

TABLE I

SUMMARY OF COLD-FLOW EXPERIMENTAL RUNS

<u>Run No.</u>	<u>Catalyst</u>	<u>Gas</u>	<u>Liquid</u>	<u>Fines, Vol% (Wt%)</u>	<u>Temperature, °F</u>
218	HDS-2A	Nitrogen	Kerosene	0.0 (0.0)	76
221	HDS-2A	Nitrogen	Kerosene	4.0 (7.11)	72-83
222	HDS-2A	Nitrogen	Kerosene	9.8 (16.7)	70-72
223	HDS-2A	Nitrogen	Kerosene	20.7 (32.4)	65-81
224	Amocat-1A	Nitrogen	Kerosene	15.4 (25.2)	68-69

Liquid Velocity Range, Ft/Sec

218	0.072-0.212
221	0.052-0.210
222	0.048-0.195
223	0.051-0.207
224	0.046-0.173

Gas Velocity Range, Ft/Sec

0-0.223
0-0.136
0-0.224
0-0.213
0-0.152

TABLE II
RICHARDSON-ZAKI CORRELATION PARAMETERS

<u>Run No.</u>	<u>218</u>	<u>221</u>	<u>222</u>	<u>223</u>	<u>224</u>
Fines, Wt%	0.0	7.11	16.7	32.44	25.2
Fines, Vol%	0.0	4.0	9.8	20.7	15.4
Viscosity, cp	1.39	3.8	4.2	4.9	4.5
Catalyst	-----HDS-2A-----				Amocat-1A
Soaked Particle Density, Lb/Ft ³	-----107.9-----				86.89
Length, Inches	-----0.247-----				0.274
Diameter, Inches	-----0.062-----				0.062
U _t , Ft/Sec	0.43	0.355	0.412	0.326	0.350
n	2.60	2.07	2.88	3.11	3.06

TABLE III
COLD-FLOW ZERO SCAN DATA
(REACTOR FILLED WITH KEROSENE ONLY)

<u>Average Scan (cps)</u>	<u>Standard Deviation (cps)</u>	<u>Radial Position (R_i/R_o)</u>
378.17	3.72	-0.75
213.43	7.95	-0.50
288.67	7.10	-0.25
276.20	3.82	0
281.80	5.75	0.25
245.50	6.28	0.50
163.67	6.09	0.75

TABLE IV
H-COAL FLUIDIZATION RADIAL SCAN DATA

RUN490-5 FINES=25 WT% GAS VEL.=0.1 FT/S LIQ. VEL.=0.1 FT/S

ELEVATION (IN)	AVERAGE SCAN (CPS)	STANDARD DEV (CPS)	RADIAL POSITION RI/RO
30	319.8	6.7	-0.75
30	186.8	2.9	-0.50
30	217.4	2.9	-0.25
30	207.8	4.4	0.0
30	214.6	4.3	0.25
30	225.8	6.5	0.50
30	172.6	7.6	0.75
50	315.0	2.3	-0.75
50	183.6	1.1	-0.50
50	223.2	8.7	-0.25
50	206.6	3.0	0.0
50	206.6	4.2	0.25
50	187.0	6.9	0.50
50	142.8	5.4	0.75
70	326.0	5.8	-0.75
70	190.2	4.2	-0.50
70	224.2	6.0	-0.25
70	212.0	3.8	0.0
70	209.2	4.1	0.25
70	185.2	5.4	0.50
70	148.8	3.5	0.75
90	364.6	10.3	-0.75
90	238.6	3.0	-0.50
90	293.6	3.9	-0.25
90	279.8	8.1	0.0
90	280.8	3.9	0.25
90	199.2	3.7	0.50
90	273.0	6.2	0.75
110	350.6	2.4	-0.75
110	227.4	4.0	-0.50
110	290.2	4.5	-0.25
110	277.4	4.7	0.0
110	279.2	4.4	0.25
110	197.6	1.7	0.50
110	255.4	2.7	0.75

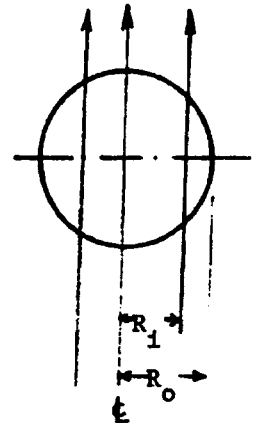


TABLE IV
H-COAL FLUIDIZATION RADIAL SCAN DATA
-2-

RUN490-6 FINES-25 WT% GAS VEL. = .08 FT/S LIQ. VEL. = .125 FT/S

ELEVATION (IN)	AVERAGE SCAN (CPB)	STANDARD DEV (CPB)	RADIAL POSITION RI/RO
30	327.2	5.4	-0.75
30	201.2	3.7	-0.50
30	230.6	3.5	-0.25
30	225.2	5.3	0.0
30	225.6	6.3	0.25
30	216.8	4.3	0.50
30	169.0	1.9	0.75
50	324.0	3.0	-0.75
50	183.8	3.6	-0.50
50	226.6	5.6	-0.25
50	222.6	2.9	0.0
50	220.6	5.1	0.25
50	213.4	3.0	0.50
50	151.8	3.3	0.75
70	331.8	4.1	-0.75
70	175.4	3.8	-0.50
70	234.0	4.4	-0.25
70	215.6	3.2	0.0
70	215.6	3.6	0.25
70	195.4	4.7	0.50
70	140.4	3.0	0.75
90	349.6	2.4	-0.75
90	206.8	2.2	-0.50
90	254.2	2.8	-0.25
90	239.2	16.6	0.0
90	238.0	4.3	0.25
90	179.8	7.1	0.50
90	150.8	6.5	0.75
110	358.6	4.2	-0.75
110	249.8	5.4	-0.50
110	289.6	3.4	-0.25
110	277.4	8.9	0.0
110	285.6	5.8	0.25
110	193.2	3.1	0.50
110	216.2	1.6	0.75

TABLE IV
H-COAL FLUIDIZATION RADIAL SCAN DATA

-3-

RUN490-7 FINES=25 WT% GAS VEL. =.08 FT/S LIQ. VEL. =0.1 FT/S

ELEVATION (IN)	AVERAGE SCAN (CPS)	STANDARD DEV (CPS)	RADIAL POSITION RI/RO
30	311.6	5.1	-0.75
30	190.8	1.8	-0.50
30	222.2	5.1	-0.25
30	209.6	3.8	0.0
30	210.8	5.6	0.25
30	203.0	4.3	0.50
30	163.2	4.6	0.75
50	318.2	3.5	-0.75
50	171.4	2.4	-0.50
50	221.2	2.4	-0.25
50	210.0	6.2	0.0
50	209.6	6.1	0.25
50	209.2	6.0	0.50
50	144.8	4.8	0.75
70	322.2	4.3	-0.75
70	168.2	5.6	-0.50
70	226.6	2.1	-0.25
70	214.6	3.0	0.0
70	207.8	4.7	0.25
70	190.2	1.5	0.50
70	141.4	3.4	0.75
90	365.8	6.7	-0.75
90	226.6	4.3	-0.50
90	289.0	4.9	-0.25
90	277.0	4.7	0.0
90	277.2	4.1	0.25
90	186.4	7.1	0.50
90	269.0	2.2	0.75
110	353.0	5.4	-0.75
110	220.4	3.8	-0.50
110	284.6	5.9	-0.25
110	277.4	4.3	0.0
110	276.0	8.2	0.25
110	190.6	3.1	0.50
110	212.8	4.1	0.75

TABLE IV

H-COAL FLUIDIZATION RADIAL SCAN DATA

-4-

RUN490-B FINES=25 WT% GAS VEL.=0.1 FT/S LIQ. VEL.=.125 FT/S

ELEVATION (IN)	AVERAGE SCAN (CPS)	STANDARD DEV (CPS)	RADIAL POSITION RI/RO
30	328.8	0.8	-0.75
30	206.6	4.8	-0.50
30	236.8	5.8	-0.25
30	223.2	7.9	0.0
30	226.8	2.3	0.25
30	223.6	4.6	0.50
30	163.0	3.2	0.75
50	324.4	4.9	-0.75
50	173.0	1.9	-0.50
50	240.0	6.7	-0.25
50	218.4	3.3	0.0
50	217.8	3.4	0.25
50	205.4	3.8	0.50
50	138.2	2.8	0.75
70	341.0	4.4	-0.75
70	174.0	2.7	-0.50
70	233.4	5.0	-0.25
70	219.0	5.2	0.0
70	216.2	5.4	0.25
70	177.2	4.9	0.50
70	139.8	5.0	0.75
90	342.0	3.5	-0.75
90	212.6	1.9	-0.50
90	253.4	5.2	-0.25
90	234.8	5.0	0.0
90	239.0	2.5	0.25
90	180.0	1.6	0.50
90	284.4	1.3	0.75
110	360.0	3.5	-0.75
110	244.8	3.1	-0.50
110	283.8	2.6	-0.25
110	282.2	2.2	0.0
110	281.4	4.4	0.25
110	196.8	3.3	0.50
110	222.0	3.4	0.75

RADIAL PHASE HOLDUPS FOR RUN491-5

BED HEIGHT=70 IN. GAS FLOW RATE=0.10 FT/S LIQ. FLOW RATE=0.10 FT/S

ELEVATION INCH	VOLUME FRACTION			RADIAL POSITION RI/RO
	CATALYST	SLURRY	GAS	
30	0.331	0.570	0.100	-0.75
30	0.331	0.563	0.107	-0.50
30	0.331	0.572	0.097	-0.25
30	0.331	0.572	0.098	0.0
30	0.331	0.572	0.098	0.25
30	0.331	0.559	0.111	0.50
30	0.331	0.546	0.123	0.75
50	0.331	0.571	0.098	-0.75
50	0.331	0.564	0.105	-0.50
50	0.331	0.570	0.099	-0.25
50	0.331	0.572	0.097	0.0
50	0.331	0.574	0.095	0.25
50	0.331	0.574	0.095	0.50
50	0.331	0.566	0.103	0.75
70	0.331	0.568	0.102	-0.75
70	0.331	0.561	0.108	-0.50
70	0.331	0.570	0.099	-0.25
70	0.331	0.570	0.099	0.0
70	0.331	0.573	0.096	0.25
70	0.331	0.575	0.095	0.50
70	0.331	0.562	0.107	0.75
90	0.0	0.881	0.119	-0.75
90	0.0	0.868	0.132	-0.50
90	0.0	0.876	0.124	-0.25
90	0.0	0.876	0.124	0.0
90	0.0	0.877	0.123	0.25
90	0.0	0.894	0.106	0.50
90	0.0	0.823	0.177	0.75
110	0.0	0.885	0.115	-0.75
110	0.0	0.872	0.128	-0.50
110	0.0	0.876	0.124	-0.25
110	0.0	0.876	0.124	0.0
110	0.0	0.877	0.123	0.25
110	0.0	0.894	0.106	0.50
110	0.0	0.830	0.170	0.75

