Figure 10

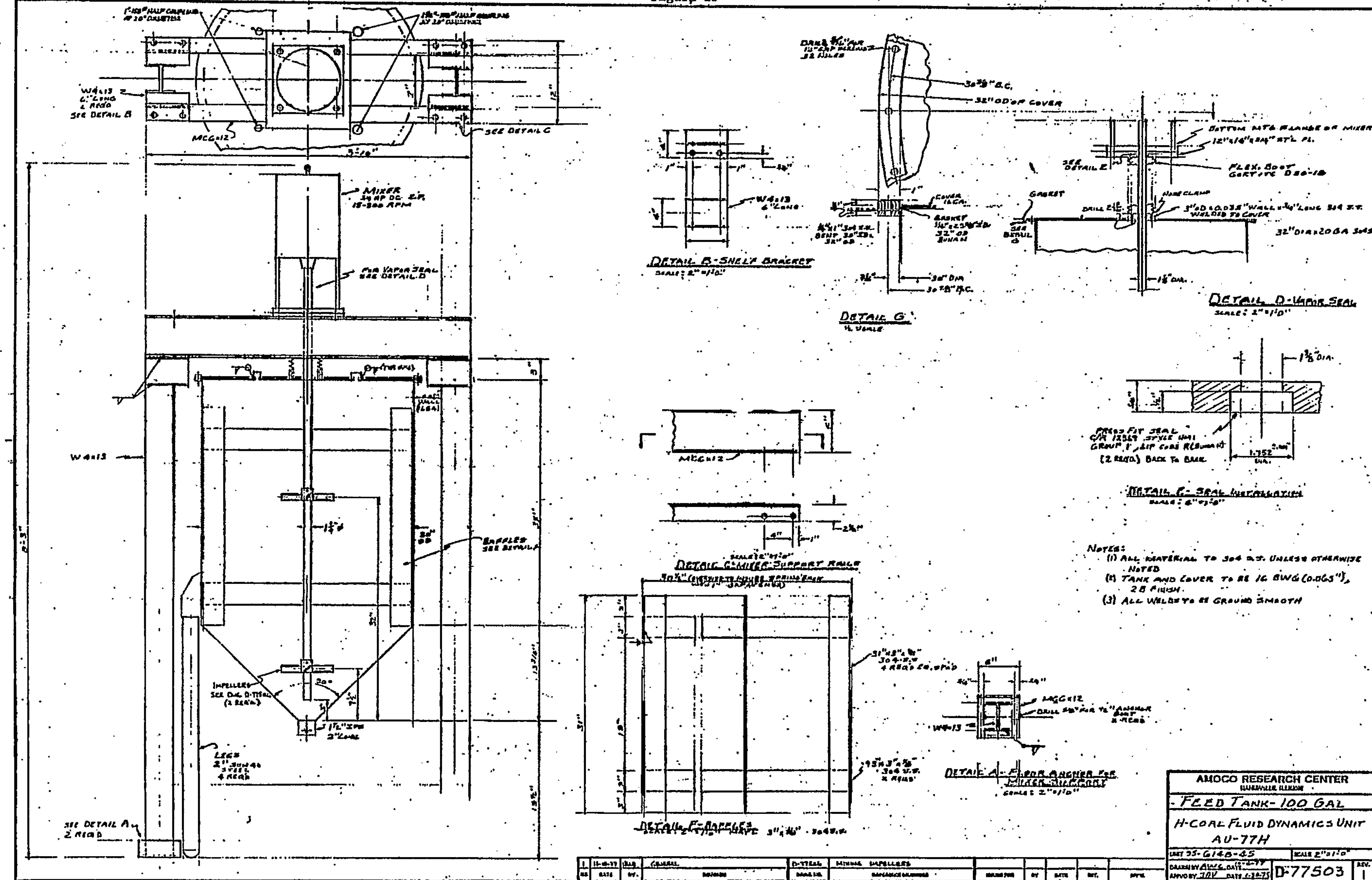

MIXER
SEE DETAIL B
SEE DETAIL C
SEE DETAIL A
W4x13
MCG x12
BAFFLES
LEGS
IMPELLERS
DETAIL B-SHELF BRACKET
DETAIL G
DETAIL D-VAPOR SEAL
DETAIL E-SEAL INSTALLATION
DETAIL C-MIXER SUPPORT RAILS
DETAIL F-BAFFLES
DETAIL A-FLOOR ANCHER FOR MIXER SUPPORT
Notes:
(1) ALL MATERIAL TO 304 S.S. UNLESS OTHERWISE NOTED
(2) TANK AND COVER TO BE 16 BWG (0.065"), 2B FINISH.
(3) ALL WELDS TO BE GROUND SMOOTH
AMOCO RESEARCH CENTER
FEED TANK-100 GAL
H-COAL FLUID DYNAMICS UNIT
AU-77H
D-77503

Figure 11

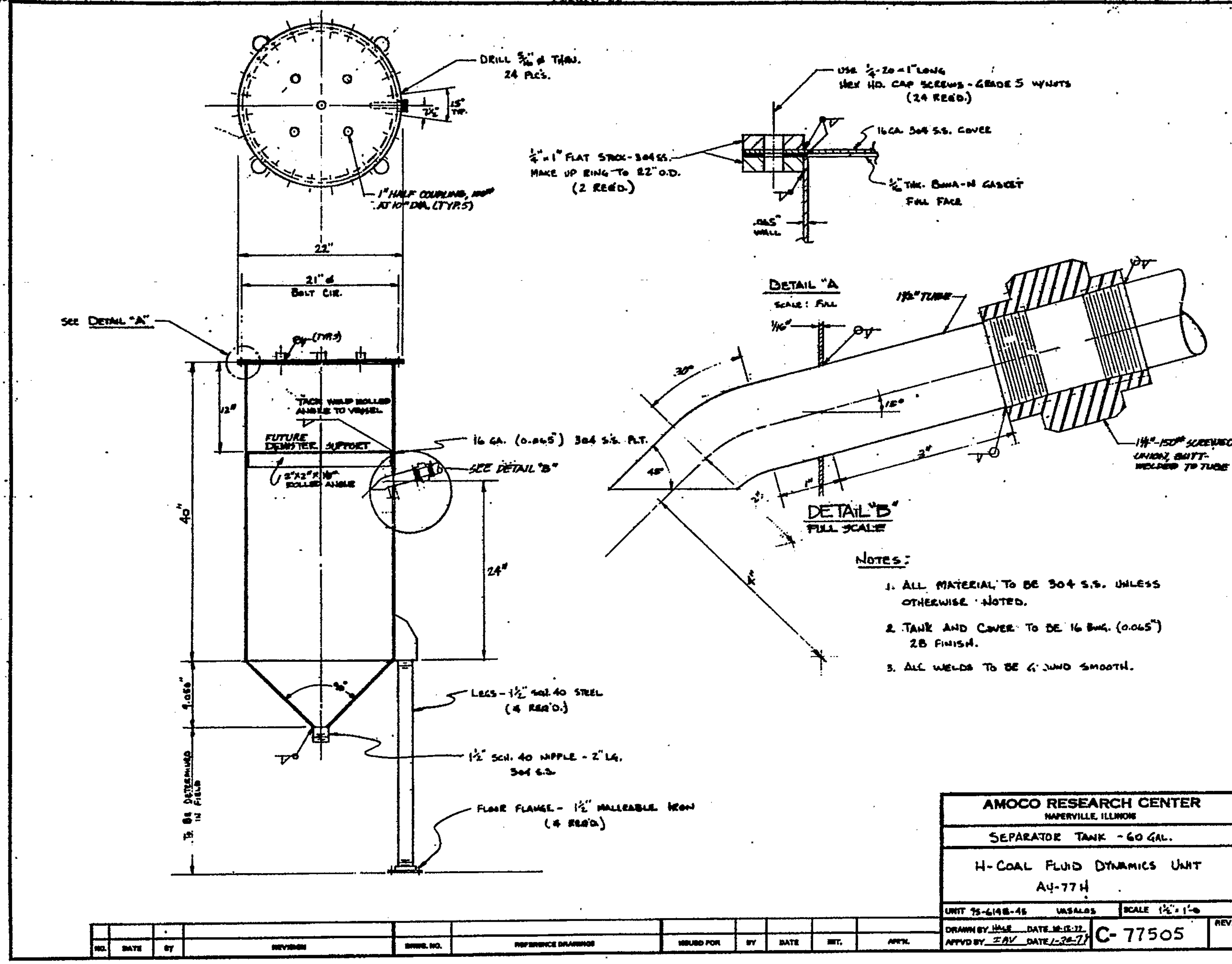
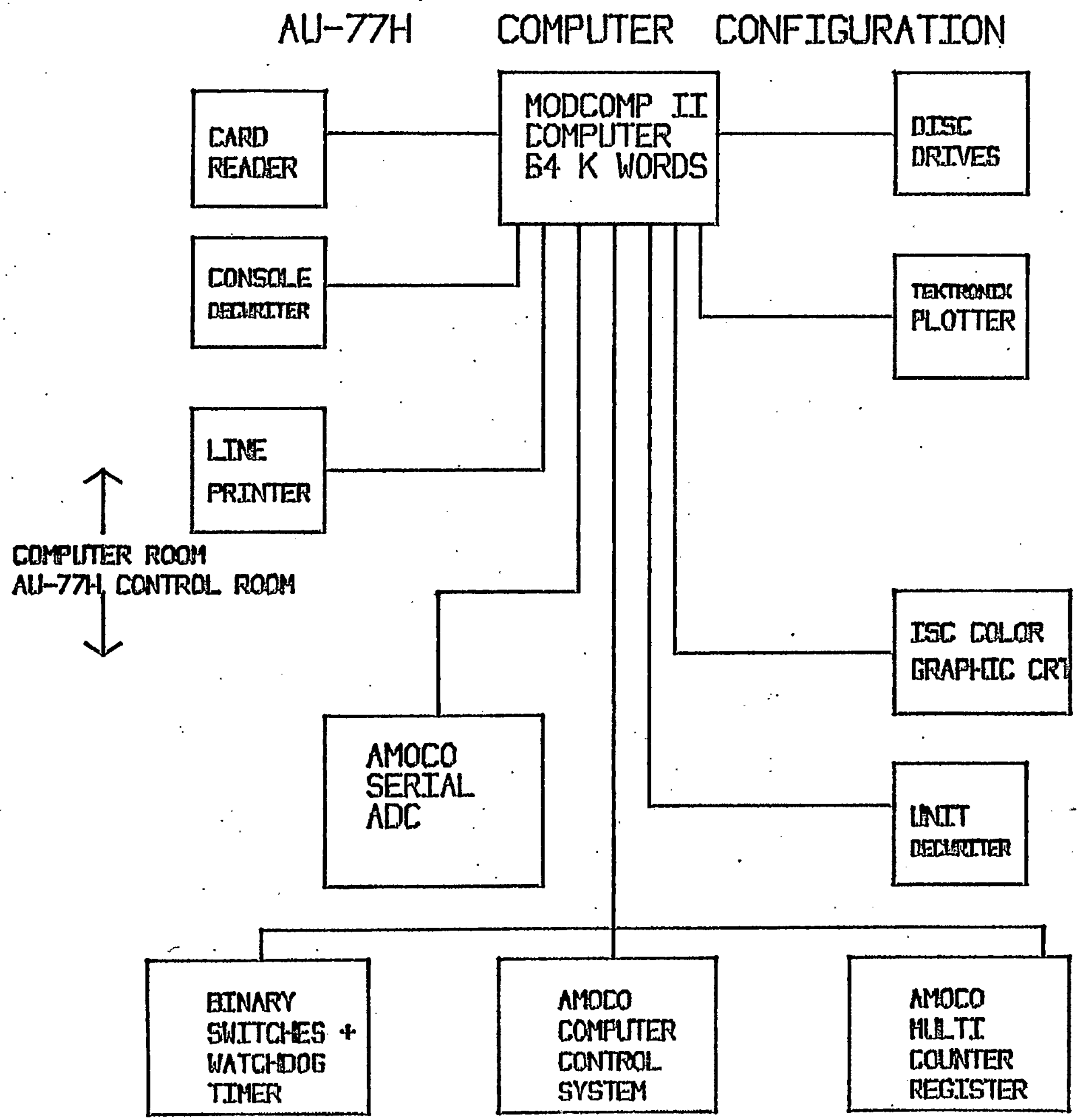

DRILL 5/16" ⌀ THRU. 24 PLCS.
15° TYP.
7½°
1" HALF COUPLING, AT 10" DIA. (TYP.5)
22"
21" ⌀ BOLT CIR.
SEE DETAIL "A"
(TYP.5)
TACK WELD ROLLED ANGLE TO VESSEL
FUTURE DEMISTER SUPPORT
2"X2"X1/8" ROLLED ANGLE
16 GA. (0.065") 304 S.S. PLT.
SEE DETAIL "B"
12"
40"
24"
90°
9.050"
TO BE DETERMINED IN FIELD
LEGS - 1½" SCH. 40 STEEL (4 REQ'D.)
1½" SCH. 40 NIPPLE - 2" LG. 304 S.S.
FLOOR FLANGE - 1½" MALLEABLE IRON (4 REQ'D.)
USE ¼-20 x 1" LONG HEX HD. CAP SCREWS - GRADE 5 W/NUTS (24 REQ'D.)
16 GA. 304 S.S. COVER
¼" x 1" FLAT STOCK - 304 S.S. MAKE UP RING TO 22" O.D. (2 REQ'D.)
1/16" THK. BUNA-N GASKET FULL FACE
.065" WALL
DETAIL "A"
SCALE: FULL
1/16"
1½" TUBE
30°
15°
45°
2"
1"
1½"-150# SCREWED UNION, BUTT-WELDED TO TUBE
DETAIL "B"
FULL SCALE
NOTES:
1. ALL MATERIAL TO BE 304 S.S. UNLESS OTHERWISE NOTED.
2. TANK AND COVER TO BE 16 BWG. (0.065") 2B FINISH.
3. ALL WELDS TO BE G.ROUND SMOOTH.
AMOCO RESEARCH CENTER
NAPERVILLE, ILLINOIS
SEPARATOR TANK - 60 GAL.
H-COAL FLUID DYNAMICS UNIT
AU-77H
UNIT 75-6148-45
SCALE 1½"=1'-0
DRAWN BY HALE
APP'D BY IAV
C-77505
REV.
NO. DATE BY REVISION DWG. NO. REFERENCE DRAWINGS ISSUED FOR BY DATE INT. APP'K.

