height (inches of wax) by use of Eqs. 5.16 and 5.17. These data (i.e. height vs time) were used to calculate bubble rise velocities and gas holdups for each bubble class via Eqs. 5.9 and 5.10, respectively. Once bubble rise velocities were obtained, bubble sizes were calculated using the correlations presented in Table 5.1. The Sauter mean bubble diameter was obtained from Eq. 5.15. Finally, the specific gas–liquid interfacial area was calculated from Eq. 5.1 using the gas holdup of the dispersion below the pressure transducer.

Discussion of Results

Dynamic gas disengagement measurements were carried out in the two stainless steel columns (0.05 m ID and 0.21 m ID, 3 m tall) during some of the two-phase experiments conducted in the batch mode of operation. DGD data were acquired during two experiments with SASOL wax (experiments 1 and 5 in Table 2.5) and one experiment with FT–300 wax (experiment 30 in Table 2.5) in the large diameter column, and during one experiment with SASOL wax (experiment 29 in Table 2.4) and one experiment with FT–300 wax (experiment 23 in Table 2.4) in the small diameter column. The 2 mm orifice plate distributor was used in the 0.05 m ID column and the 19 x 2 mm distributor was employed in the 0.21 m ID column. All disengagement data for wax were analyzed assuming Case I disengagement.

Figures 5.7 and 5.8 show the disengagement curves at heights of 1.3 and 1.9 m above the distributor plotted as normalized differential height versus time for FT–300 wax and SASOL wax, respectively. The normalized differential height is defined as

$$\text{Norm. Diff. Height} = \frac{H_t(t_i) - H_t(t_n)}{H_t(0) - H_t(t_n)} \qquad i = 1 \text{ to } n \tag{5.18}$$

where $H_t(t_n)$ is the height of the liquid above the pressure transducer at the instant the last small bubble rises above the pressure transducer, $H_t(0)$ is the height of liquid above the pressure transducer immediately prior to interrupting the gas flow (i.e. at

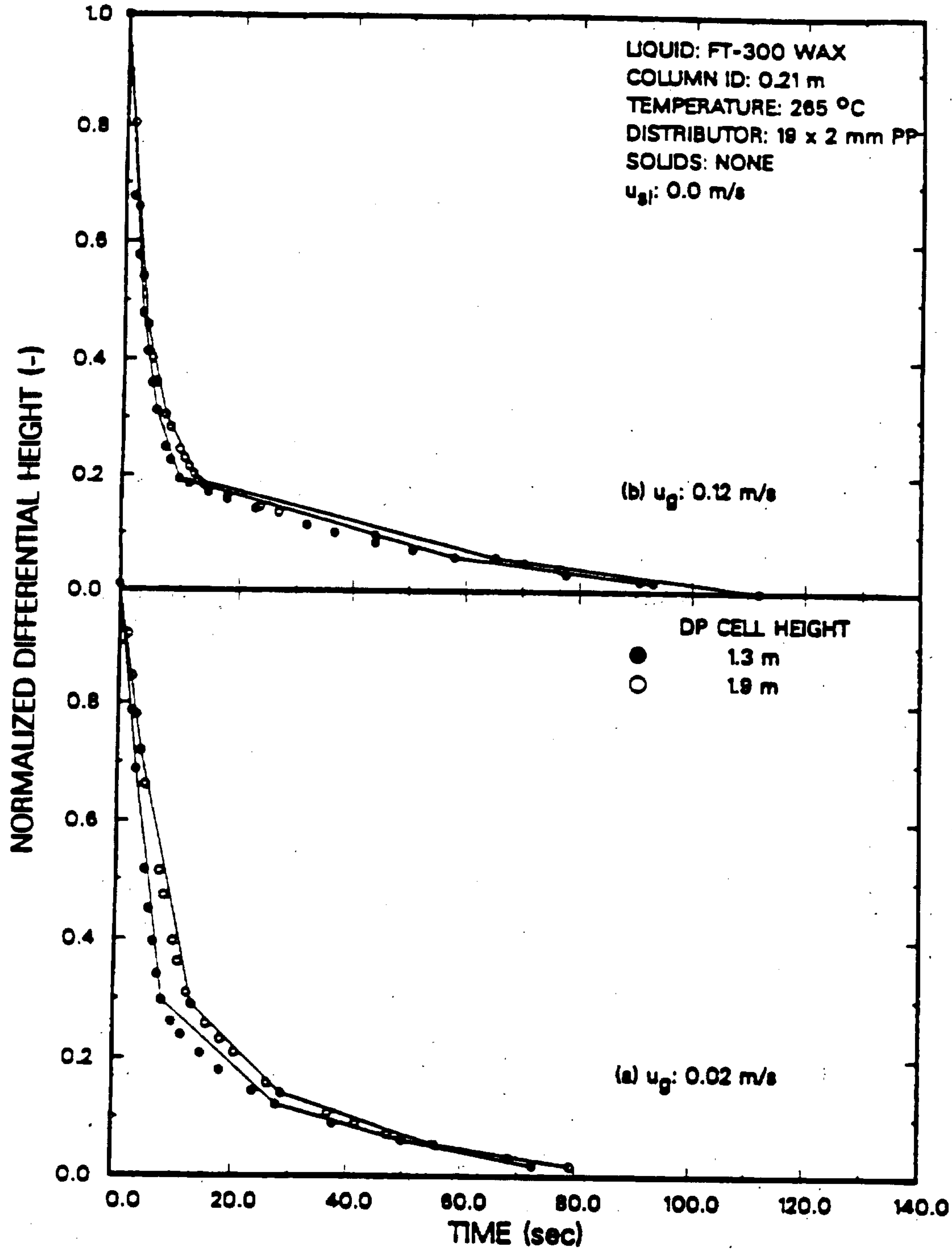

Figure 5.7 Effect of axial position on disengagement (FT-300 wax, (a) u_g= 0.02 m/s; (b) u_g=0.12 m/s).