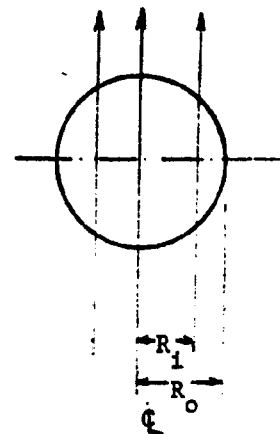


TABLE V

RADIAL PHASE HOLDUPS FOR RUN491-6

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BED HEIGHT=74 IN. GAS FLOW RATE=0.08 FT/S LIQ. FLOW RATE=0.125FT/S

ELEVATION INCH	VOLUME FRACTION			RADIAL POSITION RI/RO
	CATALYST	SLURRY	GAS	
30	0.313	0.585	0.102	-0.75
30	0.313	0.574	0.113	-0.50
30	0.313	0.586	0.102	-0.25
30	0.313	0.584	0.103	0.0
30	0.313	0.586	0.102	0.25
30	0.313	0.579	0.108	0.50
30	0.313	0.566	0.121	0.75
50	0.313	0.586	0.101	-0.75
50	0.313	0.582	0.106	-0.50
50	0.313	0.587	0.100	-0.25
50	0.313	0.585	0.103	0.0
50	0.313	0.587	0.100	0.25
50	0.313	0.580	0.107	0.50
50	0.313	0.577	0.110	0.75
70	0.313	0.583	0.104	-0.75
70	0.313	0.585	0.102	-0.50
70	0.313	0.583	0.103	-0.25
70	0.313	0.587	0.100	0.0
70	0.313	0.589	0.098	0.25
70	0.313	0.588	0.099	0.50
70	0.313	0.586	0.102	0.75
90	0.0	0.885	0.115	-0.75
90	0.0	0.879	0.121	-0.50
90	0.0	0.886	0.114	-0.25
90	0.0	0.887	0.113	0.0
90	0.0	0.889	0.111	0.25
90	0.0	0.902	0.098	0.50
90	0.0	0.885	0.115	0.75
110	0.0	0.862	0.118	-0.75
110	0.0	0.864	0.136	-0.50
110	0.0	0.877	0.123	-0.25
110	0.0	0.876	0.124	0.0
110	0.0	0.876	0.124	0.25
110	0.0	0.896	0.104	0.50
110	0.0	0.847	0.153	0.75

RADIAL PHASE HOLDUPS FOR RUN491-7

-3-

BED HEIGHT=70 IN. GAS FLOW RATE=0.08 FT/S LIQ. FLOW RATE=0.10 FT/S

ELEVATION INCH	VOLUME FRACTION			RADIAL POSITION RI/RO
	CATALYST	SLURRY	GAS	
30	0.331	0.572	0.097	-0.75
30	0.331	0.561	0.108	-0.50
30	0.331	0.571	0.099	-0.25
30	0.331	0.571	0.098	0.0
30	0.331	0.573	0.096	0.25
30	0.331	0.567	0.102	0.50
30	0.331	0.552	0.117	0.75
50	0.331	0.570	0.099	-0.75
50	0.331	0.570	0.100	-0.50
50	0.331	0.571	0.098	-0.25
50	0.331	0.571	0.098	0.0
50	0.331	0.573	0.096	0.25
50	0.331	0.565	0.105	0.50
50	0.331	0.565	0.104	0.75
70	0.331	0.569	0.100	-0.75
70	0.331	0.571	0.098	-0.50
70	0.331	0.569	0.100	-0.25
70	0.331	0.570	0.100	0.0
70	0.331	0.574	0.095	0.25
70	0.331	0.572	0.097	0.50
70	0.331	0.567	0.102	0.75
90	0.0	0.880	0.120	-0.75
90	0.0	0.872	0.128	-0.50
90	0.0	0.877	0.123	-0.25
90	0.0	0.877	0.123	0.0
90	0.0	0.878	0.122	0.25
90	0.0	0.899	0.101	0.50
90	0.0	0.824	0.176	0.75
110	0.0	0.884	0.116	-0.75
110	0.0	0.874	0.126	-0.50
110	0.0	0.878	0.122	-0.25
110	0.0	0.876	0.124	0.0
110	0.0	0.878	0.122	0.25
110	0.0	0.897	0.103	0.50
110	0.0	0.849	0.151	0.75

TABLE V

RADIAL PHASE HOLDUPS FOR RUN491-B

-4-

BED HEIGHT=74 IN. GAS FLOW RATE=0.10 FT/S LIQ. FLOW RATE=0.125FT/S

ELEVATION INCH	VOLUME FRACTION			RADIAL POSITION RI/RO
	CATALYST	SLURRY	GAS	
30	0.313	0.584	0.103	-0.75
30	0.313	0.572	0.115	-0.50
30	0.313	0.584	0.103	-0.25
30	0.313	0.584	0.103	0.0
30	0.313	0.585	0.102	0.25
30	0.313	0.577	0.110	0.50
30	0.313	0.570	0.117	0.75
50	0.313	0.586	0.102	-0.75
50	0.313	0.586	0.101	-0.50
50	0.313	0.583	0.104	-0.25
50	0.313	0.586	0.101	0.0
50	0.313	0.588	0.099	0.25
50	0.313	0.584	0.103	0.50
50	0.313	0.587	0.100	0.75
70	0.313	0.580	0.107	-0.75
70	0.313	0.586	0.101	-0.50
70	0.313	0.585	0.102	-0.25
70	0.313	0.586	0.102	0.0
70	0.313	0.589	0.099	0.25
70	0.313	0.596	0.091	0.50
70	0.313	0.586	0.101	0.75
90	0.0	0.887	0.113	-0.75
90	0.0	0.877	0.123	-0.50
90	0.0	0.866	0.114	-0.25
90	0.0	0.888	0.112	0.0
90	0.0	0.889	0.111	0.25
90	0.0	0.902	0.093	0.50
90	0.0	0.818	0.182	0.75
110	0.0	0.862	0.118	-0.75
110	0.0	0.866	0.134	-0.50
110	0.0	0.878	0.122	-0.25
110	0.0	0.875	0.125	0.0
110	0.0	0.877	0.123	0.25
110	0.0	0.895	0.105	0.50
110	0.0	0.845	0.155	0.75

TABLE VI
SUMMARY OF LIQUID-PHASE DIFFUSION COEFFICIENT MODELS

Reference	Model	System
<u>Two-Phase Bubble Column</u>		
1) Fromel and Aherman (1972) (21)	$D_1 = 73.5 d_c^{1.5} u_y^{0.5} (d_c \text{ ft}, u_y \text{ ft/h})$	Air-Water
2) Dechver, et al. (1974) (16)	$D_1 = 0.678 d_c^{1.4} u_y^{0.3} (d_c \text{ m}, u_y \text{ m/s})$	Air-Water
3) Cova (1974) (23)	$D_1 = 73.7 u_y^{0.32} \rho_1^{0.07} (\text{for } u_y \text{ ft/hr}, \rho_1 \text{ g/cm}^3, \text{ for } d_c = 1.8 \text{ in.})$ $D_1 = 23.6 u_y^{0.45} \rho_1^{0.40} (\text{for } d_c = 0.75 \text{ in.})$	Hy-Water, Acetone, Cyclohexanol, Ethanol, Etc.)
4) Mikita and Kitakawa (1974) (19)	$D_1 = (0.114 + 0.523 u_y^{0.77}) d_c^{1.25} \mu_1^{-0.12}$	Air (Water, MeOH, Sugar Solutions)
5) Kato and Nishiwaki (1972) (18)	$D_1 = \frac{1 + 6.5 (Fr)^{0.8}}{13 Fr} \cdot u_y \cdot d_c, Fr = \frac{u_y}{\sqrt{g d_c}}$	Air-Water
6) Smith, et al. (1968) (20)	$Pe = 3.0 \pm 0.3 \text{ if } 0.1 \leq u_y \leq 0.45 \text{ m/sec}$ and $d_c = 0.14 \text{ and } 0.29 \text{ m}$	Air (Water, Salt Solution)
7) Oishi and Inoue (1970) (28)	$D_1 = 75.4 d_c^2 u_y^{1.2} + 17,000 d_h$ (Bubble Regime)	Air-Water
8) Baird and Rice (1975) (27)	$D_1 = \frac{0.14 d_c}{(1-\epsilon_g)} (\text{Condensed Bubble Slug Flow})$	Air-Water
9) Pfallhofer, et al. (1978) (26)	$D_1 = 0.35 d_c^{1.33} [9 (u_y^2 \epsilon_g / (1-\epsilon_g))]^{1/3}$	Air-Water
10) Kato, et al. (1982) (37)	$D_1 = (0.15 + 0.69 u_y^{0.77}) (d_c^{1.25} [0.001/u_y])$	Air-Water
11) Joshi (1980) (14)	$D_1 = 240.1 u_y^{0.205} u_1^{-0.235} (u_1 \text{ cm/s})$	Air-Water
<u>Three-Phase Bubble Column</u>		
12) Kato, et al. (1972) (34)	$D_1 = 0.33 d_c u_c$ (where $u_c = 1.31 [9 d_c (u_y - g u_b)]^{1/3}$) $Pe = \frac{u_y d_c}{D_1} = 1 + 8 Fr^{0.85}, Fr = \frac{u_y}{\sqrt{g d_c}}$	Air-Water Slurry-(Glass Spheres, Copper Powder, Resin)
13) Kato, et al. (1982) (37)	$D_1 = 179.4 u_y^{0.336} u_{s1}^{-0.126}$ for $d_p = 10 \mu\text{m}$ $D_1 = 285.3 u_y^{0.262} u_{s1}^{-0.459}$ for $d_p = 30 \mu\text{m}$ $D_1 = 165.9 u_y^{0.249} u_{s1}^{-0.465}$ for $d_p = 70 \mu\text{m}$	Air-Water-Coke
14) Wu, et al. (1982) (35)	$Pe = 0.48 u_y^{-0.157} u_1^{0.315} d_c^{-0.018}$ for $u_1 \geq 5 \text{ cm/sec}$ $Pe = 11.58 u_y^{0.269} u_1^{1.375} d_c^{-0.222}$ for $u_1 < 5 \text{ cm/sec}$	Air-(Water, Glycerine, Ethyl Acetate)-Glass Spheres
15) Joshi (1980) (14)	$D_1 = 0.29 d_c (u_c + u_1)$ where $u_c = 1.31 [9 d_c (u_y + u_1 - \frac{\rho_1 u_1}{\epsilon_g \rho_g + \epsilon_1 \rho_1} - \epsilon_g \frac{\rho_1}{\epsilon_g \rho_g + \epsilon_1 \rho_1} - 1)]^{1/3}$ $- \epsilon_g u_{b1}^{1/3}$	Air-Water-Solids Literature Data

*Units used in the models are (dm, cm/s, m/s) unless otherwise stated.

TABLE VII
DENSE-PHASE SLURRY MIXING RESULTS

Pilot Plant Run No.	Superficial Gas Velocity (cm/Sec)	Superficial Liquid Velocity (cm/Sec)	Dispersion Coefficient (cm/Sec)	Peclet Number	Radial Sampling Position (R/R ₀)
490-6	2.74	2.96	58.8	9.48	-1.0
490-7	1.62	2.96	49.4	9.2	-1.0
490-8	0.0	2.96	9.10	54.0	-1.0
490-9	1.62	4.42	39.3	16.2	-1.0
490-10	2.76	2.96	105.0	5.20	-0.5
490-11	2.80	2.96	76.0	9.90	0
490-12	2.99	2.96	209.0	3.63	0.5
490-13	2.77	2.96	132.0	7.18	0.5
490-14	0.0	2.95	12.5	40.9	0.5
490-15	0.0	3.05	7.68	57.3	0
490-16	0.0	2.96	13.3	44.2	-0.5
490-17	4.05	2.96	123.4	4.92	0
490-18	3.11	2.96	87.7	8.34	0
490-19	1.92	2.96	58.9	9.86	0
490-20	2.90	2.95	72.2	7.39	0
490-21	4.54	2.89	129.0	4.60	-1.0
490-22	2.89	3.81	119.0	9.66	0
490-23	2.87	2.90	94.3	6.84	0

R/R₀ = 0: Liquid samples drawn from the center of the reactor.
 = -1.0: Liquid samples drawn from the near-side wall of the reactor.
 = +1.0: Liquid samples drawn from the far-side wall of the reactor.

