with the average value curves.

The above investigations indicate that the reproducibility of hold-up values in a system which has a capacity to foam, is dependent on a complex interaction between a number of factors. Some of these factors, such as the operating procedure, can be controlled independently. Whereas, effects due to the aging of wax, and the amount of foam produced, are not as predictable. Our study shows that it is possible to eliminate foaming by using a relatively high start-up velocity.

B.3. Effect of Temperature

The effect of temperature on gas hold-up was investigated for temperatures between 160 and 280°C. Experiments were done in the 0.051 m ID and the 0.229 m ID glass columns using FT-300 wax. The 40 μm SMP and 1.85 mm orifice plate distributors were used in the 0.051 m ID column, whereas the 5 X 1 mm, 19 X 1 mm and the 19 X 1.85 mm perforated plate distributors were employed in the 0.229 m ID column. Results from these experiments can be summarized as follows:

- In the "foamy" regime, an increase in temperature is accompanied with an increase in foam, and thus higher hold-up values.
- In the absence of foam, hold-ups showed a marginal decrease with a decrease in temperature.
- It was possible to avoid foaming by operating at sufficiently low temperatures (e.g. 160°C with the 1.85 mm orifice plate distributor in the 0.051 m ID column or at 170°C with the 5 X 1 mm perforated plate distributor in the 0.229 m ID column).

Results from runs with FT-300 wax in the 0.051 m ID column using the 1.85 mm orifice plate distributor at four different operating temperatures

(160, 200, 265 and 280°C) are shown in Figure V-18. All runs were conducted using increasing order of gas velocities. These results show that the effect of temperature is significant in the presence of foam. An increase in temperature results in a corresponding increase in hold-up values, and the foam persists over an extended range of velocities at higher temperatures. The highest gas hold-ups were obtained at 280°C, whereas the lowest hold-ups were obtained at 160°C. The runs conducted at 200°C and 265°C show a substantial increase in gas hold-up as foam is produced ($u_g < 0.03$ m/s) followed by a decrease in hold-up as the transition from the "foamy" regime to the "slug flow" regime takes place. The run conducted at 280°C showed a similar increase in hold-up as foam was produced, however, the transition to the "slug flow" regime was not observed in the velocity range employed (0.01-0.09 m/s). No foam was produced during the run conducted at 160°C, therefore hold-up values were consistently lower for this run. For this run the flow regime changed from "homogeneous bubbling" to the "slug flow" regime directly. In the "slug flow" regime the effect of temperature is less pronounced, with marginally lower hold-ups obtained at lower temperatures.

Results illustrating the effect of temperature on hold-up when the 40 $\mu$m sintered metal plate distributor (SMP) was used in the 0.051 m ID column, are presented in Figure V-19. Six runs were made at 265°C, two runs at 280°C and only one run at 200°C. The data for runs conducted at 265°C were divided into two groups, based on the absence or presence of foam, and averaged (curves 1 and 2), whereas data from individual runs at 200 and 280°C are presented. With this distributor a substantial amount of

