APPENDIX B

ESTIMATION OF AXIAL HOLD-UP FROM DIFFERENTIAL PRESSURES

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The equations used to estimate axial and average hold-ups values from differential pressure measurements (see Section V.C) are developed here.

The gas hold-up in a gas-liquid system can be expressed in terms of the liquid density, ρ_ℓ, and the density of gas-liquid dispersion, ρ_d (i.e. density of the expanded liquid) as,

$$\epsilon_g = \frac{\rho_\ell - \rho_d}{\rho_\ell - \rho_g} \approx 1 - \frac{\rho_d}{\rho_\ell} \tag{B-1}$$

since the density of the gas, ρ_g, is small in comparison to the density of the liquid at low pressures.

The density of the expanded liquid between any two pressure taps, i and j, (see Figure V-39) can be calculated from the measured pressure drop $(\Delta P)_{i-j}$ and the known distance between the pressure taps, h_{i-j},

$$(s_d)_{i-j} = \frac{(\Delta P)_{i-j}}{h_{i-j}} \text{ and } (\rho_d)_{i-j} = (s_d)_{i-j}\rho_{H_2O} \tag{B-2}$$

where $(s_d)_{i-j}$ is the specific gravity of the dispersion between pressure taps i and j, and $j > i$, $i = 2,3,4,5$ or 6. By substituting this expression into Equation (B-1), one obtains

$$(\epsilon_g)_{i-j} = 1 - \frac{(\Delta P)_{i-j}}{s_\ell h_{i-j}} \tag{B-3}$$

The major sources of error in calculating the average gas hold-up within a segment, h_{i-j}, are in the measurements of $(\Delta P)_{i-j}$ and s_ℓ. The pressure drop is a rapidly fluctuating quantity, particularly at higher gas flow rates due to the passage of slugs. In calculations, the arithmetic average of the maximum and the minimum observed values was employed. The specific gravity (i.e. the density) of the molten paraffin wax represents the slope of a straight line formed by plotting the measured pressure drop versus the actual liquid height. The densities for the various liquids at

265°C are given in Table VI-1 (see Section VI-A.).

The expanded bed height and the average gas hold-up can also be determined from the differential pressure measurements. Let the expanded height be in the i-th segment (see Figure B-1), i.e. the top of the dispersion is between pressure taps i and (i+1). Then, the height of the gas-liquid dispersion in this segment is given by:

$$H' = \frac{(\Delta P)_{i-(i+1)}}{(s_d)_{i-(i+1)}} \qquad \text{(B-4)}$$

where $(\Delta P)_{i-(i+1)}$ is the pressure drop across this segment. However, the specific gravity of the gas-liquid dispersion in this segment can not be calculated using Equation (B-2), because the expanded height does not occupy the entire length of the segment, i.e. in general $H' < h_{i-(i+1)}$. In order to calculate H' an estimate for the density of gas-liquid dispersion in this segment is required. This can be obtained using either

$$(s_d)_{i-(i+1)} = (s_d)_{(i-1)-i} \qquad \text{(B-5)}$$

i.e. by assuming that the density of dispersion (or the gas hold-up) in the segment i is the same as in the previous segment, (i-1), or

$$(s_d)_{i-(i-1)} = (s_d)_{2-i} \qquad \text{(B-6)}$$

i.e. the specific gravity in the segment i is the same as the average specific gravity in the column up to this segment. The latter is calculated from

$$(s_d)_{2-1} = \frac{(\Delta P)_{2-i}}{h_{2-i}} \qquad \text{(B-7)}$$

When the axial hold-up does not vary appreciably along the column the estimated values obtained from Equations (B-5) and (B-6) are about the