Figure 12



TEKTRONIX PLOT

Figure 13

APPLICATIONS SOFTWARE CONFIGURATION

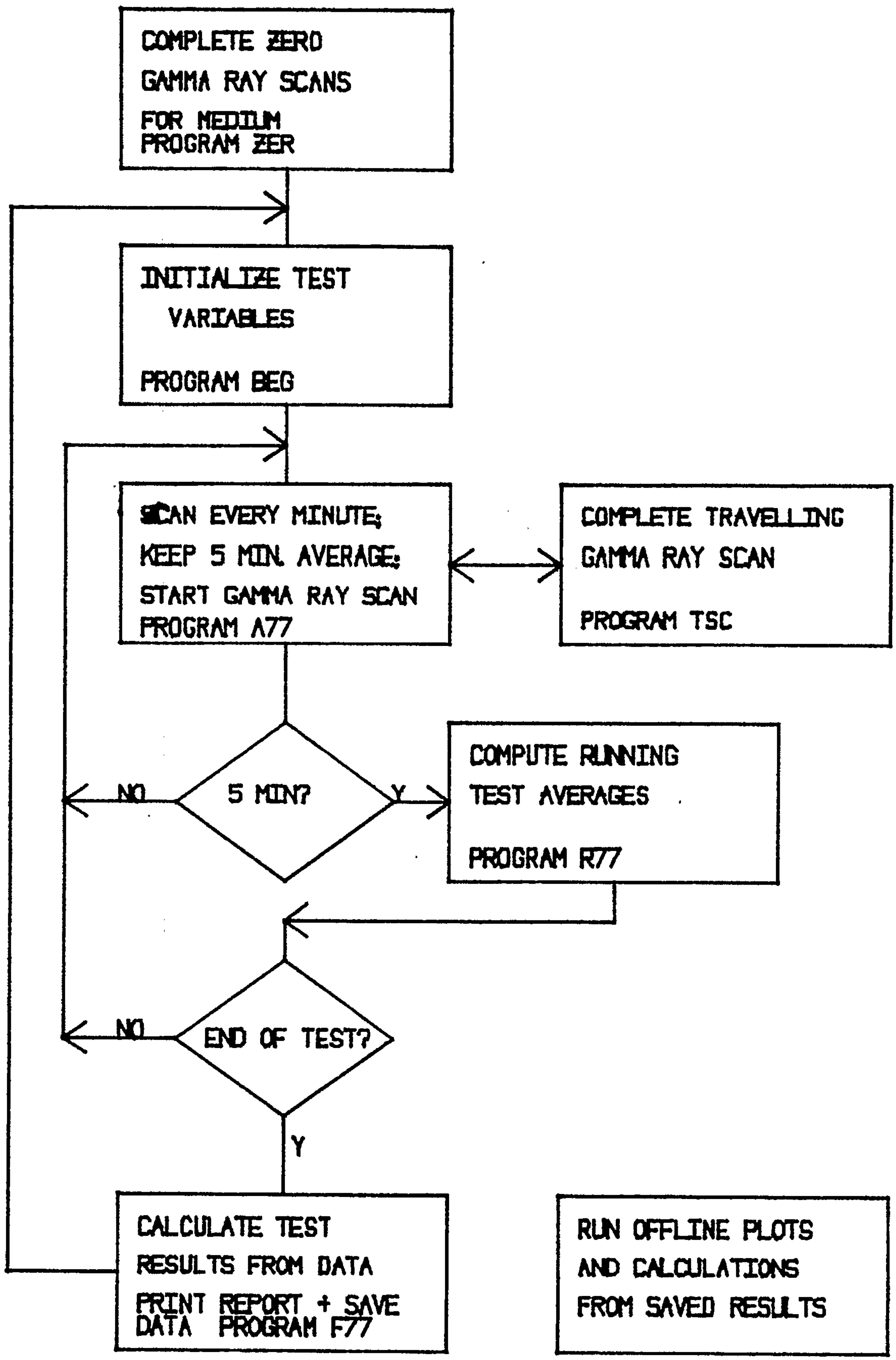


Figure 14

SCHEMATIC DIAGRAM OF EXPERIMENTAL SET-UP FOR VISCOSITY MEASUREMENT

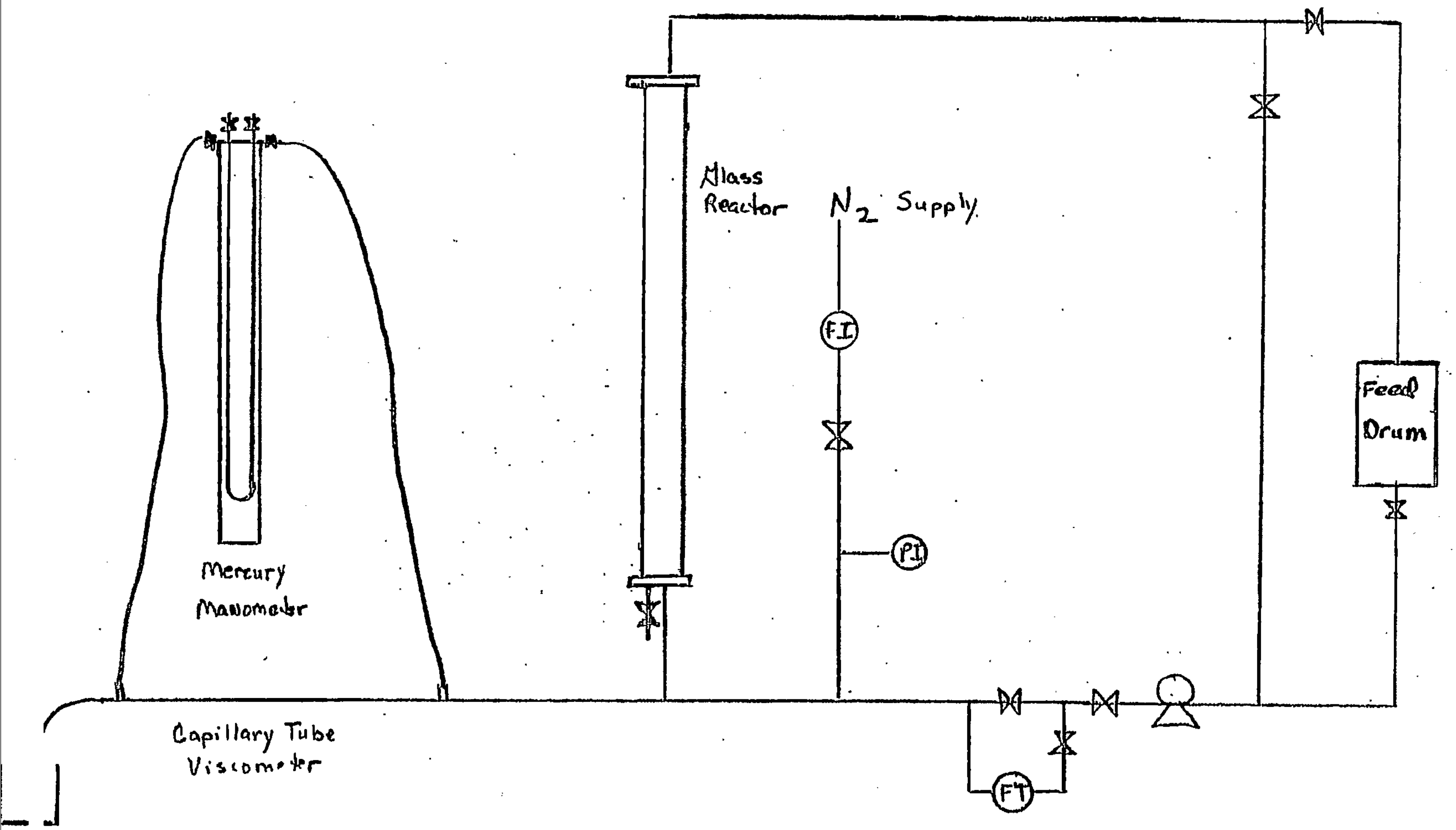


Figure 15

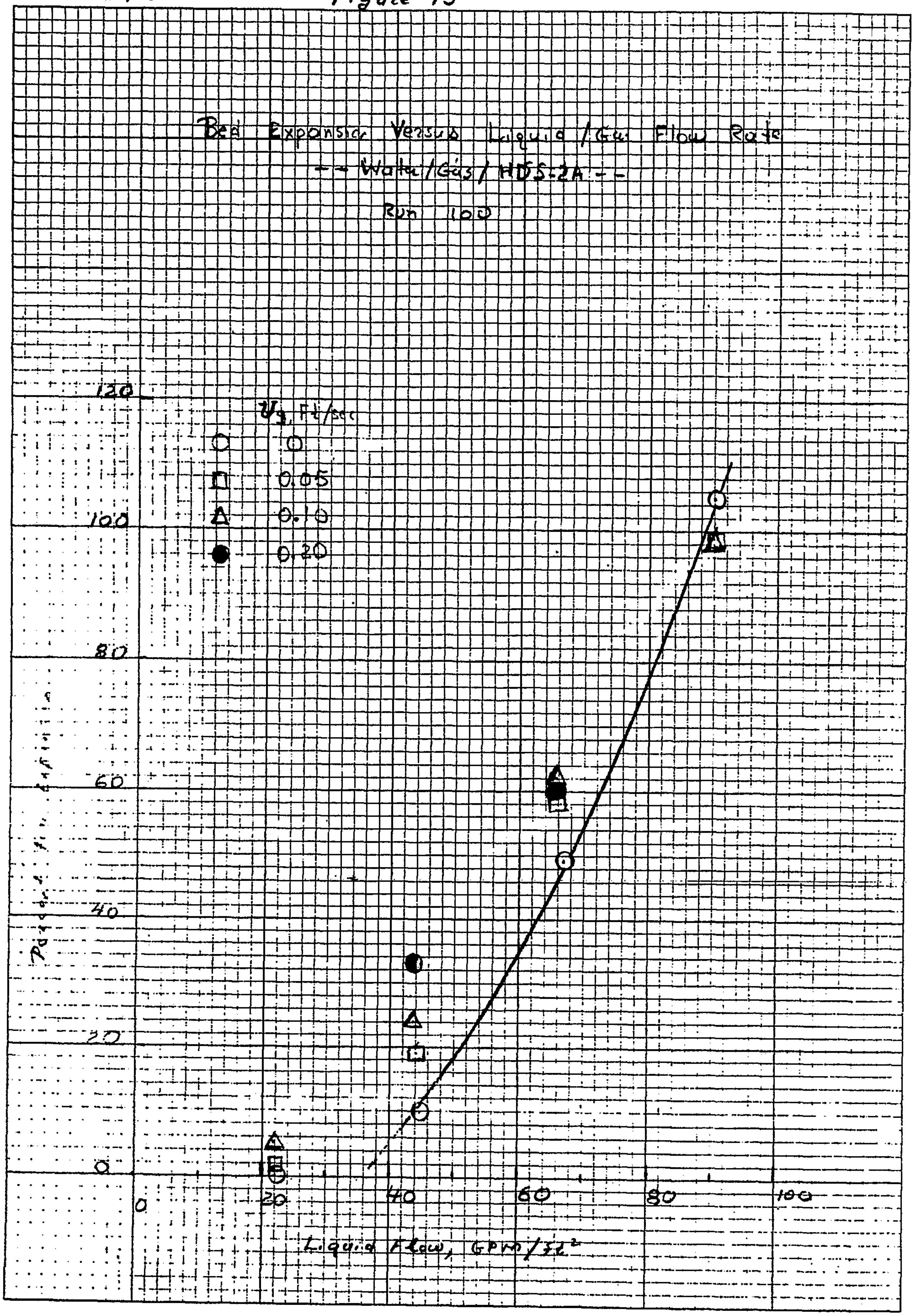
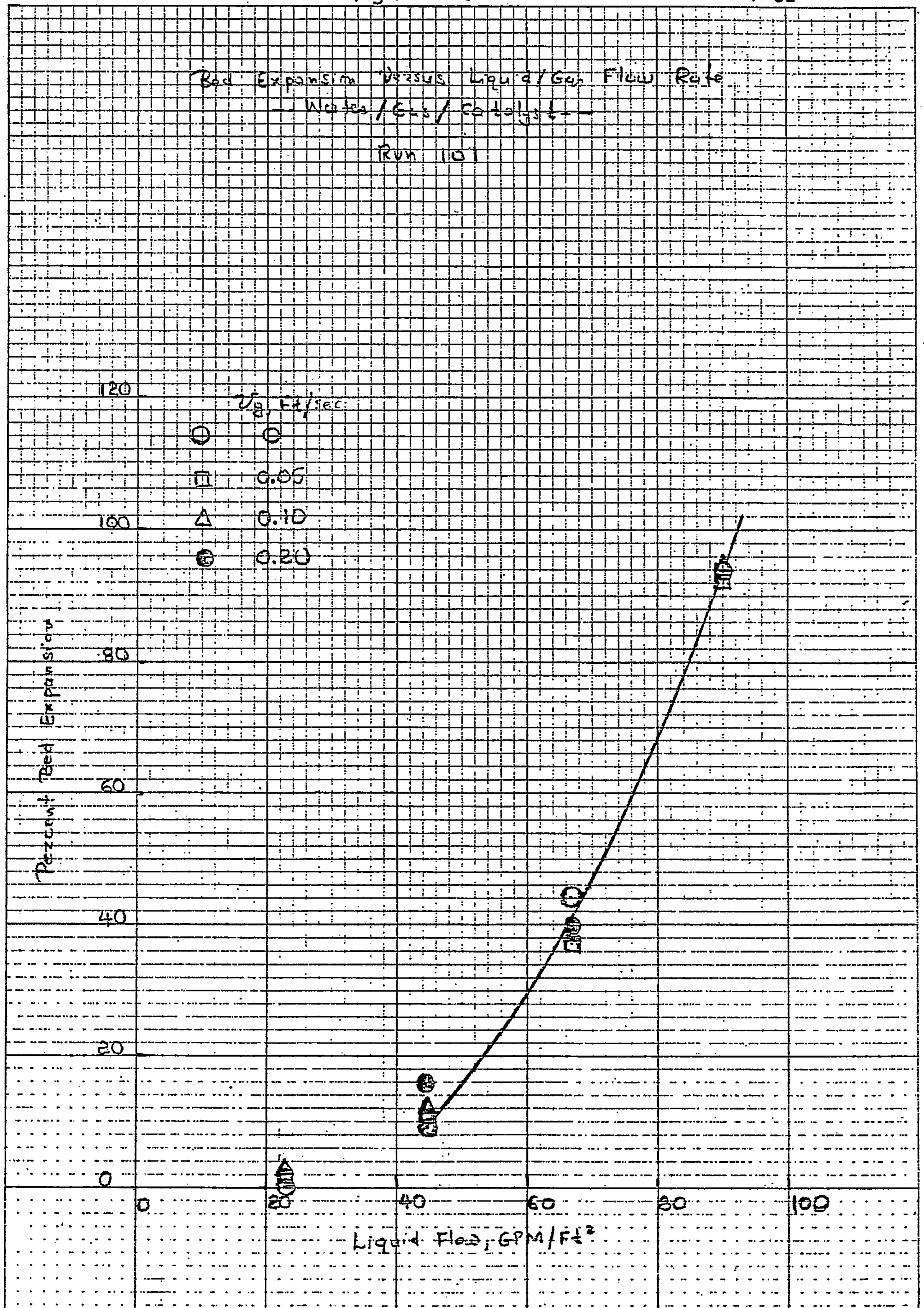

Bed Expansion Versus Liquid/Gas Flow Rate
-- Water/Gas/HDS-2A --
Run 10D
U_g, Ft/sec
0
0.05
0.10
0.20
120
100
80
60
40
20
0
0
20
40
60
80
100
Liquid Flow, GPM/Ft²

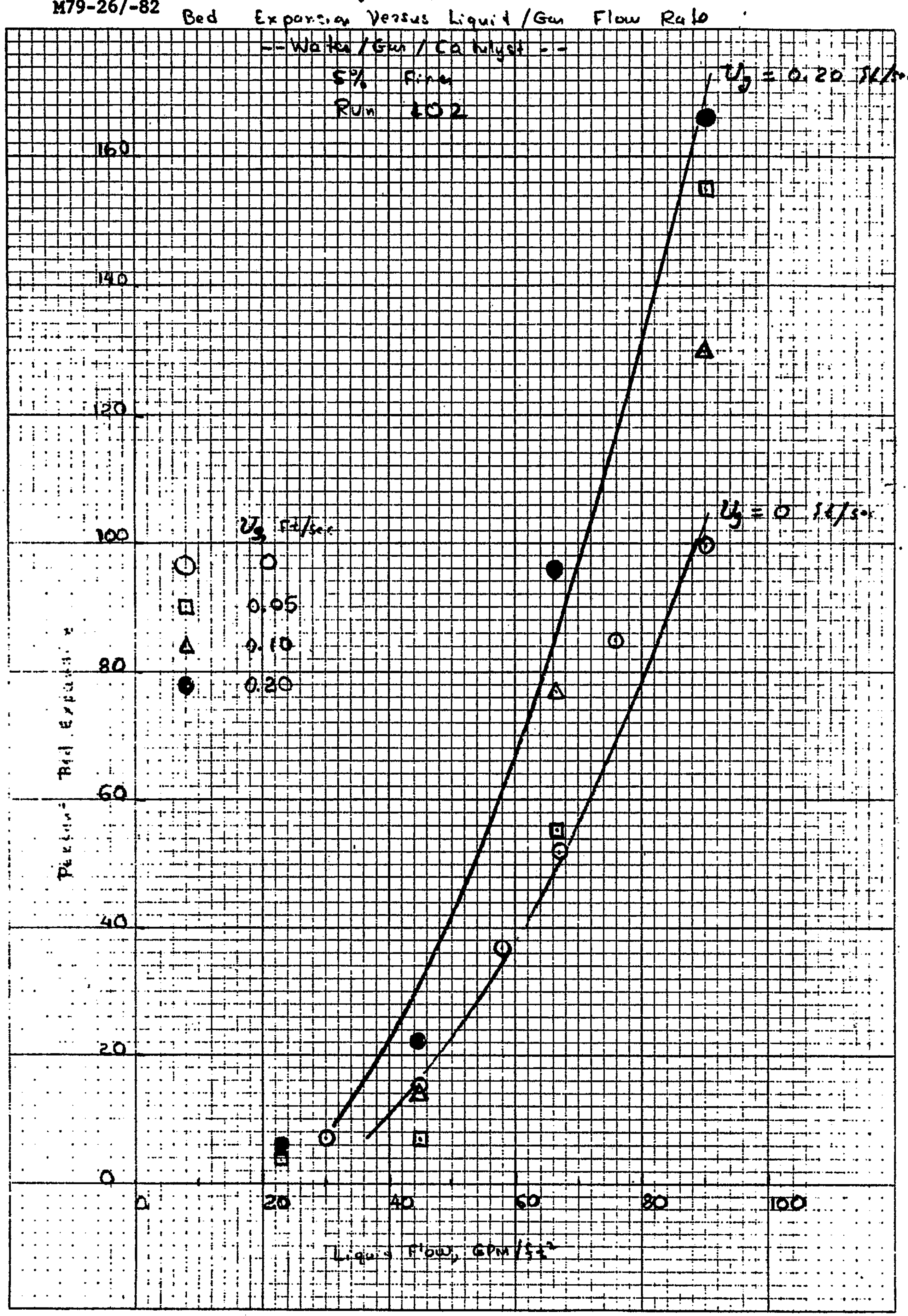
Figure 16



Bed Expansion Versus Liquid/Gas Flow Rate
— Water/Gas/Catalyst —
Run 101
v_g, Ft/sec
0
0.05
0.10
0.20
Percent Bed Expansion
0
20
40
60
80
100
120
Liquid Flow, GPM/Ft²
0
20
40
60
80
100

M79-26/-82

Figure 17



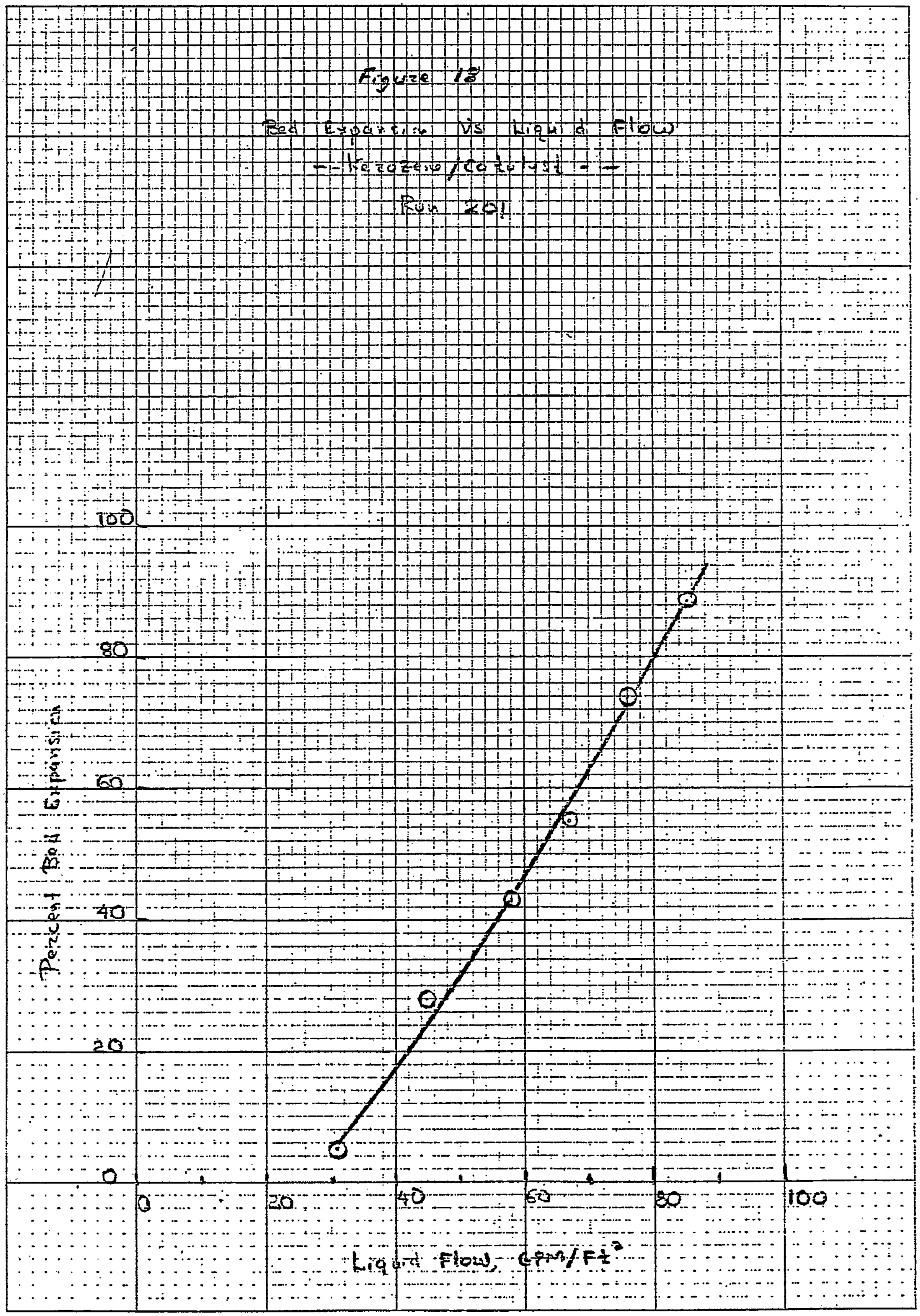
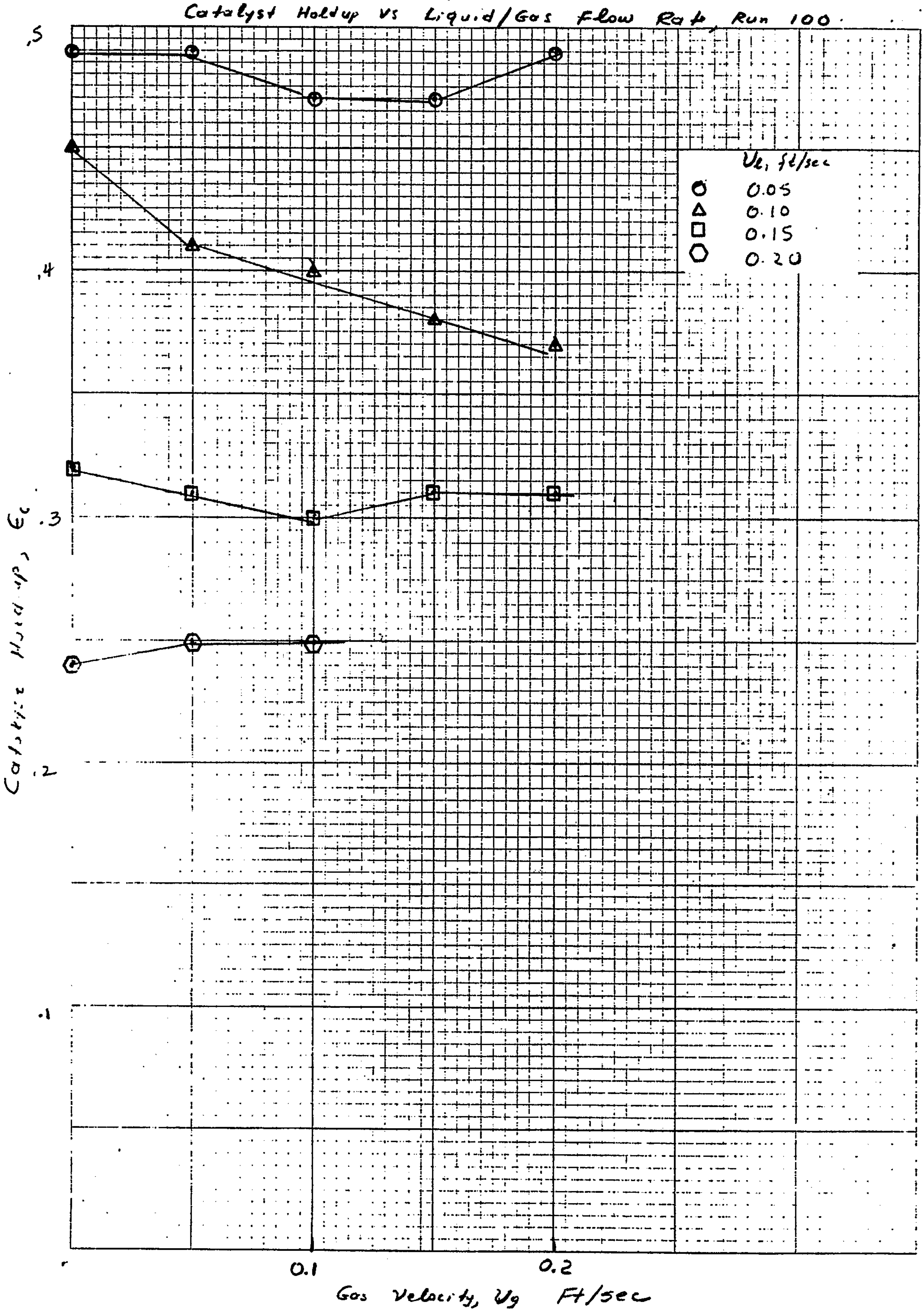


Figure 18
Bed Expansion Vs Liquid Flow
Kerosene/Catalyst
Run 201
Percent Bed Expansion
0
20
40
60
80
100
0
20
40
60
80
100
Liquid Flow, GPM/Ft²

M79-26/-84

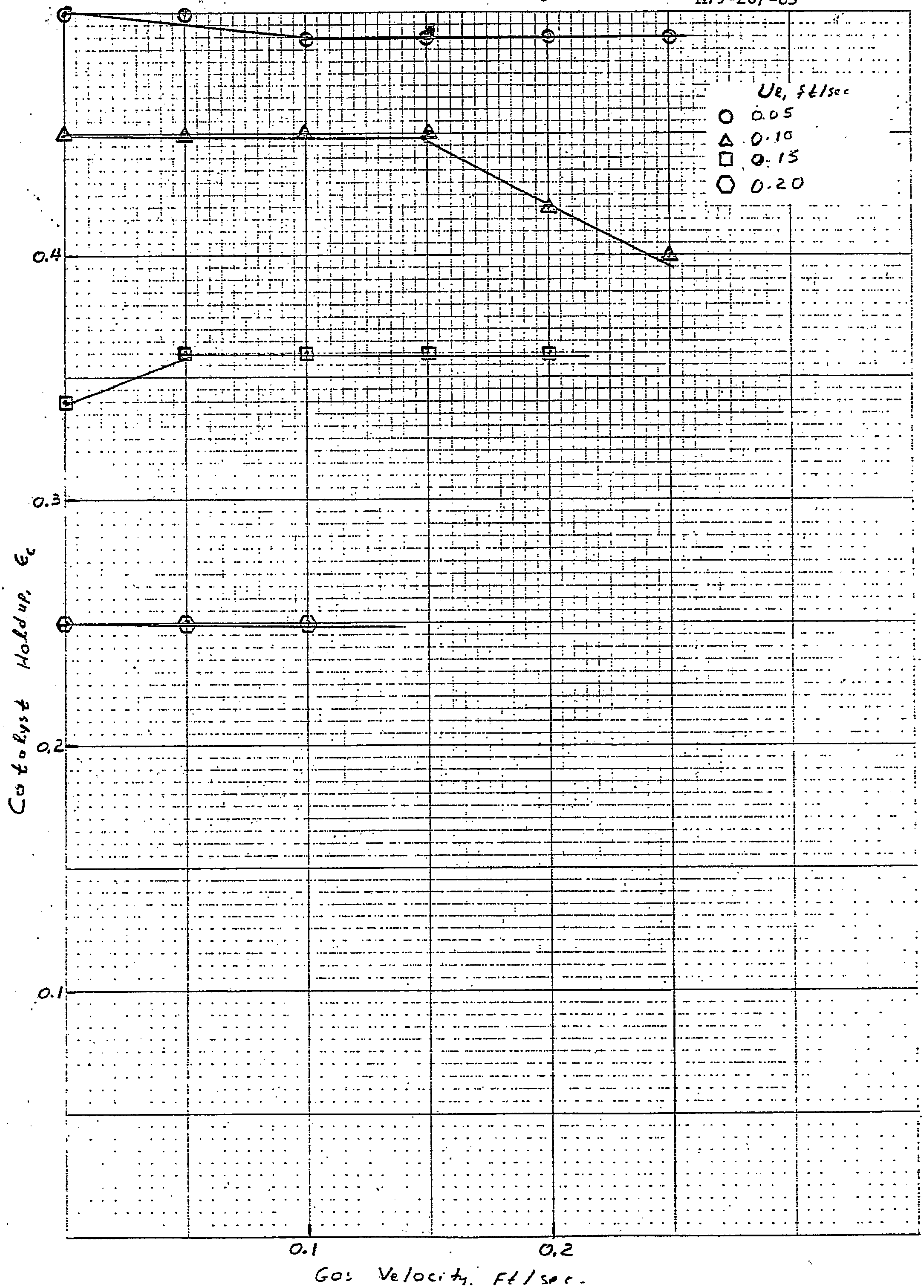


Catalyst Holdup vs Liquid/Gas Flow Rate, Run 100
U_L, ft/sec
0.05
0.10
0.15
0.20
.5
.4
.3
.2
.1
0.1
0.2
Catalyst Holdup, ϵ_c
Gas Velocity, U_g Ft/sec

Figure 20

Catalyst Holdup VS. Gas/Liquid

M79-26/-85



M79-26/-86

Figure 21

Catalyst Holdup vs. Gas/Liquid Flow Rate, Run 102.

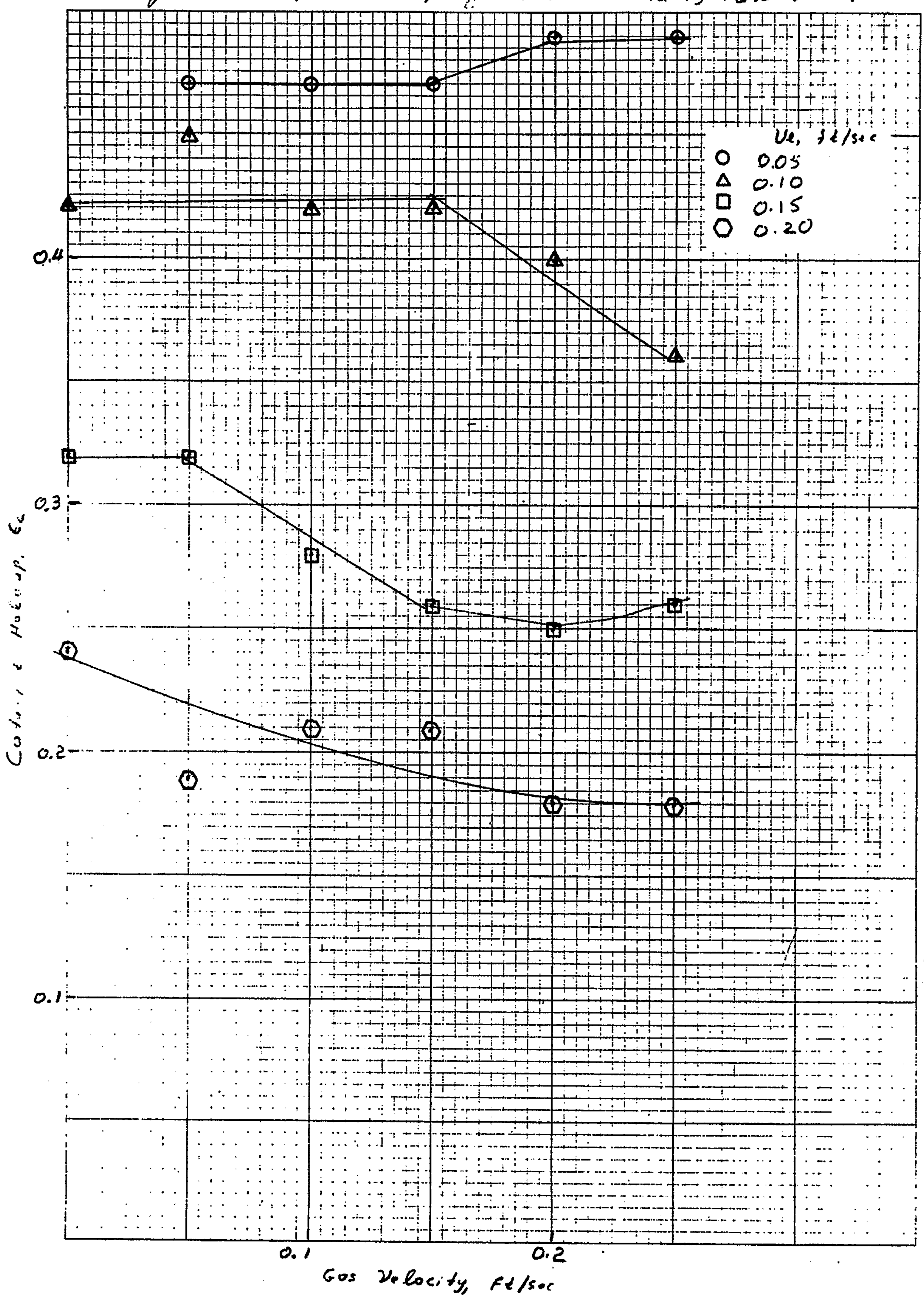


Figure 22

METHODS FOR DETERMINING THE RICHARDSON-ZAKI INDEX

Spherical Particles:

$n = 4.65 + 20\ d/D$	$Re_t < 0.2$
$n = (4.4 + 18\ d/D)Re_t^{-0.03}$	$0.2 < Re_t < 1.0$
$n = (4.4 + 18\ d/D)Re_t^{-0.1}$	$1 < Re_t < 200$
$n = 4.4\ Re_t^{-0.1}$	$200 < Re_t < 500$
$n = 2.4$	$Re_t > 500$