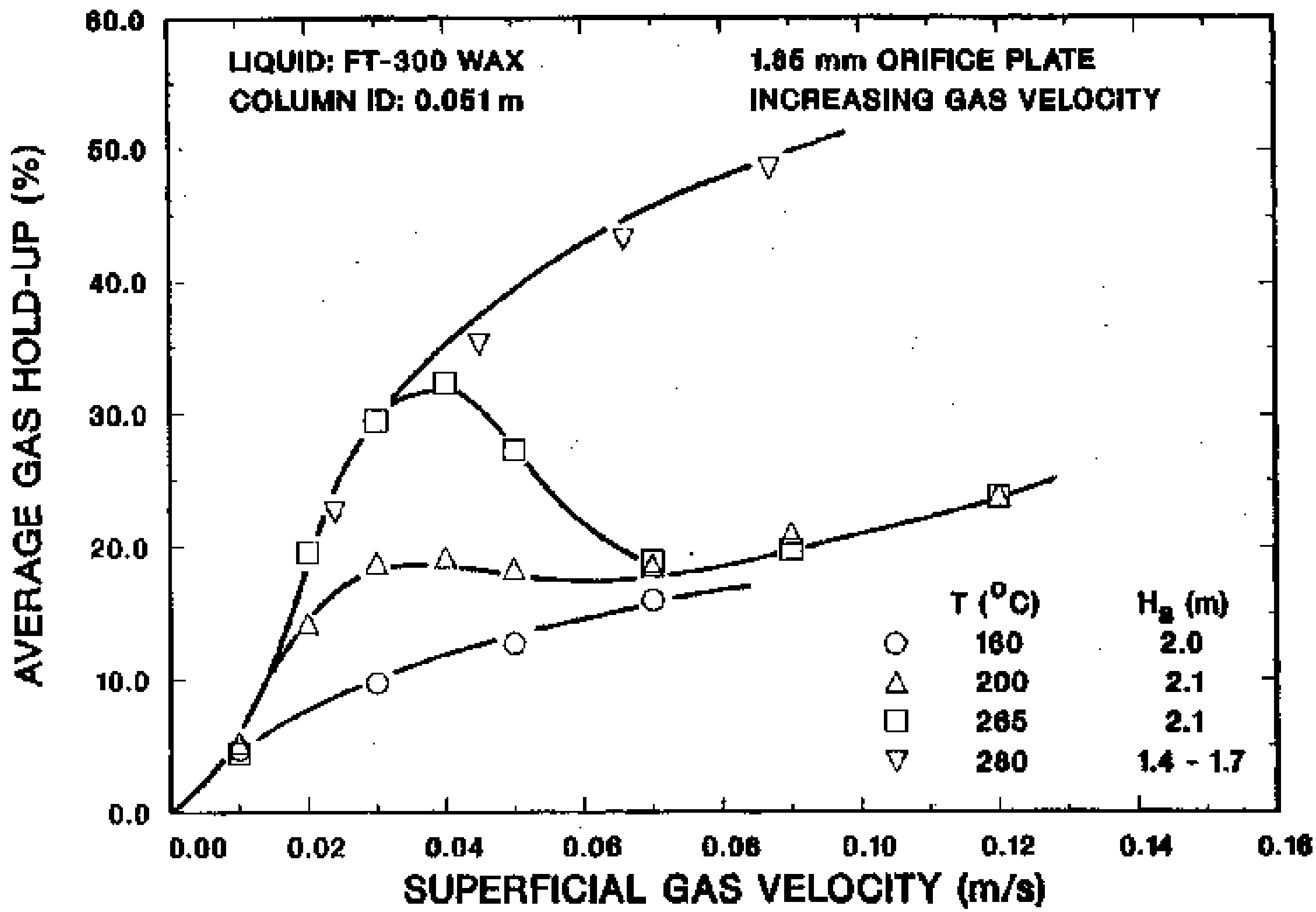


Figure V-18. Effect of operating temperature on gas hold-up (○ - Run 1-11; △ - Run 13-2; □ - Run 13-3; ▽ - Run 1-12)

