see Figure V-12). In the "slug-flow" regime, hold-up values for the two runs are similar.

The effect of the addition of oxygenates to FT-300 wax is qualitatively similar to results from studies conducted in the air-water system reported by Schugerl et al. (1977) and Kelkar et al. (1983). Their studies showed that the presence of alcohols in water resulted in higher hold-ups when compared to pure water.

The effect of oxygenates on the hydrodynamic parameters of the FT-300 wax is not significant. From our results it appears that oxygenates do not suppress foaming, and thus the reasons for low hold-ups and absence of foam in experiments with raw reactor waxes, as reported by Smith, J. et al. (1984) and Kuo et al. (1985), are not clearly understood at the present time.

B.7. <u>Effect of Liquid Medium</u>

It has been well established that paraffin waxes have a tendency to foam, the severity of which is dependent on a combination of factors. Bubble size measurements (see Section V-D) have revealed that FT-300 paraffin wax produces bubbles which are significantly smaller than those produced in other systems, such as the air-water system. Experiments were therefore conducted with different liquid media in order to investigate their effect on average gas hold-up. Results obtained with FT-300 wax were compared with those obtained in experiments conducted using FT-200 wax, two reactor waxes (Sasol's Arge reactor wax and Mobil's reactor wax), and distilled water. The investigations were carried out in the 0.051 m and the 0.229 m ID columns at 200 and 265°C with molten waxes, and at room temperature with distilled water. The 1 mm and 1.85 mm orifice plate, and the 40 μm sintered metal plate (SMP) distributors were used in the 0.051 m ID column, while the 19 x 1.85 mm perforated plate distributor was used in the 0.229 m ID column.

The major highlights of these investigations are:

- Results for FT-200 wax are qualitatively similar to those for FT-300 wax in the "foamy" regime, with higher hold-ups obtained with FT-200 wax. The transition from the "foamy" regime to the "slug flow" regime is not as pronounced with FT-200 wax as was with FT-300 wax.
- Reactor waxes and water do not have a tendency to foam for the range of conditions investigated in these studies. Therefore, they do not exhibit hysteresis behavior which is characteristic of paraffin waxes.
- Hold-up values for distilled water and reactor waxes are not significantly affected by distributor type nor by temperature (for reactor waxes).
- Hold-up values for distilled water and reactor waxes in the 0.051 m ID column are very similar to those obtained with FT-300 wax in the absence of foam.

Results illustrating the effect of temperature, distributor type and gas velocity on the average gas hold-up for Sasol's Arge wax are shown in Figure V-31. All runs were conducted using increasing order of gas velocities. Hold-up values with the 1.85 mm orifice plate distributor show a gradual increase with gas velocity, whereas the ones with the SMP distributor exhibit a slight maximum at a velocity between 0.01 and 0.02 m/s. Foam was observed only in the run with the SMP distributor at 0.01 m/s during the first 30 minutes and then disappeared. However, the small bubbles produced during this brief period persisted to some extent

