APPENDIX B

SAMPLE GAS/LIQUID/SOLIDS PROFILE CALCULATION

This sample calculation is based on the data for Survey F-1-09.

Raw Data Conversion

The first step is to convert the nuclear density gauge (NDG) voltage output to the function on the right-hand side of Equation (IV-3):

$$V_R = \ln \frac{C_R\,[V(o) - V_o]}{V - V_o} = \ln \frac{-11.1\ C_R}{V - V_o}$$

The raw data for NDG Survey No. F-1-09 (V_o = -0.048 volt) are provided in Table B-1. Relevant physical properties are given in Table B-2.

Iterative Procedure

The actual calculation procedure requires trial-and-error iteration to converge on a slurry concentration. Convergence by direct substitution is rapid. For simplicity, only the final converged solution is presented here.

The procedure starts by assuming values for the volume fraction solids in the slurry and for the bed height (the latter is usually obvious to within about an inch upon examination of the plot of solid concentration vs. height above tray). Assume $\epsilon_{SF}/(\epsilon_{LF} + \epsilon_{SF}) = 0.0147$, or $\epsilon_{SF}/\epsilon_{LF} = 0.0150$, and h = 58 in (147 cm).

TABLE B-7

RAW DATA FOR NDG SURVEY NO. F-1-09

NDG Position Above Tray in.	NDG Reading volts	Calibration Ratio C_R	$\frac{-11.1\ C_R}{V - V_o}$	V_R
15-3/4 (40 cm)	-0.093	0.67	165	5.108
22 (56 cm)	-0.100	0.69	147	4.992
30 (76 cm)	-0.140	1.00	121	4.793
37 (94 cm)	-0.148	1.00	111	4.710
42-3/4 (109 cm)	-0.159	1.00	100	4.605
49 (124 cm)	-0.169	1.00	91.7	4.519
53-1/2 (136 cm)	-0.192	0.99	76.3	4.335
57-1/2 (146 cm)	-0.295	0.99	47.4	3.795
59-1/4 (150 cm)	-0.400	0.99	31.2	3.441
62 (157 cm)	-0.541	0.99	22.3	3.104
66-1/4 (168 cm)	-0.585	0.99	20.5	3.019
71 (180 cm)	-0.598	0.99	20.0	2.995
116-1/2 (296 cm)	-0.592	0.99	20.2	3.006
176 (447 cm)	-0.576	0.96	20.2	3.005

TABLE B-2

PHYSICAL PROPERTIES FOR NDG SURVEY NO. F-1-09

ρ_G	= 0.021 g/cm^3
ρ_L	= 0.70 g/cm^3
ρ_S	= 4.4 g/cm^3
M_S	= 778 lb
M_L	= 3550 lb
$(a_G L)^{-1}$	= 0.235 g/cm^3
$(a_L L)^{-1}$	= 0.22 g/cm^3
$(a_S L)^{-1}$	= 0.264 g/cm^3
α	= 0.707

Calculation of ϵ_G

The reading at the highest available position (176 in. in this case) is used to calculate ϵ_G. At this point, there is no bed; thus $\epsilon_{SB} = \epsilon_{LP} = 0$. Equation (V-1) can then be reduced to:

$$\epsilon_{SF} a_S \rho_S L + \epsilon_{LF} a_L \rho_L L + \epsilon_G a_G \rho_G L = V_R \text{ (176 in.)} \quad \text{(Eq. B-1)}$$

or, substituting the known properties and data,

$$16.667\ \epsilon_{SF} + 3.182\ \epsilon_{LF} + 0.089\ \epsilon_G = 3.005 \quad \text{(Eq. B-2)}$$

From the assumed slurry concentration, $\epsilon_{SF} = 0.0150\ \epsilon_{LF}$, so that Equation (B-2) becomes

$$3.432\ \epsilon_{LF} + 0.089\ \epsilon_G = 3.005 \quad \text{(Eq. B-3)}$$

and Equation (V-2) becomes

$$\epsilon_{SF} + \epsilon_{LF} + \epsilon_G = 1.0153\ \epsilon_{LF} + \epsilon_G = 1 \quad \text{(Eq. B-4)}$$

Combining Equations (B-3) and (B-4) and solving for ϵ_G gives $\epsilon_G = 0.114$.

