literature correlations (Shah et al., 1982), gas holdups are expected to increase with increase in temperature.

The bubble flow-patterns revealed large bubbles and constant slugging at 23°C and at superficial gas velocities larger than 0.7 cm/s. The slugging was always accompanied by smaller bubbles in the wake of slugs forming foam in the top zone. In contrast, at higher temperatures foam was negligible and slugging occurred only at u_g greater than 3.8 cm/s. Also, the bubble sizes appeared to be smaller. These gas holdup data confirmed our previous results in small hot-flow bubble-columns: even though the viscosity and surface tension of n-hexadecane are similar to the FT-200 wax, larger bubble sizes and lower gas holdups are obtained with n-hexadecane.

The 10.2 cm ID bubble-column was shaken down later. The shakedown consisted mainly of pressure-testing the bubble-column with 239 kPa N_2 at 138°C. Also, the pressure controller was checked out. The shakedown was carried out very smoothly without any problems.

E. Hydrodynamic Studies Using 5.1 and 10.2 cm ID Tall, Hot-Flow Bubble-Columns

Except specified otherwise, the FT-200 wax was used in all studies. Since FT-200 wax is clear, it enabled us to observe and photograph the bubble flow patterns. The reactor-waxes from the two-stage BSU are dark in color and were studied later at the end of the program. The waxes studied were from Runs CT-256-7 and -8.

Four gas distributors were evaluated in the 5.1 cm ID column: a 20 micron SMP, a 1 mm single orifice, a 0.5 mm three-hole, and a 2 mm single-orifice distributor. The 20 micron SMP is similar to the one used in the two-stage BSU. A 1 mm orifice distributor was studied since it is probably the smallest commercially applicable orifice distributor. The 0.5 mm three-hole distributor is dynamically similar (i.e., similar jet velocity and Weber number at the same superficial gas velocity) to the 1 mm orifice. The 2 mm orifice distributor will provide lower pressure drop than the other two orifice distributors.

We evaluated a 2 mm single orifice, and a 1 mm 4-hole distributor in the 10.2 cm ID column. These two distributors gave the same jet velocities as the 1 mm single orifice distributor in the 5.1 cm ID column.

We also studied the effect of static height, temperature, and pressure on the gas holdup.

The major highlights of these studies are:

- The 20 micron SMP distributor produced smaller bubbles and substantially higher gas holdup than the orifice distributors. Also, in contrast to SMP distributor, little or no foam occurs with orifice distributors.

- In contrast to the SMP distributors, increasing static liquid height results in higher holdup with 1 mm single orifice distributor (using the FT-200 wax as a liquid medium).

- The two reactor-waxes (Runs CT-256-7 and -8) behaved very similarly, even though their viscosities and compositions are substantially different.

- Both reactor-waxes gave substantially lower holdups than that given by the FT-200 wax. Also, unlike FT-200 wax, the reactor-waxes [illegible] not foam.

- The column di[illegible] had no effect on the gas holdup for FT-200 wax. How[illegible]er, the reactor-waxes gave higher holdups in the larger column.

- In all cases, slugging accompanied by violent bubble-motion was observed in both columns at superficial gas velocities greater than 1.5-2 cm/s. Thus, a column diameter larger than 10.2 cm is necessary to avoid any wall effect.

- For all distributors pressure variations of 101-250 kPa had no significant effect on the gas holdups.

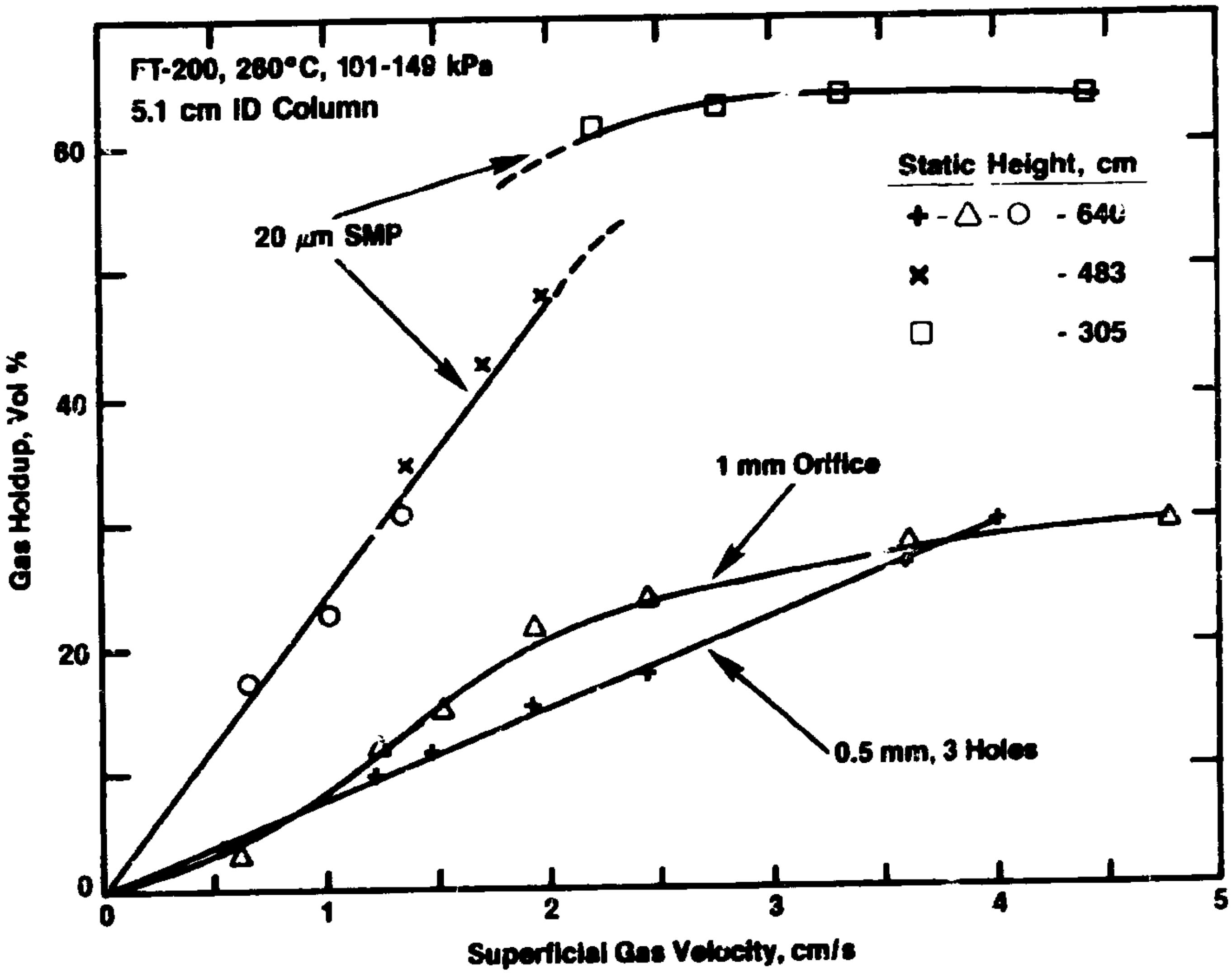
E.1. Effect of Feed-Gas Distributor Design

Figure VII-23 is a plot of the gas holdups observed using the three gas distributors. The static liquid height was 627-640 cm for both orifice distributors. In the case of the 20 micron SMP distributor the static height had to be decreased from 640 to 305 cm to allow for the high gas holdups resulting from the SMP distributor. The total expanded height is limited to 914 cm.

As seen in the figure, the hydrodynamic behavior of the two orifice type distributors is very similar. The gas holdups with the SMP distributor, however, are substantially higher (almost twice as much) than those with the orifice distributors. As reported earlier in the short hot-flow column studies, substantial foaming was observed with the SMP distributor. Also, the bubbles formed at the distributor are uniformly small and

Figure VII-23

EFFECT OF DISTRIBUTOR TYPE



they stay uniform throughout the column. Because of these very small bubbles, stable foam is formed in the upper zone, giving very high gas holdups. As the superficial velocity is increased, the foam region increases, and the boundary between the foam and small bubbles becomes less distinct. At superficial velocities greater than 2 cm/s, slugging at constant frequency was observed. The slug size and frequency increased with increasing superficial gas velocity. This slugging phenomenon was not observed earlier in the short column. Even when slugging is observed, the bubbles in the bottom 150 cm zone were small and densely packed. Many small swirling bubbles were observed in the wake of the slugs.

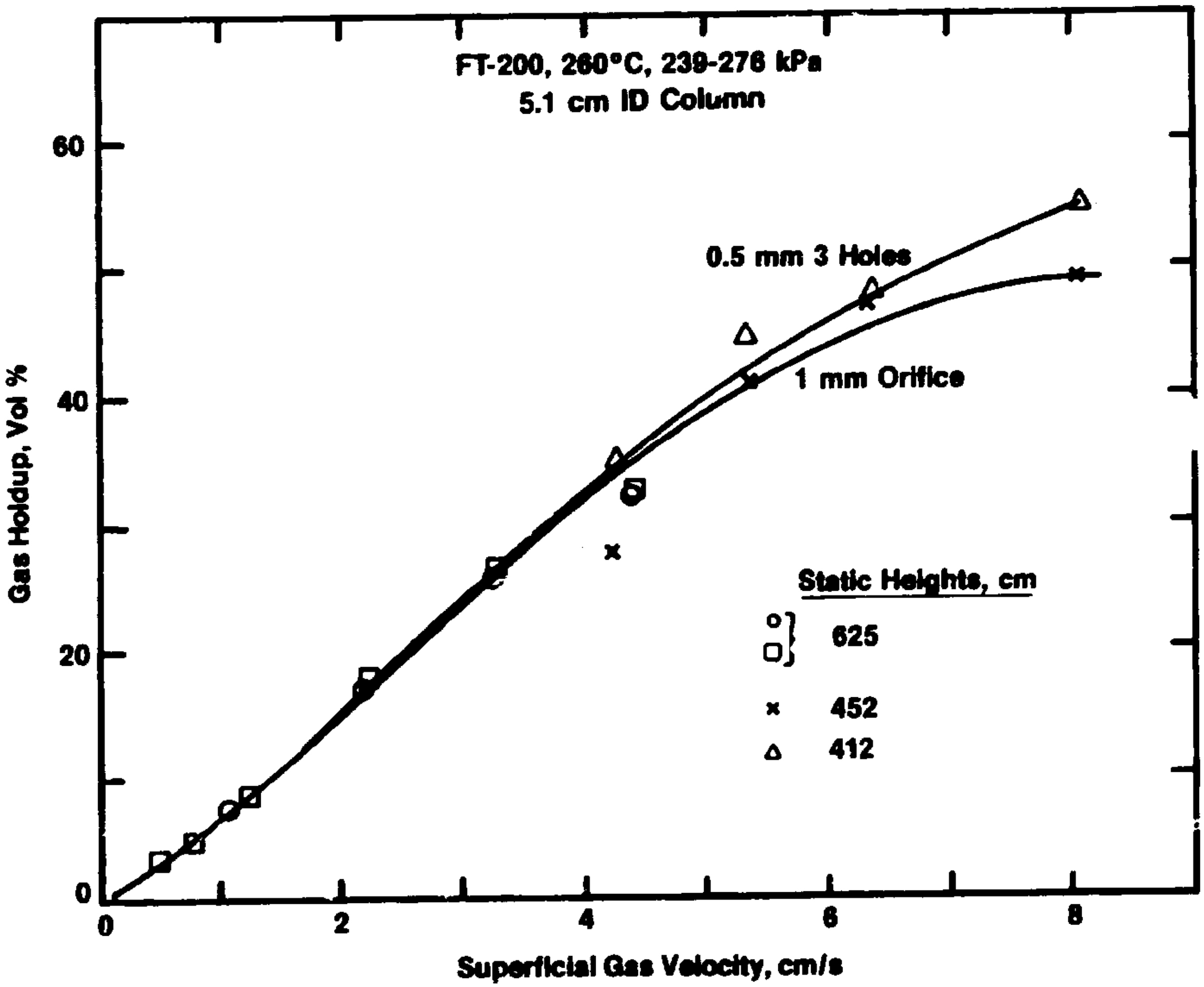
The bubble-size distribution with the orifice-type distributors was wider than with the SMP distributor. The large bubbles formed in the lower zone tended to break up in the upper zone forming uniformly small bubbles. However, even the small bubbles in the top zone were larger than those observed with the SMP distributor. Consequently, the foam height was extremely small (about 5-8 cm) compared to 20-38 cm with the SMP distributors Also, with the orifice distributors, the larger bubbles in the bottom zone created more violent bubble movement than that observed with uniformly small bubbles produced with the SMP distributor. This violent bubble movement should be beneficial to gas-liquid mass transfer.

The slugging was observed at lower superficial gas velocities (>1.5 cm/s) than those of the SMP distributors. Once again very small bubbles were observed in the wake of the slugs. As with the SMP distributor, the slug size and frequency increased with increasing superficial gas velocity. Data from literature indicate that the gas holdup is expected to level off with slugging. In this case, however, the presence of very small bubbles produced by the violent motion of slugs tend to increase the gas holdup with increasing gas velocity.