JKS/ml
3/23/83

TABLE VIII
 LEAST SQUARES EVALUATION
 OF SLURRY DISPERSION CORRELATIONS

<u>Coefficient</u>	<u>Estimate</u>	<u>SE of Estimate</u>	<u>T-Value</u>
<u>Correlation 1: $Pe = A + [B + D(U_1 - 0.1) + E(R)] \exp(-C U_g)^*$</u>			
A	5.01	1.24	4.0
B	40.1	8.12	4.9
C	35.9	9.63	3.7
D	12.5	575	0.0
E	0.00368	11.5	0.0
Residual Root Mean Square = 0.32, df = 13.			
<u>Correlation 2: $Pe = A + [B + D(U_1 - 0.1)] \exp(-C U_g)$</u>			
A	3.11	3.17	1.0
B	26.25	7.68	3.4
C	21.28	10.9	2.0
D	427.46	67.7	0.6
Residual Root Mean Square = 0.53, df = 14.			
<u>Correlation 3: $Pe = A + B * \exp(-C U_g)$</u>			
A	5.05	1.11	4.5
B	42.91	6.50	6.6
C	35.48	7.65	4.6
Residual Root Mean Square = 0.27, df = 13.			
<u>Correlation 4: $Pe = A * \exp(-B U_g)$</u>			
A	40.26	6.61	6.1
B	17.83	1.91	9.3
Residual Root Mean Square = 0.35, df = 14.			

† U_g and U_1 are in ft/sec.

*R = radial position index = R_i/R_0 , where R_i = sampling point radius and R_0 = ID of column.

TABLE IX
SLURRY-PHASE DISPERSION MODEL STATISTICS

$$\ln(Pe) = \ln (a + b e^C U_g)$$

$$\text{Min } \sum_{C=1}^n (\ln Pe_i - \ln Pe)^2$$

<u>Model</u>	<u>Coef- ficient</u>	<u>Estimate</u>	<u>Standard Error of Estimate</u>	<u>95% Confidence Interval</u>
4	b	40.26	6.61	26.1 + 54.4
	c	-17.83	1.91	-13.7 + -21.9
Residual Root Mean Square Error = 0.356, df = 14.				
3	a	5.05	1.11	2.65 + 7.45
	b	42.91	6.50	28.9 + 56.9
	c	-35.48	7.65	-19.0 + -52.0
Residual Root Mean Square Error = 0.272, df = 13.				

U_g in ft/sec.

TABLE X
LACK-OF-FIT TEST RESULTS
FOR SLURRY-PHASE DISPERSION MODELS

1) Error Estimate from $U_g = 0$ Tests (Assumes Effect of U_1 & R_1/R_0 are Negligible)

<u>U_1</u>	<u>Test</u>	<u>Pe</u>	<u>ln (Pe)</u>
2.96	490-8	54.0	3.9890
2.95	490-14	40.9	3.7111
3.05	490-15	57.3	4.0483
2.96	490-16	44.2	<u>3.7887</u>

$$\bar{x} = 3.8843$$

$$s = 0.1602, 3 \text{ df}$$

$$SSE = 3 (0.1602)^2 = 0.07698$$

2) Model 4 Lack-of-Fit Test

	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>E (MS)</u>
Regression SSR	1.78004	14		
Error SSE	<u>0.07698</u>	<u>3</u>	0.02566	σ_o^2
Difference	1.70306	11	0.15482	$\sigma_o^2 + \sigma_{LF}^2$

$$F_3^{11} = \frac{0.15482}{0.02566} = 6.03 \quad \underline{0.05 < \alpha < 0.10}$$

α = Significance level.

TABLE X
 LACK-OF-FIT TEST RESULTS
 FOR SLURRY-PHASE DISPERSION MODELS
 -2-

3) Model 3 Lack-of-Fit Test

	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>E (MS)</u>
Regression SSR	0.96131	13		
Error SSE	<u>0.07698</u>	<u>3</u>	0.02566	σ_o^2
Difference	0.88433	10	0.088433	$\sigma_o^2 + \sigma_{LF}^2$

$$F_3^{10} = \frac{0.08843}{0.02566} = 3.44$$

0.10 < α < 0.30

TABLE XI
FLUID PROPERTIES

<u>CHEMICAL</u>	<u>DENSITY</u> <u>(GM/CM³)</u>	<u>VISCOSITY</u> <u>(CP)</u>	<u>SURFACE</u> <u>TENSION</u> <u>(DYNES/CM)</u>	<u>REFRACTIVE</u> <u>INDEX</u>	<u>% IN</u> <u>MIXTURE</u>
Dipropylene Glycol Monomethyl Ether	0.95 (1)	3.3 (2)	28.8 (2)	1.419 (1)	66
Diphenyl Ether	1.07 (3)	3.9 (2)	42.0 (3)	1.579 (2)	34
Mixture	0.99 (1)	3.2 (1)	29.0 (1)	1.474 (2)	

(1) 20°C.

(2) 25°C.

(3) 30°C.

TABLE XII
PARTICLE PROPERTIES

<u>Particles</u>	<u>Density (Gm/Cm³)</u>	<u>Average Dimensions (mm)</u>	<u>Type of Glass</u>
2 x 5 mm Cylinders	2.24	Diameter 2.1, Length 5.7	Pyrex
1 mm Spheres	2.49	1.19 ± 0.10	Soda Lime
2 mm Spheres	2.49	2.04 ± 0.07	Soda Lime
3 mm Spheres	2.49	2.99 ± 0.07	Soda Lime
5 mm Spheres	2.49	4.96 ± 0.06	Soda Lime

TABLE XIII

DATA FOR BUBBLE SIZE CORRELATION

<u>Particles</u>	<u>Fluid</u>	<u>Sauter Mean Diam.</u>	$\frac{d_m}{d_3}$	$\frac{\sigma}{(\Delta\rho d_3^2 g)}$
5mm Spheres	Solvents	0.133 cm ¹	0.266	0.0789
3mm Spheres	Solvents	0.144 cm ¹	0.480	0.219
2mm Spheres	Solvents	0.181 cm ¹	0.905	0.493
Cylinders	Solvents	0.161 cm	0.481 ²	0.211
6mm Spheres	Water	0.24 cm ³	0.400	0.132

Sphere Density = 2.49 gm/cm³

Cylinder Density = 2.24 gm/cm³

Solvent Mixture Properties: Density = 0.99 gm/cm
Surface Tension = 29. dynes/cm

Water Properties: Density = 1.00 gm/cm
Surface Tension = 70. dynes/cm

¹Based upon data at gas fluxes below 0.5 cm/sec and bed expansions greater than 20%.

²Based upon a volume equivalent diameter of 0.335 cm.

³Based upon a mean bubble size of 0.24 cm in a water fluidized bed of 0.6 cm diameter glass particles. (Lee, 1965.)

TABLE XIV

PDU TEST SCHEDULE SUMMARY

<u>Date (1980)</u>	<u>Period</u>	<u>Slurry Feed Rate, Lb/Hr*</u>	<u>Slurry Recycle Rate, GPM/Ft²</u>	<u>Makeup H₂ SCFH</u>	<u>Recycle Gas SCFH</u>
7/30	04A	822	47.1	3280	4178
8/05	10A	809	16.5	3485	4171
9/04	27A	606	35.9	2949	4330
9/11	34A	621	18.5	2935	4389
9/19A	41B	699	41.5	2850	4550
9/19P	42A	644	29.5	2900	4470
9/20A	42B	636	19.1	2860	4500
9/20P	43A	637	18.8	3610	6010
9/21A	43B	628	19.1	2830	2200
9/21P	44A	639	30.5	3940	6360
9/22A	44B	641	30.5	2790	2350
9/22P	45A	660	37.1	3690	6390
9/23A	45B	623	41.2	2850	2100
9/23P	46A	696	41.2	2820	4340

*Dry coal basis.

DNR/ml
12/31/80

TABLE XV
FDU VISCOSITY SAMPLE SCHEDULE

<u>Sample ID</u>	<u>Period Sample Was Taken</u>	<u>Date</u>
AROCO-1	130-93-04A	7/30/80
-2	130-93-04A	7/30/80
-3	130-93-10A	8/05/80
-4	130-93-20A	8/28/80
-5 ORNL-1	130-93-27A	9/04/80
-6 ORNL-2	130-93-34A	9/11/80
-7	130-93-41B	9/19/80 AM
-8	139-93-42A	9/19/80 PM
-9 ORNL-3	130-93-42A	9/19/80 PM
-10	130-93-42B	9/20/80 AM
-11 ORNL-4	130-93-43A	9/20/80 PM
-12	130-93-43B	9/21/80 AM
-13	130-93-44A	9/21/80 PM
-14	130-93-44B	9/22/80 AM
-15	130-93-45A	9/22/80 PM
-16	130-93-45B	9/23/80 AM

DNR/ml
12/31/80

TABLE XVI

SLURRY MIX TANK SAMPLE CHARACTERIZATION

<u>Sample Date</u>	<u>Specific Gravity, g/cc</u>	<u>Liquid % Oil (1)</u>	<u>Solid</u>		
			<u>% Coal (2)</u>	<u>Insoluble Ash Oxide Wt% of THF Insolubles</u>	<u>% THF Soluble</u>
8/05/80	1.2244	40	48	13.1	12
9/04/80	1.2094	33	--	14.4	--
9/11/80	1.2374	38	41	15.2	18
9/19 AM	1.174	56	32	12.7	10
9/19 PM	1.1781	57	34	13.6	9
9/20 AM	1.1943	60	32	14.9	7
9/20 PM	1.1800	53	40	10.3	2
9/21 AM	1.1981	50	40	12.9	8
9/21 PM	1.1925	54	39	13.6	4
9/22 AM	1.2427	51	40	16.1	5
9/22 PM	1.2460	43	43	15.1	8
9/23 AM	1.2504	25	47	18.1	19
9/23 PM	1.2853	48	44	20.6	4
Water	1.00				0.

Note: 1) % oil determined from millipore filtration.
 2) Defined to be THF insoluble.

DNR/ml: 2/19/81

TABLE XVII

ESTIMATED REACTOR EFFLUENT COMPOSITION

Amoco Test No.	-01	-02	--	-03	-04	-05	-06	-07	-08	-09	-10	-11	-12	-13	-14
1980 Date	7/30	8/05	--	9/04	9/11	9/19 AM	9/19 PM	9/20 AM	9/20 PM	9/21 AM	9/21 PM	9/22 AM	9/22 PM	9/23 AM	9/23 PM
BRI Period	08	10A	20B	27B	34B	41B	42A	42B	43A	43B	44A	46B	45A	45B	46A
Amoco Sample	1,2	3	4	5	6	7	8,9	10	11	12	13	14	15	16	
400-97507, Wt%	59.59	34.29	50.40	49.66	39.10	54.50	51.69	52.59	52.18	45.14	54.00	52.90	43.20	44.40	45.51
975-07, Wt%	17.89	34.68	19.11	21.01	29.49	21.90	25.19	25.72	27.17	27.56	22.48	20.12	31.33	28.48	28.30
Unconverted Coal	11.98	18.68	16.22	14.89	17.14	12.45	12.06	11.37	10.91	14.65	12.16	15.32	14.44	13.48	12.87
Ash, Wt%	9.62	11.32	12.62	13.29	12.94	10.00	9.95	9.13	8.73	11.10	9.83	10.61	10.18	12.47	11.94

TABLE XVIII

PDU-10 CATALYST PARTICLE DENSITY HISTORY

<u>Amoco Test</u>	<u>Date</u>	<u>HRI Period</u>	<u>Soaked Particle Density g/cc (4)</u>	<u>Remarks</u>
1	7/30/80	4	1.552	(1)
--	8/3/80	8	1.552	(2)
2	8/5/80	10	1.552	
3	9/4/80	27	1.616	
4	9/11/80	34	1.643	
5	9/19/80 AM	41B	1.669	
6	9/19/80 PM	42A	1.673	
7	9/20/80 AM	42B	1.673	
8	9/20/80 PM	43A	1.677	
9	9/21/80 AM	43E	1.677	
10	9/21/80 PM	44A	1.681	
11	9/22/80 AM	44B	1.681	
12	9/22/80 PM	45A	1.684	
13	9/23/80 AM	45B	1.684	
14	9/23/80 PM	46A	1.688	
15	9/24/80 AM	46B	1.688	
16	9/24/80 PM	47	1.692	(3)

(1) Assumed.