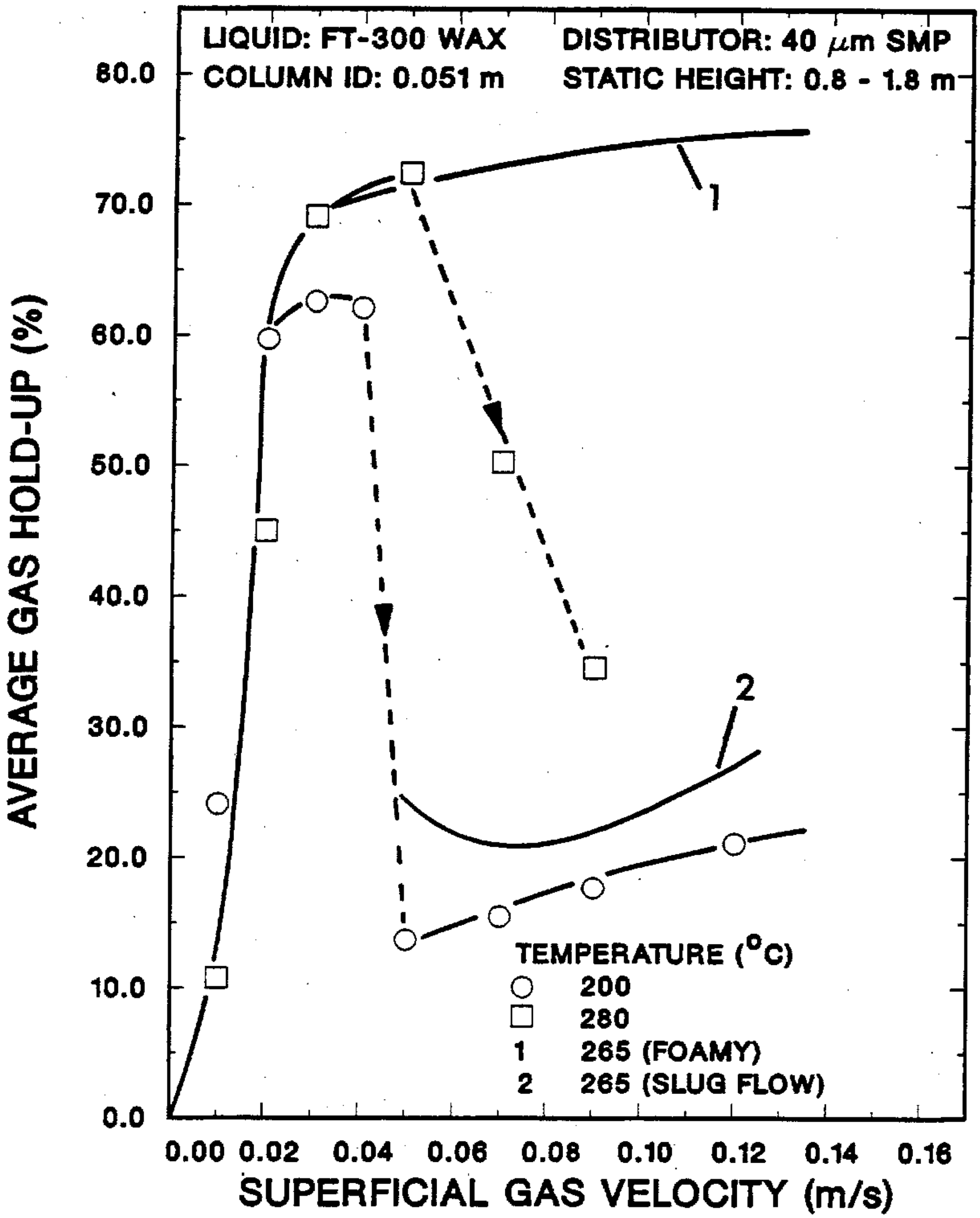


Figure V-19. Effect of operating temperature on gas hold-up (○ - Run 5-3; □ -Run 1b-4; curves 1 & 2 - arithmetic averages from 6 runs) foam was produced even at 200°C. However, the transition from the "foamy" to the "slug flow" regime occurred earlier at lower temperatures compared to higher temperatures. In the "foamy" regime hold-up values at 200°C are between 5 and 10% (absolute) lower than those at 265 and 280°C. No real difference in hold-up is evident between values at 265°C and 280°C (foam occupied the entire column and hold-ups of about 70% were obtained for $U_g \geq$ 2 cm/s). Hold-up values in the "slug flow" regime show a marginal effect of temperature, with lower values obtained at 200°C compared to 265°C. The transition from the "foamy" regime to the "slug flow" regime was not complete for the run conducted at 280°C, however, it is believed that if the gas velocity was further increased, the hold-up values would eventually approach those for the runs at 265°C.

Figure V-20 shows results illustrating the effect of temperature for runs conducted in the 0.229 m ID column using the 19 X 1.85 mm perforated plate distributor. Data from a total of 7 runs at 265°C were divided into two groups (as above) and averaged. These average values (curves 1 and 2) and data from a run conducted at 200°C are presented in Figure V-20. At 265°C foam consistently broke by 0.03 m/s, while the "foamy" regime was not observed at 200°C. In the "churn-turbulent" regime, hold-up values in the velocity range 0.02-0.07 m/s were slightly higher at 265°C compared to values obtained at 200°C. This could be attributed to a high concentration of small bubbles that were still present at 265°C over this range of velocities. At gas velocities 0.07 m/s and higher, hold-up values at the two temperatures are similar, showing no effect of temperature once the "churn-turbulent" regime is well established.