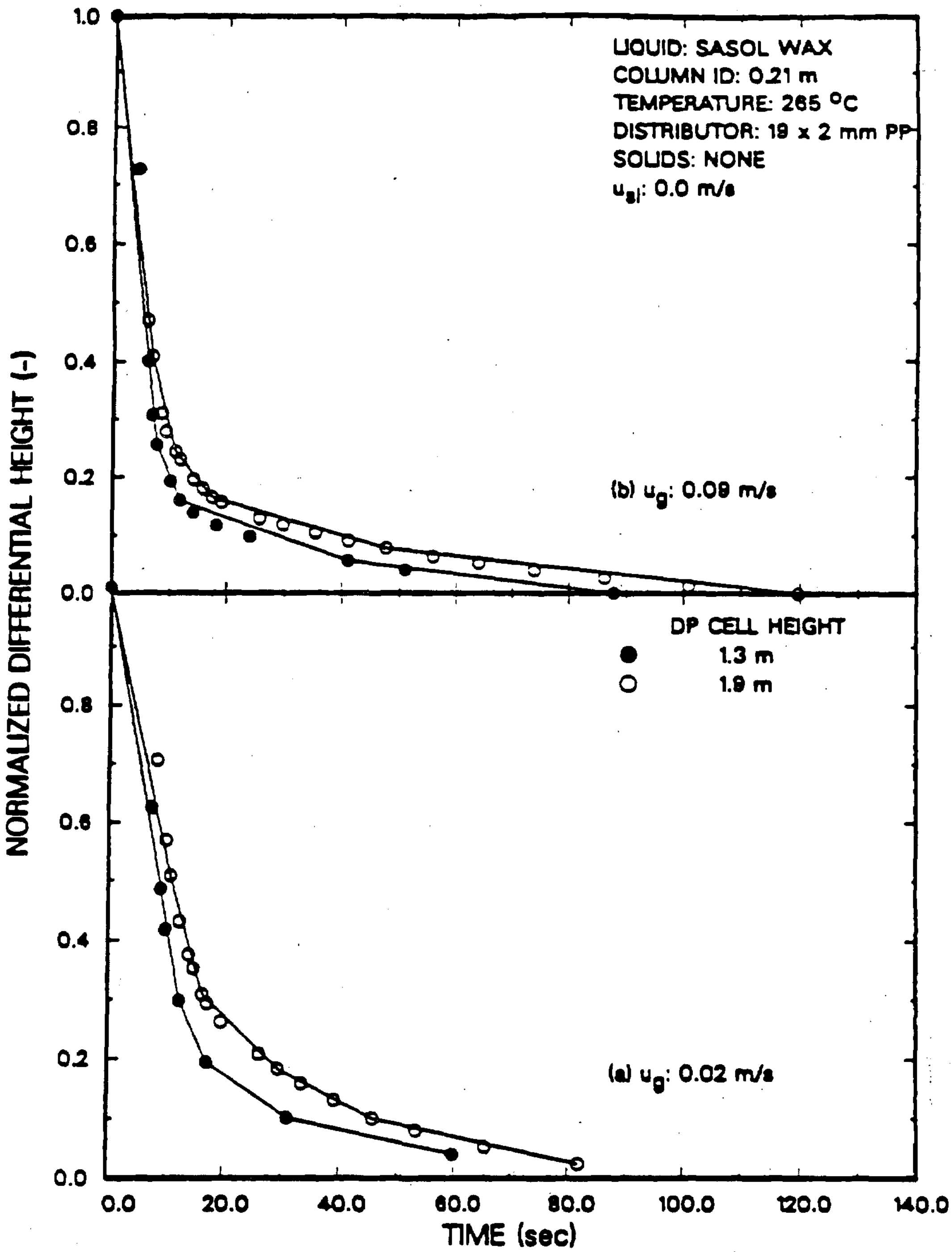

Figure 5.8. Effect of axial position on disengagement (SASOL wax, (a) u_g= 0.02 m/s; (b) u_g=0.09 m/s).

steady state conditions), and $H_t(t_i)$ is the height of liquid above the pressure transducer when the last bubble of size d_{B_i} passes above the pressure transducer. The data from experiments in the large column were also analyzed by dividing the disengagement curve into five intervals (i.e. five bubble classes, lines on Figures 5.7 and 5.8) to see what effect the number of bubble classes used has on the Sauter mean bubble diameter and specific gas–liquid interfacial area. If the dispersion is axially uniform, then the major breakpoints on the two curves (i.e. at heights of 1.3 and 1.9 m) would occur at the same normalized differential height. Also, if bubbles are rising at the same velocity as they rise past heights of 1.3 and 1.9 m, then the curve associated with the DP cell located at 1.9 m should be shifted to the right of the curve associated with the DP cell located 1.3 m. Both the trends mentioned above were observed in all experiments with wax in both the large and small diameter columns.

The gas holdups presented throughout this discussion, unless otherwise noted, correspond to the gas holdup of the dispersion below the measurement location. These gas holdups were obtained using Eq. 2.27, with $n = 3$ (for data obtained at a height of 1.3 m above the distributor) and $n = 4$ (for data obtained at a height of 1.9 m above the distributor). The specific gas liquid interfacial areas and Sauter mean bubble diameters are based on the holdup of the dispersion below the measurement location. Tables 5.2, 5.3, and 5.4 summarize the results obtained from experiments in the large diameter column with FT–300 wax and SASOL reactor wax (decreasing and increasing order of velocities), respectively. The experiment with FT–300 wax was conducted employing a decreasing order of gas velocities. The results presented in the tables for rise velocities, u_{bi}, and fractions of large bubbles f_L were based on the five bubble class analyses. The rise velocity of large bubbles was taken as the largest rise velocity, and the rise velocity of small bubbles was taken as the smallest rise velocity. The medium bubble rise velocity corresponds to the rise velocity of the middle bubble class. Sauter mean bubble

Table 5.2a. DGD Results from the Experiment with FT-300 Wax at a Height of 1.3 m (0.21 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.093	0.017	0.168	0.51	0.13	0.92	0.96	607	581
0.04	0.118	0.015	0.168	0.51	0.23	0.95	1.01	745	701
0.08	0.181	0.014	0.126	0.51	0.45	1.12	1.12	970	970
0.12	0.199	0.013	0.137	0.51	0.55	1.33	1.30	898	920

Table 5.2b. DGD Results from the Experiment with FT-300 Wax at a Height of 1.9 m (0.21 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.102	0.024	0.151	0.57	0.13	0.92	0.97	665	631
0.04	0.121	0.020	0.162	0.57	0.23	0.92	0.99	789	733
0.08	0.184	0.017	0.142	0.57	0.54	1.26	1.32	876	836
0.12	0.196	0.017	0.151	0.57	0.57	1.37	1.45	858	811

* Denotes values from analysis of all points.

Table 5.3a. DGD Results from the Experiment with SASOL Wax (Decreasing Gas Velocity) at a Height of 1.3 m (0.21 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.069	0.023	0.190	0.38	0.34	1.30	1.20	318	345
0.04	0.094	0.015	0.150	0.38	0.56	1.30	1.30	434	434
0.06	0.124	0.013	0.130	0.51	0.63	1.50	1.50	496	496
0.09	0.152	0.015	0.150	0.51	0.65	1.60	1.70	570	540

Table 5.3b. DGD Results from the Experiment with SASOL Wax (Decreasing Gas Velocity) at a Height of 1.9 m (0.21 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.074	0.024	0.174	0.38	0.33	1.10	1.10	404	404
0.04	0.109	0.024	0.174	0.38	0.60	1.30	1.40	503	467
0.06	0.130	0.015	0.113	0.45	0.65	1.40	1.50	557	520
0.09	0.154	0.016	0.133	0.56	0.67	1.60	1.60	578	578

* Denotes values from analysis of all points.

Table 5.4a. DGD Results from the Experiment with SASOL Wax (Increasing Gas Velocity) at a Height of 1.3 m (0.21 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.079	0.031	0.152	0.52	0.25	1.00	1.00	474	474
0.04	0.100	0.030	0.176	0.51	0.45	1.10	1.20	545	500
0.06	0.141	0.031	0.164	0.57	0.52	1.20	1.24	705	682
0.09	0.156	0.031	0.178	0.57	0.50	1.25	1.28	749	731

Table 5.4b. DGD Results from the Experiment with SASOL Wax (Increasing Gas Velocity) at a Height of 1.9 m (0.21 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.083	0.047	0.171	0.43	0.30	1.20	1.30	415	383
0.04	0.122	0.031	0.150	0.49	0.45	1.20	1.20	610	610
0.06	0.145	0.034	0.150	0.49	0.50	1.23	1.25	707	696

* Denotes values from analysis of all points.

diameters and specific gas–liquid interfacial areas are presented assuming five bubble classes and using all points. The Sauter mean bubble diameters and specific gas–liquid interfacial areas were comparable using both types of analyses. Similar results were obtained in the small column with SASOL and FT–300 wax (see Tables 5.5 and 5.6).

Figure 5.9 compares Sauter mean bubble diameters, specific gas liquid interfacial areas and gas holdups at a height of 1.3 m above the distributor for the experiments conducted in the large column (from 5 bubble classes analysis). The specific gas-liquid interfacial area and Sauter mean bubble diameters are based on the gas holdup of the dispersion below the pressure transducer. The gas holdup values from the experiment with FT–300 wax were slightly higher than those obtained from either of the experiments with SASOL wax (see Figure 5.9c). As shown in Figure 5.9a, the Sauter mean bubble diameters for the experiment conducted with FT–300 wax were consistently lower than those for the experiment conducted with SASOL reactor wax employing a decreasing order of gas velocities. In particular, Sauter mean bubble diameters ranged from approximately 1.0 to 1.3 mm for the experiment conducted with FT–300 wax as opposed to 1.3 to 1.6 mm for the experiment conducted in a decreasing order of gas velocities with SASOL reactor wax. However, the Sauter mean bubble diameters from the experiment conducted in an increasing order of gas velocities with SASOL reactor wax were comparable (slightly higher) to those obtained from the experiment conducted with FT–300 wax. The difference in Sauter mean bubble diameters is caused by differences in the fraction of large bubbles. For example, at a gas velocity of 0.09 m/s, the fraction of large bubbles for the experiment conducted in an increasing order of gas velocities was 0.50 whereas it was 0.65 for the experiment conducted in a decreasing order of velocities with SASOL reactor wax (see Tables 5.3a and 5.4a). These results indicate that bubble size distribution is affected by the operating procedure. Specific

Table 5.5a. DGD Results from the Experiment with FT-300 Wax (Increasing Gas Velocity) at a Height of 1.3 m (0.05 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.077	0.031	0.152	0.52	0.25	1.38	1.28	334	361
0.04	0.128	0.030	0.176	0.51	0.45	0.94	1.10	768	698
0.06	0.161	0.031	0.164	0.57	0.52	1.22	1.26	790	767
0.09	0.151	0.031	0.178	0.57	0.50	1.27	1.32	570	686

Table 5.5b. DGD Results from the Experiment with FT-300 wax (Increasing Gas Velocity) at a Height of 1.9 m (0.05 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.086	0.047	0.171	0.43	0.30	1.09	1.12	471	461
0.04	0.137	0.031	0.150	0.49	0.45	0.90	1.01	902	814
0.06	0.181	0.034	0.150	0.49	0.50	0.90	0.97	1200	1120
0.09	0.200	0.034	0.150	0.49	0.50	1.49	1.38	808	870

* Denotes values from analysis of all points.

