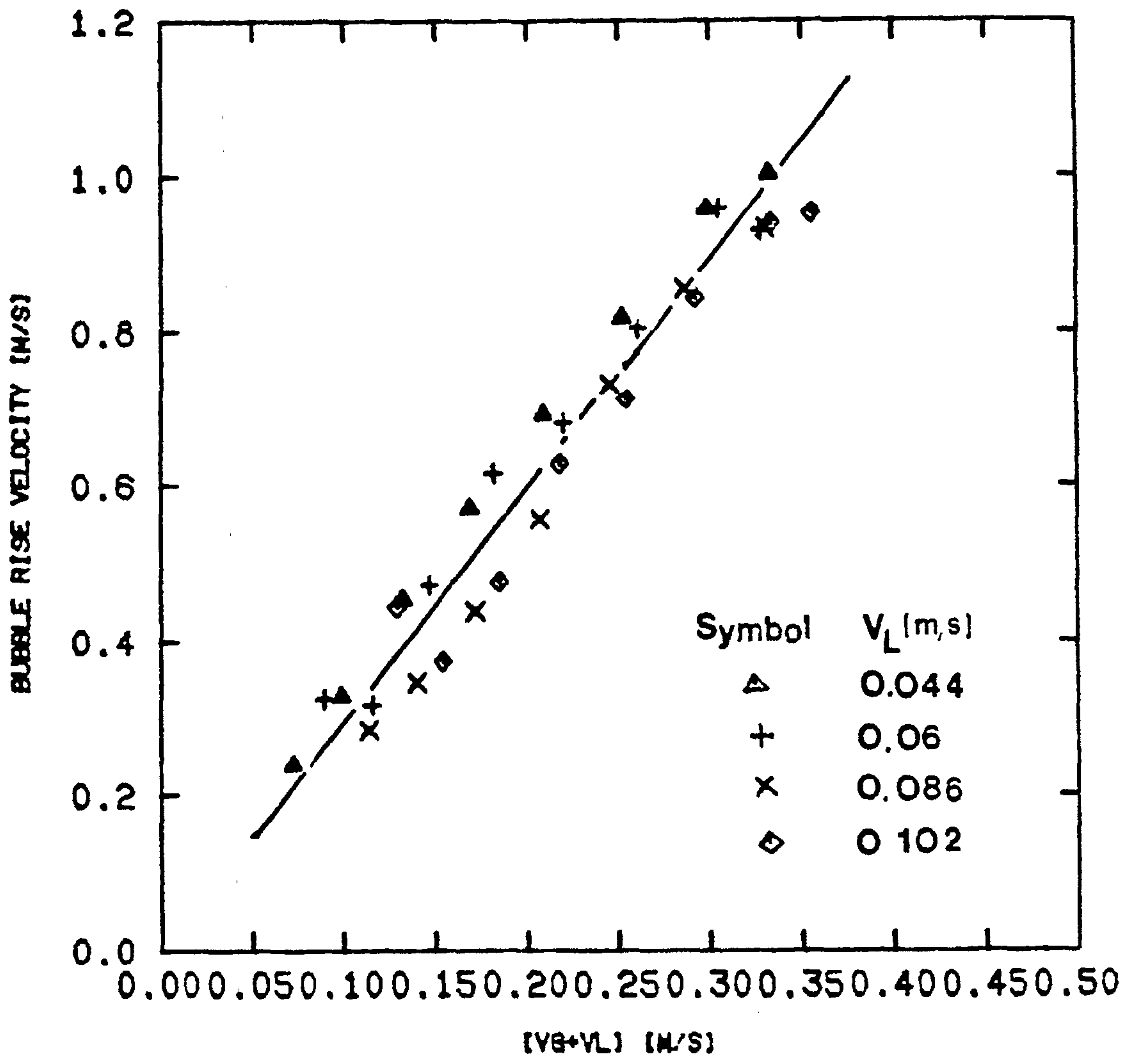
DRIFT FLUX VS GAS HOLDUP [0.05 AND 0.5 M NACL SOLUTION]

FIGURE 1.24

turbulent regime can be clearly seen. There is some effect of concentration on the transition, where for .05 M solution, the transition is earlier than .5 M solution. Up to the transition region, both the solutions show similar behavior. The value of the gas holdup at which the transition takes place, ranges from 15% to 20%, as opposed to 6% to 10% for CMC solution. This is a clear indication of the non-coalescing behavior of the solution, where even at high values of gas holdup bubble size essentially remains dependent on the gas distributor size rather than the dynamic equilibrium.

Since all the data lie in the churn turbulent regime, Zuber-Findley's[1.12] approach is employed again. Figure 1.25 shows the plot of the bubble rise velocity as a function of the total phase velocity for .05 M NaCl solution. A linear straight line can be easily fitted through all the points irrespective of the liquid velocity. When the same graph is prepared for .05 M and 0.5 M solutions together, it is observed that the effect of concentration on the bubble rise velocity is negligible (Figure 1.26). A straight line can be easily fitted through all the points. The Zuber-Findley coefficients are calculated by using a least square fit and following values as indicated in Table 1.7 are obtained.

It can be seen from the table that the values of C_o and C_1 do not change significantly with change in the concentration. Therefore an overall straight line is fitted, and the coefficients are calculated. From the values of the coefficients, it is observed that the values of C_1 are relatively smaller than the ones obtained in the case of alcohol solutions. This is a probable indication of smaller bubble size than



BUBBLE RISE VELOCITY VS [VG+VL] [0.05 M NACL SOLUTION]

FIGURE 1.25

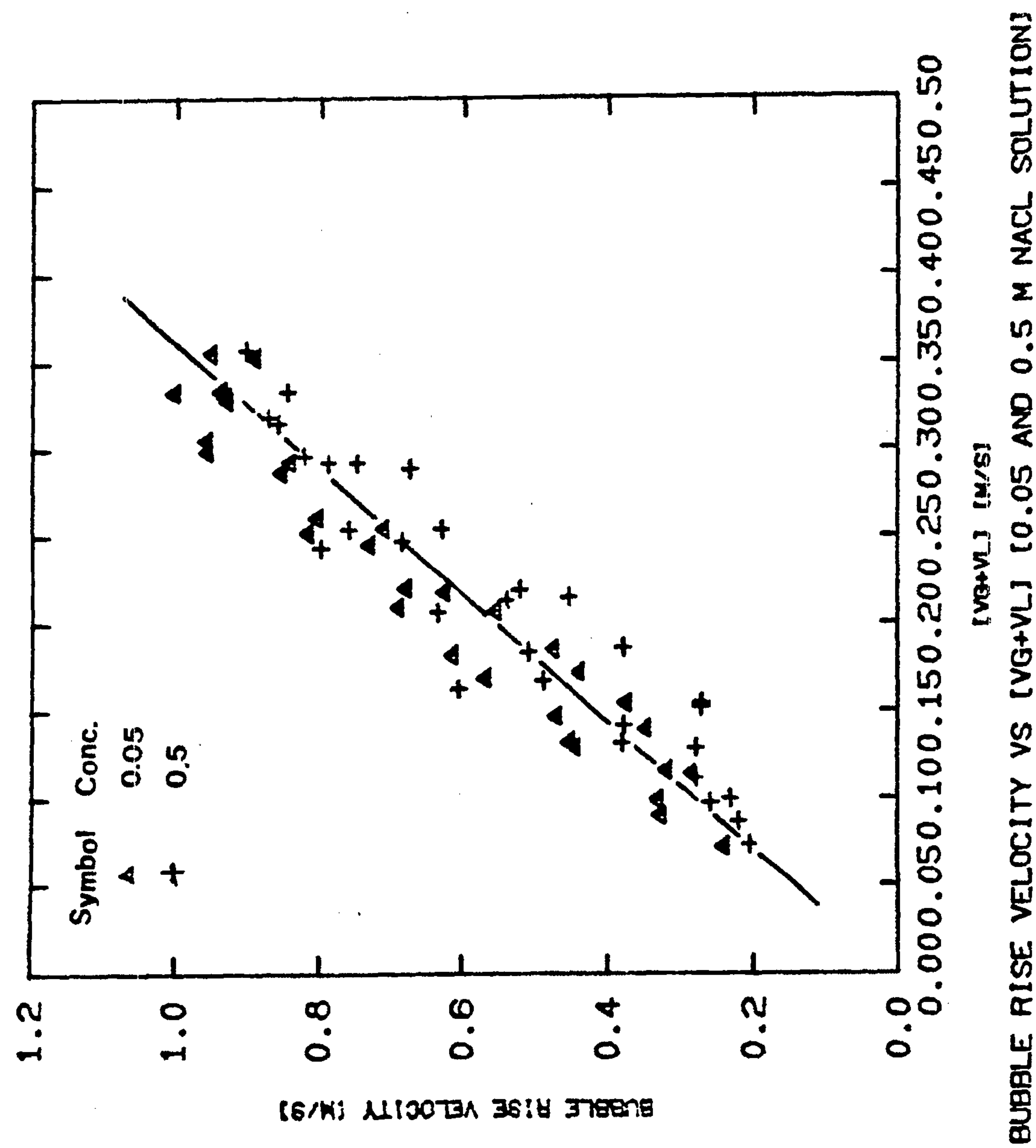

Symbol Conc.
0.05
0.5
1.2
1.0
0.8
0.6
0.4
0.2
0.0
BUBBLE RISE VELOCITY [M/S]
0.000.050.100.150.200.250.300.350.400.450.50
[VG+VL] [M/S]
BUBBLE RISE VELOCITY VS [VG+VL] [0.05 AND 0.5 M NACL SOLUTION]

FIGURE 1.26

TABLE 1.7

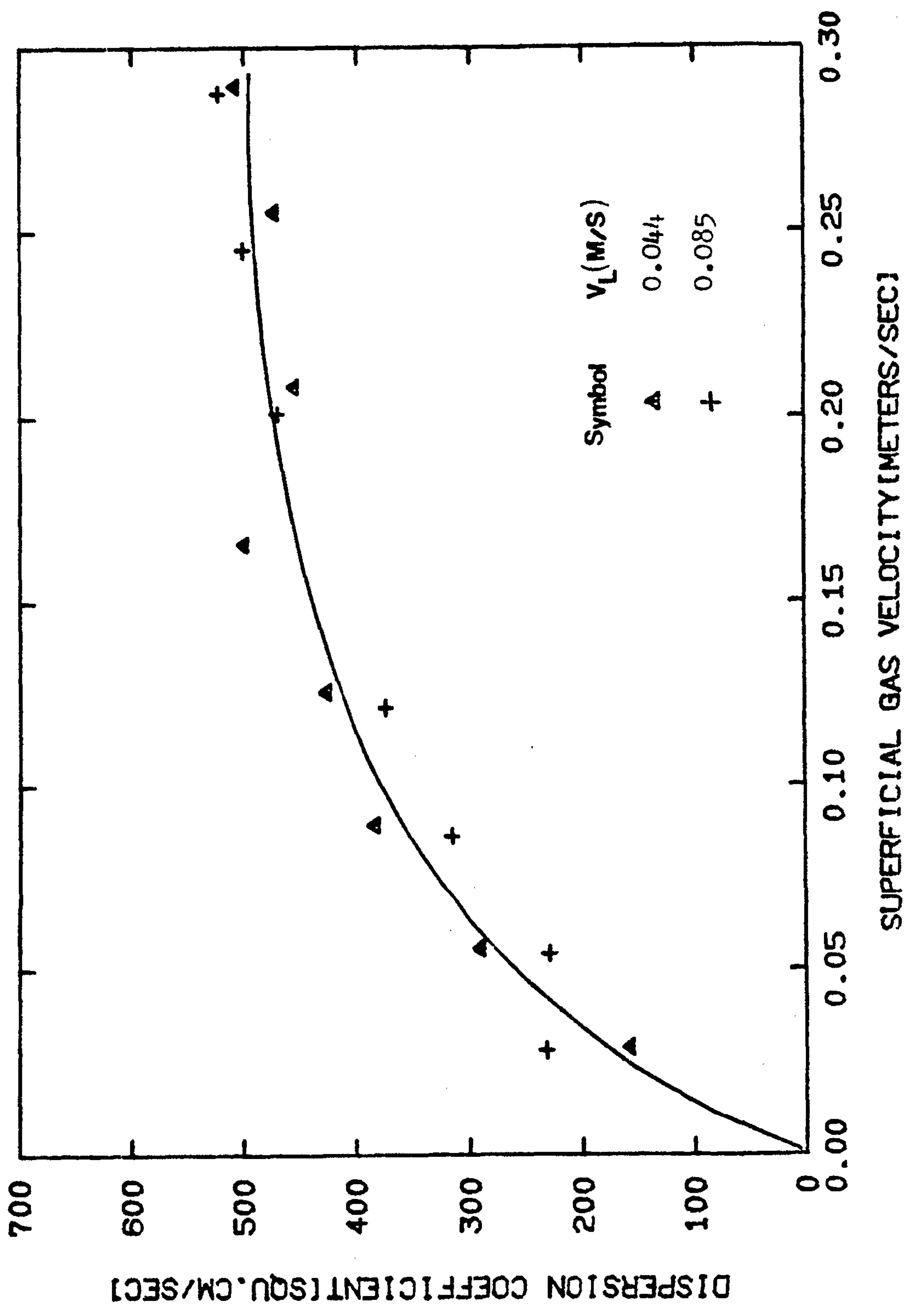
ZUBER-FINDLEY COEFFICIENTS FOR NaCl SOLUTIONS

Concentration	C_o	C_1
0.05 M	2.76	.028
0.2 M	3.07	.026
0.5 M	2.67	.019
1.0 M	2.28	.017
Overall	2.76	.020

the alcohol solutions. The values of C_o are however, much larger than propanol or butanol solutions, indicating a nonuniform radial distribution of the bubbles. The values of C_1 show a steady increase in the value with decrease in the concentration, but apparently this does not reflect in the holdup values.

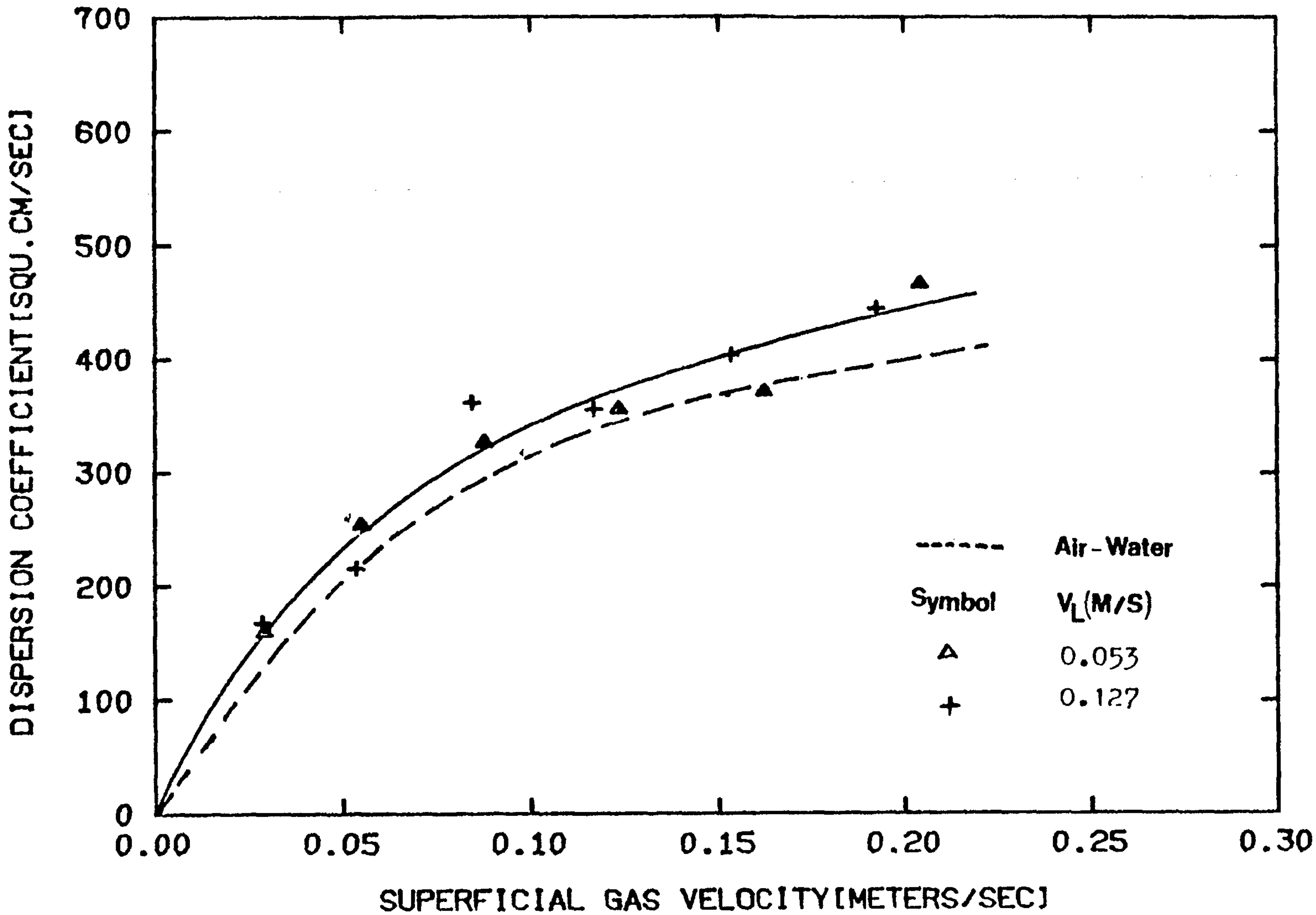
1.3.3.3 Dispersion Coefficient

The values of dispersion coefficient for .05 M are plotted as a function of the gas velocity in Figure 1.27. The dispersion coefficients show an increase with increasing gas velocity but remain independent of the liquid velocity. The dispersion coefficient values for 1.0 M NaCl solution are compared with the air-water data in Figure 1.28. It can be seen that the values of NaCl are slightly higher than the air-water data. As indicated earlier in the Section 1.3.1, these values are based on the overall cross sectional area of the column. If the values are calculated based on the cross sectional area available to the liquid phase ($D_L \varepsilon_L$), both the systems show comparable values.



DISPERSION COEFFICIENT VS SUPERFICIAL GAS VELOCITY[0.05 M NACL]

FIGURE 1.27



DISPERSION COEFFICIENT VS SUPERFICIAL GAS VELOCITY[1.0 M NACL]

FIGURE 1.28

It is interesting to note that though both electrolyte and alcohol solutions produce small bubbles due to non-coalescing tendencies, the dispersion coefficints show an entirely different trend. Higher alcohol (Propanol and butanol) solutions show almost zero values of the dispersion coefficients at low gas velocities, while the electrolyte solutions behave similar to the air-water system. This can be explained on the basis of the distribution parameter. If the values of the C_o for propanol and butanol solutions and the electrolyte solutions are compared with each other, it can be clearly seen that along with producing small bubbles, the alcohol solutions also maintain a uniform radial distribution, which is a significant contributing factor for the dispersion, while NaCl solutions have highly nonuniform radial distribution causing a significant increase in the value of the dispersion coefficient. It should be clarified that though it is mentioned earlier that the small bubbles can carry more water in the form of wakes, and hence create a higher backmixing, a special situation is created when relatively large values of holdups are obtained at low gas velocities. Due to high density of small bubbles, the microscopic eddies created by these bubbles do not propagate. In addition, if the bubbles have uniform radial distribution, the two phase flow behaves as a single phase flow causing a negligible backmixing.

APPENDIX 1.1

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
1000 PPM CMC SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02920	0.02570	165.80000	154.38925	185.25178	104.97331	88.06660	0.01541	0.28900	0.25027
0.05500	0.02570	282.00000	190.26443	229.33537	106.54569	185.65480	0.01521	0.29093	0.22971
0.08700	0.02570	700.00000	221.34387	270.18135	228.30571	278.84848	0.01440	0.29213	0.22893
0.12370	0.02570	249.80000	248.61076	304.72244	279.31033	334.56322	0.01380	0.28512	0.21437
0.16230	0.02570	275.30000	271.92118	334.23017	317.47311	379.16167	0.01336	0.27973	0.20284
0.20800	0.02570	390.30000	295.12012	363.46498	353.46191	421.20177	0.01297	0.27487	0.19108
0.25500	0.02570	481.20000	315.64301	389.35905	394.89391	457.78187	0.01265	0.27092	0.18171
0.27950	0.02570	503.40000	325.34483	401.42995	359.11773	474.09544	0.01252	0.26915	0.17591
0.02841	0.04680	180.60000	152.99718	179.61636	85.67988	101.77995	0.01647	0.28892	0.25539
0.05400	0.04680	218.50000	189.11582	224.36350	157.97554	196.13367	0.01525	0.29078	0.23989
0.08600	0.04680	236.40000	220.50701	264.80980	231.63436	271.10974	0.01442	0.29210	0.23129
0.12150	0.04680	296.60000	247.14287	299.22200	295.06701	328.85255	0.01383	0.28549	0.21956
0.16000	0.04680	336.70000	270.64344	328.55933	320.75810	371.46140	0.01338	0.28001	0.20537
0.20160	0.04680	335.70000	292.09209	356.00334	356.48875	411.94873	0.01302	0.27548	0.19639
0.24600	0.04680	392.80000	311.92235	381.14202	387.34534	447.64751	0.01271	0.27161	0.18777
0.26900	0.04680	432.60000	321.25964	392.53599	399.24488	462.75159	0.01257	0.26989	0.18151
0.02800	0.07650	166.30000	152.26499	159.45840	162.73250	119.80348	0.01650	0.28888	0.25274
0.05370	0.07650	254.70000	188.75946	217.36607	155.60316	191.72912	0.01526	0.29075	0.24200
0.08540	0.07650	259.40000	219.99814	259.19246	243.23750	265.91310	0.01443	0.29208	0.23606
0.12000	0.07650	255.20000	246.13180	291.95087	285.69680	316.63793	0.01385	0.28573	0.22017
0.15800	0.07650	362.60000	269.52233	321.35753	324.27229	360.55059	0.01340	0.28025	0.20658
0.19300	0.07650	373.50000	290.84354	350.60893	365.59063	407.21557	0.01304	0.27573	0.20397
0.24300	0.07650	469.70000	310.66190	375.23886	396.68219	440.99280	0.01273	0.27185	0.19326
0.26550	0.07650	403.40000	319.87420	385.35668	404.44676	453.02203	0.01259	0.27014	0.18393
0.02800	0.09810	219.50000	152.26499	175.23470	170.40518	156.98915	0.01650	0.28888	0.26715
0.05350	0.09810	218.40000	186.53616	216.79380	200.79431	202.43509	0.01526	0.29075	0.25069
0.08500	0.09810	234.90000	219.65756	254.16661	242.57804	255.80623	0.01444	0.29206	0.23505
0.11900	0.09810	259.50000	245.45304	288.76560	298.56939	315.69390	0.01387	0.28590	0.22572
0.15500	0.09810	300.40000	267.82269	317.31160	335.57416	358.44873	0.01343	0.28054	0.21428
0.19800	0.09810	343.40000	230.35043	346.35577	372.55464	400.97697	0.01304	0.27563	0.20449
0.23600	0.09810	361.70000	307.67973	368.93768	401.34217	433.56974	0.01277	0.27241	0.19838

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

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	SCHUGERL
0.02813	0.05919	0.10487	0.07356	0.07949	0.07682	0.11572	0.04169	0.20090
0.05400	0.05919	0.21878	0.11669	0.11557	0.12137	0.19741	0.07294	0.38676
0.08937	0.05919	0.51519	0.15882	0.15135	0.16656	0.27566	0.10882	0.68026
0.12239	0.05919	0.40067	0.18844	0.18511	0.19460	0.31929	0.13844	0.99232
0.16250	0.05919	0.44537	0.21691	0.21763	0.22362	0.34214	0.16691	1.42581
0.20435	0.05919	0.49253	0.24088	0.24931	0.24737	0.34075	0.19588	1.89107
0.22532	0.05919	0.49988	0.13699	5.00167	11.11055	0.03698	0.00000	0.00892
0.27406	0.05919	0.49865	0.27250	0.29600	0.27891	0.31119	0.23750	2.80415
0.02798	0.10467	0.13304	0.07326	0.07944	0.07636	0.11517	0.03326	0.16400
0.05321	0.10467	0.18387	0.11557	0.11595	0.11920	0.19524	0.05932	0.40704
0.08121	0.10467	0.27084	0.15027	0.14843	0.15421	0.26073	0.08527	0.64372
0.02849	0.10467	0.09385	0.07427	0.07959	0.07794	0.11700	0.03364	0.21452
0.05331	0.10467	0.17591	0.11572	0.11598	0.11941	0.19552	0.05947	0.40460
0.08474	0.10467	0.26961	0.15405	0.15199	0.15812	0.26741	0.08780	0.68829
0.11914	0.10467	0.32840	0.18583	0.18575	0.18986	0.31610	0.11583	1.03076
0.15630	0.10467	0.35719	0.21292	0.21812	0.21673	0.34041	0.14292	1.44949
0.19655	0.10467	0.41904	0.23675	0.24973	0.24034	0.34247	0.16675	1.90607
0.23773	0.10467	0.44660	0.25707	0.28024	0.26008	0.32853	0.19207	2.44573
0.26019	0.10467	0.47048	0.26684	0.29559	0.26974	0.31786	0.20184	2.72414
0.02800	0.13242	0.09446	0.07329	0.07954	0.07633	0.11523	0.03017	0.21291
0.05329	0.13242	0.16428	0.11568	0.11622	0.11918	0.19545	0.05443	0.43622
0.08315	0.13242	0.25308	0.15236	0.15173	0.15548	0.26444	0.07986	0.68266
0.11587	0.13242	0.30880	0.18313	0.18496	0.18585	0.31266	0.10563	1.01100
0.15166	0.13242	0.34249	0.20984	0.21697	0.21224	0.33873	0.12984	1.42692
0.19066	0.13242	0.39699	0.23355	0.24834	0.23570	0.34338	0.15355	1.86886
0.23010	0.13242	0.42333	0.25356	0.27834	0.25511	0.33185	0.17606	2.39645
0.25163	0.13242	0.44782	0.26321	0.29347	0.26462	0.32202	0.18821	2.64292