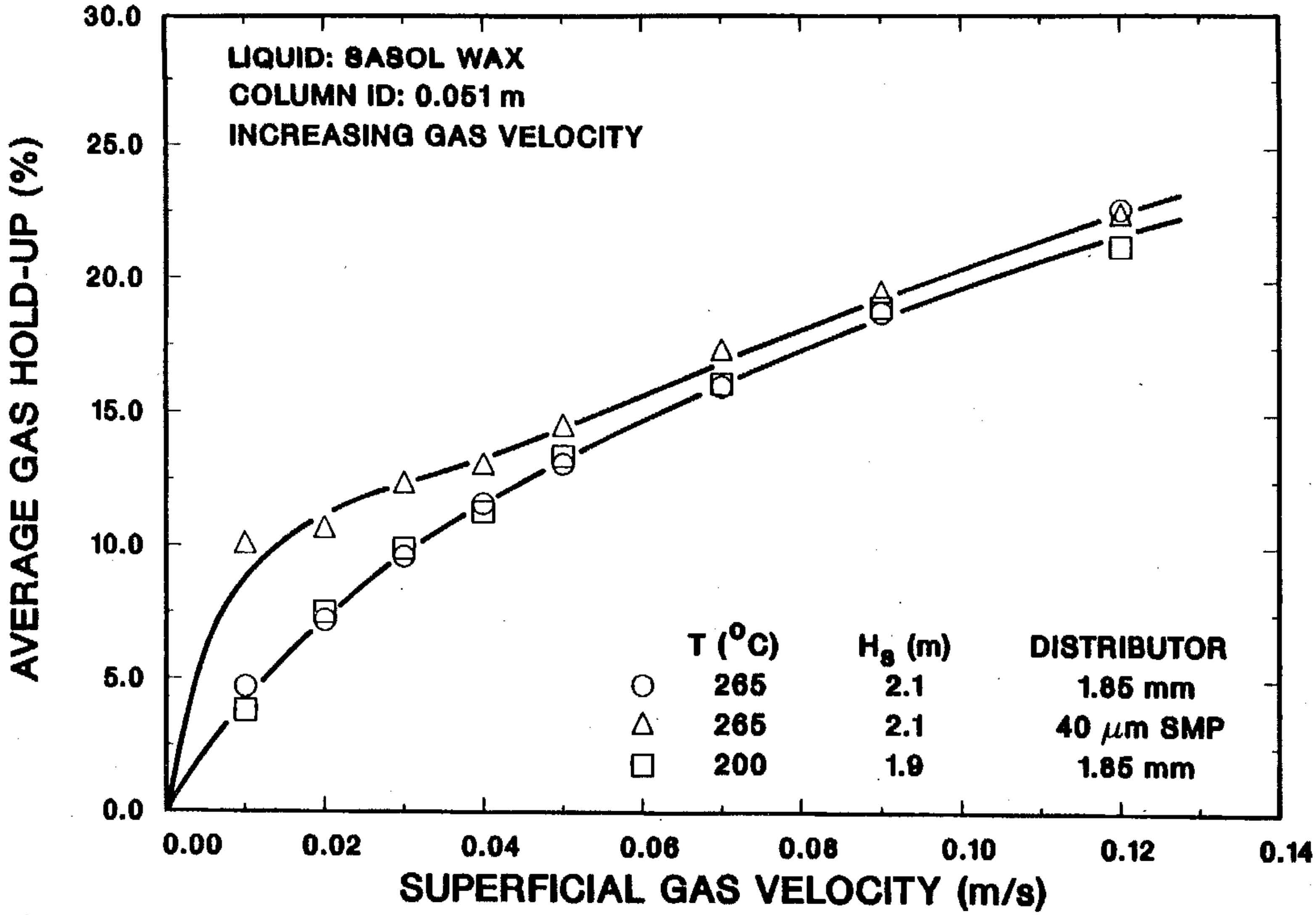

Figure V-31. Effect of superficial gas velocity, distributor type and temperature on gas hold-up (○- Run 8-1; △- Run 8-3; □- Run 10-1) resulting in higher hold-up values for gas velocities up to 0.04 m/s. Hold-up values with the 1.85 mm orifice plate distributor at 200°C are marginally lower than those obtained at 265°C with the same distributor, which is as expected. At 265°C, runs were conducted using different operating procedures (i.e. start-up velocities), however, hold-up values from these runs showed no effect of the order in which gas velocities were changed (i.e. increasing or decreasing order of velocities). In both cases there was no foam produced, therefore, the hysteresis behavior (characteristic of paraffin wax) was absent for Sasol's reactor wax. Visual observations of the flow field near the wall showed that bubbles were larger than those observed previously with FT-300 wax. A notable difference was the absence of fine bubbles (less than 1 mm) that were present in large numbers in experiments with FT-300 wax. At velocities 0.03 m/s and higher, slugs occupying the entire column cross-section were observed which was also the case in experiments with the FT-300 wax. These qualitative differences in the bubble size distributions between the two waxes are reflected in the values of the Sauter mean bubble diameter (see Section V-D).

Hold-up values with Sasol wax were also measured in the 0.229 m ID column using the 19 x 1.85 mm distributor at 265°C. These results, when compared (see Figure V-29) with hold-up values obtained using Sasol wax in the 0.051 m ID column, show that column diameter did not have a significant effect on the average gas hold-up values.

Figure V-32 shows gas hold-up values obtained from experiments conducted with Mobil's reactor wax (composite wax from runs 9, 11 and 12 in their Unit CT-256). Once again foam was not observed in the runs made with