Table 5.6a. DGD Results from the Experiment with SASOL Wax (Increasing Gas Velocity) at a Height of 1.3 m (0.05 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.052	0.031	0.152	0.52	0.25	1.40	1.45	220	215
0.04	0.088	0.030	0.176	0.51	0.45	1.80	1.78	290	297
0.06	0.110	0.031	0.164	0.57	0.52	1.81	1.83	350	361
0.09	0.137	0.031	0.178	0.57	0.50	2.10	2.21	390	372

Table 5.6b. DGD Results from the Experiment with SASOL Wax (Increasing Gas Velocity) at a Height of 1.9 m (0.05 m ID Stainless Steel Bubble Column, 265 °C)

u_g (m/s)	ϵ_{go} (-)	u_{bs} (m/s)	u_{bm} (m/s)	u_{bl} (m/s)	f_l (-)	d_s (mm)	d_s^* (mm)	a_s (m^{-1})	a_s^* (m^{-1})
0.02	0.086	0.047	0.171	0.43	0.30	1.30	1.32	400	391
0.04	0.110	0.031	0.150	0.49	0.45	1.60	1.52	410	434
0.06	0.129	0.034	0.150	0.49	0.50	1.60	1.61	480	481
0.09	0.157	0.034	0.150	0.49	0.50	2.00	2.30	420	410

* Denotes values from analysis of all points.

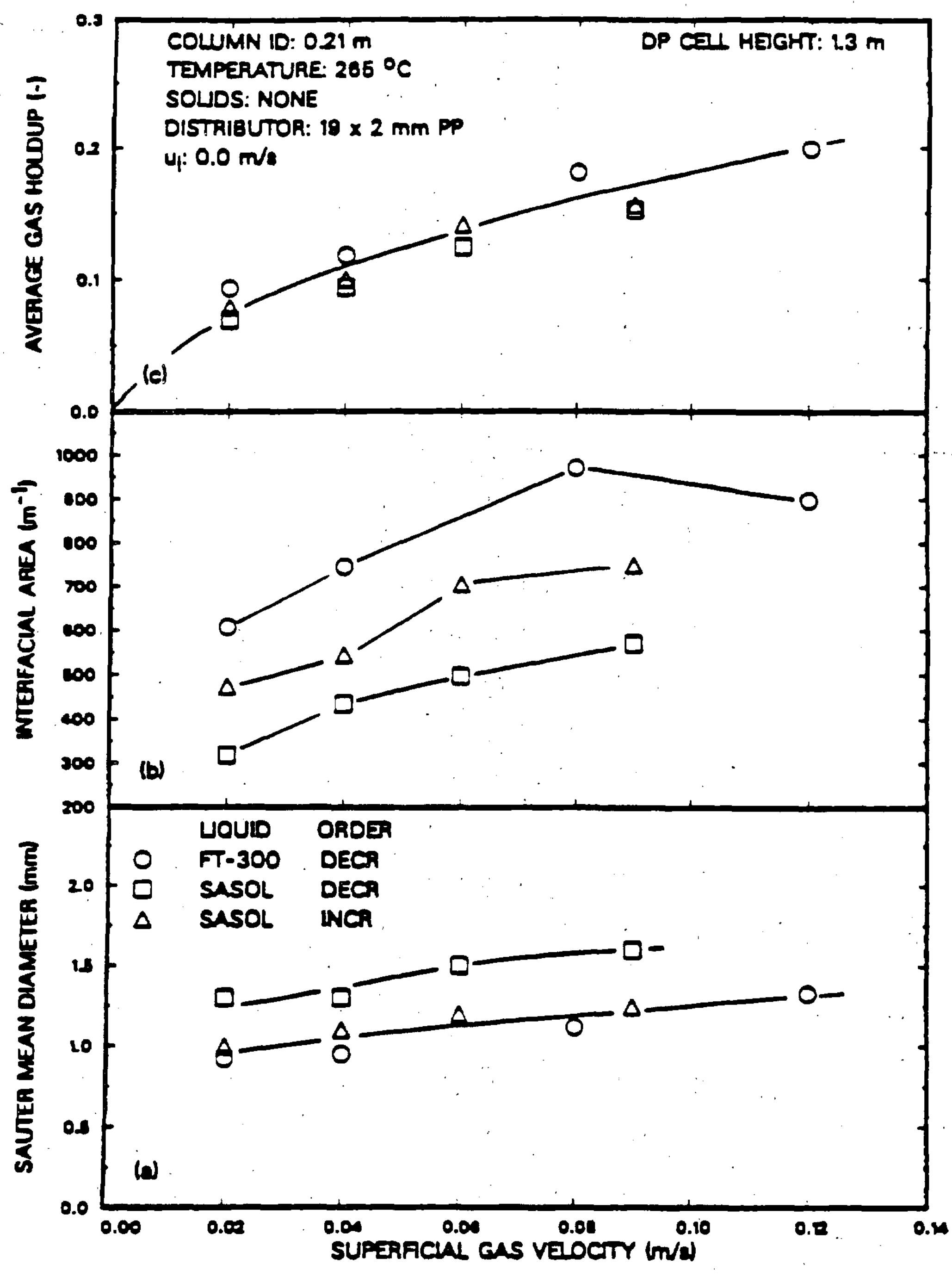

Figure 5.9. Effect of superficial gas velocity and wax type on (a) Sauter mean bubble diameter, (b) specific gas-liquid interfacial area, and (c) gas holdup in the 0.21 m ID column at a height of 1.3 m above the distributor.

gas liquid interfacial areas obtained from the three experiments were substantially different. There was almost a 100 % increase in a_s between the experiment conducted with FT–300 wax and the experiment conducted in a decreasing order of gas velocities with SASOL reactor wax. Similar results were obtained at a height of 1.9 m above the distributor (see Figure 5.10).

Figures 5.11 and 5.12 show results from experiments in the small diameter column at heights of 1.3 and 1.9 m above the distributor. As shown in Chapter II, FT–300 wax produces foam and as a result, the gas holdups with FT–300 wax are considerably larger than those produced with SASOL reactor wax (see Figures 5.11c and 5.12c). These higher gas holdups result in lower Sauter mean bubble diameters (Figures 5.11a and 5.12a), except at a gas velocity of 0.02 m/s, where the Sauter mean bubble diameters obtained for both waxes are comparable. This is expected, since homogeneous bubbly flow exists in the column at this velocity. As the gas velocity is increased to 0.04 m/s, the gas holdup from the experiment with FT–300 is significantly greater than that from the experiment with SASOL wax. This difference is holdup is due primarily to the presence of fine bubbles which accumulate in the uppermost region of the dispersion. This increase in the number of small bubbles associated with FT–300 wax results in a lower Sauter mean bubble diameter (see Figures 5.11a and 5.12a). Specific gas–liquid interfacial areas are shown in Figures 5.11b and 5.12b.

