Appropriate break points were then selected by the user and plots similar to those shown in Figure C-1 (APPENDIX C) obtained. The slopes and intercepts of the straight line segments were then computed and the corresponding rise velocities and hold-up fractions obtained. The computer then calculated bubble sizes for each class of bubbles, the number of bubbles in each class and finally the Sauter mean diameter. A summary data sheet for every run, similar to those shown in APPENDIX D, was then printed out.

D.3c. Experimental Results

DGD measurements were made after a minimum of one and a half hour per velocity for velocities between 0.01 and 0.05 m/s, and a minimum of 1 hour for velocities greater than 0.05 m/s except for a few runs as discussed below. It was necessary to wait for this duration to ensure that steady state was achieved, particularly when foam was present. Summary of results for selected runs are included in APPENDIX D.

D.3c.1. Effect of Operating Temperature

Figure V-66a is a plot of the Sauter mean bubble diameter (d_s) as a function of superficial gas velocity for experiments conducted with FT-300 wax in the 0.051 m ID column using a 1.85 mm orifice plate distributor. Average gas hold-up values for these runs are shown in Figure V-66b. Figures V-68a and V-68b show similar results for runs conducted with Sasol's Arge wax.

Sauter mean diameter values for FT-300 wax at 265°C (Figure V-66a) are consistently lower than values at 200°C for all velocities, except at 0.01 m/s. In the presence of foam (u_g = 0.02 to 0.05 m/s), d_s at 200°C is 50% higher than d_s at 265°C (0.73 mm compared to around 0.5 mm). This

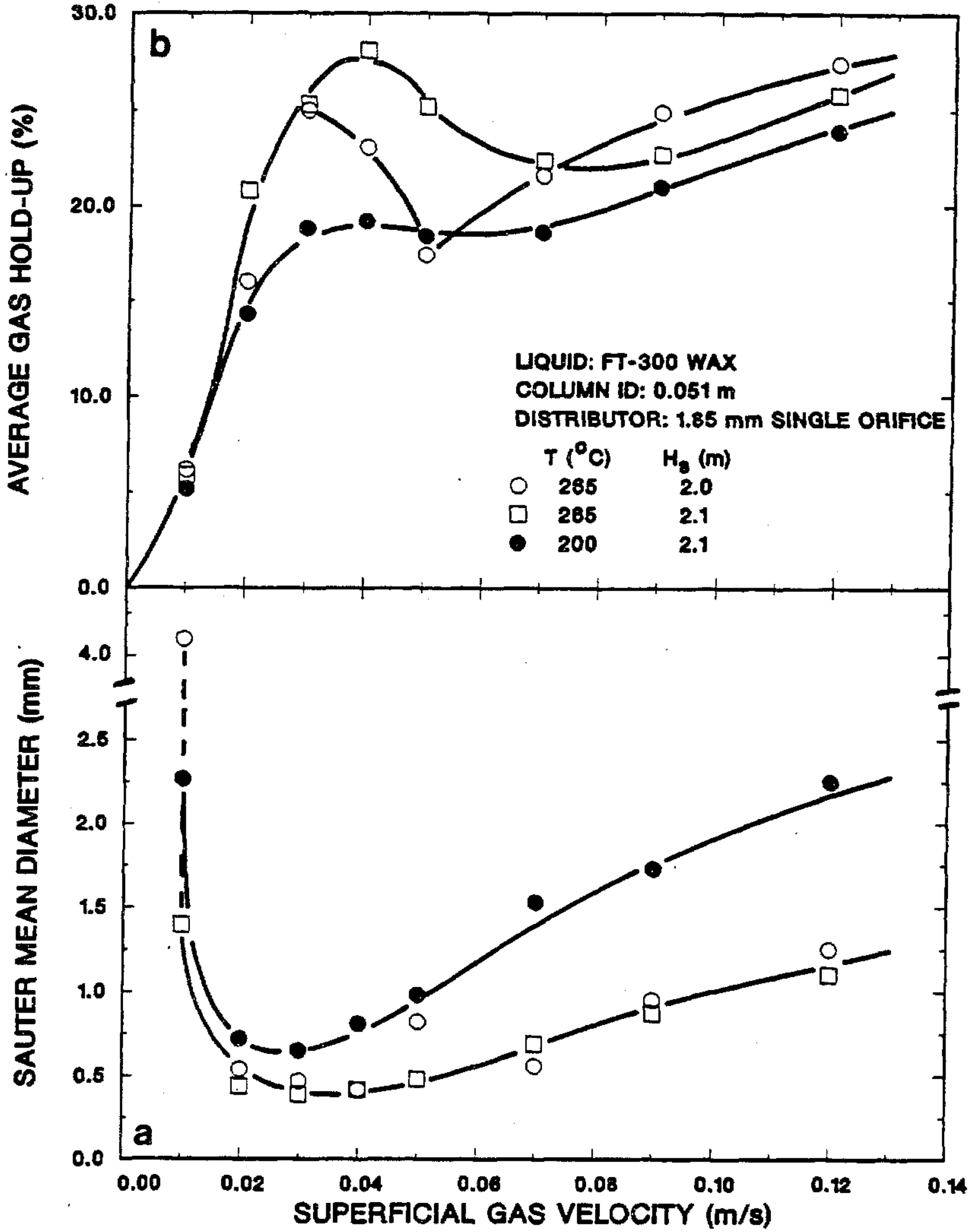

Figure V-66. Effect of temperature and superficial gas velocity on the Sauter mean bubble diameter (a) and gas hold-up (b) (○ - Run 6-1; □ - Run 13-3; ● - Run 13-2) difference increases as u_g increases and at 0.12 m/s d_s at 200°C is approximately twice as large as d_s at 265°C (2 mm compared to 1 mm). Results for Sasol reactor wax (Figure V-68a) show a similar effect of temperature on the Sauter mean diameters. Studies were also conducted with Mobil reactor wax to investigate the effect of temperature. Results from these studies showed trends that were the same as those for FT-300 and Sasol waxes, therefore, they are not shown here.

The significant differences between d_s values at the 200°C and 265°C can be attributed mainly to the different viscosities of the waxes at those temperatures. Viscosity for the three waxes investigated were between 50 to 65% higher at 200°C than at 265°C. Therefore, the effect of temperature on Sauter mean diameters can be viewed as the effect of liquid viscosity.

