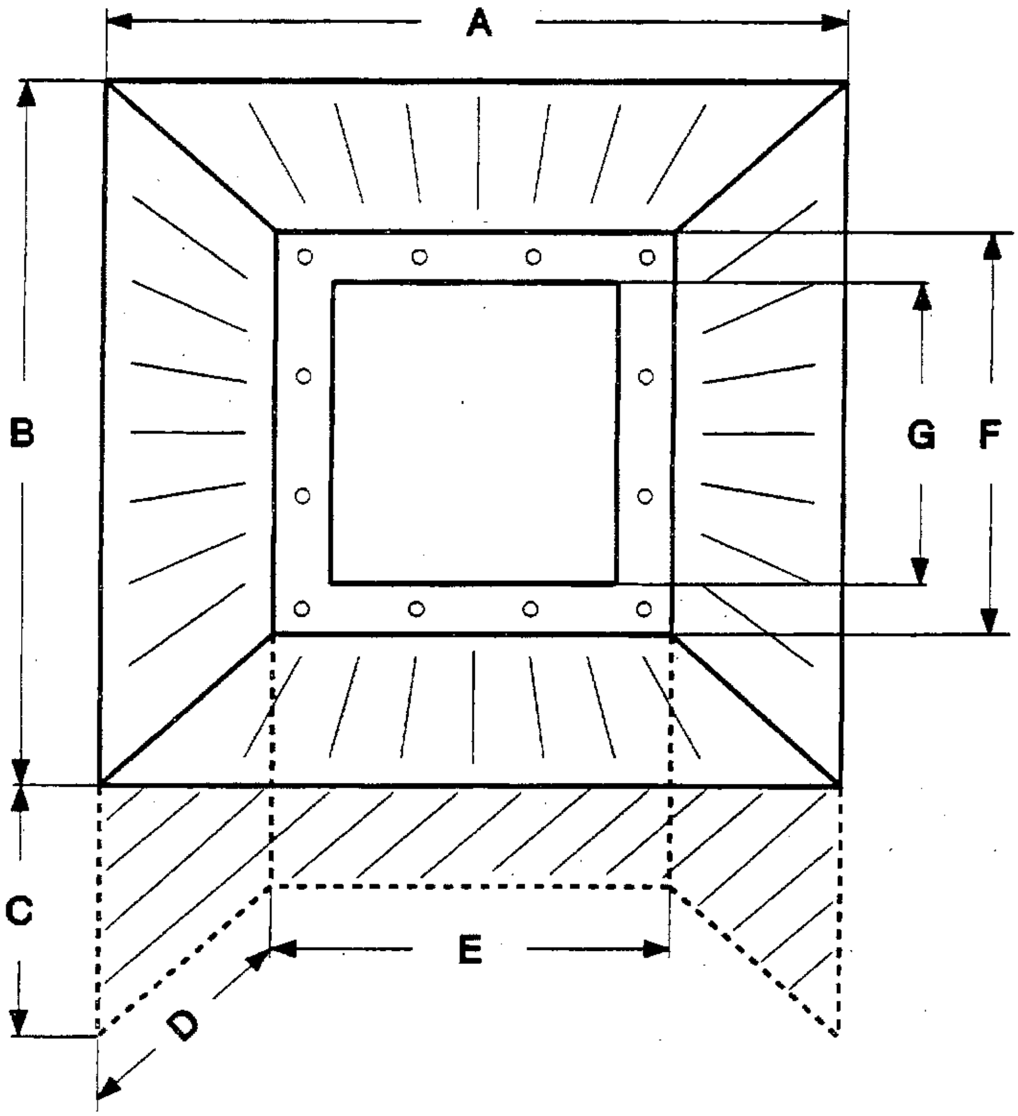
column at higher gas velocities.

The photographs were taken after a run time of one hour at a given velocity, for velocities of 0.01 to 0.05 m/s, and after 45 minutes for gas velocities greater than 0.05 m/s. A minimum of four photographs were taken at each velocity using Kodak 400 ASA Tri-X Pan film. In the 0.229 m ID column, photographs were also taken just after the gas input to the column was shut off, after each velocity. This was done in order to obtain bubble size distributions after the large bubbles had disengaged from the dispersion.

A major problem with the use of the photographic technique with cylindrical columns is the 'curvature effect'. The curvature of the column wall distorts the image of the bubbles in the column since the wall behaves like a convex lens. In order to alleviate this problem, the area of the column that was photographed was kept at a minimum (approximately 15 X 20 mm). The distance between the lens and the column wall was typically between 30 to 50 mm. This also helped in the image analysis procedure since the individual bubbles were more distinct when photographed at a close range.

D.2d. Experimental Results

The photographic technique could be used only with FT-300 wax because of its clarity and water-like appearance. Measurements were made mostly in the 0.051 m ID and 0.229 m ID glass columns, with some photographs of the flow field near the center of the column taken through the specially constructed port (see Figure V-49) in the 0.241 m ID stainless steel column. It was not possible to use this technique with the Mobil and Sasol reactor waxes due to their dark color.



A = 0.20 m B = 0.20 m C = 0.05 m D = 0.11 m

E = 0.10 m F = 0.10 m G = 0.08 m

ure V-49. Viewing port in the 0.241 m I.D. SS column

Results from photographs taken in the 0.051 m ID column are discussed qualitatively because of the relatively small number of bubbles sized per condition (400 - 500). The effect of large bubbles is significant for this case (see Section V-D.2e.). However, the technique was improved when used in the 0.229 m ID glass column and quantitative analysis was possible for this case. Data from two photographs were used at each condition for this column and the number of bubbles sized was considerably larger (1500 - 1700). As a result it would not be prudent to assess the effect of column diameter based on the photographic data.

D.2d.1. Effect of Height Above Distributor

Figure V-50 shows the Sauter mean diameter for FT-300 wax from measurements made in the 0.051 m ID column. The measurements were made at 265°C using the 1.85 mm orifice plate distributor. Results are shown for three different superficial gas velocities, 0.01, 0.03 and 0.09 m/s. Approximately 400-500 bubbles were catalogued and sized at each condition. These results show that d_s does not vary significantly in the lower half of the column (up to about 1.25 m above the distributor), however, d_s decreases above this point. The maximum drop in the value of d_s appears to be at a gas velocity of 0.09 m/s, from 1.7 mm to 0.8 mm at a height of 1.75 m. The cumulative frequency distributions presented in Figure V-51 support the trends observed in Figure V-50. At a superficial gas velocity of 0.03 m/s, Figure V-51 shows similar bubble size distributions at heights of 0.45 and 1.2 m above the distributor, however, the distribution shifts to the left at a height of 1.95 m, indicating the presence of smaller bubbles. These curves also indicate that the bubble size distribution at a height of 1.95 m above the distributor is narrower than those at lower heights (i.e.

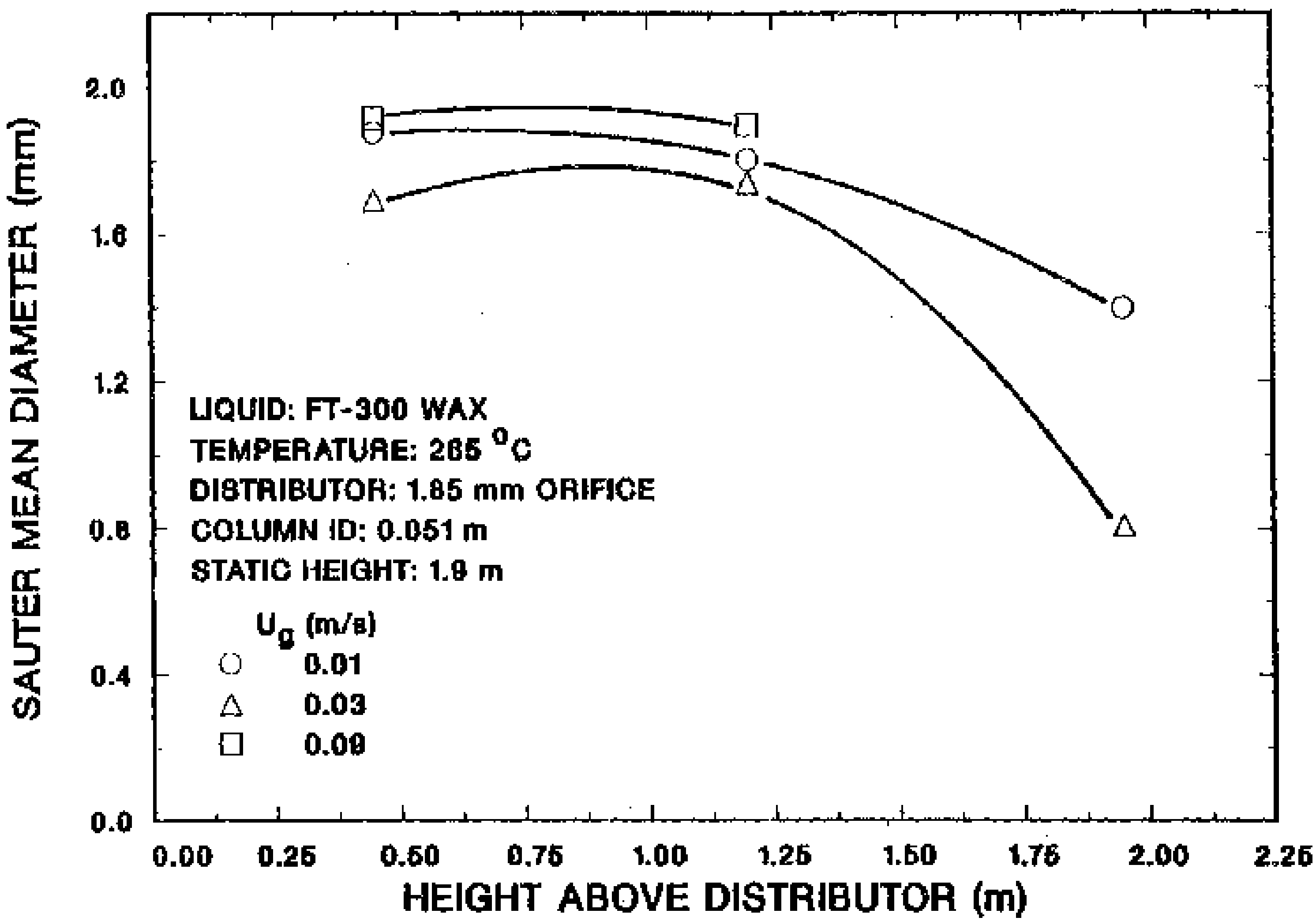


Figure V-50. Effect of superficial gas velocity and height above the distributor on the Sauter mean bubble diameter (Run 4-1)