Figure 5.13 shows axial gas holdups from the experiments conducted with FT–300 wax and SASOL wax, at gas velocities of 0.02, 0.04, and 0.09 m/s. Axial gas holdup profiles from the experiment with SASOL wax show a slight increase in gas holdup with increasing height above the distributor (see Figure 5.13b). However, for the experiment with FT–300 wax, the gas holdup in the uppermost region of the column at a gas velocity of 0.04 m/s increases significantly compared to the holdup at lower heights. In particular, at a height of 1.6 m above the distributor, the gas holdup is approximately

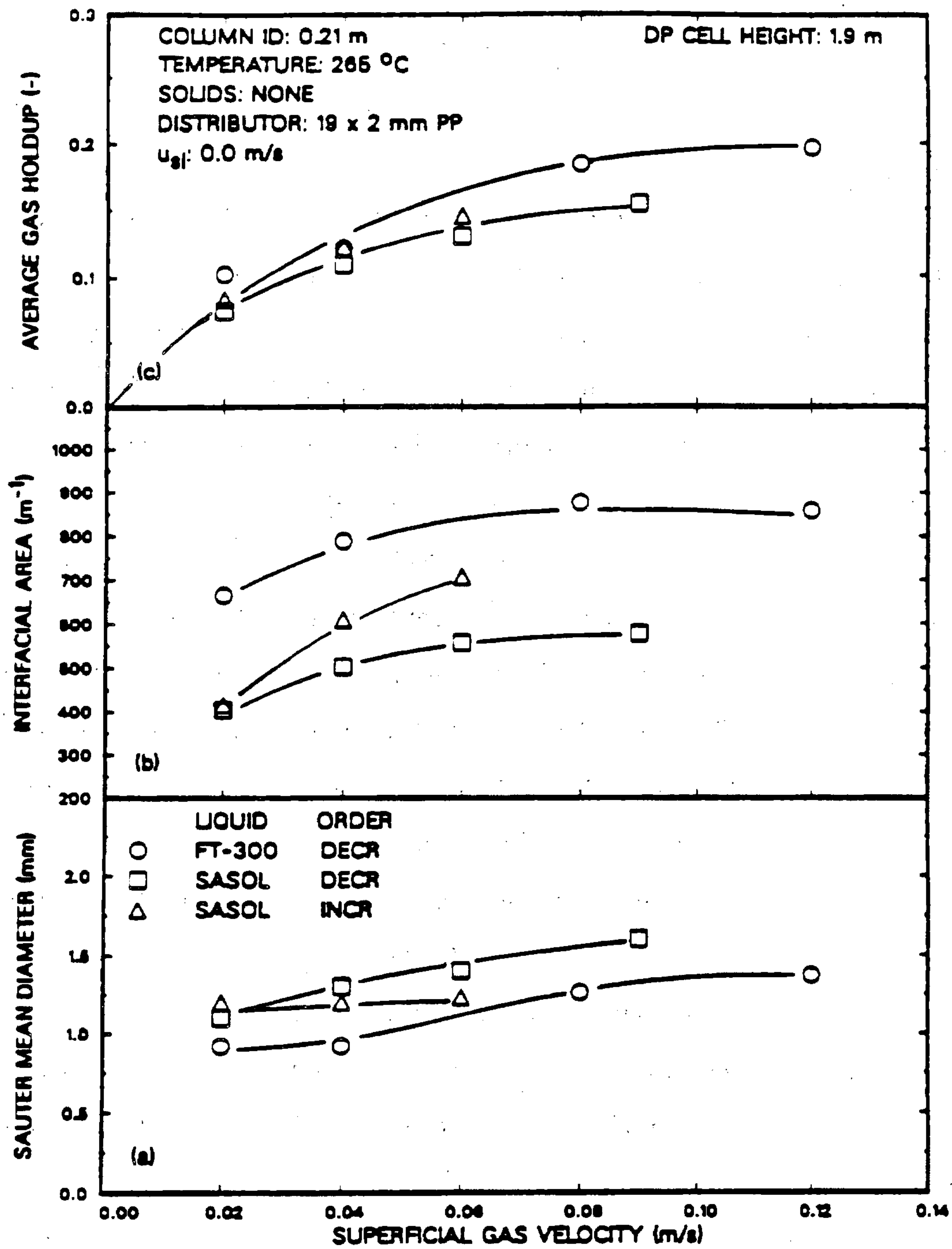

Figure 5.10. Effect of superficial gas velocity and wax type on (a) Sauter mean bubble diameter, (b) specific gas-liquid interfacial area, and (c) gas holdup in the 0.21 m ID column at a height of 1.9 m above the distributor.

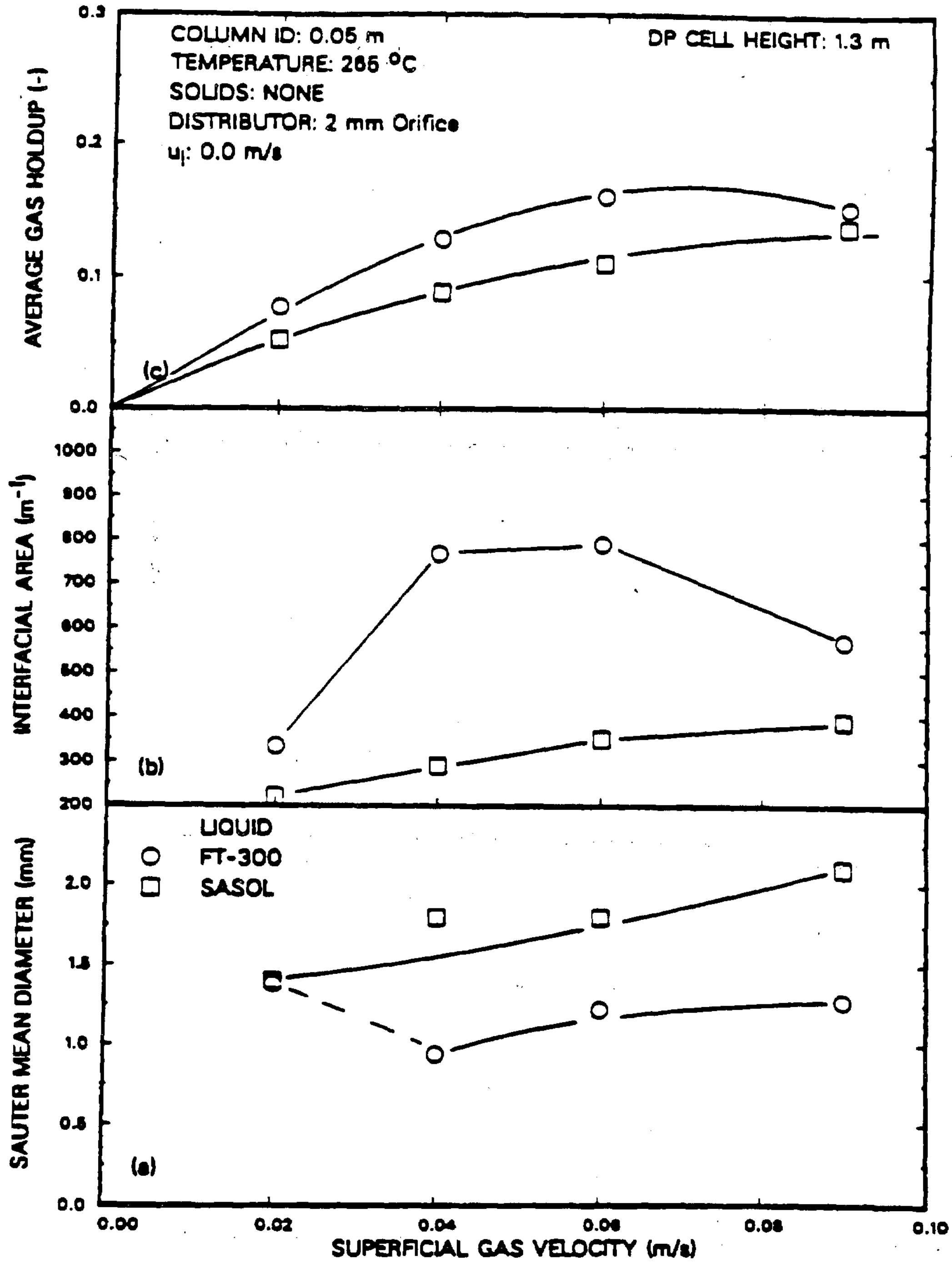

Figure 5.11. Effect of superficial gas velocity and wax type on (a) Sauter mean bubble diameter, (b) specific gas-liquid interfacial area, and (c) gas holdup in the 0.05 m ID column at a height of 1.3 m above the distributor.