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
2.0 % BUTANOL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSHANN	KUMAR	MILLER	SCHUGERL
0.02742	0.03598	0.11534	0.07364	0.08337	0.07550	0.11856	0.04739	0.20720
0.05240	0.03598	0.25034	0.11646	0.12052	0.11950	0.20088	0.08146	0.38437
0.08413	0.03598	0.37062	0.15581	0.15759	0.15993	0.27459	0.11831	0.64656
0.11977	0.03598	0.43444	0.18897	0.19235	0.19399	0.32288	0.15147	1.00332
0.15744	0.03598	0.47248	0.21643	0.22593	0.22138	0.34288	0.18143	1.43071
0.19827	0.03598	0.50869	0.24054	0.25871	0.24537	0.33944	0.21054	1.92462
0.24208	0.03598	0.53876	0.26195	0.29097	0.26662	0.32020	0.23695	2.52054
0.26506	0.03598	0.53814	0.27180	0.30696	0.27636	0.30862	0.25180	2.86036
0.02825	0.05701	0.12147	0.07532	0.08283	0.07877	0.12169	0.04220	0.21024
0.05449	0.05701	0.24727	0.11946	0.12041	0.12463	0.20675	0.07446	0.40918
0.08684	0.05701	0.34546	0.15866	0.15768	0.16464	0.27945	0.10866	0.68886
0.12302	0.05701	0.39884	0.19160	0.19274	0.19814	0.32574	0.13910	1.07542
0.16205	0.05701	0.44978	0.21940	0.22651	0.22601	0.34359	0.16940	1.51707
0.20395	0.05701	0.48844	0.24354	0.25941	0.25001	0.33755	0.19854	2.04281
0.24877	0.05701	0.50071	0.26490	0.29180	0.27115	0.31677	0.22490	2.70403
0.27263	0.05701	0.51973	0.27487	0.30789	0.28108	0.30508	0.23487	3.03299
0.02744	0.08922	0.10675	0.07367	0.08327	0.07564	0.11863	0.03492	0.22100
0.05182	0.08922	0.16013	0.11560	0.12127	0.11753	0.19920	0.06185	0.46414
0.08176	0.08922	0.27182	0.15326	0.15867	0.15500	0.27016	0.09076	0.69439
0.11455	0.08922	0.37000	0.18463	0.19371	0.18602	0.31780	0.11713	0.98745
0.15053	0.08922	0.40130	0.21184	0.22750	0.21297	0.34118	0.14434	1.45865
0.18971	0.08922	0.42094	0.23587	0.26054	0.23682	0.34175	0.17087	1.94971
0.23173	0.08922	0.46021	0.25723	0.29302	0.25797	0.32543	0.19473	2.51939
0.25217	0.08922	0.47187	0.26637	0.30864	0.26675	0.31504	0.20637	2.82270
0.02838	0.12043	0.10675	0.07558	0.08296	0.07911	0.12217	0.03183	0.22095
0.05619	0.12043	0.19082	0.12184	0.12506	0.12526	0.21138	0.05934	0.47206
0.08305	0.12043	0.28348	0.15466	0.15829	0.15756	0.27260	0.08216	0.70193
0.11544	0.14202	0.29084	0.18539	0.19254	0.18793	0.31871	0.10289	1.10456
0.15025	0.14202	0.34546	0.21164	0.22551	0.21366	0.34110	0.12664	1.50715
0.18778	0.14202	0.37737	0.23479	0.25770	0.23633	0.34217	0.14979	2.00009
0.22680	0.14202	0.41419	0.25491	0.28888	0.25586	0.32784	0.16991	2.55544
0.24763	0.14202	0.44241	0.26440	0.30445	0.26516	0.31736	0.17940	2.80995

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

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSMANN	KUMAR	MILLER	SCHUGERL
0.02776	0.06261	0.09845	0.07221	0.07855	0.07475	0.11250	0.04034	0.19706
0.05339	0.06261	0.21033	0.11497	0.11420	0.11877	0.19294	0.07122	0.37548
0.08567	0.06261	0.32099	0.15403	0.14965	0.15880	0.26616	0.10403	0.62958
0.12154	0.06261	0.39802	0.18668	0.18299	0.19200	0.31623	0.13418	0.95675
0.15983	0.06261	0.43776	0.21406	0.21506	0.21927	0.34059	0.16406	1.37627
0.20175	0.06261	0.44999	0.23834	0.24633	0.24359	0.34219	0.19334	1.87095
0.24635	0.06261	0.46772	0.25971	0.27713	0.26477	0.32670	0.21971	2.45394
0.26988	0.06261	0.49156	0.26961	0.29241	0.27459	0.31561	0.22961	2.74025
0.02750	0.09473	0.09662	0.07168	0.07836	0.07401	0.11155	0.03418	0.20452
0.05301	0.09473	0.19016	0.11443	0.11446	0.11766	0.19189	0.06068	0.38997
0.08412	0.09473	0.27575	0.15240	0.14996	0.15587	0.26328	0.08990	0.65858
0.11843	0.09473	0.33627	0.18416	0.18330	0.18762	0.31302	0.11916	0.98980
0.15598	0.09473	0.38580	0.21157	0.21538	0.21497	0.33927	0.14657	1.38895
0.19566	0.09473	0.41575	0.23510	0.24650	0.23814	0.34320	0.17010	1.83721
0.23876	0.09473	0.42859	0.25634	0.27728	0.25913	0.33006	0.19634	2.41422
0.26094	0.09473	0.44510	0.26595	0.29242	0.26854	0.31988	0.20595	2.71112
0.02794	0.13183	0.08500	0.07256	0.07852	0.07536	0.11313	0.03006	0.21736
0.05286	0.13183	0.13514	0.11423	0.11476	0.11711	0.19151	0.05423	0.45386
0.08350	0.13183	0.21278	0.15175	0.15027	0.15458	0.26213	0.07925	0.67241
0.11673	0.13183	0.29287	0.18277	0.18342	0.18523	0.31119	0.10527	1.09944
0.15311	0.13183	0.34361	0.20968	0.21538	0.21184	0.33814	0.12968	1.40809
0.19027	0.13183	0.36012	0.23216	0.24586	0.23359	0.34378	0.15216	1.86872
0.23173	0.13183	0.37479	0.25312	0.27634	0.25422	0.33298	0.17562	2.47624
0.02731	0.15326	0.09479	0.07132	0.07839	0.07338	0.11090	0.02757	0.20258
0.05197	0.15326	0.16142	0.11295	0.11467	0.11503	0.18903	0.04982	0.41751
0.08140	0.15326	0.22073	0.14950	0.14977	0.15117	0.25811	0.07450	0.68063
0.11407	0.15326	0.28370	0.18055	0.18278	0.18195	0.30820	0.09805	0.98847
0.14925	0.15326	0.33444	0.20708	0.21441	0.20807	0.33641	0.12208	1.37722
0.18477	0.15326	0.35339	0.22908	0.24436	0.22924	0.34406	0.14408	1.82452
0.22226	0.15326	0.38457	0.24864	0.27363	0.24804	0.33653	0.16364	2.28392

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

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSMANN	KUMAR	MILLER	SCHUGERL
0.02790	0.06274	0.09764	0.07354	0.08070	0.07643	0.11686	0.04042	0.21030
0.05370	0.06274	0.21819	0.11686	0.11742	0.12109	0.19944	0.07186	0.39745
0.08642	0.06274	0.33690	0.15651	0.15390	0.16193	0.27349	0.10401	0.66399
0.12161	0.06274	0.40421	0.18860	0.18816	0.19409	0.32080	0.13610	1.00795
0.16087	0.06274	0.44337	0.21668	0.22117	0.22246	0.34248	0.16418	1.44117
0.20444	0.06274	0.47397	0.24176	0.25322	0.24811	0.33964	0.19176	1.98027
0.24790	0.06274	0.49783	0.26245	0.28506	0.26806	0.32147	0.21745	2.55659
0.26839	0.06274	0.49906	0.27108	0.30043	0.27591	0.31138	0.23108	2.85440
0.02762	0.09626	0.11049	0.07297	0.08057	0.07556	0.11581	0.03422	0.21817
0.05314	0.09626	0.18942	0.11606	0.11769	0.11955	0.19789	0.06106	0.41405
0.08445	0.09626	0.28611	0.15444	0.15421	0.15827	0.26991	0.08944	0.68801
0.11632	0.09626	0.34608	0.18427	0.18908	0.18636	0.31555	0.11677	1.00056
0.15663	0.09626	0.35281	0.21394	0.22162	0.21768	0.34144	0.14394	1.46451
0.19588	0.09626	0.42807	0.23723	0.25349	0.24048	0.34183	0.16973	1.94485
0.23902	0.09626	0.47152	0.25850	0.28505	0.26154	0.32578	0.19350	2.46704
0.26106	0.09626	0.47213	0.26806	0.30058	0.27087	0.31495	0.20806	2.80765
0.02809	0.12974	0.08050	0.07392	0.08073	0.07705	0.11755	0.03017	0.23235
0.05311	0.12974	0.18147	0.11602	0.11797	0.11928	0.19782	0.05477	0.42107
0.08339	0.12974	0.25551	0.15332	0.15429	0.15635	0.26794	0.08082	0.70514
0.11628	0.12974	0.31487	0.18424	0.18821	0.18682	0.31551	0.10549	1.04548
0.15251	0.12974	0.34302	0.21122	0.22095	0.21351	0.34015	0.13122	1.48004
0.19180	0.12974	0.37300	0.23501	0.25292	0.23707	0.34264	0.15501	1.98076
0.23261	0.12974	0.42012	0.25558	0.28395	0.25718	0.32877	0.17808	2.59783
0.02747	0.16136	0.07071	0.07268	0.08055	0.07508	0.11528	0.02705	0.23489
0.05208	0.16136	0.16495	0.11454	0.11784	0.11690	0.19494	0.04892	0.42108
0.08132	0.16136	0.25674	0.15109	0.15384	0.15295	0.26401	0.07234	0.66357
0.11252	0.16136	0.25612	0.18106	0.18714	0.18219	0.31140	0.09481	1.04873
0.14626	0.16136	0.29468	0.20696	0.21904	0.20748	0.33766	0.11696	1.47395
0.18335	0.16136	0.32466	0.23027	0.25039	0.23044	0.34376	0.14027	1.98263
0.22292	0.16136	0.36566	0.25100	0.28118	0.25082	0.33301	0.16100	2.48748

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS

3.0 % PROPANOL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	SCHUGERL
0.02821	0.06324	0.11437	0.07585	0.08417	0.07933	0.12396	0.04085	0.22013
0.05424	0.06324	0.23039	0.11993	0.12244	0.12490	0.20949	0.07243	0.42915
0.08649	0.06324	0.32678	0.15928	0.16040	0.16504	0.28233	0.10428	0.72905
0.12132	0.06324	0.38571	0.19129	0.19634	0.19678	0.32666	0.13629	1.10359
0.16233	0.06324	0.43052	0.22070	0.23050	0.22740	0.34395	0.16570	1.61976
0.20379	0.06324	0.44894	0.24460	0.26401	0.25098	0.33586	0.19460	2.16804
0.24863	0.06324	0.48332	0.26601	0.29701	0.27216	0.31391	0.22101	2.81177
0.27211	0.06324	0.49069	0.27584	0.31337	0.28185	0.30256	0.23084	3.16727
0.02841	0.10463	0.07017	0.07625	0.08423	0.07997	0.12471	0.03375	0.30263
0.05349	0.10463	0.18435	0.11886	0.12280	0.12283	0.20739	0.06011	0.45125
0.08467	0.10463	0.27582	0.15736	0.16082	0.16154	0.27908	0.08736	0.75935
0.11920	0.10463	0.32678	0.18956	0.19656	0.19378	0.32483	0.11456	1.15254
0.15643	0.10463	0.35808	0.21688	0.23084	0.22089	0.34332	0.14188	1.62835
0.19729	0.10463	0.40781	0.24115	0.26447	0.24506	0.33828	0.16615	2.18262
0.23733	0.10463	0.43237	0.26097	0.29650	0.26403	0.31982	0.19097	2.75457
0.25962	0.10463	0.41886	0.27071	0.31271	0.27363	0.30834	0.20071	3.19186
0.02776	0.12722	0.08244	0.07493	0.08407	0.07784	0.12223	0.03055	0.24596
0.05280	0.12722	0.17944	0.11786	0.12280	0.12116	0.20543	0.05411	0.45911
0.08209	0.12722	0.23899	0.15458	0.16016	0.15735	0.27434	0.07958	0.77017
0.11381	0.12722	0.33169	0.18505	0.19491	0.18723	0.31972	0.10505	1.12540
0.14948	0.12722	0.36484	0.21222	0.22879	0.21420	0.34187	0.12972	1.49948
0.18648	0.12722	0.36729	0.23520	0.26124	0.23667	0.34149	0.15270	2.09277
0.22659	0.12722	0.39001	0.25597	0.29335	0.25708	0.32538	0.17597	2.67078
0.24743	0.12722	0.40597	0.26548	0.30919	0.26639	0.31453	0.18548	2.98004
0.02705	0.16893	0.07938	0.07348	0.08368	0.07569	0.11953	0.02598	0.24200
0.05123	0.16893	0.15857	0.11556	0.12233	0.11764	0.20092	0.04681	0.44827
0.08044	0.16893	0.20277	0.15278	0.15982	0.15456	0.27120	0.07028	0.77023
0.11019	0.16893	0.27828	0.18193	0.19377	0.18270	0.31589	0.09193	1.09319
0.14363	0.16893	0.32739	0.20816	0.22693	0.20843	0.33999	0.11316	1.48936
0.18043	0.16893	0.36177	0.23172	0.25966	0.23166	0.34278	0.13672	1.99639
0.22177	0.16893	0.39737	0.25366	0.29250	0.25362	0.32778	0.15866	2.59005

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
0.5 % ETHANOL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSHMANN	KUMAR	MILLER	SCHUGERL
0.02737	0.01716	0.11826	0.07135	0.07852	0.07300	0.11017	0.05885	0.18006
0.05249	0.01716	0.26831	0.11358	0.11251	0.11728	0.18909	0.09733	0.32911
0.08398	0.01716	0.36570	0.15212	0.14675	0.15706	0.26152	0.13712	0.57765
0.11832	0.01716	0.38407	0.18393	0.17889	0.18932	0.31170	0.17393	0.91822
0.15571	0.01716	0.39203	0.21124	0.20985	0.21681	0.33859	0.20624	1.34776
0.19617	0.01716	0.41592	0.23522	0.24010	0.24084	0.34337	0.23522	1.83014
0.24000	0.01716	0.43123	0.25673	0.26981	0.26246	0.33051	0.26173	2.39512
0.26255	0.01716	0.45022	0.26645	0.28464	0.27202	0.32031	0.27645	2.67419
0.02877	0.04112	0.12622	0.07411	0.07800	0.07810	0.11511	0.04786	0.18826
0.05516	0.04112	0.26402	0.11734	0.11293	0.12330	0.19632	0.08234	0.35755
0.08917	0.04112	0.36508	0.15748	0.14768	0.16542	0.27090	0.11998	0.62650
0.12688	0.04112	0.35161	0.19074	0.18040	0.19978	0.32016	0.15324	1.06082
0.16625	0.04112	0.36570	0.21796	0.21196	0.22684	0.34192	0.18296	1.51167
0.20412	0.04112	0.39326	0.23941	0.24247	0.24663	0.34211	0.20941	1.97574
0.24890	0.04112	0.42082	0.26066	0.27264	0.26770	0.32662	0.23566	2.56128
0.27297	0.04112	0.42143	0.27068	0.28764	0.27774	0.31538	0.25068	2.89995
0.02735	0.07358	0.07171	0.07131	0.07808	0.07329	0.11011	0.03756	0.23564
0.05242	0.07358	0.17093	0.11349	0.11389	0.11607	0.18891	0.06599	0.40454
0.08349	0.07358	0.28240	0.15160	0.14929	0.15447	0.26060	0.09785	0.63473
0.11747	0.07358	0.31976	0.18323	0.18264	0.18590	0.31078	0.12823	0.98879
0.15414	0.07358	0.34242	0.21021	0.21467	0.21250	0.33796	0.15521	1.40067
0.19350	0.07358	0.34487	0.23377	0.24619	0.23548	0.34366	0.18127	1.92005
0.23620	0.07358	0.37611	0.25501	0.27695	0.25646	0.33208	0.20501	2.48517
0.25721	0.07358	0.39019	0.26422	0.29195	0.26525	0.32281	0.21922	2.75992
0.02805	0.09747	0.12254	0.07270	0.07779	0.07587	0.11258	0.03457	0.20858
0.05409	0.09747	0.17583	0.11585	0.11366	0.12021	0.19345	0.06210	0.43197
0.08567	0.09747	0.27076	0.15389	0.14882	0.15861	0.26466	0.09139	0.66648
0.12058	0.09747	0.31547	0.18576	0.18187	0.19057	0.31408	0.11826	1.02111
0.15858	0.09747	0.34671	0.21310	0.21369	0.21782	0.33967	0.14810	1.44501
0.19968	0.09747	0.36202	0.23709	0.24475	0.24166	0.34289	0.17209	1.98996
0.24259	0.09747	0.37611	0.25788	0.27503	0.26205	0.32940	0.19788	2.58170
0.26499	0.09747	0.40612	0.26745	0.28998	0.27141	0.31915	0.20745	2.83374

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
0.5 % METHANOL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	SCHUGERL
0.02783	0.02120	0.12273	0.07210	0.07791	0.07460	0.11127	0.05585	0.18256
0.05278	0.02120	0.21819	0.11377	0.11202	0.11775	0.18911	0.09377	0.35855
0.08407	0.02120	0.25001	0.15195	0.14626	0.15687	0.26085	0.13195	0.65957
0.11867	0.02120	0.27081	0.18393	0.17837	0.18937	0.31140	0.16643	1.04626
0.15684	0.02120	0.29957	0.21168	0.20928	0.21757	0.33871	0.19918	1.49764
0.19812	0.02120	0.32160	0.23595	0.23944	0.24209	0.34326	0.23095	2.02718
0.24211	0.02120	0.32772	0.25736	0.26916	0.26349	0.33016	0.25736	2.67297
0.26505	0.02120	0.34914	0.26716	0.28390	0.27321	0.31979	0.27216	2.98504
0.02942	0.03710	0.20105	0.07521	0.07778	0.08001	0.11684	0.05021	0.15803
0.05579	0.03710	0.20105	0.11799	0.11245	0.12456	0.19722	0.08549	0.39406
0.08970	0.03710	0.21513	0.15775	0.14720	0.16595	0.27100	0.12275	0.75361
0.12645	0.03710	0.23593	0.19011	0.17967	0.19890	0.31915	0.15761	1.21333
0.16623	0.03710	0.23226	0.21764	0.21089	0.22661	0.34170	0.18764	1.79320
0.21236	0.03710	0.31242	0.24331	0.24166	0.25320	0.34051	0.21831	2.27256
0.25905	0.03710	0.31242	0.26467	0.27175	0.27444	0.32260	0.24467	3.01830
0.28257	0.03710	0.33567	0.27413	0.28658	0.28360	0.31161	0.25913	3.30139
0.02743	0.06040	0.10131	0.07130	0.07801	0.07316	0.10984	0.04005	0.18972
0.05243	0.06040	0.19860	0.11328	0.11335	0.11591	0.18816	0.07078	0.36634
0.08343	0.06040	0.22308	0.15128	0.14838	0.15431	0.25966	0.10378	0.68450
0.11795	0.06040	0.21819	0.18334	0.18135	0.18658	0.31061	0.13334	1.13054
0.15636	0.06040	0.26469	0.21137	0.21315	0.21495	0.33852	0.16387	1.57013
0.19742	0.06040	0.29406	0.23557	0.24415	0.23915	0.34335	0.19057	2.08022
0.24154	0.06040	0.31670	0.25710	0.27466	0.26061	0.33040	0.21710	2.70367
0.26472	0.06040	0.33139	0.26702	0.28973	0.27050	0.31995	0.23202	3.03638
0.02828	0.08570	0.08234	0.07298	0.07751	0.07642	0.11284	0.03673	0.21686
0.05466	0.08570	0.19310	0.11642	0.11315	0.12135	0.19420	0.06517	0.39855
0.08697	0.08570	0.21819	0.15497	0.14823	0.16057	0.26618	0.09622	0.73167
0.12222	0.08570	0.16801	0.18679	0.18111	0.19246	0.31509	0.12429	1.30372
0.16003	0.08570	0.24633	0.21374	0.21262	0.21916	0.33987	0.15374	1.65385
0.20125	0.08570	0.26775	0.23760	0.24344	0.24286	0.34281	0.17760	2.23766
0.24561	0.08570	0.28794	0.25890	0.27380	0.26397	0.32866	0.20390	2.87275
0.26832	0.08570	0.31976	0.26849	0.28871	0.27337	0.31825	0.21849	3.12610

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS

50 PPM CMC SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02799	0.00000	0.12137	0.06495	0.07477	0.06770	0.11260	0.06495	0.06163
0.04545	0.00000	0.20913	0.09326	0.09859	0.09710	0.16931	0.09326	0.09172
0.06895	0.00000	0.25301	0.12345	0.12509	0.12823	0.23063	0.12345	0.12899
0.09354	0.00000	0.28714	0.14895	0.14663	0.15454	0.27865	0.14895	0.16576
0.11936	0.00000	0.32127	0.17107	0.17081	0.17736	0.31311	0.17107	0.20243
0.14630	0.00000	0.36028	0.19060	0.19155	0.19753	0.33435	0.19060	0.23919
0.17441	0.00000	0.39926	0.20815	0.21137	0.21566	0.34347	0.20815	0.27626
0.26864	0.03374	0.29933	0.25339	0.27430	0.26001	0.31712	0.21835	0.39371
0.24532	0.03374	0.28287	0.24367	0.26000	0.25036	0.32796	0.20867	0.36545
0.20135	0.03374	0.25850	0.22289	0.23113	0.22983	0.34254	0.18289	0.31080
0.15777	0.03374	0.20547	0.19807	0.20206	0.20400	0.33951	0.15807	0.25447
0.11949	0.03374	0.21279	0.17117	0.17204	0.17678	0.31324	0.12867	0.20261
0.08509	0.03374	0.19572	0.14078	0.14066	0.14623	0.26396	0.10078	0.15338
0.05356	0.03374	0.18963	0.10454	0.10776	0.10914	0.19236	0.06954	0.10453
0.02789	0.03374	0.10796	0.06477	0.07467	0.06747	0.11225	0.04040	0.06145
0.02746	0.05451	0.08724	0.06393	0.07470	0.06612	0.11073	0.03461	0.06065
0.05232	0.05451	0.17317	0.10269	0.10839	0.10566	0.18897	0.06038	0.10293
0.08374	0.05451	0.19389	0.13942	0.14186	0.14326	0.26145	0.08942	0.15137
0.11798	0.05451	0.21340	0.16996	0.17333	0.17400	0.31163	0.11498	0.20051
0.15537	0.05451	0.22132	0.19654	0.20356	0.20063	0.33861	0.14154	0.25129
0.19573	0.05451	0.29506	0.21956	0.23314	0.22396	0.34337	0.16496	0.30368
0.23922	0.05451	0.28044	0.24099	0.26234	0.24465	0.33060	0.19099	0.35798
0.26157	0.05451	0.29019	0.25052	0.27673	0.25420	0.32047	0.20052	0.38519
0.02716	0.07943	0.07931	0.06344	0.07459	0.06526	0.10967	0.03000	0.06013
0.05222	0.07943	0.17561	0.10275	0.10876	0.10539	0.18870	0.05400	0.10276
0.08294	0.07943	0.19085	0.13861	0.14236	0.14157	0.25993	0.07986	0.15018
0.11650	0.07943	0.18231	0.16880	0.17395	0.17167	0.31001	0.10380	0.19844
0.15311	0.07943	0.22437	0.19509	0.20439	0.19776	0.33767	0.12759	0.24829
0.19275	0.07943	0.23838	0.21838	0.23412	0.22084	0.34369	0.15088	0.29987
0.23515	0.07943	0.27617	0.23917	0.26329	0.24141	0.33228	0.17417	0.35298
0.25746	0.07943	0.27190	0.24863	0.27772	0.25098	0.32240	0.18383	0.38024
0.02726	0.12896	0.06286	0.06361	0.07471	0.06547	0.10995	0.02486	0.06030
0.05127	0.12896	0.15489	0.10146	0.10897	0.10309	0.18606	0.04456	0.10124
0.08072	0.12896	0.17439	0.13634	0.14246	0.13775	0.25566	0.06634	0.14689
0.11212	0.12896	0.20182	0.16525	0.17361	0.16599	0.30494	0.08775	0.19230
0.14716	0.12896	0.20974	0.19117	0.20382	0.19161	0.33481	0.10867	0.24034
0.18579	0.12896	0.27800	0.21459	0.23363	0.21484	0.34406	0.12959	0.29096
0.22280	0.12896	0.25179	0.23348	0.26162	0.23277	0.33690	0.14848	0.33771
0.24316	0.12896	0.26337	0.24273	0.27572	0.24176	0.32891	0.15773	0.36280

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS

500 PPM CMC SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02779	0.00000	0.12150	0.05706	0.07096	0.05957	0.11144	0.05706	0.06125
0.04518	0.00000	0.16740	0.08299	0.09359	0.08662	0.16791	0.08299	0.09127
0.06862	0.00000	0.18514	0.11122	0.11876	0.11590	0.22932	0.11122	0.12857
0.09309	0.00000	0.19371	0.13523	0.14132	0.14069	0.27724	0.13523	0.16511
0.11866	0.00000	0.25551	0.15623	0.16223	0.16234	0.31179	0.15623	0.20145
0.14539	0.00000	0.29345	0.17497	0.18197	0.18169	0.33349	0.17497	0.23796
0.17267	0.00000	0.30447	0.19169	0.20088	0.19880	0.34315	0.19169	0.27427
0.16735	0.00000	0.32833	0.19966	0.21005	0.20709	0.34405	0.19966	0.29296
0.02777	0.02312	0.11171	0.05703	0.07093	0.05956	0.11139	0.03516	0.06123
0.05225	0.02312	0.14252	0.09218	0.10204	0.09589	0.18814	0.06093	0.10282
0.08298	0.02312	0.20044	0.12586	0.13328	0.13039	0.25932	0.08711	0.15025
0.11725	0.02312	0.22798	0.15516	0.16259	0.16032	0.31027	0.11266	0.19949
0.15483	0.02312	0.25123	0.18097	0.19081	0.18658	0.33811	0.13597	0.25057
0.19562	0.02312	0.28182	0.20400	0.21835	0.20991	0.34349	0.15900	0.30354
0.23948	0.02312	0.29345	0.22472	0.24546	0.23081	0.33093	0.18222	0.35630
0.26259	0.02312	0.29529	0.23437	0.25891	0.24052	0.32054	0.19437	0.38642
0.02953	0.03033	0.11538	0.06162	0.07196	0.06627	0.11806	0.03662	0.06439
0.05608	0.03033	0.13680	0.09932	0.10385	0.10615	0.19921	0.06307	0.10895
0.08905	0.03033	0.19677	0.13449	0.13572	0.14264	0.27118	0.09199	0.15921
0.12541	0.03033	0.21880	0.16446	0.16560	0.17336	0.31916	0.11698	0.21080
0.16661	0.03033	0.22981	0.19155	0.19450	0.20139	0.34212	0.14405	0.26610
0.20893	0.03033	0.26102	0.21432	0.22250	0.22414	0.34091	0.16682	0.32043
0.25526	0.03033	0.28611	0.23512	0.25014	0.24504	0.32336	0.19012	0.37754
0.27890	0.03033	0.29712	0.24451	0.26378	0.25430	0.31222	0.19951	0.40598
0.02794	0.05595	0.10620	0.05731	0.07075	0.06016	0.11197	0.02794	0.06154
0.05350	0.05595	0.18453	0.09374	0.10277	0.09799	0.19156	0.04999	0.10484
0.08395	0.05595	0.20778	0.12679	0.13433	0.13123	0.26115	0.07179	0.15169
0.11831	0.05595	0.23960	0.15597	0.16417	0.16069	0.31142	0.09597	0.20097
0.15567	0.05595	0.25612	0.18149	0.19295	0.18623	0.33845	0.11649	0.25169
0.19736	0.05595	0.24939	0.20489	0.22127	0.20988	0.34328	0.13739	0.30575
0.24109	0.05595	0.27203	0.22542	0.24898	0.23029	0.33026	0.16042	0.36027
0.26327	0.05595	0.29469	0.23465	0.26271	0.23924	0.32022	0.16965	0.38724
0.02855	0.08305	0.08846	0.05999	0.07170	0.06366	0.11464	0.02624	0.06264
0.05473	0.08305	0.13864	0.09766	0.10451	0.10280	0.19563	0.04766	0.10681
0.08696	0.08305	0.16984	0.13243	0.13684	0.13836	0.26729	0.06953	0.15599
0.12221	0.08305	0.19371	0.16211	0.16718	0.16838	0.31609	0.09211	0.20638
0.16089	0.08305	0.21145	0.18812	0.19642	0.19456	0.34059	0.11312	0.25856
0.20170	0.08305	0.23532	0.21069	0.22475	0.21693	0.34245	0.13569	0.31124
0.24641	0.08305	0.25123	0.23141	0.25278	0.23763	0.32740	0.15641	0.36679
0.25926	0.08305	0.26224	0.23677	0.26619	0.24036	0.32148	0.16177	0.38239