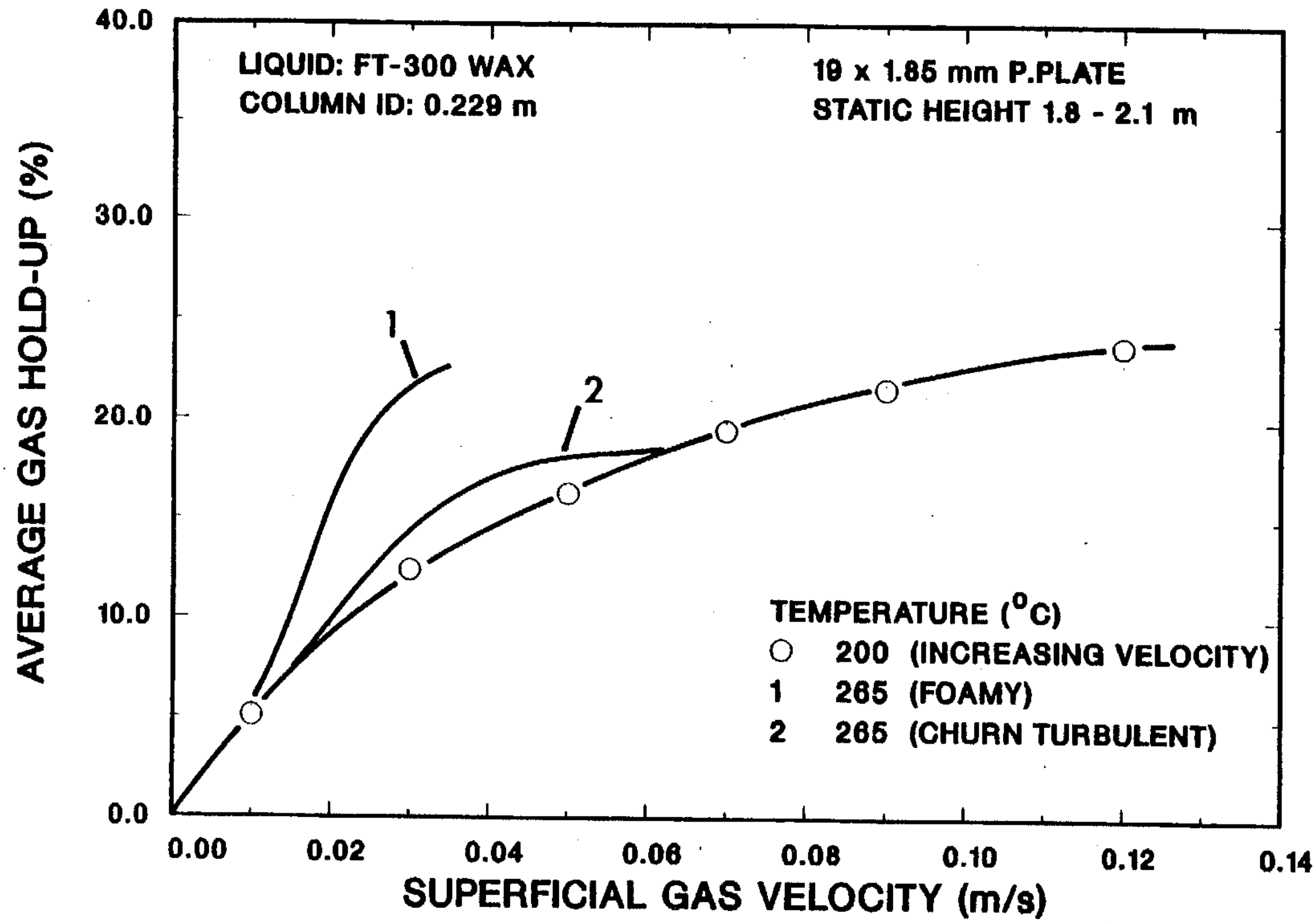


Figure V-20. Effect of operating temperature on gas hold-up (○ - Run 1-1; curves 1 & 2 - arithmetic averages from 7 runs)

Experiments were also conducted in the 0.229 m ID column using the 19 X 1 mm perforated plate distributor at 200 and 265°C. The results were similar to those obtained with the 19 X 1.85 mm perforated plate distributor. No foam was produced in the run conducted at 200°C, and hold-up values for this run were slightly lower than the corresponding values obtained with the 19 X 1.85 mm distributor.