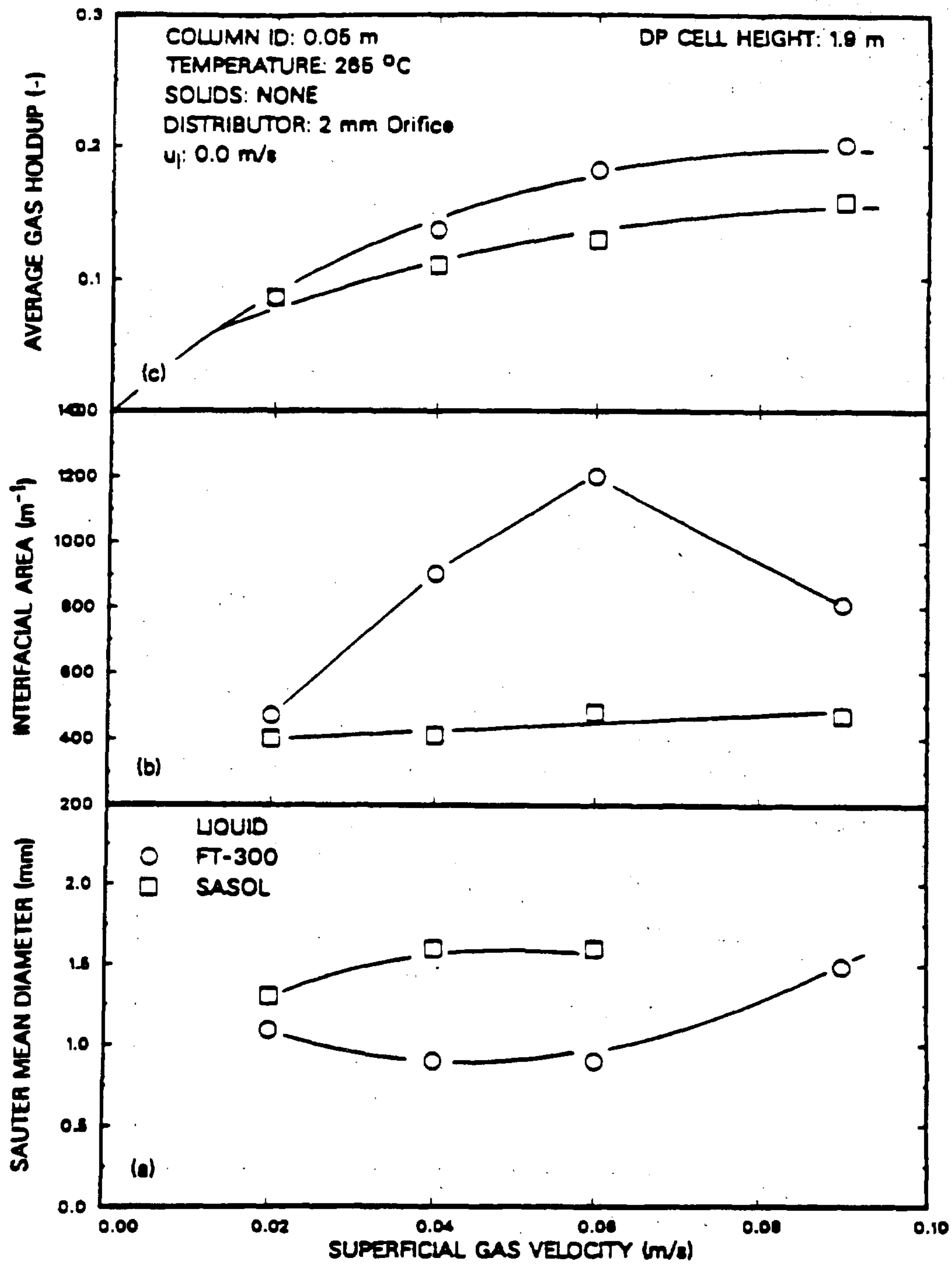

Figure 5.12. Effect of superficial gas velocity and wax type on (a) Sauter mean bubble diameter, (b) specific gas-liquid interfacial area, and (c) gas holdup in the 0.05 m ID column at a height of 1.9 m above the distributor.

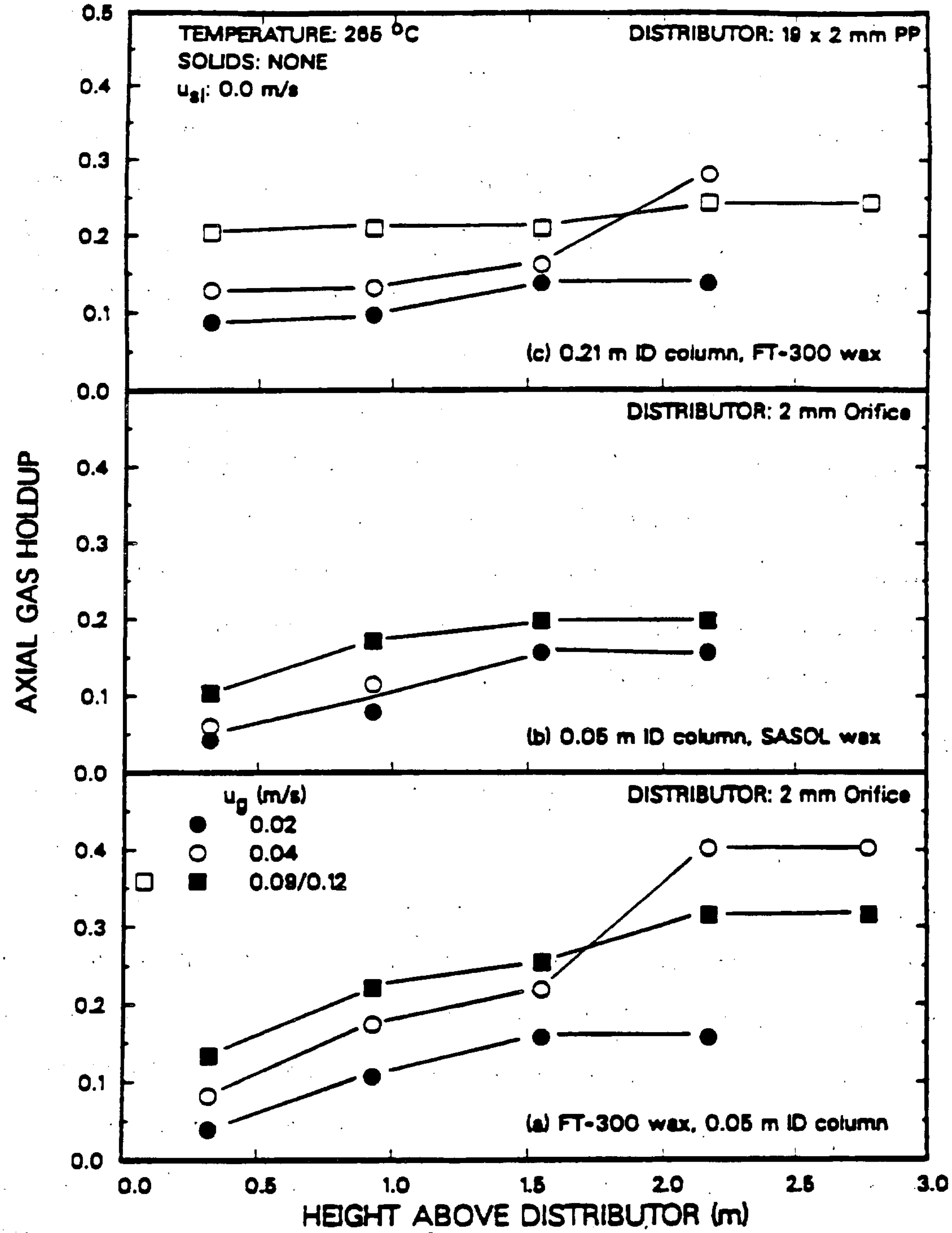

Figure 5.13. Effect of superficial gas velocity on axial gas holdup ((a) 0.05 m ID column, FT-300 wax; (b) 0.05 m ID column, SASOL wax; (c) 0.21 m ID column, FT-300 wax).

0.2; whereas, at a height of 2.2 m above the distributor, the gas holdup is approximately 0.4. At a gas velocity of 0.09 m/s, the foam layer which was present at a gas velocity of 0.04 m/s dissipates and there is a gradual increase in holdup with increasing height above the distributor. With the exception of a gas velocity of 0.02 m/s, the gas holdups with FT–300 wax are higher than those with SASOL wax, particularly at a gas velocity of 0.04 m/s, and as a result, the Sauter mean bubble diameters from the experiment with FT–300 wax are lower than those obtained from the experiment with SASOL reactor wax. The results from this study with FT–300 wax and SASOL reactor wax indicate that the Sauter mean bubble diameter is directly related to the gas holdup (i.e. the higher the gas holdup, the lower the Sauter mean bubble diameter). However, in our studies with other waxes (in the small diameter column) it was found that it is possible to have similar holdup values but significantly different Sauter mean bubble diameters (Bukur et al., 1987c; Patel et al., 1990).