Figure V-67a shows the effect of gas velocity on the small and large bubble sizes for the runs conducted at 200°C and 265°C with FT-300 wax. The variation in the volume fraction of large bubbles with gas velocity at the two temperatures is shown in Figure V-67b. The results for the two runs are given in Tables D-1 and D-2 (APPENDIX D). These results show that small bubbles determine the value of d_s at most velocities. However, at higher gas velocities, the volume fraction of large bubbles reaches as high as 80% and large bubbles have some effect on the value of d_s. This causes the Sauter mean bubble diameter to increase slightly for velocities 0.05 m/s and higher. Figure V-67a shows that the diameter of small bubbles was not affected by gas velocity, however, large bubbles increased in diameter at higher velocities (u_g = 0.07 - 0.12 m/s) mainly due to the growing number of slugs. The diameter of small bubbles at 265°C was around 0.35 mm, while the diameter for small bubbles at 200°C was around 0.45 mm. The diameters

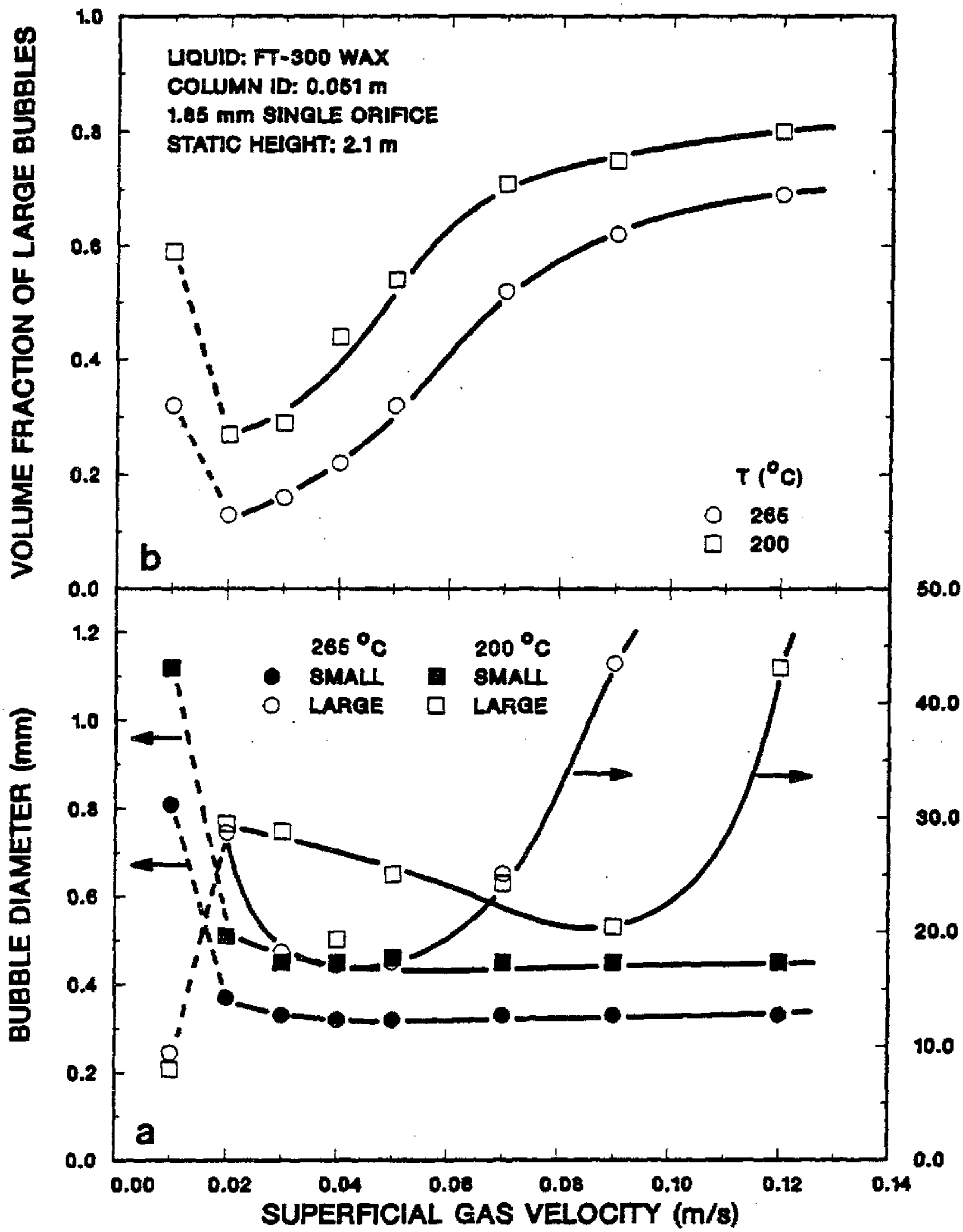

Figure V-67. Effect of temperature and superficial gas velocity on bubble size (a) and volume fraction of large bubbles (b) (○ - Run 13-3; □ - Run 13-2)