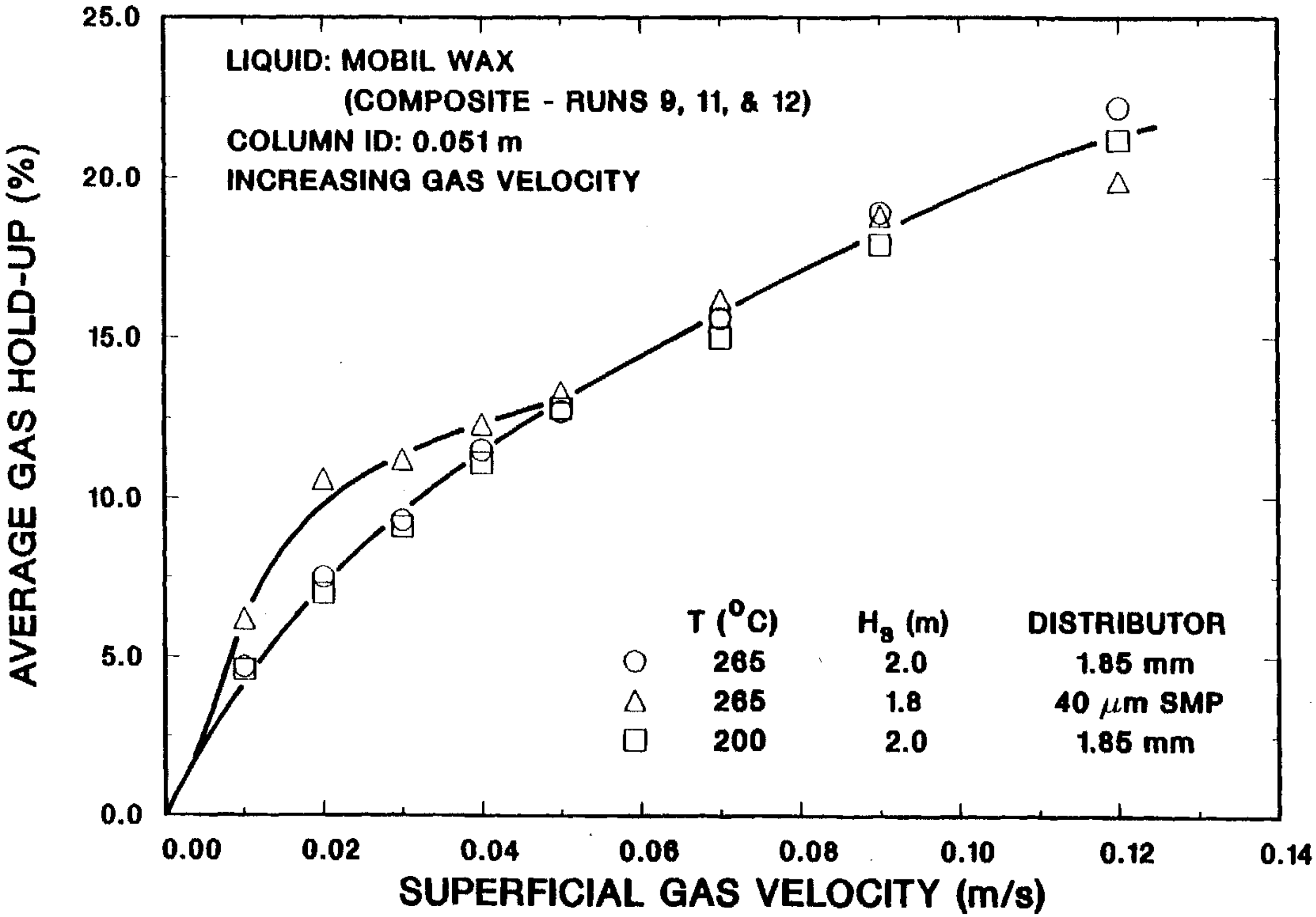

Figure V-32. Effect of superficial gas velocity, distributor type and temperature on gas hold-up (composite wax from Mobil runs CT-256-9, -11 and -12; ○ - Run 9-3; △ - Run 9-4; □ - Run 9-2) the 1.85 mm orifice plate distributor. The behavior with the SMP distributor was similar to that observed with Sasol wax, i.e. foam appeared initially at 0.01 m/s but it disappeared after approximately one hour on stream. Gas hold-up values are, in general, very similar to those obtained in the runs with Sasol wax under the same conditions. Visual observations of the flow field with this wax were limited due to its dark color which was caused by the presence of small amounts of iron catalyst particles (~ 350 ppm). However, backlighting of the column did show the presence of slugs at gas velocities of 0.03 m/s and higher.

Researchers at Mobil (Kuo et al., 1985) also conducted experiments with reactor waxes produced from runs in their pilot plant reactor (Unit CT-256). They reported hold-up values for experiments with waxes produced during runs 4,5,7 and 8. In order to compare results from the present study with those presented by Kuo et al., additional experiments were conducted with two different composites (composite of waxes produced in their runs 4 and 7; and composite of waxes produced in their runs 5 and 8). Results from these experiments and comparison with the Kuo et al. data are presented in APPENDIX E.