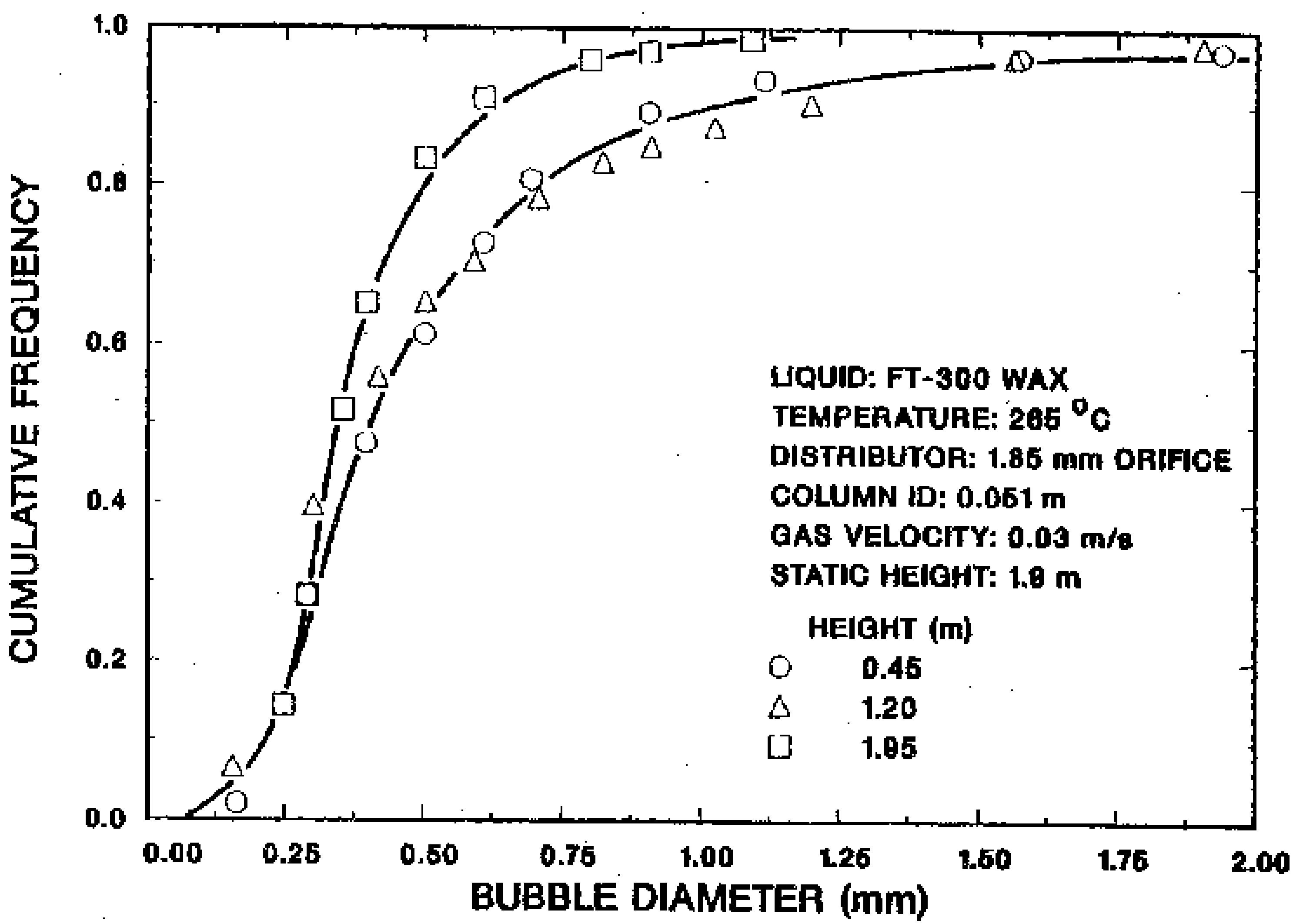


Figure V 51. Effect of height above the distributor on the bubble size distribution (Run 4-1)

0.45 and 1.2 m). Similar trends were observed at other velocities as well.

Figure V-52 shows the variation of d_s with height above distributor for a run conducted in the 0.229 m ID column with FT-300 wax at 265°C using a 19 X 1.85 mm perforated plate distributor. Results obtained at superficial gas velocities of 0.01, 0.05 and 0.09 m/s are presented in this figure. In this case two photographs were selected and analyzed for each condition, and d_s for the individual photographs was calculated. Results from the two photographs were then combined and d_s for the combined data was calculated. Thus, approximately 1500-1700 bubbles were catalogued and sized at each condition. The various symbols in Figure V-52 represent d_s from combined data, while the vertical bars connect d_s values from individual photographs. Only one photograph could be analyzed at 0.09 m/s for a height of 1.12 m above the distributor. The results once again indicate trends which are similar to those observed in the 0.051 m ID column, however, they are not as significant as in the previous case. At 0.01 m/s, d_s for the combined data (from the two photographs at each condition) decreases from 1.2 mm at 0.41 m above the distributor to 1.0 mm at a height of 1.96 m above the distributor, a relative difference of less than 20%. The significance of this difference is further diminished because of the variability in d_s values from the individual photographs for a given condition. For example, at 0.01 m/s and at a height of 0.41 m above the distributor, d_s from individual photographs is 0.9 mm and 1.5 mm compared to a d_s value of 1.2 mm for the combined data. This translates into a relative difference of ±25% between the individual and combined values. However, similar comparisons at the other conditions reveal significantly lower variations, as can be seen in Figure V-52. The limited results

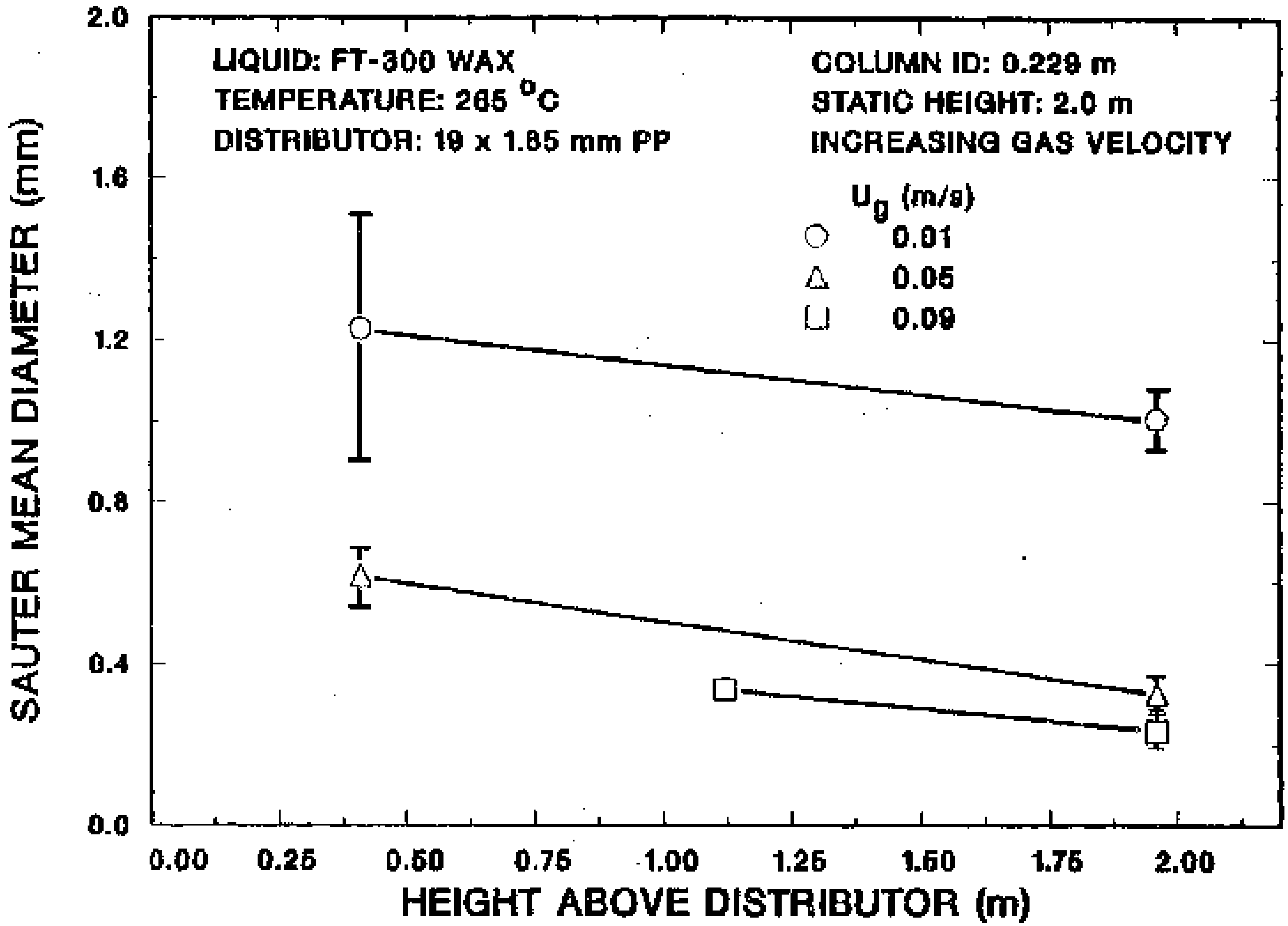


Figure V-52. Effect of superficial gas velocity and height above the distributor on the Sauter mean bubble diameter. (Run 2-3; vertical bars join Sauters from individual photographs, symbols represent Sauters when results from two photos were combined) presented in Figure V-52 also show that the variability between individual photographs is considerably lower at greater heights above the distributor (e.g. at 1.96 m) compared to values near the distributor (at a height of 0.41 m). This might be a consequence of narrower bubble size distributions at 1.96 m compared to those at 0.41 m.