(2) Table IV in Reference 54.

(3) Table 12 in Reference 2.

(4) All values are interpolated except for the 8/3/80 sample and the 9/24/80 Sample 16.

TABLE XIX

PDU REACTOR LIQUID VISCOSITIES AND DENSITIES

Sample ID	Period Sample Was Taken	Sample Date	Battelle			ORNL		
			To (1)	η_{pl} (2)	ρ (3)	To (4)	η_{pl} (5)	ρ (6)
Amoco-1	130-93-04A	7/30/80	0.115	1.40	0.832			
-2	130-93-04A	7/30/80	0.201	1.31	0.842			
-3	130-93-10A	8/05/80	0.134	3.12	0.947			
-4	130-93-20A	8/28/80	0.139	1.92	0.917			
-5	ORNL-1 130-93-27A (7)	9/04/80	0.056	1.56	0.941	0.1270	1.683	0.908
-6	ORNL-2 130-93-34A	9/11/80	0.142	2.38	0.987	0.3067	3.027	0.985
-7 (8)	130-93-41B	9/19/80 AM	0.115	1.85	0.880			
-8	130-93-42A	9/19/80 PM	0.117	2.90	0.903			
-9	ORNL-3 130-93-42A	9/19/80 PM	0.062	1.95	0.901	0.2324	1.730	0.882
-10	130-93-42B	9/20/80 AM	0.072	2.11	0.883			
-11	ORNL-4 130-93-43A	9/20/80 PM	0.308	3.12	0.936			
-12	130-93-43B	9/21/80 AM	0.065	1.66	0.894			
-13 (9)	130-93-44A	9/21/80 PM	0.115	1.85	0.880	0.1911	1.070	0.838
-14	130-93-44B	9/22/80 AM	0.002	0.90	0.914			
-15	130-93-45A	9/22/80 PM	0.085	3.37	0.954			
-16	130-93-45B	9/23/80 AM	0.048	2.63	0.947			
-17	130-93-46A	9/23/80 AM	0.105	2.37	0.938			

Notes

- (1) N/m².
- (2) mPa.s (cp).
- (3) g/cc.
- (4) N/m².
- (5) mPa.s.
- (6) g/cc.
- (7) Amoco-5 taken 9/4/80 at 1600 hours (Period 27A). ORNL-1 taken 9/4/80 at 1830 hours (Period 27B).
- (8) Sample was contaminated during testing and discarded. Properties estimated.
- (9) Sample bomb contained only gas. Properties estimated.
- (10) No sample taken in Period 46A. Properties estimated.

TABLE XX
Z BED EXPANSION FOR HRI PDU-10 TESTS

Amoco Test No.	HRI Period	Liquid Flow Rate, Ft/Sec	Gas Flow Rate, Ft/Sec	Catalyst Bed Height (in.)	Z Bed Expansion	Slurry Viscosity centipoise	Slurry Density g/cc
HRI-01	04B	0.119	0.070	161.	74.	1.71	0.837
-02	10A	0.045	0.071	148.	59.	3.42	0.947
-03	27B	0.085	0.065	148.	59.	1.69	0.941
-04	34B	0.046	0.065	148.	59.	2.69	0.987
-05	41B	0.102	0.066	151.	104.	2.11	0.880
-06	42A	0.073	0.064	124.	66.	2.50	0.902
-07	42B	0.051	0.065	112.	49.	2.27	0.888
-08	43A	0.050	0.086	124.	66.	3.80	0.900
-09	43B	0.050	0.043	112.	49.	1.8	0.894
-10	44A	0.076	0.091	157.	113.	2.11	0.880
-11	44B	0.075	0.045	117.	56.	0.91	0.914
-12	45A	0.088	0.090	161.	119.	3.56	0.954
-13	45B	0.096	0.042	129.	73.	2.74	0.947
-14	46A	0.098	0.065	145.	96.	2.6	0.938
-15	47A	-----	-----	78.	0.	---	1.058
-16	47A	-----	-----	78.	0.	---	1.080

CATALYST : AMOCAT-1A
 GAS : HYDROGEN
 LIQUID : COAL/OIL
 TEMPERATURE : 815 DEG F

TABLE XXI
RESPONSE OF CATALYST BED EXPANSION
TO PROCESS VARIABLES

<u>Test Period</u>	<u>4 34B</u>	<u>6 42A</u>	<u>14 46A</u>	<u>13 45B</u>
Plastic Viscosity, cp	2.69	2.50	2.60	2.74
Liquid Velocity, Ft/Sec	0.046	0.073	0.098	0.096
Gas Velocity, Ft/Sec	0.065	0.064	0.065	0.042
% Catalyst Bed Expansion	59	66	96	73

TABLE XXII

COMPARISON OF CATALYST BED EXPANSIONS:
PDU PILOT PLANT VERSUS COLD-FLOW PILOT PLANT (RUN 224)

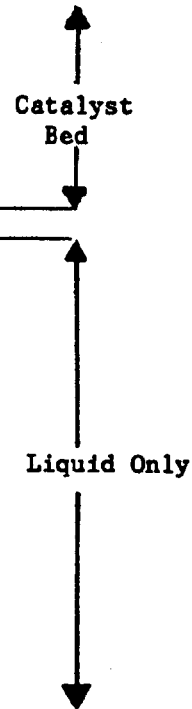
PDU Test	PDU-10 Experiments		Test 224-	Cold-Flow Experiments		Ug, Ft./Sec	% Bed Expansion	
	U ₁ , Ft./Sec	U _g , Ft./Sec		U ₁ , Ft./Sec	U _g , Ft./Sec		PDU	224
1	0.119	0.070	15	0.110	0.067	74	87	
2	0.045	0.071	11	0.048	0.070	59	22	
3	0.085	0.065	13	0.083	0.068	59	51	
4	0.046	0.065	11	0.048	0.070	59	22	
5	0.102	0.066	14	0.094	0.067	104	73	
6	0.073	0.064	15	0.110	0.067	104	93	
7	0.051	0.065	12	0.072	0.069	66	38	
8	0.050	0.086	11	0.048	0.070	49	22	
9	0.050	0.086	16	0.045	0.090	66	11	
10	0.076	0.043	10	0.047	0.043	49	7	
11	0.075	0.091	17	0.074	0.090	113	42	
12	0.088	0.045	9	0.073	0.041	56	40	
13	0.096	0.090	18	0.083	0.090	119	49	
14	0.097	0.042	7	0.093	0.046	73	71	
		0.065	14	0.094	0.067	96	73	

TABLE XXIII

PDU Fluid Dynamics Data

Date: 9/24/80 7:52 PM
 HRI Period: 47A
 Slurry Feed, Lb/Hr 0.
 Recycle, GPM/Ft2 0.
 H2 Feed Gas, SCFH 0.
 Recycle Gas, SCFH 0.
 Bed Height, Feet 6.50

Elev, Ft.	I-Zero CPS (1)	I-Flow CPS	I/I0
3.12	2497.1	448.0	0.1794
3.62	2492.5	445.6	0.1788
4.13	1206.1	327.9	0.2719
4.52	2496.2	408.8	0.1638
5.06	2195.1	545.3	0.2484
5.59	2360.5	522.5	0.2213
6.09	2540.7	556.1	0.2189
6.61	2074.1	505.6	0.2438
7.13	2527.8	676.7	0.2677
7.66	2543.7	682.4	0.2683
8.16	2439.9	682.8	0.2799
8.68	2402.5	663.5	0.2762
8.96	2705.5	660.3	0.2441
9.49	2409.2	661.0	0.2744
10.01	2476.2	686.3	0.2772
10.53	2432.0	674.8	0.2775
11.03	2384.9	656.4	0.2752
11.55	2482.2	664.0	0.2675
12.07	2533.7	690.7	0.2726
12.59	2453.5	660.8	0.2693
13.09	2453.0	653.9	0.2666
13.73	2453.0	677.5	0.2762
14.14	2453.0	672.5	0.2742
14.70	2453.0	664.5	0.2709



Note: (1). Values of I0 were interpolated from original zero scan data.

TABLE XXIV

CALCULATION OF OIL MASS ABSORPTION COEFFICIENT

<u>Amoco</u> <u>Test ID</u>	<u>Average</u> <u>Liquid</u> <u>Temp, °F</u>	<u>Liquid</u> <u>Density,</u> <u>g/cc (1)</u>	<u>L,</u> <u>In.</u>	<u>I/I_o</u>	<u>$\frac{\mu_L}{\text{Ft}^2/\text{lbm}}$ (2)</u>
924PM	203	1.080	8.5	0.2743 (3)	0.0271

(1) See Figure 76 for variation of density with temperature.

(2) Calculated from Equation 21, correcting for proper units.

(3) Average between 9.49' and 11.55' elevation. See Table XXIII.

TABLE XXV
CALCULATION OF CATALYST MASS ABSORPTION COEFFICIENT

<u>Variable</u>	<u>Value</u>	<u>Reference</u>
I/I_0	0.2249	Table XXIII, 9/24/80 PM, 4.13-6.09' Elevation
L	8.5"	--
ϵ_C	0.6019	*
ϵ_L	0.3981	$(1 - \epsilon_C)$
μ_L	0.0271 Ft ² /Lb	Table XXIV
ρ_L	67.5 Lb/Ft ³	Table XXIV
ρ_C	105.75 Lb/Ft ³	Table XVIII
μ_C	0.0217 Ft ² /Lb	Equation 20

*Calculated using $\rho_p = 1.186$ g/cc, $\rho_B = 0.714$ g/cc (Reference 63).

Various densities reported in Table 28, Reference 2, bracketed this value.