Figure V-33 shows results obtained from runs conducted under ambient conditions with distilled water in the 0.051 m ID column, using the 1.85 mm orifice plate and the 40 μm SMP distributor. These results show that neither the operating procedure (i.e. start-up velocity) nor distributor type had any significant effect on the average gas hold-up. As expected, foam was not observed in any of these runs. Visual observations of the flow field showed fewer and larger bubbles compared to FT-300 wax. Slugs were observed at gas velocities of 0.03 m/s and higher.

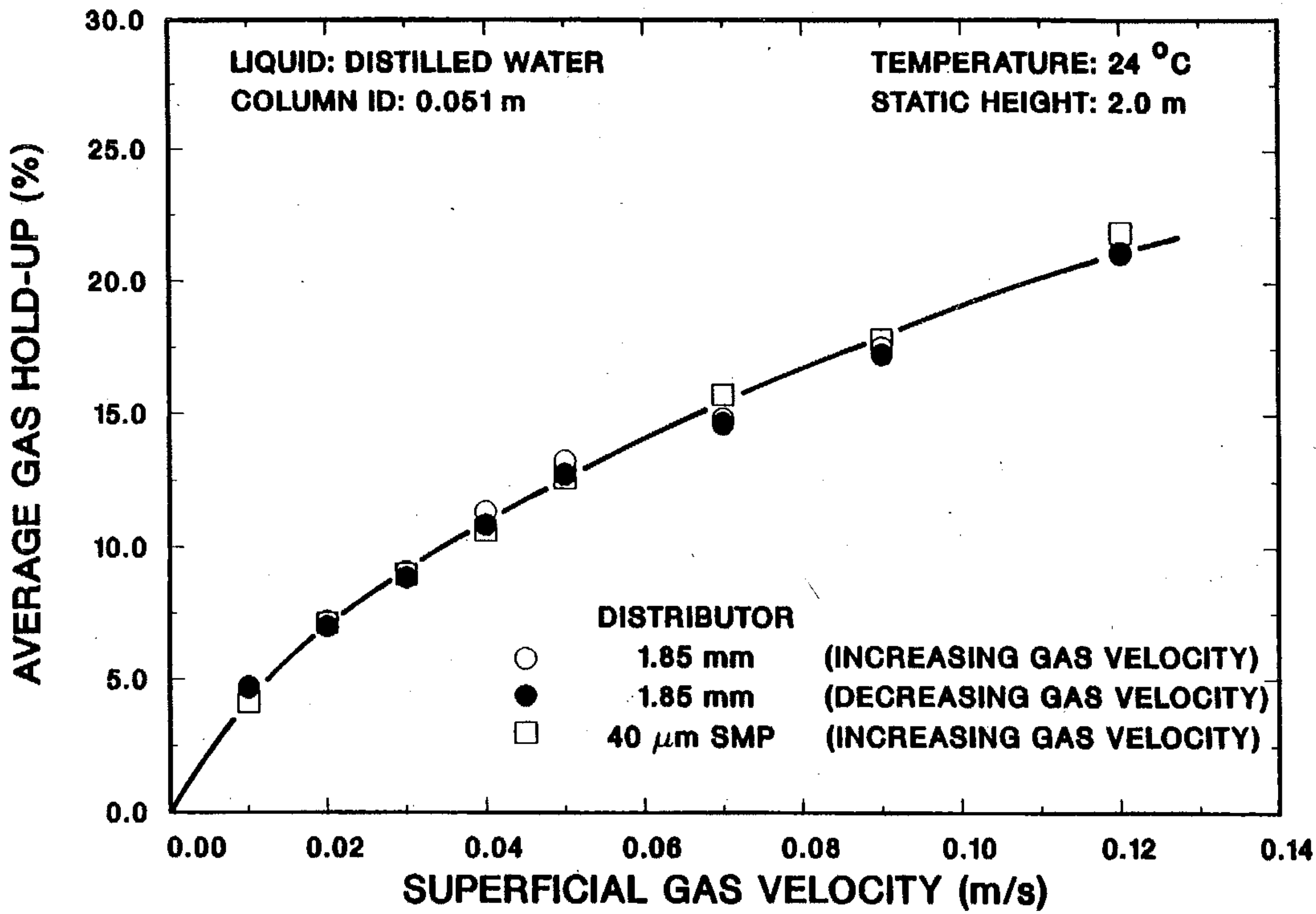

Figure V-33. Effect of superficial gas velocity, start-up procedure and distributor type on gas hold-up

