D.3d. Limitations of the DGD Technique

The dynamic gas disengagement technique provides a convenient method for the characterization of the bubble size distributions in the bubble column. However, there are problems and limitations associated with this technique which need to be understood in order to appreciate their effect on the results.

The assumption of initial axial homogeneity of the bubble size distribution (see Section V-D.3a.) is in fairly good agreement with the phenomena observed in the bubble column for majority of gas flow rates employed. However, at superficial gas velocities between 0.02 and 0.04 m/s, where slugs are present only in the top half of the column, the above assumption is likely to introduce errors. Axial homogeneity implies that the time t_1^* (see Figure V-64) corresponds to the time taken for a large bubble (bubble in class N) to travel from just above the distributor to the top of the dispersion. Therefore, the technique overestimates the rise velocity for this class of bubbles when they are distributed over only a portion of the column, as is the case with slugs. Since bubble size is obtained using the rise velocity (Figure V-65), a larger bubble size would be obtained for this class of bubbles. However, the effect of this error on the Sauter mean diameter (d_s) is insignificant. As an example, let us consider the data for FT-300 wax (Run 13-3, 265°C, u_g = 0.03 m/s). The value for d_s is 0.394 mm (see Table D-1) using a value of 18.2 mm as the diameter (d_{BL}) for the large class of bubbles. If d_{BL} was reduced to 10 mm instead (55% of the original value), the value for d_s becomes 0.393 mm, a difference of less than 0.5%. The value for d_s in this range of superficial gas velocities (0.03-0.04 m/s) is governed by the diameter of the large number of small bubbles (for the example in consideration, there were 5.15 x 10^7 small bubbles and only 73 large bubbles), therefore, errors in the estimated value of large bubble diameters in this velocity range do not have a significant effect on d_s.

The theory for DGD also assumes that significant bubble interactions do not occur during the disengagement process. Such interactions do occur since liquid flowing downwards, to displace the large bubbles that are disengaging, will affect the disengagement of the fine bubbles. Even though the magnitude of these interactions can not be quantified, it is believed that this does not have a significant effect on the results.

The experimental procedure employed, to measure the rate at which the expanded height drops, has a certain amount of subjectivity associated with it. The disengagement process lasts typically between 60 to 80 s (in some instances, where foam is present, it takes up to 120 to 140 s for bubbles to disengage). During this period, "weeping" of wax into the plenum chamber is inevitable despite the back pressure of the gas trapped below the distributor. The amount of "weeping" obviously depends on the distributor used; with negligible drainage for SMP and relatively higher amounts draining with the 4 mm distributor. Therefore, towards the end of the disengagement process, when only the very small bubbles are disengaging, special care has to be taken to interpret the rate at which the level drops. It is possible that some of the drop in the liquid level is caused by "weeping". Table V-2 compares the observed change in static height between two velocities to the change in level attributed to the small class of bubbles for a run with FT-300 wax. The observed change in static height is the difference between visual measurements of the static height at two

Table V-2. Effect of "weeping" on small bubble diameter obtained by DGD (FT-300 wax, Run 13-3, 265°C, 0.051 m ID column, 1.85 mm orifice plate distributor).

u_g (m/s)	Drop in height (m)		Error[a] (%)
	weeping	Small bubble disengagement	
0.01	0.0	0.057	0.0
0.02	0.010	0.321	3.0
0.03	0.010	0.456	2.1
0.04	0.006	0.450	1.4
0.05	0.010	0.340	2.8
0.07	0.023	0.192	12.2
0.09	0.011	0.164	7.0
0.12	–[b]	0.186	–[b]
	Average error due to weeping		3.5

[a] Error is calculated as follows:

$$\frac{\left\{\begin{array}{c}\text{Height due to}\\ \text{small bubble}\\ \text{disengagement}\end{array}\right\} - \left\{\begin{array}{c}\text{Height due}\\ \text{to weeping}\end{array}\right\}}{\left\{\begin{array}{c}\text{Height due to}\\ \text{small bubble}\\ \text{disengagement}\end{array}\right\}} \times 100$$

[b] drop in height not measured

consecutive velocities. The drop in height attributed to the disengagement of the small bubbles was obtained from the H/H_o versus t plot by subtracting the static height (H_s) from the height corresponding to the intercept (b_S) of the line for the small class of bubbles (i.e. b_S X (H_o - H_s)). Assuming that the change in static height is purely due to "weeping" of wax into the plenum chamber, and further assuming that this phenomenon occurs only during the disengagement of the small bubbles, values in Table V-2 show that for Run 13-3 this causes, on an average, a 3.5% error in the level drop attributed to disengagement of small bubbles. This translates into a 3 to 4% error in the rise velocity associated with this class of bubbles. For a superficial gas velocity of 0.07 m/s, when the error due to "weeping" appears to be significant (12.2%), the Sauter mean diameter changes from 0.69 mm to 0.68 mm after correcting for "weeping", a difference of less than 2%. This example illustrates that even though "weeping" is a problem during DGD, its affect on the value of d_s is not significant.