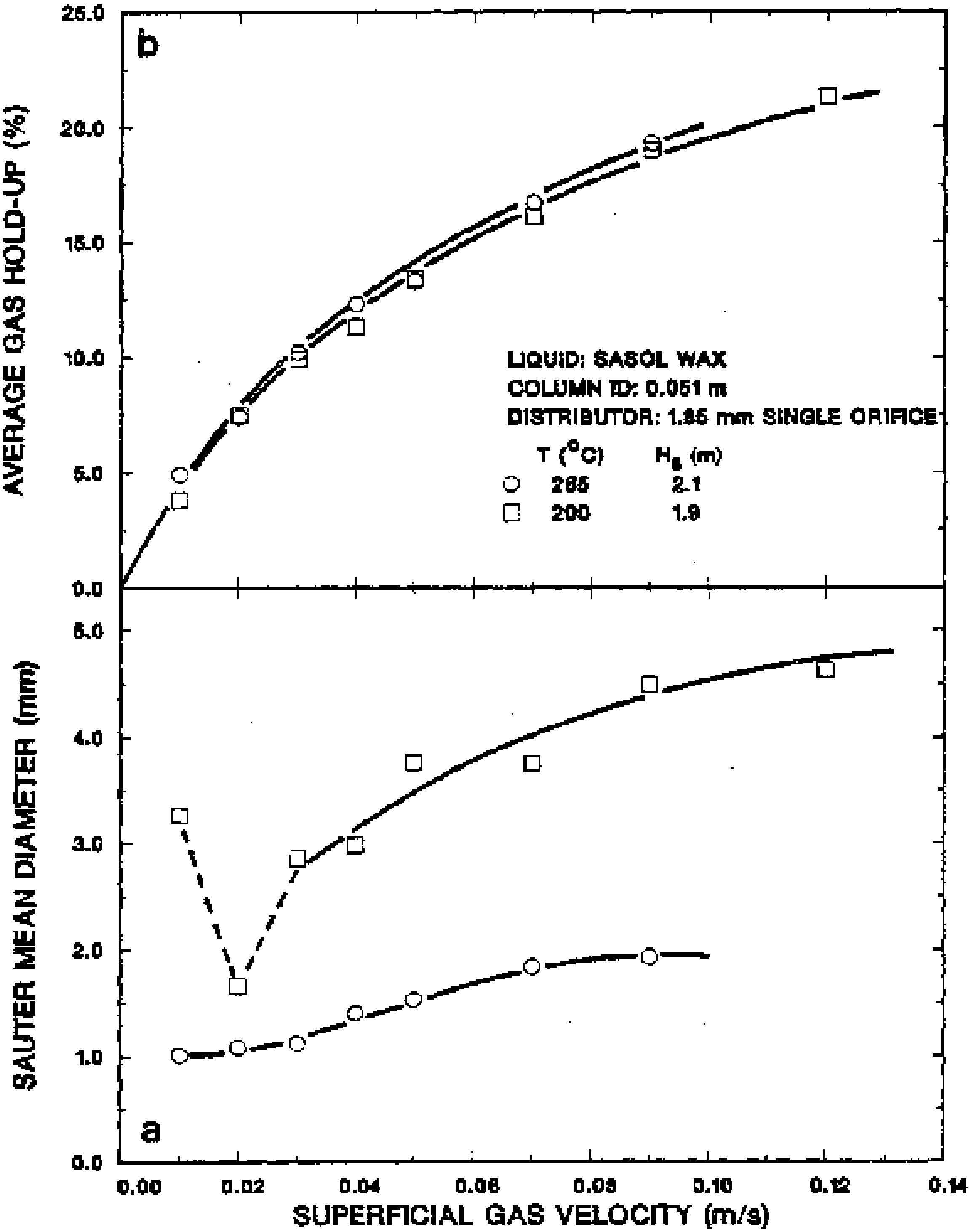

Figure V-68. Effect of temperature and superficial gas velocity on the Sauter mean bubble diameter (a) and gas hold-up (b) (○- Run 8-4 □- Run 8-3) of large bubbles are similar at the two temperatures. These results show that small bubbles are mainly responsible for the differences in d_s values at the two temperatures. This is in agreement with results reported by Schugerl (1981), who conducted studies with glycerine solutions and showed that bubbles in that system could be classified into three size ranges. The small bubbles had the strongest influence on d_s. Schugerl's studies also indicate that d_s increases with viscosity and superficial gas velocity.

Hold-ups at 200°C were consistently lower than at 265°C with all waxes for the range of superficial gas velocities employed in these studies. Figure V-66b shows a significant difference between hold-up values at the two temperatures for velocities between 0.02 and 0.05 m/s, however this is not reflected in the d_s values. The difference in hold-ups is mainly due to the extent of foaming, which was different for the different runs. In the presence of foam the number of small bubbles is exceedingly high and exerts a strong influence on d_s. However, the diameter of these bubbles is not influenced by the amount of foam and remains fairly constant (as shown in Figure V-67a), therefore, d_s, in the presence of foam, is independent of the hold-up value. Figure V-66a also illustrates reproducibility of results (d_s values) for the two runs conducted at 265°C. Results from the two runs at 265°C are in good agreement, except for discrepancies between d_s values at 0.01 and 0.05 m/s, which could be attributed to the foaming characteristics (at 0.05 m/s) or to errors in the measurement process (at 0.01 m/s). At 0.05 m/s, foam was still present in Run 13-3 but it was absent in Run 6-1.