Figure VII-24 compares the gas holdups obtained with the two orifice-type gas distributors. As discussed earlier, one of the criteria used to design an orifice-type distributor for making small gas bubbles is that the Weber number is larger than 2. The 1 mm orifice and 0.5 mm three-hole distributors were chosen to match the Weber numbers at the same superficial velocity. Due to the equipment limitations, we could not make a 0.58 mm three-hole distributor which would have had exactly the same Weber number at the same u_g. Thus, the Weber number for 0.5 mm three-hole distributor is 12% higher than that for the 1 mm orifice distributor. Also, the jet velocities for these two distributors are very similar (within 25%) at the same superficial velocity. The hydrodynamic behavior of the two distributors are, also, extremely similar (Figure VII-24). This indicates that the two distributors with similar jet velocities and similar Weber numbers give similar hydrodynamics. This is

Figure VII-24

COMPARISON OF ORIFICE DISTRIBUTORS



further illustrated in Figures VII-25 and -26 where the gas holdups are plotted as a function of Weber numbers and jet velocities respectively.

Figure VII-27 compares the gas holdups obtained with the three orifice-type gas distributors. The gas holdups shown for the 1 mm single-orifice and 0.5 mm 3-hole distributor were duplicated from Figure VII-24 and shown here as a correlation, $\epsilon_g = 6.5\ u_g^{1.1}$. As shown in the figure, the 2 mm orifice gave substantially lower gas holdups (by 50-70%) than those given by the other orifice-type distributors. The bubble-size was relatively larger. Furthermore, the bubble size did not appear to change along the length of the column as observed with the other two orifice distributors. Also, large bubbles were seen to rise near the center of the column at gas superficial velocities as low as 1.1 cm/s. These large bubbles formed slug-type bubbles as they rise upward. These large bubbles are called slug-type because they were quite large; but unlike slugs, they did not occupy the whole column-diameter.

At superficial gas velocities greater than 1.1 cm/s, the slugging at constant frequency was observed. The frequency of slugs was, however, substantially higher (three times that for other orifice distributors). Also, the small bubbles surrounding the large slugs were relatively larger. The existence of more slugs and larger bubbles is consistent with the observed lower holdup.

Thus, the 2 mm orifice distributor gave almost half the gas holdup and bubbles of approximately twice the diameter of those given by the 1 mm orifice. Consequently, the specific surface area using the 2 mm orifice is expected to be one fourth of that using a 1 mm orifice. The 1 mm orifice was, hence, used in the BSU slurry reactor.

E.2. Photographic Analysis of Bubble Flow Patterns in Bubble-Columns

During the evaluation of three feed-gas distributors in the 5.1 cm ID hot-flow bubble-column, the bubble flow patterns within the glass sections of the column were photographed. The bottom 152 cm glass section permitted the observation of bubble flow patterns forming at the distributor. The top glass section between the 610 and 914 cm levels revealed the well-developed flow patterns at the top. The bubble flow patterns were very similar in the case of the two orifice-type distributors (1 mm single-orifice and 0.5 mm-3 hole). Hence, photographs of only the 0.5 mm-3 hole distributor case are shown here.