Results from experiments conducted in the 0.229 m ID column with the 5 X 1 mm perforated plate distributor are shown in Figure V-21. Runs were made at 170°C and at 265°C. Also shown in this figure are hold-up values obtained by Quicker and Deckwer (1981) at 170°C using a 0.9 mm nozzle in a 0.095 m ID column. The jet velocities with the 5 X 1 mm distributor in the present work are the same as those in the Quicker and Deckwer study.

The run conducted at 265°C showed a substantial increase in gas hold-up as the gas velocity was increased from 0.01 to 0.02 m/s. This was accompanied by the formation of a stable layer of foam at the top of the dispersion. The transition from the "foamy" regime to the "churn-turbulent" regime took place between gas velocities of 0.03 and 0.04 m/s. Thereafter hold-ups increased gradually with an increase in gas velocity. This behavior is typical for FT-300 wax at 265°C and follows trends shown with other distributors. The run conducted at 170°C did not produce any foam for the gas velocities employed (0.01-0.05 m/s). As a result, hold-ups were substantially lower than in the run at 265°C. These results are significantly different from those obtained by Quicker and Deckwer under similar conditions. Their hold-ups appear to be too high under these conditions.

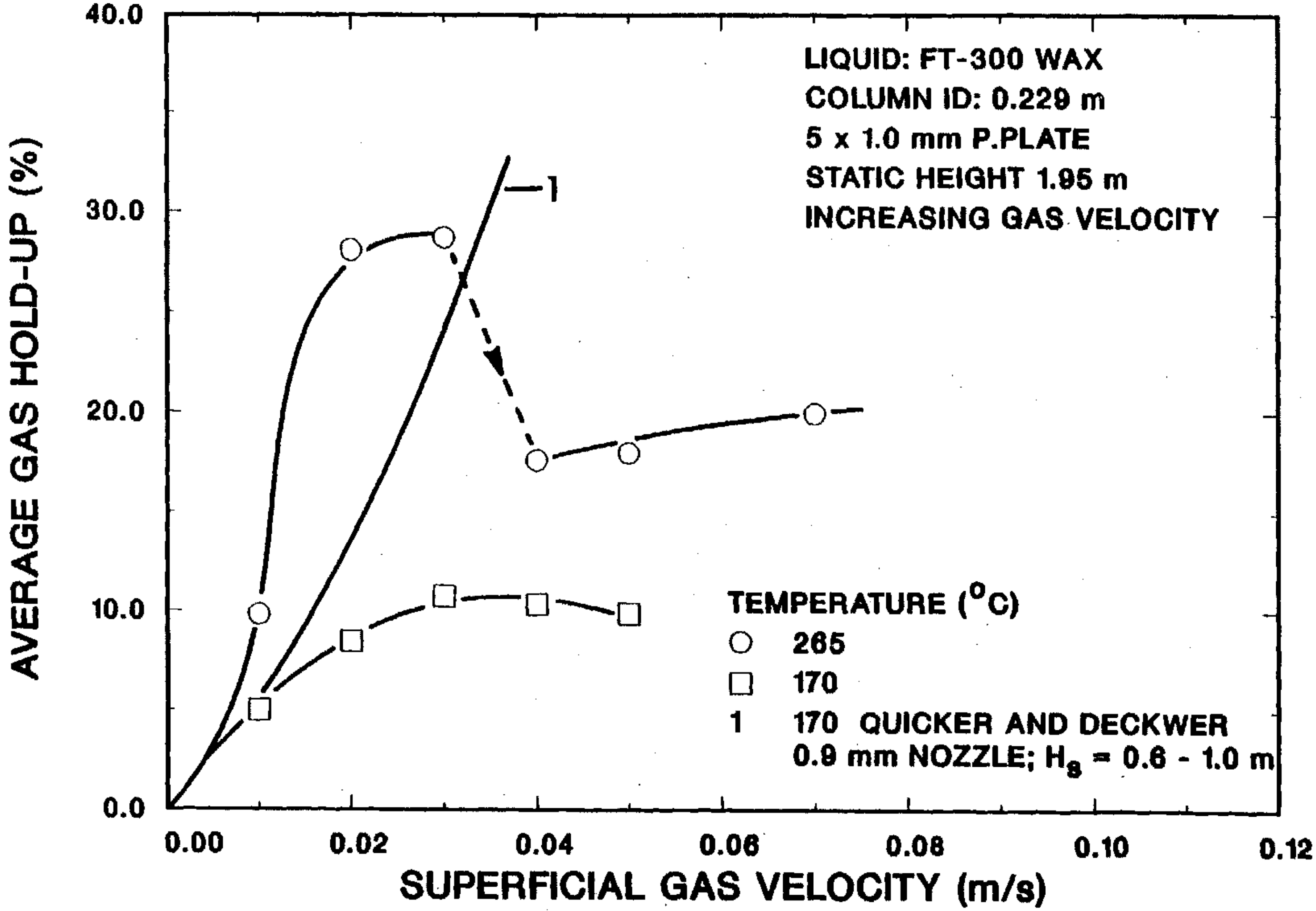


Figure V-21. Effect of operating temperature on gas hold-up and comparison with literature (○ - Run 4-1; □ - Run 4-2; 1 - Quicker and Deckwer, 1981, 0.9 mm nozzle in a 0.095 m ID column)

The results presented in Figures V-18 to V-20 show that in general temperature affects the results in the "foamy" regime, however, once the transition to the "slug flow" regime (in the 0.051 m ID column) or the "churn-turbulent" regime (in the 0.229 m ID column) occurs, hold-up values do not vary much with temperature. These results also show that at sufficiently low temperatures foaming can be completely prevented. This behavior can be qualitatively explained in terms of the liquid viscosity (e.g. $\mu_L$ = 9.8 mPa.s at 160°C vs. 2.4 mPa.s at 265°C, for FT-300 wax). Bubble coalescence increases with liquid viscosity (i.e. as temperature decreases) and fine bubbles, which are precursors of foam, do not accumulate at the top of the dispersion at low temperatures.

Experiments conducted with reactor waxes (Sasol's Arge reactor wax and Mobil's reactor wax) resulted in hold-ups similar to those for FT-300 wax in the absence of foam. A marginal decrease in hold-up was observed as temperature was decreased from 265°C to 200°C, which is as expected since virtually no foam was produced in those runs (see Section V-B.7.).