Cylinders/Plates:

$n = 2.7K^{0.16}$	$Re_t > 500$
$K = \pi/6\ d_s^3/d_p^3$	

Figure 23

BED VOIDAGE VS. SUPERFICIAL LIQUID VELOCITY:
RUNS 100, 101, 102, 201

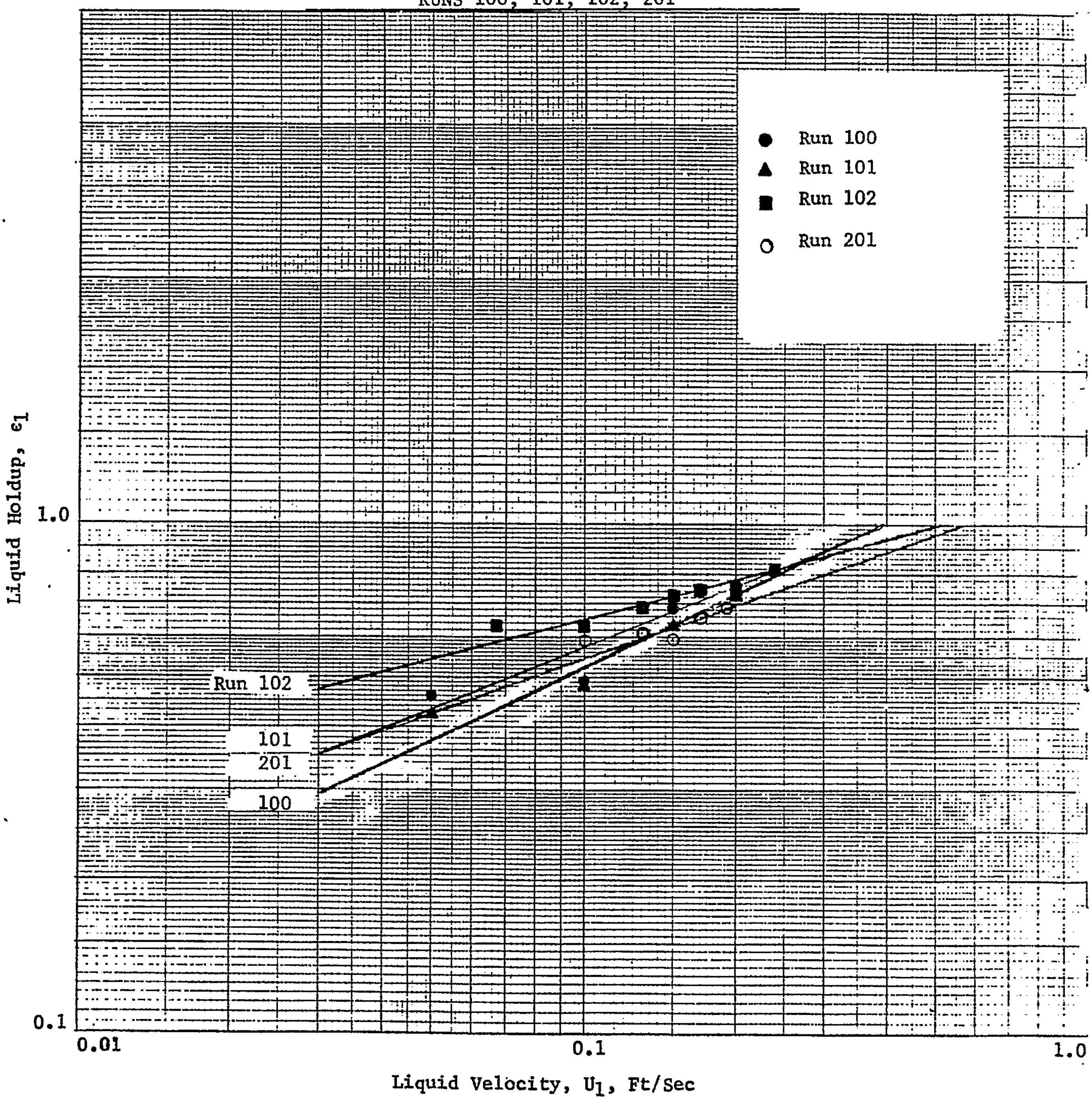
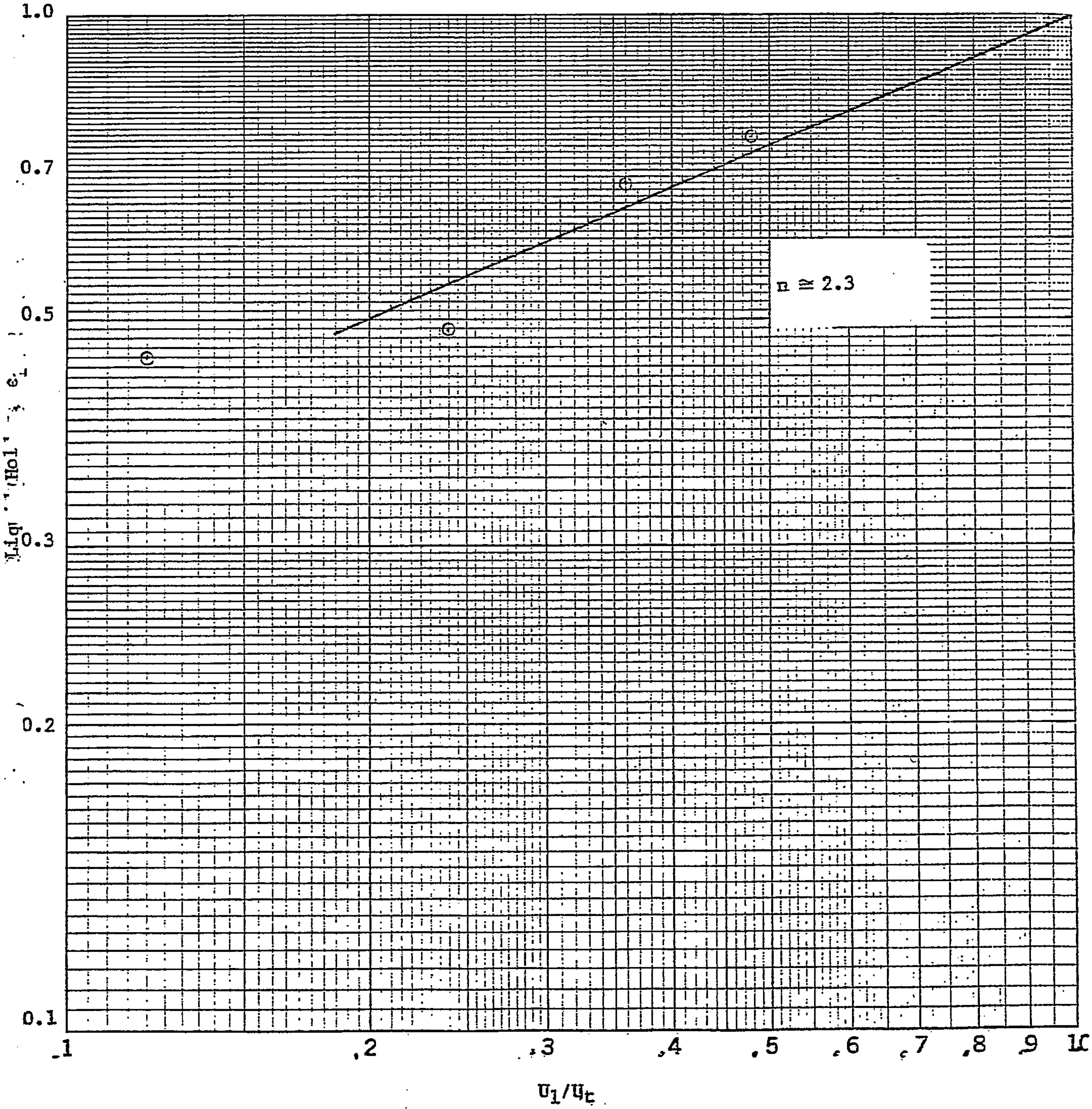


Figure 24

BED VOIDAGE VS. U_l/U_t, RUN 100



M79-26
-90

Figure 25

BED VOIDAGE VS. U_1/U_t, RUN 101

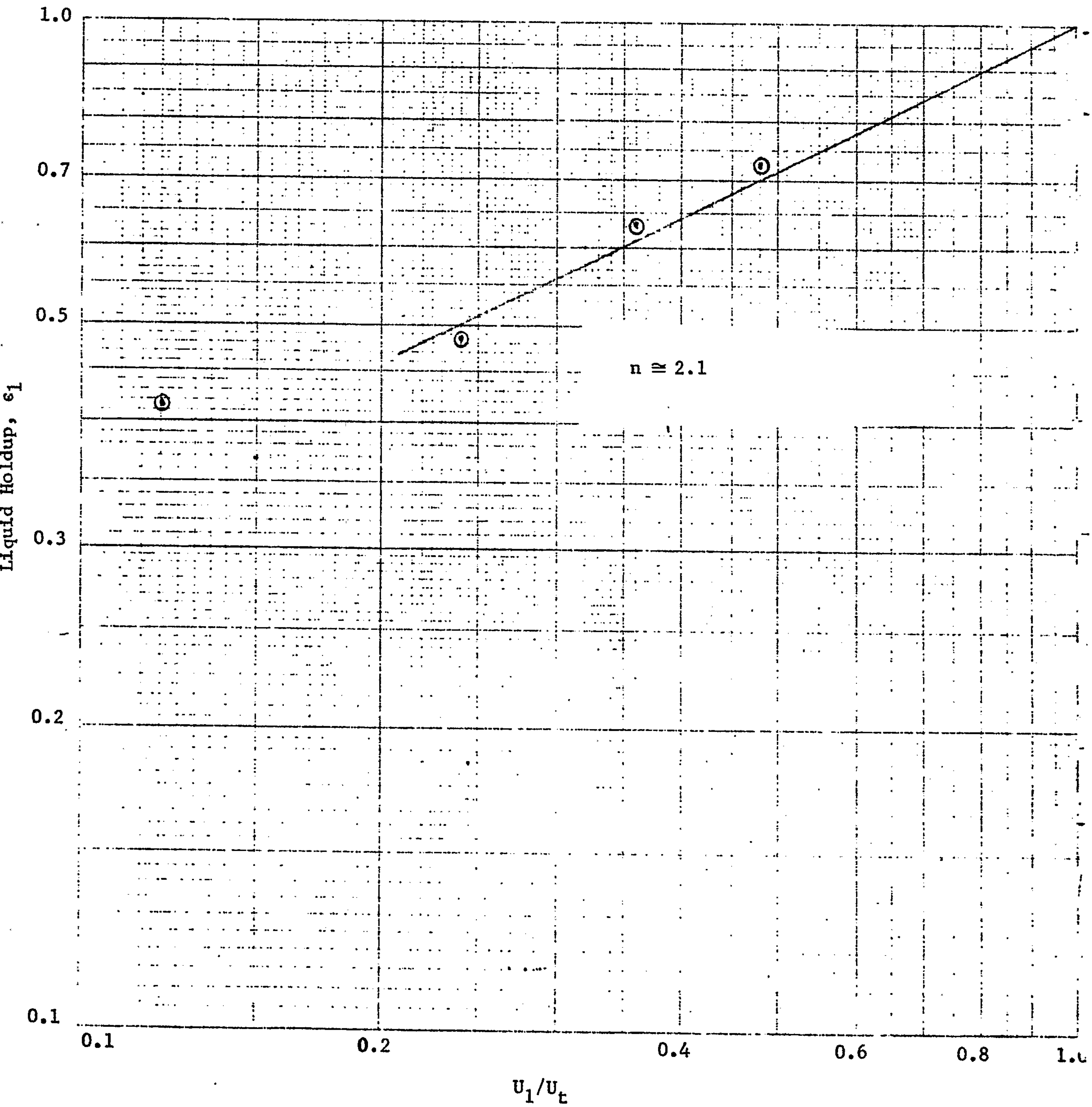
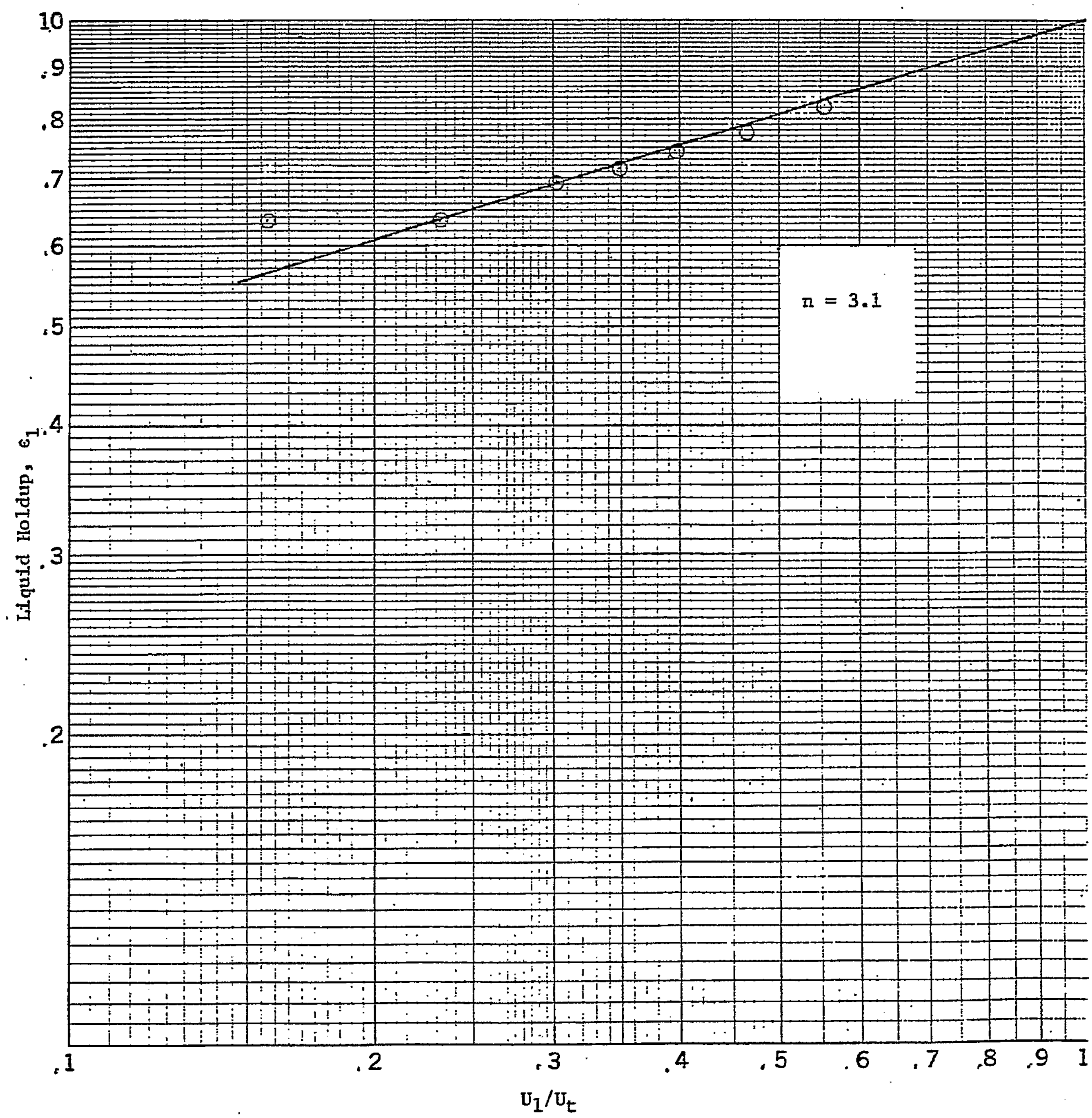


Figure 26

BED VOIDAGE VS. U_1/U_t, RUN 102



M79-26
-92

Figure 27

BED VOIDAGE VS. U_l/U_t, RUN 201

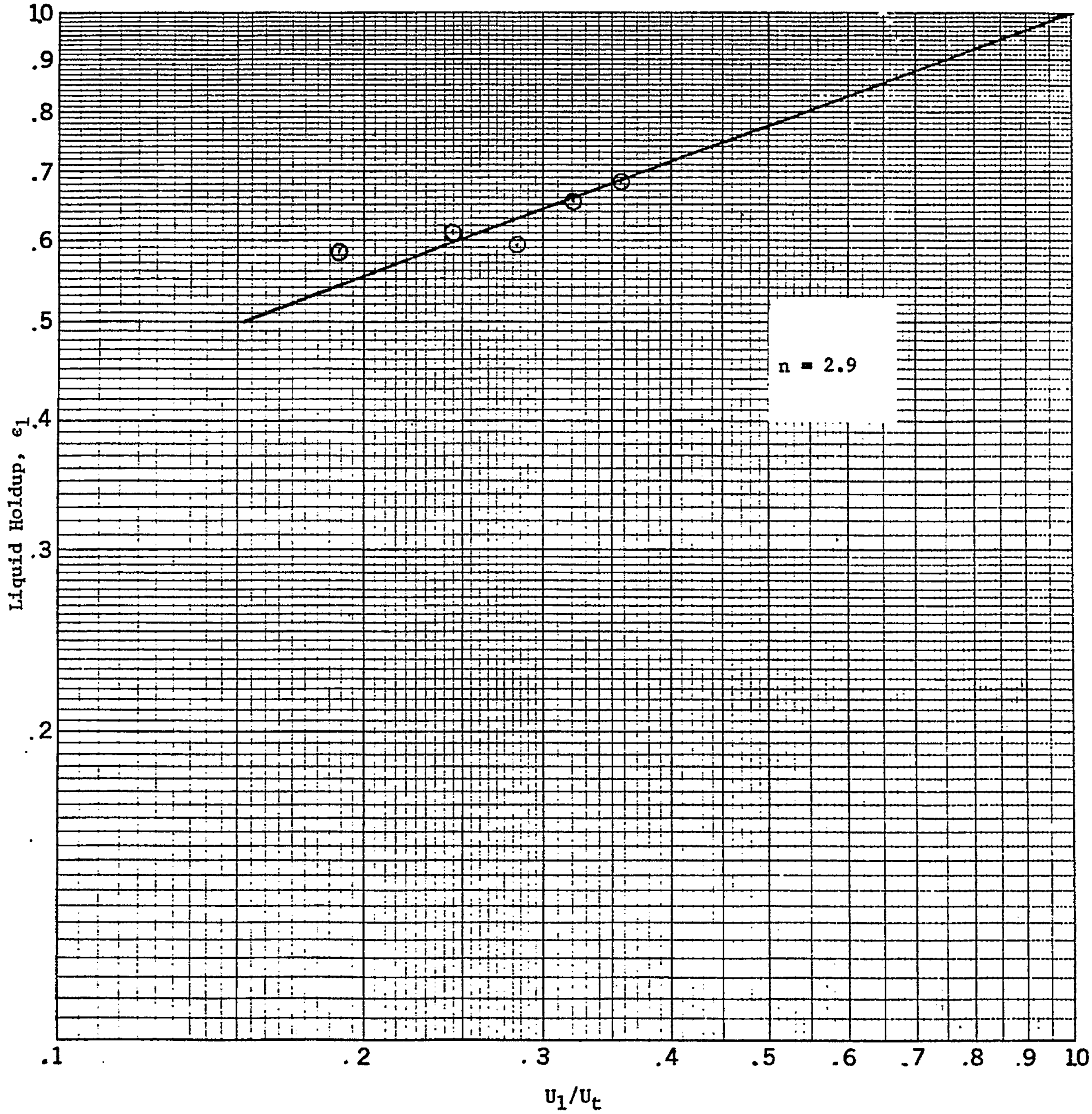


Figure 28

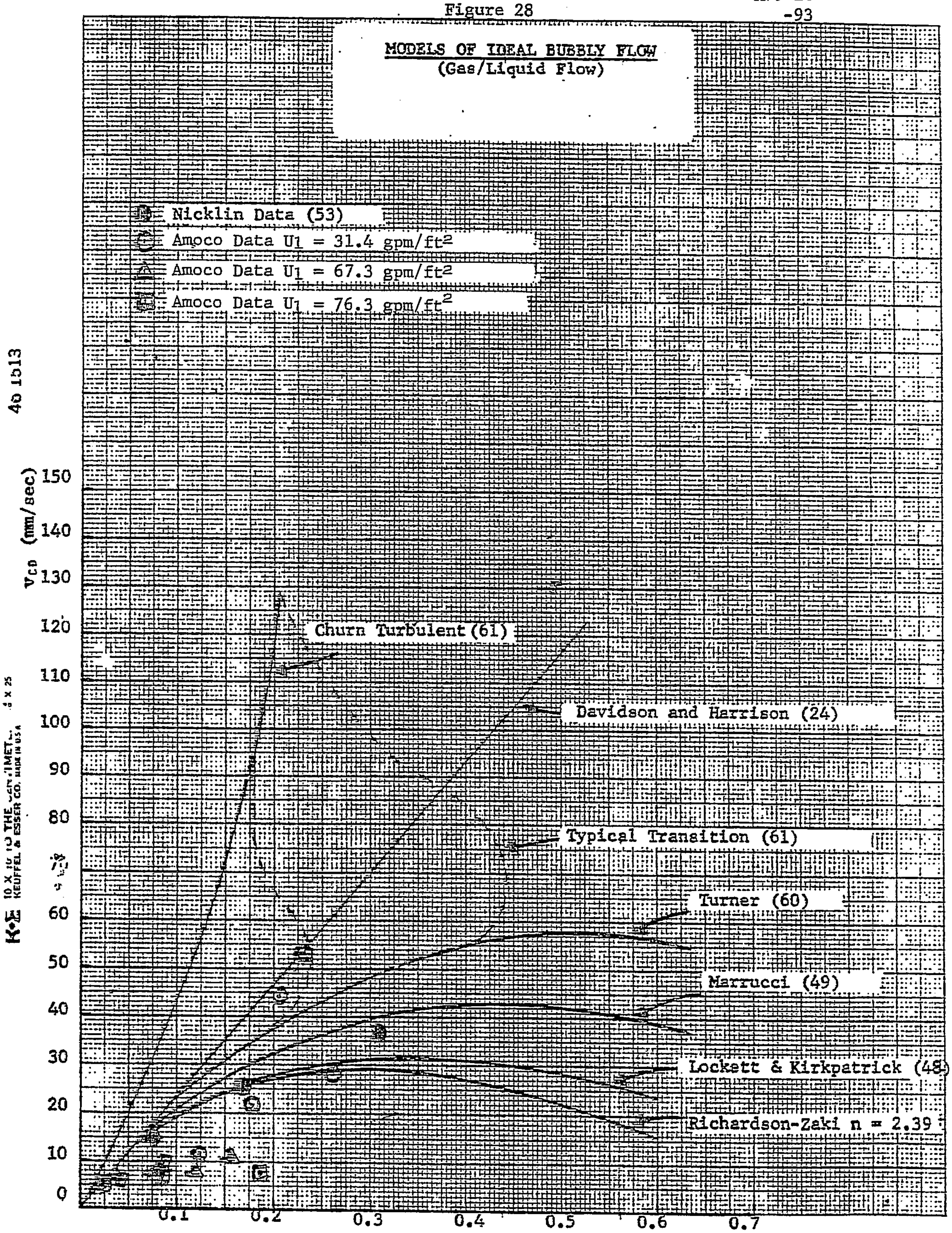

MODELS OF IDEAL BUBBLY FLOW
(Gas/Liquid Flow)
Nicklin Data (53)
Amoco Data U1 = 31.4 gpm/ft2
Amoco Data U1 = 67.3 gpm/ft2
Amoco Data U1 = 76.3 gpm/ft2
Churn Turbulent (61)
Davidson and Harrison (24)
Typical Transition (61)
Turner (60)
Marrucci (49)
Lockett & Kirkpatrick (48)
Richardson-Zaki n = 2.39
vCD (mm/sec)
150
140
130
120
110
100
90
80
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
K+E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN USA
46 1513