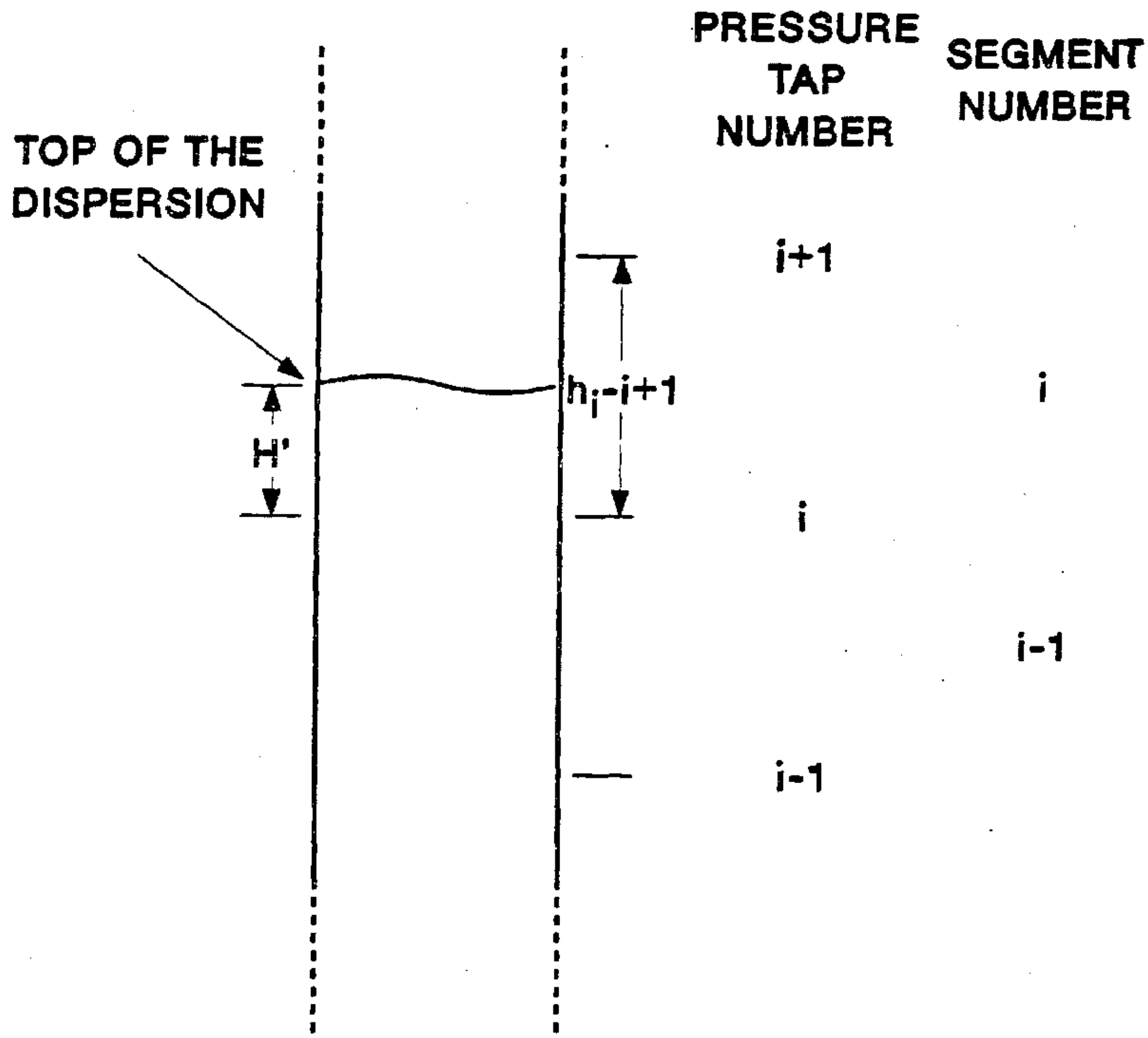

Figure B-1. Schematic diagram of the top of the dispersion with respect to pressure tap locations same. However, when the axial hold-up increases with height, the use of Equation (B-5) is preferred, but this procedure may not provide an accurate estimate for $(s_d)_{i-(i-1)}$, since in this case $(s_d)_{i-(i+1)} < (s_d)_{(i-1)-i}$. This problem is particularly severe when foam occupies the upper portion of the column.

Once the height of the gas-liquid dispersion in the last segment is calculated from Equation (B-4), the total expanded height is obtained from

$$H = H_i + H' \tag{B-8}$$

where H_i is the distance from the distributor to the port i. Then the average hold-up for the entire column can be calculated as

$$\epsilon_g = \frac{H-H_s}{H} = 1 - \frac{H_s}{H} \tag{B-9}$$

The static height is given by

$$H_s = \frac{(\Delta P)_{2-7}}{s_\ell} + b + h_{o-2} \tag{B-10}$$

where b is the intercept of a straight line on a calibration diagram, the actual liquid height versus ΔP; h_{o-2} is the distance between the distributor and pressure tap #2 (see Figure V-39); $(\Delta P)_{2-7}$ is the measured pressure drop between taps #2 and #7 at zero gas velocity.

Thus, the errors in the determination of H_s and H' will both have an effect on the average gas hold-up.

An alternative procedure to estimate the expanded bed height, and thus the average gas hold-up is as follows. Plot the total pressure (in height of the liquid medium) as a function of height determined from the various $(\Delta P)_{i-j}$ measurements and fit a curve through these data points. The intersection of this curve with the abscissa ($\Delta P = 0$) gives the expanded bed height. The average gas hold-up is then calculated using Equation (B-9).