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS

1000 PPM CMC SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02917	0.02567	0.10001	0.04087	0.06153	0.04450	0.11673	0.01712	0.06374
0.05501	0.02567	0.16266	0.06856	0.08862	0.07414	0.19626	0.03043	0.10725
0.08703	0.02567	0.16813	0.09617	0.11573	0.10311	0.26749	0.04555	0.15623
0.12373	0.02567	0.19672	0.12184	0.14126	0.13024	0.31750	0.06059	0.20849
0.16227	0.02567	0.22227	0.14416	0.16572	0.15306	0.34097	0.07541	0.26040
0.20779	0.02567	0.25207	0.16626	0.18978	0.17657	0.34123	0.09126	0.31853
0.25468	0.02567	0.27823	0.18563	0.21339	0.19652	0.32361	0.10563	0.37708
0.27953	0.02567	0.29706	0.19468	0.22509	0.20577	0.31201	0.11218	0.40674
0.02941	0.04682	0.08602	0.03996	0.06145	0.04296	0.11407	0.01465	0.06236
0.05414	0.04682	0.13346	0.06772	0.08902	0.07241	0.19393	0.02647	0.10596
0.08591	0.04682	0.16144	0.09530	0.11646	0.10112	0.26547	0.04030	0.15459
0.12152	0.04682	0.18091	0.12043	0.14228	0.12718	0.31532	0.05356	0.20542
0.15965	0.04682	0.21436	0.14276	0.16708	0.14983	0.34016	0.06651	0.25695
0.20158	0.04682	0.23382	0.16346	0.19132	0.17099	0.34250	0.07971	0.31109
0.24611	0.04682	0.25572	0.18224	0.21516	0.18992	0.32761	0.09349	0.36641
0.26900	0.04682	0.27640	0.19090	0.22692	0.19851	0.31696	0.09965	0.39413
0.02806	0.07654	0.09271	0.03954	0.06136	0.04228	0.11284	0.01266	0.06175
0.05369	0.07654	0.12677	0.06728	0.08936	0.07142	0.19271	0.02353	0.10513
0.08536	0.07654	0.14745	0.09489	0.11704	0.10002	0.26449	0.03551	0.15380
0.12001	0.07654	0.17969	0.11947	0.14296	0.12511	0.31378	0.04759	0.20333
0.15773	0.07654	0.20949	0.14173	0.16793	0.14764	0.33950	0.06048	0.25441
0.19899	0.07654	0.20767	0.16228	0.19239	0.16642	0.34293	0.07228	0.30781
0.24287	0.07654	0.23565	0.18097	0.21632	0.18720	0.32903	0.08472	0.36246
0.26549	0.07654	0.26657	0.18961	0.22810	0.19577	0.31862	0.08961	0.38991
0.02824	0.09812	0.05500	0.03975	0.06140	0.04263	0.11346	0.01194	0.06207
0.05354	0.09812	0.10305	0.06714	0.08946	0.07110	0.19230	0.02183	0.10489
0.08462	0.09812	0.14684	0.09445	0.11713	0.09922	0.26347	0.03320	0.15299
0.11871	0.09812	0.16327	0.11862	0.14297	0.12367	0.31241	0.04487	0.20152
0.15518	0.09812	0.18577	0.14034	0.16772	0.14543	0.33853	0.05534	0.25103
0.19823	0.09812	0.20645	0.16193	0.19216	0.16797	0.34304	0.06818	0.30685
0.23603	0.09812	0.21923	0.17823	0.21504	0.18327	0.33192	0.07823	0.35406

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS

1200 PPM CMC SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02808	0.00000	0.05419	0.04963	0.06683	0.05240	0.11212	0.04963	0.06179
0.04563	0.00000	0.08173	0.07300	0.08813	0.07700	0.16875	0.07300	0.09201
0.06928	0.00000	0.12823	0.09894	0.11183	0.10412	0.23025	0.09894	0.12958
0.09382	0.00000	0.17046	0.12122	0.13306	0.12723	0.27789	0.12122	0.16617
0.11945	0.00000	0.17963	0.14094	0.15275	0.14762	0.31218	0.14094	0.20255
0.14647	0.00000	0.22430	0.15885	0.17133	0.16626	0.33380	0.15885	0.23941
0.17450	0.00000	0.26224	0.17507	0.18910	0.18310	0.34330	0.17507	0.27639
0.18895	0.00000	0.28182	0.18267	0.19774	0.19098	0.34402	0.18267	0.29502
0.02949	0.02040	0.08968	0.05340	0.06778	0.05772	0.11719	0.03090	0.06432
0.05542	0.02040	0.13741	0.08689	0.09742	0.09324	0.19642	0.05314	0.10790
0.08800	0.02040	0.16311	0.11936	0.12717	0.12719	0.26822	0.07686	0.15766
0.12398	0.02040	0.20350	0.14761	0.15507	0.15638	0.31698	0.09886	0.20883
0.16352	0.02040	0.21329	0.17273	0.18191	0.18220	0.34103	0.12023	0.26204
0.20918	0.02040	0.23226	0.19657	0.20835	0.20730	0.34121	0.14157	0.32068
0.25446	0.02040	0.25551	0.21639	0.23400	0.22714	0.32456	0.16139	0.37658
0.27862	0.02040	0.28366	0.22578	0.24677	0.23658	0.31326	0.17078	0.40566
0.02786	0.04823	0.07622	0.04930	0.06673	0.05192	0.11134	0.02211	0.06139
0.05293	0.04823	0.12273	0.08159	0.09672	0.08542	0.18949	0.03971	0.10392
0.08447	0.04823	0.14231	0.11319	0.12661	0.11801	0.26156	0.05881	0.15246
0.11902	0.04823	0.15332	0.14063	0.15464	0.14591	0.31173	0.07813	0.20195
0.15677	0.04823	0.17535	0.16506	0.18165	0.17059	0.33867	0.09506	0.25314
0.19859	0.04823	0.21451	0.18750	0.20813	0.19340	0.34321	0.11500	0.30731
0.24243	0.04823	0.23532	0.20734	0.23409	0.21321	0.33006	0.13234	0.36191
0.26542	0.04823	0.24144	0.21659	0.24698	0.22240	0.31965	0.13909	0.38982
0.02849	0.07807	0.10131	0.05192	0.06754	0.05533	0.11373	0.02067	0.06254
0.05464	0.07807	0.11049	0.08600	0.09840	0.09097	0.19434	0.03787	0.10666
0.08701	0.07807	0.13619	0.11849	0.12890	0.12450	0.26646	0.05599	0.15621
0.12256	0.07807	0.15577	0.14661	0.15752	0.15312	0.31558	0.07536	0.20687
0.16212	0.07807	0.15577	0.17192	0.18522	0.17891	0.34062	0.09442	0.26020
0.20333	0.07807	0.21207	0.19377	0.21197	0.20065	0.34741	0.11127	0.31331
0.24909	0.07807	0.18881	0.21420	0.23852	0.22125	0.32699	0.12920	0.37005
0.27066	0.07807	0.25184	0.22276	0.25125	0.22943	0.31699	0.13776	0.39612

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS

1800 PPM CMC SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSHANN	KUMAR	MILLER	DECKWER
0.02949	0.02445	0.07377	0.04897	0.06571	0.05315	0.11763	0.02459	0.06433
0.05496	0.02445	0.09947	0.08015	0.09459	0.08598	0.19582	0.04328	0.10718
0.08776	0.02445	0.12395	0.11163	0.12371	0.11912	0.26844	0.06413	0.15731
0.12441	0.02445	0.16372	0.13955	0.15107	0.14830	0.31788	0.08455	0.20943
0.16454	0.02445	0.19677	0.16441	0.17740	0.17403	0.34150	0.10441	0.26339
0.20850	0.02445	0.22308	0.18697	0.20312	0.19734	0.34117	0.12197	0.31983
0.25592	0.02445	0.23654	0.20746	0.22844	0.21838	0.32340	0.14246	0.37835
0.28025	0.02445	0.25735	0.21679	0.24094	0.22778	0.31198	0.15179	0.40760
0.02804	0.04190	0.06092	0.04554	0.06462	0.04831	0.11208	0.01960	0.06171
0.05311	0.04190	0.09335	0.07605	0.09364	0.08013	0.19015	0.03543	0.10421
0.08461	0.04190	0.11538	0.10633	0.12262	0.11147	0.26199	0.05258	0.15266
0.11931	0.04190	0.14414	0.13306	0.14984	0.13881	0.31218	0.07056	0.20235
0.15717	0.04190	0.16128	0.15599	0.17607	0.16309	0.33889	0.08699	0.25367
0.19905	0.04190	0.19065	0.17906	0.20176	0.18561	0.34312	0.10406	0.30789
0.24472	0.04190	0.14659	0.19938	0.22712	0.20637	0.32896	0.12188	0.36471
0.26647	0.04190	0.23104	0.20801	0.23948	0.21468	0.31902	0.12801	0.39109
0.02881	0.07193	0.06276	0.04802	0.06574	0.05146	0.11524	0.01833	0.06310
0.05465	0.07193	0.10131	0.07981	0.09543	0.08478	0.19498	0.03356	0.10668
0.08693	0.07193	0.11844	0.11092	0.12508	0.11697	0.26695	0.04967	0.15608
0.12248	0.07193	0.14598	0.13822	0.15293	0.14485	0.31600	0.06697	0.20675
0.16100	0.07193	0.17168	0.16240	0.17972	0.16928	0.34048	0.08365	0.25872
0.20294	0.07193	0.19860	0.18433	0.20592	0.19139	0.34233	0.09933	0.31281
0.24812	0.07193	0.22675	0.20432	0.23173	0.21148	0.32696	0.11682	0.36896
0.27101	0.07193	0.22859	0.21333	0.24440	0.22036	0.31629	0.12333	0.39655
0.02737	0.08893	0.04562	0.04462	0.06449	0.04681	0.10973	0.01556	0.06051
0.05294	0.08893	-0.01740	0.07587	0.09432	0.07933	0.18967	0.02899	0.10393
0.08318	0.08893	0.10743	0.10510	0.12342	0.10885	0.25930	0.04385	0.15054
0.11727	0.08893	0.13313	0.13164	0.15095	0.13573	0.30998	0.05789	0.19952
0.15256	0.08893	0.15516	0.15430	0.17699	0.15808	0.33696	0.07305	0.24755
0.19217	0.08893	0.18086	0.17569	0.20274	0.17948	0.34384	0.08819	0.29914
0.23427	0.08893	0.19432	0.19501	0.22798	0.19869	0.33327	0.10251	0.35189
0.25683	0.08893	0.20044	0.20426	0.24059	0.20794	0.32352	0.10926	0.37945

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS

2300 PPM CMC SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02934	0.02271	0.04650	0.04688	0.06462	0.05085	0.11683	0.02313	0.06405
0.05507	0.02271	0.09734	0.07763	0.09310	0.08351	0.19573	0.04076	0.10735
0.08769	0.02271	0.12981	0.10838	0.12176	0.11587	0.26791	0.06088	0.15720
0.12387	0.02271	0.14634	0.13565	0.14868	0.14425	0.31706	0.08065	0.20868
0.16344	0.02271	0.18065	0.16003	0.17460	0.16939	0.34108	0.09878	0.26194
0.20710	0.02271	0.21740	0.18240	0.19995	0.19252	0.34160	0.11740	0.31806
0.25401	0.02271	0.24374	0.20269	0.22487	0.21335	0.32458	0.13519	0.37603
0.27993	0.02271	0.25292	0.21263	0.23732	0.22376	0.31245	0.14513	0.40722
0.02775	0.04149	0.09918	0.04174	0.06277	0.04414	0.11101	0.01674	0.06119
0.05253	0.04149	0.10102	0.07036	0.09105	0.07389	0.18847	0.03036	0.10327
0.08340	0.04149	0.13226	0.09896	0.11927	0.10329	0.25964	0.04583	0.15087
0.11824	0.04149	0.15553	0.12508	0.14590	0.13018	0.31098	0.06133	0.20088
0.15609	0.04149	0.16594	0.14847	0.17153	0.15400	0.33844	0.07597	0.25225
0.19720	0.04149	0.20147	0.16980	0.19661	0.17560	0.34337	0.09230	0.30554
0.24186	0.04149	0.20147	0.18949	0.22128	0.19560	0.33023	0.10699	0.36122
0.26472	0.04149	0.25599	0.19849	0.23348	0.20456	0.31990	0.11349	0.38898
0.02851	0.06598	0.05998	0.04577	0.06443	0.04904	0.11396	0.01733	0.06257
0.05744	0.06598	0.08754	0.08013	0.09689	0.08506	0.20196	0.03325	0.11111
0.08653	0.06598	0.11327	0.10741	0.12306	0.11331	0.26584	0.04804	0.15550
0.12196	0.06598	0.14206	0.13434	0.15050	0.14086	0.33518	0.06434	0.20603
0.16059	0.06598	0.16594	0.15842	0.17695	0.16530	0.34022	0.08092	0.25819
0.20212	0.06598	0.18677	0.18004	0.20275	0.18705	0.34257	0.09504	0.31178
0.24656	0.06598	0.20576	0.19968	0.22812	0.20669	0.32793	0.11218	0.36697
0.27010	0.06598	0.22352	0.20896	0.24074	0.21597	0.31705	0.11896	0.39545
0.02708	0.08984	-0.01108	0.04088	0.06272	0.04269	0.10865	0.01338	0.05998
0.05169	0.08984	0.02751	0.06949	0.09158	0.07204	0.18617	0.02449	0.10192
0.08168	0.08984	0.05998	0.09752	0.11997	0.10042	0.25636	0.03752	0.14832
0.11478	0.08984	0.08632	0.12271	0.14664	0.12575	0.30710	0.05021	0.19604
0.15077	0.08984	0.12552	0.14543	0.17233	0.14646	0.33609	0.06293	0.24517
0.19040	0.08984	0.11878	0.16651	0.19758	0.16961	0.34396	0.07651	0.29687
0.23281	0.08984	0.12000	0.18574	0.22237	0.18883	0.33388	0.09074	0.35010
0.25509	0.08984	0.11327	0.19478	0.23469	0.19782	0.32438	0.09728	0.37734

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
0.05 M NACL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02900	0.04357	0.12069	0.07258	0.07658	0.07681	0.11471	0.04570	0.06345
0.05573	0.04357	0.16874	0.11543	0.11096	0.12179	0.19609	0.07918	0.10841
0.08921	0.04357	0.19672	0.15434	0.14522	0.16208	0.26912	0.11434	0.15944
0.12565	0.04357	0.22044	0.18632	0.17734	0.19452	0.31763	0.14632	0.21114
0.16572	0.04357	0.23991	0.21398	0.20830	0.22249	0.34128	0.17648	0.26493
0.20855	0.04357	0.25511	0.23793	0.23848	0.24642	0.34171	0.20293	0.31988
0.25542	0.04357	0.26667	0.25962	0.26827	0.26821	0.32504	0.22962	0.37774
0.28943	0.04357	0.28857	0.27320	0.28887	0.28165	0.30938	0.24820	0.41851
0.02790	0.06252	0.08541	0.07047	0.07658	0.07321	0.11089	0.03922	0.06147
0.05337	0.06252	0.16753	0.11218	0.11133	0.11601	0.18978	0.06843	0.10463
0.08476	0.06252	0.17969	0.14980	0.14574	0.15410	0.26110	0.09980	0.15288
0.11958	0.06252	0.19429	0.18153	0.17810	0.18605	0.31153	0.12903	0.20273
0.15783	0.06252	0.23200	0.20900	0.20929	0.21366	0.33869	0.15900	0.25454
0.19847	0.06252	0.24660	0.23271	0.23964	0.23718	0.34338	0.18521	0.30716
0.24279	0.06252	0.25329	0.25415	0.26959	0.25856	0.33055	0.20915	0.36235
0.26571	0.06252	0.28553	0.26390	0.28438	0.26818	0.32030	0.22390	0.39017
0.02822	0.08588	0.09879	0.07108	0.07636	0.07443	0.11199	0.03483	0.06204
0.05419	0.08588	0.15597	0.11331	0.11136	0.11789	0.19199	0.06206	0.10594
0.08604	0.08588	0.19611	0.15113	0.14586	0.15623	0.26346	0.09238	0.15478
0.12131	0.08588	0.21801	0.18291	0.17830	0.18823	0.31334	0.12041	0.20513
0.15962	0.08588	0.21801	0.21015	0.20948	0.21547	0.33936	0.14765	0.25691
0.20097	0.08588	0.23504	0.23402	0.23989	0.23923	0.34306	0.17402	0.31032
0.24492	0.08588	0.26241	0.25510	0.26971	0.26007	0.32965	0.20010	0.36496
0.26727	0.08588	0.29952	0.26453	0.28431	0.26927	0.31957	0.20953	0.39206
0.02740	0.10231	0.06169	0.06948	0.07633	0.07174	0.10911	0.03198	0.06056
0.05225	0.10231	0.13955	0.11060	0.11151	0.11322	0.18672	0.05685	0.10282
0.08261	0.10231	0.17361	0.14755	0.14594	0.15021	0.25704	0.08380	0.14969
0.11614	0.10231	0.18516	0.17873	0.17828	0.18130	0.30774	0.11123	0.19794
0.15224	0.10231	0.21375	0.20535	0.20926	0.20763	0.33629	0.13535	0.24713
0.19049	0.10231	0.22592	0.22840	0.23923	0.23025	0.34401	0.15840	0.29698
0.23172	0.10231	0.24660	0.24915	0.26875	0.25067	0.33489	0.18415	0.34875
0.25344	0.10231	0.26606	0.25878	0.28340	0.26016	0.32593	0.19378	0.37534

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
0.2 M NACL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	MERSMANN	KUMAR	MILLER	DECKWER
0.02514	0.03271	0.17009	0.07151	0.07640	0.07612	0.11750	0.04776	0.06370
0.05605	0.03271	0.25467	0.11404	0.11040	0.12122	0.20032	0.08154	0.10892
0.08921	0.03271	0.26220	0.15219	0.14434	0.16065	0.27266	0.11719	0.15943
0.12664	0.03271	0.25641	0.18474	0.17631	0.19424	0.32119	0.14974	0.21250
0.16554	0.03271	0.27436	0.21140	0.20685	0.22081	0.34218	0.17890	0.26470
0.21168	0.03271	0.29232	0.23695	0.23707	0.24736	0.33977	0.20695	0.32382
0.25909	0.03271	0.28305	0.25855	0.26655	0.26912	0.32060	0.23355	0.38218
0.28257	0.03271	0.32592	0.26795	0.28107	0.27824	0.30952	0.24795	0.41036
0.26636	0.03187	0.29580	0.26154	0.28112	0.26759	0.31713	0.24154	0.39095
0.19891	0.03187	0.29116	0.23040	0.23701	0.23650	0.34266	0.20040	0.30771
0.11883	0.03187	0.25583	0.17861	0.17634	0.18396	0.31362	0.14361	0.20169
0.05305	0.03187	0.26452	0.10994	0.11052	0.11417	0.19221	0.07869	0.10411
0.02794	0.05020	0.17125	0.06923	0.07642	0.07221	0.11325	0.04048	0.06153
0.05321	0.05020	0.24945	0.11017	0.11092	0.11425	0.19266	0.07017	0.10437
0.08448	0.05020	0.24308	0.14740	0.14520	0.15199	0.26416	0.10115	0.15246
0.11894	0.05020	0.25351	0.17869	0.17739	0.18346	0.31372	0.13119	0.20184
0.15681	0.05020	0.25756	0.20590	0.20842	0.21076	0.33965	0.15840	0.25319
0.19780	0.05020	0.27089	0.22982	0.23872	0.23468	0.34285	0.18482	0.30631
0.24104	0.05020	0.29058	0.25079	0.26844	0.25539	0.32893	0.21079	0.36022
0.26393	0.05020	0.31897	0.26055	0.28322	0.26506	0.31828	0.22055	0.38803
0.02831	0.06657	0.14750	0.06994	0.07619	0.07361	0.11458	0.03682	0.06221
0.05391	0.06657	0.20659	0.11113	0.11076	0.11600	0.19457	0.06488	0.10550
0.08570	0.06657	0.22918	0.14865	0.14499	0.15424	0.26641	0.09490	0.15427
0.12055	0.06657	0.24366	0.17999	0.17709	0.18579	0.31539	0.12249	0.20408
0.15849	0.06657	0.25641	0.20698	0.20797	0.21280	0.34022	0.14948	0.25541
0.19909	0.06657	0.26799	0.23050	0.23800	0.23616	0.34263	0.17550	0.30793
0.24304	0.06657	0.28247	0.25167	0.26760	0.25723	0.32805	0.20167	0.36266
0.26543	0.06657	0.28885	0.26117	0.28215	0.26653	0.31757	0.21117	0.38984
0.02723	0.07554	0.14229	0.06788	0.07640	0.06993	0.11073	0.03413	0.06025
0.05264	0.07554	0.22107	0.10937	0.11139	0.11256	0.19110	0.06062	0.10346
0.11754	0.07554	0.24482	0.17757	0.17817	0.18111	0.31224	0.11757	0.19989
0.19488	0.07554	0.28827	0.22826	0.23967	0.23153	0.34327	0.16826	0.30259

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
0.5 M NACL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSMANN	KUMAR	MILLER	DECKWER
0.02895	0.04486	0.14061	0.07096	0.07596	0.07529	0.11584	0.04346	0.06335
0.05486	0.04486	0.23625	0.11218	0.11000	0.11800	0.19571	0.07468	0.10702
0.08711	0.04486	0.22926	0.14979	0.14388	0.15650	0.26745	0.10729	0.15635
0.12260	0.04486	0.25025	0.18128	0.17568	0.18837	0.31626	0.13628	0.20692
0.16160	0.04486	0.25375	0.20860	0.20631	0.21595	0.34072	0.16610	0.25952
0.20259	0.04486	0.29515	0.23197	0.23606	0.23908	0.34236	0.19197	0.31237
0.24723	0.04486	0.31265	0.25314	0.26538	0.26017	0.32723	0.21814	0.36779
0.26994	0.04486	0.31382	0.26262	0.27979	0.26945	0.31666	0.23012	0.39526
0.02723	0.05956	0.12312	0.06770	0.07600	0.06969	0.10979	0.03707	0.06025
0.05193	0.05956	0.18668	0.10813	0.11042	0.11086	0.18773	0.06563	0.10231
0.08225	0.05956	0.21759	0.14480	0.14447	0.14773	0.25845	0.09480	0.14917
0.12383	0.05956	0.24267	0.18224	0.18291	0.18557	0.31746	0.12974	0.20863
0.15340	0.05956	0.28349	0.20334	0.20749	0.20655	0.33772	0.15084	0.24867
0.19447	0.05956	0.25550	0.22769	0.23784	0.23110	0.34354	0.17769	0.30207
0.23644	0.05956	0.28699	0.24836	0.26728	0.25139	0.33187	0.20336	0.35456
0.25862	0.05956	0.29574	0.25799	0.28189	0.26089	0.32200	0.21299	0.38162
0.02828	0.10062	0.10154	0.06971	0.07579	0.07329	0.11352	0.03159	0.06216
0.05387	0.10062	0.19893	0.11082	0.11055	0.11528	0.19304	0.05707	0.10543
0.08494	0.10062	0.22459	0.14759	0.14463	0.15228	0.26351	0.08259	0.15315
0.11860	0.10062	0.22751	0.17811	0.17643	0.18260	0.31216	0.10811	0.20138
0.15387	0.10062	0.24383	0.20365	0.20658	0.20756	0.33792	0.13365	0.24930
0.19136	0.10062	0.25491	0.22600	0.23578	0.22933	0.34382	0.15600	0.29810
0.23271	0.10062	0.27474	0.24666	0.26482	0.24970	0.33336	0.17666	0.34998
0.25652	0.10062	0.28349	0.25711	0.27983	0.26032	0.32298	0.19211	0.37908
0.05289	0.04486	0.20418	0.10946	0.11036	0.11313	0.19036	0.07196	0.10385
0.11818	0.04486	0.19485	0.17776	0.17630	0.18211	0.31170	0.13276	0.20078
0.19878	0.04486	0.24850	0.22998	0.23731	0.23515	0.34299	0.18998	0.30754
0.26800	0.04486	0.25783	0.26184	0.28171	0.26732	0.31758	0.22684	0.39293
0.05183	0.10062	0.19077	0.10799	0.11094	0.11023	0.18744	0.05424	0.10214
0.11424	0.10062	0.25200	0.17454	0.17709	0.17629	0.30729	0.10454	0.19528
0.18809	0.10062	0.27882	0.22421	0.23783	0.22535	0.34401	0.15421	0.29392
0.25082	0.10062	0.35172	0.25469	0.28190	0.25543	0.32561	0.18719	0.37215