Figure 29

DRIFT FLUX VS. GAS HOLDUP, RUN 100

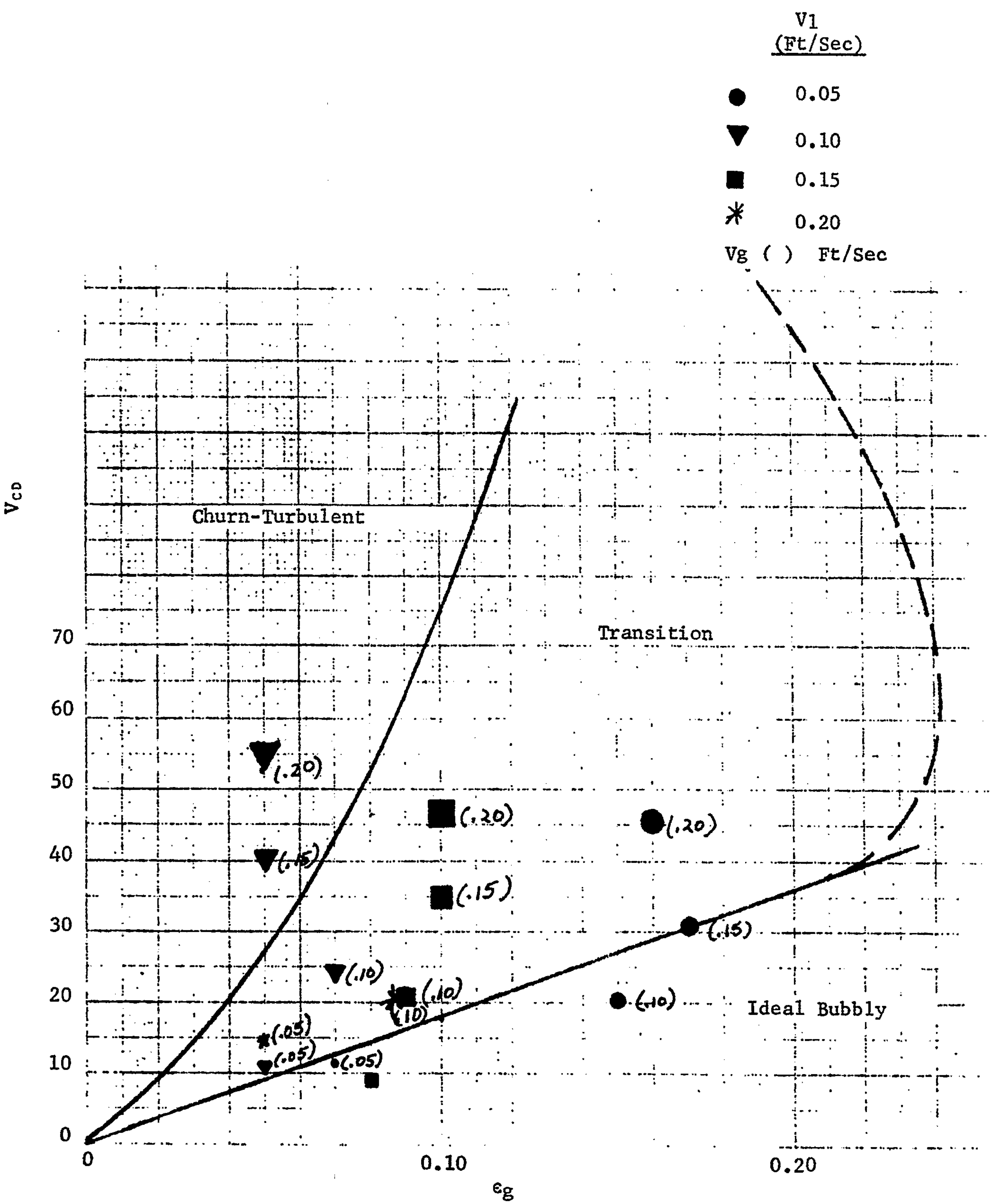


Figure 30

DRIFT FLUX VS. GAS HOLDUP, RUN 101

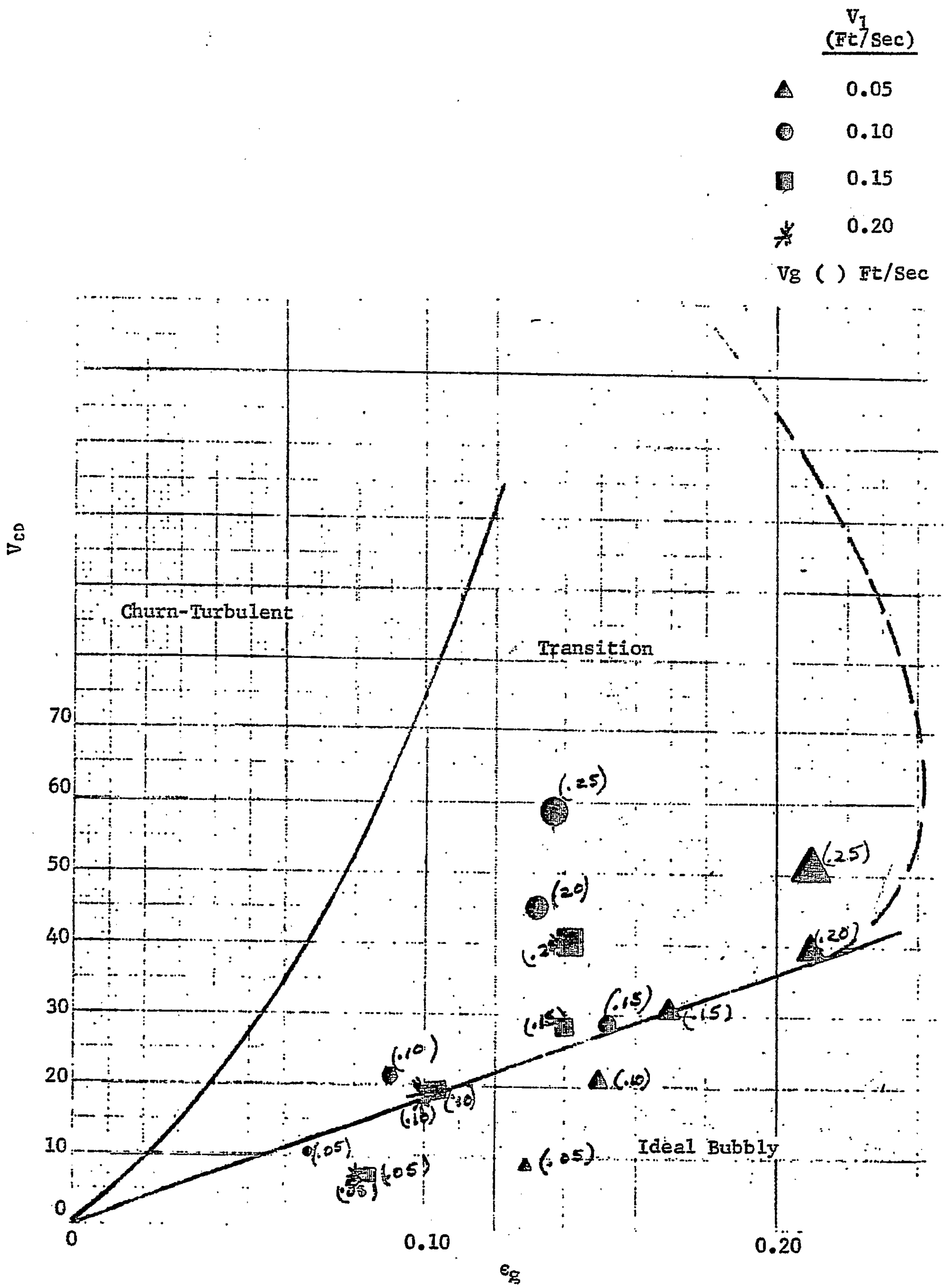
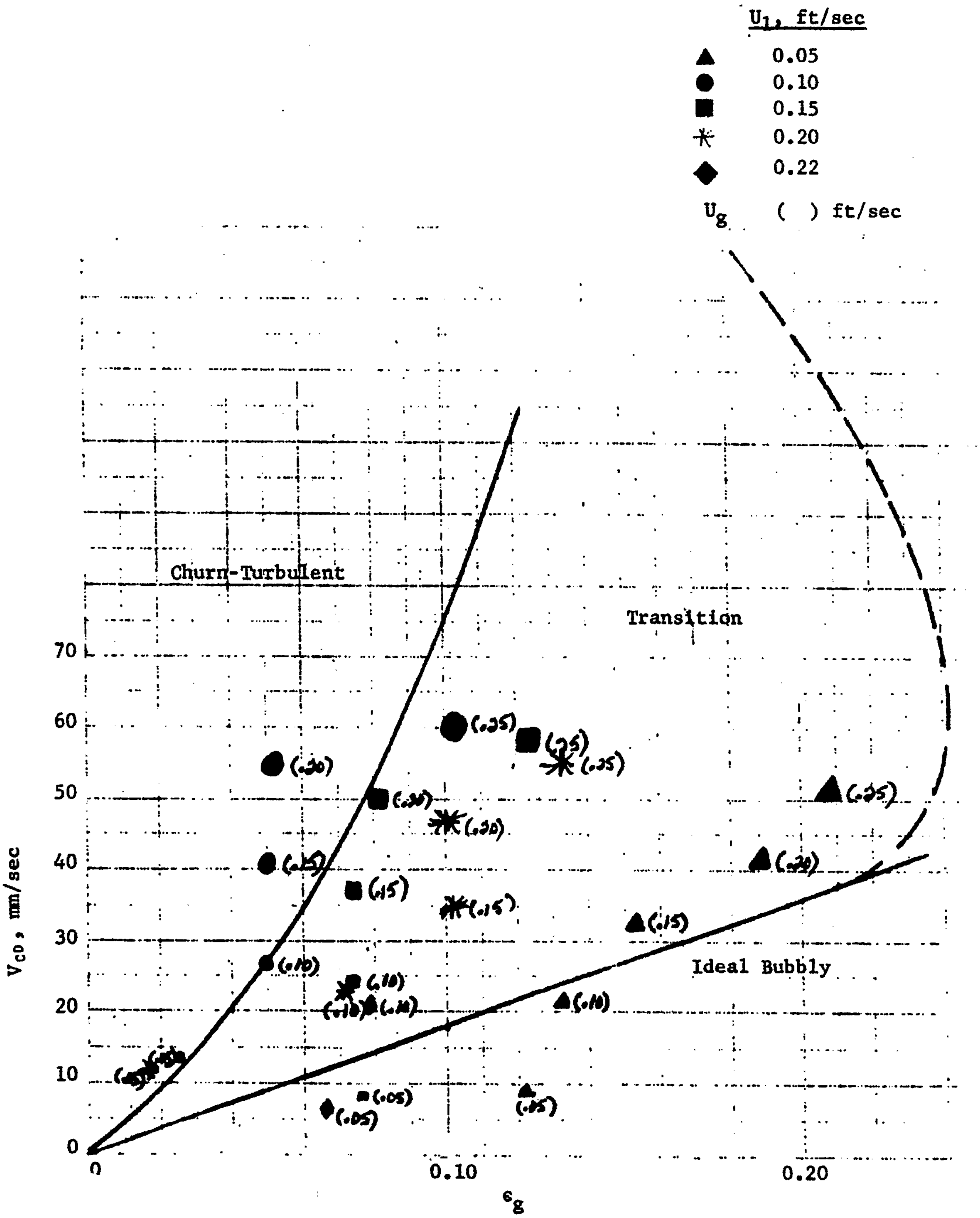


Figure 31

DRIFT FLUX VS. GAS HOLDUP: RUN 102



M79-26
-97

Figure 32

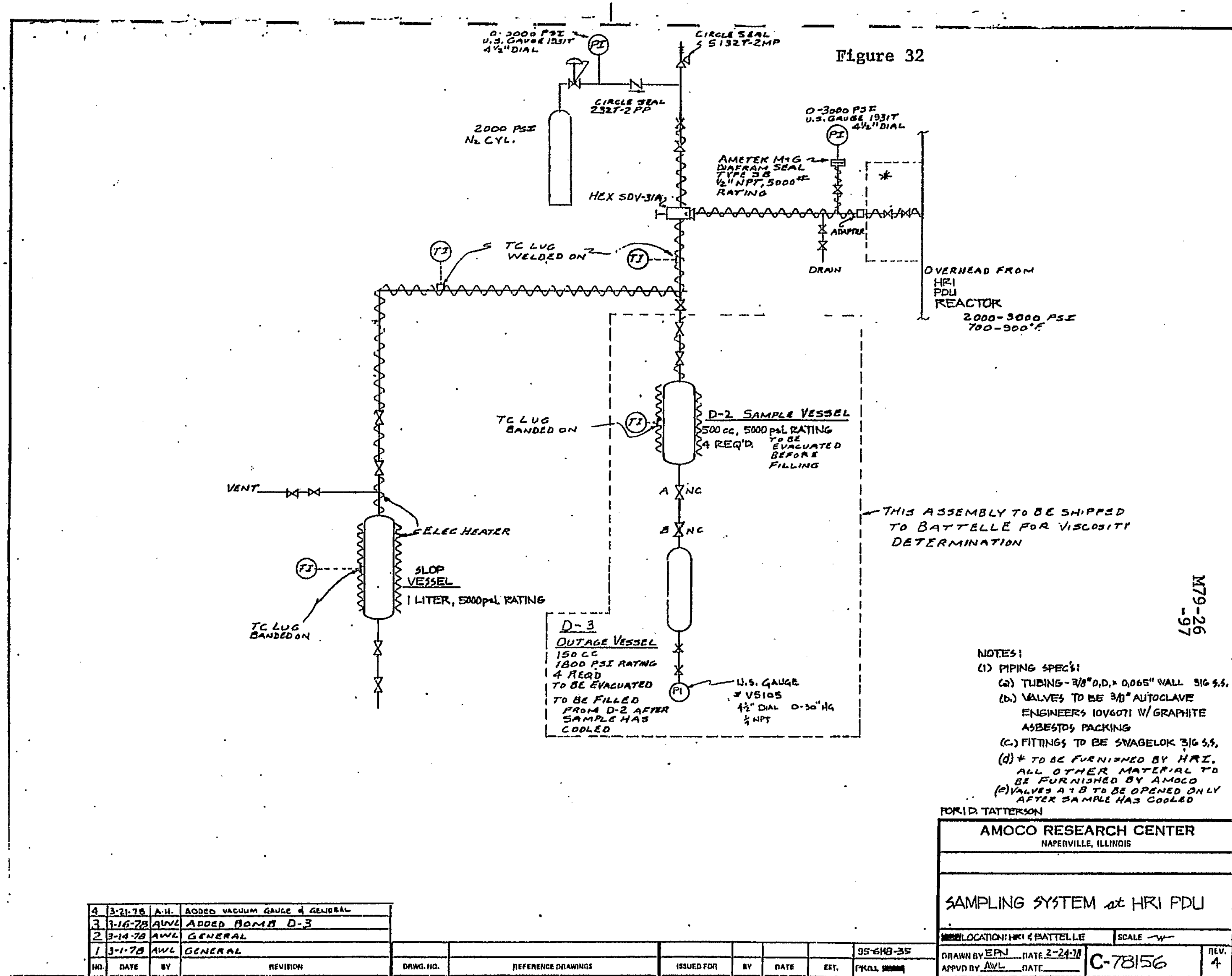
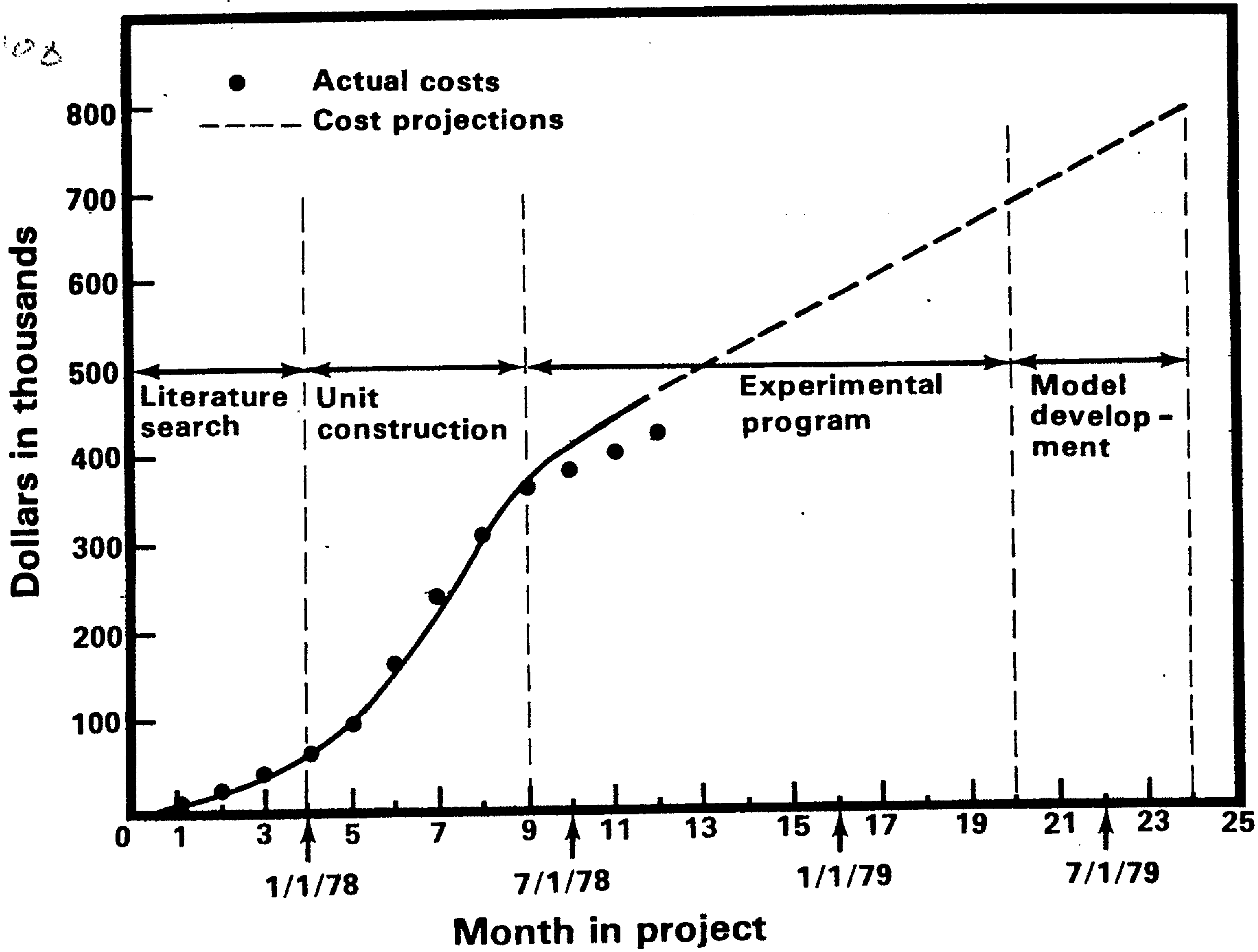