Figure VII-25

COMPARISON OF ORIFICE DISTRIBUTORS

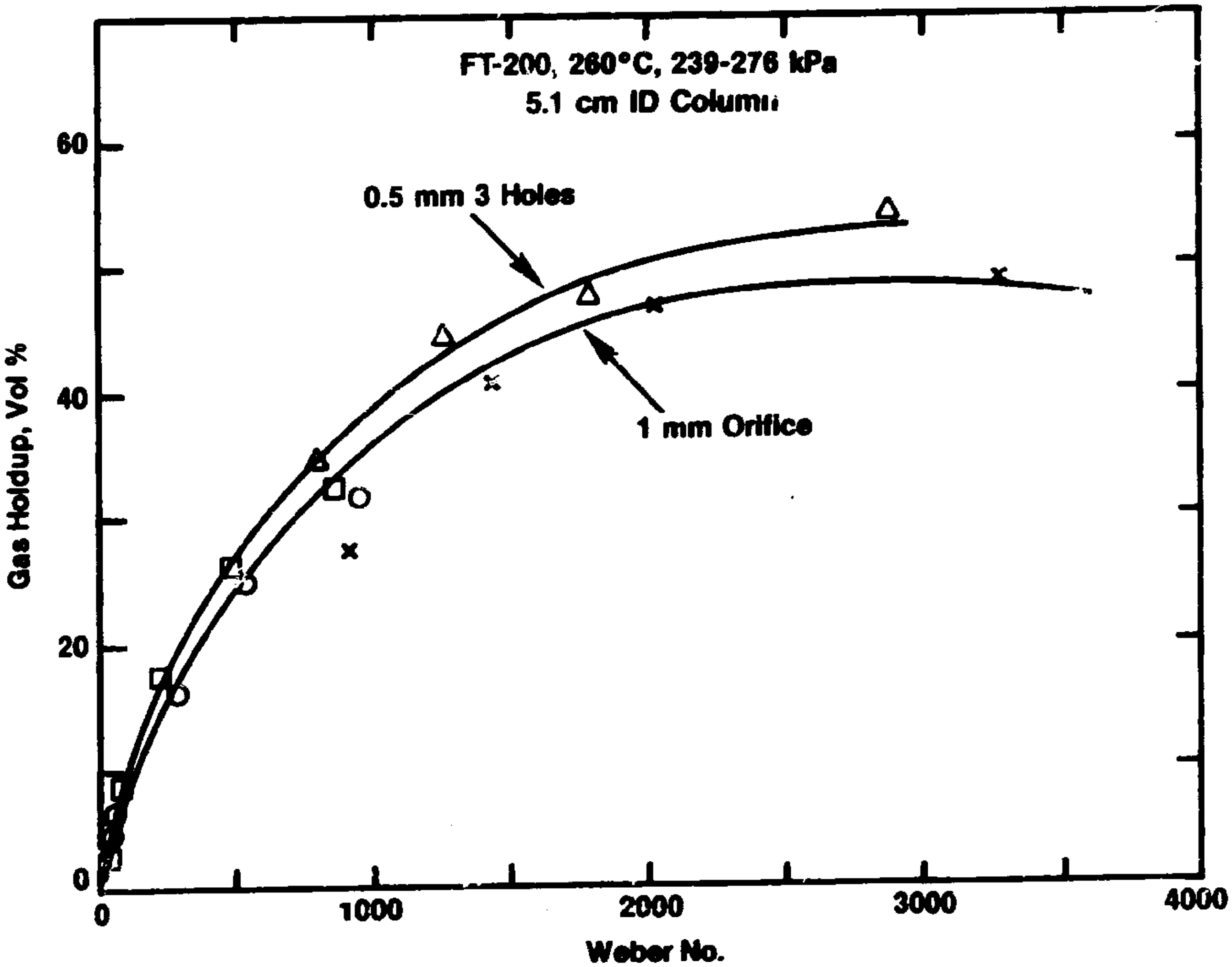


Figure VII-26

COMPARISON OF ORIFICE DISTRIBUTORS

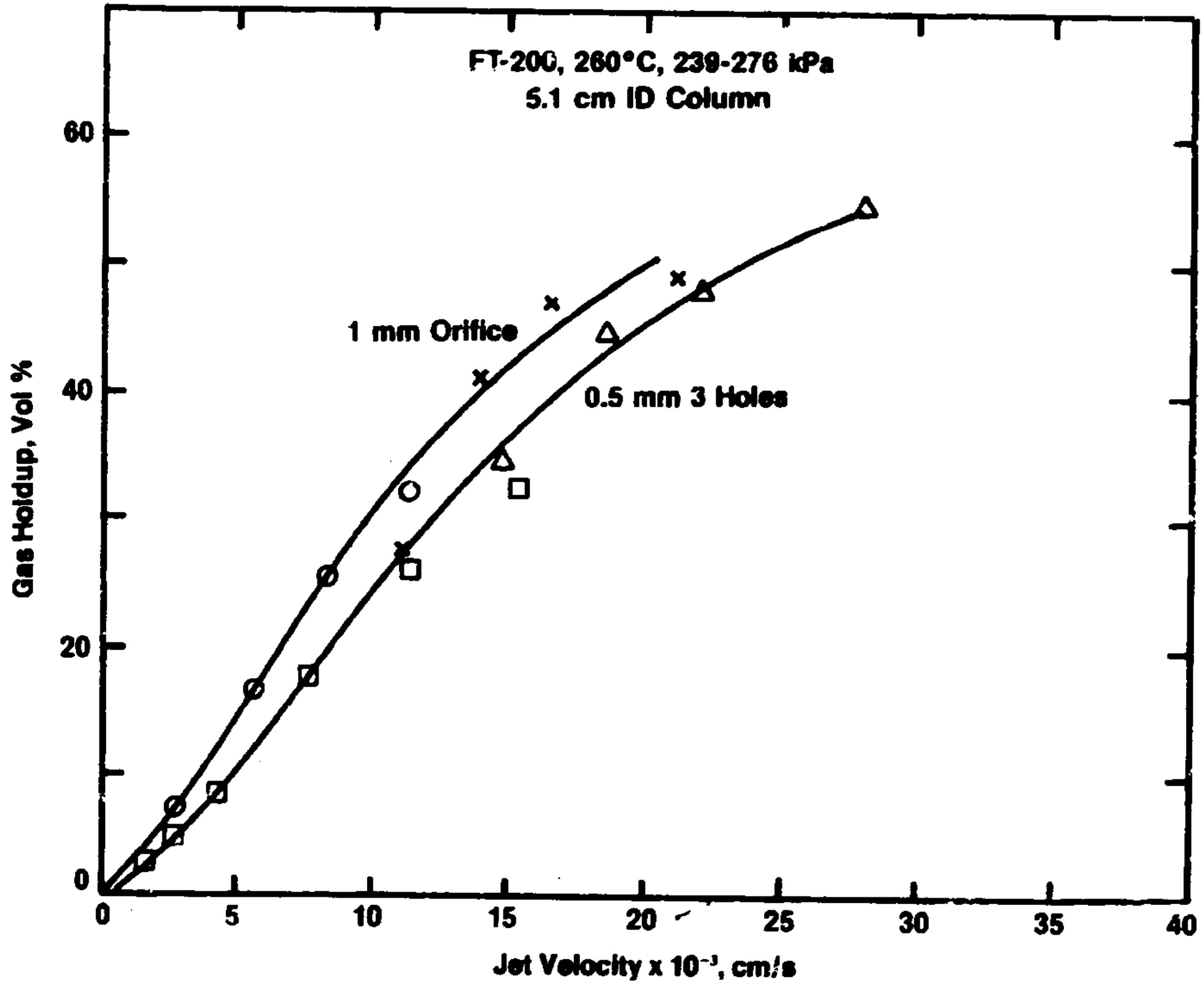


Figure VII-27

COMPARISON OF ORIFICE DISTRIBUTORS

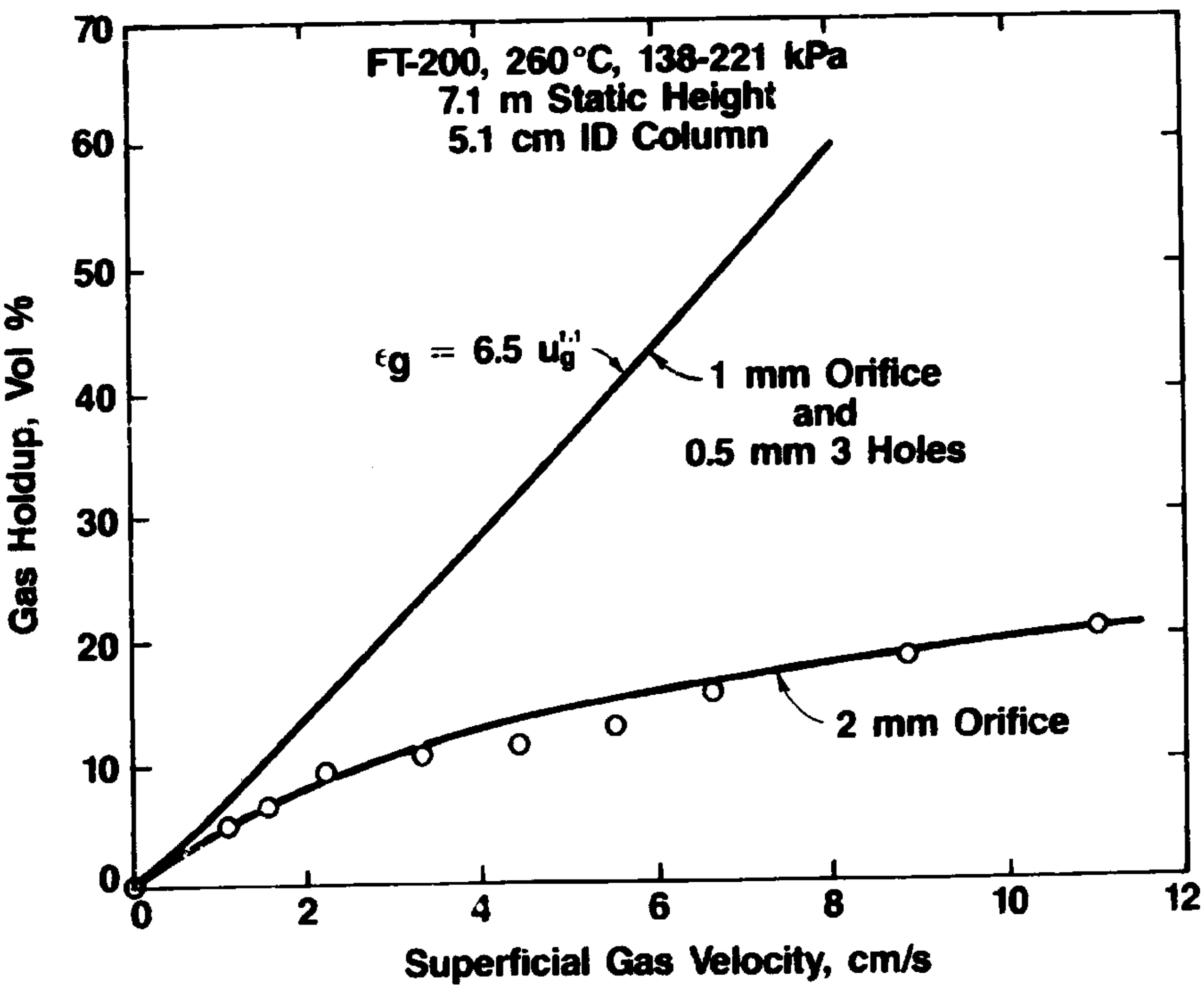


Figure VII-28 shows bubbles produced by a 20 micron SMP distributor. As reported earlier, the bubbles formed at the distributor are uniformly small and they stay uniform throughout the column. Figure VII-28 clearly shows the uniform, densely packed bubbles. The bubble size distribution did not change noticeably at different locations along the column or at different superficial gas velocities. Hence, only one typical photograph is shown here. The bubble size from the photographs for the SMP case was found to be less than 1 mm.

In contrast to the uniformly small bubbles produced by he SMP distributor, the orifice-type distributors give a wider bubble size distribution as shown in Figure VII-29. In this photograph the bubble flow patterns at three different locations along the column have been shown for a 0.5 mm-3 hole gas distributor operating at 1.2 cm/s superficial gas velocity. In the zone very close to the distributor (between 13 to 25 cm) large bubble can be seen. The black vertical strips seen in the photograph are the heating rods used to heat the column. These heating rods are 8 mm in diameter and can be used as a reference for bubble size measurement. From the photograph (13-25 cm above the distributor) a few bubbles as large as 6-7 mm can be seen. Around these large bubbles a lot of small bubbles (~2 mm) can be observed. As seen from the middle photograph in the figure (127-142 cm above the distributor), the large bubbles seem to have broken up into smaller bubbles. In the very top zone (663-678 cm from the distributor) bubbles appear to be of more uniform size (~1 to 2 mm). However, even the small bubbles in the top zone are larger than those observed with the SMP distributor. Consequently, the gas holdups with the orifice distributors are lower than those with the SMP. Also, the larger bubbles at the top zone in the case of orific -type distributors substantially reduced the foam height.

As reported earlier, the slugging at constant frequency was observed with all three distributors. A typical photograph of the slug is shown in Figure VII-30 produced by 0.5 mm-3 hole distributor at 4 cm/s. Since a slug is a lot more transparent, it appears as a white patch in the photograph. A lot of small bubbles can be clearly seen to be moving around the rising slug. Due to presence of very small bubbles around a slug, the overall gas holdup can be still substantially high.

E.3. Gas Holdup Profiles in Hot-Flow Columns

E.3a. Gas Holdup Profiles in the 5.1 cm ID Hot-Flow Bubble-Column

In the 5.1 cm ID hot-flow bubble-column we measured gas holdup profiles using a DP-cell arrangement. The overall holdup was obtained by visual observation of the expanded slurry height.

Figure VII-28

BUBBLES PRODUCED BY 20μm SINTERED-METAL-PLATE

(FT-200 Wax at 260°C)

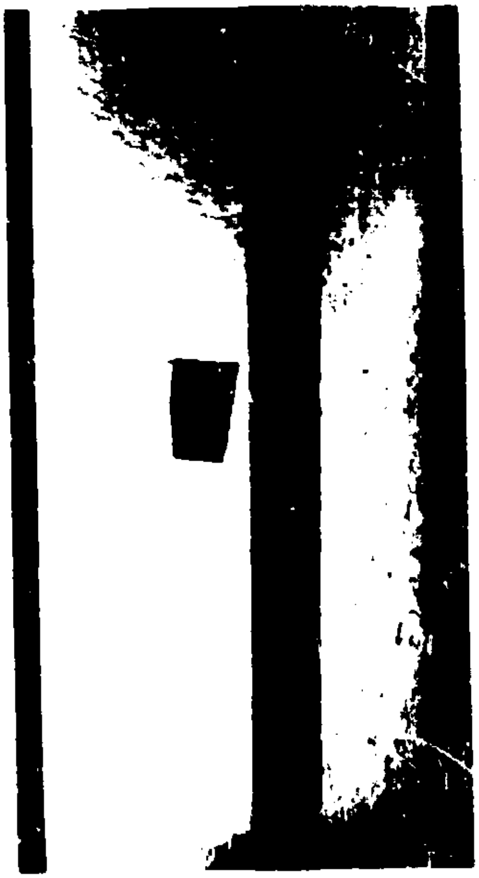
Figure VII-29

BUBBLE FLOW PATTERNS PRODUCED BY 0.5 mm 3-HOLE DISTRIBUTOR AT 1.2 cm/s

a. 13-25 cm b. 127-142 cm c. 663-678 cm

FT-200 Wax, 260°C, 101-150 kPa, 640 cm Static Height

Figure VII-30
SLUG PRODUCED BY 0.5 mm 3-HOLE DISTRIBUTOR AT 4 cm/s



663-678 cm

The local gas holdup along the length of the column was measured using DP-cells. Figure VII-31 gives local gas holdup along the bubble-column at various superficial gas velocities for the 1 mm single-orifice distributor. The data at lower gas velocities of 2.2 and 3.3 cm/s were taken with a higher static height of 627 cm. The rest of the data at higher superficial velocities were taken at the lower static height of 452 cm. In all cases the gas holdup was found to increase along the length of the bubble-column. This observation is consistent with the bubble flow patterns shown in the preceding Subsection. In the case of orifice-type distributor the bubbles formed at the bottom are large (~6-7 mm) giving lower holdup at the bottom. These large bubbles tend to break up as they rise upward. Hence, the gas holdup increases along the height of the column.

The lower gas holdup in the bottom zone also substantiates our later results showing the effect of static liquid height (see Subsection E.5). Figure VII-32 illustrates the effect of decreasing static liquid height on the gas holdup. Additional local holdups (marked by ∇ and Δ) in the bottom zone (between 30-305 cm) for the higher static height case are also shown on the same plot. The local gas holdup in the bottom zone compares well with the overall gas holdup at lower static height cases. Thus, the bubble flow patterns in the lower zone close to the distributor seems to be similar at all static liquid heights. This supports our explanation of lower gas holdup for very low static height discussed in Subsection E.5.

E.3b. Gas Holdup in BSU Bubble-Column

During Run CT-256-7, gas holdups were measured using the newly installed purgeless DP-cell system in the BSU bubble-column. A plot of the overall gas holdup as a function of time is presented in Figure VII-33. The scatter in the data is substantial, thus preventing the development of a correlation for gas holdup as a function of superficial gas velocity.

It is clear, however, that the gas holdup jumped from an average of 25 vol % to 40 vol % after the feed-gas distributor was repaired at 76 DOS. This indicates that smaller bubbles were being formed following the repair of the feed-gas distributor, a direct consequence of higher gas jet velocity.

E.4. Dynamic Gas-Disengagement for Bubble-Rise Velocity Measurement in Hot-Flow Bubble-Columns

E.4a. Theory

Sriram and Mann (1977) developed a dynamic gas-disengagement technique to measure bubble-rise velocity in bubble-columns. The technique requires measurement of the steady

Figure VII-31

GAS HOLDUP PROFILES
(1 mm ORIFICE DISTRIBUTOR)

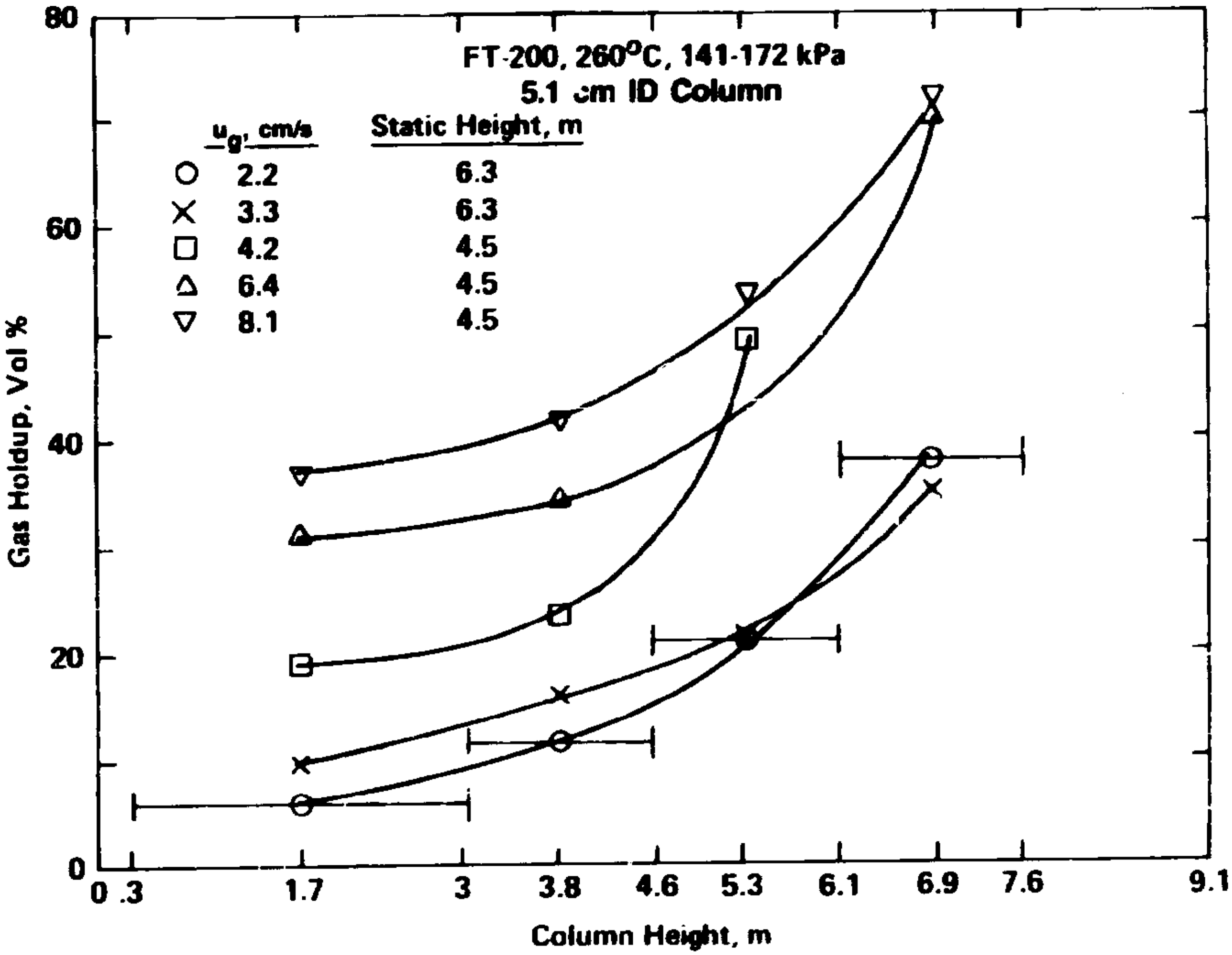


Figure VII-32

EFFECT OF STATIC LIQUID HEIGHT (1 mm ORIFICE DISTRIBUTOR)