Hold-up values for the five liquid media used in these studies (i.e. FT-300, FT-200, Sasol's Arge wax, Mobil's reactor wax, and distilled water) are compared in Figures V-34 to V-36 for runs conducted using increasing order of gas velocities. Results for the different systems obtained using the 1.85 mm orifice plate distributor (Figure V-34) are very similar when the "slug flow" regime persists. However, with paraffin waxes (FT-300 and FT-200) it is also possible to operate in the "foamy" regime at lower gas velocities (usually < 0.05 m/s with FT-300 wax). For this range of gas velocities, hold-ups with paraffin waxes are significantly higher than values with either reactor waxes or distilled water. For the results presented in Figure V-34, both FT-200 and FT-300 waxes showed a significant increase in hold-up as gas velocity was increased from 0.01 to 0.03 m/s. As gas velocity was further increased, a transition from the "foamy" regime to the "slug flow" regime occurred with FT-200 wax. With FT-200 wax, this transition was not as pronounced as was with FT-300. The gradual decrease in hold-up at velocities 0.05 m/s and higher could be attributed to the initiation of the foam breakage process. There were instances when foam was not produced in runs with FT-300 wax at 265°C (see Figure V-10). The hold-up values for such cases were similar to those indicated by the lower curve in Figure V-34. These results indicate that liquid medium does not have a significant effect on the average gas hold-up when foam is not produced. Figure V-35 shows results obtained using the SMP distributor. The curves for FT-200 and FT-300 waxes illustrate behavior typical for paraffin waxes, a sharp increase in gas hold-up as gas velocity increases from 0.01 m/s to 0.02 m/s accompanied by the formation of foam, followed by a sudden drop as foam breaks. There is no significant difference between