Effect of Axial Position

Figure 5.14 shows the effect of height above the distributor on gas holdup and Sauter mean bubble diameter. The gas holdup values shown in this figure correspond to the average gas holdup below the given pressure transducer. Figures 5.14a and 5.14b show results from the experiments conducted in the large diameter column, and Figures 5.14c and 5.14d show results from experiments conducted in the small diameter column. In the large diameter column, we did not observe a significant difference in gas holdup with axial position, and as a result, there is excellent agreement in gas holdups and Sauter mean bubble diameters obtained at heights of 1.3 and 1.9 m above the distributor. However, in the small column, gas holdup increases with increasing height above the distributor, and as a result, gas holdups are slightly higher at a height of 1.9 m as compared to a height of 1.3 m. This increase in gas holdup with increasing height

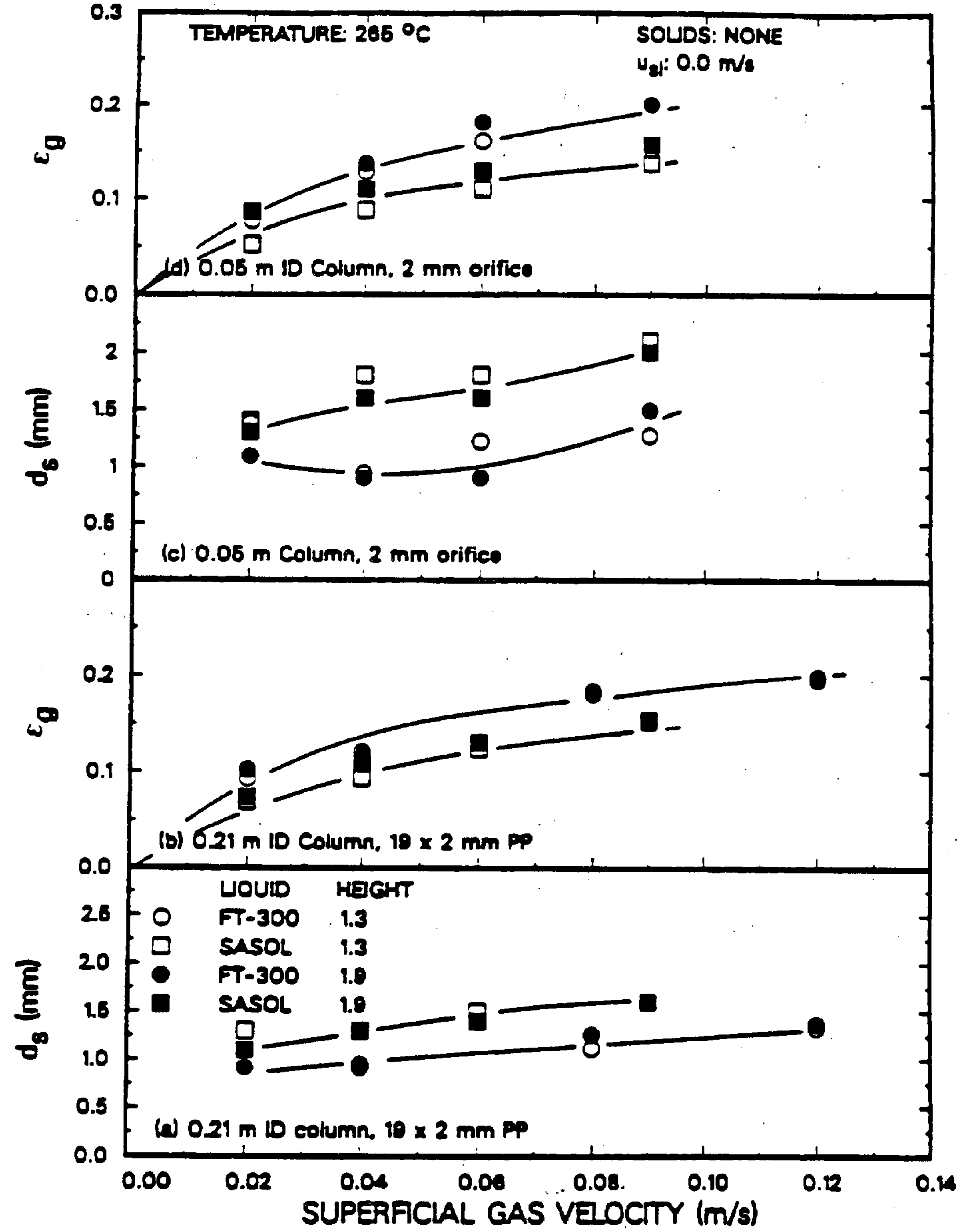

Figure 5.14. Effect of axial position on (a and c) Sauter mean bubble diameter and (b and d) gas holdup in 0.05 and 0.21 m ID bubble columns with wax (decreasing gas velocity - SASOL wax, 0.21 m ID column).

above the distributor results in slightly lower Sauter mean bubble diameters at a height of 1.9 m.

Effect of Column Diameter

Figures 5.15a and 5.15b show the effect of column diameter on the Sauter mean bubble diameter for experiments conducted with FT–300 wax and SASOL reactor wax (decreasing gas velocities) in the 0.05 and 0.21 m ID bubble columns at a height of 1.9 m above the distributor. Sauter mean bubble diameters for experiments conducted with FT–300 wax were similar in both columns for gas velocities less than 0.09 m/s (see Figure 5.15a). This is expected, since very small bubbles are formed with FT–300 at low gas velocities, and as a result, the Sauter mean bubble diameters are similar. At gas velocities greater than 0.09 m/s, the Sauter mean bubble diameter remains fairly constant in the large diameter column. Results from our previous experiments conducted in the small diameter glass column (Patel et al., 1990) indicate that the Sauter mean bubble diameter increases with increasing gas velocity between gas velocities of 0.09 and 0.12 m/s. The differences in trends with increasing gas velocities are due to differences in flow regimes in the 0.21 and 0.05 m ID columns. In the small diameter column, the slug flow regime exists; whereas, in the large diameter column, the churn–turbulent flow regime exists.

The Sauter mean bubble diameters were consistently higher in the small diameter column compared to the large diameter column for the experiments conducted with SASOL wax (see Figure 5.15b). The primary reason for differences in the Sauter mean bubble diameters is due to differences in the flow regimes. The large diameter column operates in the churn–turbulent flow regime and the small diameter column operates in the slug flow regime. The increase in turbulence associated with the large diameter column results in the formation of smaller bubbles.