The results presented above imply that, in general the Sauter mean bubble diameter has a tendency to decrease with an increase in height above the distributor. This behavior is supported by visual observations and by results obtained from axial hold-up measurements (see Section V-C.3.). Figure V-40 shows that local hold-up values at different axial locations along the column increases with height. The extent of increase was more pronounced when foam was present in the system (e.g. at 0.05 and 0.07 m/s in Figure V-40). Since higher hold-ups are caused by smaller bubbles, axial hold-up measurements imply that bubble size decreased with an increase in column height. This is in agreement with the relatively large decreases in d_s at 0.03 m/s in Figure V-50, where foam was present. However, in the absence of foam, axial hold-up values show only a marginal increase with an increase in column height (e.g. Figure V-41). This is once again in agreement with the weak trends shown by d_s under similar conditions (Figure V-52). Visual observations of the flow-field near the bottom of the column reveal relatively large bubbles with high rise velocities - resulting in the lower hold-ups and larger d_s values at this location. However, these bubbles begin to disperse resulting in smaller bubbles and higher hold-ups higher up in the column. At velocities where foam is produced, a large number of very fine bubbles are present in the system, producing higher hold-ups and lower Sauters towards the top of the column.

Towell et al. (1965) present some results from experiments conducted in a 0.406 m diameter and 3.05 m tall column with the air-water system. They report a variation in axial hold-up which is similar to that observed in the present study, however, bubble size distribution measurements, using the photographic technique, did not reveal any trends. A possible explanation for this could be that Towell et al. measured bubble sizes up to a height of 2.59 m above the distributor, while the expanded height was around 3 m. Therefore, it is likely that the layer of froth (that they refer to in their investigations), which is expected to be accompanied by smaller bubbles was not accounted for in their photographic measurements. Furthermore, the air-water system studied by Towell et al., is less conducive to producing the fine bubbles present in the molten wax-nitrogen system, thus, the effect of height above distributor might be different in the two systems despite similar variations in axial hold-up values. Similar results have been reported more recently by Ueyama et al. (1980) in studies that were also conducted with the air-water system. They used a medium size (0.6 m diameter and 3.05 m tall) bubble column in their investigations and made bubble size distribution measurements using both, the photographic technique and electric resistivity probes. Their studies also reveal that bubble size does not vary significantly with height above the distributor even though they report the presence of a layer of froth on top of the dispersion. Results obtained in the present study in the absence of foam (higher gas velocities) and in the larger column (0.229 m ID) show a weak dependence of d_s on column height, which is in agreement with the findings of Towell et al. and Ueyama et al.

D.2d.2. Effect of Flow Regime and Operating Procedure

Results presented earlier (see Section V-B.2.) indicate that the flow regime at a given velocity is affected by the operating procedure. The tendency to foam was greater when increasing order of gas velocities were employed compared to runs conducted using decreasing order of gas velocities. Therefore, the effects of flow regime and operating procedure are grouped together in the following discussion.

Figure V-53 shows the cumulative frequency curves obtained from photographs taken in the 0.051 m ID column equipped with the 1.85 mm orifice plate distributor using FT-300 wax at a temperature of 265°C and a gas velocity of 0.03 m/s. The open circles indicate results obtained when foam was present (increasing order of velocities), while the solid circles denote results in the absence of foam (decreasing order of velocities). The differences between the two curves are obvious. In the presence of foam, a greater number of smaller bubbles are produced in the dispersion compared to the case where foam is absent. Results at other heights indicate similar trends, i.e. d_s was lower in the presence of foam. This was illustrated in Figure V-50, where d_s at a gas velocity of 0.03 m/s (when foam was present) was consistently lower than d_s at other velocities.

Figure V-54 gives cumulative frequency curves obtained using the 40 μm sintered metal plate (SMP) distributor under conditions similar to those for the 1.85 mm distributor. However, the superficial gas velocity in this instance is 0.07 m/s. These results indicate that bubble sizes are significantly greater in the presence of foam when compared to the case when no foam was present. However, it should be noted that foam, when present, filled the entire column ($\epsilon_g \approx 70\%$) in experiments with SMP.

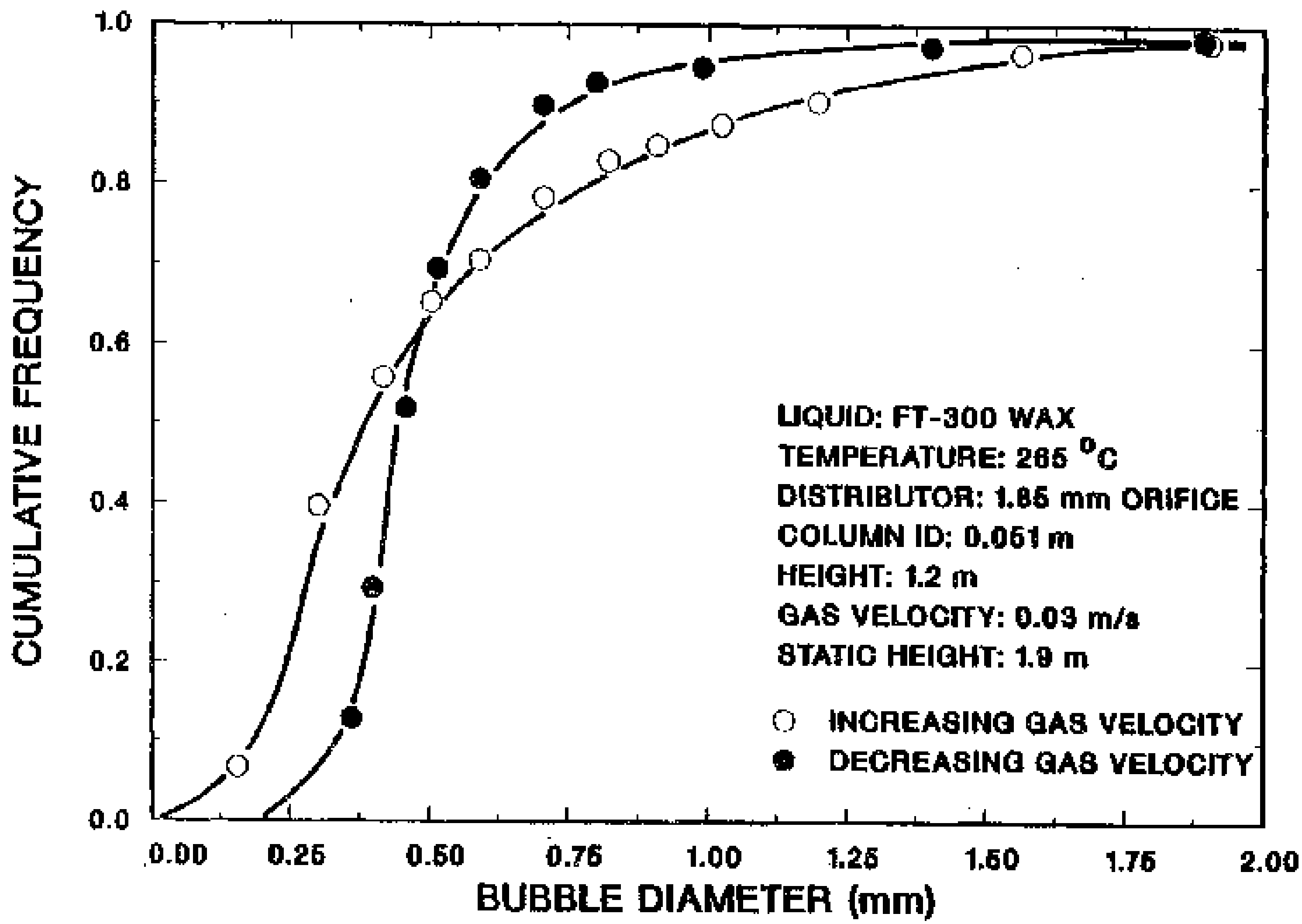


Figure V-53. Effect of flow regime on the bubble size distribution (○ - Run 4-1; ● -Run 4-2)

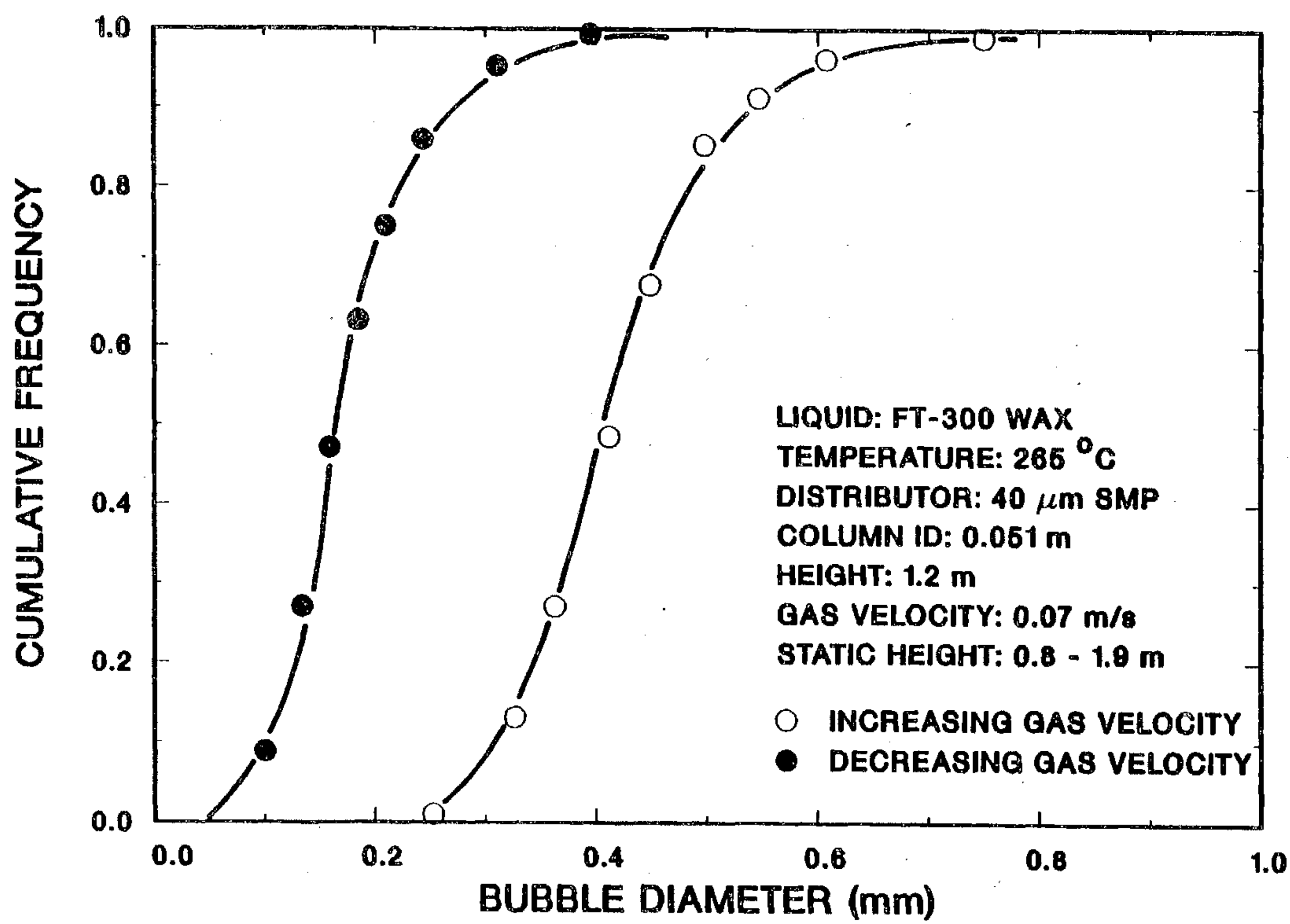


Figure V-54. Effect of flow regime on the bubble size distribution (○ - Run 5-1; ● -Run 5-2)