COMPARISON OF THE HOLDUP DATA WITH EXISTING CORRELATIONS
1.0 M NACL SOLUTION

VG(M/S)	VL(M/S)	EXPTL	AKITA/YOSHIDA	HIKITA	HERSMANN	KUMAR	MILLER	DECKWER
0.02890	0.05310	0.15176	0.07074	0.07551	0.07508	0.11540	0.04074	0.06326
0.05497	0.05310	0.22775	0.11214	0.10955	0.11802	0.19560	0.07089	0.10718
0.08767	0.05310	0.26089	0.15014	0.14340	0.15712	0.26804	0.10264	0.15718
0.12365	0.05310	0.27517	0.18187	0.17518	0.18932	0.31697	0.13187	0.20837
0.16210	0.05310	0.29289	0.20868	0.20566	0.21607	0.34074	0.16118	0.26018
0.20425	0.05310	0.30774	0.23258	0.23549	0.24001	0.34214	0.18758	0.31447
0.02738	0.08709	0.12434	0.06786	0.07523	0.07039	0.11006	0.03223	0.06052
0.05272	0.08709	0.22432	0.10906	0.10979	0.11263	0.18953	0.05781	0.10358
0.08385	0.08709	0.24204	0.14625	0.14382	0.15029	0.26106	0.08625	0.15154
0.11831	0.08709	0.25632	0.17764	0.17580	0.18187	0.31150	0.11264	0.20096
0.15505	0.08709	0.30088	0.20418	0.20639	0.20819	0.33824	0.13918	0.25086
0.19415	0.08709	0.30031	0.22726	0.23604	0.23092	0.34363	0.16226	0.30166
0.23642	0.08709	0.32068	0.24809	0.26526	0.25149	0.33213	0.18559	0.35455
0.25880	0.08709	0.33231	0.25781	0.27978	0.26111	0.32224	0.19781	0.38183
0.02839	0.10591	0.07635	0.06978	0.07536	0.07356	0.11362	0.03103	0.06235
0.05357	0.10591	0.17176	0.11023	0.10981	0.11458	0.19183	0.05523	0.10494
0.08435	0.10591	0.20490	0.14677	0.14359	0.15132	0.26199	0.08177	0.15228
0.11722	0.10591	0.25746	0.17676	0.17490	0.18097	0.31032	0.10676	0.19945
0.15335	0.10591	0.26889	0.20307	0.20514	0.20704	0.33752	0.13057	0.24861
0.19219	0.10591	0.28374	0.22620	0.23458	0.22989	0.34380	0.15370	0.29916

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
0.5 % BUTANOL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02810	0.05919	700.00000	152.44423	170.58042	148.62058	97.48496	0.00566	0.23283	0.19781
0.05400	0.05919	117.60000	189.11582	207.47033	195.20909	76.77676	0.00523	0.23460	0.16987
0.08930	0.05919	130.30000	223.26410	243.52108	205.96676	177.37896	0.00492	0.23596	0.14724
0.12240	0.05919	202.20000	247.74550	271.60061	179.48604	244.26747	0.00474	0.23680	0.13559
0.16250	0.05919	318.50000	272.03171	302.83194	171.92164	307.33944	0.00458	0.23755	0.12850
0.20440	0.05919	601.10000	293.42466	327.42375	230.17558	349.43782	0.00446	0.23816	0.12016
0.24940	0.05919	561.60000	313.33849	356.31364	299.90417	398.01965	0.00435	0.23869	0.11851
0.27400	0.05919	679.60000	323.21804	368.04781	317.86837	416.17374	0.00430	0.23894	0.11525
0.02800	0.10470	0.00000	152.26499	157.68746	176.82142	128.03522	0.00566	0.23282	0.20132
0.05320	0.10470	0.00000	188.18662	151.76995	294.31120	242.76876	0.00524	0.23456	0.15905
0.08121	0.10812	371.80000	216.37598	215.04408	239.72503	99.93608	0.00498	0.23570	0.15983
0.02850	0.10470	0.00000	153.15696	159.28809	175.78616	122.69846	0.00565	0.23287	0.20136
0.05330	0.10470	0.00000	188.30328	190.00158	220.17823	142.53914	0.00524	0.23457	0.17756
0.08470	0.10470	219.50000	219.40142	224.26172	217.92247	126.91042	0.00496	0.23581	0.16079
0.11940	0.10470	265.00000	245.72500	254.41980	190.21729	214.59063	0.00476	0.23673	0.14850
0.15630	0.10470	255.70000	268.56189	283.78412	176.84500	277.33671	0.00460	0.23745	0.14106
0.19700	0.10470	700.00000	289.87568	307.15510	229.71539	317.66595	0.00448	0.23806	0.13224
0.23800	0.10470	575.60000	308.53775	332.83062	289.69780	361.95642	0.00438	0.23856	0.12840
0.26020	0.10470	700.00000	317.75275	342.12996	301.48808	376.19379	0.00433	0.23880	0.12448
0.02800	0.13240	0.00000	152.26499	149.29370	199.76671	144.14086	0.00566	0.23282	0.20251
0.05330	0.13240	0.00000	188.30328	189.66165	200.92609	88.76624	0.00524	0.23457	0.18628
0.08315	0.13240	0.00000	218.06826	209.42614	248.84705	120.91854	0.00497	0.23577	0.16344
0.11600	0.13240	290.00000	243.39355	238.08654	236.79163	163.86921	0.00477	0.23666	0.15162
0.15160	0.13240	343.90000	265.86958	270.24263	80.71558	251.32587	0.00462	0.23737	0.14563
0.19070	0.13240	611.50000	286.78315	291.53506	194.51557	289.29637	0.00450	0.23798	0.13626
0.23000	0.13240	572.80000	305.07604	318.84471	280.03330	339.60754	0.00440	0.23847	0.13314
0.25160	0.13240	607.30000	314.24793	324.94456	279.82346	347.78477	0.00435	0.23871	0.12782

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
2.0 % BUTANOL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02825	0.05700	700.00000	152.71230	169.11221	151.38440	99.65033	0.00393	0.20900	0.17420
0.05450	0.05700	264.00000	189.69189	205.37882	196.33523	59.62758	0.00364	0.21054	0.14759
0.08650	0.05700	216.20000	220.92926	237.29465	207.65477	172.13863	0.00344	0.21161	0.12849
0.12300	0.05700	285.00000	248.14561	273.13563	95.92046	261.72309	0.00330	0.21242	0.12102
0.16200	0.05700	313.90000	271.75521	301.94321	200.41562	314.63023	0.00319	0.21306	0.11351
0.20400	0.05700	732.30000	293.23505	329.41006	262.50852	361.12048	0.00310	0.21358	0.10833
0.24900	0.05700	631.50000	313.17256	359.23396	323.64074	409.36534	0.00303	0.21403	0.10798
0.27300	0.05700	705.20000	322.82829	370.84345	339.80967	426.69185	0.00300	0.21424	0.10522
0.02840	0.12040	0.00000	152.97941	146.66372	203.07818	152.83094	0.00393	0.20901	0.17757
0.05620	0.12040	0.00000	191.62444	188.13397	213.07568	115.77373	0.00362	0.21061	0.15942
0.08310	0.12040	181.10000	218.02498	202.93609	254.98135	141.82691	0.00346	0.21152	0.14014
0.11540	0.14200	462.60000	242.97737	236.48051	203.16846	189.57397	0.00332	0.21228	0.13839
0.15030	0.14200	366.70000	265.11504	259.91825	154.01041	239.13083	0.00322	0.21288	0.12926
0.18800	0.14200	599.80000	285.43683	287.63877	235.94780	293.85680	0.00313	0.21339	0.12421
0.22680	0.14200	530.10000	303.66877	313.38134	294.83918	338.78134	0.00306	0.21382	0.12059
0.24760	0.14200	703.90000	312.59039	318.59769	293.57998	345.30414	0.00303	0.21402	0.11577

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
0.5% PROPANOL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02700	0.06260	153.80000	150.44853	168.04642	142.91296	88.76799	0.00568	0.23272	0.20006
0.05340	0.06260	151.40000	188.41980	205.66017	195.06730	83.52803	0.00524	0.23457	0.17131
0.08567	0.06260	119.80000	220.22743	237.67255	214.56103	156.18750	0.00495	0.23585	0.14872
0.12200	0.06260	186.80000	247.47803	268.66993	191.99676	236.63004	0.00474	0.23679	0.13558
0.16000	0.06260	325.90000	270.64344	301.17527	183.42499	305.79681	0.00459	0.23751	0.13127
0.20200	0.06260	700.00000	292.28321	330.27637	261.47845	357.10175	0.00447	0.23813	0.12687
0.24640	0.06260	556.30000	312.08964	357.83634	316.01376	402.11720	0.00436	0.23866	0.12441
0.27000	0.06260	495.30000	321.65326	368.58791	329.60884	418.13236	0.00431	0.23890	0.12053
0.02750	0.09470	0.00000	151.36230	162.55630	149.40018	84.19381	0.00567	0.23277	0.20365
0.05300	0.09470	0.00000	187.95287	194.51547	208.22827	122.60170	0.00524	0.23455	0.17755
0.08400	0.09470	360.10000	218.80139	227.74814	208.80271	143.64178	0.00496	0.23579	0.15989
0.11800	0.09470	268.60000	244.77044	257.64989	176.55781	222.62356	0.00476	0.23670	0.14770
0.15600	0.09470	355.70000	268.39167	286.40536	171.17459	281.10905	0.00461	0.23745	0.13892
0.19600	0.09470	432.30000	289.38927	311.50389	237.49380	325.52613	0.00448	0.23805	0.13157
0.24000	0.09470	649.50000	309.39096	341.69390	308.10440	377.54041	0.00437	0.23859	0.12972
0.26000	0.09470	515.90000	317.67214	352.94849	327.53027	395.39738	0.00433	0.23880	0.12820
0.02790	0.13200	0.00000	152.08532	156.24467	165.16226	92.74608	0.00566	0.23281	0.20639
0.05290	0.13200	0.00000	187.83577	200.04614	153.98159	159.09268	0.00524	0.23455	0.19435
0.08350	0.13200	289.20000	218.37074	212.01335	241.60240	93.70707	0.00496	0.23578	0.16436
0.11700	0.13200	277.00000	244.08397	262.84482	238.66746	260.28215	0.00477	0.23668	0.16732
0.15300	0.13200	533.10000	266.67733	272.00175	138.59791	255.46735	0.00462	0.23739	0.14564
0.19000	0.13200	591.80000	286.43534	300.39974	255.88632	310.77136	0.00450	0.23797	0.14137
0.23200	0.13200	428.30000	305.94894	333.87759	332.65170	369.96501	0.00439	0.23850	0.14169
0.02730	0.15300	0.00000	150.99814	141.02972	215.15734	155.11691	0.00568	0.23275	0.20364
0.05200	0.15300	0.00000	186.77512	181.54267	217.94130	123.40073	0.00525	0.23450	0.18842
0.08140	0.15300	0.00000	216.54291	209.28727	232.59120	44.61773	0.00498	0.23571	0.17116
0.11400	0.15300	475.30000	242.00064	231.14901	245.23980	143.85879	0.00478	0.23661	0.15592
0.14900	0.15300	700.00000	264.35613	261.68411	172.25413	234.07963	0.00463	0.23732	0.14887
0.18500	0.15300	364.60000	283.92562	290.32451	244.89270	293.37846	0.00451	0.23790	0.14445

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
1.0% PROPANOL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02800	0.06270	0.00000	152.26499	170.81408	131.19809	32.64779	0.00539	0.22944	0.19723
0.05370	0.06270	0.00000	188.76846	205.39598	196.31061	85.05234	0.00498	0.23117	0.16786
0.08640	0.06270	161.00000	220.84494	236.04546	223.24588	145.00006	0.00471	0.23243	0.14409
0.12160	0.06270	316.80000	247.20998	267.36744	194.75041	234.73043	0.00452	0.23332	0.13292
0.16100	0.06270	499.00000	271.20048	298.28313	146.62090	299.28392	0.00437	0.23405	0.12597
0.20440	0.06270	544.70000	293.42466	328.56715	250.32595	353.84310	0.00424	0.23467	0.12170
0.24800	0.06270	700.00000	312.75695	354.40946	302.39123	396.14761	0.00415	0.23517	0.11802
0.26840	0.06270	696.00000	321.02299	366.37733	325.27652	415.17158	0.00411	0.23538	0.11749
0.02762	0.09670	0.00000	151.57994	162.29703	148.15670	79.34225	0.00540	0.22940	0.20070
0.05310	0.09670	0.00000	188.06982	193.71517	208.06021	121.22672	0.00499	0.23114	0.17496
0.08450	0.09670	0.00000	219.23033	223.58173	236.89515	17.62145	0.00570	0.24582	0.16375
0.11630	0.09630	108.40000	243.60109	249.84392	216.76665	196.49320	0.00454	0.23321	0.14233
0.15660	0.09630	376.20000	268.73188	284.00484	149.37746	276.40337	0.00438	0.23398	0.13551
0.19600	0.09630	462.60000	289.38927	311.72001	245.81984	327.66209	0.00427	0.23457	0.13046
0.23900	0.09630	687.90000	308.96495	330.44134	268.21136	356.76748	0.00417	0.23508	0.12128
0.26100	0.09630	554.00000	318.07482	346.82290	309.27261	384.79761	0.00412	0.23531	0.12203
0.02810	0.13000	0.00000	152.44423	157.49752	157.65192	77.87167	0.00539	0.22945	0.20341
0.05311	0.13000	0.00000	188.08151	179.09104	238.47893	164.61208	0.00499	0.23114	0.17700
0.08340	0.13000	0.00000	218.28441	211.36302	251.58878	127.63160	0.00567	0.24531	0.17006
0.11630	0.12900	458.90000	243.60109	240.66800	225.12538	178.35394	0.00454	0.23321	0.14941
0.15250	0.12970	410.10000	266.38941	272.77156	161.49409	259.08970	0.00440	0.23391	0.14351
0.19200	0.12970	515.00000	287.42685	301.02359	255.14043	312.26943	0.00428	0.23451	0.13790
0.23300	0.12970	695.00000	306.38350	332.68814	327.21914	367.86356	0.00418	0.23501	0.13750
0.02747	0.16100	0.00000	151.30779	150.89991	171.70905	88.28419	0.00531	0.22819	0.20468
0.05210	0.16100	0.00000	186.89357	165.83739	257.52914	181.46623	0.00491	0.22988	0.17939
0.08130	0.16100	0.00000	216.45509	173.81369	304.84462	218.00896	0.00466	0.23105	0.15667
0.11300	0.16140	279.60000	241.29804	232.01199	229.24680	163.56417	0.00456	0.23313	0.15700
0.14630	0.16140	464.20000	262.76562	265.31054	205.75322	252.01598	0.00442	0.23381	0.15242
0.18340	0.16140	497.60000	283.11292	295.85857	288.34542	310.31047	0.00430	0.23439	0.14859
0.22300	0.16140	558.70000	301.98023	315.42170	312.09912	339.93912	0.00420	0.23490	0.14044

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
3.0 % PROPANOL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02820	0.06320	406.20000	152.62305	167.36712	162.27622	118.58634	0.00478	0.22158	0.18578
0.05420	0.06320	55.20000	189.34667	203.64575	203.00521	103.24977	0.00442	0.22324	0.15938
0.08650	0.06320	109.70000	220.92926	237.65254	206.14362	168.87726	0.00418	0.22442	0.14077
0.12130	0.06320	330.00000	247.00854	269.17301	158.35591	247.03933	0.00401	0.22526	0.13046
0.16230	0.06320	527.90000	271.92118	303.47360	213.71648	315.30297	0.00388	0.22599	0.12553
0.20400	0.06320	700.00000	293.23505	330.58453	270.03878	360.89441	0.00377	0.22655	0.11993
0.24860	0.06320	700.00000	313.00645	356.52004	315.99639	402.18600	0.00368	0.22704	0.11592
0.27200	0.06320	700.00000	322.43758	368.82012	335.67251	421.06368	0.00364	0.22726	0.11405
0.02840	0.10460	0.00000	152.97941	173.73742	185.32647	169.10043	0.00478	0.22160	0.20345
0.05350	0.10460	62.80000	188.53616	189.06127	217.09169	136.06482	0.00443	0.22321	0.16799
0.08470	0.10460	151.10000	219.40142	221.45918	220.34197	121.22842	0.00419	0.22437	0.15110
0.11900	0.10460	462.50000	245.45304	253.98340	170.11942	221.64891	0.00402	0.22522	0.14127
0.15640	0.10460	575.50000	268.61858	285.23793	209.91608	286.40084	0.00389	0.22590	0.13506
0.19730	0.10460	700.00000	290.02127	312.54336	269.34530	333.76224	0.00379	0.22647	0.12902
0.23700	0.10460	538.90000	308.10934	335.07010	307.48880	369.99113	0.00370	0.22692	0.12400
0.25960	0.10460	676.40000	317.51077	354.79235	350.81140	403.25685	0.00366	0.22715	0.12746
0.02780	0.12720	0.00000	151.90522	154.84210	168.19552	100.71696	0.00479	0.22155	0.19497
0.05280	0.12720	0.00000	187.71852	182.22058	224.03058	143.17116	0.00443	0.22318	0.17214
0.08210	0.12720	168.90000	217.15566	217.39754	206.16348	135.40521	0.00421	0.22429	0.15923
0.11400	0.12720	277.80000	242.00064	244.72342	178.16492	205.77121	0.00404	0.22511	0.14754
0.14950	0.12720	327.30000	264.64854	257.57878	225.84055	217.53317	0.00391	0.22578	0.13210
0.18650	0.12720	476.20000	284.68326	301.20588	269.33847	317.15477	0.00381	0.22633	0.13532
0.22660	0.12720	700.00000	303.58037	324.76101	308.95148	355.37098	0.00372	0.22681	0.12987
0.24740	0.12720	589.30000	312.50705	335.80105	325.95186	372.63020	0.00368	0.22703	0.12739
0.02710	0.16900	0.00000	150.63219	140.98993	205.86713	135.75360	0.00480	0.22148	0.19635
0.05120	0.16900	0.00000	185.82195	158.01877	265.18009	189.46072	0.00445	0.22310	0.17410
0.08044	0.16900	0.00000	215.69680	198.66994	250.41404	121.45009	0.00422	0.22424	0.16283
0.11020	0.16900	0.00000	239.30834	218.92680	260.39920	82.30593	0.00406	0.22503	0.14990
0.14360	0.16900	392.30000	261.15532	240.52654	254.69386	174.94453	0.00393	0.22568	0.13991
0.18040	0.16900	584.90000	281.57622	271.76824	135.78662	257.12576	0.00383	0.22625	0.13527
0.22200	0.16900	472.00000	301.53268	298.00228	257.75347	307.02291	0.00373	0.22676	0.12984

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

0.5 % ETHANOL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02880	0.04110	129.80000	153.68711	176.19319	153.99852	110.98754	0.00581	0.23501	0.19473
0.05516	0.04110	151.80000	190.44691	196.69672	275.60930	216.56134	0.00538	0.23679	0.14157
0.89170	0.04110	400.60000	477.10076	593.69709	637.47530	735.39407	0.00385	0.24422	0.14983
0.12700	0.04110	482.50000	250.78014	291.19899	178.43849	291.58283	0.00487	0.23906	0.14129
0.16600	0.04110	479.00000	273.95144	322.12350	255.77158	346.85643	0.00471	0.23978	0.13729
0.20400	0.04110	449.10000	293.23505	347.28879	299.97281	387.46946	0.00460	0.24033	0.13350
0.27300	0.04110	457.50000	322.82829	387.57159	366.73126	449.83666	0.00444	0.24111	0.13242
0.02805	0.09750	0.00000	152.35467	163.35235	150.08120	82.03694	0.00583	0.23493	0.20555
0.05400	0.09750	0.00000	189.11582	205.78224	100.79116	151.38386	0.00539	0.23673	0.18910
0.08567	0.09750	166.30000	220.22743	228.72632	209.89881	145.51310	0.00510	0.23799	0.16138
0.12060	0.09750	241.80000	246.53724	263.12385	70.46710	239.84311	0.00490	0.23892	0.15226
0.15860	0.09750	275.10000	269.85966	293.97369	230.32276	299.94191	0.00474	0.23965	0.14552
0.19970	0.09750	335.40000	291.18076	326.62563	305.33497	358.14676	0.00461	0.24027	0.14440
0.24260	0.09750	483.40000	310.49305	353.48177	348.95286	400.54941	0.00450	0.24079	0.14160
0.26500	0.09750	577.00000	319.67528	362.01626	354.91902	411.70853	0.00445	0.24103	0.13593

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
0.5% METHANOL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02830	0.08570	326.70000	152.80144	170.25267	99.38695	114.81709	0.00583	0.23496	0.20830
0.05470	0.08570	122.00000	189.92132	202.34829	190.18248	34.19180	0.00538	0.23677	0.17922
0.08700	0.08570	319.30000	221.34987	247.26170	185.33454	230.99494	0.00509	0.23803	0.17285
0.12220	0.08570	345.90000	247.61184	285.41636	272.39610	305.16278	0.00489	0.23895	0.17108
0.16000	0.08570	475.30000	270.64344	315.89997	316.94165	353.12587	0.00473	0.23968	0.16616
0.20120	0.08570	397.90000	291.90070	344.35963	356.54715	396.10572	0.00460	0.24029	0.16294
0.24560	0.08570	615.40000	311.75489	369.67156	387.57781	431.94172	0.00450	0.24083	0.15784
0.26830	0.08570	524.50000	320.98352	379.24083	394.66629	443.58427	0.00445	0.24106	0.15121
0.02940	0.03710	294.90000	154.73642	181.26332	101.18298	102.81079	0.00580	0.23506	0.19971
0.05580	0.03710	330.60000	191.17328	222.65627	130.75788	164.23017	0.00537	0.23682	0.17394
0.08970	0.03710	506.60000	223.59363	266.69843	212.76951	270.54452	0.00507	0.23811	0.17096
0.12640	0.03710	474.00000	250.38854	303.06980	283.28548	336.30760	0.00487	0.23904	0.17211
0.16600	0.03710	427.60000	273.95144	333.87756	327.67821	383.87965	0.00471	0.23978	0.17022
0.21230	0.03710	577.80000	297.11968	361.38880	351.72968	418.64594	0.00458	0.24044	0.15528
0.25900	0.03710	588.90000	317.26841	387.63532	387.00348	456.80371	0.00447	0.24097	0.15357
0.28260	0.03710	534.60000	326.53123	398.63366	397.14272	470.91585	0.00442	0.24120	0.14798

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
50 PPM CMC SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.26900	0.03370	449.30000	321.25964	394.29646	395.59863	466.39113	0.00525	0.24916	0.16221
0.24530	0.03370	449.80000	311.62917	382.30246	382.41457	450.28198	0.00531	0.24892	0.16584
0.20140	0.03370	520.80000	291.99643	357.48341	352.96878	415.82638	0.00544	0.24838	0.17112
0.15800	0.03370	276.50000	269.52233	330.09747	326.92218	380.92214	0.00560	0.24772	0.18391
0.11950	0.03370	292.70000	245.79289	298.53278	276.77766	329.40406	0.00579	0.24696	0.18144
0.08570	0.03370	342.40000	220.25287	265.35926	224.28042	274.36051	0.00602	0.24605	0.18526
0.05360	0.03370	309.20000	188.65238	222.58599	75.73761	174.49689	0.00637	0.24475	0.18591
0.02790	0.03370	188.30000	152.08532	179.14981	106.84447	89.08739	0.00689	0.24293	0.20792
0.02750	0.05450	221.40000	151.36230	175.27712	96.68731	123.31043	0.00691	0.24289	0.21439
0.05230	0.05450	186.20000	187.13002	214.48516	101.56078	159.43664	0.00639	0.24469	0.19039
0.08370	0.05450	266.90000	218.54321	257.22416	217.01386	258.81641	0.00604	0.24599	0.18566
0.11800	0.05450	334.70000	244.77044	291.95863	274.86123	318.17670	0.00580	0.24693	0.18136
0.15500	0.05450	369.50000	267.82269	322.75985	321.29986	367.24012	0.00561	0.24767	0.17985
0.19600	0.05450	434.40000	289.38927	346.83960	337.84294	395.76753	0.00546	0.24831	0.16275
0.23900	0.05450	405.00000	308.96495	374.32204	381.19873	438.76846	0.00533	0.24885	0.16636
0.26200	0.05450	444.30000	318.47647	386.50011	396.08863	455.81914	0.00527	0.24909	0.16437
0.02716	0.07940	291.40000	150.74216	169.91981	105.44699	117.16176	0.00692	0.24286	0.21679
0.05220	0.07940	187.20000	187.01187	204.19930	169.87942	100.76735	0.00639	0.24468	0.18966
0.08290	0.07940	324.10000	217.85168	249.17370	210.78600	242.97418	0.00605	0.24596	0.18645
0.11650	0.07940	339.00000	243.73925	287.70543	290.99682	317.57110	0.00581	0.24689	0.18953
0.15300	0.07940	378.60000	266.67733	315.26101	319.94099	354.76506	0.00562	0.24764	0.17896
0.19300	0.07940	349.90000	287.91999	343.43917	358.02649	396.83519	0.00547	0.24827	0.17590
0.23500	0.00000	1.00000	307.24888	383.93877	461.02718	504.83679	119.34810	7.00978	6.25629

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
500 PPM CMC SOLUTION

VG M/S	VL M/S	DL CM**2/S EXP'L	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02900	0.03030	263.90000	154.03849	182.21021	121.15731	64.59203	0.00819	0.25199	0.21346
0.05610	0.03030	356.00000	191.51186	231.27945	186.50187	225.50502	0.00756	0.25365	0.20820
0.08910	0.03030	321.00000	223.09897	269.97509	226.80418	279.66179	0.00716	0.25515	0.19147
0.12500	0.03030	318.00000	249.46934	303.93965	279.06186	335.16098	0.00687	0.25609	0.18649
0.16700	0.03030	431.20000	274.45494	336.35882	325.91529	365.48922	0.00664	0.25689	0.18417
0.20900	0.03030	438.10000	295.58759	362.83055	356.33615	422.09025	0.00646	0.25750	0.17679
0.25500	0.03030	409.60000	315.64301	388.16978	396.42053	457.24513	0.00631	0.25804	0.17120
0.27900	0.03030	404.20000	325.15266	400.21201	400.72278	473.86610	0.00624	0.25828	0.16883
0.02900	0.08310	207.20000	154.03849	171.73893	103.83207	90.63372	0.00819	0.25199	0.22209
0.05500	0.08310	232.20000	190.26443	215.67507	163.07779	186.16569	0.00758	0.25380	0.20754
0.08700	0.08310	343.20000	221.34987	256.49075	239.70241	262.53659	0.00718	0.25508	0.19934
0.12200	0.08310	321.00000	247.47803	290.77547	290.34025	317.99910	0.00689	0.25602	0.19324
0.16100	0.08310	354.20000	271.20048	322.17208	333.83245	366.11445	0.00667	0.25676	0.18914
0.20200	0.08310	429.90000	292.28321	349.01161	366.39727	404.16528	0.00649	0.25741	0.18325
0.24600	0.08310	486.20000	311.92236	374.54434	398.23356	440.42406	0.00633	0.25794	0.17956
0.25900	0.08310	447.90000	317.26841	359.92194	404.69591	448.71091	0.00630	0.25808	0.17634