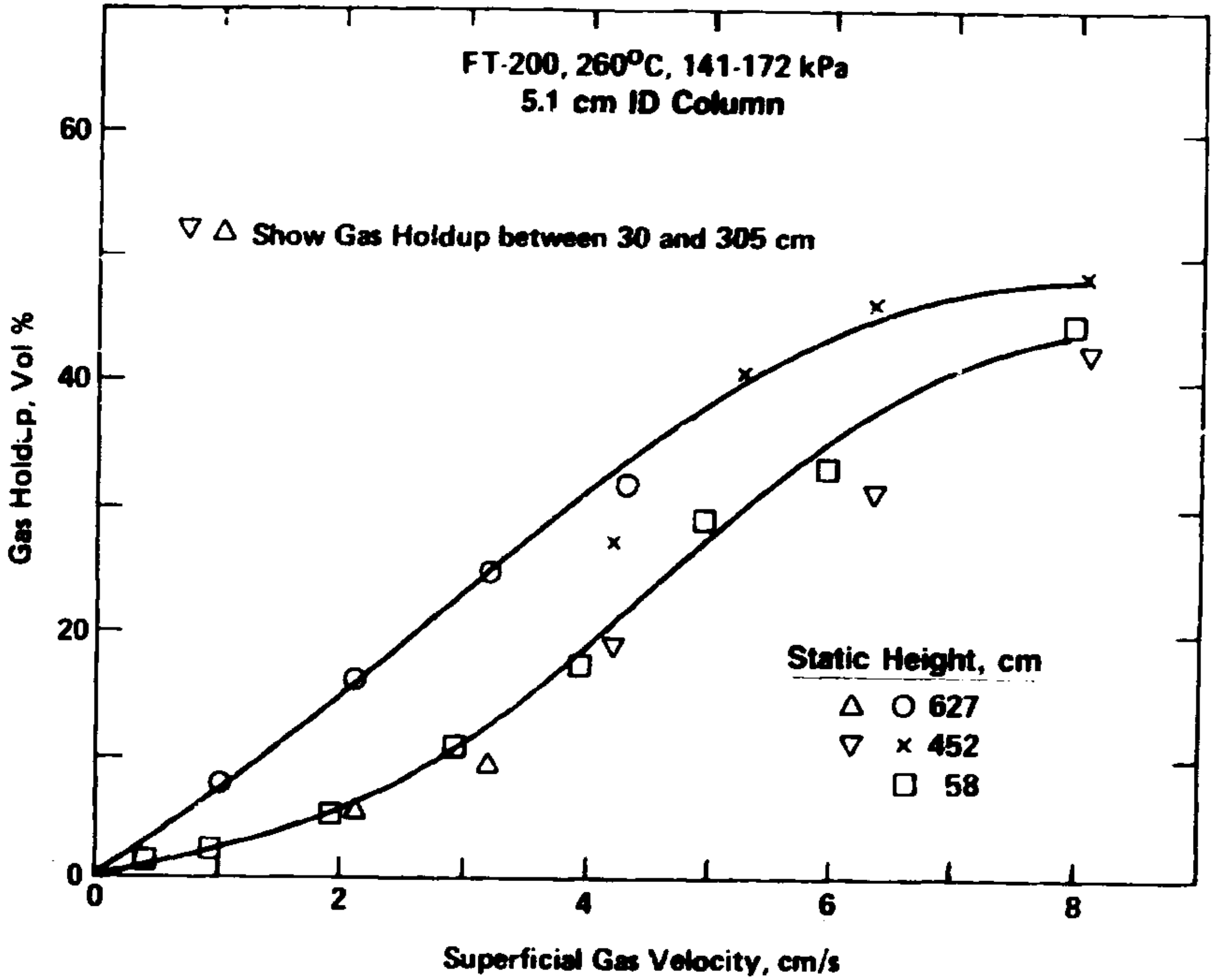
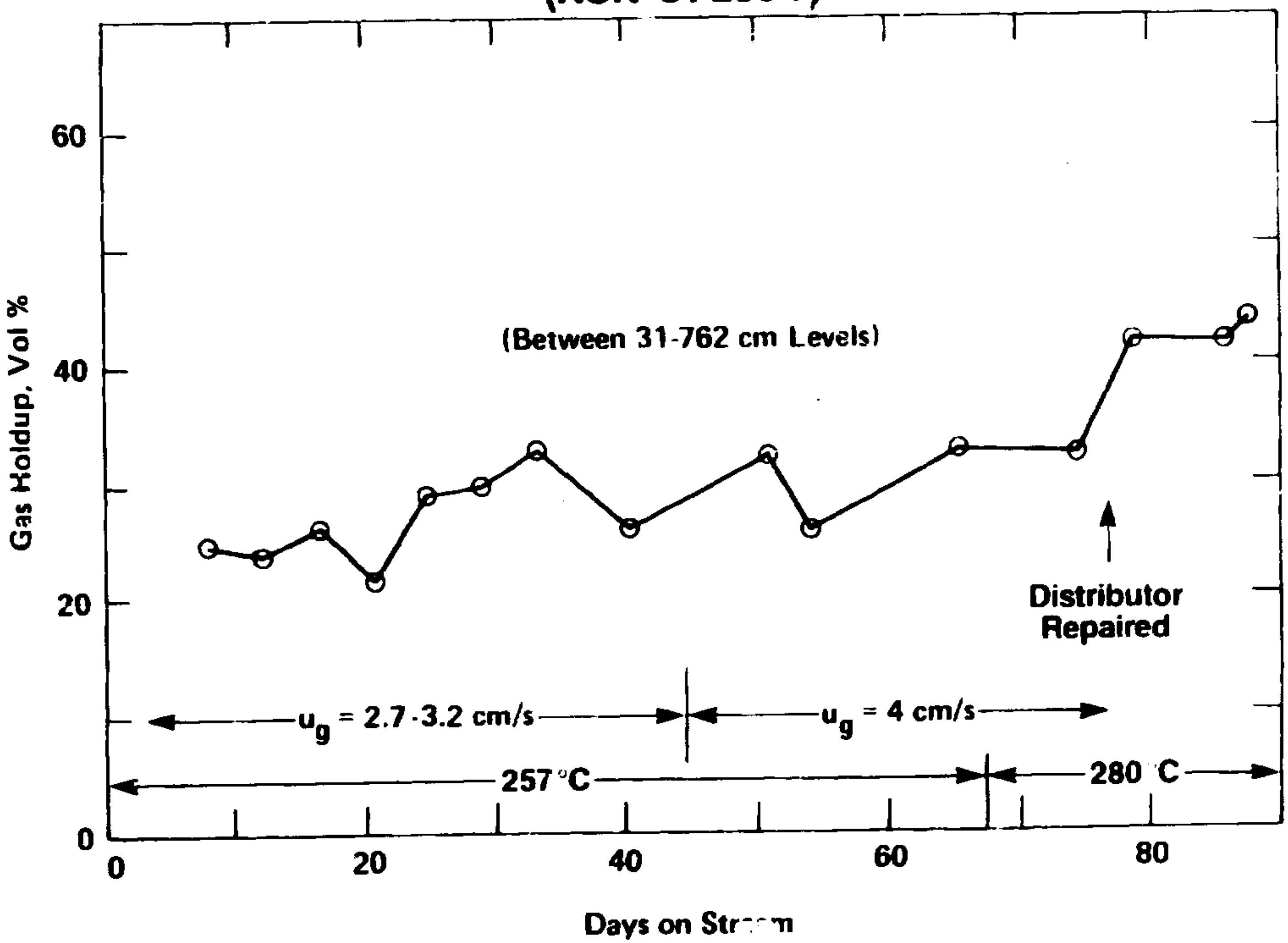


Figure VII-33

OVERALL GAS HOLDUP
(RUN CT-256-7)



state gas holdup, ϵ_{go}, and measurement of the transient gas holdup, ϵ_g, following the interruption of the gas flow. The transient gas holdup can be measured by recording with a video camera the expanded liquid level as a function of time.

Sriram and Mann (1977) showed that for a certain bubble-size distribution $f_B(d_B)$, and in absence of liquid flow and axial nonhomogeneity,

$$\epsilon_{go} = u_g / \int_0^\infty f_B(d_B)\ u_B\ dd_B \qquad \text{(VII-8)}$$

$$\epsilon_g = \epsilon_{go} \int_0^\infty f_B(d_B)\ [1 - tu_B/L(t)]dd_B \qquad \text{(VII-9)}$$

The term in the bracket of Equation (VII-9) represents the fraction of bubbles of size d_B remaining in the column after time t. This term is taken as zero for $tu_B > L(t)$.

For a narrow uni-modal bubble-size distribution ($f_B(d_B)$=1 in Equation (VII-8)), the average bubble-rise velocity is:

$$\bar{u}_B = u_g/\epsilon_{go} \qquad \text{(VII-10)}$$

From correlation of $\bar{u}_B$ versus $\bar{d}_B$ (e.g. Abou-El-Hassan (1983), Mendelson (1967)), the average bubble-size $\bar{d}_B$ can be calculated.

For narrow bi-modal distributions, Equation (VII-9) can be rewritten as:

$$\epsilon_g = \epsilon_{go}[f_{BS}(1 - t\bar{u}_{BS}/L) + f_{BL}(1 - t\bar{u}_{BL}/L) \qquad \text{(VII-11)}$$

where S and L stand for small and large bubbles, respectively. It can be shown that Equation (VII-11) can be rewritten as L (the dynamic expansion height) versus t:

$$L/L_o = 1 - (\epsilon_{goS}\bar{u}_{BS} + \epsilon_{goL}\bar{u}_{BL})\ t/(1 - \epsilon_{go})L_o; \quad t \leq t^* \qquad \text{(VII-12a)}$$

$$L/L_o = (1 - \epsilon_{go})/(1 - \epsilon_{goS}) - \bar{u}_{BS}\epsilon_{goS}t/(1 - \epsilon_{goS})L_o; \quad t > t^* \qquad \text{(VII-12b)}$$

where t^* is the time taken by the large bubbles to disengage, and ϵ_{goS} is the gas holdup caused by small bubbles.

Some publications present Equation (VII-11) as a linear function of t (e.g. Godbole et al., 1982), by substituting the initial height L_o for L. This, of course, is only valid for low ϵ_{go}, where L does not change much. Our derivation, Equations (VII-12a) and (VII-12b), are valid for any ϵ_{go}, and L/L_o is always a linear function of t.

To evaluate ϵ_{goS}, $\bar{u}_{BS}$, $\bar{u}_{BL}$, $\bar{d}_{BS}$, $\bar{d}_{BL}$, the following procedure is recommended:

a. Find breakpoint ϵ_g^*, t^*

b. Find $\bar{u}_{BS}$ and ϵ_{goS} from Equation (VII-12b)

c. Find $\bar{u}_{BL}$ from Equation (VII-12a)

d. Use correlation between $\bar{d}_B$ and $\bar{u}_g$ to calculate d_{BS} and d_{BL}

E.4b. Application to 5.1 cm ID Hot-Flow Bubble-Column

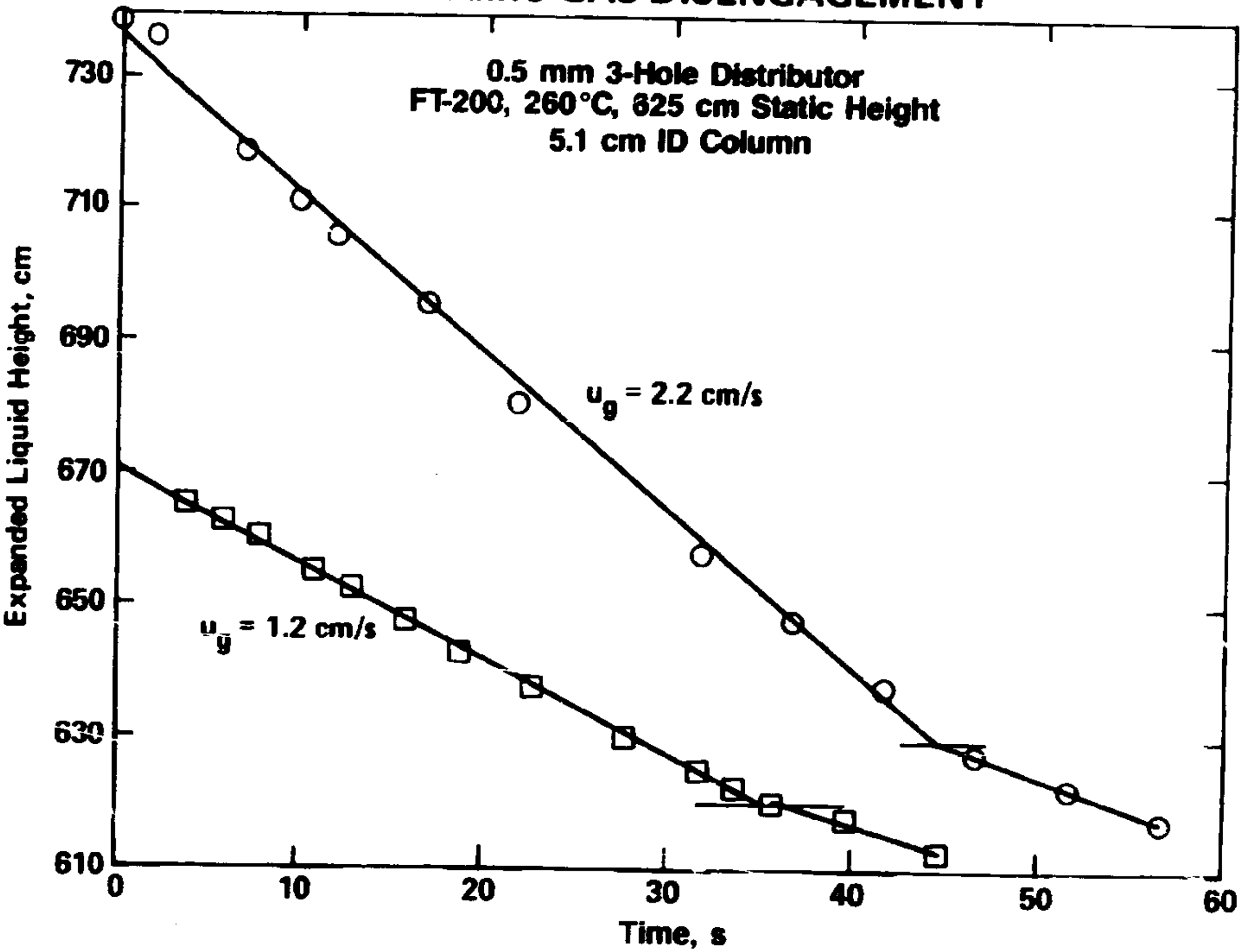
To obtain information about the bubble-rise velocity, dynamic gas-disengagement experiments were carried out using the 5.1 cm ID bubble-column. In this experiment, upon shutting off the feed gas the decrease in the expanded liquid height was monitored by a video camera and a timer. Figure VII-34 is a plot of expanded liquid height as a function of elapsed time for the 0.5 mm 3-hole distributor. Any foam at the top was not considered for this experiment; i.e., the decrease of foam-liquid interface was recorded instead of the top of the foam. The experiments were carried out at two superficial gas velocities (1.2 and 2.2 cm/s). At higher velocities the gas holdup was very large and hence it required a longer length of the column to be recorded by a video camera. Due to the space limitation the video camera setup could not cover the necessary length of column.