D.3c.2. Effect of Distributor Type

Figures V-69 and V-71a illustrate the effect of distributor type on

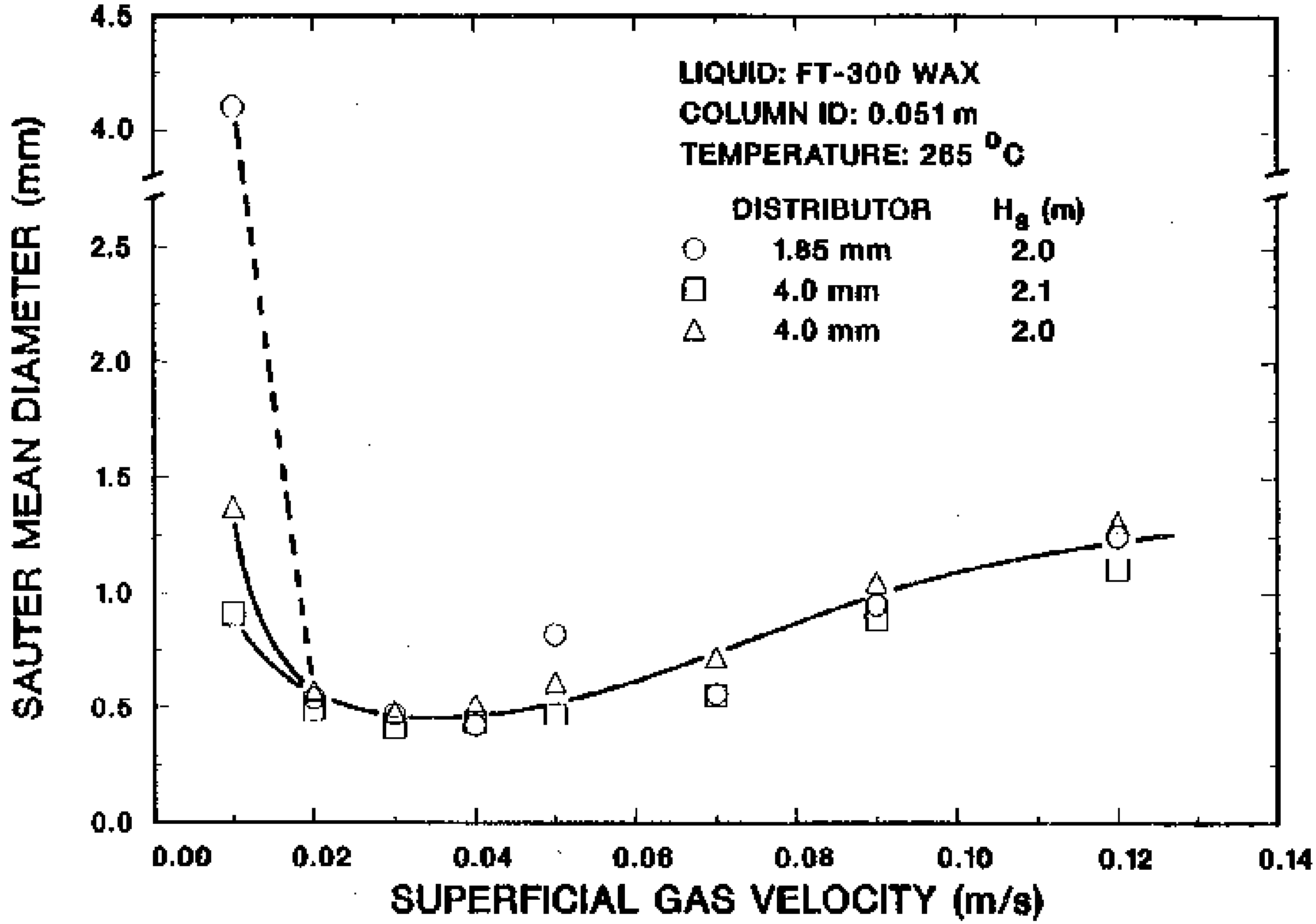

Figure V-69. Effect of distributor type and superficial gas velocity on the Sauter mean bubble diameter (○- Run 6-1; □ - Run 6-2; △ - Run 6-3) the Sauter mean diameter for FT-300 and Mobil reactor wax. Results for Sasol reactor wax are qualitatively similar to those for Mobil wax and are not shown. Only orifice plate distributors (1.85 mm and 4 mm) were used in experiments with FT-300 wax. Runs with a 40μm SMP distributor caused excessive foaming preventing the use of the DGD technique for bubble size distribution measurements. The 1.85 mm orifice plate distributor and the 40μm SMP were used for experiments with the reactor waxes. With these waxes foaming was not a problem and DGD measurements could be made with both distributors. All runs were conducted at a temperature of 265°C. Figure V-71b shows hold-up values for the two runs conducted using Mobil reactor wax.

Results for runs made using FT-300 wax (Figure V-69) show no significant effect of distributor type, with similar d_s values resulting for both 1.85 and 4 mm distributors. There is, however, significant variation in d_s values at a superficial gas velocity of 0.01 m/s. This variation might be indicative of the inability of the DGD technique to predict Sauter mean diameters at very low gas velocities (or low gas hold-up values). However, trends are similar for all runs made with FT-300 wax, i.e. d_s is significantly greater at 0.01 m/s compared to values in the velocity range 0.02 - 0.05 m/s. Results for FT- 300 wax once again show that when foam is present the Sauter mean diameter is approximately constant (i.e. independent of the gas velocity and the amount of foam present).

Figure V-70a shows the effect of gas velocity on the small and large bubble diameters for experiments conducted with the 1.85 mm and 4 mm orifice plate distributors using FT-300 wax. The size of small bubbles, with the 4 mm orifice, is around 0.35 mm which is similar to values with the

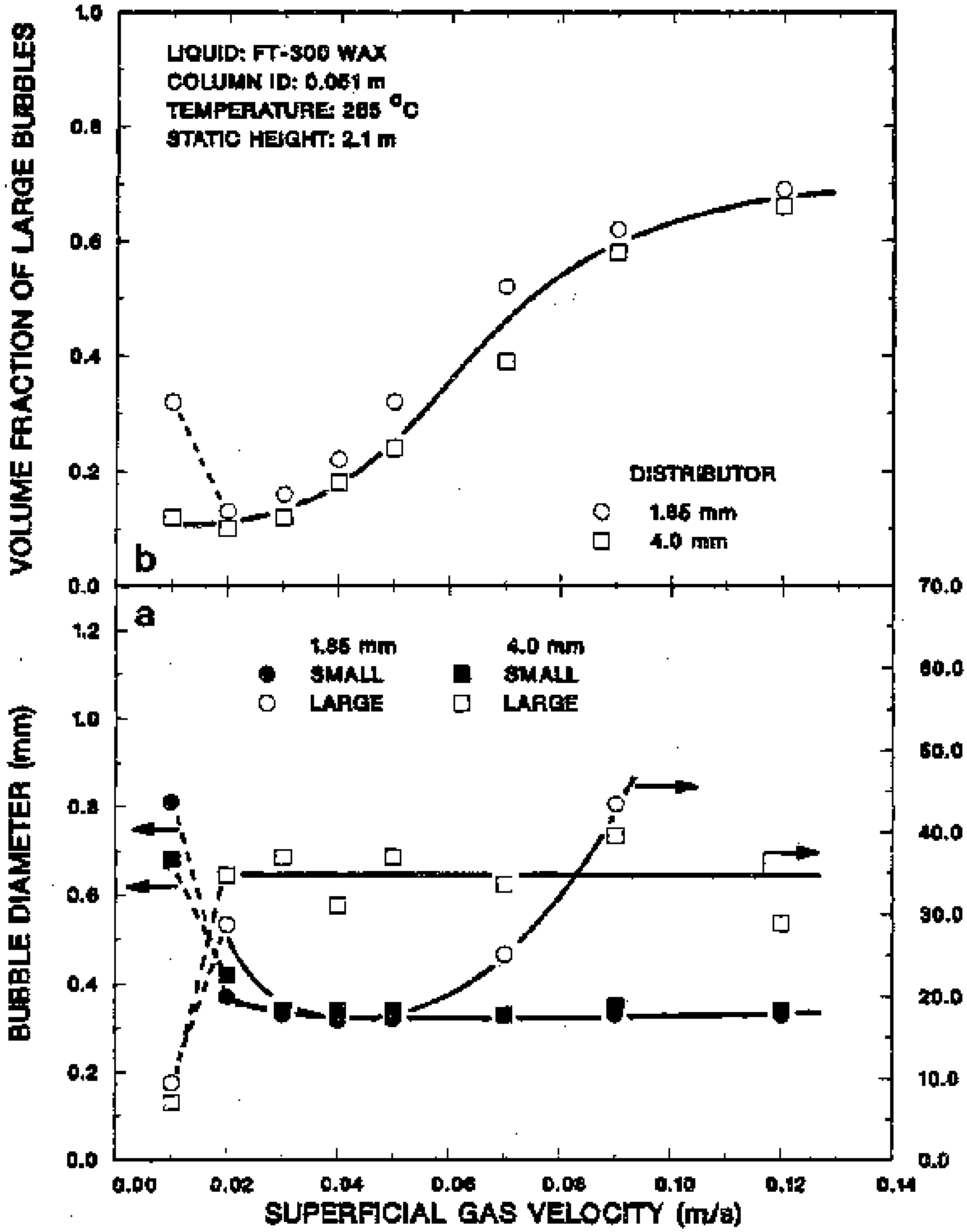

Figure V-70. Effect of distributor type and superficial gas velocity on bubble size (a) and volume fraction of large bubbles (b) (○ - Run 13-3 □ - Run 6-2)

1.85 mm orifice (0.33 mm). Table D-3 (APPENDIX D) gives results for experiments with the 4 mm distributor. These results indicate little variation in the size of small bubbles with gas velocity, similar to observations with the 1.85 mm distributor. The variation in the volume fraction of large bubbles with gas velocity is similar for the two runs (Figure V-70b). Therefore, the influence of large bubbles on the Sauter mean diameters for the two distributors (for u_g > 0.05 m/s) is expected to be the same, as is shown in Figure V-69. Figure V-69 once again shows that results from two different runs with FT-300 wax, using the 4 mm orifice plate distributor, are in fairly good agreement with one another.