TABLE XXVI
MISCELLANEOUS DATA

		<u>Value Used</u>
α	Steel linear expansion coefficient	$6.7 \cdot 10^{-6}$ in./in. $^{\circ}$ F
L_{st}	2X thickness of PDU steel wall at 77 $^{\circ}$ F	2.75"
ρ_{st}	Steel density	490 lb/ft 3
ΔT	Temperature difference between ambient and process conditions	740 $^{\circ}$ F
μ_{gas}	Gas mass absorption coefficient	0.0542 ft 2 /lbm
μ_{sl}	Slurry mass absorption coefficient	0.0271 ft 2 /lbm
μ_c	Catalyst mass absorption coefficient	0.0217 ft 2 /lbm
μ_{st}	Steel mass absorption coefficient	0.0271 ft 2 /lbm

TABLE XXVII

CALCULATED HRI PDU HOLDUPS, DENSE PHASE

<u>Amoco Test Number</u>	<u>HRI Period</u>	Catalyst		Amocat-1A			<u>V_{CD}, mm/Sec</u>
		<u>Liquid Flow Rate, Ft/Sec</u>	<u>Gas Flow Rate, Ft/Sec</u>	<u>Gas Liquid Temperature</u>	<u>Hydrogen Coal/Oil 815°F</u>	<u>ε_c</u>	
HRI-01	04B	0.119	0.070	0.346	0.786	-0.132	0.0
-02	10A	0.045	0.071	0.378	0.675	-0.053	0.0
-03	27B	0.085	0.065	0.378	0.467	0.155	9.4
-04	34B	0.046	0.065	0.378	0.430	0.191	11.0
-05	41B	0.102	0.066	0.295	0.333	0.372	-9.1
-06	42A	0.073	0.064	0.363	0.438	0.199	7.5
-07	42B	0.051	0.065	0.405	0.310	0.285	4.0
-08	43A	0.050	0.086	0.363	0.566	0.070	22.5
-09	43B	0.050	0.043	0.405	0.347	0.247	1.7
-10	44A	0.076	0.091	0.283	0.690	0.027	26.2
-11	44B	0.075	0.045	0.387	0.456	0.158	4.9
-12	45A	0.088	0.090	0.275	0.553	0.172	15.8
-13	45B	0.096	0.042	0.348	0.520	0.132	4.7
-14	46A	0.098	0.065	0.308	0.495	0.198	6.3

TABLE XXVIII

CALCULATED HRI PDU HOLDUPS, DILUTE PHASE

<u>Amoco Test Number</u>	<u>HRI Period</u>	<u>Catalyst</u>		<u>Temperature</u>	<u>Amocat-1A Hydrogen Coal/Oil 815°F</u>
		<u>Gas Liquid</u>	<u>Flow Rate, Ft/Sec</u>		
-01	04B	0.119	0.070	0.823	0.177
-02	10A	0.045	0.071	0.763	0.237
-03	27B	0.085	0.065	0.776	0.224
-04	34B	0.046	0.065	0.756	0.244
-05	41B	0.102	0.066	0.571	0.429
-06	42A	0.073	0.064	0.659	0.341
-07	42B	0.051	0.065	0.496	0.504
-08	43A	0.050	0.086	0.810	0.190
-09	43B	0.050	0.043	0.575	0.425
-10	44A	0.076	0.091	0.927	0.073
-11	44B	0.075	0.045	0.630	0.370
-12	45A	0.088	0.090	0.778	0.222
-13	45B	0.096	0.042	0.727	0.273
-14	46A	0.098	0.065	0.768	0.232

TABLE XXIX
 COMPARISON OF SLURRY AND CATALYST PROPERTIES
 OF AMOCO COLD-FLOW AND HRI PDU TESTS

	<u>Amoco</u>	<u>Amoco</u>	<u>Amoco</u>	<u>Amoco</u>	<u>HRI</u>
Run	221	222	223	224	PDU-10
Slurry Fines, Wt%	7.11	16.7	32.44	25.0	~25.0
Slurry Density, g/cc	0.82	0.85	0.93	0.89	0.84-0.99
Slurry Viscosity, cp	3.8	4.2	4.9	4.5	0.9-3.5
Catalyst	----- HDS-1442A-----		----- Amocat-1A-----		

TABLE XXX

AMOCAT-1A COMPARISON OF FLUID DYNAMIC VARIABLES:
PDU PILOT PLANT VERSUS COLD-FLOW PILOT PLANT (RUN 224)

Test	PDU		Test	Run 224		Test	εg	
	U _l	U _g		U _l	U _g		PDU	224
1	0.119	0.070	15	0.110	0.067	--	0.09	
2	0.045	0.071	11	0.048	0.070	--	0.03	
3	0.085	0.065	13	0.083	0.068	0.15	0.08	
4	0.046	0.065	11	0.048	0.070	0.19	0.03	
5	0.102	0.066	14	0.094	0.067	--	0.09	
6	0.073	0.064	15	0.110	0.067	--	0.09	
7	0.051	0.065	12	0.072	0.068	0.20	0.10	
8	0.050	0.086	11	0.048	0.070	0.25	0.03	
9	0.050	0.043	16	0.045	0.010	0.07	0.06	
10	0.076	0.091	10	0.047	0.043	0.25	0.06	
11	0.075	0.045	17	0.074	0.090	0.03	0.09	
12	0.088	0.090	9	0.073	0.041	0.16	0.05	
13	0.096	0.042	18	0.083	0.090	0.17	0.09	
14	0.097	0.065	7	0.093	0.046	0.13	0.06	
			14	0.094	0.067	0.20	0.08	

TABLE XXXI

BHATIA-EPSTEIN MODEL

<u>Equation</u>	<u>Comment</u>
1) $\epsilon_c + \epsilon_g + \epsilon_l = 1$	Gas + liquid + solid phase volume fractions add up to unity.
1a) $\epsilon_f + \epsilon_g + \epsilon_w = 1$	Fluidized bed + gas + wake phase volume fractions sum to unity.
2) $\epsilon_l = \epsilon_k (1 - X_k) + \epsilon_{lf}'' (1 - \epsilon_g - \epsilon_k + X_k \epsilon_k)$	Distribution of liquid between wake and fluidized liquid/solid phase.
3) $U_g = V_g \epsilon_g$	Defines linear gas velocity V_g . Assumes bubbles rise in plug flow.
4) $\epsilon_{lf}'' = \left[\frac{U_l - V_g \epsilon_k (1 - X_k)}{U_l (1 - \epsilon_g - \epsilon_k)} \right]^{1/n}$	Assumes that Richardson-Zaki correlation describes behavior of particulate liquid fluidized phase. Modifications to U_l/U_t account for existence of gas bubble and wake phases and transport of catalyst and liquid in bubble wakes.
5) $V_g = \frac{U_l + U_g + \epsilon_{lf}'' (1 - \epsilon_g - \epsilon_k) V_{gl}'''}{1 - \epsilon_c}$	A definition of V_{gl}''' , where $V_{gl}''' =$ relative velocity between gas in the bubble phase and liquid in the particulate phase. The manner in which V_{gl}''' is related to the bubble rise velocity will be discussed in the text.
6) Variation of (ϵ_k/ϵ_g) two-phase with operating conditions.	Independent model parameter. Correlate against U_l .
7) Prediction of X_k .	Independent model parameter or literature correlation (Reference 67).
8) (ϵ_k/ϵ_g) three-phase = $K_0 e^{-5.08 \epsilon_g}$ Where $K_0 = (\epsilon_k/\epsilon_g)$ for two-phase gas/liquid bed.	Wake volume ratio in a three-phase fluidized bed.

(Table Continued)

TABLE XXXI

BHATIA-EPSTEIN MODEL

-2-

6
8

Equation

9) $V_{gl}''' = U_{tb} + 2U_g$

Comment

Relationship between bubble rise velocity and relative gas/liquid velocity. (This format was originally proposed by Towell (21) for two-phase systems to account for systematic circulation of the liquid.

TABLE XXXII
PREDICTED RICHARDSON-ZAKI TERMINAL VELOCITIES (U_t) AND INDICES (n)

Amoco Test Number	HRI Period	Catalyst Density, g/cc	Slurry Density, g/cc	Slurry Viscosity, cp	Galileo Number	Terminal Reynolds Number	Terminal Velocity, Ft/Sec	Index n
1	04B	1.55	0.837	0.0171	7.49 • 10 ³	100.5	0.48	2.81
2	10A	1.55	0.947	0.0342	1.79 • 10 ³	45.4	0.38	3.04
3	27B	1.62	0.941	0.0169	8.14 • 10 ³	105.1	0.44	2.79
4	34B	1.64	0.987	0.0269	3.27 • 10 ³	63.94	0.406	2.93
5	41B	1.67	0.880	0.0211	5.71 • 10 ³	86.82	0.484	2.85
6	42A	1.67	0.902	0.0250	4.08 • 10 ³	72.20	0.466	2.90
7	42B	1.67	0.888	0.0227	4.955 • 10 ³	80.38	0.478	2.87
8	43A	1.68	0.900	0.0380	1.77 • 10 ³	45.08	0.443	3.04
9	43B	1.68	0.894	0.0180	7.91 • 10 ³	103.47	0.484	2.80
10	44A	1.68	0.880	0.0211	5.78 • 10 ³	87.49	0.488	2.85
11	44B	1.68	0.914	0.0091	3.11 • 10 ⁴	209.6	0.485	2.61
12	45A	1.68	0.954	0.0356	2.00 • 10 ³	48.46	0.421	3.02
13	45B	1.68	0.947	0.0274	3.41 • 10 ³	65.35	0.440	2.92
14	46A	1.69	0.938	0.0260	3.81 • 10 ³	69.54	0.449	2.91

Note: Slurry viscosities as measured by Battelle.

TABLE XXXIII

PREDICTED RICHARDSON-ZAKI TERMINAL VELOCITIES (U_t) AND INDICES (n) ($\mu = 4 \mu$ Battelle)

Amoco Test Number	HRI Period	Catalyst Density, g/cc	Slurry Density, g/cc	Slurry Viscosity, CP	Galileo Number	Terminal Reynolds Number	Terminal Velocity, Ft/Sec	Index, n
1	04B	1.55	0.837	0.0683	4.68 • 10 ²	20.3	0.386	3.29
2	10A	1.55	0.947	0.1368	1.12 • 10 ²	7.97	0.268	3.62
3	27B	1.62	0.941	0.0676	5.088 • 10 ²	21.33	0.356	3.28
4	34B	1.64	0.987	0.1076	2.047 • 10 ²	11.92	0.303	3.47
5	41B	1.67	0.880	0.0844	3.567 • 10 ²	17.07	0.381	3.35
6	42A	1.67	0.902	0.0999	2.55 • 10 ²	13.75	0.355	3.42
7	42B	1.67	0.888	0.0908	3.097 • 10 ²	15.59	0.371	3.38
8	43A	1.68	0.900	0.152	1.11 • 10 ²	7.91	0.311	3.62
9	43B	1.68	0.894	0.0719	4.94 • 10 ²	20.94	0.392	3.28
10	44A	1.68	0.880	0.0843	3.62 • 10 ²	17.21	0.384	3.35
11	44B	1.68	0.914	0.0364	1.93 • 10 ³	47.41	0.439	3.03
12	45A	1.68	0.954	0.1424	1.256 • 10 ²	8.61	0.299	3.58
13	45B	1.68	0.947	0.1096	2.13 • 10 ²	12.23	0.329	3.46
14	46A	1.69	0.938	0.1040	2.38 • 10 ²	13.16	0.339	3.43

Note: Slurry viscosities = 4X values measured by Battelle.

TABLE XXXIV

TERMINAL VELOCITY OF ISOLATED BUBBLES IN LIQUIDS

<u>Region</u>	<u>Terminal Velocity, U_t</u>	<u>Range of Applicability</u>
1	$\frac{2r_e^2(\rho_l - \rho_g)g}{9\mu_l}$	$Re_b < 2$ where Re_b bubble Reynolds number = $\frac{2\rho_l U_t r_e}{\mu_l}$
2	$0.33g^{0.76} \left(\frac{\rho_l}{\mu_l}\right)^{0.52} r_e^{1.28}$	$2 < Re_b < 4.02M^{-0.214}$ where M Morton Number = $\frac{8\mu_l^4}{\rho_l \sigma^3}$
3	$1.35 \left(\frac{\sigma}{\rho_l r_e}\right)^{1/2}$	$4.02M^{-0.214} < Re_b < 3.10M^{-1/4}$ or $16.32M^{0.144} < G < 5.75$ where $G = \frac{8 r_e^4 U_t^4 \rho_l^3}{\sigma^3}$
4	$1.18 \left(\frac{g \sigma}{\rho_l}\right)^{0.25}$	$3.10 G < Re_b$ $5.75 < G$

Reference: Peebles, F. N., and Garber, H. J., "Studies on the Motion of Gas Bubbles in Liquids," Chemical Engineering Progress, 49, 2 (1953).