Therefore, the photographs taken under these conditions were of foam. Whereas, in experiments conducted with the 1.85 mm orifice plate distributor, foam does not fill the entire column; hence, photographs taken are those of the bubbles in the gas-liquid dispersion near the wall of the column. Photographs of the foam reveal that the d_s for foam is around 0.5 mm and the bubble frequency distribution is relatively narrow, as can be seen from Figure V-54. The difference in trends observed with the SMP distributor, compared to the 1.85 mm orifice plate distributor, can be explained by the fact that foam tends to be comprised of larger bubbles than those in the liquid (except for slugs). Results for this distributor at other velocities (0.01 and 0.03 m/s) showed similar behavior. Foam was present in the whole column and d_s was consistently around 0.5 mm at these velocities.

Results illustrating the effect of operating procedure on the bubble size distribution, for the 0.229 m ID column, are presented in Figure V-55. These runs were conducted at 265°C using a 19 X 1.85 mm perforated plate distributor. The photographs were taken at a height of 1.12 m above the distributor using a superficial gas velocity of 0.02 m/s. Bubbles produced using increasing order of velocities appear to be smaller than those produced using decreasing order of velocities, however, the difference does not appear to be significant and can be accounted for by the differences in hold-up values for the two cases (14.4% with increasing order of velocities and 12.0% with decreasing order of velocities).

D.2d.3. Effect of Superficial Gas Velocity

The effect of velocity on Sauter mean diameter for experiments conducted in the 0.051 m ID column using the 1.85 mm orifice plate

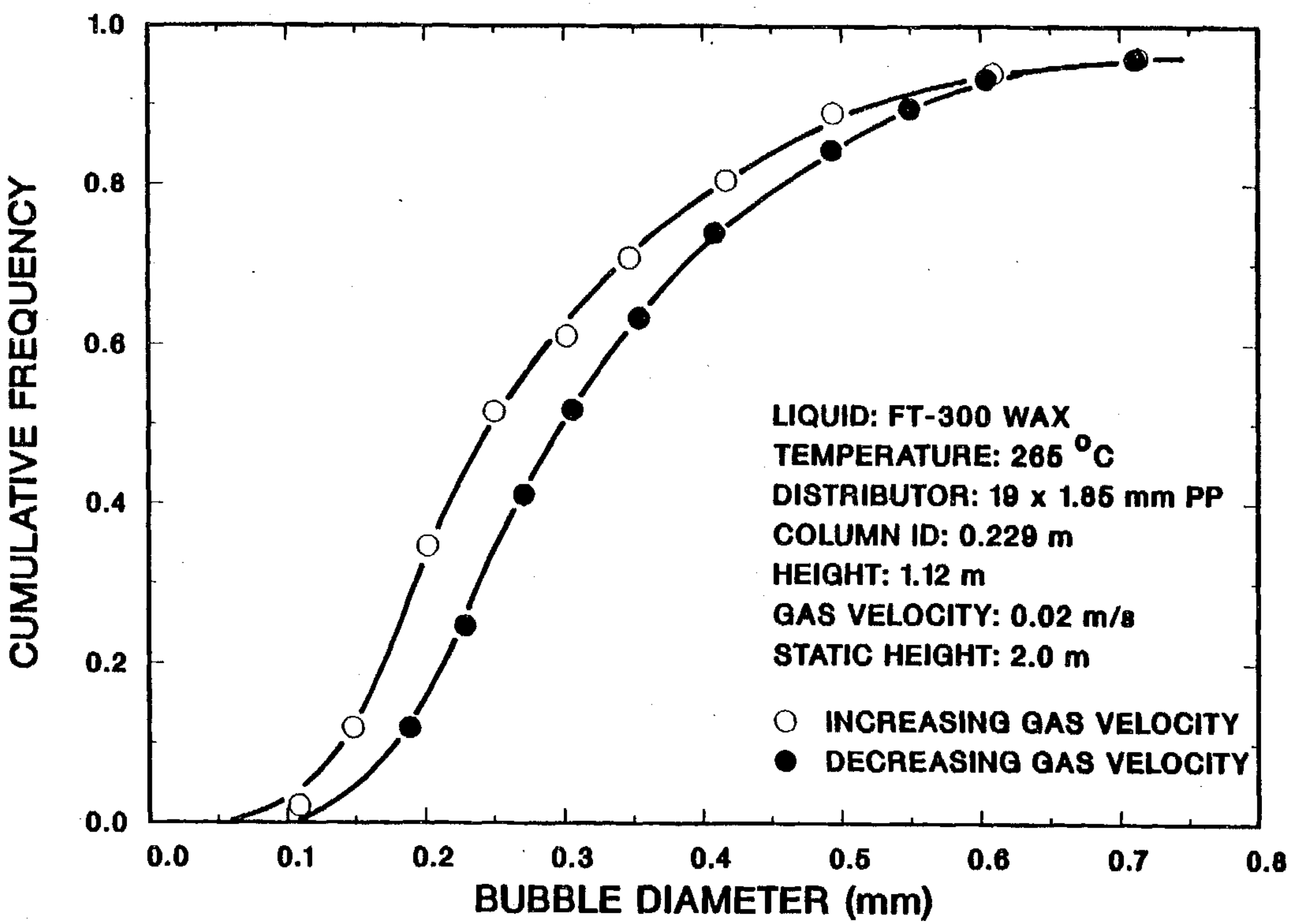


Figure V-55. Effect of flow regime on the bubble size distribution (○ - Run 2-3; ● -Run 2-4)

distributor at 265°C is shown in Figure V-56 for a height of 1.2 m above the distributor. In general, d_s appears to remain fairly constant (around 1.8 mm) regardless of operating procedure and gas velocity. The effect of large bubbles is more pronounced for these results because of the limited number of bubbles sized (around 400 to 500 per condition). This might help explain the scatter in results shown in Figure V-56. Results obtained using the 40 μm SMP distributor are shown in Figure V-57. The Sauter mean diameter for this distributor also appears to remain fairly constant around 0.6 mm over the range of gas velocities employed. Zaidi et al. (1979) and Deckwer et al. (1980) report Sauter mean diameters of about 0.7 mm for molten paraffin wax in bubble columns equipped with porous plate spargers which is in good agreement with results obtained in our study.

Figure V-58 illustrates the effect of gas velocity on the Sauter mean diameter for experiments conducted in the 0.229 m ID glass column. These results indicate that the Sauter mean diameter tends to decrease initially as gas velocity is increased and approaches a constant value at higher gas velocities. At 0.41 m above the distributor d_s decreases from approximately 1.2 mm at 0.01 m/s to approximately 0.7 mm at higher velocities. Visual observations of the flow field support these results. However, at 1.12 m and 1.96 m above the distributor, bubbles are significantly smaller at high velocities, approaching 0.4 mm at a gas velocity of 0.09 m/s. Again, this is in agreement with visual observations. At high velocities, bubbles near the wall form a very fine dispersion.

Quicker and Deckwer (1981) estimated d_s for FT-300 wax in a bubble column using porous plate and perforated plate spargers. They took photographs of bubbles along the column wall for experiments performed in the