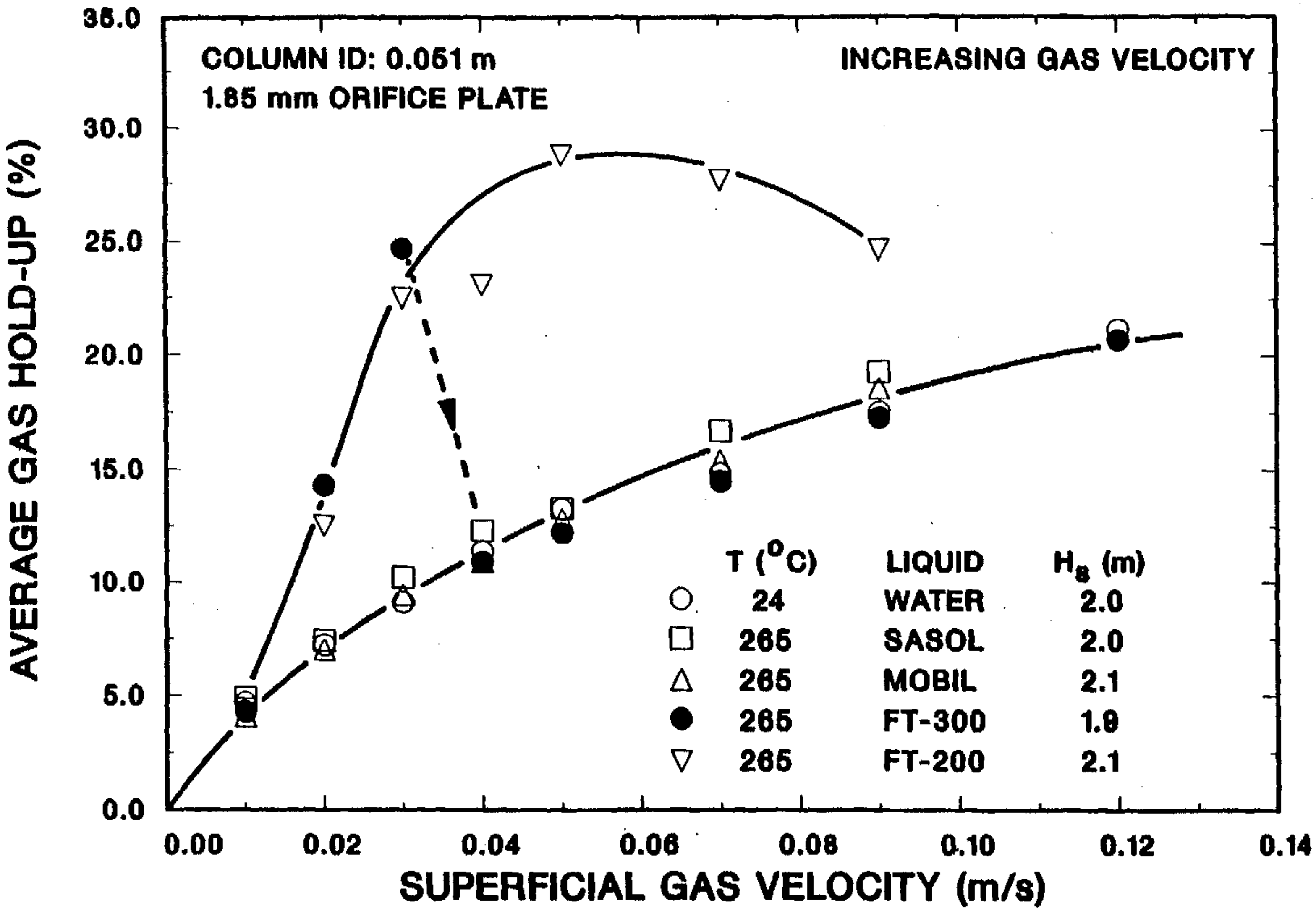

Figure V-34. Effect of liquid medium and superficial gas velocity on gas hold-up (□ - Run 8-4; △ - Run 9-1; ● - Run 4-1; ▽ - Run 11-5)