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
1200 PPM CMC SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02950	0.02040	147.40000	154.90990	187.77665	107.59277	145.36226	0.01059	0.26567	0.23278
0.05540	0.02040	221.60000	190.71996	232.37618	173.15447	219.91714	0.00982	0.26749	0.21778
0.08800	0.02040	231.80000	222.18626	272.47503	238.96232	289.77435	0.00929	0.26880	0.21099
0.12400	0.02040	237.20000	248.80957	305.56075	274.18908	335.32994	0.00891	0.26977	0.19729
0.16350	0.02040	274.40000	272.58301	336.40301	323.35091	385.74903	0.00862	0.27054	0.19899
0.20920	0.02040	396.80000	295.68090	365.39916	356.01124	425.37352	0.00837	0.27122	0.19013
0.25440	0.02040	329.20000	315.39773	390.44223	386.94994	460.67625	0.00818	0.27176	0.18632
0.27860	0.02040	358.20000	324.99874	402.37761	399.03439	476.18014	0.00809	0.27201	0.18120
0.02850	0.07810	194.20000	153.15696	171.69099	126.53556	57.74246	0.01063	0.26557	0.23406
0.05464	0.07810	260.70000	189.85256	220.91118	200.55770	212.49384	0.00984	0.26745	0.22722
0.08700	0.07810	253.20000	221.34987	264.84539	278.73555	294.74085	0.00930	0.26877	0.22834
0.12256	0.07810	391.60000	247.85233	296.67801	309.35740	334.37601	0.00893	0.26974	0.21578
0.16200	0.07810	400.70000	271.75521	327.23781	346.45544	377.75642	0.00863	0.27051	0.20987
0.20330	0.07810	382.40000	292.90261	353.12272	373.63743	411.68139	0.00840	0.27114	0.20057
0.24900	0.07810	393.80000	313.17256	379.80454	407.57311	449.85858	0.00820	0.27170	0.19870
0.27100	0.07810	317.20000	322.04591	389.28620	413.44499	460.08732	0.00812	0.27193	0.18957

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
1800 PPM CMC SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKNER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02900	0.02450	291.20000	154.03849	186.88134	145.32327	169.68874	0.00930	0.26176	0.23547
0.05500	0.02450	206.80000	190.26443	232.77578	212.57432	246.21623	0.00887	0.26187	0.22594
0.08800	0.02450	274.20000	222.18626	273.14569	253.72240	305.94049	0.00818	0.26194	0.21898
0.12400	0.02450	305.40000	249.80957	306.25897	297.63684	348.73652	0.00771	0.26199	0.20654
0.16500	0.02450	353.30000	273.40574	337.09475	331.95042	390.49426	0.00735	0.26202	0.19691
0.20900	0.02450	412.10000	295.58759	365.05291	364.22066	428.84464	0.00705	0.26204	0.18974
0.25600	0.02450	478.00000	316.05096	391.06934	395.95885	455.19681	0.00681	0.26205	0.18604
0.28000	0.02450	427.70000	325.53678	402.86112	407.78898	480.27282	0.00671	0.26205	0.18092
0.02880	0.07190	158.50000	153.69711	179.51475	165.34388	155.35200	0.00991	0.26176	0.23927
0.05470	0.07190	252.50000	189.92132	224.00364	216.67455	228.41049	0.00888	0.26187	0.22634
0.08700	0.07190	251.00000	221.34987	265.22295	275.60787	294.86499	0.00820	0.26194	0.22091
0.12250	0.07190	281.70000	247.81228	298.35872	313.40355	340.34245	0.00773	0.26199	0.21205
0.16100	0.07190	536.20000	271.20049	327.70985	346.70099	380.30959	0.00738	0.26201	0.20417
0.20300	0.07190	416.60000	292.75931	354.52698	376.60737	416.43351	0.00709	0.26204	0.19636
0.24800	0.07190	384.50000	312.75695	375.47240	403.78451	449.45070	0.00685	0.26205	0.18868
0.27100	0.07190	469.30000	322.04591	391.74603	419.39904	466.88802	0.00675	0.26205	0.18815

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
2300 PPM CMC SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02900	0.06600	148.10000	154.03849	181.54083	171.04503	173.45537	0.01018	0.26338	0.24181
0.05740	0.06600	211.00000	192.96513	230.89087	235.20595	248.70608	0.00897	0.26302	0.23191
0.08700	0.06600	213.60000	221.34987	266.59816	277.09470	298.70173	0.00831	0.26279	0.22326
0.12200	0.06600	269.50000	247.47903	299.15007	313.10937	342.41181	0.00780	0.26260	0.21380
0.16100	0.06600	281.50000	271.20049	329.04848	347.42295	383.30763	0.00741	0.26244	0.20629
0.20200	0.06600	314.70000	292.28321	355.69662	378.00784	419.57031	0.00711	0.26230	0.19999
0.24700	0.06600	385.20000	312.34021	381.13087	407.25178	454.03949	0.00685	0.26218	0.19450
0.27000	0.06600	400.80000	321.65326	392.42623	418.50835	468.32680	0.00674	0.26212	0.18953
0.02930	0.02270	209.20000	154.56254	169.45509	180.70502	203.18121	0.01016	0.26338	0.24639
0.05500	0.02270	211.40000	190.25443	233.16102	213.56637	247.81695	0.00904	0.26304	0.22669
0.08770	0.02270	258.60000	221.93602	272.90454	259.82709	303.49488	0.00829	0.26279	0.21775
0.12400	0.02270	259.80000	248.80957	307.04874	303.56369	353.74481	0.00778	0.26259	0.21254
0.16300	0.02270	250.40000	272.30764	336.38287	334.18724	391.83344	0.00740	0.26243	0.20183
0.20700	0.02270	385.30000	294.65114	364.29322	363.32723	428.38961	0.00708	0.26228	0.19155
0.25400	0.02270	406.70000	315.23399	390.18736	392.69974	463.23991	0.00691	0.26216	0.18429
0.28000	0.02270	496.50000	325.53678	403.24918	408.15287	481.15022	0.00669	0.26210	0.18195

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

0.05 M NACL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02900	0.04360	1.00000	154.03849	191.28236	227.87955	244.25298	473.13116	9.39212	9.39212
0.05570	0.04360	290.30000	191.06016	224.41348	147.08317	197.80340	0.00553	0.23884	0.18701
0.08920	0.04360	382.70000	223.18157	266.52134	233.16964	278.18111	0.00522	0.24014	0.18055
0.12560	0.04360	426.50000	249.86447	301.10752	284.59539	333.70596	0.00501	0.24108	0.17521
0.16570	0.04360	499.30000	273.78796	332.03600	326.57918	380.25787	0.00485	0.24183	0.17096
0.20860	0.04360	455.20000	295.40078	359.99212	362.98969	420.91324	0.00472	0.24246	0.16785
0.25540	0.04360	472.80000	315.80631	386.38142	396.37278	458.36379	0.00460	0.24300	0.16546
0.28940	0.04360	507.50000	329.10345	402.93637	414.50045	480.39963	0.00454	0.24334	0.16079
0.02820	0.08500	232.60000	152.62305	165.81167	150.89473	90.42148	0.00600	0.23695	0.20556
0.05420	0.08500	230.20000	189.34667	210.19087	111.63896	164.66191	0.00555	0.23877	0.19045
0.08600	0.08500	316.40000	220.50701	250.61963	216.77067	246.64872	0.00525	0.24004	0.18065
0.12130	0.08500	374.00000	247.00854	286.54287	279.01112	309.27239	0.00503	0.24098	0.17574
0.15960	0.08500	373.10000	270.41997	319.93598	333.06573	364.40371	0.00487	0.24173	0.17628
0.20100	0.08500	470.10000	291.80492	347.96551	369.06562	405.09722	0.00474	0.24236	0.17254
0.24500	0.08500	500.40000	311.50335	372.63174	397.34764	438.83341	0.00463	0.24289	0.16653
0.28730	0.08500	522.90000	328.31345	392.43125	417.30101	464.58220	0.00454	0.24332	0.15852

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS

0.2 M NACL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02900	0.03270	911.00000	154.03849	175.25352	191.89960	166.06643	0.00601	0.23554	0.18404
0.05800	0.03270	311.50000	193.62844	224.34225	177.46848	135.77726	0.00553	0.23743	0.16437
0.08920	0.03270	357.00000	223.18157	265.46280	182.55780	259.23487	0.00525	0.23859	0.16358
0.12660	0.03270	401.50000	250.51922	302.93274	270.51254	331.17561	0.00504	0.23954	0.16560
0.16550	0.03270	369.10000	273.67886	332.90865	314.31804	377.74922	0.00488	0.24025	0.16193
0.21170	0.03270	480.90000	296.84231	362.76677	354.58254	421.82927	0.00474	0.24091	0.15847
0.25910	0.03270	527.80000	317.30883	389.93424	393.78999	462.45789	0.00462	0.24144	0.16084
0.28260	0.03270	624.70000	326.53123	400.50451	400.78724	474.71624	0.00457	0.24167	0.15200
0.02830	0.06660	145.10000	152.80144	159.41339	207.65555	178.82369	0.00603	0.23547	0.19017
0.05380	0.06660	167.30000	188.88439	206.42929	187.83598	40.94516	0.00558	0.23722	0.17584
0.08570	0.06660	224.70000	220.25287	251.40680	182.15444	237.57239	0.00528	0.23849	0.17118
0.12050	0.06660	278.30000	246.46976	287.93927	262.80959	307.04489	0.00507	0.23940	0.16837
0.15850	0.06660	354.70000	269.80350	319.64674	313.60125	358.78857	0.00490	0.24014	0.16592
0.19910	0.06660	342.20000	290.89177	347.85118	353.51500	401.58682	0.00477	0.24074	0.16370
0.24200	0.06660	376.50000	310.23942	373.18189	386.31099	438.11339	0.00466	0.24126	0.16083
0.26500	0.06660	421.60000	319.67528	385.52578	401.95504	455.61478	0.00461	0.24150	0.15957

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
0.5 M NACL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKKER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02830	0.10060	193.10000	152.80144	159.91423	175.93569	125.28546	0.00613	0.23683	0.20464
0.05390	0.10060	140.60000	189.00018	191.07785	224.84516	150.41980	0.00568	0.23861	0.17880
0.08500	0.10060	345.80000	219.65756	237.85312	128.62998	204.09681	0.00538	0.23985	0.17318
0.11900	0.10060	425.30000	245.45304	278.25876	265.83929	292.28496	0.00516	0.24076	0.17323
0.15400	0.10060	464.70000	267.25125	308.24598	313.60300	341.56505	0.00501	0.24146	0.16974
0.19100	0.10060	426.20000	286.93196	335.37527	353.06244	383.55247	0.00488	0.24204	0.16756
0.23300	0.10060	484.50000	306.38350	360.71169	385.22070	420.02919	0.00476	0.24257	0.16336
0.25700	0.10060	459.30000	316.45783	373.94027	401.90296	438.85460	0.00471	0.24283	0.16154
0.02895	0.04490	132.30000	153.95080	173.41949	174.52943	141.69493	0.00612	0.23690	0.19327
0.05490	0.04490	132.30000	190.15020	225.52798	183.93663	216.70375	0.00567	0.23866	0.19470
0.05490	0.04490	168.30000	190.15020	214.71406	188.78504	80.12398	0.00567	0.23866	0.16966
0.08710	0.04490	283.40000	221.43380	261.02883	200.75818	258.20936	0.00536	0.23992	0.17225
0.12300	0.04490	287.00000	248.14561	296.37328	265.69648	320.40625	0.00514	0.24085	0.16783
0.16200	0.04490	366.20000	271.75521	328.19334	317.64018	372.48219	0.00498	0.24159	0.16748
0.20300	0.04490	353.10000	292.75991	354.03589	346.29249	408.09941	0.00484	0.24220	0.15874
0.24700	0.04490	386.50000	312.34021	379.30281	379.06118	444.52200	0.00473	0.24273	0.15539

COMPARISON OF DISPERSION COEFFICIENT DATA WITH DIFFERENT CORRELATIONS
1.0 M NACL SOLUTION

VG M/S	VL M/S	DL CM**2/S EXPTL	DLD CM**2/S DECKWER	DLB CM**2/S BAIRD-RICE	DLJ CM**2/S JOSHI	DLF CM**2/S FIELD-DAVIDSON	DVS M	UT M/S	US M/S
0.02890	0.05310	160.50000	153.86300	167.30572	196.95606	168.79139	0.00614	0.23690	0.19012
0.05497	0.05310	252.90000	190.23018	211.63307	191.84983	44.18331	0.00569	0.23867	0.17160
0.08767	0.05310	325.60000	221.91096	255.18625	149.57730	235.37058	0.00538	0.23994	0.16473
0.12370	0.05310	355.50000	248.61076	292.24925	250.20644	308.67590	0.00516	0.24088	0.16222
0.16210	0.05310	370.80000	271.81055	323.18709	301.53905	359.52124	0.00500	0.24161	0.15878
0.20430	0.05310	465.70000	293.37728	351.75165	343.42265	403.36692	0.00486	0.24223	0.15602
0.02840	0.12460	167.90000	152.97941	163.47386	64.97109	98.87657	0.00616	0.23685	0.21232
0.05360	0.12460	215.80000	188.65238	188.42147	216.87169	129.72121	0.00570	0.23860	0.18592
0.08440	0.12460	361.40000	219.14468	232.74249	155.32936	199.65683	0.00540	0.23984	0.17818
0.11700	0.12460	355.40000	244.08397	261.05782	210.54952	249.75334	0.00519	0.24073	0.16607
0.15340	0.12460	403.40000	266.90720	295.95161	292.24640	316.25573	0.00503	0.24146	0.16396
0.19220	0.12460	444.30000	287.52561	325.29100	339.77219	363.99869	0.00489	0.24207	0.16110

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2. BATCH BUBBLE COLUMN

2.1 Introduction

The effect of the physical properties of the liquid phase on the hydrodynamics of bubble columns is not clearly understood. While Akita and Yoshida,[2.1] Hikita et al.,[2.2] Bach and Pilhofer,[2.3] Ueyama and Miyauchi,[2.4] Schugerl et al.,[2.5] and Oels et al.[2.6] have studied the effect of physical properties, a clear picture of the hydrodynamics, especially of the bubble dynamics, has yet to emerge.

Aqueous solutions of alcohols have been used to lower the liquid surface tension. The operation of bioreactors and fermenters involves the use of alcohol solutions in the presence of other additives. It is desirable to know the hydrodynamics of an SRC-II reactor, where the surface tension of the liquid phase is believed to be very low. Akita and Yoshida,[2.1] Hikita et al.,[2.2] and Kim et al.[2.7] have studied systems with a wide range of surface tensions (0.0124-0.0796 N/m) and have developed correlations for the gas holdup which show only a slight dependence on the surface tension. Botton et al.[2.8] and Miller,[2.9] using continuous flow systems, have found no effect of surface tension on gas holdup. Schugerl et al.[2.5] and Oels et al.[2.6] have studied aqueous solutions of alcohols and reported a significant increase in gas holdup as the surface tension is decreased. The SRC-II reaction medium may behave like aqueous solutions of higher alcohols and therefore the hydrodynamics of these alcohol solutions at higher gas velocities have been studied in the present work. Schugerl et al.[2.5] have studied the hydrodynamics of aqueous alcohol solutions in the bubbly flow regime. In the experiments reported here, the dynamic gas disengagement technique along with the determination of gas holdup are used to gain better insight about the bubble rise velocities and relative holdups of small and large bubbles. It is easy to obtain this information using a transparent batch bubble column.

Akita and Yoshida[2.1] and Hikita et al.[2.2] have observed a decrease in gas holdup with an increase in viscosity in experiments which covered viscosities over the range of 0.001 to 0.070 kg/m·sec. All of these experiments were carried out in an 0.152 m diameter column. The hydrodynamics of a bubble column operating in the churn-turbulent regime is more complex than that in the bubbly flow regime and is expected to depend on the column diameter. When the viscous forces predominate and the liquid has a coalescing tendency, the bubbles try to reach the equilibrium bubble size by coalescing. As a rule of thumb, the bubble size in the column is independent of the initial bubble size if the perforated plate has holes of diameter greater than 10^{-3} m. Thus, the bubbles grow to reach the dynamic equilibrium size as they move up the column. For small diameter columns (diameter up to 0.15 m), slugs are formed and the transition occurs from bubbly to slug flow. For a column diameter of 0.305 m, as used in the present work, the transition is from bubbly to churn-turbulent flow and the bubble clusters coalesce to form large, fast rising bubbles (but not slugs). The study of the hydrodynamics of large fast rising bubbles in the presence of small bubbles is only reported by Vermeer and Krishna.[2.10] Hills and Darton[2.11] found the rise velocities of large bubbles to be as high as 1.0 m/s. Schumpe[2.12] studied the hydrodynamics of CMC solutions in the presence of large irregular bubbles, but slugs formed due to the small column diameter. In this work, glycerine and CMC solutions are used to study the effect of viscosity on gas holdup and the hydrodynamics of the fast rising bubbles in Newtonian and non-Newtonian solutions.

The effect of solids on the holdup is demonstrated by the use of coal and sand of various concentrations and sizes added to an air-water system. The main objective behind analyzing air-water-solid data is to have a reference for air-CMC or glycerine solution-solid systems.

The physical properties of the aqueous alcohol, CMC, and glycerine solutions are listed in Tables 2.1-2.3. Properties of the coal slurries and the coal and sand particles are given in Tables 2.4-2.6.

TABLE 2.1

PHYSICAL PROPERTIES OF ALCOHOL SOLUTIONS

Alcohol	Concentration wt%	Density kg/m^3	Surface Tension N/m	Viscosity kg/m·s
Methanol	1.0	1006	0.06674	0.00100
	5.0	1000	0.06143	0.00100
Ethanol	1.0	995	0.06608	0.00100
n-Propanol	0.5	999	0.06416	0.00100
	1.0	998	0.06091	0.00100
	1.5	997	0.05615	0.00100
n-Butanol	0.5	999	0.06319	0.00100
	1.6	996	0.04823	0.00100

TABLE 2.2

PHYSICAL PROPERTIES OF GLYCERINE SOLUTIONS

Glycerine Concentration vol %	Density kg/m^3	Surface Tension N/m	Viscosity kg/m·s
10	1039	0.05860	0.00170
20	1071	0.05800	0.00221
30	1096	0.05760	0.00302
40	1124	0.05790	0.00423
50	1147	0.05890	0.00666
60	1168	0.05920	0.01140
70	1194	0.06720	0.02060
80	1216	0.06530	0.05040
85	1227	0.06450	0.05900
90	1228	0.06380	0.07620
95	1243	0.06410	0.14100
99.5	1249	0.06450	0.24600

TABLE 2.3

PHYSICAL PROPERTIES OF CMC SOLUTIONS

Approximate CMC Concentration wt%	Density kg/m^3	Surface Tension N/m	Consistency Index kg/m·s	Flow Behavior Index
* 500 ppm	996	0.07090	0.00266	1.000
*1000 ppm	996	0.06990	0.00455	1.000
0.05	1000	0.07030	0.00781	1.000
0.10	1001	0.06670	0.0266	1.000
0.15	1001	0.06800	0.0590	0.975
0.20	1002	0.07030	0.0943	0.067
0.25	1002	0.07130	0.161	0.943
0.30	1001	0.07000	0.232	0.952
0.40	1002	0.06500	0.738	0.931
0.50	1008	0.07210	1.728	0.913

*These solutions are prepared differently to yield different viscosities compared to 0.05 wt%, 0.1 wt% CMC solutions.

TABLE 2.4

PHYSICAL PROPERTIES OF COAL SLURRIES

Coal Concentration wt%	Slurry Density kg/m^3	Surface Tension N/m	Viscosity kg/m·s
12	1027	0.07095	0.00170
18	1047	0.07069	0.00202
25	1068	0.07084	0.00270
30	1085	0.07089	0.00367

TABLE 2.5

PHYSICAL PROPERTIES OF COAL PARTICLES

Coal Density: 1373 kg/m^3

Particle Size Distribution, wt%

on 80 mesh	0.0
thru 80 on 200 mesh	6.3
thru 200 on 325 mesh	21.1
thru 325 on 625 mesh	35.2
thru 625 mesh	37.4

TABLE 2.6

PHYSICAL PROPERTIES OF SAND PARTICLES

Sand Density: 2650 kg/m^3

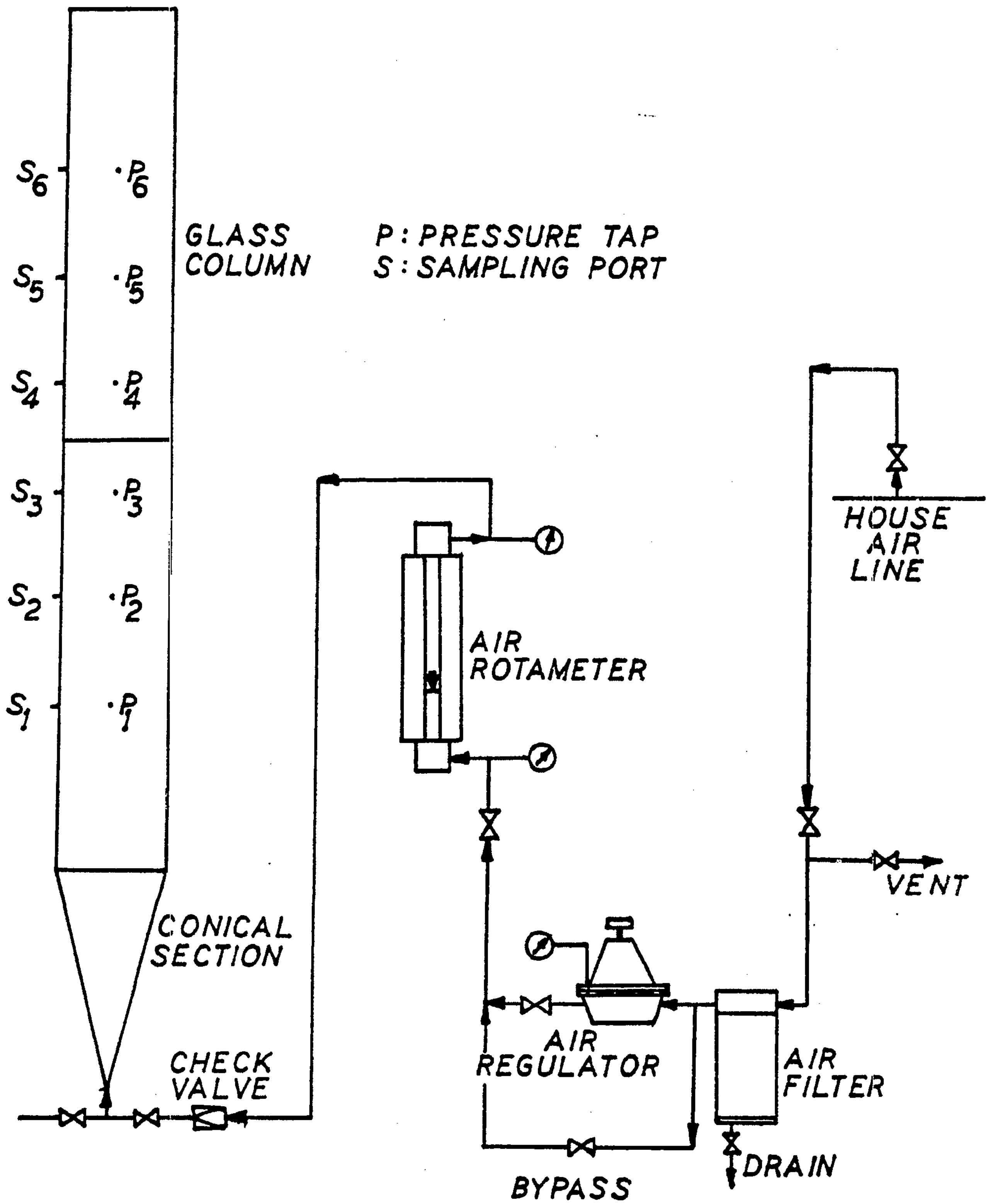
Sand Size Range $m \times 10^{-6}$	Concentrations Used in the Bubble Column, wt%
74-149	18, 38, 47
250-297	10, 20, 30
590-710	10, 20

2.2 Experimental Setup and Procedure

A schematic diagram of the experimental setup is shown in Figure 2.1. The glass column used in these experiments is 0.305 m in diameter and 2.44 m tall. The conical section below the column is 0.610 m in height and is packed with Berl saddles. This section acts as a calming section to give a uniform gas distribution. A perforated plate having a large number of 1.6×10^{-3} m diameter holes serves as a gas distributor and separates the cone from the column. Air is used as the gas for all experiments. From the house line, the air passes through a filter, a pressure regulator, and a rotameter before entering the column. Superficial gas velocities of up to 0.38 m/sec can be achieved.

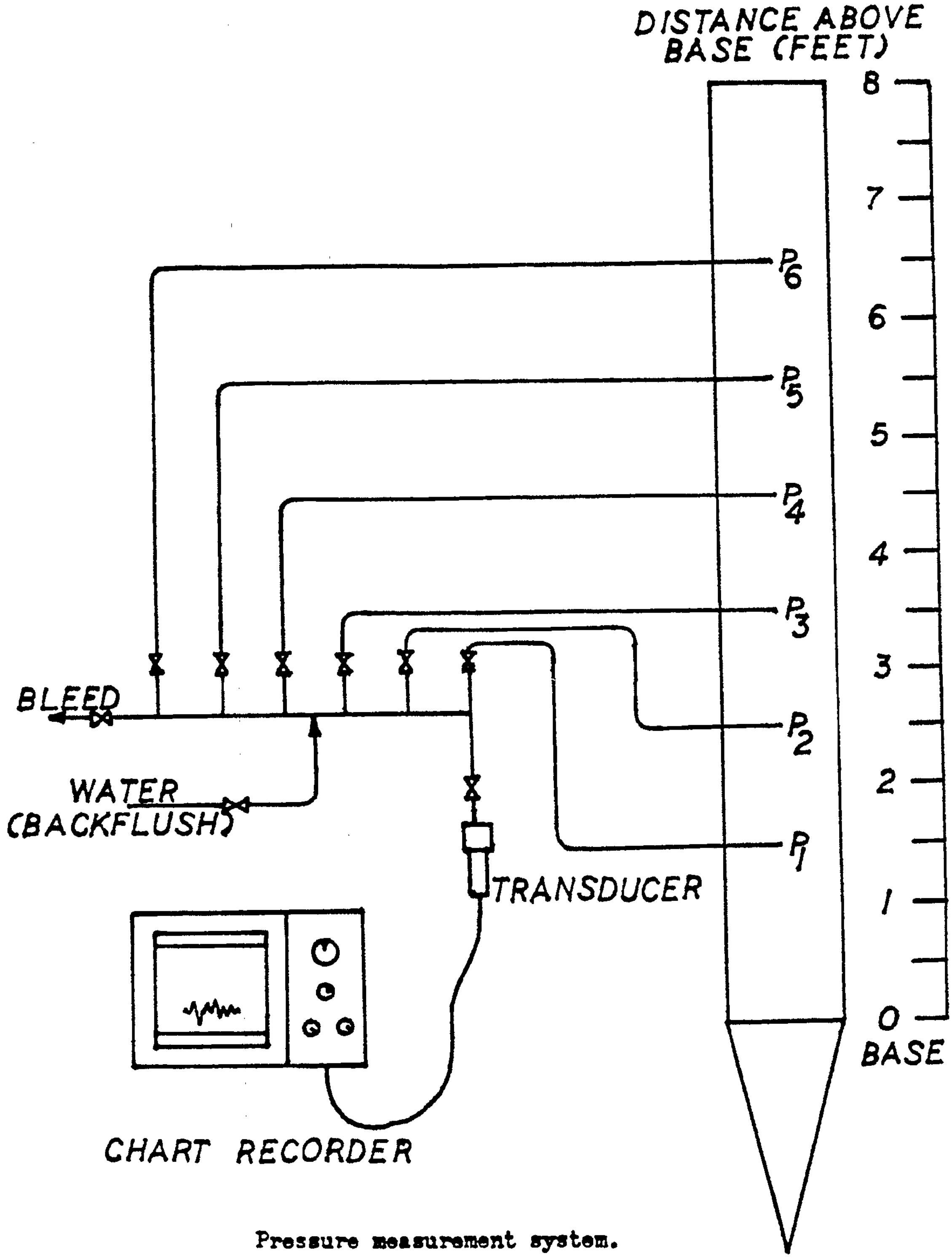
Pressure taps and sampling ports are located along the length of the column as shown. Pressure is measured using a transducer and chart recorder and is used in the calculation of holdup. The pressure measurement system is shown in Figure 2.2. The sampling ports allow samples to be taken directly from the column. The sampling tubes extend to the column center and have openings along the radius of the column to take a representative sample. These are used to determine the solid fraction present in slurry systems as a function of height. Solid-liquid samples are weighed, dried in an oven to remove the liquid, and then reweighed. From the weights before drying and after drying, the ratio of solid to liquid can be found.