Results from experiments conducted with Mobil reactor wax (Figure V-71a) showed a minimal effect of distributor type, with the SMP distributor resulting in d_s values that are somewhat lower than those with the 1.85 mm orifice plate distributor. Sauter mean diameter increased with gas velocity from around 1 mm at 0.01 m/s to approximately 5 mm at 0.12 m/s using the 1.85 mm distributor. These values are about 20% higher than those with the SMP distributor at most velocities.

Most of the literature dealing with the influence of distributor type on bubble size indicates that bubble sizes in fully established gas-liquid dispersion is independent of distributor type (e.g. Akita and Yoshida, 1974; Mersmann, 1978). Findings from the present study with waxes appear to be in good agreement with trends reported in literature.

D.3c.3. Effect of Column Diameter

The effect of column diameter was investigated using FT-300 wax in the 0.051 m ID and 0.229 m ID glass columns. Figure V-72 shows results from these studies. Sauter mean diameters from three runs in the 0.229 m ID

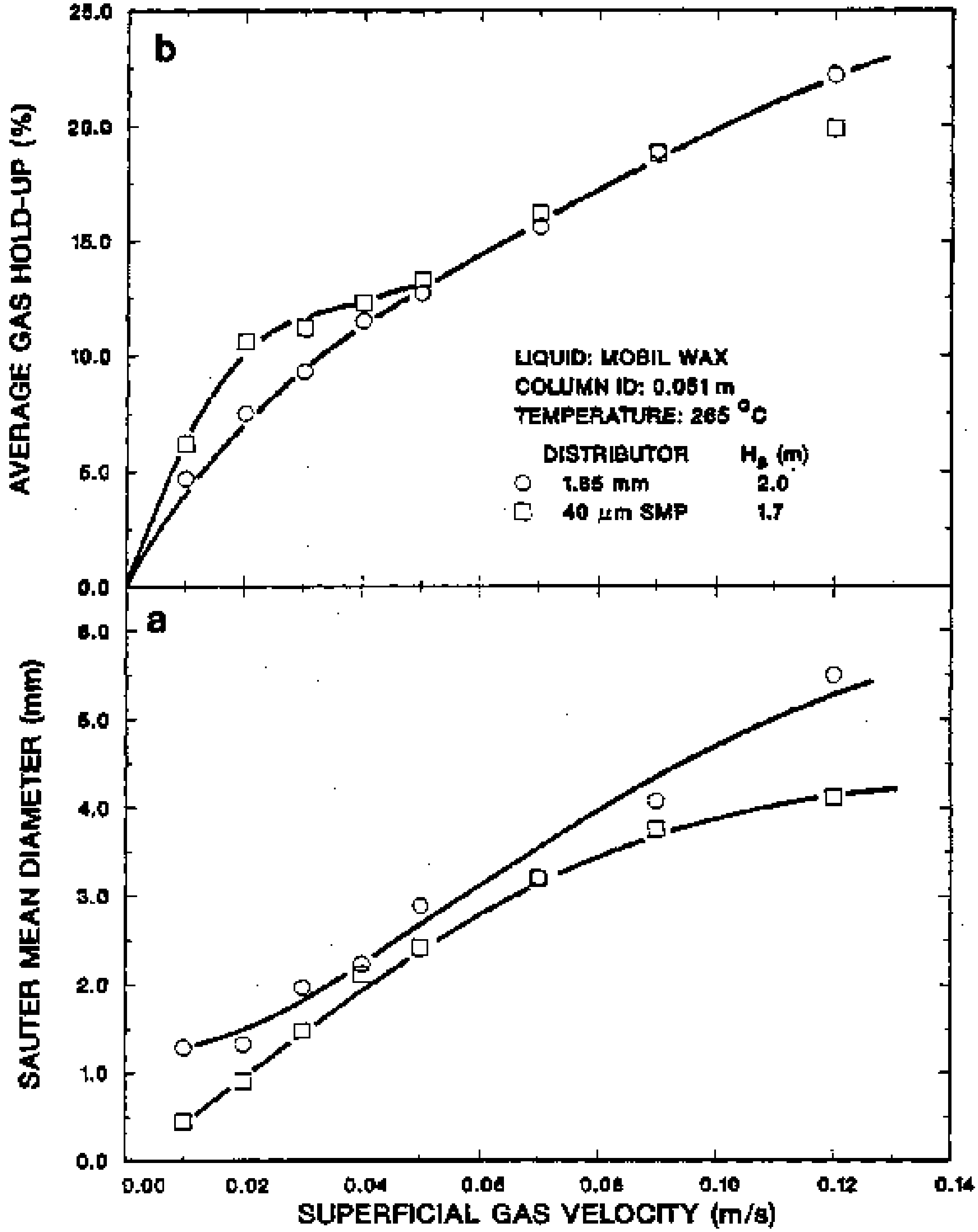

Figure V-71. Effect of distributor type and superficial gas velocity on the Sauter mean bubble diameter (a) and gas hold-up (b) (○ - Run 9-3; □ - Run 9-4) column and one run in the 0.051 m ID column are presented in Figure V-72a. Figure V-72b shows hold-up values for these runs. All runs were conducted at a temperature of 265°C. A 19 X 1.85 mm distributor was used for runs made in the large column, while the 1.85 mm orifice plate distributor was used in the 0.051 m ID column.

Sauter mean diameters from runs made in the two columns appear to be qualitatively similar with d_s approaching a constant value of around 0.8 mm at higher velocities (u_g greater than 0.05 m/s). The flow field in the two columns is different, with runs in the smaller column having a greater tendency to produce more foam and slugs were present at higher velocities. This difference manifests itself in the shape of the curves shown in Figure V-72. All runs in the 0.051 m ID column produced slugs that were distributed along the entire column length at u_g values greater than 0.05 m/s, however, this was not seen in the larger column. Churn-turbulent flow prevailed in this column for these high gas flow rates. The effect of gas velocity on the small and large bubbles for the run in the 0.051 m ID column and one run in the 0.229 m ID column is shown in Figure V-73a. The variation in the volume fraction of large bubbles with gas velocity for the two runs is shown in Figure V-73b. A significant difference between the two columns is the contribution of large bubbles to the Sauter mean diameter. The volume fraction of large bubbles (f_L) in the 0.051 m ID column increased steadily with gas velocity and reached 70% at 0.12 m/s, whereas f_L in the large column appears to reach a constant value of around 50% for gas velocities above 0.05 m/s. Slugs in the smaller column are stabilized by the wall and continue to grow in size with an increase in gas velocity, however, large bubbles in the 0.229 m ID column are relatively