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TABLE XXXV

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

RUN : 221
 CATALYST : HDS2A
 GAS : NITROGEN
 LIQUID : KEROSENE
 COAL CHAR CONC: 4.0 VOL %
 COAL CHAR CONC: 7.1 WT %
 TEMPERATURE : 83. DEG F

Test	U1		Ug		Ut		Xt		Eps(Cat)		Eps(Liq)		Eps(Gas)		Delta	Ko	Ug-U1	D#
	Ft/Sec	Ft/Sec	Ft/Sec	Ft/Sec	Ft/Sec	Ft/Sec	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred				
-25	0.052	0.049	0.322	0.229	0.53	0.54	0.38	0.37	0.09	0.09	0.02	0.107	-0.003	0.136				
-26	0.055	0.079	0.545	0.544	0.52	0.52	0.39	0.38	0.10	0.10	0.02	0.104	0.024	0.206				
-27	0.053	0.103	0.709	0.656	0.54	0.53	0.36	0.37	0.10	0.10	0.02	0.114	0.050	0.253				
-28	0.052	0.128	0.907	0.730	0.52	0.53	0.38	0.37	0.10	0.10	0.03	0.103	0.079	(1)				
-29	0.080	0.047	0.391	0.355	0.46	0.46	0.47	0.47	0.07	0.07	0.01	0.111	-0.033	0.159				
-30	0.080	0.077	0.324	0.330	0.44	0.44	0.44	0.44	0.12	0.12	0.00	0.289	-0.002	0.137				
-31	0.080	0.104	0.353	0.410	0.43	0.43	0.43	0.43	0.15	0.15	0.00	0.474	0.024	0.147				
-32	0.079	0.129	0.462	0.539	0.43	0.43	0.42	0.42	0.15	0.15	0.00	0.513	0.050	0.181				
-33	0.106	0.048	0.749	0.633	0.38	0.41	0.57	0.54	0.05	0.05	0.05	0.103	-0.058	(1)				
-34	0.106	0.080	0.426	0.464	0.38	0.37	0.51	0.52	0.10	0.10	0.02	0.112	-0.026	0.170				
-35	0.106	0.108	0.422	0.379	0.38	0.45	0.47	0.40	0.15	0.16	0.14	2.327	0.002	0.169				
-36	0.107	0.134	0.404	0.463	0.37	0.37	0.46	0.46	0.17	0.17	0.00	1.124	0.027	0.163				
-37	0.131	0.050	0.582	0.525	0.36	0.36	0.58	0.58	0.06	0.06	0.00	0.925	-0.082	0.217				
-38	0.132	0.083	0.427	0.417	0.35	0.35	0.55	0.55	0.11	0.11	0.00	1.220	-0.049	0.170				
-39	0.134	0.111	0.399	0.405	0.33	0.33	0.52	0.52	0.14	0.14	0.00	1.426	-0.022	0.161				
-40	0.132	0.136	0.967	0.135	0.40	0.39	0.41	0.51	0.20	0.10	0.21	0.586	0.004	(1)				
-41	0.161	0.093	0.649	0.545	0.31	0.31	0.63	0.63	0.06	0.06	0.00	1.678	-0.108	0.236				
-42	0.159	0.087	0.554	0.511	0.30	0.30	0.60	0.60	0.10	0.10	0.00	1.667	-0.073	0.209				
-43	0.198	0.116	0.546	0.528	0.29	0.29	0.58	0.58	0.12	0.12	0.00	1.605	-0.042	0.206				
-44	0.177	0.052	0.672	0.572	0.28	0.28	0.67	0.67	0.05	0.05	0.00	1.493	-0.125	0.243				
-45	0.181	0.086	0.670	0.573	0.26	0.26	0.65	0.65	0.09	0.09	0.00	1.805	-0.095	0.242				
-46	0.206	0.052	0.525	0.416	0.24	0.24	0.70	0.70	0.06	0.06	0.00	2.572	-0.154	0.200				
-47	0.201	0.077	0.504	0.417	0.24	0.24	0.67	0.67	0.09	0.09	0.00	2.319	-0.124	0.194				
-48	0.102	0.068	0.524	0.524	0.38	0.40	0.54	0.52	0.08	0.08	0.03	0.111	-0.034	0.200				
-49	0.102	0.106	0.379	0.433	0.38	0.38	0.48	0.48	0.14	0.14	0.00	0.609	0.004	0.155				
-50	0.102	0.134	0.414	0.508	0.37	0.37	0.47	0.47	0.16	0.16	0.00	0.728	0.033	0.166				
-51	0.131	0.135	0.375	0.464	0.31	0.31	0.53	0.52	0.16	0.16	0.01	1.187	0.003	0.154				

Note: (1). Out of range for Peebles and Garber correlation.

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TABLE XXXVI

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

Test	U1	Ug	Uth	Xt	Eps(Cat)	Eps(Liq)	Eps(Gas)	Delta	Ko	Ug-U1	Dh
	Ft/Sec	Ft/Sec	Ft/Sec		Obs Pred	Obs Pred	Obs Pred			Ft/Sec	Cm
- 7	0.049	0.049	0.903	0.635	0.47 0.49	0.48 0.46	0.04 0.04	0.05	0.105	-0.000	(1)
- 8	0.072	0.049	0.454	0.314	0.43 0.43	0.50 0.50	0.07 0.07	0.00	0.559	-0.023	0.183
- 9	0.088	0.050	0.521	0.417	0.39 0.38	0.58 0.56	0.06 0.07	0.09	0.102	-0.038	0.203
-10	0.122	0.051	0.410	0.323	0.32 0.31	0.61 0.62	0.07 0.07	0.02	0.105	-0.071	0.169
-11	0.146	0.052	0.462	0.327	0.28 0.28	0.65 0.65	0.07 0.07	0.00	0.642	-0.093	0.185
-12	0.171	0.054	0.362	0.185	0.24 0.24	0.68 0.68	0.08 0.08	0.00	0.796	-0.117	0.153
-13	0.191	0.054	0.368	0.198	0.21 0.21	0.71 0.71	0.08 0.08	0.00	0.904	-0.136	0.153
-15	0.047	0.079	0.941	0.665	0.49 0.49	0.44 0.44	0.07 0.07	0.00	0.195	0.032	(1)
-16	0.074	0.077	0.586	0.497	0.40 0.40	0.51 0.51	0.09 0.09	0.00	0.197	0.003	0.223
-17	0.098	0.075	0.367	0.193	0.37 0.37	0.51 0.51	0.12 0.12	0.00	1.121	-0.023	0.155
-18	0.122	0.078	0.313	0.149	0.30 0.30	0.57 0.57	0.12 0.12	0.00	0.880	-0.044	0.137
-19	0.145	0.080	0.356	0.255	0.26 0.26	0.63 0.63	0.11 0.11	0.00	0.717	-0.065	0.151
-20	0.170	0.081	0.507	0.424	0.23 0.23	0.67 0.67	0.09 0.09	0.00	0.821	-0.089	0.199
-21	0.195	0.078	0.500	0.276	0.20 0.27	0.70 0.63	0.10 0.10	0.13	3.500	-0.117	0.197
-22	0.049	0.107	0.801	0.615	0.51 0.51	0.39 0.39	0.10 0.10	0.00	0.859	0.058	(1)
-23	0.073	0.107	0.678	0.578	0.41 0.41	0.49 0.49	0.11 0.11	0.00	0.494	0.034	0.250
-24	0.097	0.108	0.388	0.289	0.37 0.37	0.48 0.48	0.15 0.15	0.00	1.342	0.011	0.161
-25	0.122	0.109	0.408	0.376	0.29 0.29	0.57 0.57	0.14 0.14	0.00	0.804	-0.012	0.168
-26	0.145	0.102	0.325	0.256	0.25 0.25	0.61 0.61	0.14 0.14	0.00	0.852	-0.043	0.141
-27	0.168	0.102	0.350	0.286	0.22 0.22	0.64 0.64	0.13 0.13	0.00	1.038	-0.066	0.149
-28	0.188	0.102	0.401	0.334	0.20 0.20	0.67 0.67	0.12 0.12	0.00	1.235	-0.086	0.166
-29	0.048	0.126	0.966	0.683	0.49 0.49	0.41 0.41	0.10 0.10	0.00	0.544	0.078	(1)
-30	0.073	0.128	0.834	0.661	0.40 0.40	0.50 0.50	0.11 0.11	0.00	0.315	0.055	(1)

Note: (1). Out of range for Peebles and Garber correlation.

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TABLE XXXVI (cont'd)

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

RUN : 222
 CATALYST : MDS2A
 GAS : NITROGEN
 LIQUID : KEROSENE
 COAL CHAR CONC: 9.8 VOL %
 COAL CHAR CONC: 16.7 WT %
 TEMPERATURE : 70. DEG F

Test	U1		Ug		Ut		Xt	Eps(Cat)		Eps(Liq)		Eps(Gas)		Delta	Ke	Ug-U1	Dp
	Ft/Sec	Ft/Sec	Ft/Sec	Ft/Sec	Obs	Pred		Obs	Pred	Obs	Pred	Obs	Pred				
-31	0.096	0.131	0.131	0.481	0.460	0.34	0.34	0.51	0.51	0.15	0.15	0.00	0.862	0.034	0.191		
-32	0.121	0.134	0.355	0.318	0.318	0.29	0.29	0.53	0.53	0.18	0.18	0.00	1.235	0.014	0.151		
-33	0.132	0.137	0.399	0.451	0.451	0.25	0.25	0.60	0.60	0.16	0.16	0.00	0.159	0.005	0.165		
-34	0.049	0.149	1.914	0.935	0.710	0.47	0.48	0.46	0.45	0.07	0.06	0.02	0.105	0.100	(1)		
-35	0.073	0.153	0.969	0.710	0.39	0.39	0.39	0.50	0.50	0.11	0.11	0.00	0.229	0.080	(1)		
-36	0.098	0.157	0.640	0.590	0.34	0.33	0.33	0.52	0.52	0.15	0.15	0.00	0.741	0.059	0.239		
-37	0.097	0.104	0.435	0.403	0.34	0.34	0.34	0.53	0.53	0.13	0.13	0.00	0.544	0.007	0.177		
-38	0.050	0.046	0.703	0.540	0.47	0.49	0.48	0.46	0.46	0.05	0.05	0.03	0.107	-0.004	0.257		
-39	0.122	0.117	0.332	0.267	0.29	0.29	0.29	0.54	0.54	0.16	0.16	0.00	1.128	-0.005	0.143		
-40	0.120	0.155	0.451	0.424	0.31	0.31	0.31	0.51	0.51	0.18	0.18	0.00	1.657	0.035	0.182		
-41	0.144	0.160	0.387	0.396	0.25	0.25	0.25	0.56	0.56	0.19	0.19	0.00	1.394	0.016	0.161		
-42	0.171	0.166	0.422	0.421	0.21	0.21	0.21	0.61	0.61	0.18	0.18	0.00	1.518	-0.005	0.172		
-43	0.169	0.178	1.240	0.130	0.22	0.22	0.22	0.60	0.60	0.18	0.18	0.00	1.430	-0.042	0.111		
-44	0.049	0.178	1.263	0.760	0.49	0.49	0.49	0.40	0.40	0.11	0.11	0.00	0.636	0.129	(1)		
-45	0.074	0.185	1.063	0.738	0.40	0.40	0.40	0.48	0.48	0.12	0.12	0.00	0.552	0.112	(1)		
-46	0.099	0.186	0.874	0.670	0.36	0.36	0.36	0.50	0.50	0.14	0.14	0.00	1.197	0.088	(1)		
-47	0.121	0.186	0.485	0.551	0.31	0.31	0.31	0.51	0.45	0.18	0.24	0.11	3.497	0.065	0.192		
-48	0.146	0.179	0.432	0.444	0.25	0.25	0.25	0.59	0.55	0.20	0.20	0.00	1.624	0.033	0.176		
-49	0.049	0.187	0.425	0.466	0.20	0.20	0.20	0.60	0.60	0.19	0.19	0.00	1.465	0.018	0.173		
-50	0.049	0.218	1.231	0.758	0.51	0.51	0.51	0.35	0.35	0.13	0.13	0.00	0.959	0.170	(1)		
-51	0.073	0.213	1.176	0.764	0.40	0.40	0.40	0.47	0.47	0.13	0.13	0.00	0.594	0.140	(1)		
-52	0.098	0.224	1.093	0.730	0.36	0.36	0.36	0.49	0.49	0.15	0.15	0.00	1.303	0.126	(1)		
-53	0.049	0.050	0.868	0.622	0.47	0.49	0.48	0.46	0.46	0.05	0.05	0.04	0.108	0.000	(1)		
-54	0.075	0.178	1.179	0.743	0.41	0.41	0.41	0.47	0.48	0.11	0.11	0.01	0.743	0.103	(1)		
-55	0.098	0.183	0.889	0.684	0.35	0.34	0.34	0.52	0.52	0.14	0.14	0.00	0.823	0.085	(1)		
-56	0.116	0.217	0.732	0.593	0.35	0.35	0.35	0.46	0.46	0.19	0.19	0.00	2.169	0.101	(1)		