Figure 33

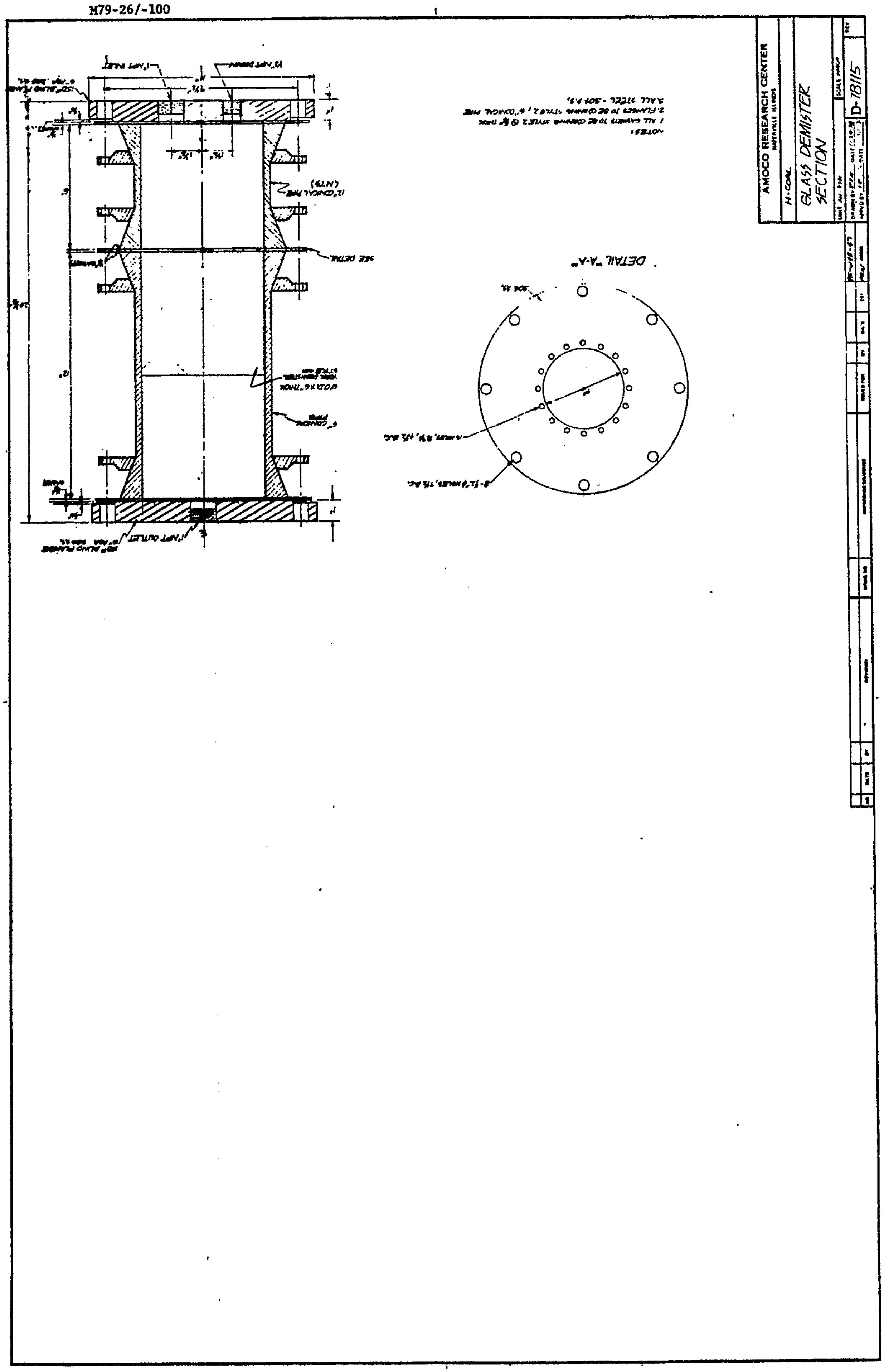
Cost projections



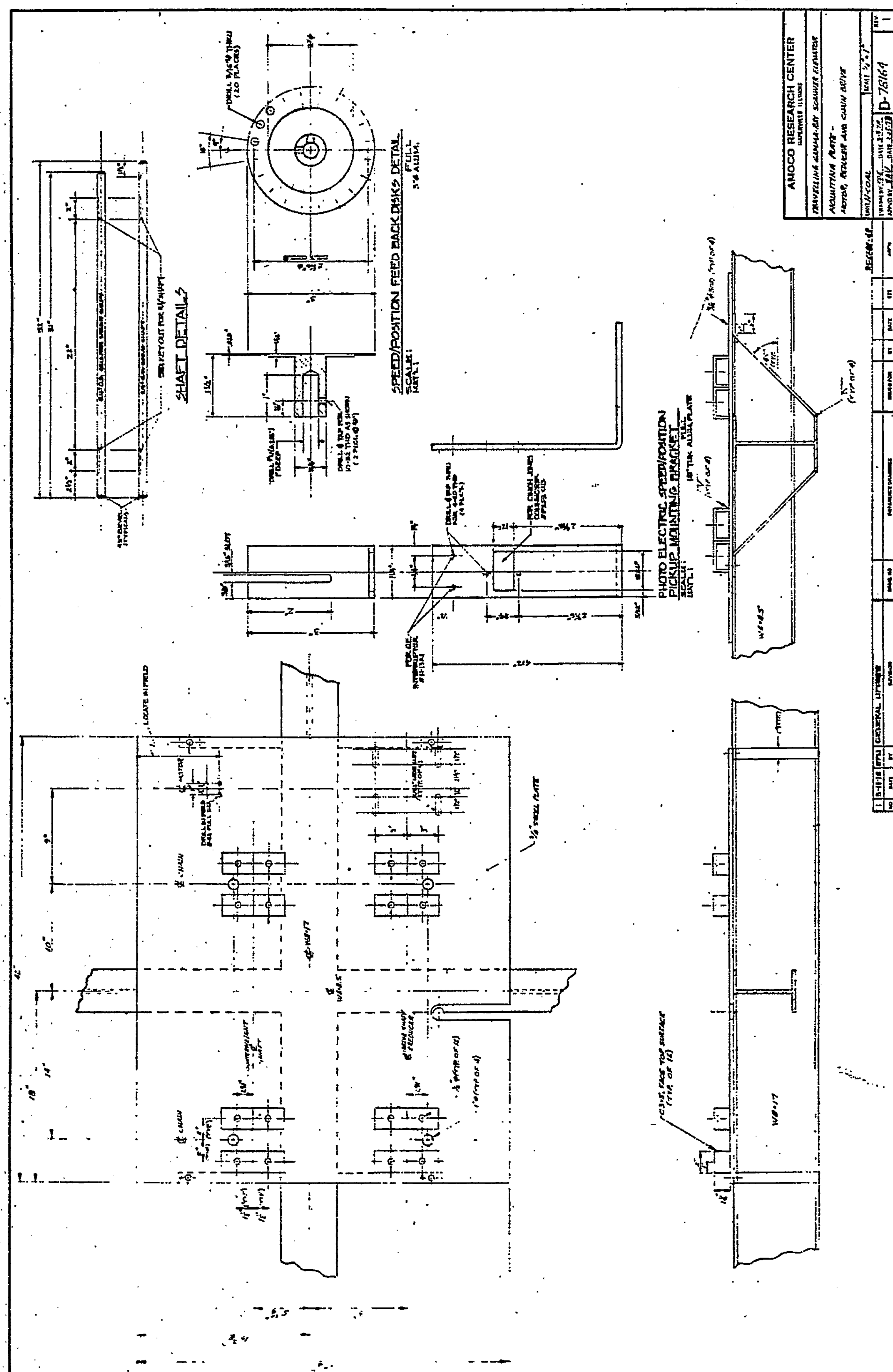
APPENDIX A

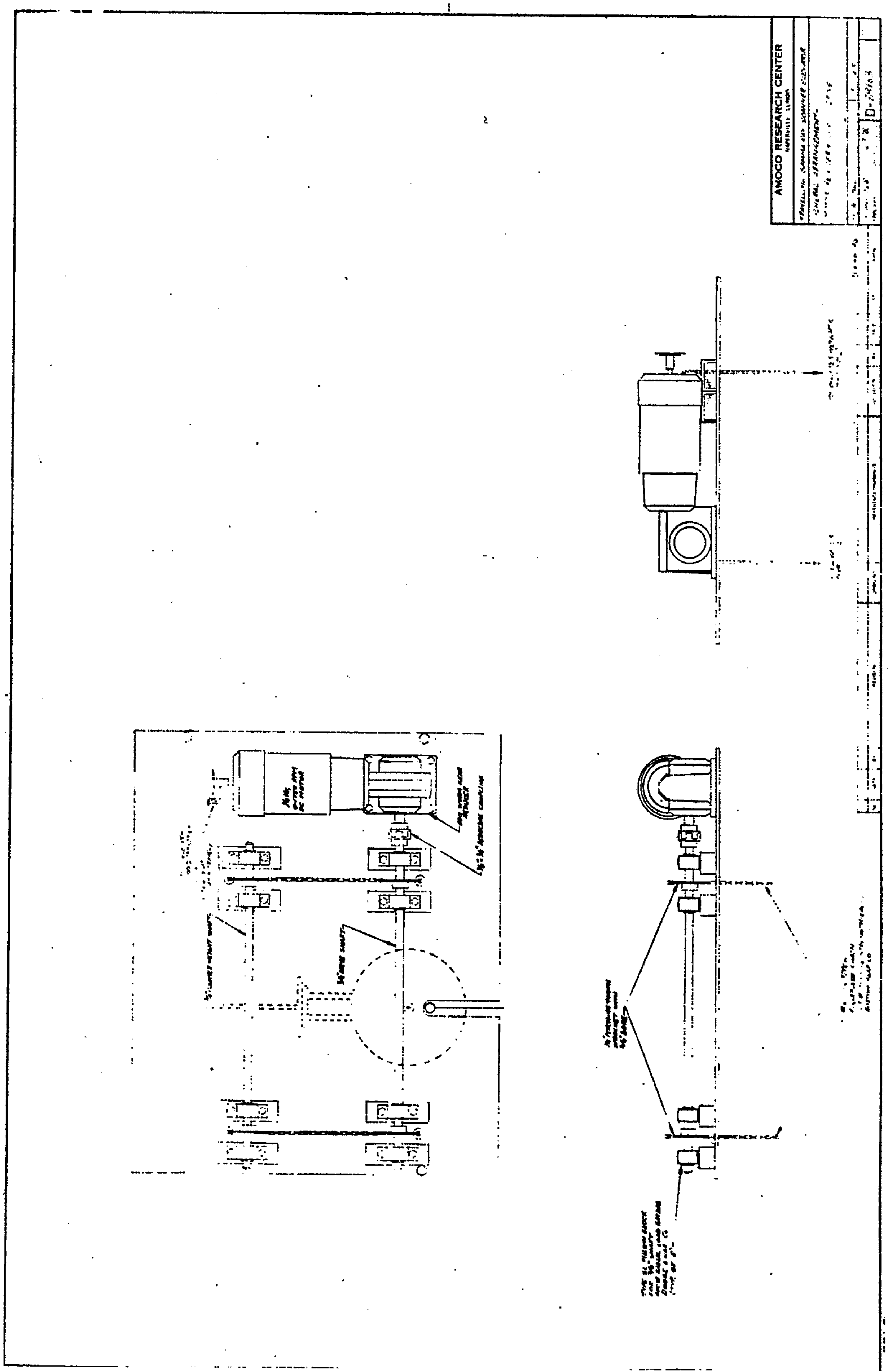
MECHANICAL DESIGN DRAWINGS

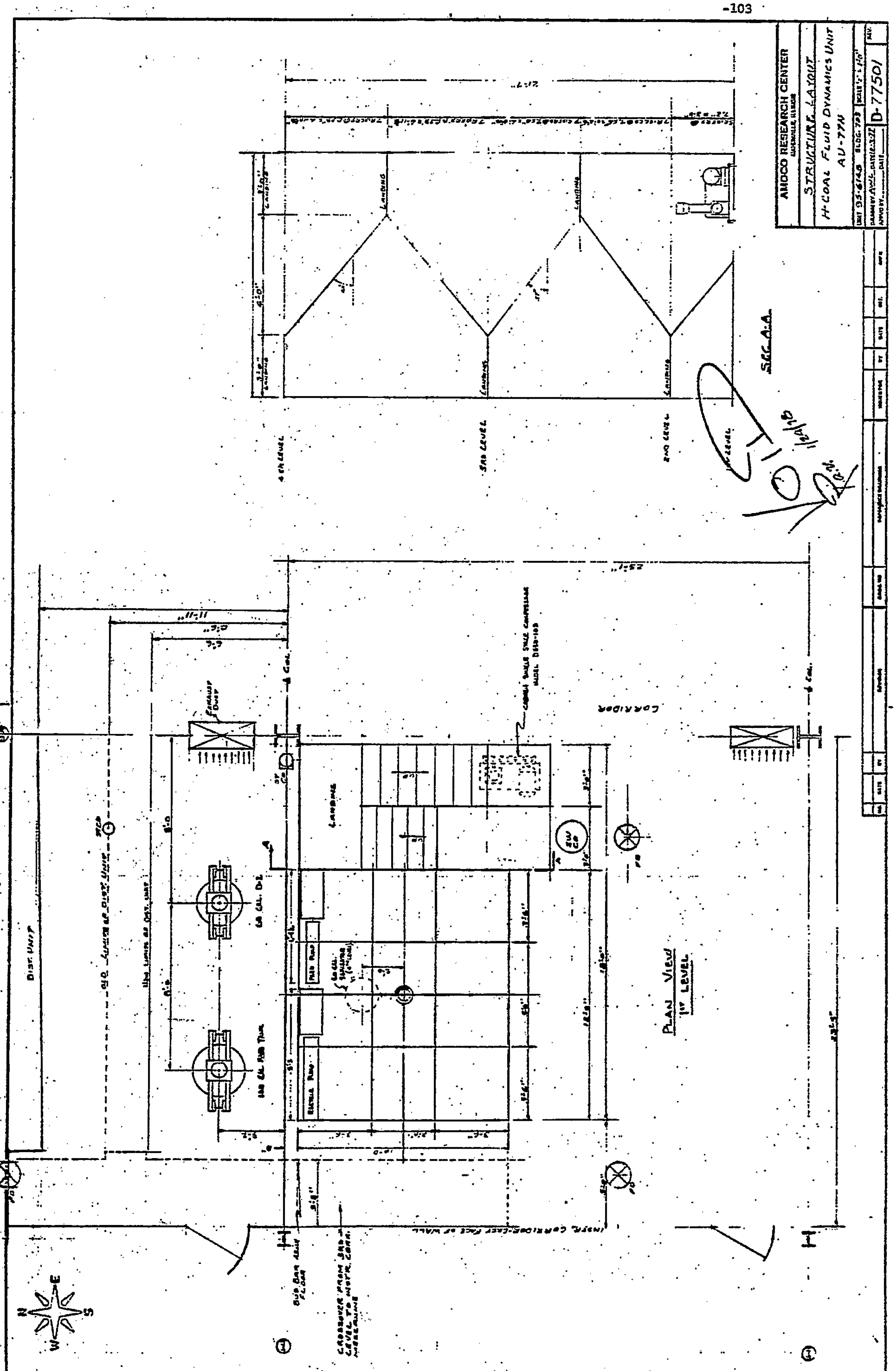
M79-26/-100



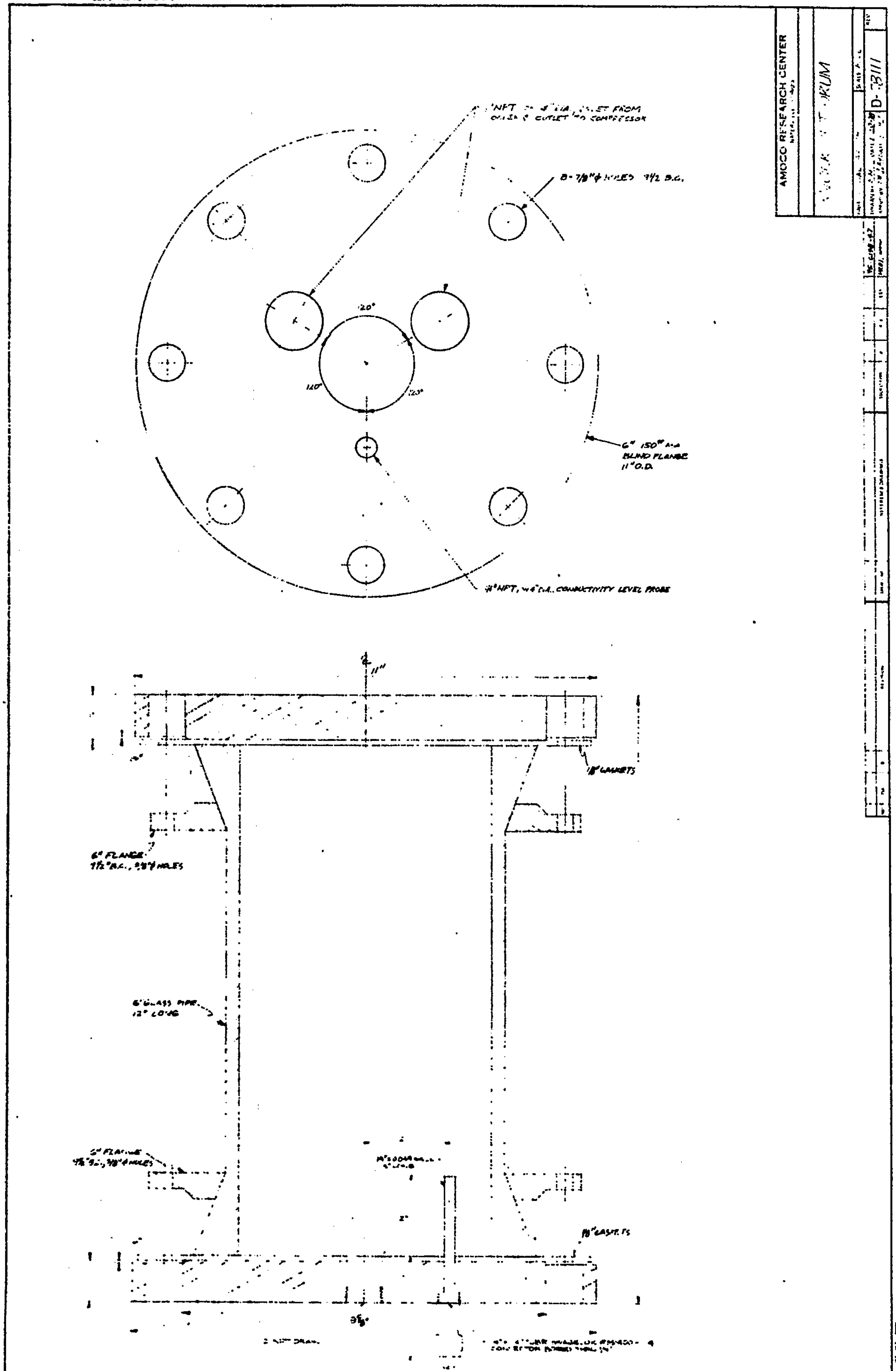
AMOCO RESEARCH CENTER
NAPERVILLE ILLINOIS
H-COAL
GLASS DEMISTER SECTION
D-78115
DETAIL "A-A"

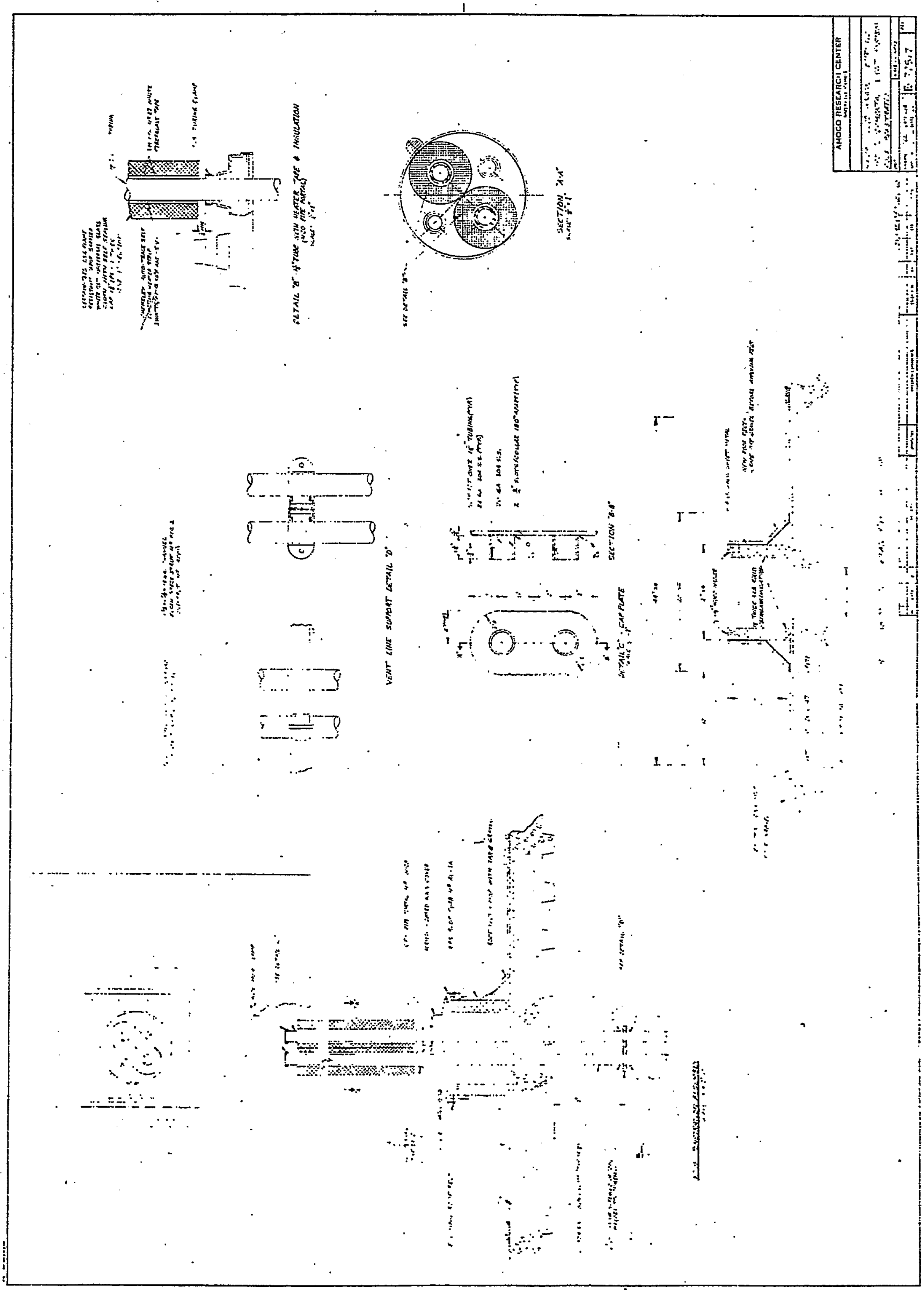

AMOCO RESEARCH CENTER
SHAFT DETAILS
SPEED/POSITION FEED BACK DISKS DETAIL
PHOTO ELECTRIC SPEED/POSITION PICKUP MOUNTING BRACKET
D-78164

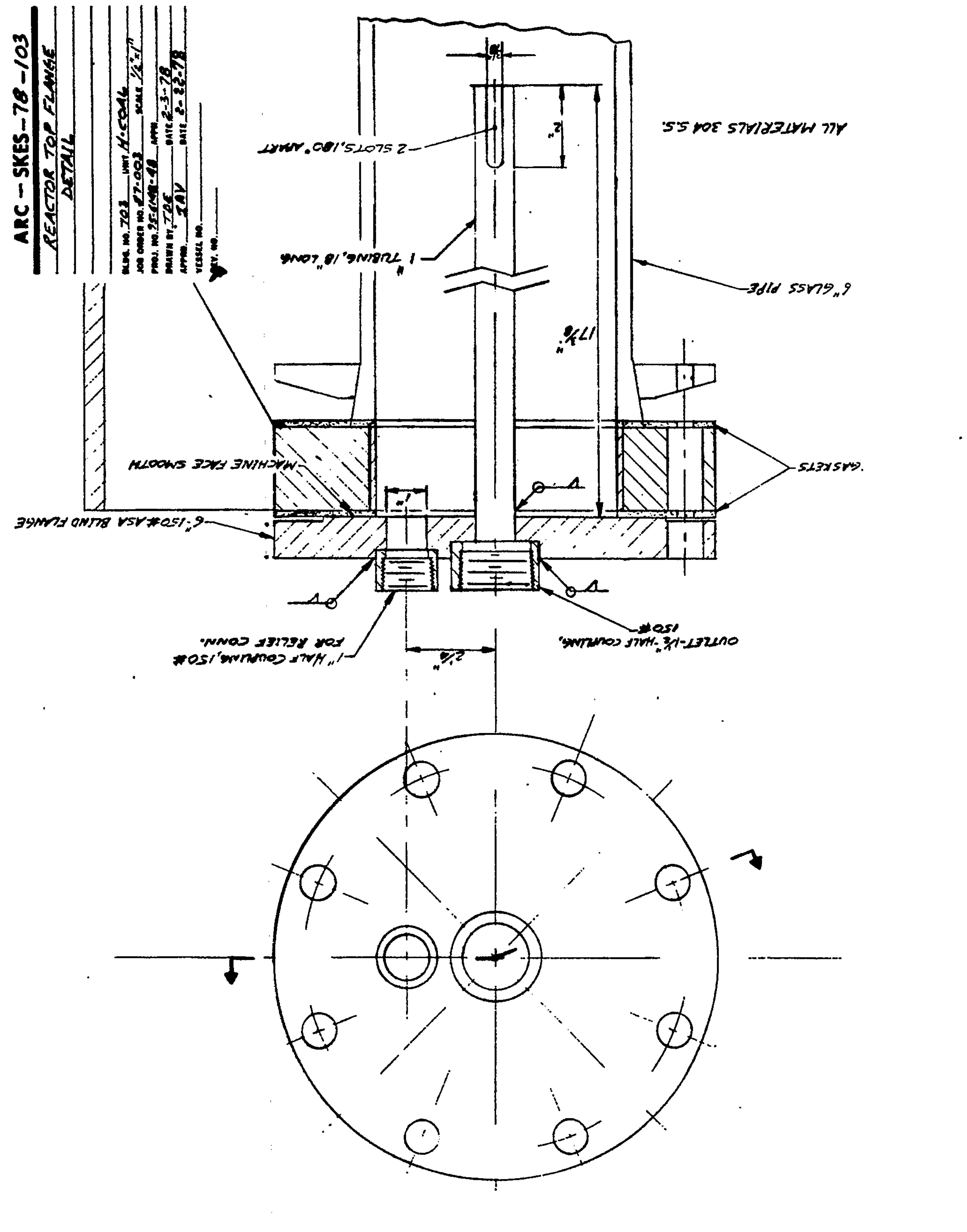

AMOCO RESEARCH CENTER

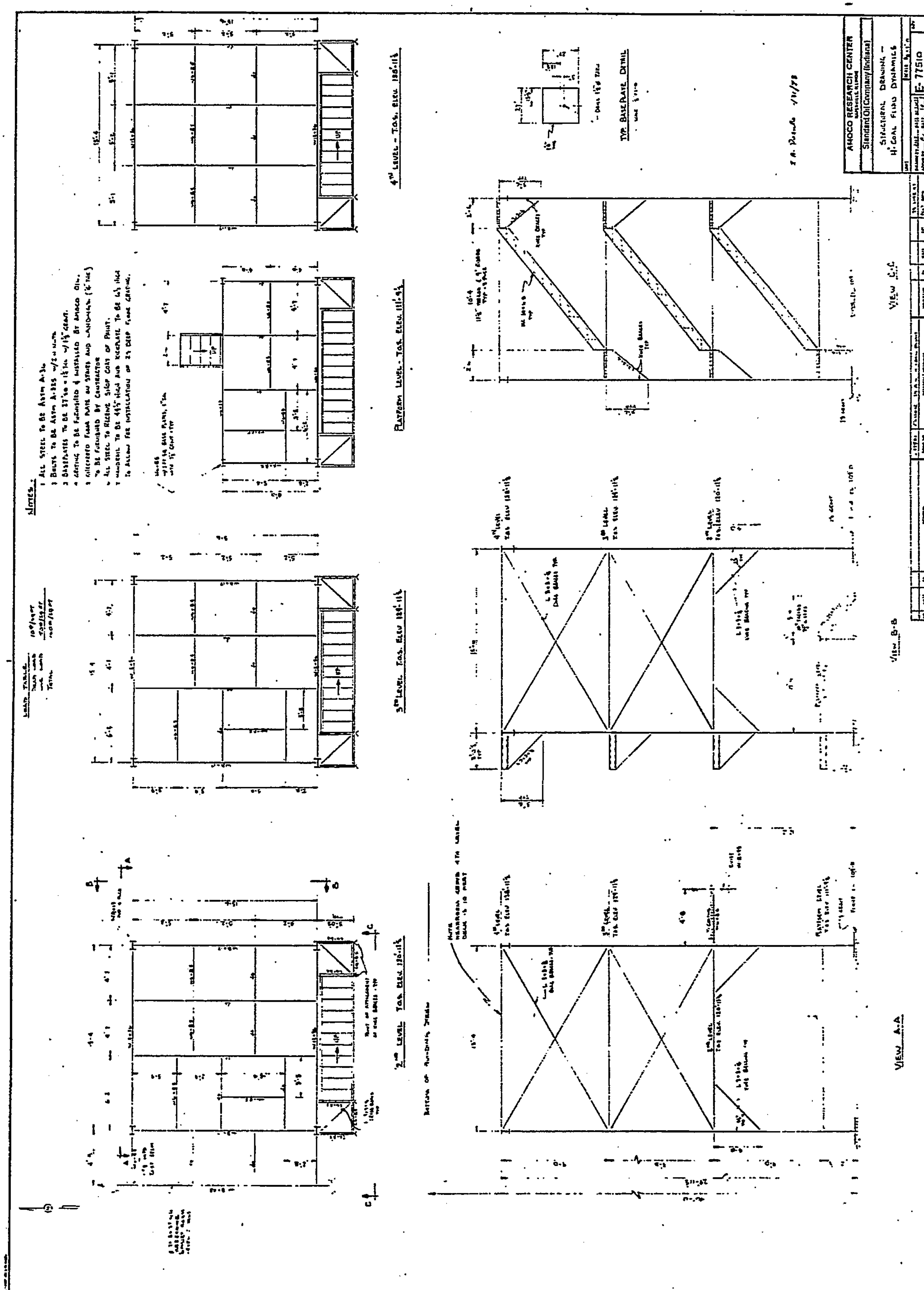

AMOCO RESEARCH CENTER
NAPERVILLE, ILLINOIS
STRUCTURE LAYOUT
H-COAL FLUID DYNAMICS UNIT
AU-77H
D-77501
SEC A-A
4TH LEVEL
3RD LEVEL
2ND LEVEL
1ST LEVEL
LANDING
PLAN VIEW
1ST LEVEL
CORRIDOR
DIST. UNIT
EXHAUST DUCT
N
E
S
W