As seen in the figure the data can be fitted by a straight line, except for the last few seconds. As shown in the preceding Subsection, the straight line plot indicates that bubble-rise velocity distribution is very narrow. The following equation describes the dynamic decrease in the expanded liquid height:

$$L = L_o - (L_o - L_s)\bar{u}_B\, t/L_s \qquad \text{(VII-13)}$$

Figure VII-34

DYNAMIC GAS-DISENGAGEMENT



where L_S is the static liquid height and $\bar{u}_B$ is the average bubble-rise velocity. Table VII-7 gives the average bubble rise velocities obtained from the slope of the plots.

By using a literature correlation of $\bar{u}_B$ versus $\bar{d}_B$ by Abou-El-Hassan (1983), the average bubble size can de deduced from the bubble rise velocity. Even though the correlation was not developed for F-T wax mediums, due to lack of any other data, we have used this correlation. The average bubble diameter (of 1.2 and 2.2 mm) obtained here agrees well with the photographic observation.

For a uniform bubble size distribution the overall gas holdup is related to superficial gas velocity by Equation (VII-10). Thus, a plot of ϵ_g versus u_g should have a slope = $1/\bar{u}_B$. The plot of ϵ_g versus u_g for this case is included in Figure VII-27, described by following correlation:

$$\epsilon_g = 6.5\ u_g^{1.1} \qquad \text{(VII-14)}$$

The above correlation indicates that the bubble-rise velocity is not quite constant over the full range of superficial gas velocity. However, by fitting a straight line to this data, the average bubble-rise velocity (= 1/slope) can be determined to be 14 cm/s. Clearly this average bubble-rise velocity compares well with that obtained from dynamic gas-disengagement data.

Dynamic gas-disengagement experiments were also carried out in the 5.1 cm ID hot-flow bubble-column using the FT-200 wax and a 2 mm single-orifice distributor. Figure VII-35 shows a plot of expanded liquid height as a function of elapsed time for three superficial gas velocities. As seen from the figure the data cannot be fitted by a single straight line. This data can again be explained by a bi-modal bubble-size distribution. The initial straight lines represent time periods where both large and small bubbles are disengaging and leaving the column. The straight lines after the break in the slopes represent the disengagement of small bubbles only.

The bubble-rise velocities and volume fraction of the bubbles in the two size ranges are summarized in Table VII-8. The fraction of small bubbles having bubble-rise velocities of 5.1 to 7.6 cm/s was found to decrease with increasing superficial gas velocity. The bubble-rise velocities of larger bubbles range from 32 to 36 cm/s.

Table VII-7

Summary of
Dynamic Gas-Disengagement Results
(0.5 mm 3-Hole Distributor)

u_g, cm/s	$\bar{u}_B$, cm/s	$\bar{d}_B$, mm
1.2	15.4	2.2
2.2	13.1	1.2

Figure VII-35

DYNAMIC GAS-DISENGAGEMENT

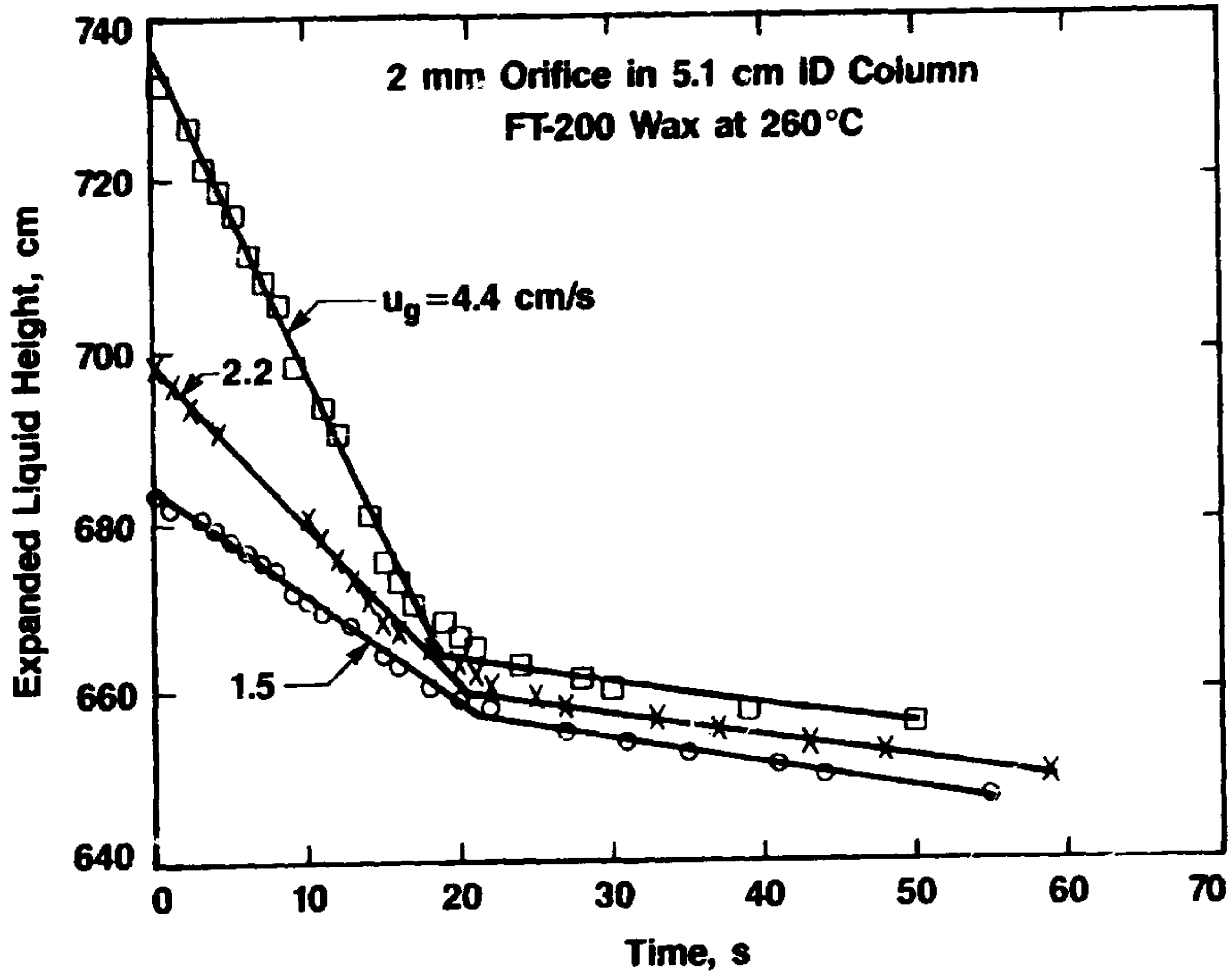


Table VII-8

Dynamic Gas-Disengagement Results
(2 mm Orifice Distributor)

u_g, cm/s	ϵ_g, Vol %	Fraction of Small Bubbles Vol %	$\bar{u}_{BL}$ cm/s	$\bar{u}_{BS}$ cm/s
1.5	6.6	57	32	7.4
2.2	9.4	52	35	5.1
4.4	11.5	25	36	7.6

E.5. Effect of Static Liquid Height

Figure VII-36 shows the effect of static liquid height on the gas holdup in the case of the 20 micron SMP distributor. In the 5.1 cm ID hot-flow bubble-column the liquid height was varied from 305 to 640 cm. As described earlier, the static liquid height had to be lowered to allow for the high gas holdups which occurred at the high superficial gas velocities.

It can be seen from the figure that when the static liquid height is lowered substantially (i.e., 640 to 305 cm) the gas holdup goes up. Also, substantially higher holdups are observed at 61 cm static height in the short column (5.3 cm ID). This observation is consistent with the literature results. Such an effect of static height is observed because of the existence of a high holdup zone at the top due to slow disengagement of bubbles from the liquid. When the static liquid height is lowered, the upper high holdup zone (the height of which stays about the same) contributes more to the overall holdup. Higher overall holdups are, hence, observed for lower static height. It is not clear why the increase in gas holdup was not that significant when the static height was lowered from 640 cm.

Figure VII-32 shown earlier shows the static liquid height effect with the 1 mm orifice distributor. Once again, as with the SMP case, no significant effect on gas holdup can be seen when the static height was lowered from 627 to 452 cm.

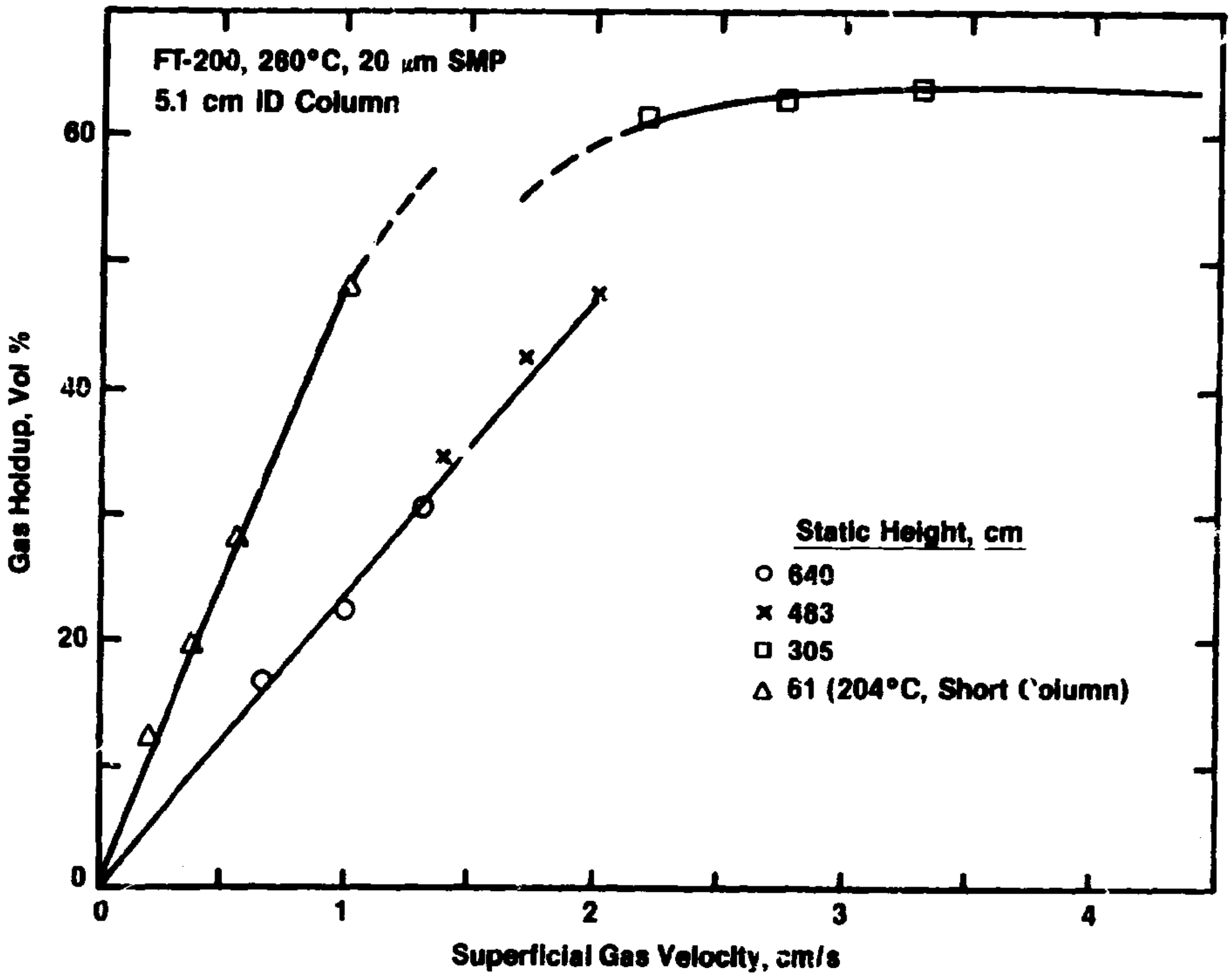
In contrast to the SMP distributor, the gas holdup decreased when the static liquid height was lowered to 56 cm. This is mainly due to different bubble-size distributions observed with the two distributors. In the case of an orifice distributor the lower zone is occupied by many large bubbles. The lower zone is hence a low holdup zone. The large bubbles tend to break up as they rise upward, giving uniformly small bubbles in the upper zone. Thus, a shorter bed height does not permit the large bubbles to break up, preventing the formation of a high holdup zone. The overall holdup at a low static liquid height is hence lower than that with a high static liquid height.