Note: (1). Out of range for Pebbles and Garber correlation.

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TABLE XXXVII

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

Test	U1	Ug	Utb	Xk	Eps(Cat)		Eps(Liq)		Eps(Gas)		Delta	Ko	Ug-U1	Db
					Ft/Sec	Ft/Sec	Obs	Pred	Obs	Pred				
-7	0.052	0.047	0.636	0.585	0.44	0.44	0.50	0.50	0.06	0.06	0.00	0.975	-0.005	0.245
-8	0.077	0.048	0.401	0.401	0.34	0.34	0.58	0.58	0.08	0.08	0.00	0.440	-0.029	0.171
-9	0.100	0.049	0.354	0.300	0.30	0.30	0.61	0.61	0.09	0.09	0.00	1.170	-0.051	0.159
-10	0.126	0.050	0.354	0.423	0.24	0.23	0.69	0.68	0.07	0.08	0.01	0.772	-0.076	0.155
-11	0.146	0.051	0.373	0.349	0.21	0.21	0.71	0.71	0.08	0.08	0.00	1.093	-0.095	0.161
-12	0.049	0.078	1.891	0.862	0.44	0.43	0.52	0.53	0.04	0.04	0.02	0.116	0.028	(1)
-13	0.063	0.078	3.852	0.701	0.39	0.44	0.54	0.54	0.07	0.02	0.11	0.655	0.015	(1)
-14	0.087	0.079	0.489	0.497	0.33	0.33	0.57	0.57	0.11	0.11	0.00	1.206	-0.009	0.199
-15	0.109	0.079	0.505	0.521	0.27	0.27	0.63	0.63	0.10	0.10	0.00	1.072	-0.030	0.204
-16	0.133	0.079	0.406	0.425	0.23	0.23	0.66	0.66	0.11	0.11	0.00	1.398	-0.054	0.172
-17	0.048	0.101	1.227	0.790	0.44	0.45	0.49	0.49	0.07	0.07	0.00	0.643	0.053	(1)
-18	0.064	0.102	1.104	0.764	0.40	0.40	0.52	0.52	0.08	0.08	0.00	1.051	0.038	(1)
-19	0.088	0.102	0.727	0.664	0.33	0.33	0.57	0.57	0.10	0.10	0.00	1.222	0.014	(1)
-20	0.126	0.108	0.408	0.479	0.22	0.22	0.63	0.63	0.14	0.14	0.00	1.263	-0.019	0.173
-21	0.151	0.106	0.371	0.431	0.19	0.19	0.67	0.67	0.15	0.15	0.00	1.647	-0.045	0.161
-22	0.051	0.128	1.395	0.814	0.45	0.45	0.47	0.47	0.08	0.08	0.00	1.104	0.077	(1)
-23	0.076	0.126	1.020	0.762	0.35	0.35	0.56	0.56	0.09	0.09	0.00	0.846	0.050	(1)
-24	0.100	0.130	0.875	0.717	0.30	0.30	0.59	0.59	0.11	0.11	0.00	1.420	0.030	(1)
-25	0.126	0.129	0.593	0.602	0.24	0.24	0.62	0.62	0.14	0.14	0.00	1.724	0.002	0.232
-26	0.151	0.128	0.439	0.492	0.19	0.19	0.65	0.65	0.16	0.16	0.00	1.980	-0.023	0.183
-27	0.091	0.145	1.272	0.807	0.43	0.43	0.48	0.48	0.09	0.09	0.00	0.738	0.094	(1)
-28	0.076	0.151	1.310	0.810	0.35	0.35	0.56	0.56	0.09	0.09	0.00	0.837	0.075	(1)
-29	0.100	0.156	1.231	0.793	0.30	0.30	0.60	0.60	0.10	0.10	0.00	1.316	0.056	(1)
-30	0.126	0.160	0.836	0.698	0.25	0.25	0.61	0.61	0.14	0.14	0.00	2.068	0.034	(1)

Note: (1). Out of range for Peebles and Garber correlation.

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TABLE XXXVII (cont'd)

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

Test	U1		Ug		Uth		Xk	Eps(Cat)		Eps(Liq)		Eps(Gas)		Delta	Ko	Ug-U1	Db
	Ft/Sec	U1	Ft/Sec	Ug	Ft/Sec	Uth		Obs	Pred	Obs	Pred	Obs	Pred				
-31	0.051	0.173	1.565	0.847	0.39	0.40	0.52	0.51	0.09	0.09	0.02	0.106	0.122	(1)			
-32	0.076	0.183	1.577	0.852	0.34	0.33	0.57	0.58	0.09	0.09	0.03	0.107	0.107	(1)			
-33	0.100	0.184	1.206	0.789	0.31	0.31	0.57	0.57	0.12	0.12	0.00	1.840	0.083	(1)			
-34	0.126	0.185	1.023	0.735	0.26	0.26	0.59	0.59	0.14	0.14	0.00	2.588	0.059	(1)			
-35	0.177	0.056	0.446	0.417	0.17	0.17	0.75	0.75	0.08	0.08	0.00	1.899	-0.121	0.185			
-36	0.052	0.203	1.283	0.816	0.43	0.43	0.44	0.44	0.12	0.12	0.00	1.059	0.153	(1)			
-37	0.051	0.210	1.313	0.818	0.43	0.43	0.45	0.45	0.12	0.12	0.00	0.949	0.152	(1)			
-38	0.076	0.213	1.367	0.843	0.35	0.35	0.54	0.54	0.11	0.11	0.00	1.043	0.134	(1)			
-39	0.100	0.213	1.488	0.810	0.34	0.34	0.53	0.53	0.13	0.13	0.00	2.551	0.113	(1)			
-42	0.100	0.111	0.741	0.672	0.29	0.29	0.60	0.60	0.11	0.11	0.00	1.237	0.011	(1)			
-44	0.051	0.053	0.646	0.607	0.43	0.43	0.51	0.51	0.06	0.06	0.00	0.511	0.002	0.248			
-45	0.126	0.168	0.849	0.702	0.25	0.25	0.61	0.61	0.14	0.14	0.00	2.191	0.041	(1)			
-53	0.147	0.158	0.606	0.573	0.22	0.22	0.61	0.61	0.17	0.17	0.00	2.783	0.010	0.235			
-54	0.177	0.145	0.541	0.512	0.17	0.17	0.66	0.66	0.17	0.17	0.00	3.071	-0.032	0.216			
-55	0.177	0.104	0.480	0.428	0.19	0.19	0.68	0.68	0.14	0.14	0.00	3.021	-0.073	0.196			
-56	0.177	0.085	0.493	0.432	0.19	0.19	0.70	0.70	0.11	0.11	0.00	2.853	-0.093	0.200			
-59	0.199	0.058	0.517	0.453	0.15	0.15	0.78	0.78	0.07	0.07	0.00	2.672	-0.142	0.208			
-60	0.199	0.072	0.434	0.386	0.15	0.15	0.76	0.76	0.10	0.10	0.00	2.470	-0.127	0.181			
-61	0.198	0.119	0.518	0.480	0.15	0.15	0.71	0.71	0.14	0.14	0.00	3.117	-0.079	0.209			
-62	0.198	0.131	0.561	0.509	0.15	0.15	0.70	0.70	0.15	0.15	0.00	3.283	-0.067	0.222			
-63	0.207	0.144	1.072	0.687	0.15	0.15	0.73	0.73	0.12	0.12	0.00	4.303	-0.062	(1)			
-64	0.198	0.087	0.502	0.446	0.16	0.16	0.73	0.73	0.11	0.11	0.00	3.053	-0.111	0.203			

Note: (1). Out of range for Peebles and Garber correlation.

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TABLE XXXVIII

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

Test	U1	Ug	Utb	Xk	Eps(Cat)	Eps(Liq)	Eps(Gas)	Delta	Ko	Ug-U1	Db
	Ft/Sec	Ft/Sec	Ft/Sec		Obs	Obs	Obs			Ft/Sec	Cm
- 6	0.112	0.097	0.522	0.455	0.30	0.30	0.62	0.08	1.448	-0.056	0.206
- 7	0.093	0.046	0.514	0.460	0.34	0.34	0.60	0.06	0.958	-0.047	0.203
- 8	0.083	0.040	0.575	0.506	0.37	0.37	0.58	0.05	0.991	-0.043	0.222
- 9	0.073	0.041	0.594	0.503	0.41	0.41	0.53	0.05	1.997	-0.031	0.228
-10	0.047	0.043	0.677	0.536	0.54	0.54	0.40	0.06	1.891	-0.004	0.252
-11	0.048	0.070	1.939	0.850	0.47	0.47	0.49	0.03	0.739	0.022	(1)
-12	0.072	0.069	0.515	0.453	0.42	0.42	0.48	0.10	1.596	-0.003	0.204
-13	0.083	0.068	0.649	0.545	0.38	0.38	0.53	0.08	1.533	-0.014	0.244
-14	0.094	0.067	0.587	0.531	0.33	0.33	0.58	0.08	1.120	-0.027	0.226
-15	0.110	0.067	0.482	0.440	0.30	0.30	0.61	0.09	1.309	-0.043	0.193
-16	0.045	0.090	1.219	0.759	0.52	0.52	0.41	0.06	1.414	0.044	(1)
-17	0.074	0.090	0.772	0.630	0.41	0.41	0.50	0.09	1.329	0.016	(1)
-18	0.083	0.090	0.780	0.624	0.39	0.39	0.52	0.09	1.715	0.007	(1)
-19	0.093	0.090	0.569	0.537	0.34	0.34	0.55	0.11	1.411	-0.004	0.220
-20	0.113	0.102	0.523	0.454	0.30	0.30	0.58	0.12	1.644	-0.023	0.193
-21	0.094	0.101	0.740	0.628	0.34	0.34	0.56	0.10	1.511	-0.010	0.206
-22	0.083	0.100	0.914	0.699	0.37	0.37	0.54	0.09	1.410	0.007	(1)
-23	0.073	0.100	0.994	0.705	0.42	0.42	0.50	0.09	1.365	0.018	(1)
-24	0.046	0.100	1.235	0.759	0.52	0.52	0.41	0.07	1.658	0.028	(1)
-25	0.046	0.148	1.718	0.827	0.54	0.54	0.38	0.08	1.449	0.054	(1)
-26	0.073	0.151	1.165	0.767	0.39	0.39	0.50	0.10	1.650	0.102	(1)
-27	0.083	0.152	1.144	0.745	0.39	0.40	0.49	0.11	1.274	0.078	(1)
-28	0.093	0.150	1.043	0.714	0.37	0.37	0.51	0.12	1.907	0.069	(1)
-33	0.112	0.152	0.765	0.607	0.34	0.34	0.51	0.15	2.111	0.057	(1)
-34	0.140	0.151	0.382	0.535	0.26	0.18	0.57	0.17	2.650	0.040	(1)
-35	0.140	0.096	0.289	0.342	0.23	0.19	0.63	0.14	0.004	0.011	0.161
-36	0.140	0.084	0.369	0.359	0.23	0.23	0.65	0.12	0.054	-0.044	0.129
-37	0.143	0.067	0.385	0.310	0.24	0.24	0.66	0.10	1.369	-0.055	0.157
-38	0.140	0.039	0.344	0.266	0.24	0.23	0.69	0.06	1.460	-0.076	0.162
									0.116	-0.102	0.148

Note: (1). Out of range for Pebbles and Garber correlation.