M79-26/-104

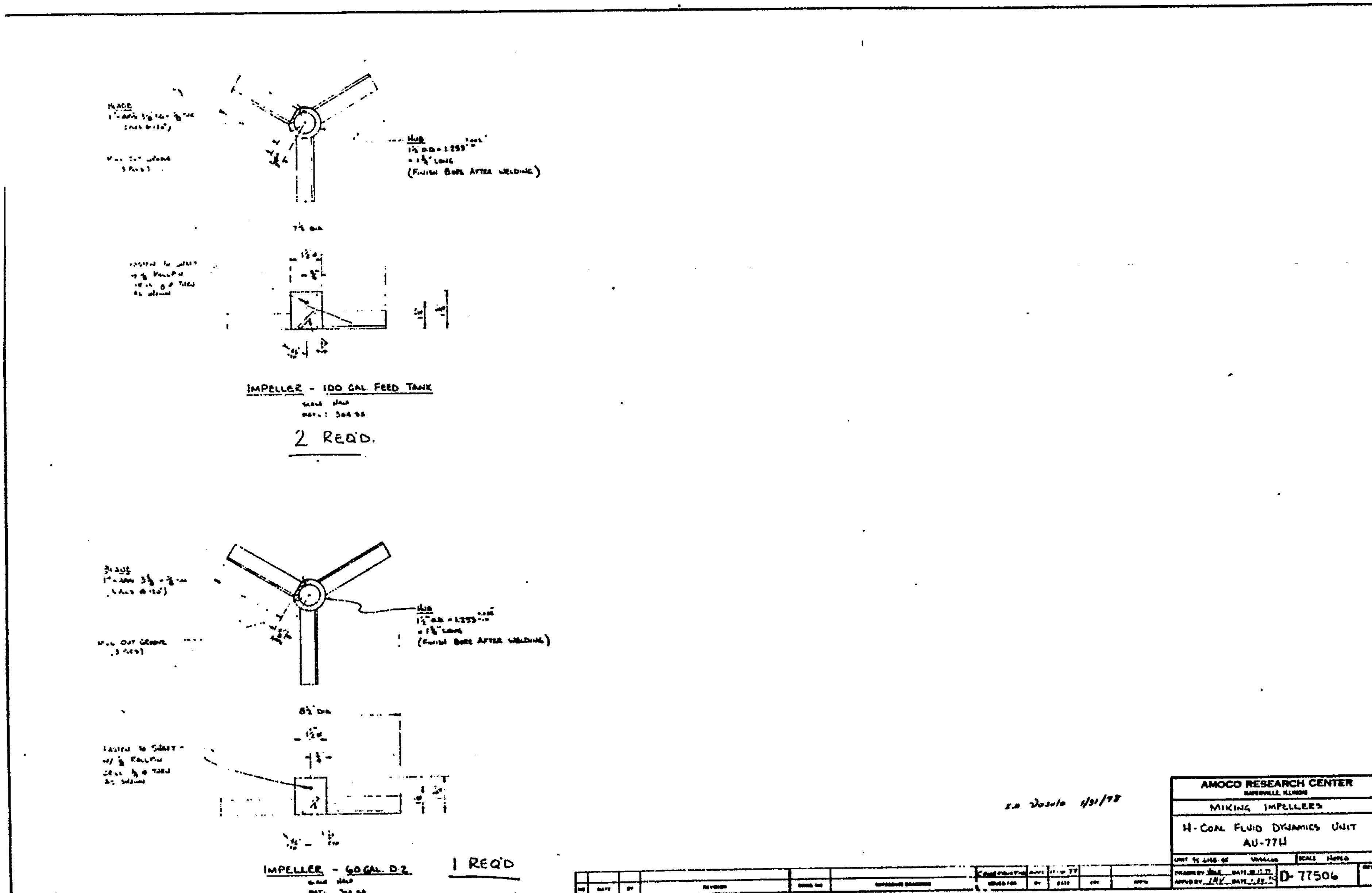



AMOCO RESEARCH CENTER
SECTION 'A-A'
SECTION 'B-B'
VENT LINE SUPPORT DETAIL 'D'
DETAIL 'C' - CAP PLATE


ARC - SKES-78-103
REACTOR TOP FLANGE
DETAIL
ALL MATERIALS 304 S.S.
2 SLOTS, 180° APART
1" TUBING, 18" LONG
6" GLASS PIPE
GASKETS
MACHINE FACE SMOOTH
6"-150# ASA BLIND FLANGE
1" HALF COUPLING, 150#
FOR RELIEF CONN.
OUTLET-1½"-HALF COUPLING,
150#


AMOCO RESEARCH CENTER
Standard Oil Company (Indiana)
E-77510
VIEW A-A
VIEW B-B
VIEW C-C
NOTES:
LOAD TABLE
TYP. BASE PLATE DETAIL

M79-26/-108

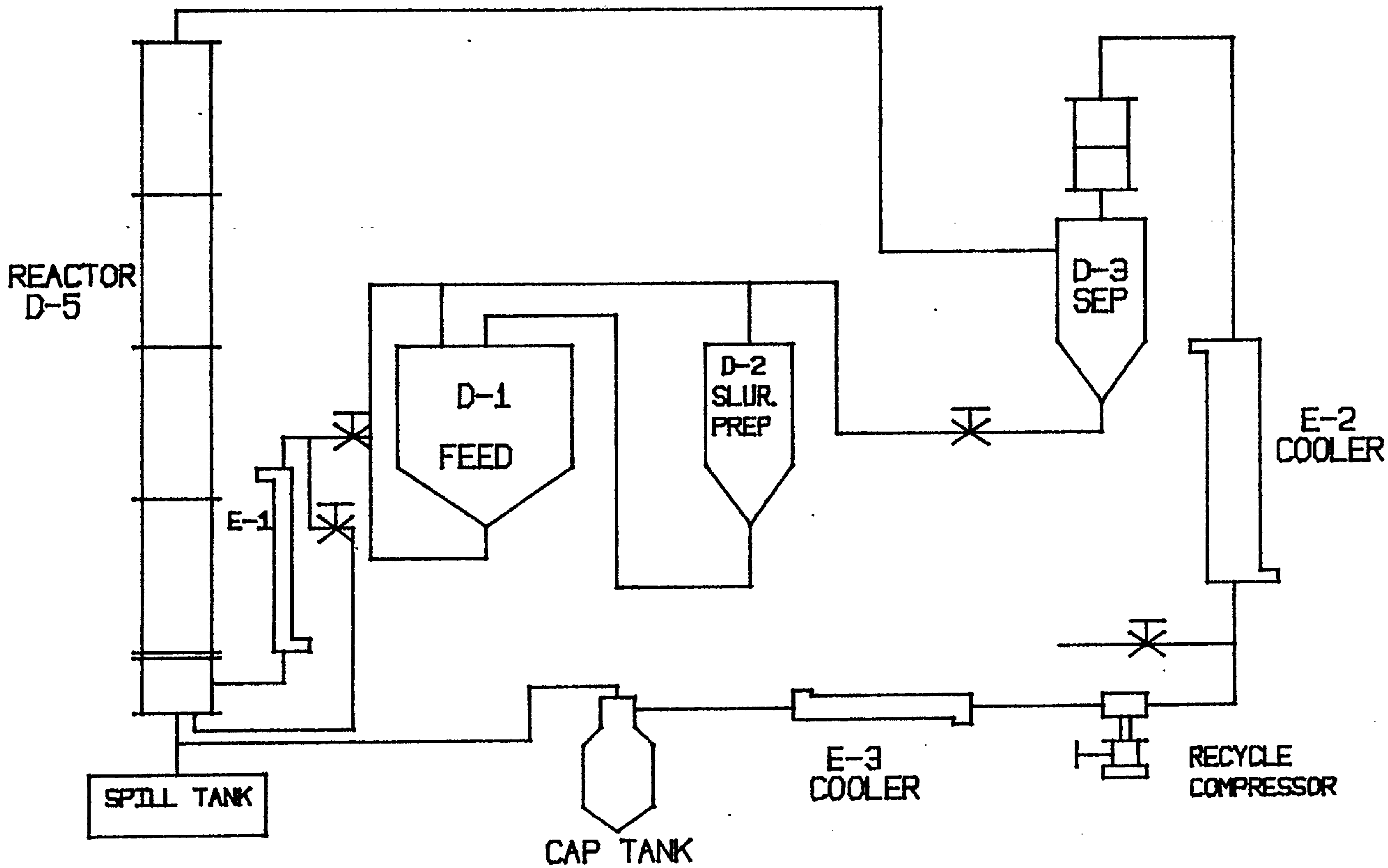


HUB
(FINISH BORE AFTER WELDING)
IMPELLER - 100 GAL. FEED TANK
2 REQ'D.
IMPELLER - 60 GAL. D-2
1 REQ'D
AMOCO RESEARCH CENTER
MIXING IMPELLERS
H-COAL FLUID DYNAMICS UNIT
AU-77H
D-77506

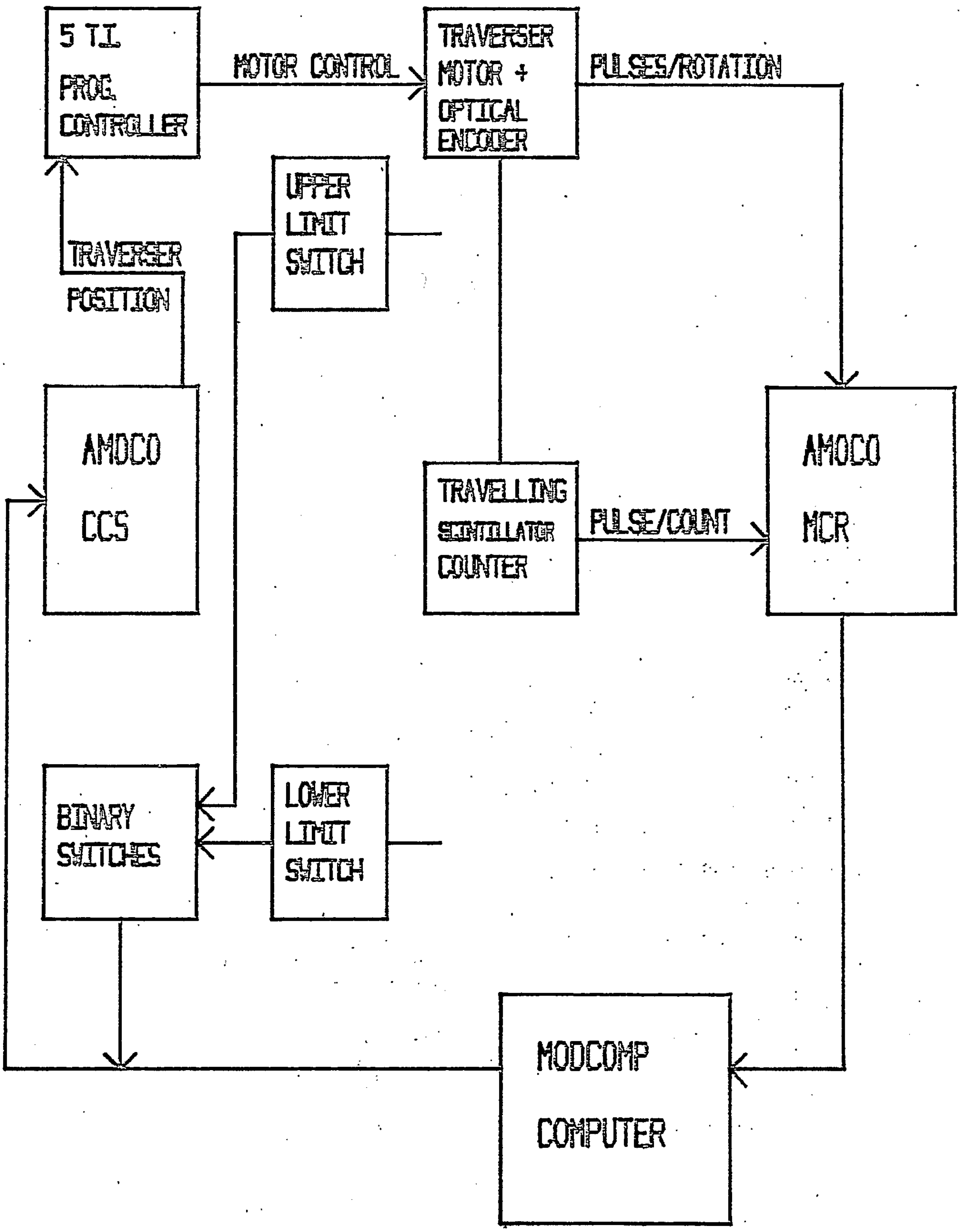
APPENDIX B

EXAMPLES OF COMPUTER OUTPUT

AU-77H PILOT PLANT FLOWCHART



GAMMA RAY TRAVERSER FLOWCHART



M79-26
-112

AU-77H END OF TEST REPORT FOR TEST #201-25
START OF TEST 15:45
END OF TEST 16:14

SEP 0 8 1978

TEST AVERAGES

P77-01	2.144	PSIG
P77-02	27.195	PSIG
P77-03	0.502	PSIG
F77-01	5.996	GPM
F77-02	-39.467	LB/M
F77-03	9.806	CUFT
L77-01	9.472	INH2
PD77-01	69.146	INH2
PD77-02	52.896	INH2
PD77-03	-24.741	INH2
PD77-04	-25.012	INH2
PD77-05	-100.054	INH2
PD77-06	-100.027	INH2
PD77-07	-100.004	INH2
PD77-08	-100.045	INH2
PD77-09	3.704	INH2
T77-01	70.809	DEGF
T77-02	61.110	DEGF
T77-03	62.821	DEGF
T77-04	61.905	DEGF
T77-05	61.458	DEGF
T77-06	70.150	DEGF
T77-07	87.279	DEGF
T77-08	55.952	DEGF
T77-09	76.178	DEGF
T77-10	-17.307	DEGF
X77-01	0.000	

201 25

*****AVERAGE FLOW RATES

SEP 0 8 1978

RECYCLE GAS FLOW	9.806	CU.FT./HR
	23.977	STD.CU.FT./HR
	0.014	FT/SEC
SLURRY FEED FLOW	5.996	GAL/MIN
	30.591	GPM/FT2
	0.068	FT/SEC
SLURRY RECYCLE FLOW	0.000	LB/MIN
	0.000	GPM
	0.000	GPM/FT2
	0.000	FT/SEC
TOTAL LIQUID FLOW	0.068	FT/SEC

*** PRESSURE DIFFERENCES

REACTOR ΔP	72.289 IN.H2O
DP(1)	69.146 IN.H2O
DP(2)	52.896 IN.H2O
DP(3)	-24.741 IN.H2O
DP(4)	-25.012 IN.H2O
DP(5)	-100.054 IN.H2O
DP(6)	-100.027 IN.H2O
DP(7)	-100.004 IN.H2O
DP(8)	-100.045 IN.H2O

*****AVERAGE GAMMA RAY SCANS
OF SCANS= 1   STEP SIZE= 5.00
EQUIL. TIME= 5 SEC. DELAY TIME= 20 SEC.

POSITION(IN.)	COUNTS/SEC
0.00	140.9339
5.00	251.8132
10.00	264.9777
15.00	266.9802
20.00	263.4194
25.00	255.8751
30.00	260.0995
35.00	263.1788
40.00	266.1185
45.00	262.5809
50.00	259.6412
55.00	245.6403
60.00	4.0359
65.00	242.7504
70.00	256.3029
75.00	253.4628
80.00	359.8405
85.00	358.9436
90.00	363.3282
95.00	354.8081
100.00	357.4489
105.00	354.9077
110.00	355.5555
115.00	343.3483
120.00	335.5256
125.00	306.9756
130.00	339.3622
135.00	336.0737
140.00	339.8105
145.00	339.7109
150.00	338.2162
155.00	342.7504
160.00	342.8002
165.00	341.1061
170.00	340.4086
175.00	342.0527
180.00	354.7085
185.00	1.0463
190.00	331.4897
195.00	271.7488
200.00	239.0959
REACTOR TOP	238.3309
SLURRY RECYCLE	456.4524

M79-26/-114

*****THREE PHASE SYSTEM-VOLUMETRIC FRACTIONS

VOLUME FRACTION CATALYST= 0.2290

POSITION (IN.)	VOLUME FRACT. LIQUID DELTA P	VOLUME FRACT. LIQUID GAMMA RAY	VOLUME FRACT. FINES DELTA P	VOLUME FRACT. FINES GAMMA RAY	VOLUME FRACT. GAS DELTA P	VOLUME FRACT. GAS GAMMA RAY
0.00	0.939	0.582	0.000	0.000	-0.168	0.189
5.00	0.939	0.745	0.000	0.000	-0.168	0.026
10.00	0.939	0.731	0.000	0.000	-0.168	0.040
15.00	0.939	0.717	0.000	0.000	-0.168	0.054
20.00	0.939	0.717	0.000	0.000	-0.168	0.054
25.00	0.939	0.743	0.000	0.000	-0.168	0.028
30.00	0.939	0.722	0.000	0.000	-0.168	0.049
35.00	0.939	0.712	0.000	0.000	-0.168	0.059
40.00	0.939	0.697	0.000	0.000	-0.168	0.074
45.00	0.939	0.706	0.000	0.000	-0.168	0.065
50.00	0.939	0.709	0.000	0.000	-0.168	0.062
55.00	0.939	0.702	0.000	0.000	-0.168	0.069
60.00	0.597	0.273	0.000	0.000	0.174	0.498
65.00	0.597	0.724	0.000	0.000	0.174	0.047
70.00	0.597	0.731	0.000	0.000	0.174	0.040
75.00	0.597	0.738	0.000	0.000	0.174	0.033
80.00	0.597	0.370	0.000	0.000	0.174	0.401
85.00	0.597	0.364	0.000	0.000	0.174	0.407
90.00	0.597	0.868	0.000	0.000	0.174	0.132
95.00	0.597	0.898	0.000	0.000	0.174	0.102
100.00	0.597	0.892	0.000	0.000	0.174	0.108
105.00	0.597	0.903	0.000	0.000	0.174	0.097
110.00	0.597	0.903	0.000	0.000	0.174	0.097
115.00	0.597	0.892	0.000	0.000	0.174	0.108
120.00	-0.522	-0.081	0.000	0.000	1.522	1.081
125.00	-0.522	0.814	0.000	0.000	1.522	0.186
130.00	-0.522	0.896	0.000	0.000	1.522	0.104
135.00	-0.522	0.906	0.000	0.000	1.522	0.094
140.00	-0.522	0.899	0.000	0.000	1.522	0.101
145.00	-0.522	0.893	0.000	0.000	1.522	0.107
150.00	-0.522	0.896	0.000	0.000	1.522	0.104
155.00	-0.522	0.881	0.000	0.000	1.522	0.119
160.00	-0.522	0.883	0.000	0.000	1.522	0.117
165.00	-0.522	0.890	0.000	0.000	1.522	0.110
170.00	-0.522	0.890	0.000	0.000	1.522	0.110
175.00	-0.522	0.886	0.000	0.000	1.522	0.114
180.00	-0.527	0.814	0.000	0.000	1.527	0.186
185.00	-0.527	5.091	0.000	0.000	1.527	-4.091
190.00	-0.527	0.936	0.000	0.000	1.527	0.064
195.00	-0.527	0.831	0.000	0.000	1.527	0.169
200.00	-0.527	1.548	0.000	0.000	1.527	-0.548
REAC TOP	-0.527	1.222	0.000	0.000	1.527	-0.222

201 25

SEP 08 1978

SLURRY RECYCLE= 456.4524 COUNTS/SEC

DRIFT FLUX= 34.7474 MM/SEC

CONSTANTS USED FOR CALCULATIONS FOR TEST #201-25
DIA= 0.500 UL= 0.038 UC= 0.039UF= 0.039
PL= 49.300 PC= 111.700 PF= 0.000
WT % FINES= 0.000 HEIGHT BETWEEN DPS= 60.000
BED HEIGHT= 82.500 CATALYST MASS= 34.470

AU-774 END OF TEST REPORT FOR TEST 8201-25
START OF TEST 15:45
END OF TEST 16:14

SEP 08 1978

TEST AVERAGES

P77-01	2.144	PSIG
P77-02	27.19[illegible]	PSIG
P77-03	1.56[illegible]	PSIG
F77-01	5.996	GPM
F77-02	-39.467	LB/M
F77-03	9.8[illegible]	CUFT
L77-01	9.47[illegible]	INH2
PD77-01	69.[illegible]	INH2
PD77-02	52.876	INH2
PD77-03	-24.71[illegible]	INH2
PD77-04	-[illegible]	INH2
PD77-05	-100.054	INH2
PD77-06	[illegible]	INH2
PD77-07	-100.004	INH2
PD77-08	-100.045	INH2
PD77-09	3.70[illegible]	INH2
T77-01	72.90[illegible]	DEGF
T77-02	61.11[illegible]	DEGF
T77-03	62.821	DEGF
T77-04	61.905	DEGF
T77-05	61.458	DEGF
T77-06	70.156	DEGF
T77-07	37.279	DEGF
T77-08	55.[illegible]	DEGF
T77-09	76.[illegible]	DEGF
T77-10	-17.307	DEGF
X77-01	0.000	

201 25

*****AVERAGE FLOW RATES

RECYCLE GAS FLOW	[illegible].906	CU.FT./HR
	[illegible].977	STD.CU.FT./HR
	0.014	FT/SEC
SLURRY FEED FLOW	3.996	GAL/MIN
	30.591	GPM/FT2
	0.068	FT/SEC
SLURRY RECYCLE FLOW	0.000	LB/MIN
	0.000	GPM
	0.000	GPM/FT2
	0.000	FT/SEC
TOTAL LIQUID FLOW	0.068	FT/SEC

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***** PRESSURE DIFFERENCES**

REACTOR DP	72.289 IN.H2O
DP(1)	69.146 IN.H2O
DP(2)	52.896 IN.H2O
DP(3)	-24.741 IN.H2O
DP(4)	-25.012 IN.H2O
DP(5)	-100.054 IN.H2O
DP(6)	-100.027 IN.H2O
DP(7)	-100.004 IN.H2O
DP(8)	-100.045 IN.H2O

201 25

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*****AVERAGE GAMMA RAY SCANS
OF SCANS= 1   STEP SIZE= 5.00
EQUIL. TIME= 5 SEC. DELAY TIME= 20 SEC.

POSITION(IN.)	COUNTS/SEC
0.00	140.9339
5.00	251.8132
10.00	264.9777
15.00	266.9802
20.00	263.4194
25.00	255.8751
30.00	260.0995
35.00	263.1788
40.00	266.1185
45.00	262.5809
50.00	259.6412
55.00	245.6403
60.00	4.0359
65.00	242.7504
70.00	256.3029
75.00	253.4628
80.00	359.8405
85.00	358.9436
90.00	363.3282
95.00	354.8081
100.00	357.4489
105.00	354.9077
110.00	355.5555
115.00	343.3483
120.00	335.5256
125.00	306.9756
130.00	339.3622
135.00	336.0737
140.00	339.8105
145.00	339.7109
150.00	338.2162
155.00	342.7504
160.00	342.8002
165.00	341.1061
170.00	340.4086
175.00	342.0527
180.00	354.7085
185.00	1.0463
190.00	331.4897
195.00	271.7488
200.00	239.0959
REACTOR TOP	238.3309
SLURRY RECYCLE	456.4524

*****THREE PHASE SYSTEM-VOLUMETRIC FRACTIONS

VOLUME FRACTION CATALYST= 0.2290

POSITION (IN.)	VOLUME FRACT. LIQUID DELTA P	VOLUME FRACT. LIQUID GAMMA RAY	VOLUME FRACT. FINES DELTA P	VOLUME FRACT. FINES GAMMA RAY	VOLUME FRACT. GAS DELTA P	VOLUME FRACT. GAS GAMMA RAY
0.00	0.939	0.582	0.000	0.000	-0.168	0.189
5.00	0.939	0.745	0.000	0.000	-0.168	0.026
10.00	0.939	0.731	0.000	0.000	-0.168	0.040
15.00	0.939	0.717	0.000	0.000	-0.168	0.054
20.00	0.939	0.717	0.000	0.000	-0.168	0.054
25.00	0.939	0.743	0.000	0.000	-0.168	0.028
30.00	0.939	0.722	0.000	0.000	-0.168	0.049
35.00	0.939	0.712	0.000	0.000	-0.168	0.059
40.00	0.939	0.697	0.000	0.000	-0.168	0.074
45.00	0.939	0.706	0.000	0.000	-0.168	0.065
50.00	0.939	0.709	0.000	0.000	-0.168	0.062
55.00	0.939	0.702	0.000	0.000	-0.168	0.069
60.00	0.597	0.273	0.000	0.000	0.174	0.498
65.00	0.597	0.724	0.000	0.000	0.174	0.047
70.00	0.597	0.731	0.000	0.000	0.174	0.040
75.00	0.597	0.738	0.000	0.000	0.174	0.033
80.00	0.597	0.370	0.000	0.000	0.174	0.401
85.00	0.597	0.364	0.000	0.000	0.174	0.407
90.00	0.597	0.868	0.000	0.000	0.174	0.132
95.00	0.597	0.898	0.000	0.000	0.174	0.102
100.00	0.597	0.892	0.000	0.000	0.174	0.108
105.00	0.597	0.903	0.000	0.000	0.174	0.097
110.00	0.597	0.903	0.000	0.000	0.174	0.097
115.00	0.597	0.892	0.000	0.000	0.174	0.108
120.00	-0.522	-0.031	0.000	0.000	1.522	1.081
125.00	-0.522	0.814	0.000	0.000	1.522	0.186
130.00	-0.522	0.896	0.000	0.000	1.522	0.104
135.00	-0.522	0.906	0.000	0.000	1.522	0.094
140.00	-0.522	0.899	0.000	0.000	1.522	0.101
145.00	-0.522	0.893	0.000	0.000	1.522	0.107
150.00	-0.522	0.896	0.000	0.000	1.522	0.104
155.00	-0.522	0.881	0.000	0.000	1.522	0.119
160.00	-0.522	0.883	0.000	0.000	1.522	0.117
165.00	-0.522	0.890	0.000	0.000	1.522	0.110
170.00	-0.522	0.890	0.000	0.000	1.522	0.110
175.00	-0.522	0.886	0.000	0.000	1.522	0.114
180.00	-0.527	0.814	0.000	0.000	1.527	0.186
185.00	-0.527	5.091	0.000	0.000	1.527	-4.091
190.00	-0.527	0.936	0.000	0.000	1.527	0.064
195.00	-0.527	0.831	0.000	0.000	1.527	0.169
200.00	-0.527	1.548	0.000	0.000	1.527	-0.548
REAC TOP	-0.527	1.222	0.000	0.000	1.527	-0.222