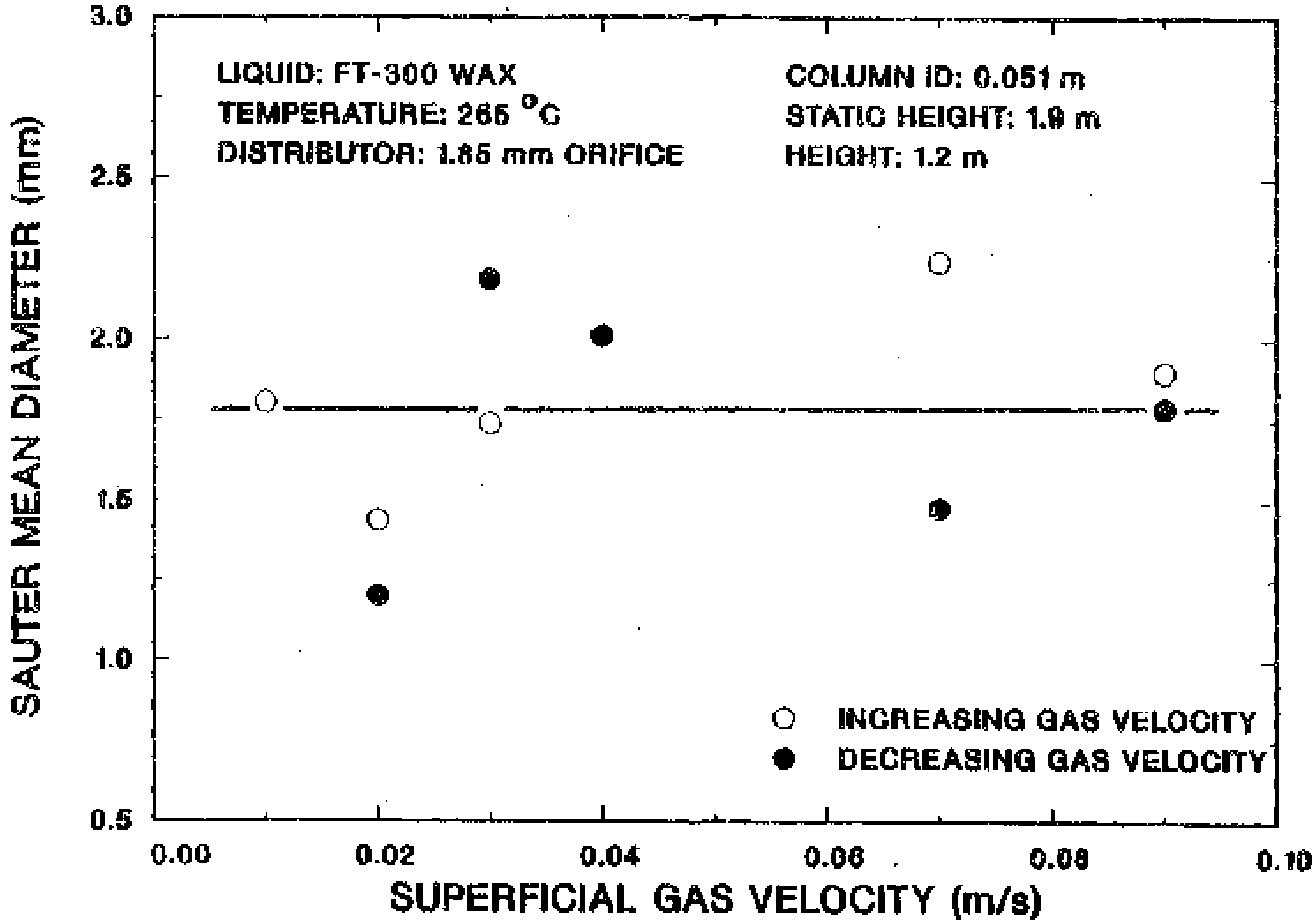


Figure V-56. Effect of superficial gas velocity on the Sauter mean bubble diameter (○ - Run 4-1; ● - Run 4-2)

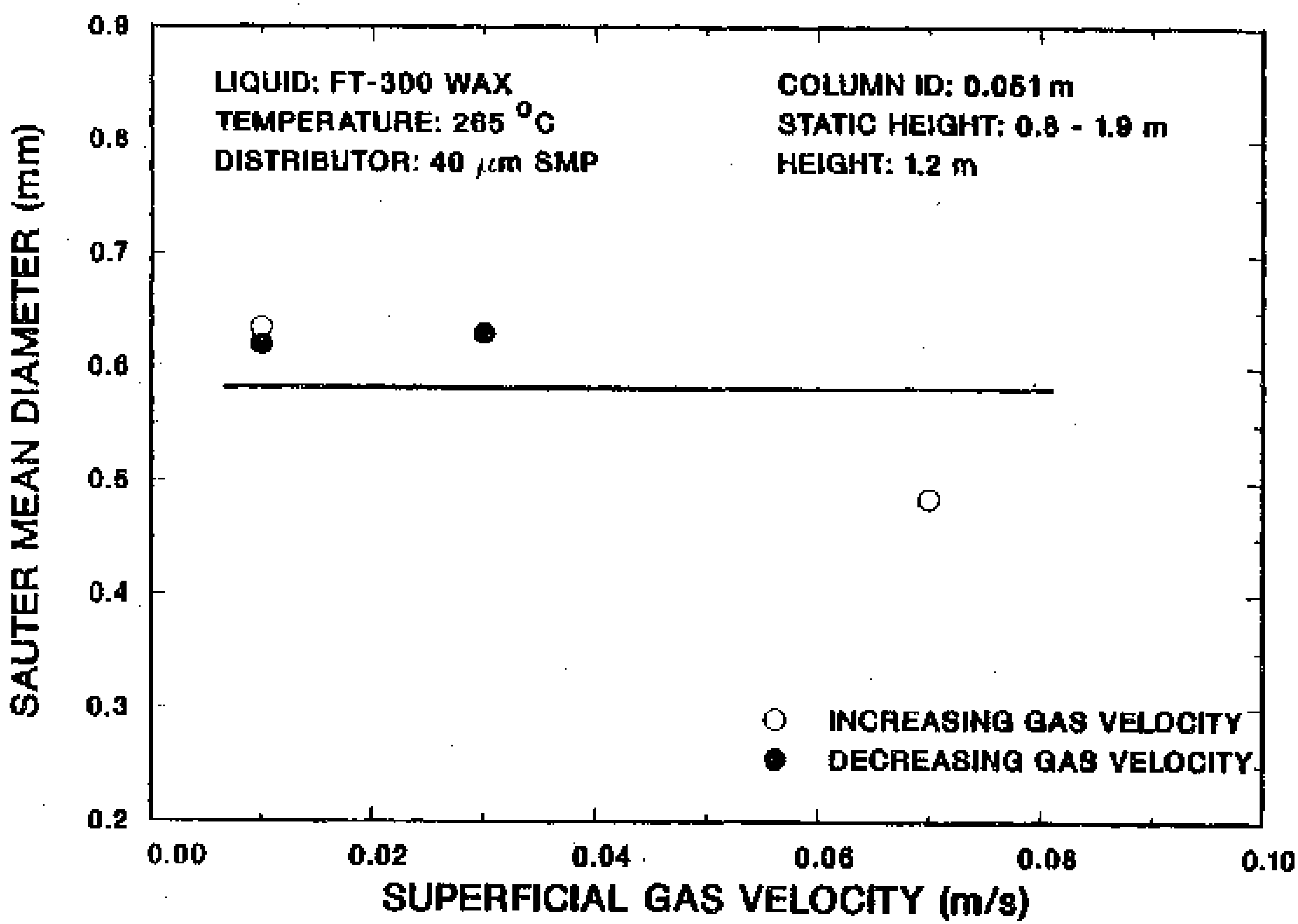


Figure V 57. Effect of superficial gas velocity on the Sauter mean bubble diameter (○ - Run 5-1; ● - Run 5-2)

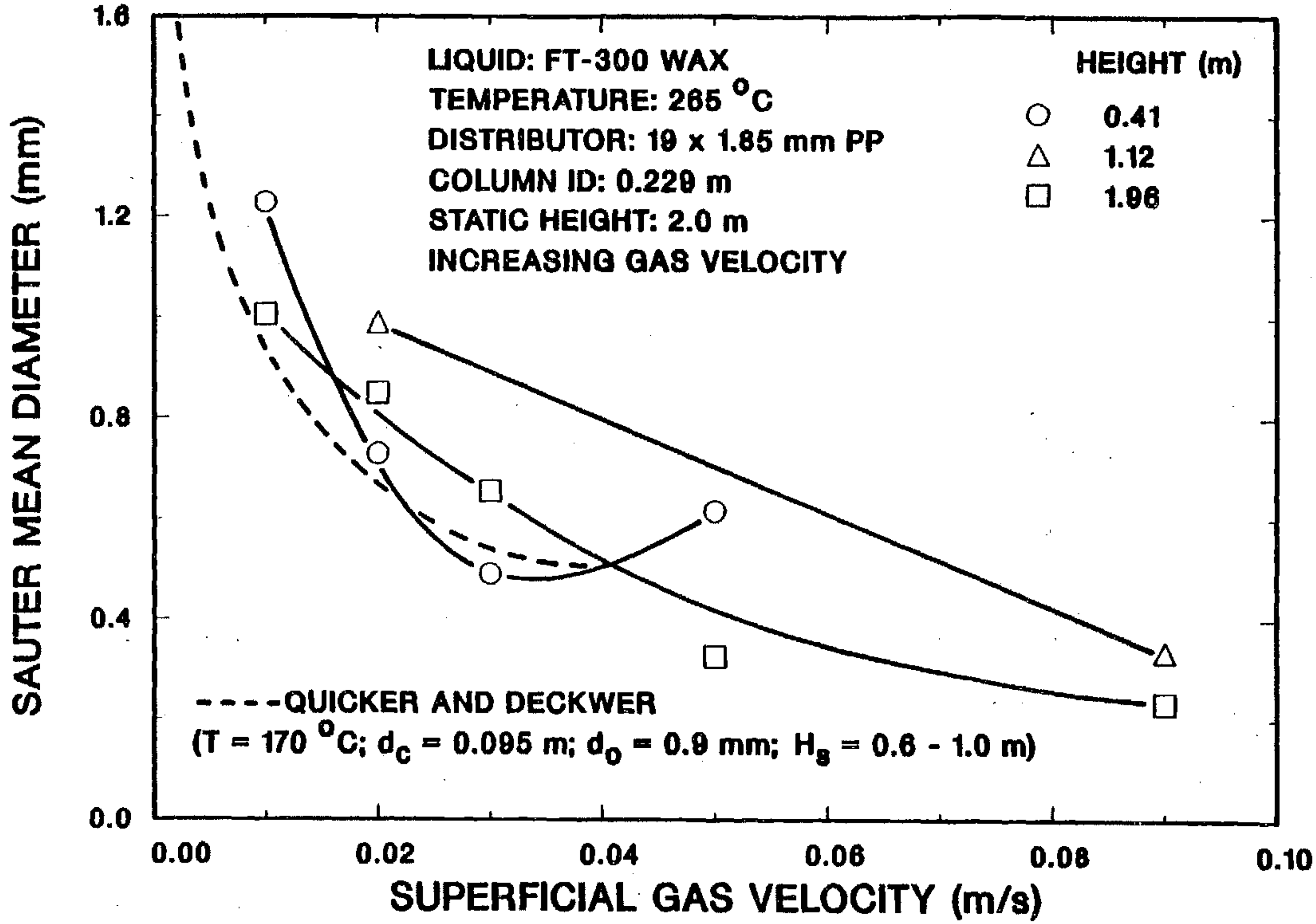


Figure V-58. Effect of superficial gas velocity on the Sauter mean bubble diameter and comparison with literature (Run 2-3) homogeneous flow regime. Their results show that d_s is around 1.5 mm at low velocities (u_g = 0.005 m/s) and it decreases to about 0.5 mm at a velocity of 0.035 m/s (Figure V-58). Sauter mean diameters for FT-300 wax from the current study at a height of 0.41 m above the distributor are in good agreement with the findings of these workers considering the differences in distributors and operating conditions.