For each system studied, the liquid (or slurry) density, surface tension, and viscosity are measured. Densities are measured using a pycnometer. A Fisher Surface Tensiomat (Model 21) and a Brookfield Synchro-Lectric Viscometer (Model LVT) are used to measure the surface tension and viscosity, respectively.



Experimental setup.

Figure 2.1



Pressure measurement system.

Figure 2.2

The dynamic gas disengagement technique requires the measurement of the decline of the aerated liquid height with time when the gas flow to the column is suddenly stopped. This is done with the use of a video tape recorder (VTR), a color monitor and a camera. Frame-by-frame analysis is possible on a VTR with stop-action; by knowing the number of frames per second, one can determine the height as a function of time.

2.3 Analysis of Raw Data

2.3.1 Holdups

The pressure is measured at each tap along the length of the column and converted to absolute pressure by hydrostatic correction. For both the two- and three-phase systems studied, the pressure is found to vary linearly with height. Therefore, the pressure gradient can be determined by fitting a straight line through a plot of pressure vs. height.

For the gas-liquid systems, the pressure gradient is given by:

$$-\frac{dP}{dx} = \varepsilon_L \rho_L + \varepsilon_G \rho_G \quad (2.3.1)$$

Since ρ_G is so small compared to ρ_L and sum of the gas and liquid holdups must be 1.0, equation (2.3.1) can be rewritten as:

$$\varepsilon_G = 1 + \frac{1}{\rho_L}\frac{dP}{dx} \quad (2.3.2)$$

The use of equation (2.3.1) or (2.3.2) assumes no local variation of gas holdup and negligible frictional pressure drop.

For gas-liquid-solid systems, the pressure gradient is given by:

$$-\frac{dP}{dx} = \varepsilon_L \rho_L + \varepsilon_s \rho_s + \varepsilon_G \rho_G \qquad (2.3.3)$$

As before, the term $\varepsilon_G \rho_G$ can be neglected and Equation (2.3.3) rearranged to give:

$$-\frac{dP}{dx} = \varepsilon_L \left(\rho_L + \frac{\varepsilon_s}{\varepsilon_L} \rho_s\right) \qquad (2.3.4)$$

Sampling data provides the ratio of solid holdup to liquid holdup.

$$\frac{\text{solid volume}}{\text{liquid volume}} = \frac{\varepsilon_s}{\varepsilon_L} \equiv C \qquad (2.3.5)$$

The last two equations can be combined to give ε_L.

$$\varepsilon_L = \frac{-dP/dx}{\rho_L + C \cdot \rho_s} \qquad (2.3.6)$$

From equation (2.3.5):

$$\varepsilon_s = C \cdot \varepsilon_L \qquad (2.3.7)$$

Finally, ε_G is calculated by knowing that the sum of the three holdups is unity.

$$\varepsilon_G = 1 - \varepsilon_s - \varepsilon_L \qquad (2.3.8)$$

2.3.2 Dynamic Gas Disengagement

Measurement of the gas holdup during gas disengagement (i.e., after the gas flow to the aerated bubble column is cut off) can provide some information about the size and distribution of the gas bubbles.

The following assumptions will be made to simplify the analysis.

1. The initial bubble size distribution is axially homogeneous.
2. No significant bubble coalescence or breakup occurs during disengagement.

In the gas-liquid dispersions, any sized bubble will have an equal chance of being at any point in the aerated liquid height at the point of gas cut off. Pictorally the liquid dispersion at the point of cut off is represented in Figure 2.3. The large bubbles which rise much faster than small bubbles will be the first to disengage. All bubbles of size d_b rising with a rise velocity U_{br} will disengage in a time t_{max} where,

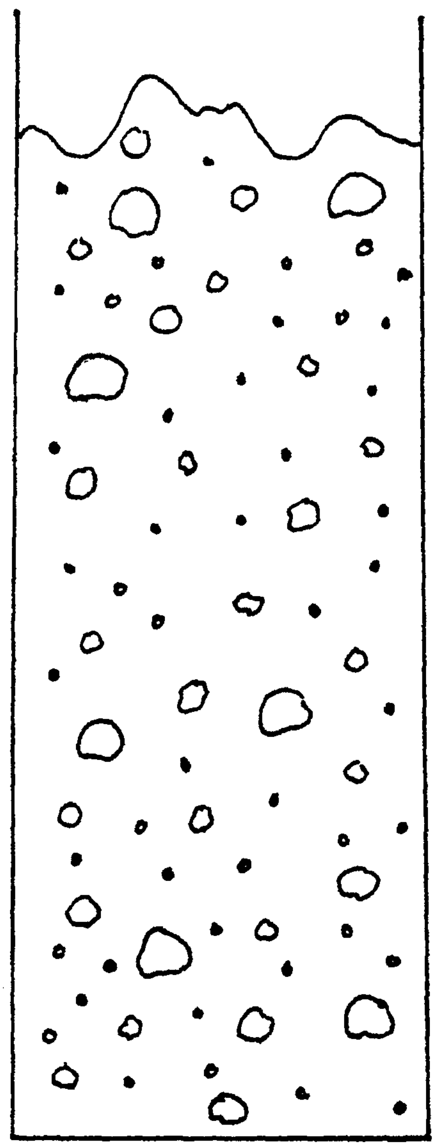
$$t_{max}(d_b) = \frac{h(t)}{U_{br}(d_b)} \qquad (2.3.9)$$

and, $h(t)$ is the height of the dispersion at time $t = t_{max}$.

At any time t, the fraction of bubbles of size d_b still present in the dispersion after an elapsed time t is given by $(1 - t/t_{max})$.

Now we develop the relation between dynamic gas holdup $\varepsilon_G(t)$ and the static holdup $\varepsilon_G(o)$ for uniform sized bubbles, two sized bubbles and n sized bubbles.

For the case of uniform sized bubbles, the gas holdup will decline according to



Dynamic gas disengagement: dispersion just prior to gas shut-off.

Figure 2.3

$$\varepsilon_G(t) = \varepsilon_G(o)\ (1-t/t_{max}) \qquad (2.3.10)$$

where, $t_{max} = \frac{hi}{U_{br}}$ and hi = unaerated liquid height. By plotting $\varepsilon_G(t)$ vs t one can determine t_{max} and, therefore, U_{br}.

When there are two classes of bubbles, large and small, $\varepsilon_G(t)$ will be given by

$$\varepsilon_G(t) = \varepsilon_{G,\ell}\ (1 - \frac{t}{t_{max,\ell}}) + \varepsilon_{G,s}\ (1 - \frac{t}{t_{max,s}}) \qquad (2.3.11)$$

when both size bubbles are disengaging and by

$$\varepsilon_G(t) = \varepsilon_{G,s}\ (1 - \frac{t}{t_{max,s}}) \qquad (2.3.12)$$

when all of the large bubbles have disengaged. The rise velocity of the small bubbles is calculated from

$$t_{max,s} = \frac{hi}{U_{br,s}} \qquad (2.3.13)$$

For the large bubbles, $t_{max,\ell}$ is given by

$$t_{max,\ell} = \frac{h(t)}{U_{br,\ell}} \qquad (2.3.14)$$

where h(t) is defined at the time when the expression for $\varepsilon_G(t)$ switches from equation (2.3.11) to (2.3.12), i.e. when the last large bubble disengages. From the slope and intercept of equation (2.3.12), $\varepsilon_{G,s}$ and $U_{br,s}$ can be calculated; with this information and the slope and intercept of equation (2.3.11), $\varepsilon_{G,\ell}$ and $U_{br,\ell}$ are calculated.

This analysis can be extended to n distinct bubble sizes for which $\varepsilon_G(t)$ will be given by

$$\varepsilon_G(t) = \sum_{i=1}^{n} \varepsilon_{G,i} \left(1 - \frac{t}{t_{max,i}}\right) \tag{2.3.15}$$

when all bubble sizes are disengaging, by

$$\varepsilon_G(t) = \sum_{i=1}^{n-1} \varepsilon_{G,i} \left(1 - \frac{t}{t_{max,i}}\right) \tag{2.3.16}$$

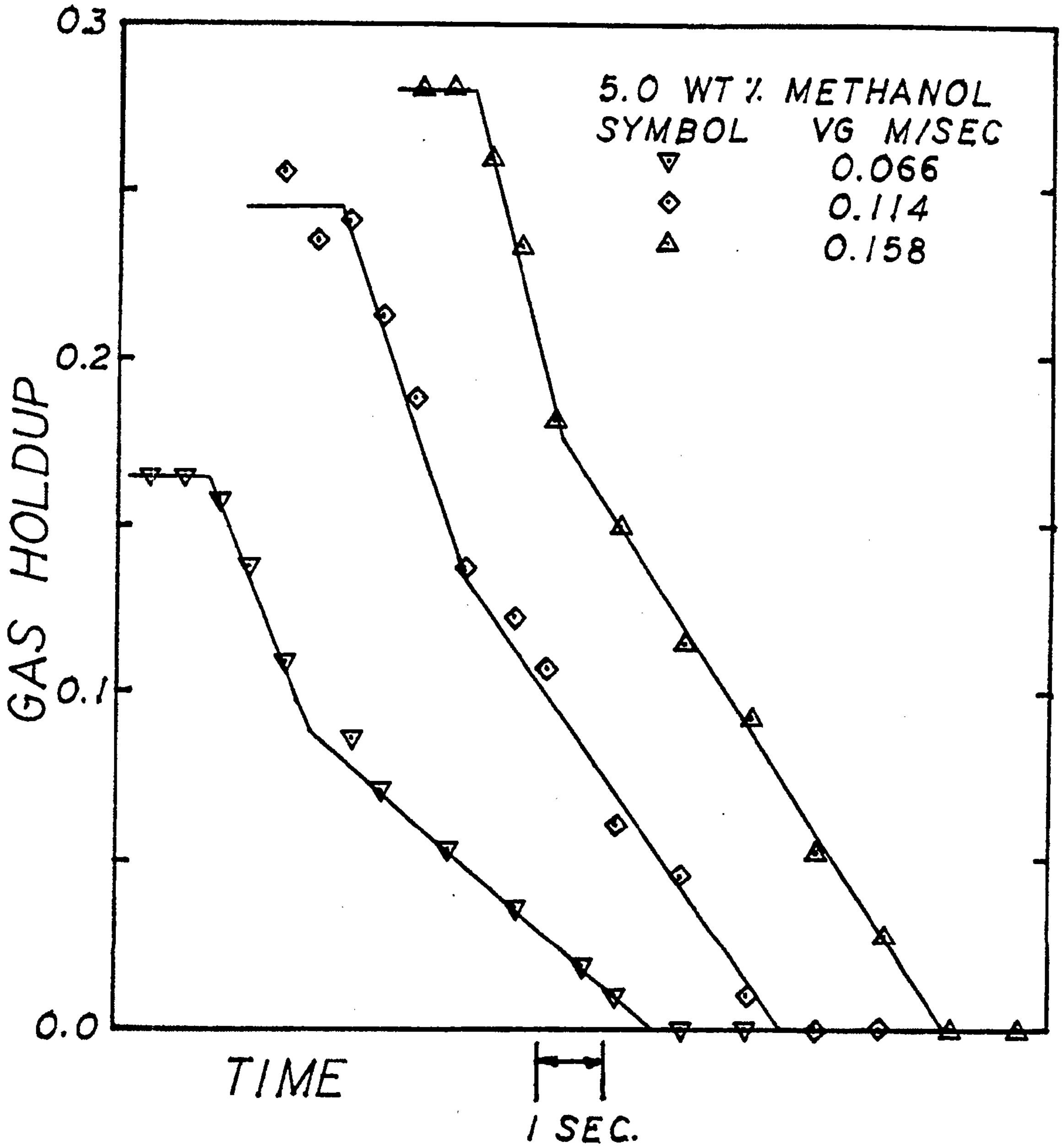
when the nth sized bubbles have disengaged and so on until all bubble sizes have disengaged.

An illustrative plot of $\varepsilon_G(t)$ vs. t is shown in Figure 2.4 for the 5.0 wt% methanol system. The sharp break in the curves clearly indicates the existence of two distinct bubble sizes.

2.4 Results and Discussion

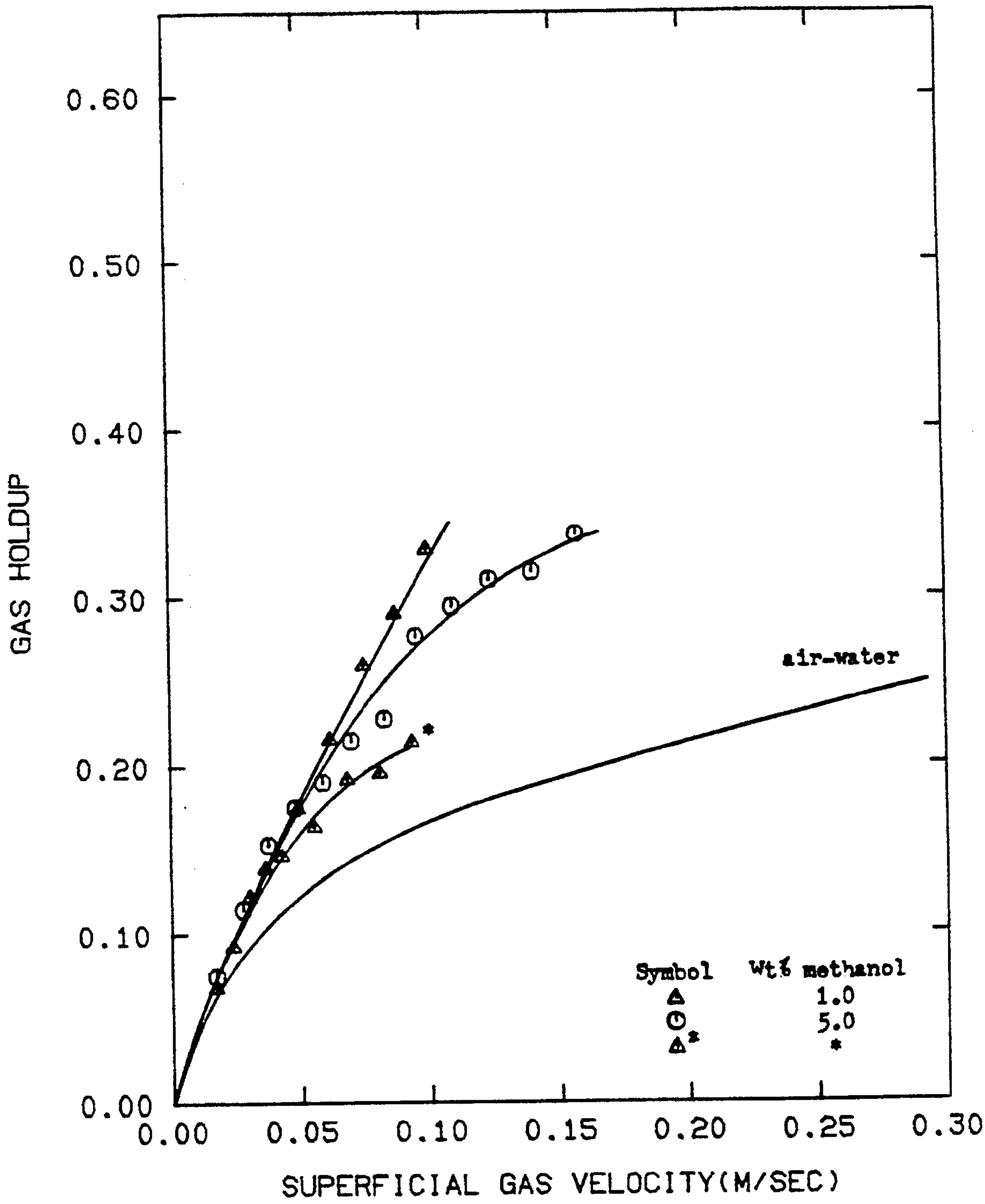
2.4.1 Effect of Addition of Alcohols

Gas holdup increases with an increase in gas velocity and behaves completely different from air-water. The gas holdup can be two times that for air-water as evident from Figures 2.5 to 2.8 which depict a comparison between gas holdup data for alcohol solutions and for air-water. The gas holdup data for alcohols is compared with many existing correlations in Tables A.2.1 to A.2.8. Though Akita and Yoshida[2.1] and Hikita et al.[2.2] have included the effect of surface tension in their gas holdup correlations, their correlations fail to predict the observed values of high gas holdup. The semitheoretical equation proposed by Mersmann[2.13] also fails to explain this high gas holdup . The equation proposed by Schugerl



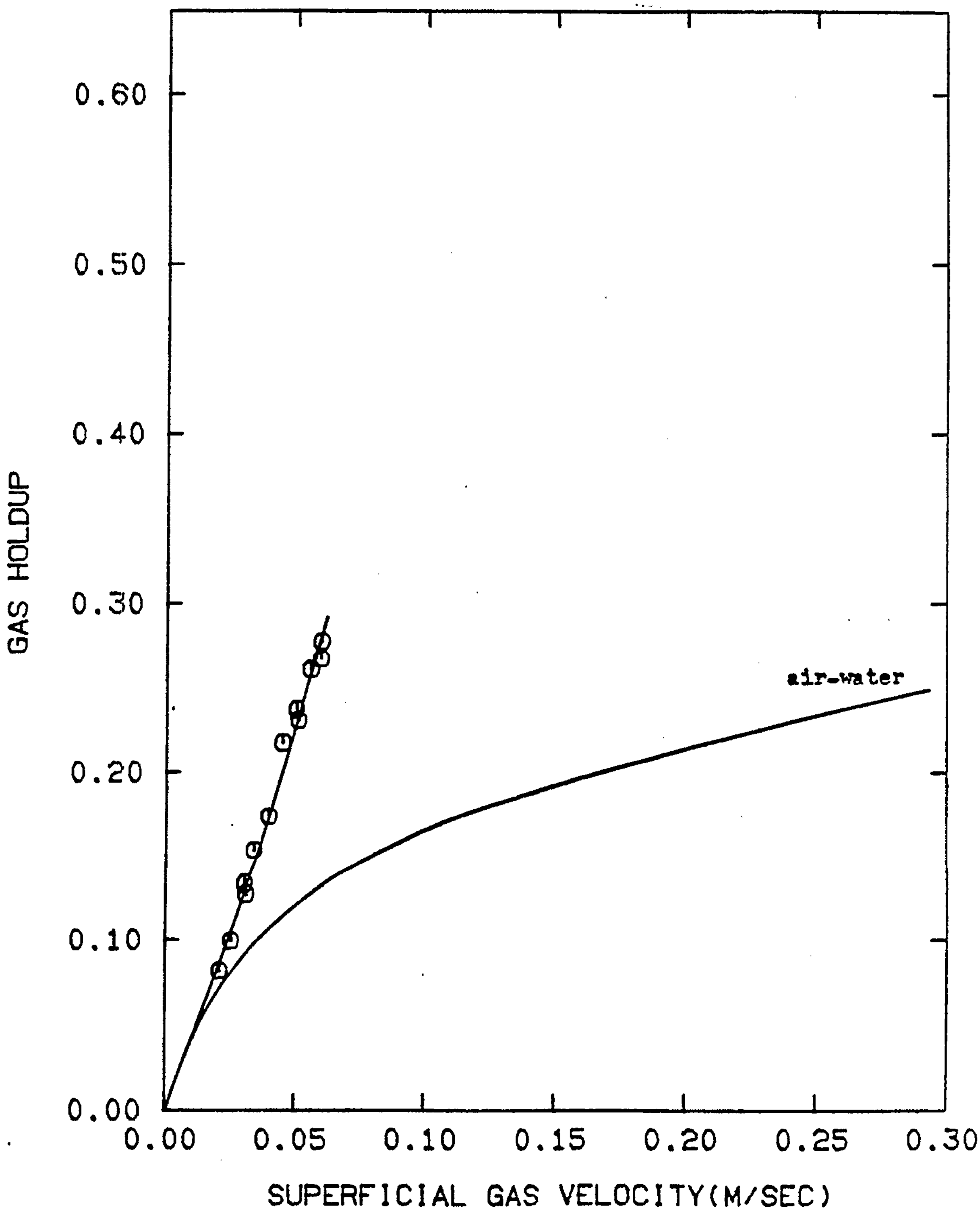
Dynamic gas disengagement: gas holdup vs time for 5.0 wt% methanol

Figure 2.4



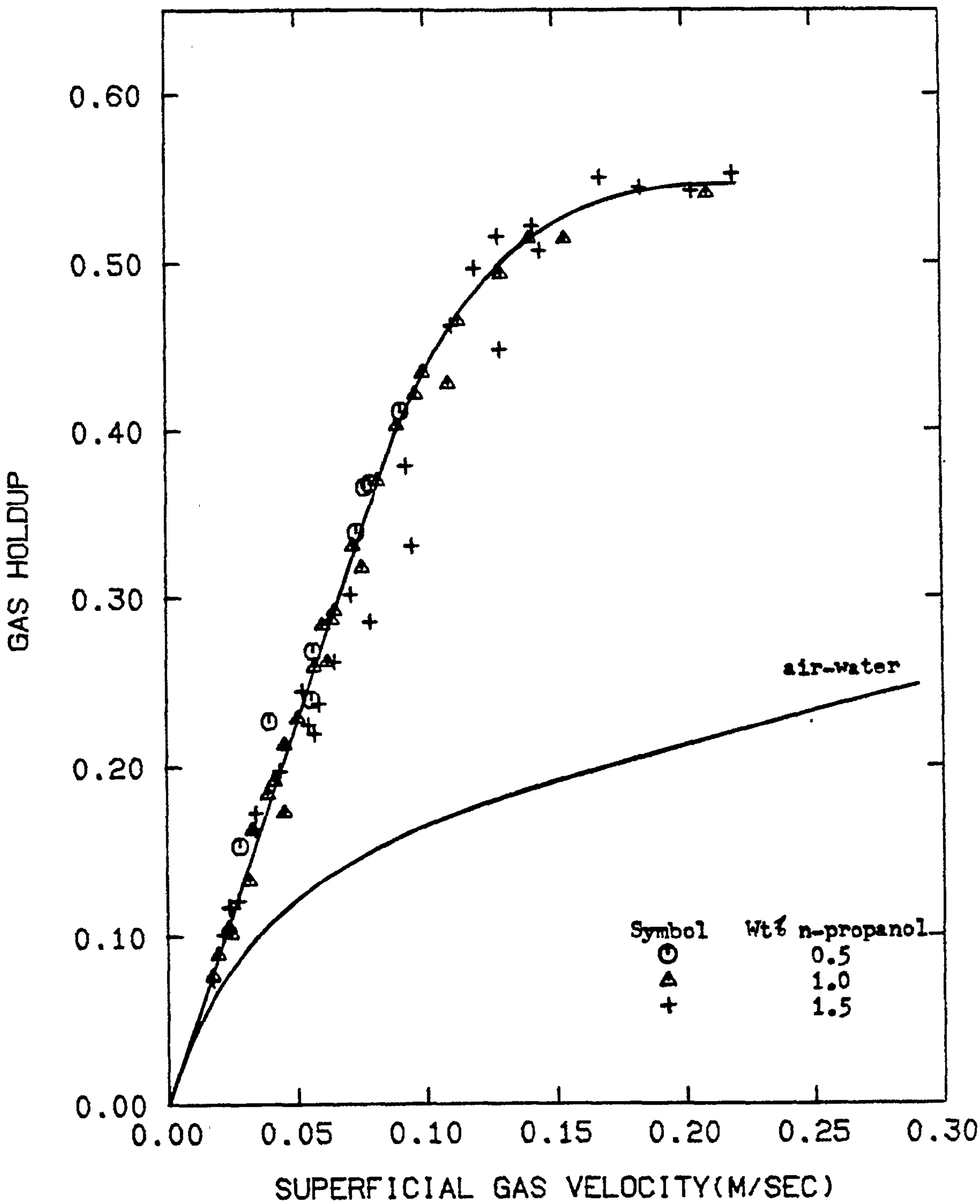
GAS HOLDUP VS.SUPERFICIAL GAS VELOCITY FOR METHANOL-WATER.