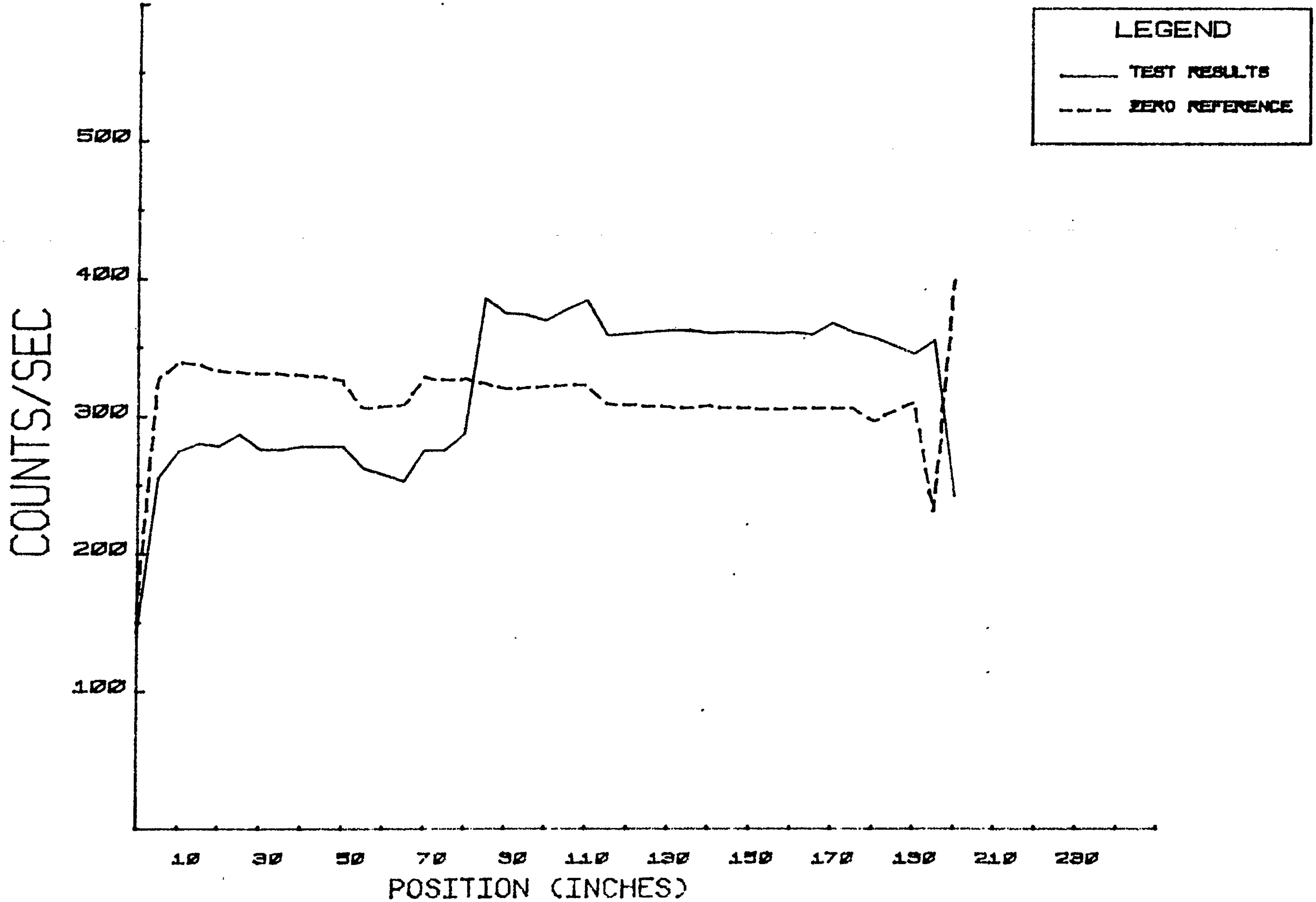
SLURRY RECYCLE= 456.4524 COUNTS/SEC

DRIFT FLUX= 34.7474 MM/SEC

CONSTANTS USED FOR CALCULATIONS FOR TEST #201-25
DIA= 0.500 UL= 0.038 UC= 0.039UF= 0.039
PL= 49.300 PC= 111.700 PF= 0.000
WT % FINES= 0.000 HEIGHT BETWEEN DPS= 60.000
BED HEIGHT= 82.500 CATALYST MASS= 34.470

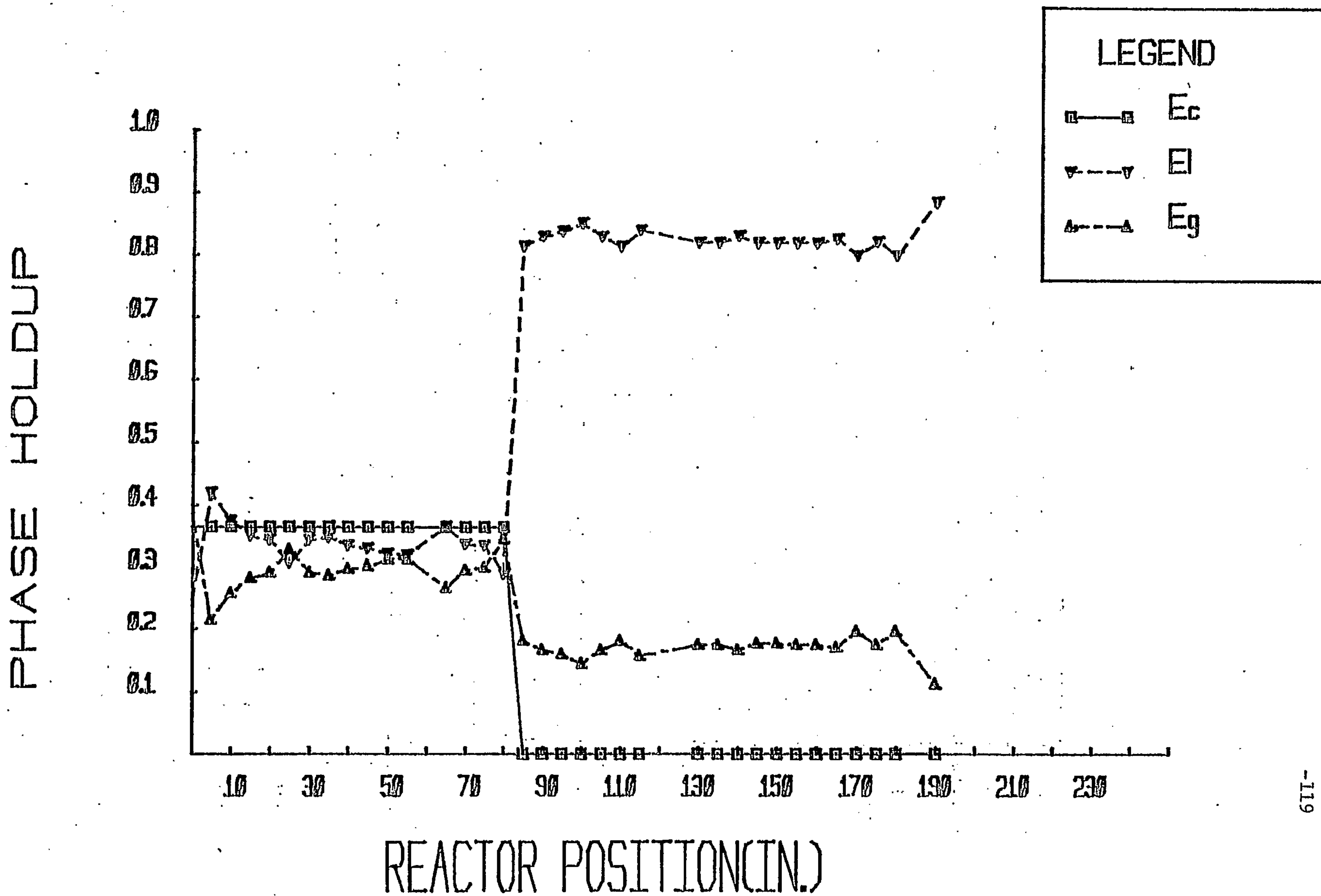
201 25 SEP 08 1978

AU-77H GAMMA RAY PLOT FOR TEST #201-26 AND ZERO REFERENCE #1

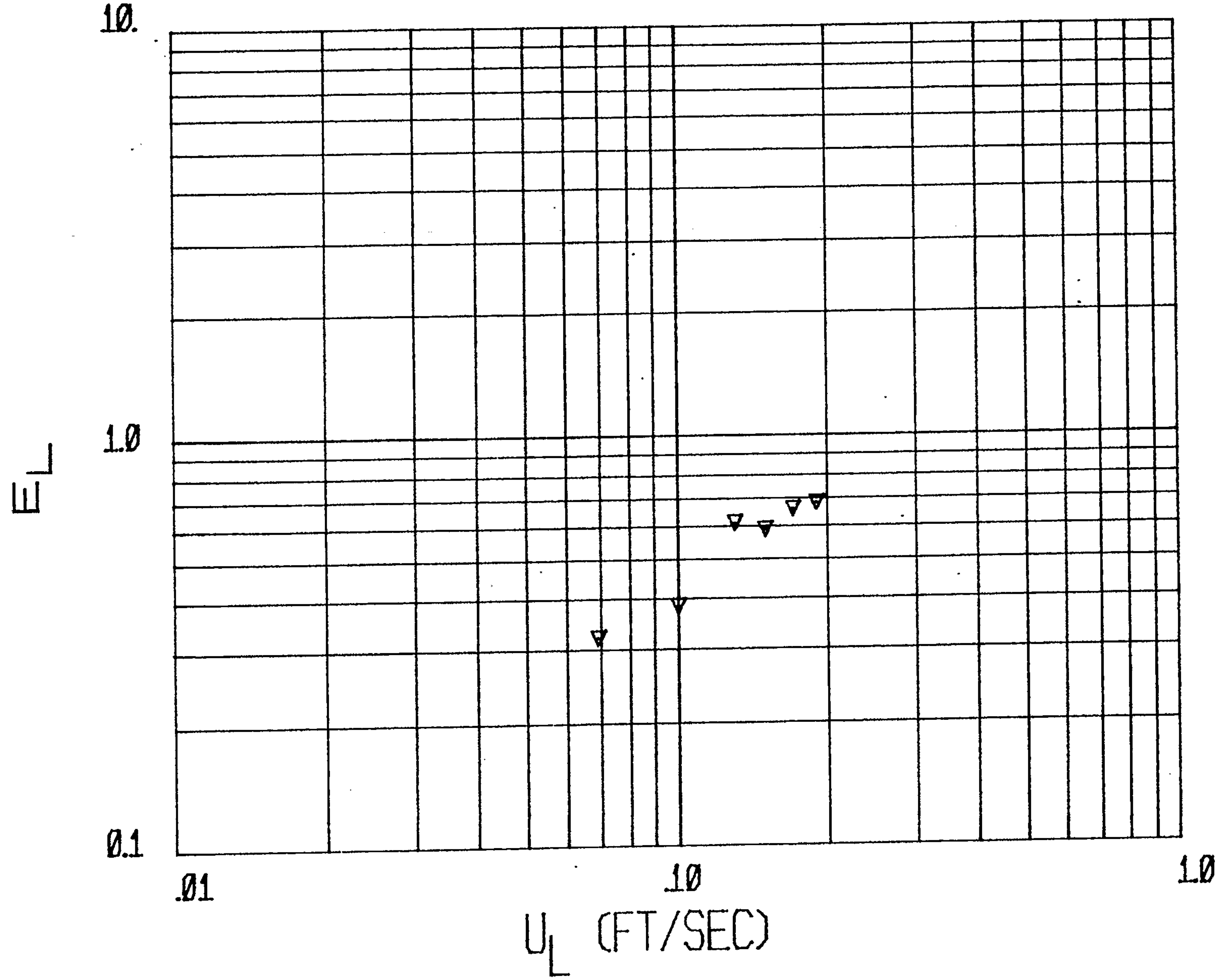


M79-26/-118

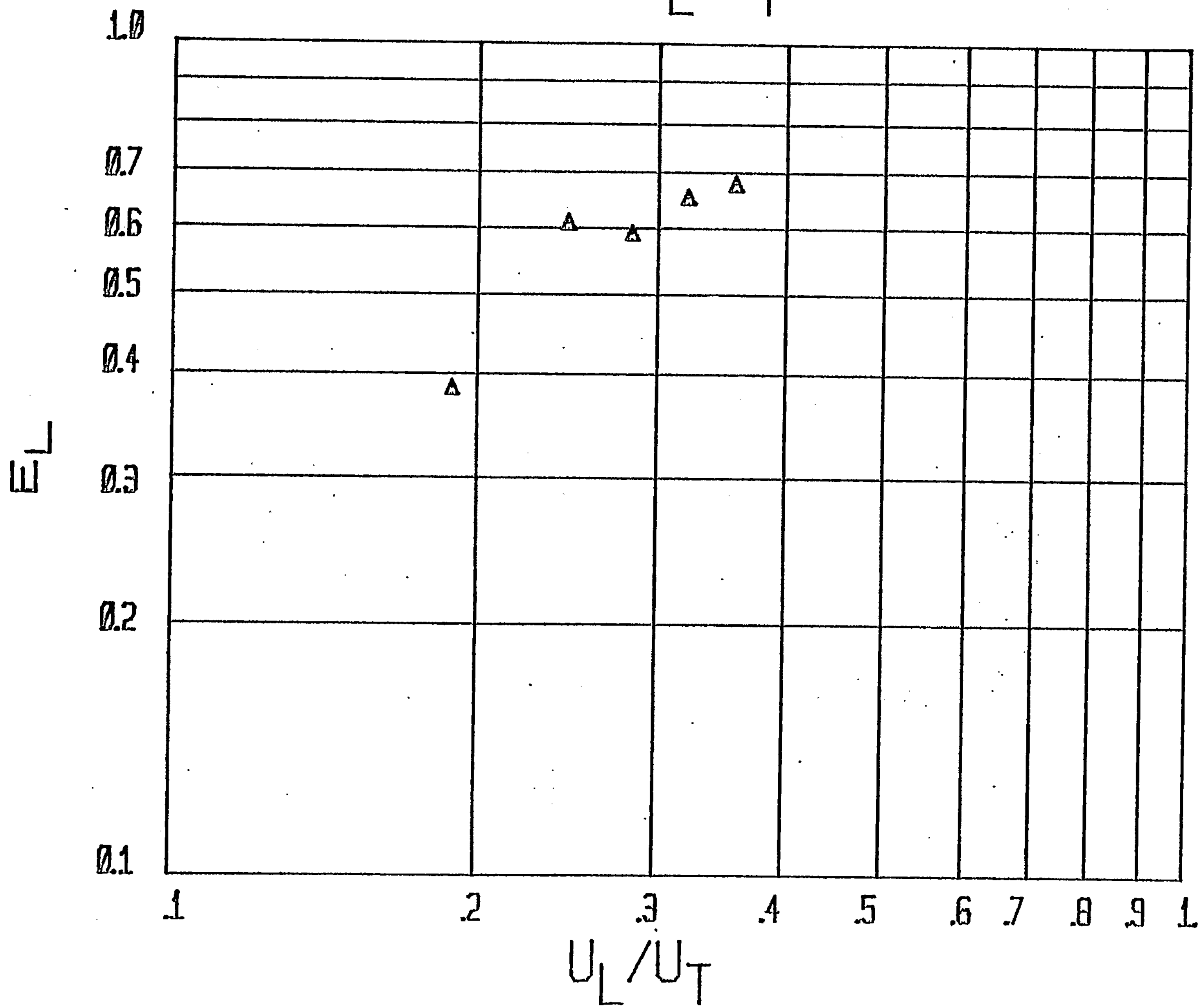
PHASE HOLDUP VS. REACTOR POSITION FOR TEST #201-26



BED VOIDAGE VS. SUPERFICIAL LIQUID VELOCITY, RUN 201



BED VOIDAGE VS. U_L/U_T RUN #201



APPENDIX C

CALCULATION OF GAS/LIQUID/FINE/CATALYST VOLUME FRACTIONS IN THE REACTOR

APPENDIX C

CALCULATION OF GAS/LIQUID/FINE/CATALYST VOLUME FRACTIONS IN THE REACTOR

The volume fraction of catalyst is calculated from measurement of the bed height and mass of catalyst in the reactor:

$$\epsilon_c = \frac{M}{\rho_c A H}$$

where: M = mass of dry catalyst added to the reactor.
ρ_c = density of a dry catalyst particle.
A = cross-sectional area of the reactor.
H = catalyst bed height

The volume fraction of liquid can then be calculated using either gamma-ray scan or pressure drop measurements.

For liquid/catalyst tests, the following equations should be used:

For gamma-ray scan data:

$$\epsilon_1 = \frac{\dfrac{\ln\frac{I_1}{I_m}}{d} - \mu_c\rho_c + \mu_1\rho_1}{\mu_1\rho_1 - \mu_c\rho_c + \dfrac{\omega_f\rho_1(\mu_f\rho_f - \mu_c\rho_c)}{\rho_f(100 - \omega_f)}}$$

For pressure drop measurements:

$$\epsilon_1 = \frac{\dfrac{\Delta P}{HD} - \rho_c}{\rho_1 - \rho_c + \dfrac{\rho_1\omega_f}{100 - \omega_f}\left(1 - \dfrac{\rho_c}{\rho_f}\right)}$$

When three phases are in the reactor, gas/liquid/catalyst, these equations should be used:

Gamma-ray:

$$\frac{\dfrac{\ln\frac{I_1}{I_m}}{d} - \mu_c\rho_c\epsilon_c + \mu_1\rho_1}{\mu_1\rho_1 + \dfrac{\mu_f\omega_f\rho_1}{(100 - \omega_f)}}$$

Pressure drop:

$$\epsilon_l = \frac{\frac{\Delta P}{HD} - \rho_c \epsilon_c}{\rho_l + \frac{\omega_f \rho_l}{100 - \omega_f}}$$

In either case:

$$\epsilon_f = \frac{\epsilon_l \rho_l \omega_f}{\rho_f (100 - \omega_f)}$$

$$\therefore \quad \epsilon_g = 1 - \epsilon_l - \epsilon_c - \epsilon_f$$

In the dilute phase above the catalyst bed, ϵ_c is set to 0.0 and the same equations are solved.

HD = height between pressure taps
I_l = gamma-ray intensity through liquid
I_m = gamma-ray intensity at test conditions
ΔP = pressure drop

ϵ_c = volume fraction catalyst
ϵ_f = volume fraction fines
ϵ_g = volume fraction gas
ϵ_l = volume fraction liquid
ρ_c = catalyst density
ρ_f = fines density
ρ_l = liquid density
μ_c = catalyst mass absorption coefficient
μ_f = fines mass absorption coefficient
μ_l = liquid mass absorption coefficient
ω_f = wt% fines

APPENDIX D

THE LITERATURE SEARCH--SCOPE AND METHODOLOGY

APPENDIX D

THE LITERATURE SEARCH--SCOPE AND METHODOLOGY

The subject matter covered by this search was rather narrowly defined as "the fundamental hydrodynamics of fluidized-bed technology." Within this definition, two aspects of the subject were pursued: 1) Experimental data on 2 and 3-phase system behavior, and the theory and mathematical analysis of same; 2) The experimental and analytical techniques applicable to the study of such systems. The time period covered was 1950 to present.

A sequential plan was used in conducting the search. First, the presumed applicable literature files were searched, by interactive computer means where possible, and through manual indices for earlier years. The output from this, primarily abstracts, was then sifted and sorted to reduce it to the truly pertinent materials. Quantitatively, these two steps produced about 125 documents from a total of 454 citations. The reference lists from these documents were then utilized to "zero-in" on additional papers, of which another 87 were retrieved. The complete document output of the search was thus 212 items which was narrowed down to 200 in the final analysis. Seven additional references were supplied by H-Coal participants.

The indexed literature files searched were: Chemical Abstracts, American Petroleum Institute, Engineering Index, and the U. S. Energy R&D Administration's RECON file. Of the papers ending up in the final bibliography, the journal Chemical Engineering Science was the largest single contributor, with 36, while AIChE publications (papers, journals, and symposia) were second with 24. Foreign publications (non-Canadian) accounted for 53 of the utilized papers.

While the earliest literature reference to fluidization technology was that of Agricola in "De re Metallica" in 1556, and the first patent using it was issued in 1910 to Phillips and Bulteel, it started gaining widespread attention and basic scientific study in the early 1940's when it was applied to the catalytic cracking of vaporized petroleum fractions. The studies of the 40's and 50's provided a solid theoretical foundation for describing and analyzing fluidized systems, then the more sophisticated and system-specific work of the 60's and 70's has built from that. This literature review concentrates on the latter period but includes several basic works from the former. The 200 references included in this bibliography show the following time distribution:

		No. of Papers
pre-1960	-	15
1960-1970	-	89
1971-1977	-	96

The complete bibliography for this search is divided inzo 5 tables, according to subject matter, with Table I having 4 subdivisions. The organization is as follows:

Table D-I	-	Fundamental Hydrodynamics of Fluidization:
		A. Liquid-Solid systems
		B. Vertical Gas-Solid systems
		C. Gas-Liquid-Solid systems
		D. Gas-Solid systems
Table D-II	-	Experimental and Analytical Techniques and Equipment
Table D-III	-	Properties of Coal-Oil Mixtures
Table D-IV	-	General Literature Related to Fluidization
Table D-V	-	Literature Provided by H-Coal Participants

Each table gives a very brief indication of the systems or techniques covered and the significance of the paper relative to this study.