Figure V-59 shows results from photographs taken at a temperature of 265°C in the 0.241 m ID stainless steel column through the special viewing port located at a height of 1.37 m above the distributor. Two photos at each velocity were selected and analyzed, and d_s from the individual photos was calculated. The data from the two photographs were then combined and d_s for the combined data was also calculated. Approximately 1500-1700 bubbles were catalogued and sized at each velocity (combined total from the two photographs). The open circles in Figure V-59 represent d_s for the combined data, whereas the d_s values for individual photographs are connected by the vertical bar at each velocity. Sauter mean diameters reach a maximum of 1.5 mm at 0.03 m/s and then stabilize at approximately 0.9 mm for higher velocities. Sauter mean diameters from the individual photographs compare satisfactorily considering the limitations of this procedure. These results indicate that for gas velocities in the range 0.02-0.04 m/s larger bubbles were present near the center of the column. However, bubbles were much smaller at velocities greater than 0.04 m/s. This indicates that at lower gas velocities, there might be significant circulation patterns in the column when larger bubbles are moving upwards in the center of the column. However, at higher gas velocities when flow is in the "churn-turbulent" regime, these circulations give way to intense mixing, resulting in

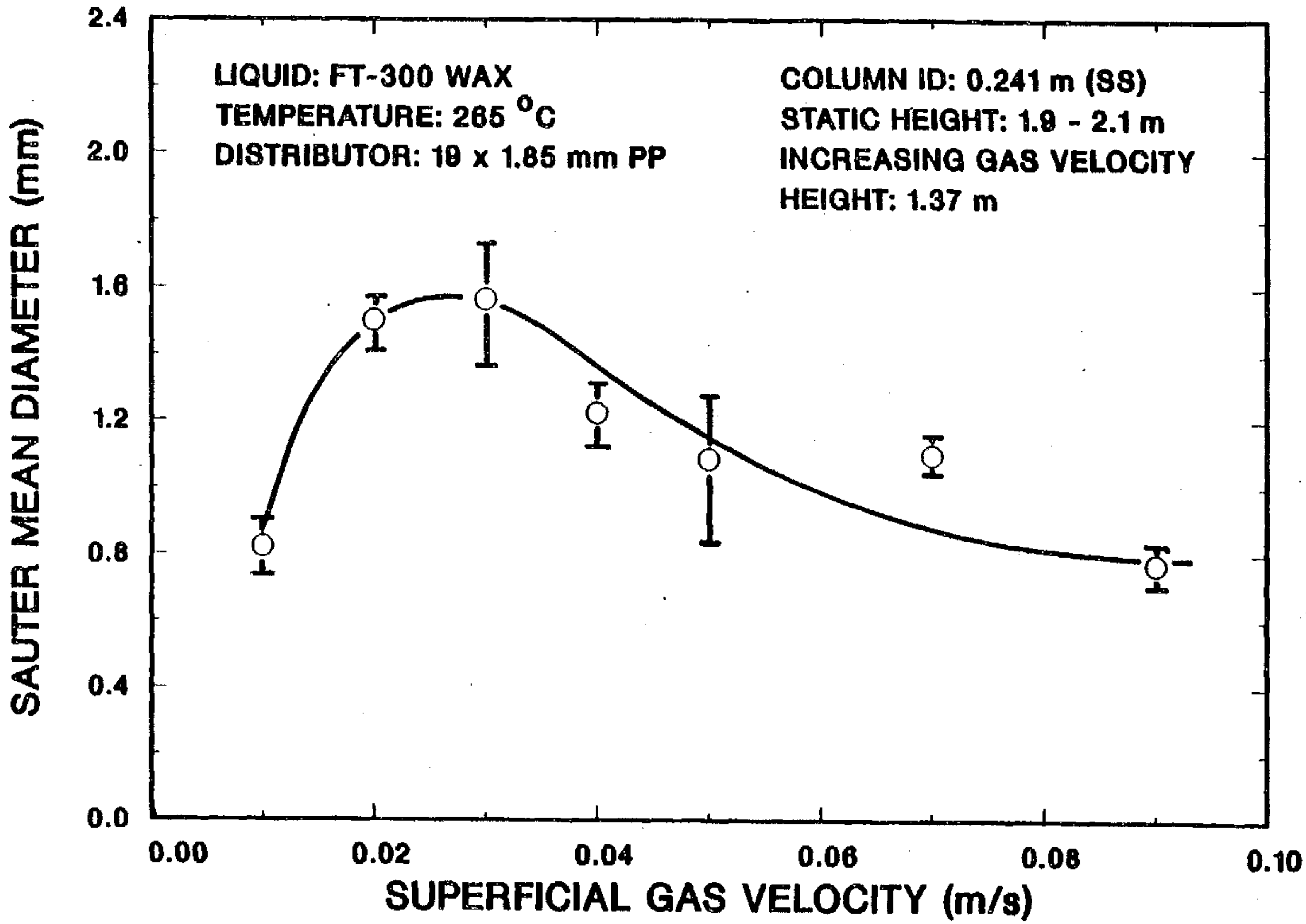


Figure V-59. Effect of superficial gas velocity on the Sauter mean bubble diameter (Run 2-7 - vertical bars join Sauter mean diameters from individual photographs, open circles represent Sauter mean diameters when results from the two photos were combined) relatively small bubble sizes. Visual observations of the dispersion support these findings.

Selected cumulative frequency curves for measurements made in the 0.24 m ID column are shown in Figure V-60. As expected, these curves show that the size of small bubbles remains almost constant at all velocities. However, the large bubbles change in size with gas velocity and this is reflected by the variation in the upper half of these curves. The change in distributions with gas velocity is in agreement with the trend shown in Figure V-59. At 0.01 m/s the bubbles are small and the distribution is relatively narrower (implying homogeneous flow). However, as velocity is increased to 0.03 m/s, larger bubbles start forming as a result of coalescence and higher gas flow rates. As velocity is further increased to 0.05 m/s these large bubbles begin to breakup due to increased turbulence and the distribution once again shifts to the left (towards smaller bubble sizes). Further increases in velocity result in only a marginal shift in the cumulative frequency curve (e.g. the curve at 0.09 m/s).

D.2d.4. Effect of Distributor

This effect was investigated only in the 0.051 m ID column. Cumulative frequency curves for measurements made at 265°C and at a gas velocity of 0.07 m/s are presented in Figure V-61. The photographs were taken at a height of 1.2 m above the distributor. It was not possible to compare results for the 1.85 mm distributor and the SMP distributor at velocities where foam was present because of reasons mentioned earlier (see Section V-E.2.). The results presented in Figure V-61 show that the SMP distributor produced smaller bubbles compared to the 1.85 mm orifice plate distributor. This is expected for a medium with low coalescence rates, such as paraffin

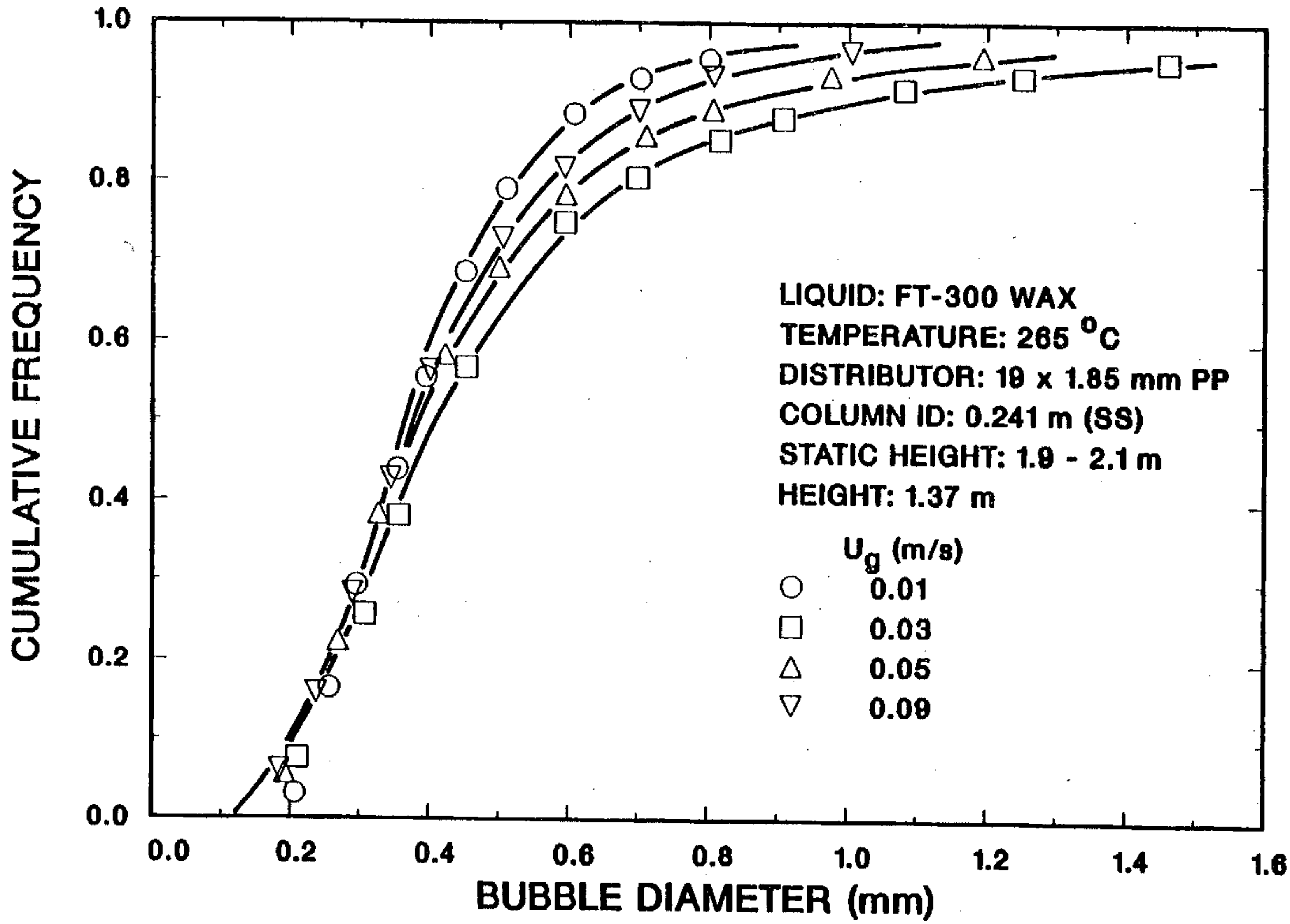


Figure V-60. Effect of superficial gas velocity on the bubble size distribution (Run 2-7)