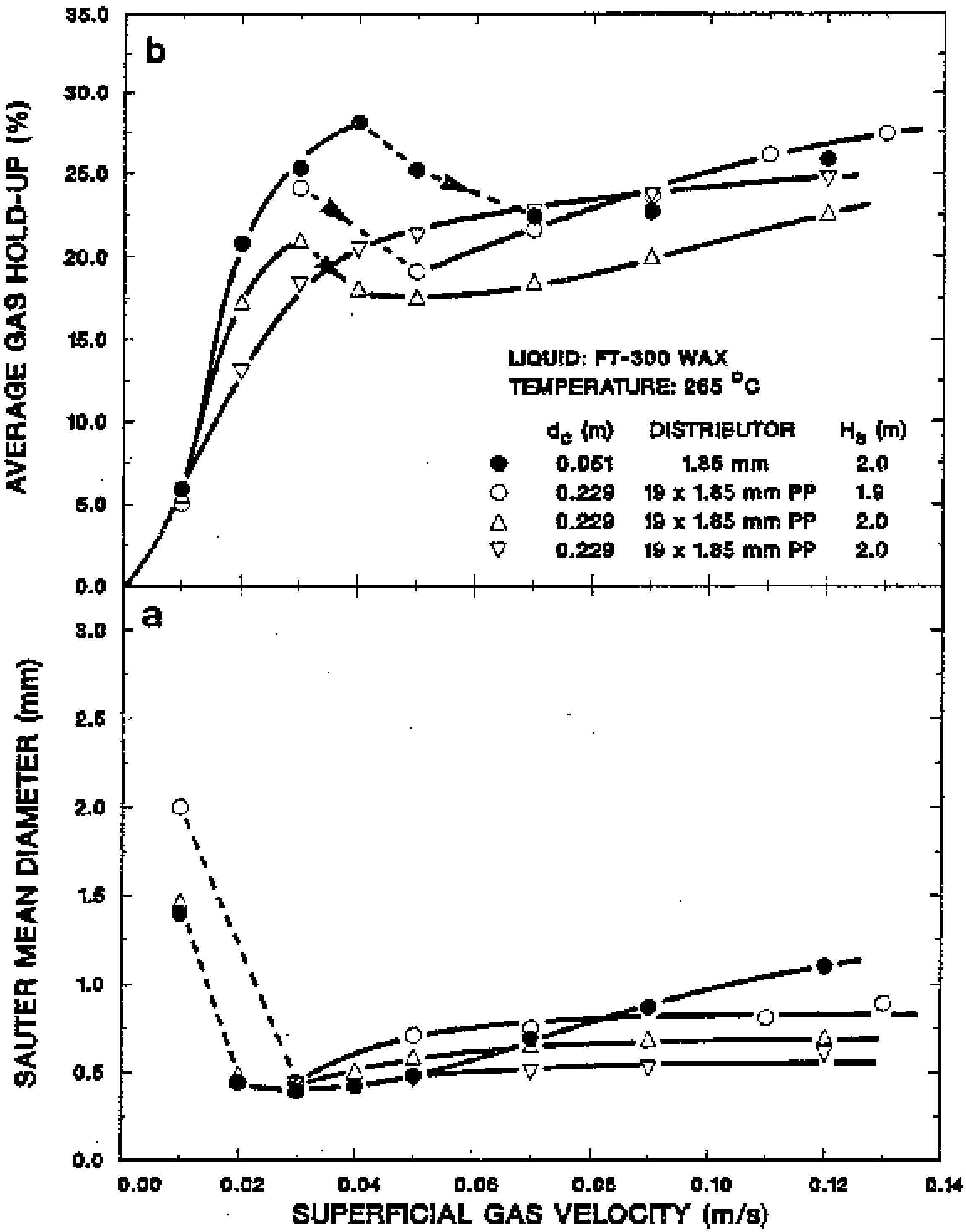

Figure V-72. Effect of column diameter and superficial gas velocity on the Sauter mean bubble diameter (a) and gas hold-up (b) (● - Run 13-3; ○ - Run 1-3; △ - Run 2-8; ▽ - Run 2-9)