Calculation of ϵ_{SB}

For all points below the highest available elevation, Equation (B-2) becomes

$$16.667\ (\epsilon_{SB} + \epsilon_{SF}) + 3.182\ (\epsilon_{LP} + \epsilon_{LF}) = V_R - 0.089\ \epsilon_G \quad \text{(Eq. B-5)}$$

and Equation (V-2) becomes

$$\epsilon_{SB} + \epsilon_{SF} + \epsilon_{LP} + \epsilon_{LF} = 1 - \epsilon_G \quad \text{(Eq. B-6)}$$

Using Equation (V-3), with $\alpha = 0.707$ (i.e., $\epsilon_{LP} = 2.413\ \epsilon_{SB}$) and the assumed slurry concentration (i.e., $\epsilon_{SF} = 0.015\ \epsilon_{LF}$) to eliminate ϵ_{LP} and ϵ_{LF} leads to

$$24.345\ \epsilon_{SB} + 228.80\ \epsilon_{SF} = V_R - 0.089\ \epsilon_G \quad \text{(Eq. B-7)}$$

and

$$3.413\ \epsilon_{SB} + 67.667\ \epsilon_{SF} = 1 - \epsilon_G \quad \text{(Eq. B-8)}$$

Combining Equations (B-7) and B-8),

$$12.806\ \varepsilon_{SB} = V_R + 3.292\ \varepsilon_G - 3.381 \qquad \text{(Eq. B-9)}$$

Since ε_G is known (at least by assumption), Equation (B-9) can be used to convert the raw data to values of ε_{SB}, as shown in Table B-3. This is the calculated bed density profile, and it shows a reasonably well-defined bed height of about 58 in. (147 cm.) as assumed.

Convergence Test

The solution is converged if the material balance is satisfied. M_{SB} is calculated by numerically integrating Equation (V-6). Since the bed profile below 15-3/4 in. (40 cm.) cannot be observed, linear extrapolation of the two lowest points to 6 in. (15 cm.) (the top of the bubble caps) is assumed, i.e., ε_{SB} at 6 in. (15 cm.) is taken as

$$\varepsilon_{SB}\ (6\ \text{in.}) = 0.164 + (0.164 - 0.155)\ \frac{(15.75 - 6)}{(22 - 15.75)} = 0.178$$

The integration is shown in Table B-4. (Note that $A_C = 2.76\ ft^2$ and a simple linear interpolation is used between measured points.)

TABLE B-3

CALCULATED BED DENSITY PROFILE FOR NDG SURVEY NO. F-1-09

NDG Position Above Tray in.	V_R	ϵ_G	ϵ_{SB}	$-\frac{\Delta\epsilon_{SB}}{\Delta z}$, in^{-1}
15-3/4 (40 cm)	5.108	0.114	0.164	--
22 (56 cm)	4.992	0.114	0.155	0.001
30 (76 cm)	4.793	0.114	0.140	0.002
37 (94 cm)	4.710	0.114	0.133	0.001
42-3/4 (109 cm)	4.605	0.114	0.125	0.001
49 (124 cm)	4.519	0.114	0.118	0.001
53-1/2 (136 cm)	4.335	0.114	0.104	0.003
57-1/2 (146 cm)	3.795	0.114	0.062	0.011
59-1/4 (150 cm)	3.441	0.114	0.034	0.016
62 (157 cm)	3.104	0.114	0.008	0.010
66-1/4 (168 cm)	3.019	0.114	0.001	0.002
71 (180 cm)	2.995	0.114	0.0	--
116-1/2 (296 cm)	3.006	0.114	0.0	--
176 (447 cm)	3.005	0.114	0.0	--

TABLE B-4

NUMERICAL INTEGRATION FOR ϵ_{SB} FOR NDG SURVEY NO. F-1-09

Range, in.	ϵ_{SB}	Solids Volume ft.^{3}
6 - 15-3/4 (15-40 cm)	0.171	0.38 (.0109 m^3)
15-3/4 - 22 (40-56 cm)	0.160	0.23 (.0065 m^3)
22 - 30 (56-76 cm)	0.148	0.27 (.0077 m^3)
30 - 37 (76-94 cm)	0.137	0.22 (.0062 m^3)
37 - 42-3/4 (94-109 cm)	0.129	0.17 (.0048 m^3)
42-3/4 - 49 (109-124 cm)	0.122	0.17 (.0049 m^3)
49 - 53-1/2 (124-136 cm)	0.111	0.11 (.0033 m^3)
53-1/2 - 57-1/2 (136-146 cm)	0.083	0.08 (.0022 m^3)
57-1/2 - 59-1/4 (146-150 cm)	0.048	0.02 (.0005 m^3)
59-1/4 - 62 (150-157 cm)	0.021	0.01 (.0004 m^3)
Total bed (true solids) volume, ft.^{3}		1.67 (.0474 m^3)
Total bed mass, lb		461 (209 kg)

From Equation (V-5),

$$M_{LP} = \frac{(0.70)\ (461)}{4.4} \times \frac{0.707}{0.291} = 177 \text{ lb.}$$

Finally, from Equation (V-4),

$$\frac{\epsilon_{SF}}{\epsilon_{LF}} = \frac{0.70}{4.4} \frac{(778 - 461)}{(3,550 - 177)} = 0.0150$$

Since this result is equal to the initial assumption, the solution is converged. If it did not agree, this value would be used as the starting point for the next iteration.