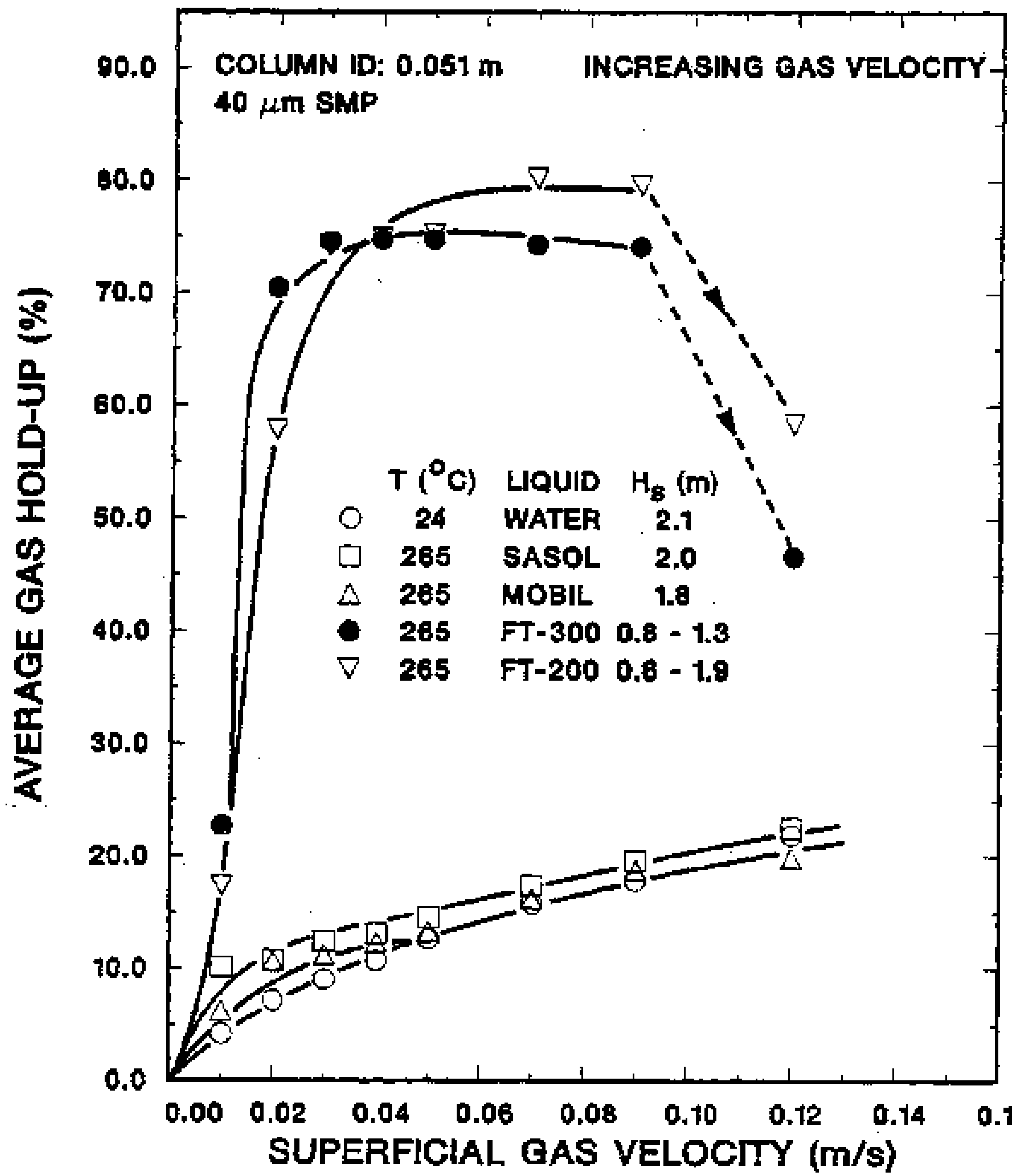

Figure V-35. Effect of liquid medium and superficial gas velocity on gas hold-up (□- Run 10-1; △ - Run 9-4; ● - Run 5-1; ▽ - Run 20-1) hold-ups for the two waxes for the examples shown in Figure V-35. Hold-up values for the two reactor waxes and for distilled water are significantly lower than those for paraffin wax. The reactor waxes showed slightly higher hold-ups in the velocity range 0.01-0.04 m/s compared to values for distilled water. This could be attributed to the presence of fine bubbles in these waxes following the small amount of foam produced at 0.01 m/s.

Figure V-36 compares hold-up values obtained with FT-200 and FT-300 waxes using the 1 mm orifice plate distributor in the 0.051 m ID column. Results for FT-200 wax are similar to those for FT-300 wax in the velocity range 0.01-0.03 m/s. For velocities greater than 0.03 m/s, hold-ups continued to increase for FT-200 wax, while a transition from the "foamy" to the "slug flow" regime was observed with FT-300 wax. These results are as expected and illustrate the foaming capacity of paraffin waxes.

The results presented above indicate that the hydrodynamic properties of paraffin waxes (FT-200 and FT-300) are significantly different from those for the reactor waxes and distilled water. The absence of foam and lower hold-up values for the two reactor waxes and water could be attributed to high coalescence rates for these systems. Visual observations of the flow field with water showed virtually no difference in flow patterns between the run using the 1.85 mm orifice plate and the run using the SMP distributor. The presence of foam in FT-300 wax is indicative of low coalescence rates. Heijnen and van't Riet (1984) have discussed the differences between liquids that have high coalescence rates and liquids with low coalescence rates. They postulate that for the former, the flow is independent of the distributor since bubbles coalesce just above the distributor and their size continues to grow as gas