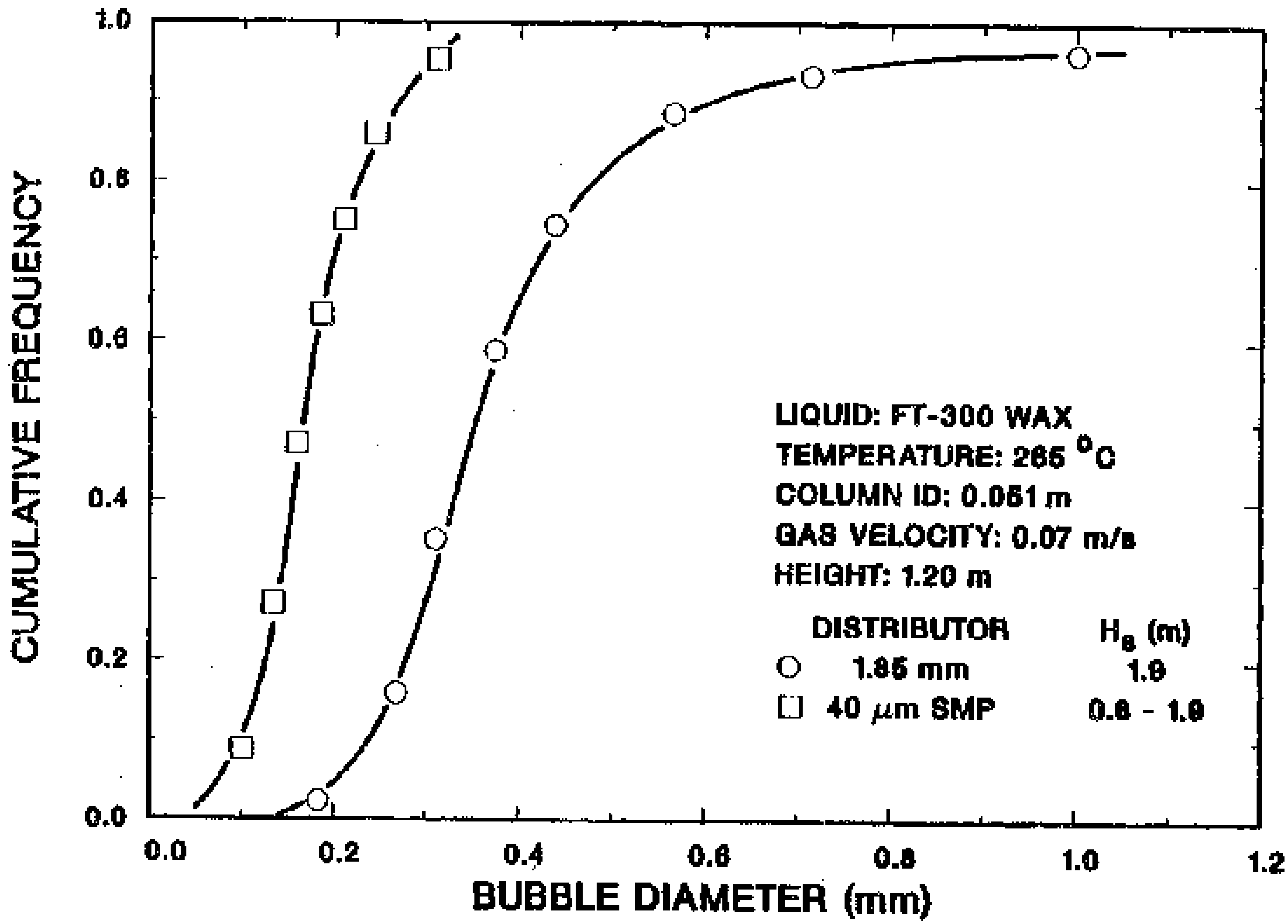


Figure V-61. Effect of distributor type on the bubble size distribution (○ - Run 4-1; □ - Run 5-1) waxes. These results are qualitatively in agreement with the arguments put forward by Heijnen and van't Riet (1984) relating the bubble sizes in a non-coalescing medium with the type of distributor used.

D.2d.5. Effect of Radial Position

The special viewing port constructed in the 0.241 m ID stainless steel column made it possible to compare the results obtained at the wall with those obtained from photographs taken near the center of the column (approximately 0.028 m from the center of the column). One of the major limitations of the photographic technique is its inability to predict the bubble size distribution across the entire cross-section for a non-homogeneous flow field. The following results illustrate this limitation clearly.

Sauter mean diameters near the center of the column were obtained in the 0.241 m ID column from photographs taken at a height of 1.37 m above the distributor and the results were shown in Figure V-59. Photographs of bubbles near the wall were taken in the 0.229 m ID glass column at three different heights (0.41 m, 1.12 m and 1.96 m above the distributor). These results, presented in Figure V-52, showed that the Sauter mean diameter did not change significantly with height above the distributor. Therefore, it can be assumed that d_s values at a height of 1.37 m, near the wall, should be approximately the same as those at 1.12 m or 1.96 m. Based on this assumption, it is possible to study the effect of radial position on the Sauter mean bubble diameter. Figure V-62 shows the variation of d_s with the normalized radial position at a temperature of 265°C for different superficial gas velocities. Values at the wall are based on photographs taken at a height of 1.96 m above the distributor.

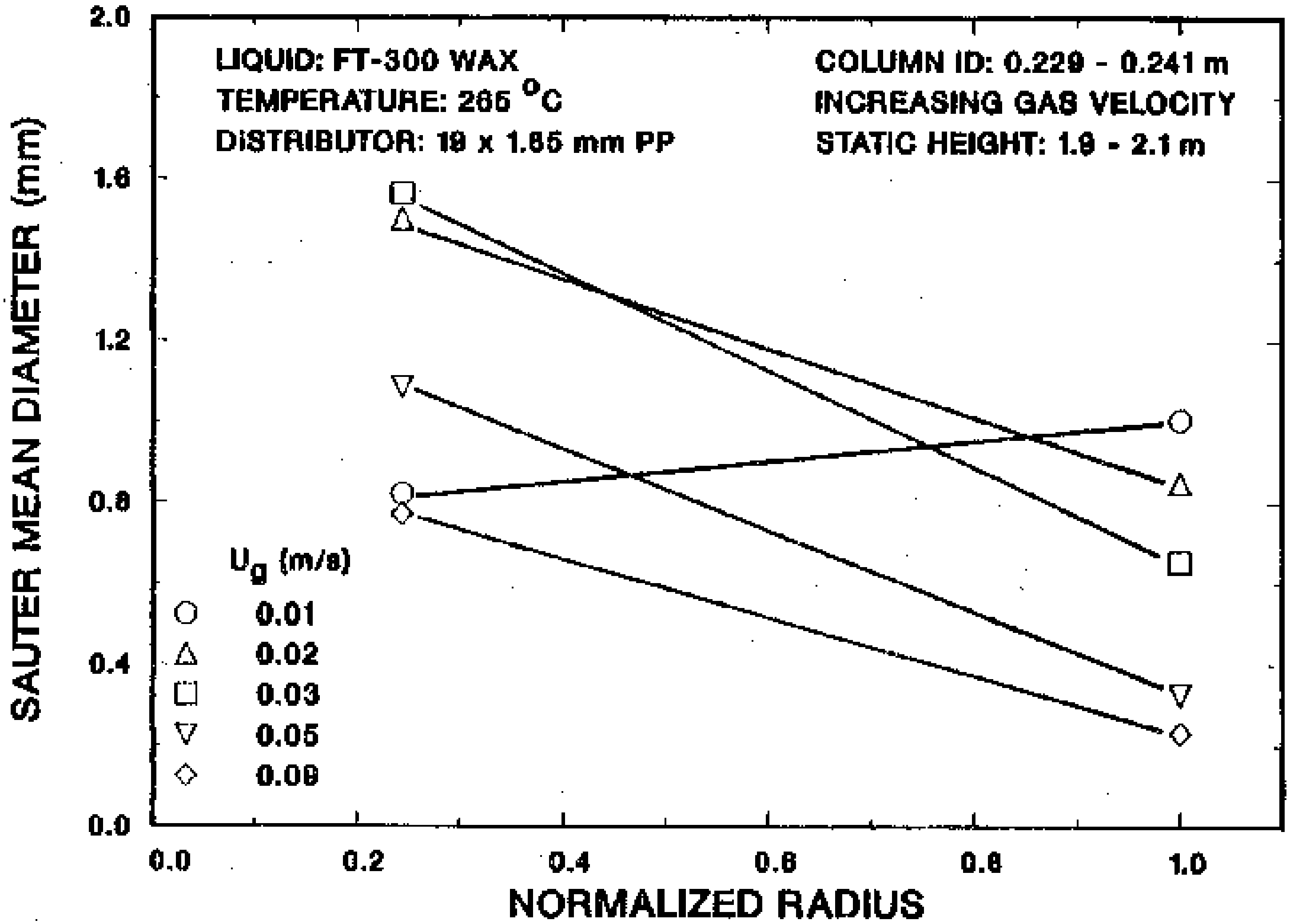


Figure V-62. Effect of radial position and superficial gas velocity on the Sauter mean bubble diameter (photos near the center - Run 2-7; photos near the wall - Run 2-3)

Results presented in Figure V-62 show that d_s is significantly affected by radial position at all velocities, except at 0.01 m/s. At 0.01 m/s the Sauter mean diameter is approximately the same at the two locations. These results imply that the dispersion is not homogeneous at this height (1.37 m above the distributor) once the gas velocity exceeds 0.01 m/s and significant gradients begin to develop. Figure V-63 shows cumulative frequency distribution curves for the two locations at a superficial gas velocity of 0.03 m/s. These results show that the bubble size distribution at the wall is significantly different from that near the center of the column.