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TABLE XXXIX

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

Test	U _l		U _g		U _{tb}		X _k	Eps(Cat)		Eps(Liq)		Eps(Gas)		Delta	K _o	U _g -U _l		D _b
	Ft/Sec	Obs	Ft/Sec	Pred	Ft/Sec	Pred		Obs	Pred	Obs	Pred	Ft/Sec	Obs			Ft/Sec	Obs	
-03	0.085	0.045	0.337	0.583	0.38	0.38	0.47	0.47	0.15	0.15	0.00	0.00	0.00	4.751	-0.020	0.096	0.096	0.047
-04	0.046	0.065	0.108	0.016	0.38	0.40	0.43	0.41	0.19	0.19	0.04	0.04	0.04	0.104	0.019	0.047	0.047	0.047
-06	0.073	0.064	0.030	0.018	0.36	0.34	0.44	0.46	0.20	0.20	0.04	0.04	0.04	0.110	-0.009	0.022	0.022	0.022
-07	0.051	0.065	0.099	0.169	0.41	0.41	0.31	0.31	0.29	0.29	0.00	0.00	0.00	3.861	0.014	0.043	0.043	0.043
-08	0.050	0.086	1.940	0.999	0.36	0.36	0.57	0.57	0.07	0.07	0.00	0.00	0.00	8.684	0.036	(2)	(2)	(2)
-09	0.050	0.043	0.000	0.112	0.41	0.41	0.35	0.38	0.29	0.21	0.07	0.07	0.07	0.298	-0.007	0.002	0.002	0.002
-10	0.076	0.091	2.219	0.997	0.28	0.29	0.69	0.64	0.03	0.07	0.10	0.10	0.10	9.793	0.015	(2)	(2)	(2)
-11	0.075	0.045	4.207	0.546	0.39	0.51	0.46	0.48	0.16	0.01	0.30	0.30	0.30	0.103	-0.030	0.101	0.101	0.101
-12	0.088	0.090	0.247	0.987	0.28	0.27	0.55	0.55	0.17	0.17	0.00	0.00	0.00	1.808	0.002	0.079	0.079	0.079
-13	0.096	0.042	0.205	0.328	0.35	0.35	0.52	0.52	0.13	0.13	0.00	0.00	0.00	4.965	-0.054	0.079	0.079	0.079
-14	0.098	0.065	0.187	0.339	0.31	0.31	0.49	0.50	0.20	0.20	0.00	0.00	0.00	4.925	-0.033	0.072	0.072	0.072

Note: (1). PDU Reactor slurry viscosities assumed to be equal to Battelle measured viscosities of separator bottoms streams.

(2). Out of range for Peebles and Garber correlation.

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TABLE XXXX

BHATIA-EPSTEIN MODEL WITH PEBBLES/GARBER CORRELATION

RUN : MRI PBU-10 Tests

CATALYST : AMCAT
 GAS : HYDROGEN
 LIQUID : COAL/OIL
 TEMPERATURE : 615. DEG F

Test	U1		Ug		Utb		Xt		Eps(Cat)		Eps(Liq)		Eps(Gas)		Delta	Ko	Ug-U1		Db
	Ft/Sec	Ft/Sec	Ft/Sec	Ft/Sec	Ft/Sec	Ft/Sec	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred			Ft/Sec	cm	
-03	0.085	0.065	0.291	0.318	0.38	0.38	0.47	0.47	0.15	0.15	0.00	0.00	0.15	0.15	0.00	3.504	-0.020	0.150	0.150
-04	0.046	0.065	0.297	0.640	0.38	0.38	0.43	0.43	0.19	0.19	0.00	0.00	0.19	0.19	0.00	4.273	0.019	0.181	0.181
-06	0.073	0.064	0.224	0.321	0.36	0.36	0.44	0.44	0.20	0.20	0.00	0.00	0.20	0.20	0.00	4.204	-0.009	0.146	0.146
-07	0.051	0.065	0.114	0.128	0.41	0.42	0.31	0.31	0.29	0.27	0.03	0.03	0.29	0.27	0.03	3.233	0.014	0.084	0.084
-08	0.050	0.086	1.507	0.946	0.36	0.36	0.57	0.56	0.07	0.07	0.00	0.00	0.07	0.07	0.00	4.312	0.036	(1)	(1)
-09	0.050	0.043	0.052	0.011	0.41	0.40	0.35	0.35	0.25	0.25	0.01	0.01	0.25	0.25	0.01	4.130	-0.007	0.049	0.049
-10	0.076	0.091	3.130	1.000	0.28	0.28	0.69	0.68	0.03	0.04	0.02	0.02	0.03	0.04	0.02	9.994	0.019	(1)	(1)
-11	0.075	0.045	0.136	0.176	0.39	0.39	0.46	0.46	0.16	0.16	0.00	0.00	0.16	0.16	0.00	3.741	-0.030	0.073	0.073
-12	0.088	0.090	0.301	0.395	0.28	0.28	0.55	0.55	0.17	0.17	0.00	0.00	0.17	0.17	0.00	2.297	0.002	0.208	0.208
-13	0.096	0.042	0.284	0.310	0.35	0.35	0.52	0.52	0.13	0.13	0.00	0.00	0.13	0.13	0.00	5.981	-0.054	0.180	0.180
-14	0.098	0.065	0.229	0.245	0.31	0.31	0.49	0.49	0.20	0.20	0.00	0.00	0.20	0.20	0.00	5.095	-0.033	0.149	0.149

Notes:

- (1). Out of Range of Peebles and Garber Correlation
- (2). Reactor liquid viscosity assumed to be 4 times separator bottoms viscosity measured by Battelle

TABLE XXXXI

EFFECTIVE WAKE VOLUME RATIOS FOR BHATIA-EPSTEIN MODEL:
HRI PDU-10 TESTS

<u>Test Number</u>	<u>Gas Volume Fraction ϵ_g</u>	<u>Wake Ratio 2-Phase, K_o</u>	<u>Wake Volume to Bubble Volume Ratio, $K_o \text{ exp}$ ($-5.08 \epsilon_g$)</u>
3	0.15	3.504	1.64
4	0.19	4.273	1.63
6	0.20	4.204	1.52
7	0.29	3.233	0.74
8	0.07	4.312	3.02
9	0.25	4.130	1.16
10	0.03	9.994	8.58
11	0.16	3.741	1.66
12	0.17	2.257	0.95
13	0.13	5.981	3.09
14	0.20	5.055	1.83

TABLE XXXII
 EFFECTIVE WAKE VOLUME RATIOS
 FOR BHATIA-EPSTEIN MODEL:
COLD-FLOW RUN 224 TESTS

<u>Test Number</u>	<u>ϵ_{gas} Gas Holdup</u>	<u>K_o</u>	<u>$\epsilon_w/\epsilon_{\text{gas}}$ Wake Volume Ratio</u>
-6	0.076	1.450	0.986
-7	0.064	0.972	0.702
-8	0.053	1.002	0.765
-9	0.055	1.551	1.173
-10	0.056	1.901	1.430
-11	0.033	0.749	0.633
-12	0.097	1.596	0.975
-13	0.082	1.592	1.050
-14	0.082	1.131	0.746
-15	0.092	1.313	0.823
-16	0.065	1.398	1.005
-17	0.092	1.530	0.959
-18	0.092	1.731	1.085
-19	0.108	1.389	0.802
-20	0.118	1.659	0.911
-21	0.126	1.516	0.799
-22	0.101	1.430	0.856
-23	0.086	1.353	0.874
-24	0.084	1.658	1.082
-25	0.072	1.456	1.010
-26	0.078	1.663	1.119
-27	0.103	1.303	0.772
-28	0.111	1.916	1.090
-32	0.119	2.118	1.157
-33	0.151	2.636	1.224
-34	0.167	2.636	1.129
-35	0.139	1.605	0.792
-36	0.121	1.371	0.741
-37	0.101	1.451	0.869
-38	0.062	1.048	0.765

TABLE XXXXI

EFFECTIVE WAKE VOLUME RATIOS FOR BHATIA-EPSTEIN MODEL:
HRI PDU-10 TESTS

<u>Test Number</u>	<u>Gas Volume Fraction -ϵ_g-</u>	<u>Wake Ratio, 2-Phase, K_o</u>	<u>Wake Volume to Bubble Volume Ratio, K_o exp (-5.08 ϵ_g)</u>
3	0.15	3.504	1.64
4	0.19	4.273	1.63
6	0.20	4.204	1.52
7	0.29	3.233	0.74
8	0.07	4.312	3.02
9	0.25	4.130	1.16
10	0.03	9.994	8.58
11	0.16	3.741	1.66
12	0.17	2.257	0.95
13	0.13	5.981	3.09
14	0.20	5.055	1.83

TABLE XXXII
 EFFECTIVE WAKE VOLUME RATIOS
 FOR BHATIA-EPSTEIN MODEL:
COLD-FLOW RUN 224 TESTS

<u>Test Number</u>	<u>ϵ_{gas}, Gas Holdup</u>	<u>K_o</u>	<u>$\epsilon_w/\epsilon_{\text{gas}}$, Wake Volume Ratio</u>
- 6	0.076	1.450	0.986
- 7	0.064	0.972	0.702
- 8	0.053	1.002	0.765
- 9	0.055	1.551	1.173
-10	0.056	1.901	1.430
-11	0.033	0.749	0.633
-12	0.097	1.596	0.975
-13	0.082	1.592	1.050
-14	0.082	1.131	0.746
-15	0.092	1.313	0.823
-16	0.065	1.398	1.005
-17	0.092	1.530	0.959
-18	0.092	1.731	1.085
-19	0.108	1.389	0.802
-20	0.118	1.659	0.911
-21	0.126	1.516	0.799
-22	0.101	1.430	0.856
-23	0.086	1.353	0.874
-24	0.084	1.658	1.082
-25	0.072	1.456	1.010
-26	0.078	1.663	1.119
-27	0.103	1.303	0.772
-28	0.111	1.916	1.090
-32	0.119	2.118	1.157
-33	0.151	2.636	1.224
-34	0.167	2.636	1.129
-35	0.139	1.605	0.792
-36	0.121	1.371	0.741
-37	0.101	1.451	0.869
-38	0.062	1.048	0.765