Figure 2.5



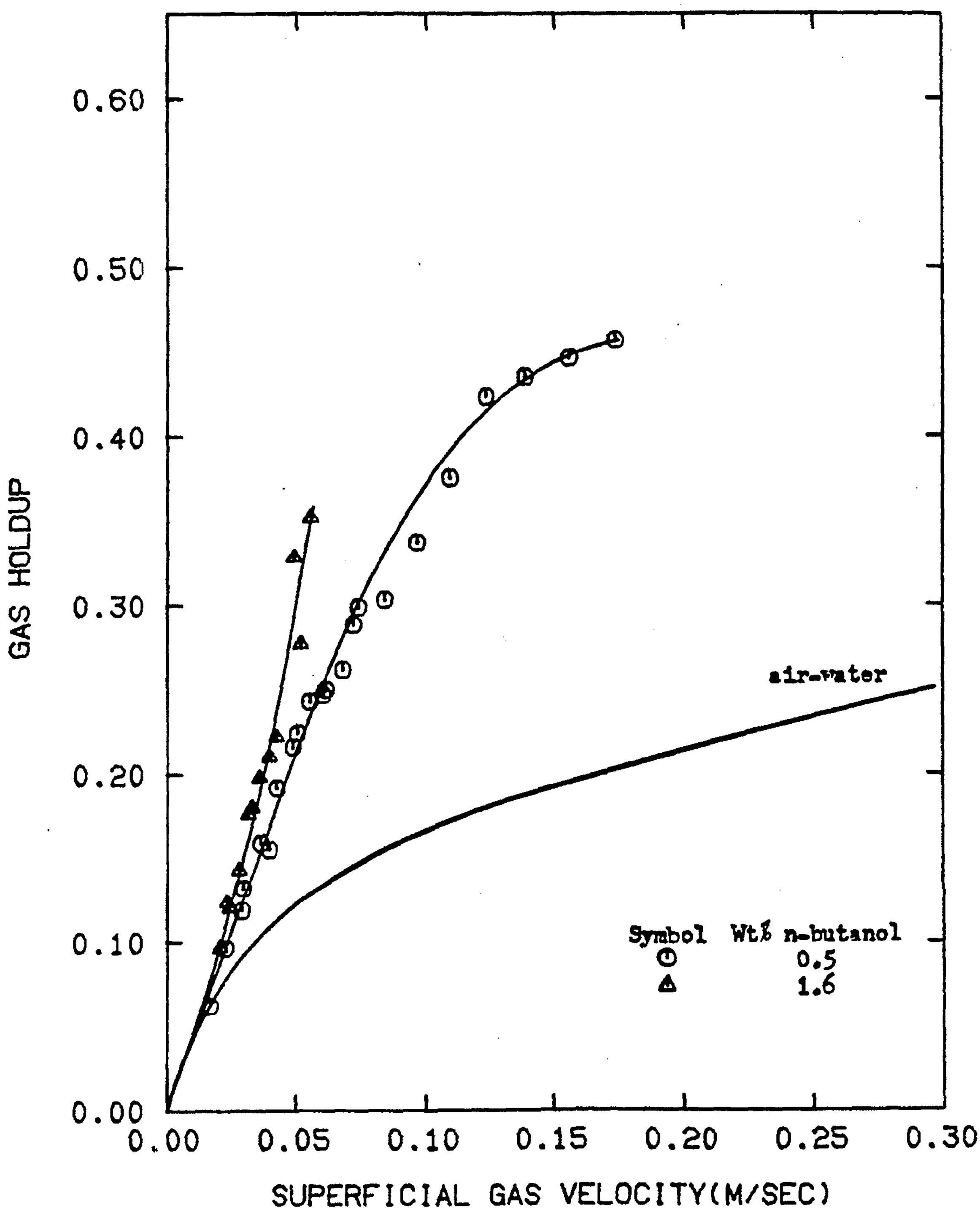
GAS HOLDUP VS.SUPERFICIAL GAS VELOCITY FOR (1.0WT%)ETHANOL-WATER.

Figure 2.6



GAS HOLDUP VS.SUPERFICIAL GAS VELOCITY FOR PROPANOL-WATER.

Figure 2.7



GAS HOLDUP VS.SUPERFICIAL GAS VELOCITY FOR BUTANOL-WATER.

Figure 2.8

et al.[2.5] consistently predicts higher values of gas holdup than realized for any alcohol. Since it gives implausible values of gas holdup after 6-7 cm/sec, it is not valid outside the range of gas velocities they studied. The effect of alcohol concentration on the gas holdup is insignificant for propanol solutions where the surface tension varies from 0.06319 N/m to 0.04823 N/m. The 1.6 wt% butanol solution shows higher gas holdups than 0.5 wt% butanol. The effect of concentration of alcohol on gas holdup can explain the results in Figure 2.5. ε_G against V_G data for (5 wt%) methanol lie above the data for 1 wt% methanol, but data taken at the end of the run are for a very low concentration of methanol, say *wt%, (which is due to vaporization of methanol) and this data usually lie nearer to the air-water data. The gas holdup is greatly influenced by the type of alcohol added as shown in Figure 2.9. The gas holdup increases in the following order:

methanol < ethanol < propanol < butanol

which is in agreement with Schugerl et al.[2.5] and Oels et al.[2.6] From Figure 2.9 it can be seen that 1.6 wt% butanol shows the highest gas holdups followed by propanols and 0.5 wt% butanol (which has a surface tension higher than propanols). 0.5 wt% butanol is followed by 1 wt% ethanol and methanols in the gas holdup curve. The systems below a surface tension of 0.048 N/m have not been studied because of flooding and/or foaming observed at very low gas velocities.

This strange behavior of alcohols is explained with the help of the theoretical development of Oels et al.,[2.6] Schugerl et al.,[2.5] flow regime charts, graphs of bubble rise velocities against gas velocity

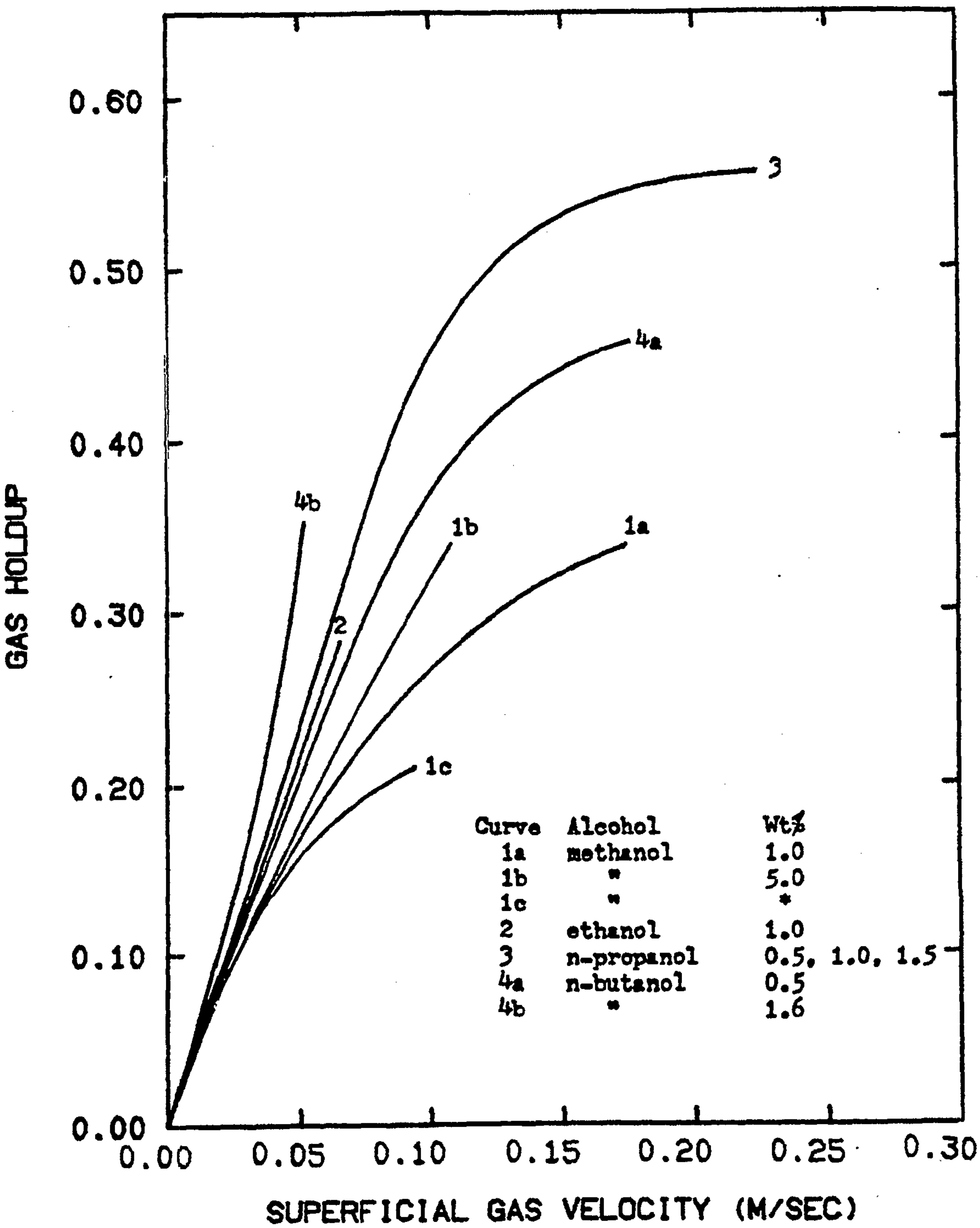
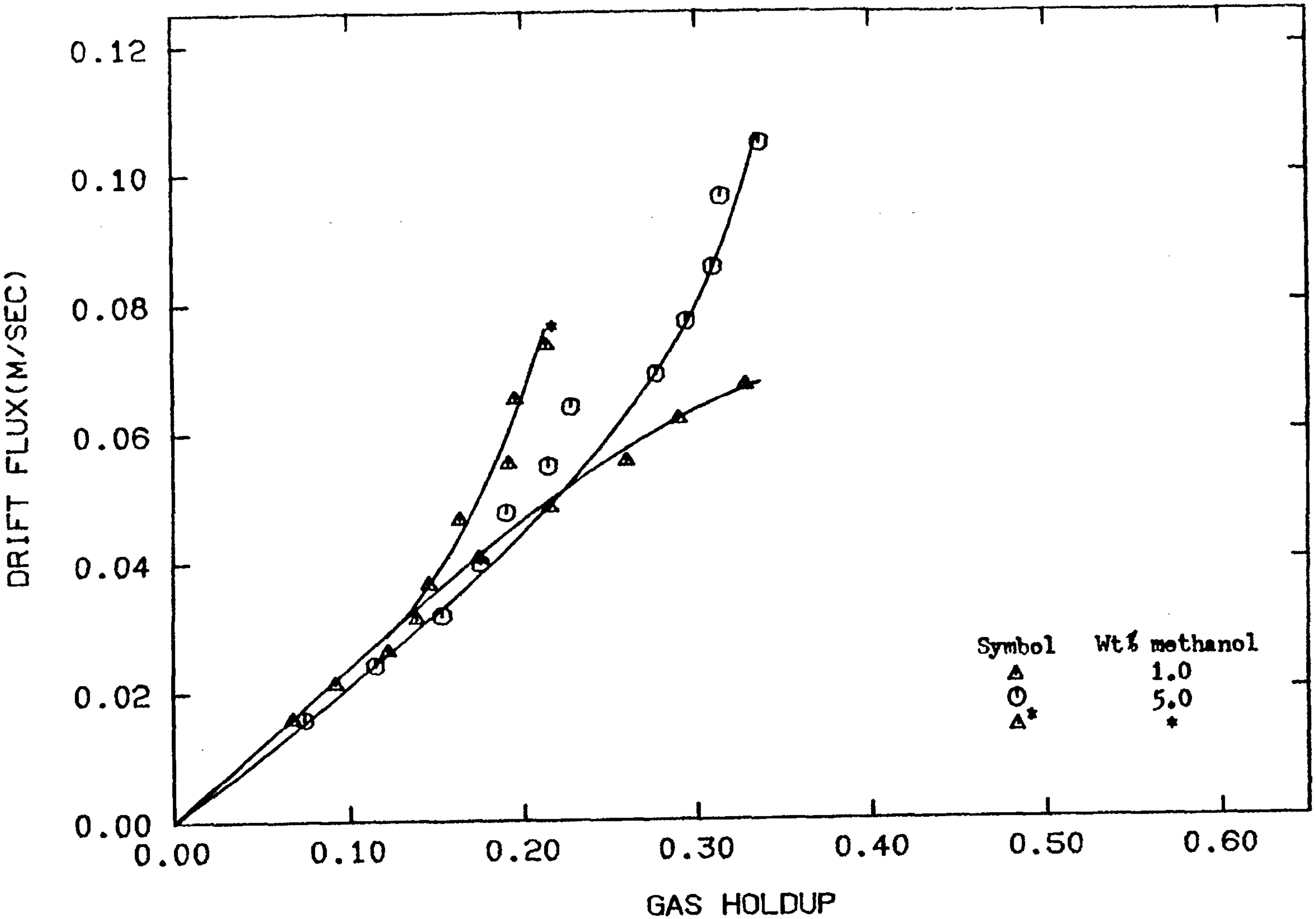

0.60
0.50
0.40
0.30
0.20
0.10
0.00
GAS HOLDUP
0.00
0.05
0.10
0.15
0.20
0.25
0.30
SUPERFICIAL GAS VELOCITY (M/SEC)
3
4a
4b
1b
1a
2
1c
Curve Alcohol Wt%
1a methanol 1.0
1b " 5.0
1c " *
2 ethanol 1.0
3 n-propanol 0.5, 1.0, 1.5
4a n-butanol 0.5
4b " 1.6

Figure 2.9

and the information obtained from the dynamic gas disengagement method. The unusual increase in gas holdup based on the theoretical development of Oels et al.[2.6] and Schugerl et al.[2.5] has been explained in Section 1.3. It is important to note that alcohol solutions with larger chain lengths and lower surface tension will behave mostly like small rigid spheres rising with very low bubble rise velocity. For aqueous solutions of C_1, C_2, and C_3 alcohols as the gas velocity increases the bubbles coalesce and form fast rising large bubbles. The result is an increase in the rise velocity of bubble swarm as a whole and the leveling out of gas holdup. In the case of aqueous solutions of C_4 alcohols with low surface tension, the bubbles stay as small rigid spheres, they do not coalesce and hence the gas holdup keeps on increasing with a net reduction in bubble rise velocity. Because there is no transition from the bubbly flow regime to the churn turbulent regime flooding occurs. Occurrence of foaming acts as a booster for an early flooding point. For a soltuion similar to higher alcohol solutions with a very low surface tension (near 0.025-0.03 N/m) the evaluation of a flooding chart may be very useful information as far as the hydrodynamics is concerned. In the cocurrent bubble column for a similar C_4 alcohol solution, flooding was not observed, though there was considerable foaming. Probably, the point of flooding, enhanced by intense foaming, is present for C_5 or C_6 alcohols in the cocurrent bubble column.

Upon visual observation, the bubbles appeared to be small, spherical and uniformly distributed. Schugerl et al.[2.5] have reported that the size of bubbles in alcohol solutions, is mainly governed by the dynamic equilibrium between the pressure and surface tension forces, if the holes of the perforated plate are $\geq$ 0.5 mm in diameter. As the energy input to the liquid phase is increased by increasing the superficial gas velocity, even for a non-coalescing medium like alcohol solutions, large bubbles form and a transition from the bubbly flow regime to the churn turbulent regime is expected. Flow regime charts for alcohol solutions are shown in Figures 2.10-2.13. Data for 5 wt% methanol, 1wt% ethanol, 0.5 wt% propanol and 1.6 wt% butanol lies solely in the bubbly flow regime. There is a transition from bubbly flow to churn turbulent flow at gas holdup of 28%, 50%, and 43% for 1 wt% methanol, 1.0 wt% and 1.5 wt% propanol and 0.5 wt% butanol which is in agreement with the order in which gas holdup increases for these systems. Though the transition gas velocity for all the three cases lies near 0.10-0.12 m/sec. Dynamic gas disengagement data are available for methanols and butanols. For methanol, 1 wt% and * wt% (*: it behaves closer to the air-water data in gas holdup, drift flux, bubble rise velocity charts), the transition from uniform bubbles to two sized bubbles occurs around 0.10 m/sec and 0.065 m/sec respectively. The summarized gas disengagement data for alcohols is as shown in Table 2.7 and Figures 2.14 and 2.15. It can be seen that the relative fraction of large bubbles to small bubbles is constant for 1 wt% methanol and levels out for * wt%. The fraction of large bubbles for * wt% case is larger than that for 1 wt% and is closer to air-water data. For 0.5 wt% butanols all the data are taken in the bubbly flow regime.

The bubble rise velocity defined as $V_M = V_G/\varepsilon_G$ is plotted against V_G as shown in Figures 2.16-2.19 for the alcohols. It can be seen that V_M is either remaining constant or increasing with gas velocity for methanol, propanol and 0.5 wt% butanol. The same observation can be made looking at



DRIFT FLUX VS.GAS HOLDUP FOR METHANOL-WATER.

Figure 2.10

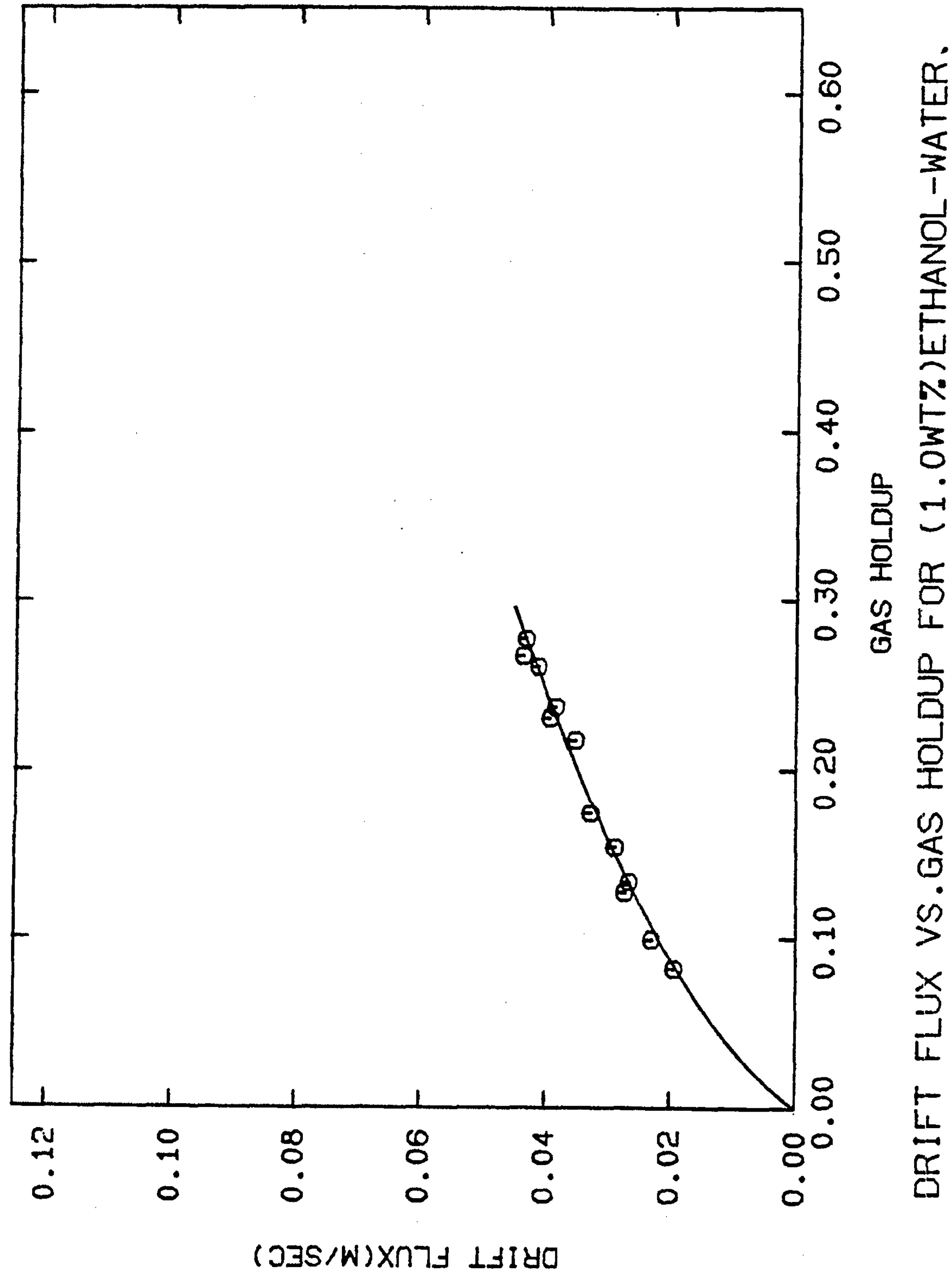
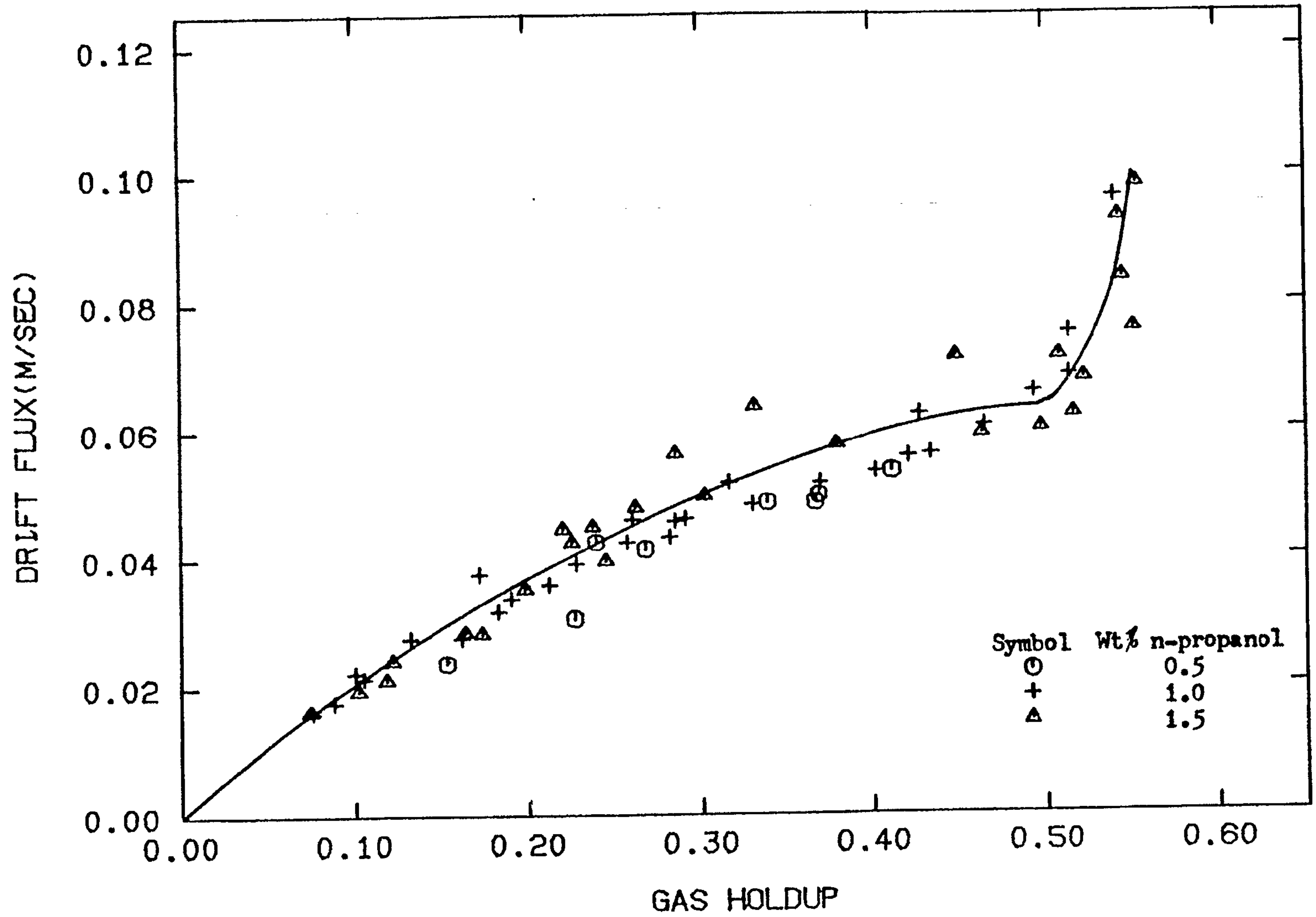
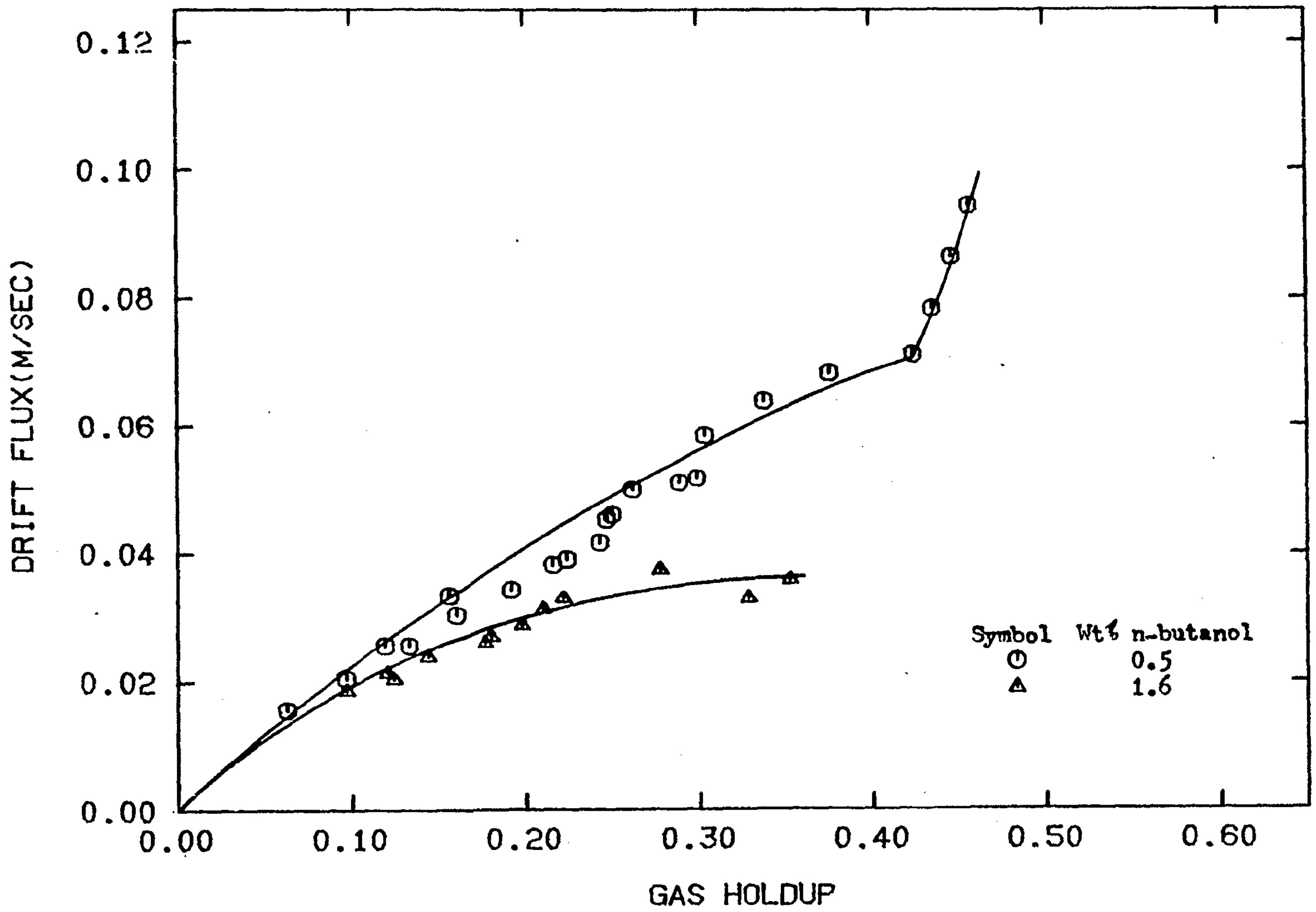

DRIFT FLUX VS. GAS HOLDUP FOR (1.0WT%)ETHANOL-WATER.
GAS HOLDUP
DRIFT FLUX(M/SEC)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.00
0.02
0.04
0.06
0.08
0.10
0.12

Figure 2.11



DRIFT FLUX VS.GAS HOLDUP FOR PROPANOL-WATER.