The application of the DGD technique has a severe limitation under conditions where foam is produced at the top of the gas-liquid dispersion. For FT-300 wax foam was present for superficial gas velocities in the range 0.02 to 0.05 m/s in most cases. Under these conditions, the bubbles of interest are those which are in the dispersion between the distributor and the foam-liquid interface. In order to circumvent this problem, researchers at Mobil (Kuo et al., 1985) followed the drop in the foam-liquid interface during the disengagement process instead of the top of the foam. However the use of this alternative was not found useful in our experiments. First, the foam-liquid interface is not distinct at most velocities; it usually consists of a zone 0.05 to 0.10 m in height where foam appears to be thoroughly mixed with the liquid. Secondly, the foam-liquid interface, when distinct, appears to drop initially when large bubbles disengage, however, it begins to rise beyond this point. Even though small bubbles are still disengaging, the breakage of foam (which is approximately 30% liquid) results in a net increase in the liquid level. Consequently, all measurements made in this study are based on the rate of drop of the top of the dispersion (including foam, when present). Therefore, d_s values for instances where foam was present, should be interpreted with caution. A possible solution for this problem is to recalculate d_s after subtracting the hold-up attributed to foam (which is measured during the experiments) from the hold-up corresponding to small bubbles.

The data reduction step also involves a certain amount of subjectivity. The selection of the number of break points for a given set of data, which in turn determines the number of bubble classes (see Figure V-64, for example), is subject to some variability. For majority of cases this was not a problem and break points were obvious. For instances where this was not the case, several different break points were tried and the lines that gave the lowest value for sum of squared errors were selected. Since the value for d_s is dictated by the size of the small bubbles, its sensitivity to errors in the selection of break points is of importance. Earlier calculations for problems due to "weeping" showed that an error of 12.2% in the height corresponding to the disengagement of small bubbles (which is approximately equal to a 12.2% error in the slope for the line corresponding to this class of bubbles, or the rise velocity for these bubbles) translated to an error of less than 2% in the d_s value. This is because bubble diameter is not very sensitive to variations in rise velocity in this range (refer to Figure V-65 for rise velocities between 0.03 and 0.10 m/s). Therefore, the error caused by the subjectivity in the selection of break points is not expected to be significant.

The process of converting rise velocities to bubble diameters involves the use of available correlations as discussed previously. Even though these correlations are dependent on the physical properties of the liquid medium, the assumption that they can be used for waxes cannot be verified due to lack of data. The following discussion is therefore limited to the sensitivity of DGD results to errors in the measurement of physical properties. Experimentally determined values for density and viscosity appear to be in agreement with values reported in the literature (see Section VI-A.). The relative error in density measurements is expected to be less than 3%, while the error in viscosity measurements is less than 5% (based on variation in measurements with fluids of known viscosities). The effect of these errors on the value of d_s was determined for FT-300 wax (Run 13-3, 265°C, 0.051 m ID column). At a superficial gas velocity of 0.07 m/s, d_s is 0.69 mm. An error of 5% in the value for viscosity translates to a change of less than 3% in the d_s value. Similarly, an error of 3% in density measurements translates to a change of approximately 1% in the value of d_s. Therefore, d_s values are expected to have a maximum relative error of less than 5%, based on possible errors in physical property measurements.

The contribution from the various problems and limitations to the overall error in results obtained from DGD measurements is expected to be within an acceptable range, as shown above. Even though the applicability of the technique to instances where foam is present is questionable, results for FT-300 wax are in good agreement with values obtained using the photographic method, in the present study and those reported for paraffin waxes by Deckwer and coworkers.

D.4. Comparison of Techniques Used to Measure Bubble Size Distributions

Three different approaches were used to estimate the Sauter mean diameters of bubbles in the large columns (0.229 m ID and 0.24 m ID) and two techniques were used in the smaller column (0.051 m ID). Results from the various techniques are compared here. The discussion is limited to results from the larger columns since results are qualitatively similar for the two cases.

The dynamic gas disengagement (DGD) technique gives an average value of the Sauter mean bubble diameter for the entire column; whereas photographs near the column wall and center give only point estimates of the Sauter mean bubble diameter. Results from the DGD technique could be considered as the base case since this technique accounts for all bubbles unlike the photographic technique. Figure V-76 shows the variation of Sauter mean bubble diameter for FT-300 wax at 265°C in the large columns equipped with the 19 X 1.85 mm perforated plate distributor. Results obtained using DGD, photos at the wall (at a height of 1.96 m above the distributor), and photos obtained near the center of the column (at a height of 1.37 m above the distributor) are included in this figure. These results show that d_s values obtained from DGD measurements lie between those obtained from photographs near the center and near the wall of the column (for gas velocities greater than 0.04 m/s). This is as expected, since the DGD gives