Shah et al. (1985) have presented radial gas hold-up profiles for studies conducted in the air-water system. These profiles indicate that the hold-up is the highest at the column center and gradually decreases to a minimum at the column wall. Ueyama et al. (1980) also report similar findings with their studies with the air-water system. Ueyama et al. also present radial profiles for the bubble sizes based on measurements made using photography and electrical resistivity probes. Their results show trends which are similar to those found in the present study with FT-300 wax. Smith, D.N. et al. (1984a) conducted studies with the aqueous ethanol and nitrogen system and found that bubble size increased slightly from the column wall to the center of the column, however, d_s was found to be fairly constant within a distance of half a radius from the column center. Radial gas hold-up profiles from their studies are similar to those reported by Ueyama et al. Gas hold-up profiles presented in literature are as expected since it is well known that the greater part of the gas moves through the central core of the bubble column. For the column used in the present

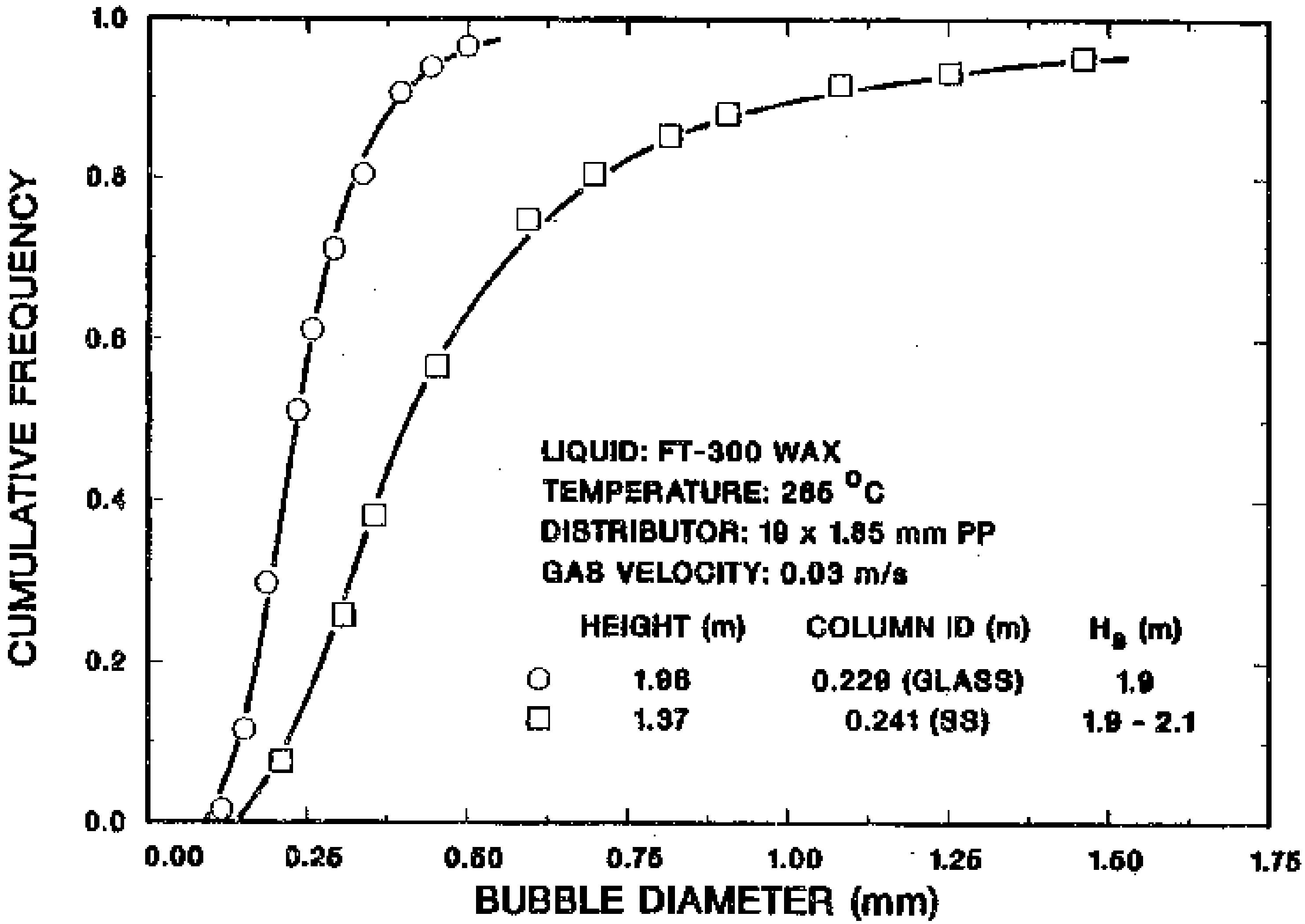


Figure V-63. Effect of radial position on the bubble size distribution (○ - Run 2-3; □ - Run 2-7) study, circulation patterns begin to develop in the column so that large bubbles move upwards in the center of the column and small bubbles entrained in the liquid move down along the wall of the column. This phenomenon explains the difference in results between photographs taken at the wall of the column and those taken near the center of the column.

D.2d.6. Effect of Oxygenates

The effect of oxygenates was investigated using mixtures of known composition of 1-octadecanol, octadecanoic acid (stearic acid) and FT-300 wax. These runs were made in the 0.051 m ID column using increasing order of velocities at 265°C. Both, the SMP and 1.85 mm orifice plate distributors were used in these studies. Up to 10 wt.% of oxygenates were added to FT-300 wax during these experiments.

For runs made using the 1.85 mm distributor, the addition of oxygenates resulted in a decrease in the value of the Sauter mean bubble diameter (around 1 mm for velocities greater than 0.03 m/s compared to around 1.8 mm with pure FT-300 wax). This can be partially explained by the fact that in the runs with oxygenated compounds, slightly higher hold-ups were obtained than in runs without oxygenates. Results from measurements made using the SMP distributor are qualitatively similar to those obtained using the 1.85 mm distributor. Zieminski et al. (1967) and Keitel and Onken (1982) conducted studies to investigate the effect of the addition of electrolytes to the air-water system. Their studies using alcohols show that the Sauter mean bubble diameter for the air-water system decreases with an increase in the length of the carbon chain of the alcohol.

D.2d.7. Effect of Operating Temperature

The effect of operating temperature (200 and 265°C) was investigated in the 0.051 m ID column using both, the SMP and the 1.85 mm orifice plate distributors; and in the 0.241 m ID stainless steel column using the 19 X 1.85 mm perforated plate distributor. Results from measurements made in the 0.051 m ID column revealed little or no effect of temperature on the bubble size distributions. Sauter mean diameters at 200°C were similar to those at 265°C. Photographs taken near the center of the column in the 0.24 m ID column showed that the value of d_s dropped as temperature was decreased from 265°C to 200°C. At 0.02 m/s d_s at 265°C was 1.5 mm compared to around 1.3 mm at 200°C, a relative decrease of around 13%. Similarly, at 0.07 m/s the relative difference was about 50% (1.1 mm compared to 0.5 mm). These results are contrary to the belief that lower temperatures result in higher viscosities and therefore should produce larger bubbles (as shown by DGD measurements). However, Quicker and Deckwer (1981) reported similar results with FT-300 wax. Their results show a decrease in d_s of as much as 50% at 0.01 m/s, when temperature was decreased from 170°C to 130°C, and about 10% at a velocity of 0.03 m/s. Results for other systems show that an increase in viscosity (equivalent to a decrease in temperature) results in an increase in d_s (e.g. Schugerl, 1981). There appears to be no obvious explanation for the results with FT-300 wax.

D.2c. Limitations of the Photographic Method

There are several limitations and drawbacks to the photographic technique for determining the Sauter mean diameter. The photographic technique only allows for the analysis of bubbles near the wall of the column which may not be representative of the bubbles in the entire column. However, in the present work the severity of this limitation was alleviated to a great extent by constructing a special viewing port in the 0.241 m ID stainless steel column. This port, shown in Figure V-49, is indented into the column for the purpose of obtaining photographs of bubbles near the center of the column. The construction of such a port is likely to influence the flow field because it creates an obstruction. However, the possibility of such an occurrence was greatly reduced by constructing a skirt (or a curtain) below the window as shown in Figure V-49. This metal piece extended around 0.05 m below the window. The purpose was to trap the bubbles close to the wall and allow the bubbles near the center of the column to proceed upwards unhindered. Visual observations of the flow field, through the viewing port confirm this. However, occasionally a sudden surge of small bubbles could be seen at the viewing port. This happens when the cavity under the window is saturated with tiny bubbles and as a result the bubbles are suddenly released in a large swarm. The photographs of the flow field were taken between such surges.

Once photographs of bubbles have been taken, the bubble sizes associated with the bubbles in the picture need to be determined by either a mechanical method or by image analysis equipment. Regardless of the method employed, the bubble sizes will be biased toward larger bubbles. The prejudice toward larger bubbles arises from the fact that in general, most of the large bubbles will be sized in a photograph (since they are clearly defined and in focus); whereas, not all of the small bubbles will be sized (too many and a lot are out of focus). In addition to this the measuring process involves some subjectivity and therefore introduces a certain amount of human error as well. Due to the finite number of bubbles which are counted the Sauter mean diameter will be significantly affected by the presence of large bubbles. This is evident in the following example.

Given a bimodal distribution with 500 bubbles of 0.5 mm diameter and 1 bubble 10 mm in diameter, the Sauter mean diameter is 4.7 mm (using Equation (V-5)). However, given 500 bubbles of 1 mm in diameter and 1 bubble 10 mm in diameter, the Sauter mean diameter is 2.5 mm. These results show that for a distribution containing smaller bubbles (0.5 mm), the Sauter mean bubble diameter is significantly greater than the distribution containing larger bubbles (1 mm), i.e. 4.7 mm for the former versus 2.5 mm for the latter. The obvious problem is the presence of the one large (10 mm) bubble in each of the distributions. If 100,000 small bubbles were sized instead of 500, only then does the value of d_s approaches 0.5 mm for the first case and 1.0 mm for the second. For the molten wax - nitrogen system the problem is further aggrevated because of the large number of fine bubbles present in the dispersion, whereas only a few large bubbles are visible. Therefore, by counting only a relatively small number of these fine bubbles the calculated values for the Sauter mean diameter will be larger than the actual values. The margin of this type of error can be reduced by increasing the bubble count (by analyzing more than one photograph per condition). However, this is an arduous task.

D.3. Bubble Size Distribution Using the Dynamic Gas Disengagement Method

Bubble size measurements were made using the dynamic gas disengagement technique (DGD) developed by Sriram and Mann (1977). Experiments were conducted in the 0.051 m ID and the 0.229 m ID glass columns in order to study the effect of operating temperature (200 and 265°C), distributor type, column diameter, and wax type. Majority of the experiments were conducted in the 0.051 m ID column using FT-300 wax, and reactor waxes