The behavior of the 0.5 mm three hole distributor was similar to that of the 1 mm orifice distributor.

Unlike the SMP distributor and the other two orifice-type distributors, the 2 mm orifice distributor gave the same gas holdup when the static liquid height was lowered from 7.1 m to 75 cm. In the case of the 20 micron SMP distributor, the existence of a high holdup zone of constant length at the top results in a higher gas holdup when the static liquid height is lowered. In contrast to the SMP distributor, the gas holdup in

Figure VII-36

EFFECT OF STATIC LIQUID HEIGHT



the case of the two orifice distributors (1 mm orifice and 0.5 mm 3-hole distributor) decreased when the static liquid height was lowered. This was mainly due to presence of large bubbles in the lower holdup bottom zone. In the case of the 2 mm orifice distributor, however, the bubble size distribution and consequently gas holdup did not vary significantly along the column height. Hence, the gas holdup did not change when the static height was lowered from 7.1 m to 75 cm.

E.6. Effect of Pressure

The effect of pressure on the gas holdup was insignificant with all three distributors. Since the hydraulic height of the liquid column was high, the relative pressure variation from bottom to top of the column was substantial (35-49 kPa). It was, therefore, necessary to observe the effect of such pressure variation on the gas holdup. Even though the absolute pressure was varied over a limited range (101-184 kPa), a percentage change from top to bottom of 17-50% was achieved. As seen from Figures VII-37 and -38, no significant effect on gas holdup was observed.

Similar studies were carried out for the 2 mm orifice distributor. No significant differences in the hydrodynamic behavior were observed for pressure variations of 138 to 221 kPa.

E.7. Effect of Temperature

In one experiment with the 20 micron SMP distributor, gas holdup data was taken at 138°C to 260° to determine the effect of temperature. As shown in Figure VII-39 the gas holdup increased substantially when the temperature was increased from 138°C to 260°. This is consistent with the results from the literature, i.e. the lower the viscosity of the liquid medium, the higher the gas holdup. The bubbles are also larger at lower temperature. Although slugging started at about the same superficial gas velocity of 2 cm/s, substantially larger bubbles (2-3 cm) were observed at all velocities at the lower temperature, 138°C.

E.8. Effect of Liquid Mediums

Figure VII-40 depicts the gas holdups obtained with three liquid mediums. Both water and hexadecane behaved very similarly at 32°C. Table VII-9 summarizes the relevant physical properties of these liquids. Since the viscosity of hexadecane is higher than that of water, the gas holdup with hexadecane is expected to be lower. On the other hand, the lower surface tension of hexadecane is expected to cause higher gas holdups. This may explain why the gas holdup was similar for both liquids. The gas holdup correlation of Akita and Yoshida (1973) predicts the observed gas holdups reasonably well.

Figure VII-37

EFFECT OF PRESSURE
(20 μm SMP)

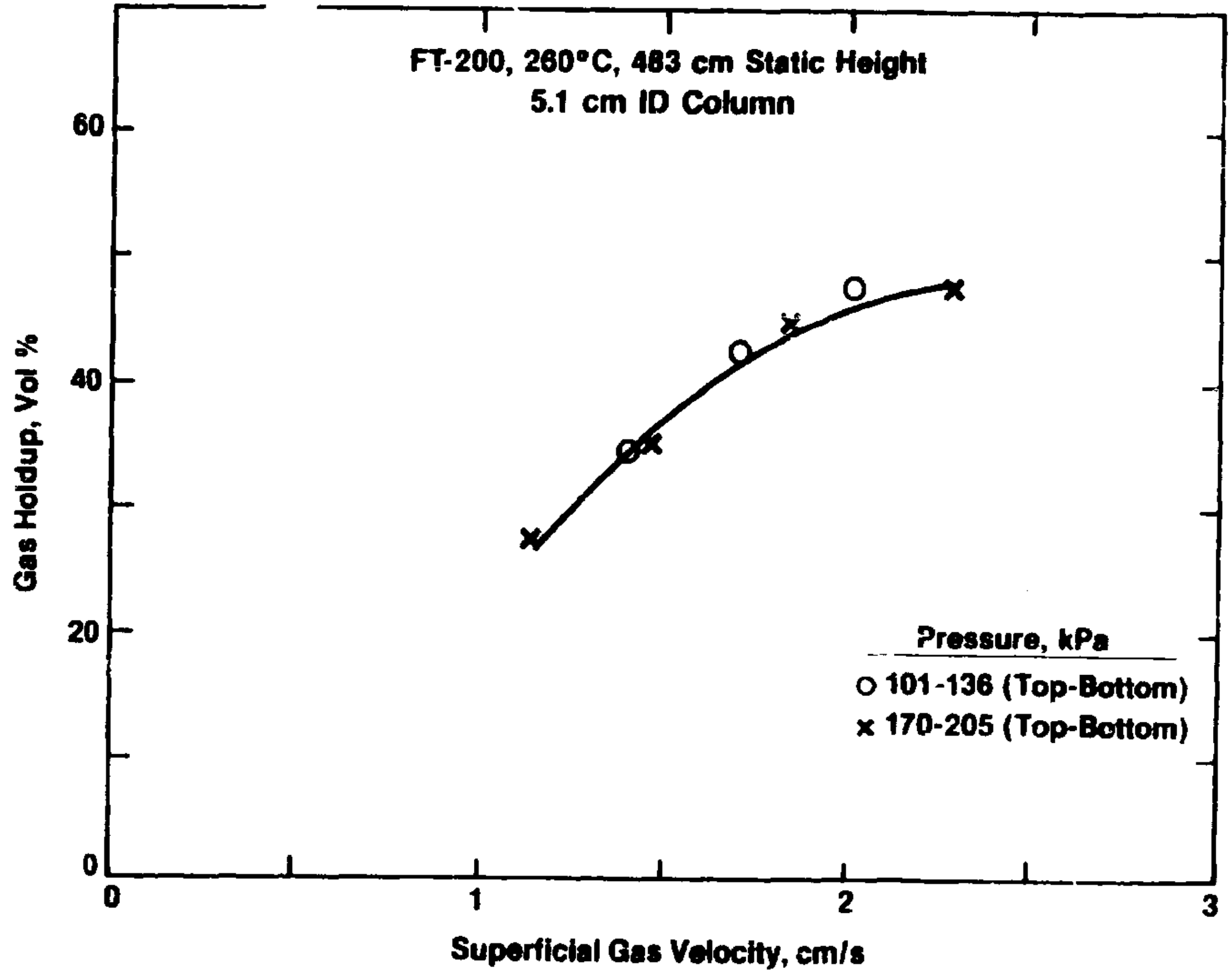


Figure VII-38

EFFECT OF PRESSURE
(1 mm ORIFICE)

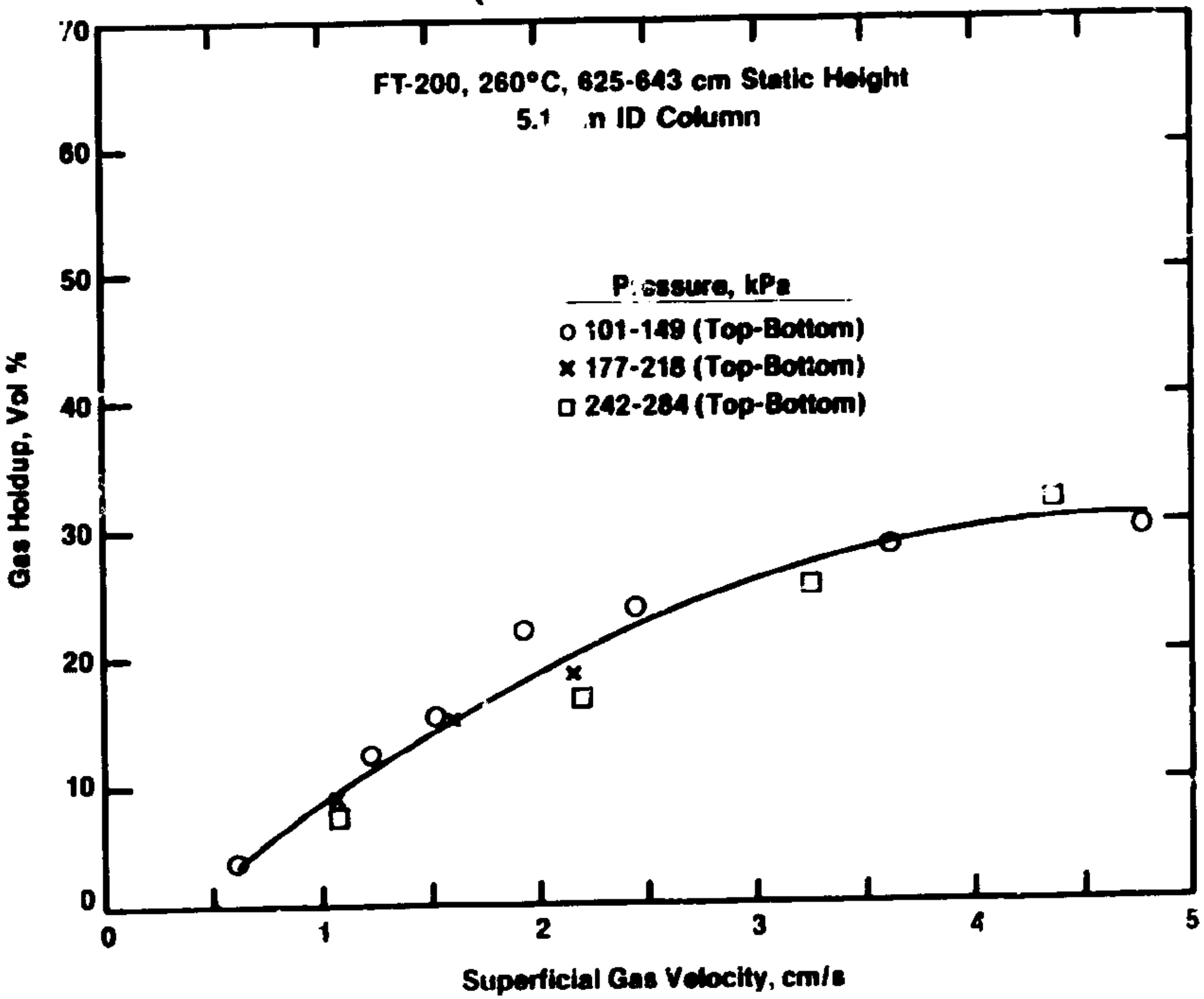


Figure VII-39

EFFECT OF TEMPERATURE ON GAS HOLDUP
(20 μm SMP)