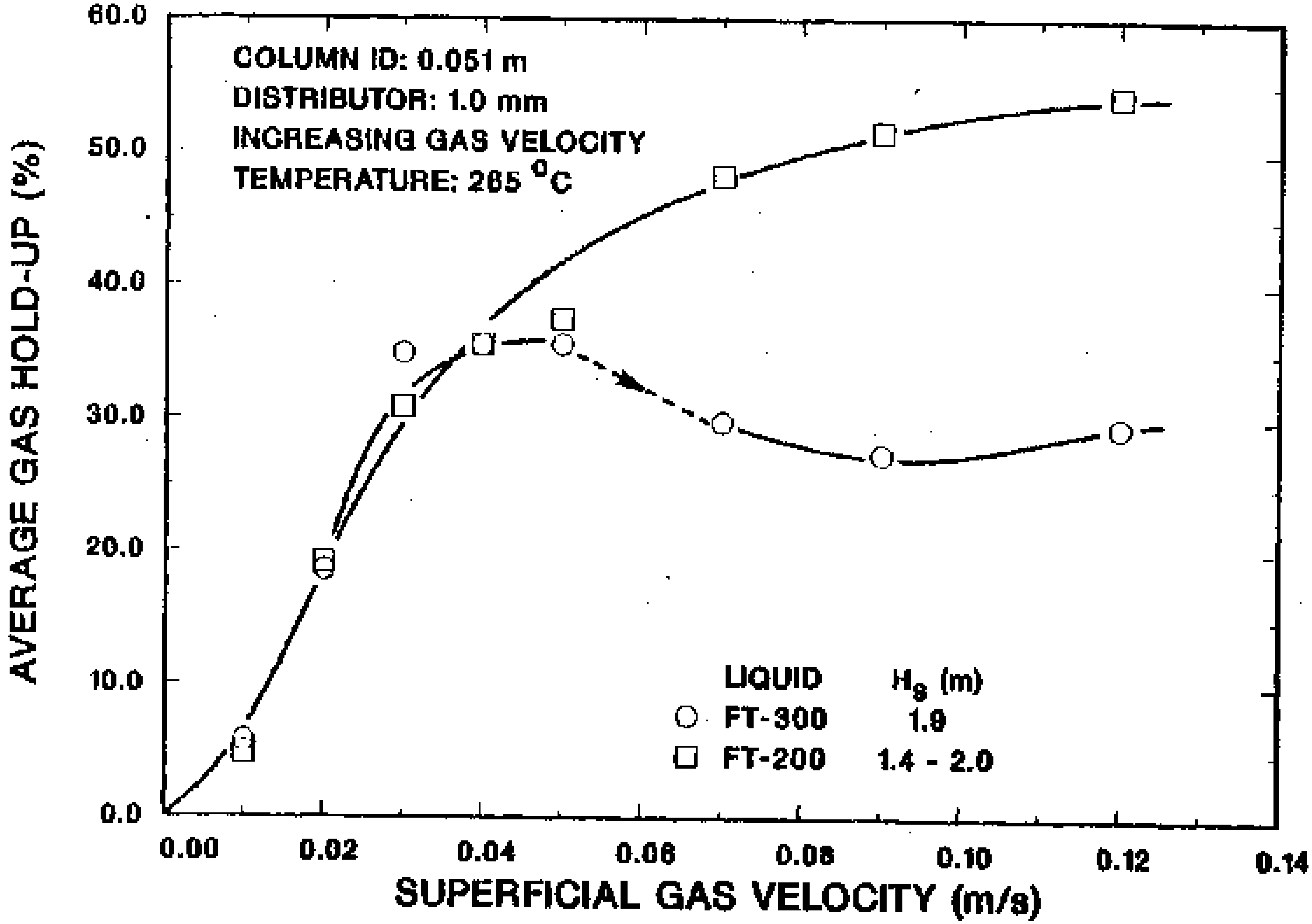

Figure V-36. Effect of liquid medium and superficial gas velocity on gas hold-up (○ - Run 15-1; □ - Run 17-1) velocity is increased. However, for liquids that have low coalescence rates, the bubbles formed at the distributor are further dispersed, forming smaller bubbles. Results from the present studies are in general agreement with these observations.

Results from dynamic gas disengagement (DGD) measurements indicate that large bubbles (slugs) are responsible for up to 85% of the gas hold-up at higher velocities (greater than 0.07 m/s) for FT-300 and the two reactor waxes when runs were conducted in the 0.051 m ID column. For FT-300 wax smaller bubbles account for most of the hold-up at velocities less than 0.07 m/s, whereas, for the other three systems, large bubbles dictate the hold-up values even at lower velocities. Vermeer and Krishna (1981) showed that hold-up in a bubble column could be classified into two components; one due to the entrained bubbles, and the other due to the large bubbles or the transport portion of the hold-up. It is expected that if the entrained portion of the hold-up is substantially greater than the transport portion, a higher hold-up value will result, e.g. with FT-300 wax in the presence of foam. However, when the transport portion of the hold-up is high, e.g. with reactor waxes and water, and with FT-300 wax at higher gas velocities, the average hold-up will be relatively lower. Since slugs with all systems are of the same relative size (i.e. almost equal to the column diameter) it is expected that in the presence of slugs, hold-up values should be independent of the liquid medium, as is the case in the present study.

The above studies with the different liquid media show that the differences between the hydrodynamic parameters for paraffin waxes and reactor waxes are significant, therefore the choice of liquid medium is critical for investigations aimed at obtaining parameters for bubble column design and scale-up.

3.8. Comparison with Literature

Qualitative comparisons between average gas hold-up values obtained in the present study and those that have appeared in the literature have been made in the previous sections. Here some quantitative comparisons will be made. Only the results from runs conducted using paraffin waxes are compared here. Hold-up values obtained from runs conducted with Mobil's reactor waxes are compared with Mobil's data with similar waxes in APPENDIX E.

The major highlights of the comparisons are:

- Literature data on hold-up values obtained using the SMP distributor is limited to the "foamy" regime and shows that hold-ups increase with a decrease in pore size. Results obtained from the present studies using the 40 μm SMP distributor are in fairly good agreement with the data reported for SMP distributors having pore sizes in the range 20-60 μm
- Results obtained using the orifice plate and the perforated plate distributors also show a dependency on the distributor hole size in the "foamy" regime. Higher hold-ups are produced with distributors having smaller holes or perforations. This is in good agreement with data reported in literature. In the absence of foam, hold-up values are not affected significantly by the distributor hole size.

3.8.a Sintered Metal Plate Distributors

Figure V-57 shows a comparison of hold-up values obtained in the present study, using the 40 μm SMP distributor in the 0.051 m ID column,