Figure 2.12



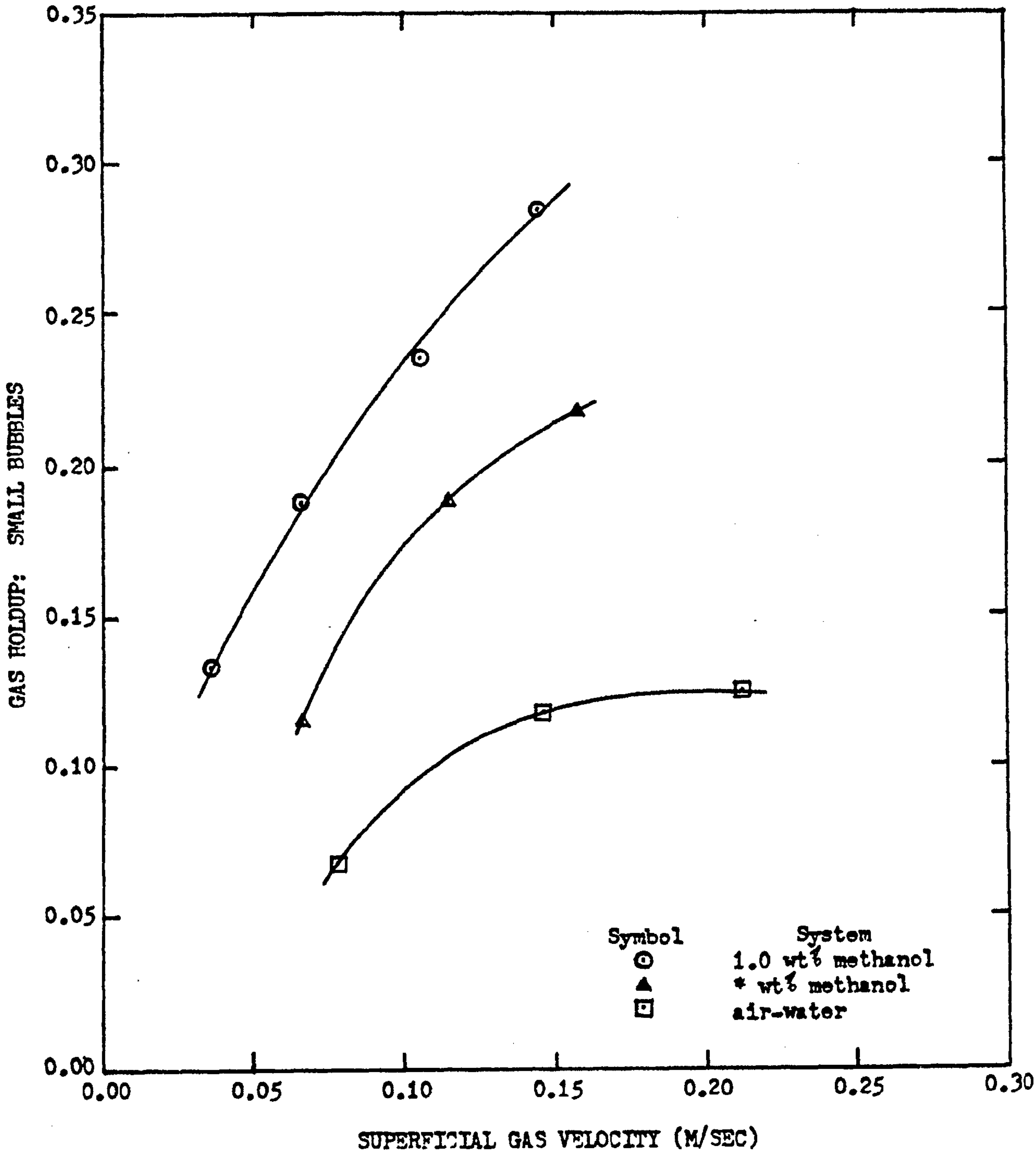
DRIFT FLUX VS.GAS HOLDUP FOR BUTANOL-WATER.

Figure 2.13

TABLE 2.7

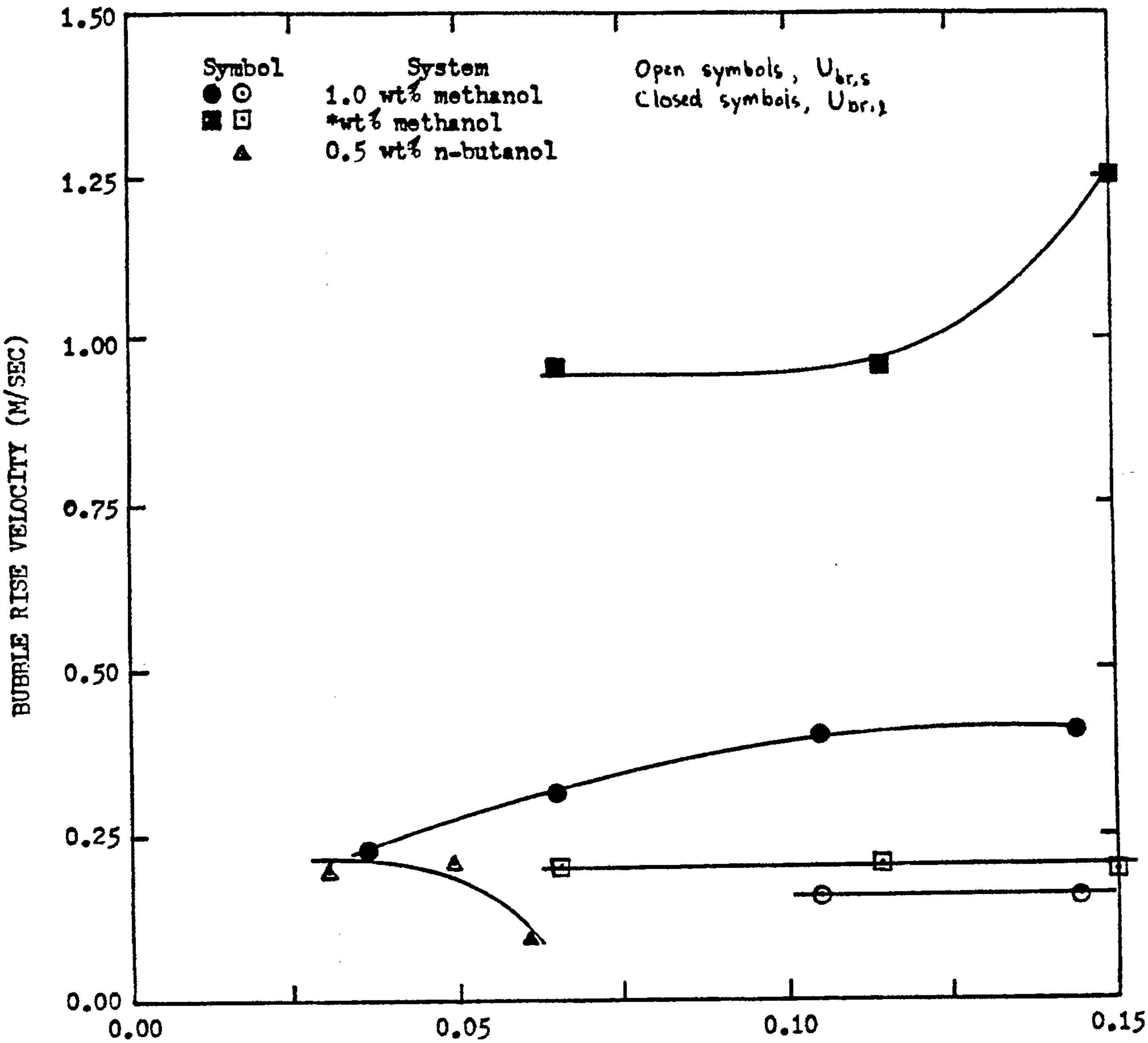
DYNAMIC GAS DISENGAGEMENT RESULTS FOR ALCOHOL SOLUTIONS

<table>
<tr><th></th><th colspan="4">1.0 wt% Methanol</th><th colspan="3">* wt% Methanol</th><th colspan="3">0.5 wt% n-Butanol</th><th>1.0 wt% Ethanol</th></tr>
<tr><td>V_G m/sec</td><td>0.036</td><td>0.065</td><td>0.105</td><td>0.144</td><td>0.066</td><td>0.114</td><td>0.158</td><td>0.030</td><td>0.048</td><td>0.061</td><td>0.035</td></tr>
<tr><td>$\varepsilon_G(0)$</td><td>0.133</td><td>0.188</td><td>0.288</td><td>0.348</td><td>0.164</td><td>0.246</td><td>0.280</td><td>0.130</td><td>0.287</td><td>0.355</td><td>0.148</td></tr>
<tr><td>$\varepsilon_{G,s}$</td><td rowspan="2">0.133</td><td rowspan="2">0.188</td><td>0.235</td><td>0.284</td><td>0.115</td><td>0.188</td><td>0.218</td><td rowspan="2">0.130</td><td rowspan="2">0.287</td><td rowspan="2">0.355</td><td rowspan="2">0.148</td></tr>
<tr><td>$\varepsilon_{G,\ell}$</td><td>0.053</td><td>0.064</td><td>0.049</td><td>0.058</td><td>0.062</td></tr>
<tr><td>$U_{br,s}$ m/sec</td><td rowspan="2">0.226</td><td rowspan="2">0.330</td><td>0.154</td><td>0.155</td><td>0.204</td><td>0.204</td><td>0.195</td><td rowspan="2">0.199</td><td rowspan="2">0.214</td><td rowspan="2">0.094</td><td rowspan="2">0.192</td></tr>
<tr><td>$U_{br,\ell}$ m/sec</td><td>0.405</td><td>0.413</td><td>0.961</td><td>0.958</td><td>1.25</td></tr>
<tr><td>$V_G/\varepsilon_G(0)$ m/sec</td><td>0.270</td><td>0.346</td><td>0.365</td><td>0.414</td><td>0.402</td><td>0.463</td><td>0.564</td><td>0.231</td><td>0.168</td><td>0.172</td><td>0.239</td></tr>
</table>



Dynamic gas disengagement: $\varepsilon_{G,s}$ vs V_G

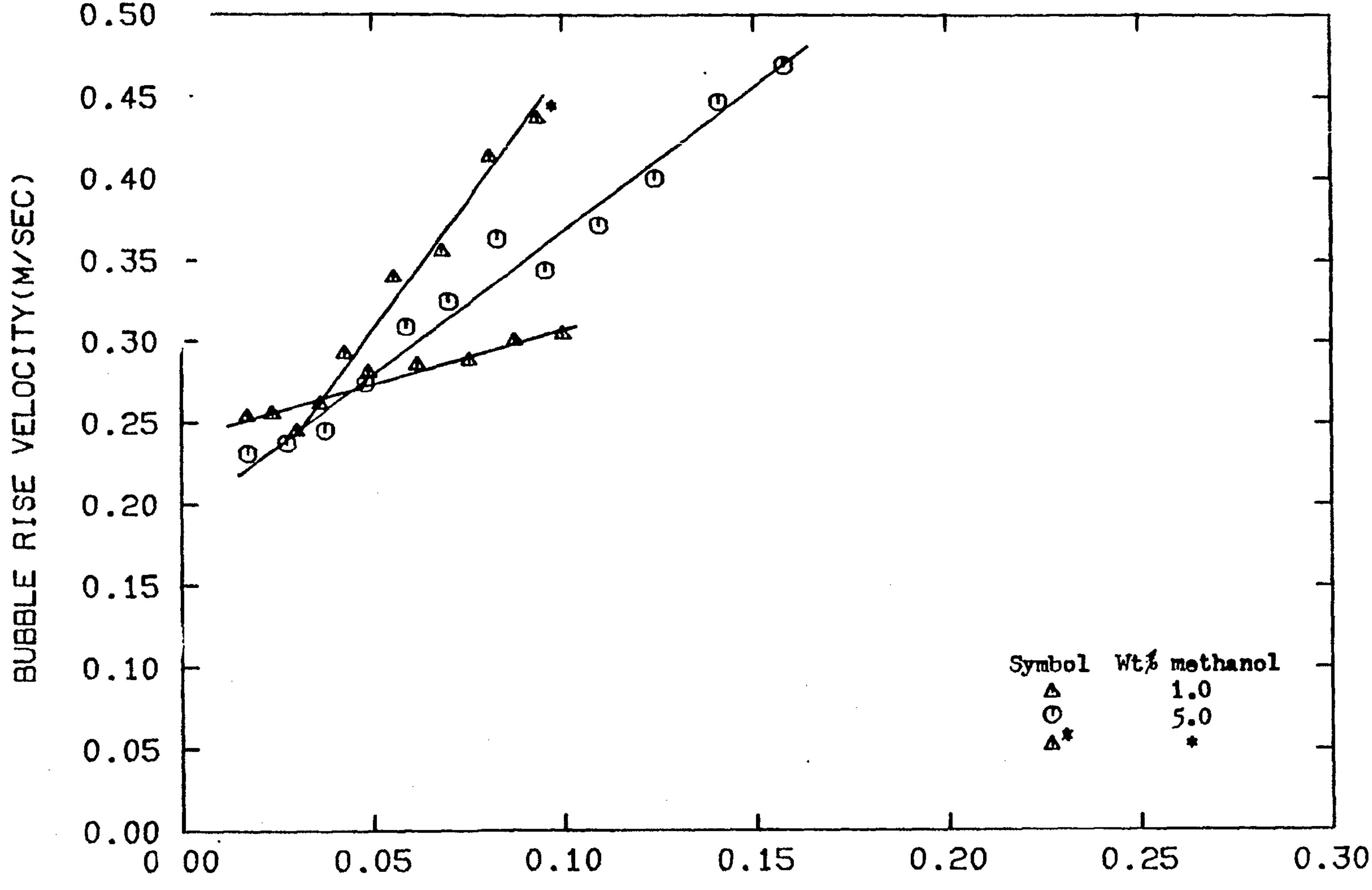
Figure 2.14



SUPERFICIAL GAS VELOCITY (M/SEC)

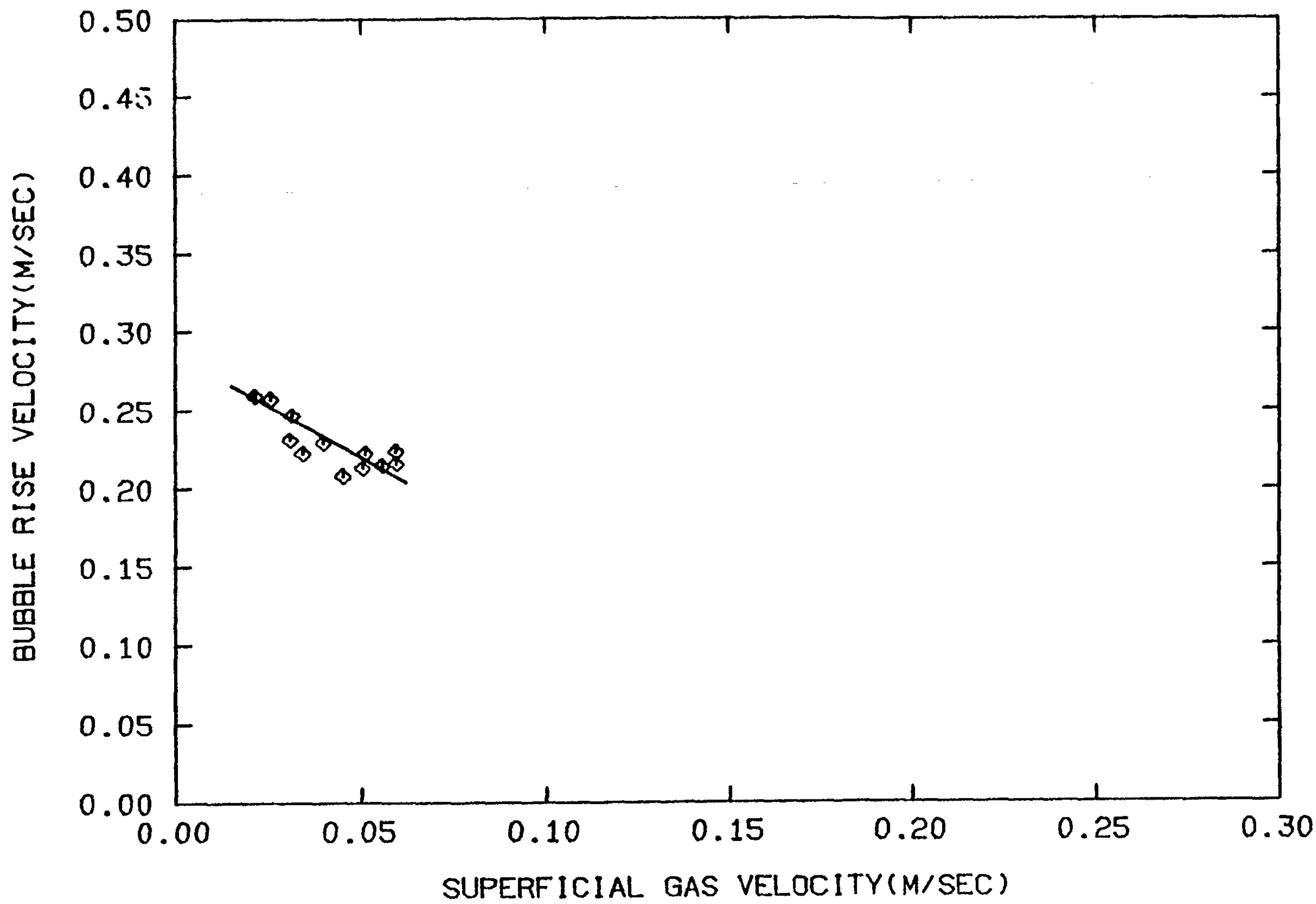
Dynamic gas disengagement: U_{br} vs V_G

Figure 2.15



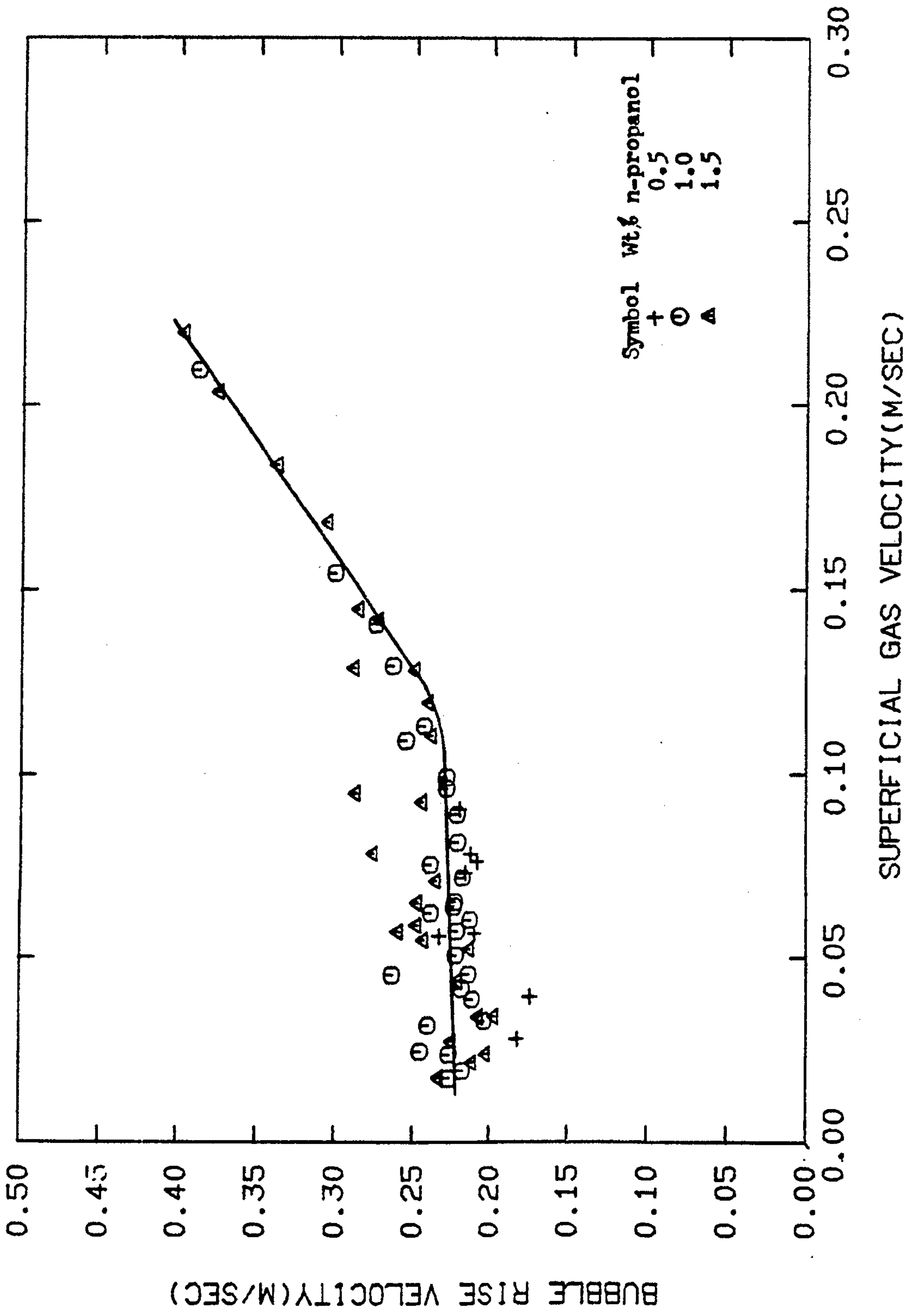
VM VS.VG FOR METHANOL-WATER.

Figure 2.16



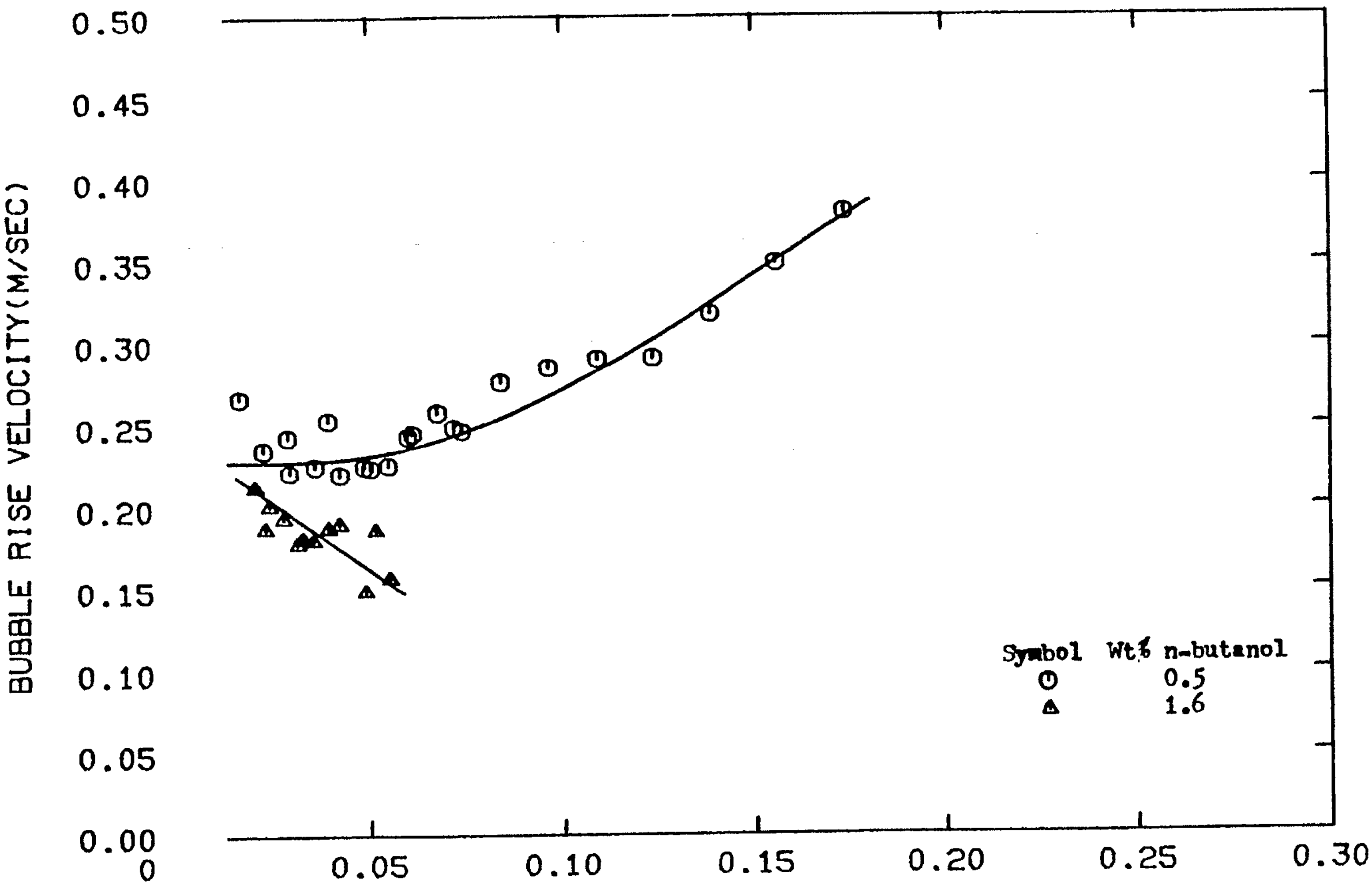
VM VS.VG FOR (1.0WT%)ETHANOL-WATER.

Figure 2.17



VM VS. VG FOR PROPANOL-WATER.

Figure 2.18



VM VS.VG FOR BUTANOL-WATER.

Figure 2.19

dynamic gas disengagement data. The foaming and/or flooding for 1.6 wt% butanol is observed by presence of foam layer height decline. From disengagement analysis, 1 wt% methanol and * wt% methanol have bubble rise velocities uniformly increasing with gas velocity. The bubble rise velocity for * wt% methanol being larger at any gas velocity. This observation can be confirmed from Figure 2.16. Surface tension of ethanol solutions showed unaccountable foaming tendency, which could have been because of presence of additives in the ethanol.

After analysis of all the holdup data points for alcohol solutions, the effect of surface tension is found to be negligible. The gas holdup is correlated with the gas velocity and the number of carbon atoms in the alcohol to yield an equation:

$$\varepsilon_G \approx 1.4156\ V_G^{0.692}\ (C_N)^{0.213} \qquad (2.4.1)$$

The overall percent error defined as

$$\text{Error} = \frac{\sum \frac{ABS(\varepsilon_{Go}-\varepsilon_{Gp})}{\varepsilon_{Go}}}{N} * 100.0 \qquad (2.4.2)$$

Error is 13% between the correlation and the data. When the correlation developed in Section 1.3 is used, it always tends to predict lower gas holdup values and the overall percent error is as high as 21%. Figure 2.20 shows a plot of gas holdup predicted vs. gas holdup observed.

Thus, it is evident that most of the gas transported through the aqueous alcohol solutions, flows in the form of small bubbles. For lower alcohols the fraction of large bubbles is significant, being as high as