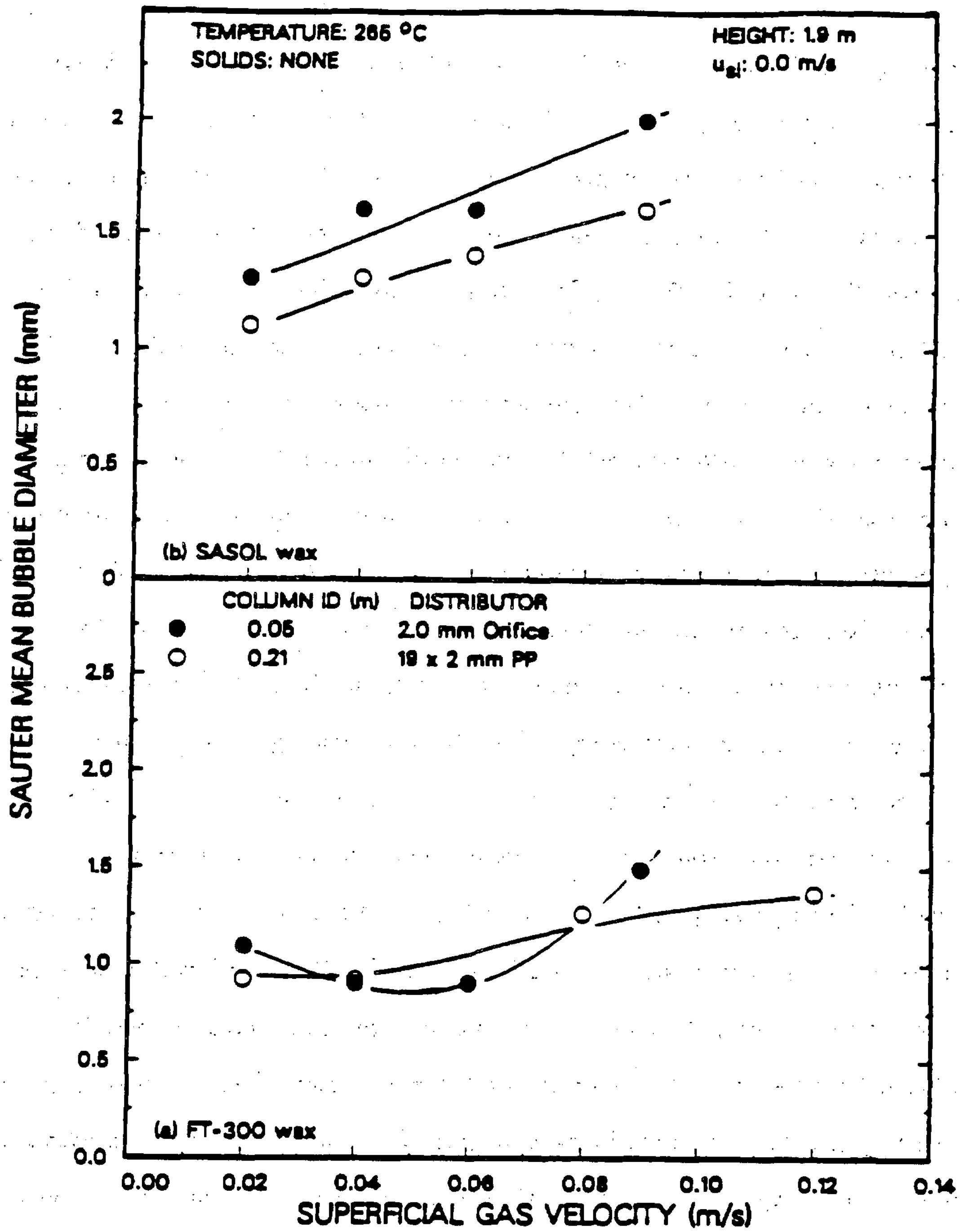

Figure 5.15. Effect of column diameter on Sauter mean bubble diameter for (a) FT-300 wax and (b) SASOL reactor wax - decreasing gas velocity in 0.21 m ID column.

Comparison of Results Obtained in the Glass and Stainless Steel Bubble Columns

The dynamic gas disengagement technique was used to obtain bubble size distributions in both the stainless steel and glass bubble columns. A VCR/video camera system was used to measure the disengagement profile during experiments conducted in the glass column (Bukur et al., 1987a,b; Patel et al., 1990); whereas, pressure transducers were used to measure the disengagement rate in the stainless steel columns. Since disengagement profiles in the glass column were measured for the entire dispersion, only results obtained at a height of 1.9 m above the distributor in the stainless steel columns are used for comparison. Figure 5.16 compares values of d_s and gas holdup from experiments conducted in the large diameter glass and stainless steel columns with FT–300 wax. Results from two experiments in the glass column are shown. There was excellent agreement in Sauter mean bubble diameters in the glass and stainless steel columns when gas holdups were comparable. However, during one experiment in the glass column, a substantial amount of foam was produced and the values of d_s were markedly lower than those obtained in either of the other two experiments.

Figure 5.17 compares d_s values and gas holdups from experiments conducted in the small diameter glass and stainless steel columns. For the experiment conducted in the stainless steel column, the average gas holdup in the entire column, as well as the gas holdup in the column below a height of 1.9 m is shown. The overall gas holdup is substantially greater than that below a height of 1.9 m, indicating the presence of foam in the upper region of the column. While the overall gas holdups in the two columns (glass and stainless steel) were similar for gas velocities greater than 0.02 m/s, the Sauter mean bubble diameters are significantly different. This difference is a result of the data acquisition technique. For the experiment in the glass column, d_s is based on the entire dispersion; whereas, in the stainless steel column, d_s, is based only on the dispersion below a height of 1.9 m. This illustrates one of the problems associated

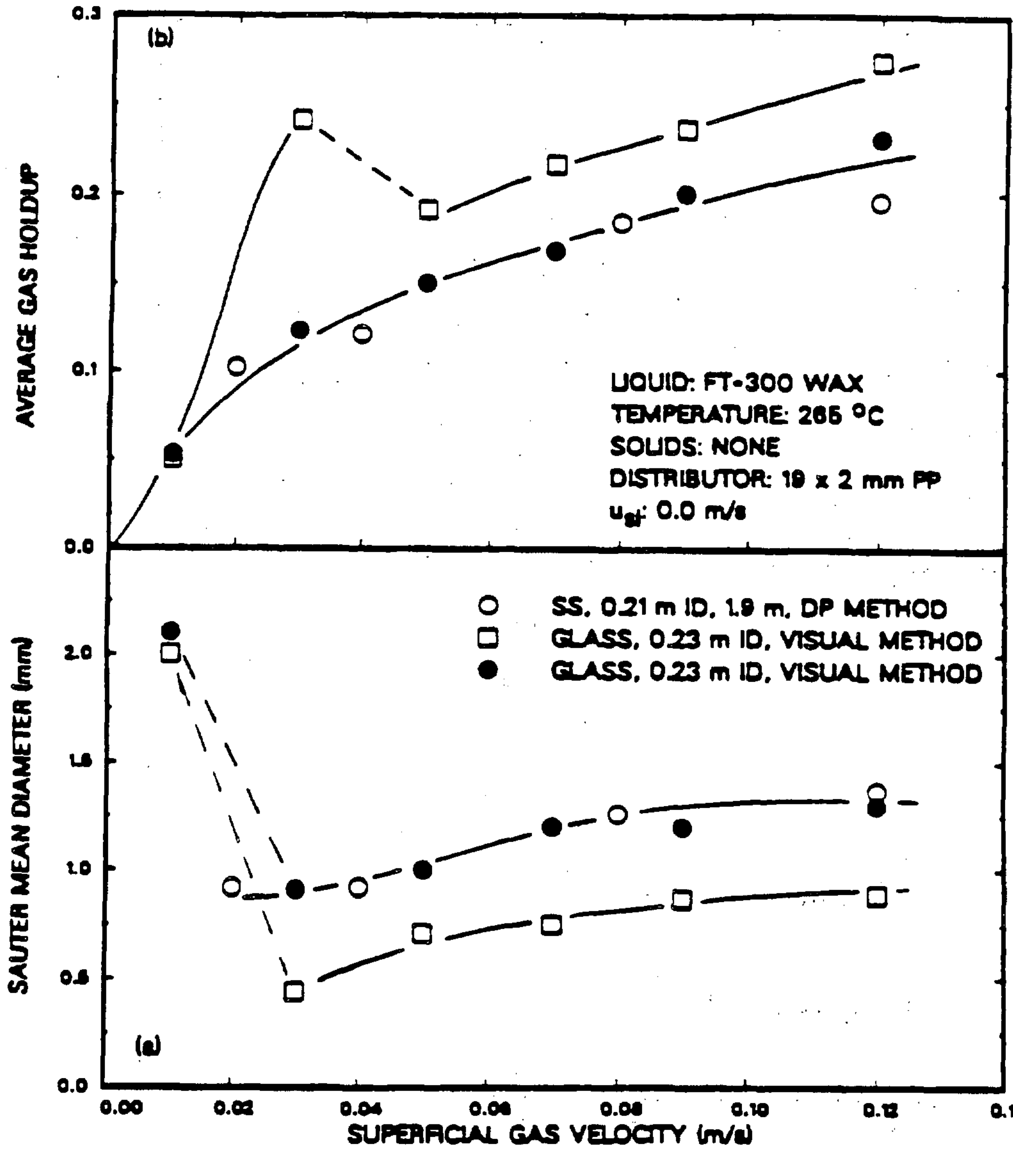

Figure 5.16. Comparison of (a) Sauter mean bubble diameters and (b) gas holdup obtained in the 0.21 m ID stainless steel column (DP method, 1.9 m) and the 0.23 m ID glass column (visual method) with FT-300 wax.