Several researchers have investigated the effect of temperature using paraffin waxes as the liquid medium. The majority of these studies were conducted in the "foamy regime" and there are some discrepancies in results from these studies. Deckwer et al. (1980) found a significant decrease in hold-up as temperature was increased from 180°C to 270°C for experiments conducted in a 0.041 m ID column, while no effect of temperature was found for runs conducted in the 0.10 m ID column. Experiments conducted by Quicker and Deckwer (1981), using FT-300 wax, showed consistently higher hold-up values at 170°C compared to values at 130°C with both, a 0.9 mm nozzle and a 19 X 1.1 mm perforated plate distributor. Researchers at Mobil

(Kuo et al., 1985) used FT-200 wax as the liquid medium and found that hold-up values at 138°C were substantially lower than those at 265°C. Despite some inconsistency in results, the overall trend is that hold-up increases with an increase in temperature, in the "foamy" regime (note that all of the literature dealing with this system reports results for runs with velocities less than 0.04 m/s, i.e. in the "foamy" regime). Results from our study are in agreement with these findings.

Due to the lack of literature data, with molten wax as the liquid medium, on the effect of temperature on hold-up in the "slug flow" regime or the "churn-turbulent" regime, only a comparison with results from other systems is possible. Shah et al. (1982) have shown that the increase in viscosity, by increasing the CMC (carboxy methyl cellulose) concentration, did not have an effect on gas hold-up in the "slug flow" regime, a behavior similar to that for FT-300 wax as shown in the present study.

B.4. Effect of Column Diameter

Commercial size bubble columns are expected to operate in the heterogeneous ("churn-turbulent") flow regime, while majority of the studies, with a molten wax as the liquid medium, were carried out in small diameter columns (up to 0.12 m) and thus only the ideal bubbly (homogeneous) and "slug flow" regimes were observed. Results from studies conducted in the 0.051 m ID and 0.229 m ID glass columns are reported here showing the effect of column diameter. The comparison is based on runs conducted at 265°C using the 1 mm and 1.85 mm orifice plate distributors in the 0.051 m ID column, and the 19 X 1 mm and the 15 X 1.85 mm perforated plate distributors in the 0.229 m ID column. Data from a total of 13 runs in the 0.051 m ID column and from 6 runs in the 0.229 m ID column are available for