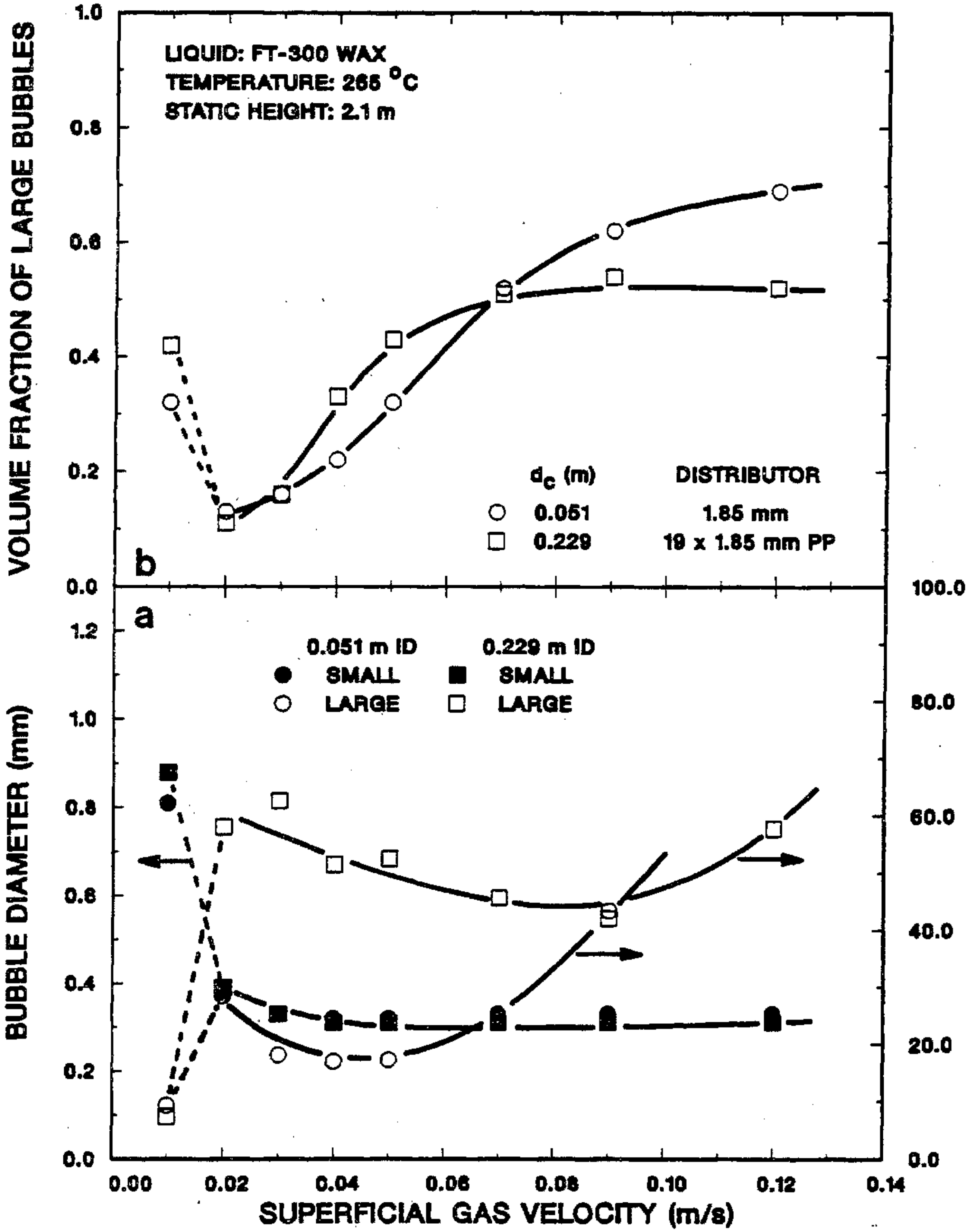

Figure V-73. Effect of column diameter and superficial gas velocity on bubble size (a) and volume fraction of large bubble (b) (○- Run 13-3; □- Run 2-8) unstable and do not grow with an increase in gas velocity. Figure V-73a shows that in the 0.229 m ID column, large bubbles remained between 50 and 60 mm in diameter for gas velocities greater than 0.02 m/s, however, results for the 0.051 m ID column indicate that large bubbles (or slugs) continue to grow for velocities greater than 0.05 m/s. This explains the different trends observed for the variation of d_s with u_g in the two columns. The diameter of small bubbles for the large column is 0.31 mm and remains fairly constant over the entire range of superficial gas velocities (Table D-4). This value compares well with the value of 0.33 mm for the 0.051 m ID column (Table D-1). This is also illustrated in Figure V-73a.

The correlation presented by Akita and Yoshida (1974), based on studies conducted with other systems, indicates that d_s should be higher for 0.051 m ID column compared to d_s for the 0.229 m ID column. This is not clear from results illustrated in Figure V-72 due to the discrepancy in values from the different runs made in the 0.229 m ID column.

Results from the three runs in the 0.229 m ID column show similar trends, i.e. d_s reaches a fairly constant value at around 0.05 to 0.07 m/s, however, there is some discrepancy between values from the different runs. This can be partly attributed to different run times employed and to different foaming characteristics. Run 1-3 was conducted using shorter run times compared to Runs 2-8 and 2-9 (20-30 minutes per velocity for the former compared to 60-90 minutes for the latter runs). Hold-up values for the runs conducted in the 0.229 m ID column (Figure V-72b) reflect these differences.

D.3c.4. Effect of Wax Type

Figure V-74a illustrates the effect of wax type on the Sauter mean bubble diameter. Results are presented for runs made in the 0.051 m ID column using a 1.85 mm orifice plate distributor at a temperature of 265°C. Figure V-74b shows the effect of wax type on the volume fraction of large bubbles (f_L). Hold-up values for the three runs are shown in Figure V-75. Results for these three runs are summarized in Tables D-1, D-5 and D-6 in APPENDIX D.

Sauter mean diameters for the three waxes are significantly different as shown in Figure V-74a. FT-300 wax shows a decrease in d_s as gas velocity increases from 0.01 m/s to 0.02 m/s, and stays at around 0.5 mm for velocities in the range 0.02 to 0.05 m/s. It increases to around 1 mm as u_g approaches 0.12 m/s. These values for the Sauter mean diameter are in good agreement with those reported in literature. Quicker and Deckwer (1981) have reported a value of around 0.7 mm for FT-300 wax. Workers at Mobil (Kuo et al., 1985) conducted DGD studies with FT-200 wax and reported average bubble diameters of 2.2 mm at 0.012 m/s and 1.2 mm at 0.022 m/s. The decrease in d_s values when the flow regime changes from bubbly flow (u_g around 0.01 m/s) to foamy flow regime was also observed by Quicker and Deckwer.

Sauter mean diameters for Sasol wax are around 1 mm at a gas velocity of 0.01 m/s and increase steadily to around 2 mm at 0.09 m/s. Similarly, Mobil wax gives d_s values that range from around 1 mm at 0.01 m/s to 5.5 mm at 0.12 m/s. The volume fraction of large bubbles shows similar behavior for these two reactor waxes (Figure V-74b). In the absence of foam, the concentration of larger bubbles increases due to coalescence. FT-300 wax,