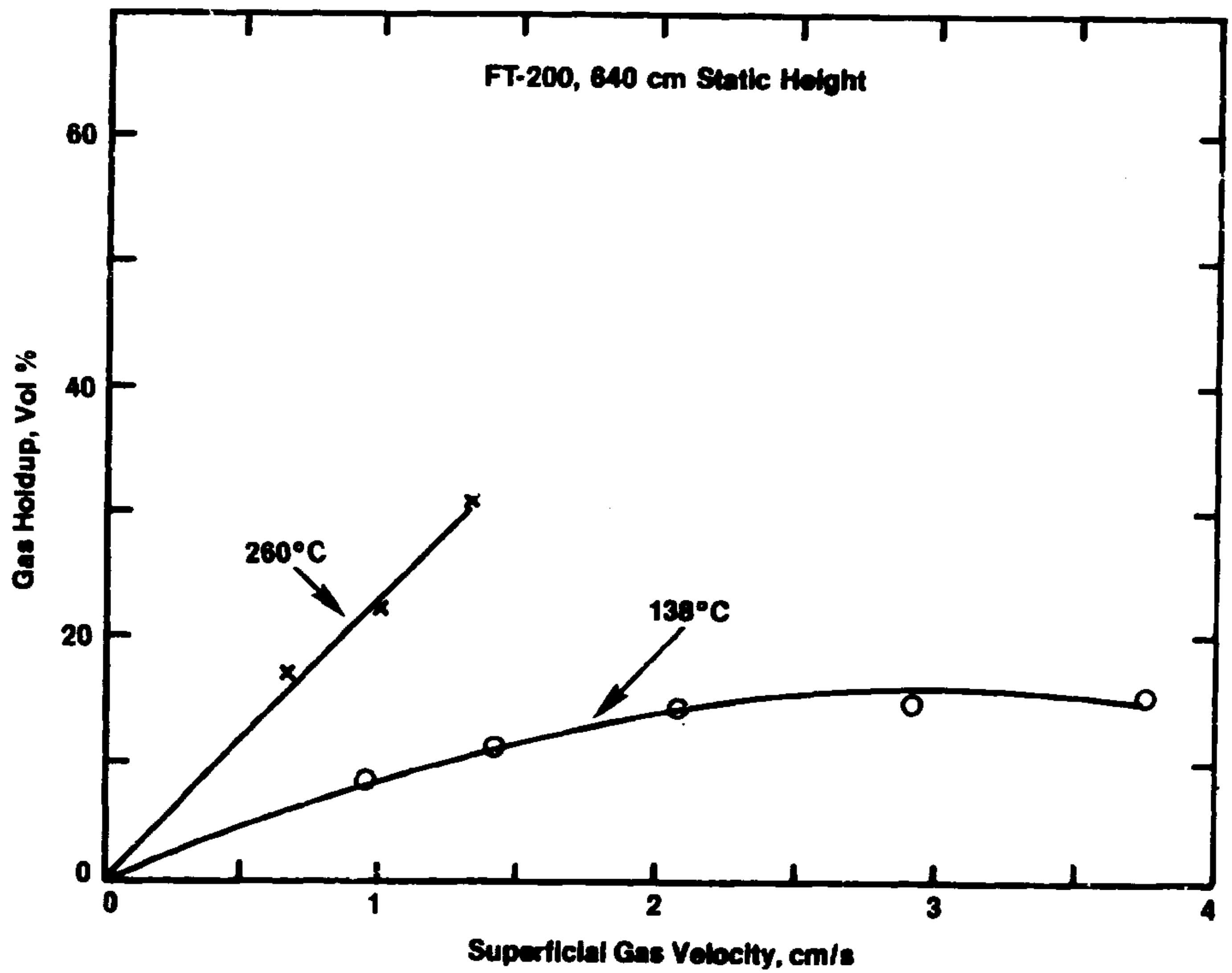


Figure VII-40

EFFECT OF LIQUID MEDIUM
(10.2 cm ID COLUMN)

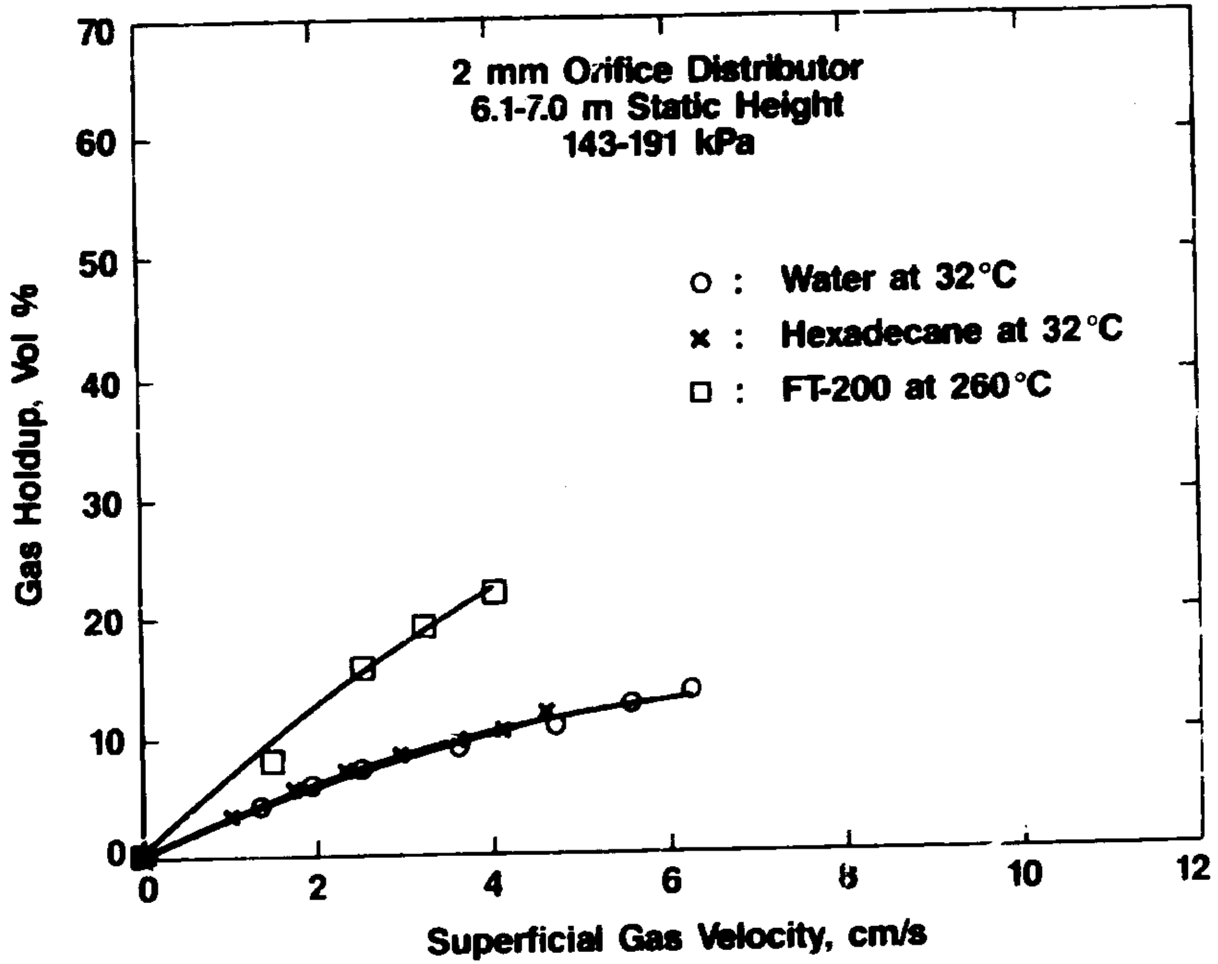


Table VII-9

Physical Properties of Liquid Mediums Used in Hot-Flow Studies

	Temperature, °C	Viscosity, cP	Surface Tension dynes/cm
Water	32	0.82	70
Hexadecane	32	3.80	26
FT-200 Wax	260	1.7	24

In contrast to the behavior of water and hexadecane, FT-200 wax gave gas holdups twice as high. The surface tension of the FT-200 wax at 260°C is very similar to that of hexadecane at 32°C, while the viscosity is about 55% lower. In agreement with earlier discussions, this difference in gas holdup cannot be accounted for by the difference in the viscosities using the existing literature correlations. Furthermore, FT-200 wax gave smaller bubbles (2-4 mm) than those given by water and hexadecane (3-8 mm). A small amount of foam (1-15 cm in height) at the top was observed for the FT 200 wax while no foam was observed with either water or hexadecane.

We have also studied bubble-column hydrodynamics using reactor-waxes produced in our BSU. These studies were planned to be carried out at the end, fearing that these reactor-waxes may darken the glass column permanently. We have studied two reactor-waxes produced in Runs CT-256-7 and -8 using both 5.1 and 10.2 cm ID hot-flow columns. The results were compared with those obtained with the FT-200 wax. Also, gas holdup profiles along the column have been obtained.

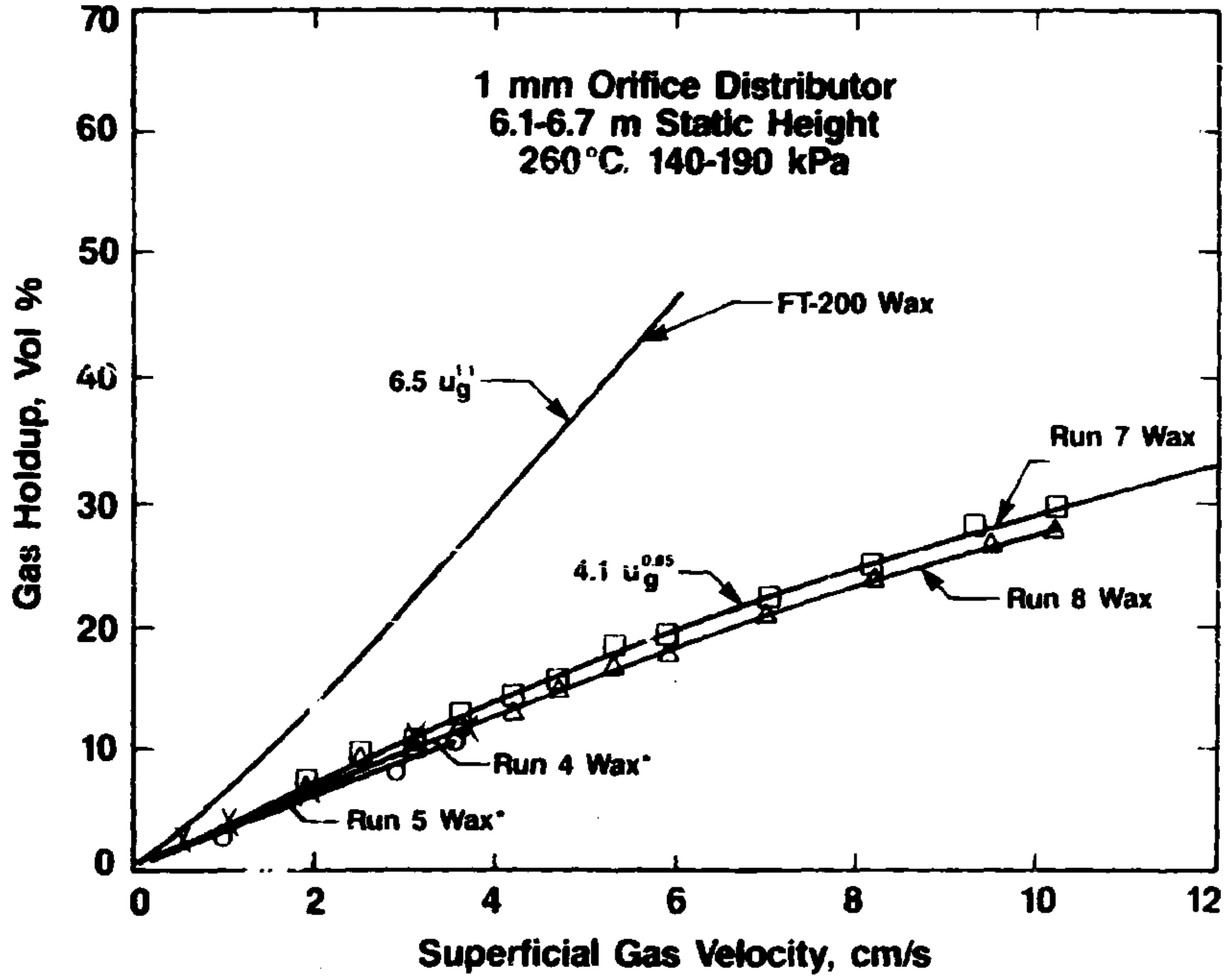
Figure VII-41 shows gas holdups given by Runs CT-256-7 and -8 reactor-waxes using 5.1 cm ID hot-flow bubble-column at 260°C. The gas distributor used was a 1 mm orifice. Also, the gas holdups obtained previously with FT-200 wax are depicted here as a correlation ($\epsilon_g = 6.5 \ u_g^{1.1}$).

Major conclusions from these studies are:

- Both reactor-waxes behave very similarly, even though their viscosities and compositions are substantially different.
- Both reactor-waxes gave substantially lower gas holdup than that given by FT-200 wax.
- Unlike FT-200 wax, the reactor-waxes did not foam.
- In contrast to FT-200 wax, the gas holdup of Run CT-256-7 reactor-wax decreased along the hot-flow column above superficial gas velocity of 2.5 cm/s.

Table VII-10 compares the physical properties of different reactor-waxes and FT-200 wax. Clearly the Run CT-256-8 reactor-wax has significantly higher viscosity and average molecular weight than Run CT-256-7 reactor-wax. The two reactor-waxes were produced under different operating conditions and using different catalysts. The difference in their

Figure VII-41
EFFECT OF LIQUID MEDIUM
(5.1 cm ID COLUMN)



*: 2.1 m Short Column Data at 200°C

Table VII-10

Physical Properties of Liquid Mediums

	Molar Average Carbon No.	Viscosity 149/204/260°C cP	Surface Tension[1] Dynes/cm
FT-200 Wax	36	4.4/2.2/1.7	24
Run 3 Reactor-Wax	30	2.8/1.7/ -	26-27
Run 4 Reactor-Wax	58	6.1/4.3/3.4	"
Run 5 Reactor-Wax	70	17.6/8.5/5.5	28
Run 7 Reactor-Wax	61	8.2/4.1/2.3	26-27
Run 8 Reactor-Wax	-	13.1/6.8/ -	"
Run 9 Wax (2.7 DOS)	-	7.5/4.0/ -	-
Run 9 Wax (5.4 DOS)	-	6.4/3.5/ -	-
Run 9 Wax (8.5 DOS)	-	6.2/3.4/ -	
Run 9 Wax (9.3 DOS)	-	5.7/3.1/ -	-
Run 9 Wax (14.8 DOS)	-	6.2/3.3/ -	-
Run 11 Wax (8.3 DOS)	-	6.7/3.7/ -	-
Run 11 Wax (11.6 DOS)	-	6.2/3.3/ -	-
Run 11 Wax (12.5 DOS)	-	6.1/3.2/ -	-
Run 13 Wax (8.3 DOS)	-	6.7/3.7/ -	-
Run 13 Wax (16.7 DOS)	-	5.7/3.2/ -	-
Run 13 Wax (33.8 DOS)	-	5.0/2.6/ -	-
Run 13 Wax (35.4-36.9 DOS)	-	6.1/2.8/ -	-

(1)At 260°C

compositions is hence expected. The surface tensions of all waxes are, however, very similar. In spite of the differences in their physical properties, the Runs CT-256-7 and -8 reactor-waxes behaved very similarly and also appeared to have similar bubble sizes.