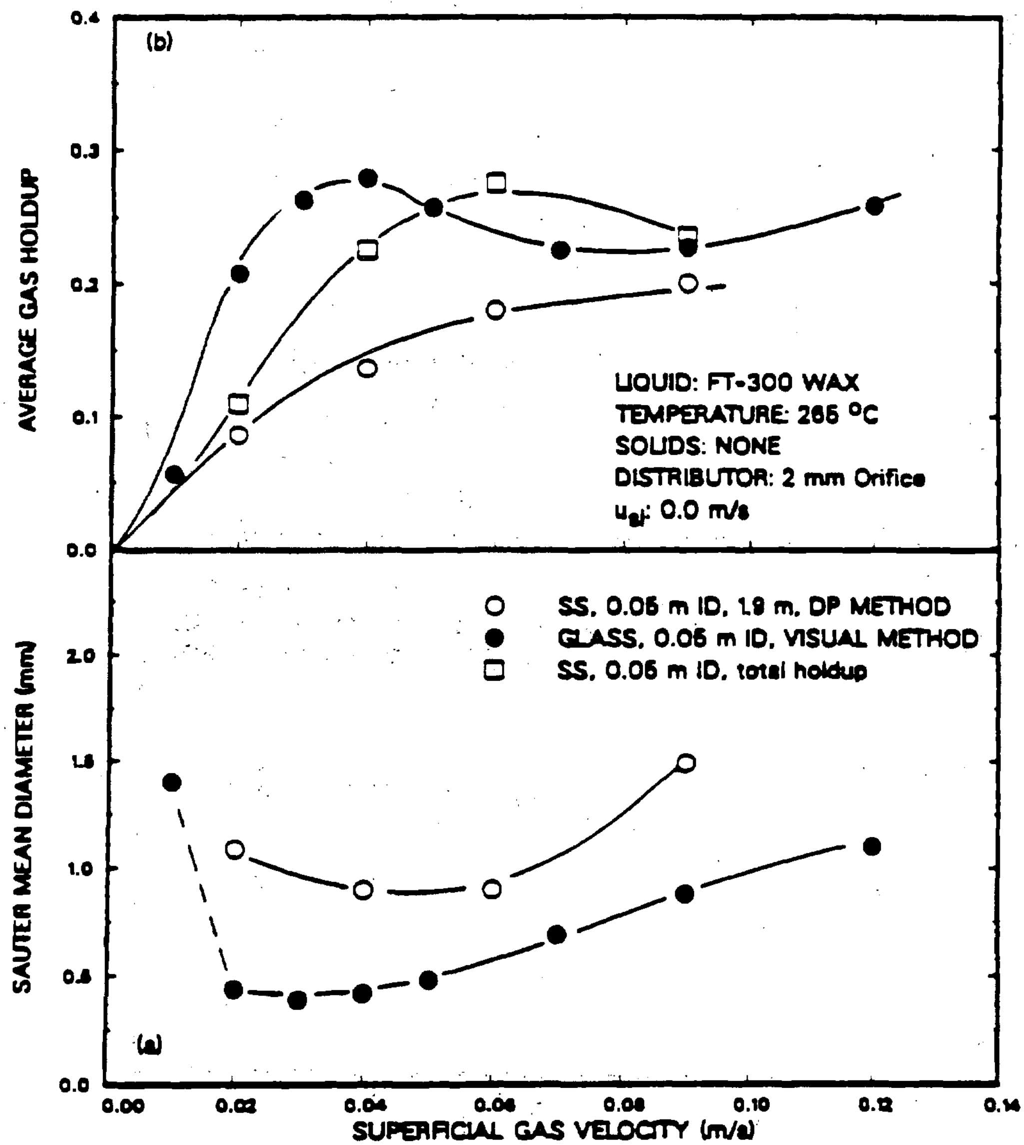

Figure 5.17. Comparison of (a) Sauter mean bubble diameters and (b) gas holdup obtained in the 0.05 m ID stainless steel column (DP method, 1.9 m) and the 0.05 m ID glass column (visual method) with FT-300 wax.

with the DGD technique (i.e. a non–uniform axial gas holdup). For the FT–300 wax system in the small diameter column, the gas holdup remains fairly uniform in the lower region of the column, but increases significantly in the uppermost region of the column for gas velocities between 0.02 and 0.09 m/s. The disengagement rate in the glass column was obtained by recording the drop in dispersion level with time via a VCR/video camera system. Thus, the disengagement profile was based on the entire dispersion. However, in the stainless steel column, the disengagement profile was based only on the dispersion below a given pressure transducer. Hence, the assumption of axial homogeneity is violated for measurements in the glass column, but not for measurements in the stainless steel column. If there is a significant amount of small bubbles located in the uppermost region of the column, which do not disengage continuously (e.g. stable foam), then there will be a bias towards small bubbles which results in a lower Sauter mean bubble diameter. Measurements made with the pressure transducers do not take into account the small bubbles in the uppermost region of the dispersion. However, these bubbles should be included in the overall Sauter mean bubble diameter. Thus, the actual values of d_s are probably within the range of values shown in Figure 5.17.

Figure 5.18 compares Sauter mean bubble diameters and gas holdups obtained from experiments conducted with SASOL wax in the small diameter glass and stainless steel columns. As stated earlier, SASOL wax does not produce foam, and as a result, the axial gas holdups remained fairly uniform. Thus, it is not surprising that Sauter mean bubble diameters and gas holdups measured using different techniques in the two columns (i.e. video/VCR - glass column; pressure transducers - stainless steel column) are in excellent agreement.

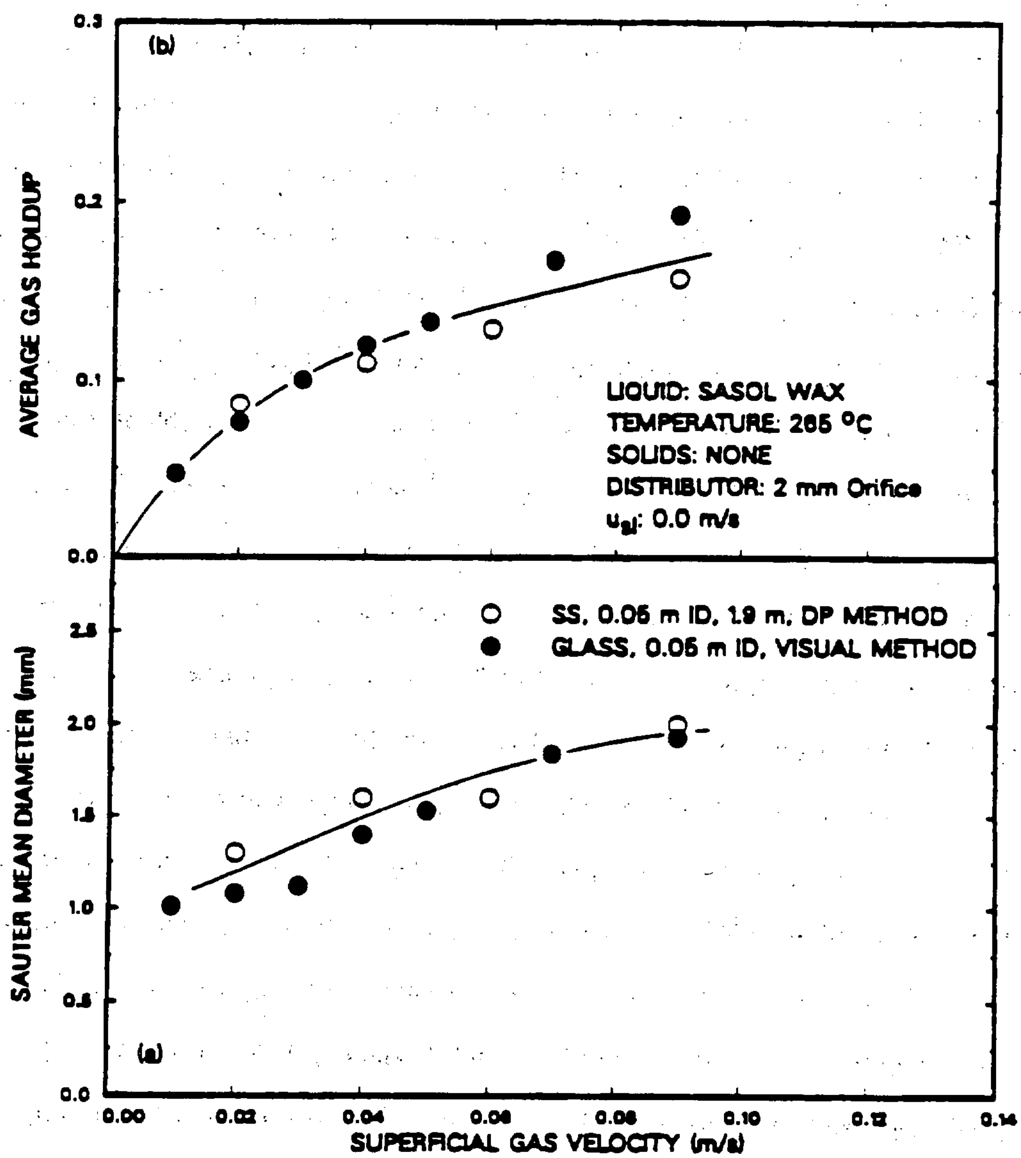

Figure 5.18. Comparison of (a) Sauter mean bubble diameters and (b) gas holdup obtained in the 0.05 m ID stainless steel column (DP method, 1.9 m) and the 0.05 m ID glass column (visual method) with SASOL wax.