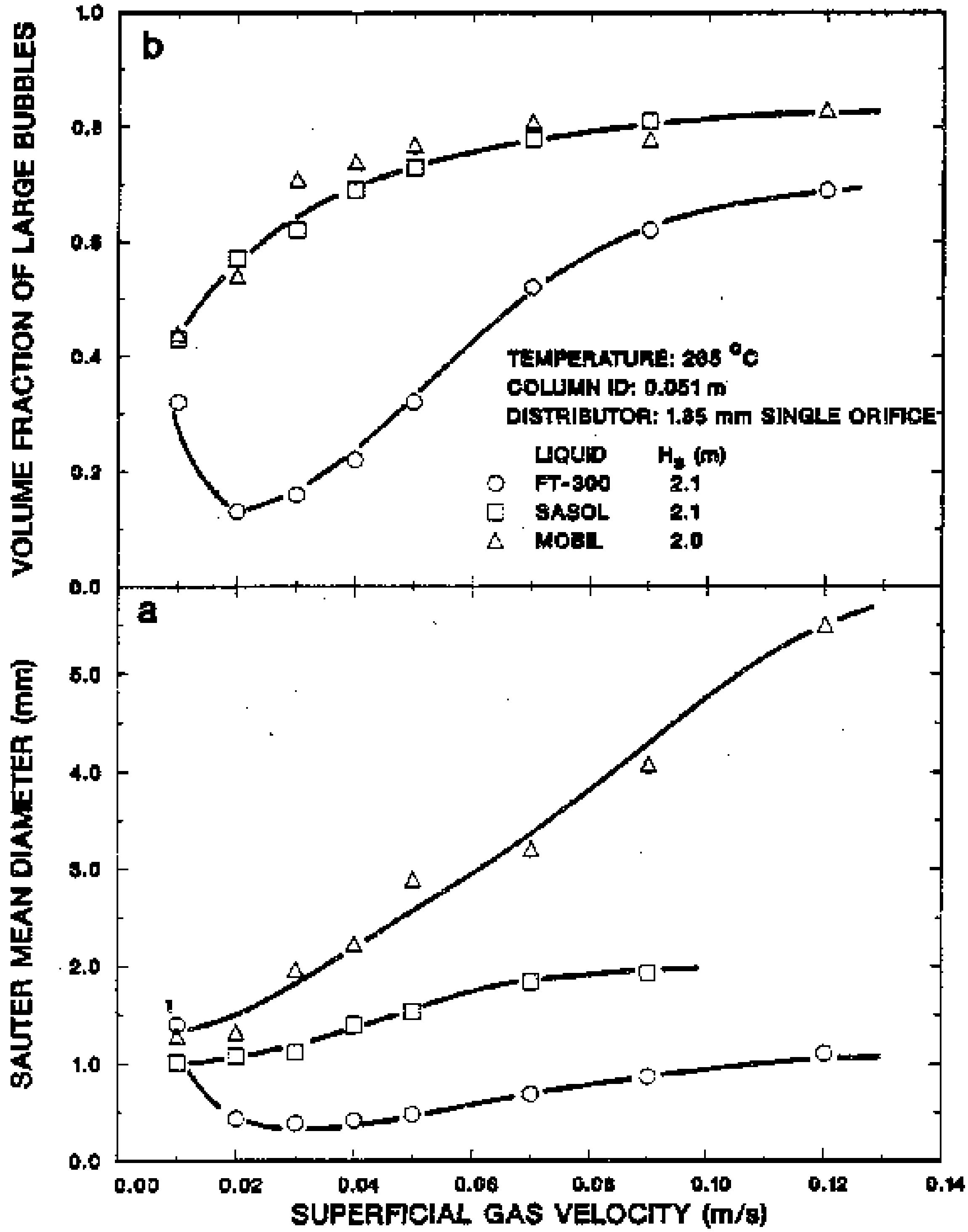

Figure V-74. Effect of liquid medium and superficial gas velocity on the Sauter mean bubble diameter (a) and volume fraction of large bubbles (b) (○- Run 13-3; □- Run 8-4; △- Run 9-3) on the other hand, has a large fraction of small bubbles which remains entrained in the dispersion. However, once gas velocities reach around 0.05 to 0.07 m/s, slugs begin to dominate and the hold-up begins to be dominated by large bubbles. Therefore, f_1 appears to increase beyond this point, showing a trend similar to that for the reactor waxes.

Figure V-75 shows that hold-up values for the two reactor waxes (Sasol and Mobil) are very similar, despite significant differences in the Sauter mean bubble diameters (as shown in Figure V-74a). Hold-up values for FT-300 wax are significantly higher than those for the reactor waxes in the velocity range 0.02-0.07 m/s, therefore, the lower Sauters for this wax are as expected. For velocities above 0.07 m/s, the difference in hold-ups is less than 5% (absolute), however, d_s values for FT-300 wax are still significantly lower. These results indicate that even though different waxes give similar hold-ups, the Sauter mean bubble diameters can be significantly different.

Experiments were also conducted at 200°C with the three waxes using the 1.85 mm orifice plate distributor. The trends observed in these experiments are qualitatively similar to those at 265°C and are not shown here.

Schumpe and Grund (1986) have recently applied the DGD technique to study the gas hold-up structure for the air-water system in a bubble column. In their studies, two distinct bubble classes were observed for all experiments. They show that the rise velocity for small bubbles (and therefore the diameter of small bubbles) remained almost constant for the velocity range 0.01-0.20 m/s. This is similar to the behavior of small bubbles found in the present work.

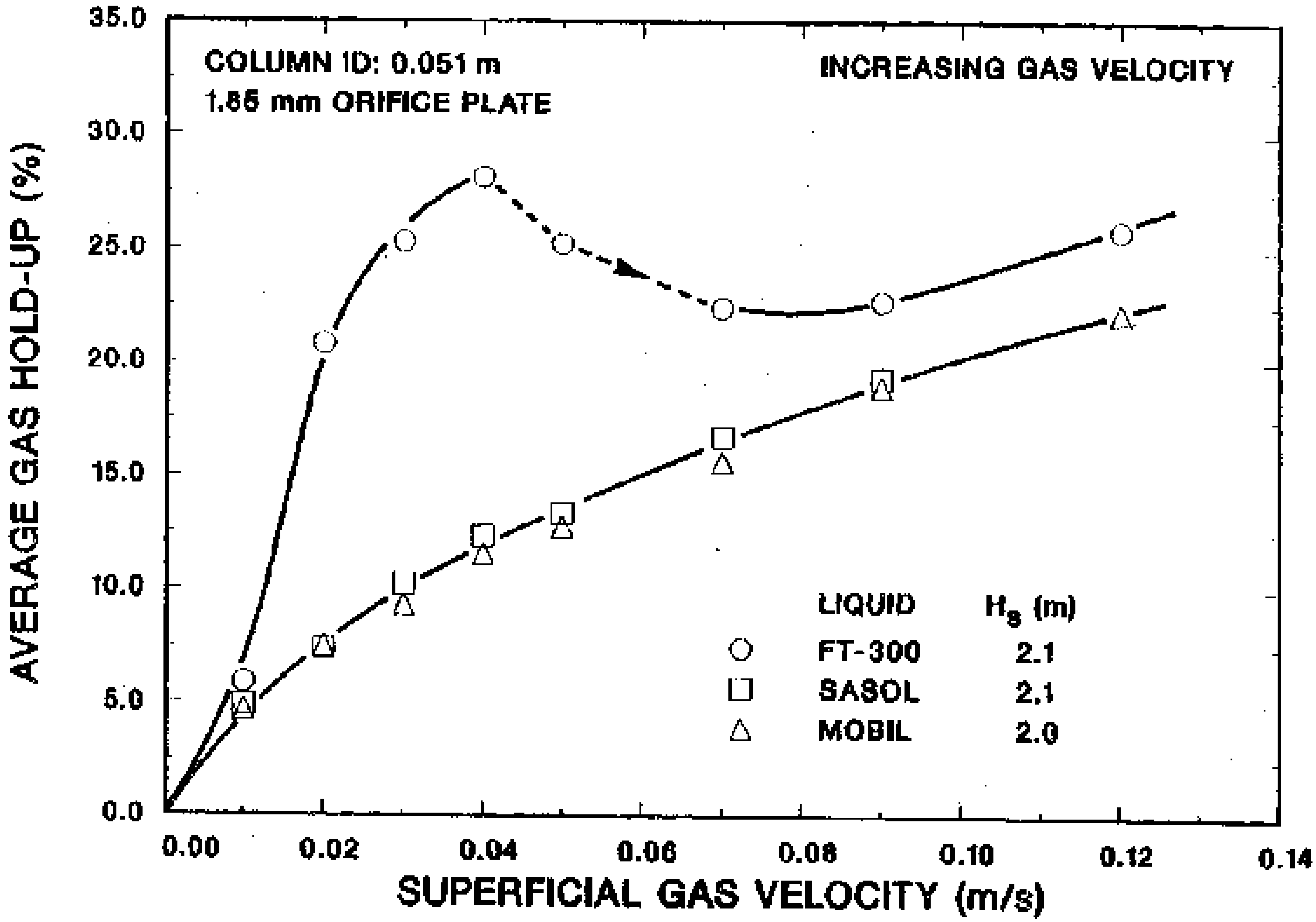

Figure V-75. Effect of liquid medium and superficial gas velocity on gas hold-up (○ - Run 13-3; □ - Run 8-4; △ - Run 9-3)