Similar behavior was also observed previously using short hot-flow bubble-column (5.2 cm ID x 2.2 m height) with Runs CT-256-4 and -5 reactor-waxes, which were produced under operating conditions similar to those of Runs 7 and 8, respectively. These results have also been shown in Figure VII-41 for comparison. Based on our previous knowledge of effect of static height on gas holdup, the holdups of Runs 4 and 5 reactor-waxes in the short column are expected to be higher than those of Runs 7 and 8 reactor-waxes in the tall column. However, the short column studies were carried out at 200°C instead of 260°C. The slightly lower gas holdups in the short column may, therefore, be due to lower temperature.

Unlike FT-200 wax, the reactor-waxes did not produce very fine bubbles (e.g. <1 mm) which are conducive to foaming. The bubbles produced by the reactor-waxes appeared to be larger than those produced by FT-200 wax. Consequently, the gas holdups were substantially lower with the reactor-waxes. Slugging was observed with all waxes, and the slug frequency was found to increase with increasing superficial velocity.

Figure VII-42 gives the gas holdup profiles along the column obtained at various superficial velocities using Run CT-256-7 reactor-wax. In the earlier work using FT-200 wax the relatively larger bubbles produced at the column bottom tended to break up along the column. Hence, the gas holdup was found to increase along the height. In the case of reactor-wax, however, the gas holdup was found to decrease along the column at superficial gas velocities greater than 2.5 cm/s. This may be due to the presence of slugs in the top zone (which cause lower holdup). With FT-200 wax, the large number of very fine bubbles accompanying the foam seem to compensate for the lower holdup of slugs. Therefore, even in the presence of slugs the gas holdup increases along the column height. At superficial gas velocities lower than 2.5 cm/s slugging was very infrequent, and consequently the holdup increased along the column height for both the reactor-wax and FT-200 wax.

E.9. Effect of Column Diameter

The effect of column diameter was first studied using FT-200 wax in the 10.2 cm ID hot-flow bubble-column. The gas distributor used was a 2 mm orifice. Previously we had studied the same FT-200 wax in the 5.1 cm ID column using a 1 mm orifice distributor. Thus, the gas jet velocities at the orifices in both columns were identical for a given superficial velocity.

Figure VII-42
GAS HOLDUP PROFILES

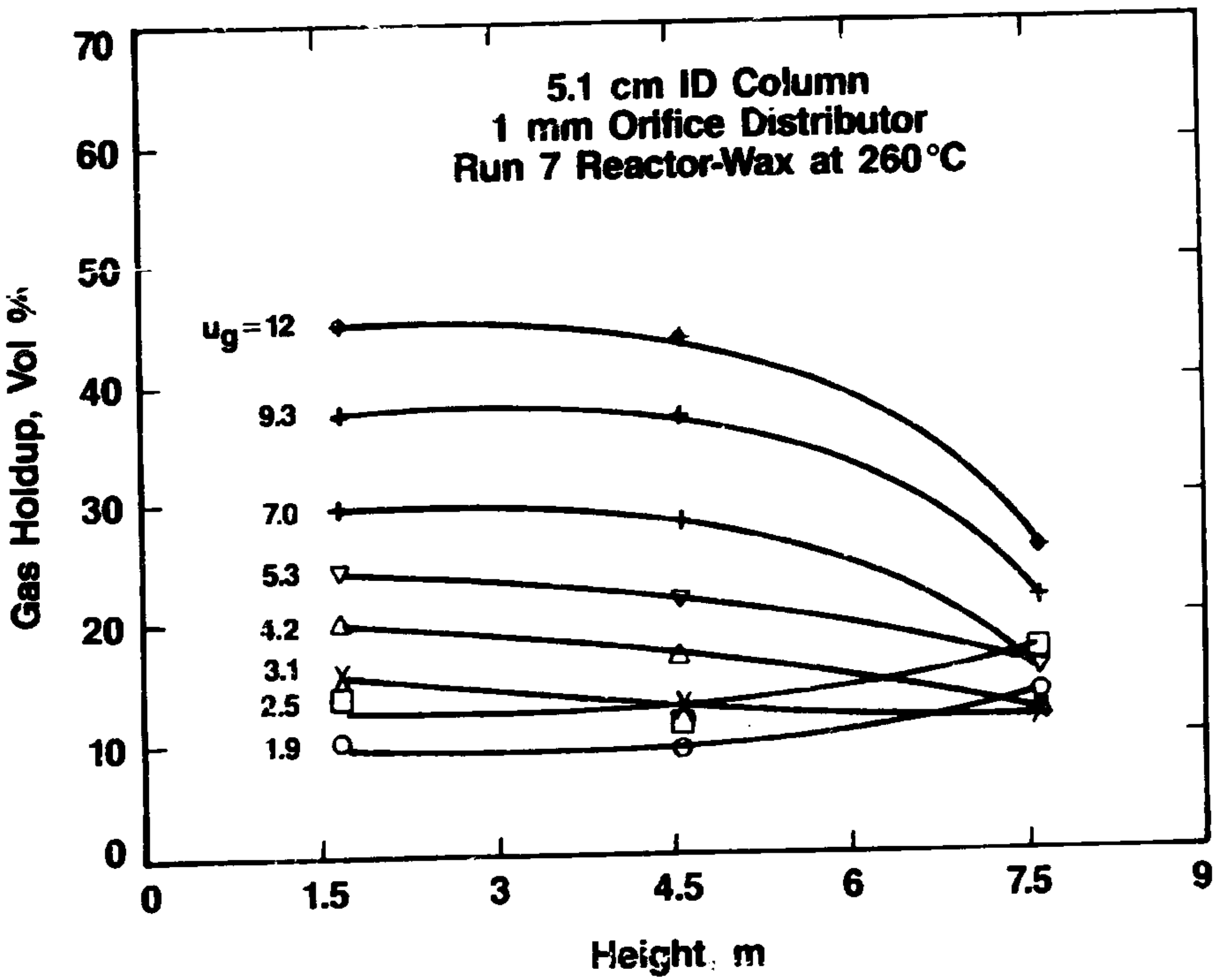


Figure VII-43 compares the gas holdups for these two cases. As seen from the figure, the gas holdups in the larger column are lower. Also, the bubbles in the larger column appeared larger. Similar to the smaller column slugging was observed in the 10.2 cm ID column. However, unlike the slugs in the 5.1 cm ID column, the slugs in the larger column did not occupy the whole cross-section of the column. These were really large bubbles with diameter about 80-90% of the column diameter. Also, they were only 5 10 cm long compared to the 5-25 cm long slugs in the 5.1 cm ID column. For simplicity, we always refer to them as slugs. The larger bubbles produced in the larger column may have been due to a larger size orifice, even though the jet velocities were the same in both columns. Hence, the gas distributors was changed to a 1 mm 4-hole distributor.

With the new distributor the orifice size as well as the jet velocities are identical in both columns. Using this distributor, we have studied the same three liquid mediums (FT-200 wax, CT-256-7 and -8 reactor-waxes), which were studied previously (see last Subsection) in the 5.1 cm ID column. Figure VII-44 compares the gas holdups obtained in the two columns for these waxes.

The two reactor-waxes gave about 30-40% higher gas holdups in the larger column over the superficial gas velocity range of 1.5 to 6.5 cm/s. The bubble sizes appeared similar in both columns. However, there was less slugging in the larger column and the slugs were also shorter than those in the smaller column. Again, the slugs were large bubbles about 5-10 cm long and occupied 80-90% of the column diameter. The higher gas holdup in the larger column may have been due to fewer and smaller slugs. This trend is consistent with the studies of Koelbel et al. (1968) using silicon oil-oxygen system.

In contrast to the reactor-waxes, FT-200 wax gave the same gas holdup in both columns. Even though large slug-like bubbles were observed in the larger column with the 1 mm 4-hole distributor, a large number of smaller bubbles accompanied by foam gave higher holdups. In this case, the contribution of slugs to the gas holdup is relatively less. Hence, unlike the case of reactor-waxes, the fewer and smaller slugs in the larger column probably did not increase the gas holdup.

E.10. Effect of Solids in a Reactor-Wax

The last experiment in the hot-flow column hydrodynamic studies was to use an actual slurry containing F-T catalyst. We reserved this experiment as the last one to avoid the possibility that use of a slurry will prevent further visual observation

Figure VII-43

EFFECT OF COLUMN DIAMETER

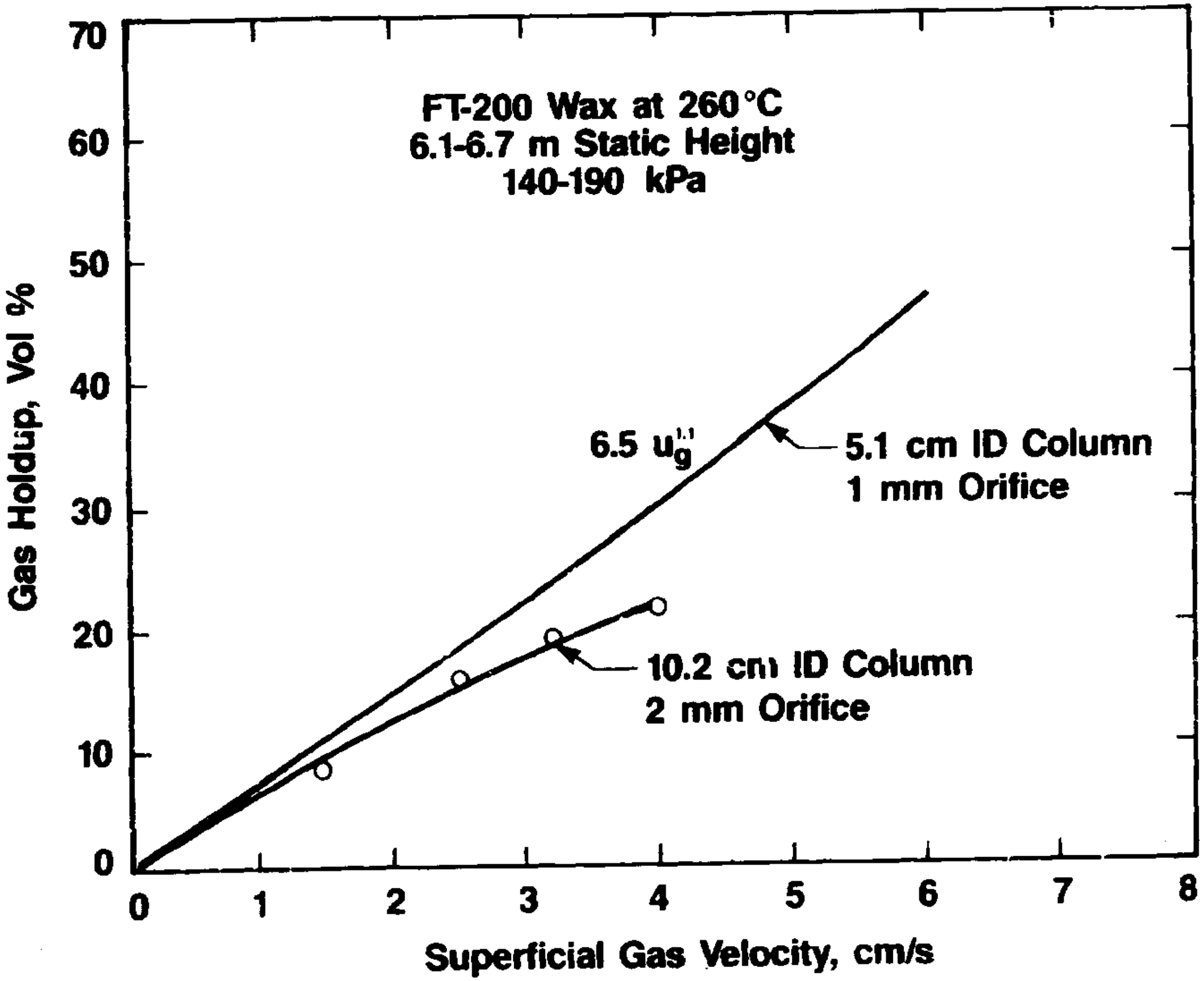


Figure VII-44

EFFECT OF COLUMN DIAMETER