IAV:md
2/15/78

TABLE D-I

Literature on The Hydrodynamics of Fluidization

A. Liquid-Solid Fluidization:

Reference No.	Reference	Systems Covered	Significance to Project
1	Barnea, E. and Mizrahi, J. A Generalized Approach to the Fluid Dynamics of Particulate Systems Part 1 - General Correlation for Fluidization and Sedimentation in Solid Multiparticle Systems Chemical Engineering Journal, Vol. 5, pp. 171-189, 1973	No Experimental Work	Review Article, Model
2	Brea, F. M., Edwards, M. F., and Wilkerson, W. L. The Flow of Non-Newtonian Slurries Through Fixed and Fluidized Beds Chemical Engineering Science, Vol. 31, pp. 329-336, 1976	Water, Glycerol, Water-TiO_2 Slurries/Glass, Lead or Steel Spheres	Fluidization with Slurries
3	Finkestein, E., Letan, R., and Elgin, J. C. Mechanics of Vertical Moving Fluidized Systems with Mixed Particle Sizes A.I.Ch.E. Journal, Vol. 17, p. 867, 1971	Water - Glass Beads	Particle Size Effects
4	Fouda, A. E. and Capes, C. E. Hydrodynamic Particle Volume and Fluidized Bed Expansion Canadian Journal of Ch. Eng., Vol. 55, p. 386, 1977	Water - Glass Beads, Crushed Silica, Mica	Model
5	Garside, John and Al-Dibouni, M. R. Velocity - Voidage Relationships for Fluidization and Sedimentation in Solid-Liquid Systems Ind. Eng. Chem., Process Des. Dev., Vol. 16, No. 2, p. 206, 1977	No Experimental Work	Review Article
6	Richardson, J. F. and Zaki, W. N. Sedimentation and Fluidization: Part I Trans. Instn. Chem. Eng., Vol. 32, p. 35, 1954	Various Liquids and Solids	Model
7	Upson, P. C. and Pyle, D. L. The Behavior of Liquid Fluidized Beds Following Stepwise Changes in Flow Rate Chem. Eng. Science, Vol. 29, pp. 71-75, 1974	Water/Glass Ballotini	Fluidized Bed Stability
8	Volpicelli, G., Massimilla, L., and Zenz, F. A. Nonhomogeneities in Solid-Liquid Fluidization Chem. Eng. Progress Symposium Series, Vol. 62, No. 67, p. 42, 1966	Water and Glycerine/Steel Beads " " " /Aluminum Beads " " " /Plastic "	Background
9	Wallis, G. B. A Simple Correlation for Fluidization and Sedimentation Trans. Instn. Chem. Eng., Vol. 55, p. 74, 1977	No Experimental Work	Correlation
10	Wen, C. Y. and Yu, Y. H. The Mechanics of Fluidization Chem. Eng. Prog. Symp. Series, Vol. 62, No. 62, 1966		Correlation
11	Yu, Y. H., Wen, C. Y. and Bailie, R. C. Power-Law Fluids Flow Through Multiparticle System Canadian Journal of Chem. Eng., Vol. 46, p. 149, 1968	Water-Polyox 205/Glass Balls-Cubes " " 301/ " " "	Fluidization with Non-Newtonian Fluid

TABLE D-I

Literature on The Hydrodynamics of Fluidization
-2-

B. Vertical Gas-Liquid Systems

Reference No.	Reference	Systems Covered	Significance to Project
12	Anderson, J. L. and Quinn, J. A. Bubble Columns: Flow Transitions in the Presence of Trace Contaminants Chem. Eng. Science, Vol. 25, pp. 373-380, 1970	Air/Water and Impurities	Bubble Coalescence
13	Astarita, G. and Apuzzo, G. Motion of Gas Bubbles in Non-Newtonian Liquids A.I.Ch.E. Journal, Vol. 11, No. 5, p. 815, 1965	Gases/Non-Newtonian Liquids	Bubble Behavior in Non-Newtonian Fluids
14	Baker, J.L.L. and Chao, B. T. An Experimental Investigation of Air Bubble Motion in a Turbulent Water Stream A.I.Ch.E. Journal, Vol. 11, No. 2, p. 268, 1965	Air/Water	Bubble Behavior in Turbulent Flow
15	Bellman, R. and Pennington, R. H. Effects of Surface Tension and Viscosity on Taylor Instability Quart. Appl. Math., Vol. 12, p. 151, 1954	Theoretical Study	Bubble Break-up
16	Bridge, A. G., Lapidus, L., and Elgin, J. C. The Mechanics of Vertical Gas-Liquid Fluidized System I: Countercurrent Flow A.I.Ch.E. Journal, Vol. 10, No. 6, p. 819, 1964	Air/Water-Glycerine Solutions	Bubble Swarm Behavior
17	Calderbank, P. H., Moo-Young, M. B., and Bibby, R. Coalescence in Bubble Reactors and Absorbers 3rd Euro. Symp. on CH. React. Eng., No. 43, p. 91, 1964	Air/Water CO_2/Water Air, CO_2/Aqueous Glycerol	Bubble Coalescence
18	Chandrasekhar, S. The Character of the Equilibrium of an Incompressible Heavy Viscous Fluid of Variable Density Proc. Cambridge Philological Society, p. 162, 1955	Theoretical Study	Bubble Break-up
19	Clift, R. and Grace, J. R. The Mechanism of Bubble Break-up in Fluidized Beds Chem. Eng. Science, Vol. 27, pp. 2309-10, 1972	Air/Aqueous Sugar Solution Water/Lead Shot	Bubble Break-up
20	Collins, R. The Effect of a Containing Cylindrical Boundary on the Velocity of a Large Gas Bubble in a Liquid Journal, Fluid Mech., Vol. 28, pp. 97-112, 1967	Air/Water	Rise Velocity of Large Bubbles
21	Collins, R. Structure and Behavior of Wakes Behind Two-Dimensional Air Bubbles in Water Chem. Eng. Science, Vol. 20, pp. 851-853, 1965	Air/Water	Bubble-Wake Behavior
22	Crabtree, J. R. and Bridgwater, J. Bubble Coalescence in Viscous Liquids Chem. Eng. Science, Vol. 26, pp. 839-851, 1971	Air/Water-Sucrose	Bubble Coalescence

TABLE D-I

Literature on The Hydrodynamics of Fluidization

B. Vertical Gas-Liquid Systems

Reference No.	Reference	Systems Covered	Significance to Project
23	Crabtree, J. R. and Bridgwater, J. The Wakes Behind Two-Dimensional Air Bubbles Chem. Eng. Science, Vol. 22, pp. 1517-1518, 1967	Air/Water-Glycerol Solution	Bubble Wakes
24	Davidson, J. F. and Harrison, D. The Behavior of a Continuously Bubbling Fluidized Bed Chem. Eng. Science, Vol. 21, pp. 731-738, 1966	Theoretical Study	Gas-Liquid Model
25	Davidson, J. F. and Harrison, D. Fluidized Particles Cambridge U. Press, 1963		Bubble Formation
26	Davidson, J. F. and Schuler, B. O. G. Bubble Formation at an Orifice in a Viscous Liquid Trans. Instn. Ch. Eng., Vol. 38, pp. 144-154, 1960	Air/High Viscosity Liquids	Bubble Formation
27	Davies, R. M. and Taylor, G. I. The Mechanics of Large Bubbles Rising Through Extended Liquids and Through Liquids in Tubes Proc. Roy. Soc., Vol. A200, p. 375, 1950	Air/Nitrobenzene Air/Water	Single Bubble and Slug Behavior
28	Davenport, W. G., Richardson, F. D., Bradshaw, A. V. Spherical Cap Bubbles in Low Density Liquids Chem. Eng. Sci., Vol. 22, pp. 1221-1235, 1967	Air, Nitrogen, CO_2/Water, Aqueous Polyvinyl Alcohol, Ethyl Alcohol	Rise Velocity of Single Bubbles
29	Grace, J. R., Wairegi, T., and Nguyen, T. H. Shapes and Velocities of Single Drops and Bubbles Moving Freely Through Immiscible Liquids Trans. Instn. Eng., Vol. 54, p. 167, 1976	Air/Ethylene Glycol Air/Paraffin Oil	Behavior of Single Bubbles
30	Grace, J. R. Shapes and Velocities of Bubbles Rising in Infinite Liquids Trans. Instn. Ch. Eng., Vol. 51, p. 116, 1973	Various Gases/21 Liquids	Behavior of Single Bubbles
31	Grace, J. R. and Harrison, D. The Influence of Bubble Shape on the Rising Velocities of Large Bubbles Chem. Eng. Science, Vol. 22, pp. 1337-1347, 1967	Air/Water	Bubble-Slug Shape
32	Grace, J. R., Krochmalnek, I. S., Clift, R., and Farkas, E. G. Expansion of Liquids and Fluidized Beds in Slug Flow Chem. Eng. Science, Vol. 26, pp. 617-628, 1971	Air/Water Air/Aqueous Sugar Solution	Slug Behavior
33	Guthrie, R. I. L. and Bradshaw, A. V. Spherical Capped Gas Bubbles Rising in Aqueous Media Chem. Eng. Science, Vol. 28, pp. 191-203, 1973	CO_2/Water CO_2/PVA Solutions	Behavior of Single Bubbles
34	Hide, R. The Character of the Equilibrium of an Incompressible Heavy Viscous Fluid of Variable Density: An Approximate Theory Proc. Cambridge Phil. Society, p. 179, 1955	Theoretical Study	Bubble Break-up

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Literature on The Hydrodynamics of Fluidization

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B. Vertical Gas-Liquid Systems

Reference No.	Reference	Systems Covered	Significance to Project
35	Hills, J. H. The Rise of a Large Bubble Through a Swarm of Smaller Ones Trans. Instn. Ch. Eng., Vol. 53, p. 224, 1975	Air/Water	Behavior of Bubble Swarms
36	Hills, J. H. Radial Non-Uniformity of Velocity and Voidage in a Bubble Column Trans. Instn. Ch. Eng., Vol. 52, p. 1, 1974	Air/Water	Behavior of Bubble Swarms
37	Hinze, J. O. Fundamentals of the Hydrodynamic Mechanism of Splitting in Dispersion Processes A.I.Ch.E. Journal, Vol. 1, No. 3, p. 289, 1955	Theoretical Study	Bubble Break-up
38	Hughmark, G. A. Holdup in Vertical Upward Slug Flow A.I.Ch.E. Journal, Vol. 12, No. 5, p. 1023, 1966	Steam/Water Air/Water - Salt. Sol.	Slug Behavior
39	Jameson, G. J. and Kupferberg, A. Pressure Behind a Bubble Accelerating from Rest: Simple Theory and Applications Chem. Eng. Science, Vol. 22, pp. 1053-1055, 1967	Theoretical Study	Bubble Formation
40	Kirkpatrick, R. D. and Lockett, M. J. The Influence of Approach Velocity on Bubble Coalescence Chem. Eng. Science, Vol. 29, pp. 2363-2373, 1974	Air/Water	Bubble Coalescence
41	Kojima, E., Akehata, T., and Shirai, T. Rising Velocity and Shape of Single Air Bubbles in Highly Viscous Liquids	Air/Glycerine, Castor Oil, Corn Syrup	Single Bubble Behavior
42	Koide, K., Kato, S., Tanaka, Y., and Kubota, H. Bubbles Generated from Porous Plate Journal Ch. Eng. of Japan, Vol. 1, No. 1, p. 51, 1968	Air/Water, Hydrocarbons, Aqueous Solutions	Coalescence Bubble Formation
43	Koide, K., Hirahara, T., and Kubota, H. Average Bubble Diameter, Slip Velocity and Gas Hold-up of Bubble Swarms Kagaku Kogaku, Vol. 5, No. 1, p. 38, 1967	Air/Water Air/Aqueous Glycerine	Bubble Formation
44	Krishnamurthi, S., Kumar, R., and Kuloor, N. R. Bubble Formation in Viscous Liquids Under Constant Flow Conditions Ind. and Eng. Chem., Vol. 7, No. 4, p. 549, 1968	Air/Glycerol	Bubble Formation
45	Krishnamurthi, S., Kumar, R., and Kuloor, N. R. Formation of Bubbles Chem. and Process Eng., p. 91, Jan. 1968		Bubble Formation
46	Kutateledze, S. S. and Styrikovich, M. A. Hydraulics of Gas-Liquid Systems Moscow, Wright Field Trans., F-TS -9814/V, 1958		Bubble Formation

TABLE D-I

Literature on The Hydrodynamics of Fluidization

B. Vertical Gas-Liquid Systems

Reference No.	Reference	Systems Covered	Significance to Project
47	Lindt, J. T. Note on the Wake Behind a Two-Dimensional Bubble Chem. Eng. Science, Vol. 26, pp. 1776-1777, 1971	Air/Water	Wake Behavior
48	Lockett, M. J. and Kirkpatrick, R. D. Ideal Bubbly Flow and Actual Flow in Bubble Columns Trans. Instn. Chem. Eng. Vol. 53, p. 267, 1975	Air/Water	Coalescence Mechanisms Review of Gas-Liquid Bubble Models
49	Marrucci, G. Rising Velocity of a Swarm of Spherical Bubbles Ind. and Eng. Chem., Vol. 4, p. 224, May 1965	Theoretical Study	Behavior of Bubble Swarms
50	Mendelson, H. D. The Prediction of Bubble Terminal Velocities from Wave Theory A.I.Ch.E. Journal, Vol. 13, p. 250, 3/1967	Non-Soluble Gas/Low Viscosity Liquids	Single Bubble Rise Velocity
51	Narayanan, S., Goossens, L. H. J., and Kossen, N. W. F. Coalescence of Two Bubbles Rising in Line at Low Reynolds Numbers Chem. Eng., Science, Vol. 29, pp. 2071-2082, 1974	Air/Glycerine	Bubble Wakes Bubble Coalescence
52	Nicklin, D. J., Wilkes, J. O., and Davidson, J. F. Two-Phase Flow in Vertical Tubes Trans. Instn. Ch. Eng., Vol. 40, p. 61, 1962	Air/Water	Slug Behavior
53	Nicklin, D. J. Two-Phase Bubble Flow Chem. Eng. Science, Vol. 17, pp. 693-702, 1962	Air/Water	Behavior of Swarms
54	Nicolitsas, A. J. and Murgatroyd, W. Precise Measurements of Slug Speeds in Air-Water Flows Chem. Eng. Science, Vol. 23, pp. 934-936, 1968	Air/Water	Slug Behavior
55	Peebles, F. N. and Garber, H. J. Studies on the Motion of Gas Bubbles in Liquids Chem. Eng. Progress, Vol. 49, p. 88, 1953	Air/22 Liquids	Single Bubble Behavior
56	Rippin, D. W. T. and Davidson, J. F. Free Streamline Theory for a Large Gas Bubble in a Liquid Chem. Eng. Science, Vol. 22, pp. 217-228, 1967	Theoretical Study	Background
57	Schwerdtfeger, K. Velocity of Rise of Argon Bubbles in Mercury Chem. Eng. Science, Vol. 23, pp. 937-938, 1968	Argon/Mercury	Single Bubble Behavior
58	Slaughter, I. and Wraith, A. E. The Wake of a Large Gas Bubble Chem. Eng. Science, Vol. 23, p. 932, 1968	Gas/Water-Glycerol	Wake Behavior
59	Taylor, G. I. The Instability of Liquid Surfaces When Accelerated in a Direction Perpendicular to Their Planes Proc. Royal Society, Vol. 201, Series A, p. 192, 1950	Theoretical Study	Bubble Break-up

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Literature on The Hydrodynamics of Fluidization

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B. Vertical Gas-Liquid Systems

Reference No.	Reference	Systems Covered	Significance to Project
60	Turner, J. C. R. On Bubble Flow in Liquids and Fluidized Beds Chem. Eng. Science, Vol. 21, pp. 971-974, 1966	Theoretical Study	Gas-Liquid Model
61	Wallis, G. B. One Dimensional Two-Phase Flow McGraw-Hill, N. Y., 1969	Various	Background in Many Areas
62	Zieminski, S. A. and Raymond, D. R. Experimental Study of the Behavior of Single Bubbles Chem. Eng. Science, Vol. 23, pp. 17-28, 1968	CO_2/Water	Background
63	Zuber, N. and Findlay, J. A. Average Volumetric Concentration in Two-Phase Flow Systems Journal of Heat Transfer, Vol. 87, C, p. 453, 1965	Review of Literature Data	Gas-Liquid Flow Models

C. Gas-Liquid-Solid Systems:

Reference No.	Reference	Systems Covered	Significance to Project
64	Adlington, D. and Thompson, E. Desulphurization in Fixed and Fluidized Bed Catalyst Systems Proc. Euro. Symp. on Chem. React. Eng., p. 203, Pergamon Press, 1965	Gas/White Spirit/Alumina Gas/Water/Sand	Three-Phase Data
65	Bhatia, V. K. and Epstein, N. Three Phase Fluidization: A Generalized Wake Model Proc. Euro. Symp. on Fluidization, p. 380, 1974	Air/Water/Spheres	Model
66	Blum, D. B. and Toman, J. J. Three-Phase Fluidization in a Liquid Phase Methanator A.I.Ch.E. Symp., Vol. 73, No. 167, p. 115, 1977	Nitrogen/Mineral Oil/Cylindrical Catalysts	Empirical Holdup Correlation
67	Bruce, P. N. and Revel-Chion, L. Bed Porosity in Three-Phase Fluidization Powder Technology, Vol. #4, pp. 243-249, 1974	Air/Water/Glass Spheres	Three-Phase Data
68	Dakshinamurty, P., Subranmanyam, V., and Rao, J. N. Bed Porosities in Gas-Liquid Fluidization Ind. Eng. Ch. Process Des. Devl., Vol. 10, No. 3, p. 322, 1971	Air/Water and Kerosene/Rockwool Shot Glass Beads, Sand, Iron Shot	Empirical Hold-up Correlation
69	Dakshinamurty, P., Subrahmanyam, V., and Rao, J. N. Bed Porosities in Gas-Liquid Fluidization Ind. Eng. Ch. Process Des. Devl., Vol. 11, No. 2, p. 318, 1972	Air/Water/Shot, " " /Glass Beads Nitrogen/Electrolyte/Glass Beads " " /Rockwool Shot	Empirical Hold-up Correlation
70	Darton, R. C. and Harrison, D. Gas and Liquid Hold-up in Three-Phase Fluidization Chem. Eng. Science, Vol. 30, pp. 581-586, 1975	No Experimental Work	Model

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Literature on The Hydrodynamics of Fluidization

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C. Gas-Liquid-Solid Systems:

Reference No.	Reference	Systems Covered	Significance to Project
71	Darton, R. C. and Harrison, D. The Rise of Single Bubbles in Liquid Fluidized Beds Trans Instn. Chem. Eng., Vol. 52, p. 301, 1974	Air/Water/Sand	Single Bubble Behavior
72	Efremov, G. I. and Vakhrushev, I. A. A Study of the Hydrodynamics of Three-Phase Fluidized Beds International Chem. Eng., Vol. 10, No. 11, p. 37, 1970	Air/Water/Glass Beads	Model
73	Epstein, Norman Criterion for Initial Contraction or Expansion of Three-Phase Fluidized Beds Canadian Journal Chem. Eng., Vol. 54, p. 259, 1976	No Experimental Work	Model
74	Epstein, N., Evans, K. A., and Bhatia, V. K. Effects of Solid Wettability on Expansion of Gas-Liquid Fluidized Beds Ind. Eng. Chem. Des. Devl., Vol. 11, No. 1, p. 151, 1972	Air/Kerosene/Rockwool Shot Air/Water/Rockwool Shot	Background
75	Henriksen, H. K. and Ostergaard, K. On the Mechanism of Break-up of Large Bubbles in Liquids and Three-Phase Fluidized Beds Chem. Eng. Science, Vol. 29, pp. 626-629, 1974	Air/Water/Glass Spheres Air/Water/Steel Spheres Air/Methanol/Glass Spheres	Bubble Break-up
76	Henriksen, H. K. PhD Dissertation Danmark Tekniske Hojskole, 1972		Background
77	Henriksen, H. K. and Ostergaard, K. Characteristics of Large Two-Dimensional Air Bubbles in Liquids and in Three-Phase Fluidized Beds Chem. Eng. Journ., Vol. 7, p. 141-146, 1974	Air/Water/Glass Beads Air/Water-Glycerol/Glass Beads Air/Water-Methanol/Beads	Single Bubble Behavior
78	Kim, S. D., Baker, C. G. J., and Bergouginou, M. A. Hold-up and Axial Mixing Characteristics of Two and Three-Phase Fluidized Beds Canadian Journ. Chem. Eng., Vol. 50, p. 695, 1972	Air/Water/Gravel Air/Water/Glass Beads	Three-Phase Data Behavior of Bubble Swarms
79	Kim, S. D., Baker, C. G. J., and Bergouginou, M. A. Bubble Characteristics in Three-Phase Fluidized Beds Chem. Eng. Science, Vol. 32, pp. 1299-1306, 1977	Air/Water/Glass Beads-Gravel Air/Water-Acetone/Glass Beads-Gravel Air/Aqueous Sugar-Carboxymethyl Cellulose/Glass Beads-Gravel	Behavior of Bubble Swarms
80	Kim, S. D., Baker, C. G. J., and Bergouginou, M. A. Phase Hold-up Characteristics of Three-Phase Fluidized Beds Canadian Journ. Chem. Eng., Vol. 53, p. 134, 1975	Air/Solution/Glass Beads Air/Solution/Gravel	Empirical Hold-up Correlations
81	Lee, J. C. 4th Euro. Symp. Chem. Reaction Eng., p. 27, Pergamon Press, Oxford, 1971		Bubble Break-up
82	Lee, J. C. 3rd Euro. Symp. Chem. Reaction Eng., p. 211, Pergamon Press, Oxford, 1965	Air/Water/Glass Beads	Effect of Particle Size on Bubble Coalescence

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C. Gas-Liquid-Solid Systems:

Reference No.	Reference	Systems Covered	Significance to Project
83	Levsh, I. P., Krainev, N. F., and Niyazov, M. I. Calculations of the Pressure Drop and Heights of Three-Phase Fluidized Beds International Chem. Eng., Vol. 8, No. 2, p. 311, 1968	Air/Water/Packing	Background
84	Mach, I. W. Suspension of Solid Bodies in the Turbulent Gas/Liquid Stream Chem. Eng. Tech., Vol. 42, p. 311, March 1970	No Experimental Work	Background
85	Massimilla, L., Solimando, A., and Squillace, E. Gas Dispersion in Solid-Liquid Fluidized Beds British Chem. Eng., Vol. 6, p. 232, 1961	Air/Water/Glass Beads	Single Bubble Behavior Bubble Coalescence
86	Michelsen, M. L. and Ostergaard, K. Hold-up and Fluid Mixing in Gas-Liquid Fluidized Beds Chem. Eng. Journal, Vol. 1, p. 37, 1970	Air/Water/Ballotini	Three-Phase Data Gas and Liquid Tracers
87	Nemets, L. L., Razumov, and Manshilin, V. V. Volumetric Contents of Liquid and Solid Phases in Three-Phase Fluidized Bed in Relation to Viscosity of Liquid Medium Khimiya i Tekhnologiya Topliv i Masel, No. 2, pp. 37-40, Feb. 1975	Air/Heptane/Sand Air/Water/Sand Air/Water-Glycerol/Sand	Three-Phase Hold-up Data
88	Ostergaard, K. Gas-Liquid-Particle Operations in Chemical Reaction Engineering Advances in Chem. Eng., Vol. 7, p. 71, 1968 Academic Press.	No Experimental Work	Review
89	Ostergaard, K. Fluidization p. 58, Society of Chem. Industry, 1964	Air/Water/Ballotini	Three-Phase Hold-up Data
90	Ostergaard, K. and Theisen, P. I. The Effect of Particle Size and Bed Height on the Expansion of Mixed Phase (Gas-Liquid) Fluidized Beds Chem. Eng. Science, Vol. 21, pp. 413-417, 1966	Air/Water/Glass Ballotini	Three-Phase Hold-up Data
91	Ostergaard, K. and Michelsen, M. L. Hold-up and Axial Dispersion in Gas-Liquid Fluidized Beds, The Effect of Fluid Velocities and Particle Size 2nd Joint A.I.Ch.E.-IIQPR Meeting, Preprint 31D, A.I.Ch.E., May 1968	Air/Water/Particles	Three-Phase Hold-up Data
92	Ostergaard, K. Fluidization (edited by Davidson, J. F. and Harrison, D.) Academic Press, N. Y., 1971		Review
93	Ostergaard, K. On Bed Porosity in Gas-Liquid Fluidization Chem. Eng. Science, Vol. 20, pp. 165-167, 1965	No Experimental Work	Model
94	Ostergaard, K. Flow Phenomena of Three-Phase (Gas-Liquid-Solid) Fluidized Beds A.I.Ch.E. Symposium Series, Vol. 69, No. 128, p. 28, 1973	No Experimental Work	Review of Fundamentals

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Literature on The Hydrodynamics of Fluidization

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C. Gas-Liquid-Solid Systems:

Reference No.	Reference	Systems Covered	Significance to Project
95	Ostergaard, K. On the Growth of Air Bubbles Formed at a Single Orifice in a Water Fluidized Bed Chem. Eng. Science, Vol. 21, pp. 470-472, 1966	Water/Air/Sand	Bubble Coalescence
96	Ostergaard, K. and Fosbol, P. Transfer of Oxygen Across the Gas-Liquid Interface in Gas-Liquid Fluidized Beds Chem. Eng. Journal, Vol. 3, p. 105, 1972	Oxygen/Water/Glass Ballotini	Background
97	Ostergaard, K. Hold-up, Mass Transfer, and Mixing in Three-Phase Fluidization Paper, A.I.Ch.E., 69th Annual Meeting, Chicago, Nov. 28-Dec. 2, 1976	Air/Water/Glass Ballotini	Background
98	Razumov, I. M., Manshilin, V. V., and Nemets, L. L. The Structure of Three-Phase Fluidized Beds International Chem. Eng., Vol. 13, No. 1, p. 57, 1973	Air/Water/Sand	Empirical Hold-up Correlation
99	Rigby, G. R. and Capes, C. E. Bed Expansion and Bubble Wakes in Three-Phase Fluidization Canadian Journal Ch. Eng., Vol. 48, p. 343, 1970	Air/Water/Ballotini-Sand	Bubble Wake Structure
100	Rigby, G. R., Van Blockland, G. P., Parks, W. H., and Capes, C. E. Properties of Bubbles in Three-Phase Fluidized Beds as Measured by an Electroresistivity Probe Chem. Eng. Science, Vol. 25, pp. 1729-1741, 1970	Air/Water/Glass Beads-Sand	Behavior of Bubble Swarms
101	Roy, N. K., Guma, D. K., and Rao, M. N. Suspension of Solids in a Bubbling Liquid (Critical Gas Flow Rates for Complete Suspension) Chem. Eng. Science, Vol. 19, pp. 215-225, 1964	Air/Pure Liquids/Quartz, Coal, or Catalyst Powder Air/Solutions/Quartz, Coal, or Catalyst Powder	Background
102	Schuman, S. C., Wolk, R., Chervenak, M. C. Hydrogenation of Oils U. S. Patent No. 3, 183, 180, May 11, 1965	Hydrogen/Oil/Catalyst	Background
103	Stewart, P. S. B. and Davidson, J. F. Three-Phase Fluidization: Water, Particles and Air Chem. Eng. Science, Vol. 19, pp. 319-322, 1964	Air/Water/Ballotini, Lead, and Iron Shot	Bubble Wake Structure
104	Stewart, P. S. B. PhD Dissertation University of Cambridge, 1965		Model
105	Turner, R. Proceedings of Chem. Eng. Group, Soc. Chem. Ind., Vol. 42, p. 47, 1963		Bed Construction Data
106	Turner, R. Fluidization Soc. of Chem. Ind., p. 147, 1964	Air, Nitrogen/Water/Sand	Three-Phase Hold-up Data

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C. Gas-Liquid-Solid Systems:

Reference No.	Reference	Systems Covered	Significance to Project
107	Vail, Y. K., Manakov, N. K., and Manshilin, V. V. The Gas Contents of Three-Phase Fluidized Beds Intern. Ch. Eng., Vol. 10, No. 2, p. 244, 1970	Air/Water/Glass Beads	Three-Phase Data
108	Verbitskii, B. G. and Vakhrushev, I. A. Rate of Ascent of Isolated Gas Bubbles in a Bed Fluidized by a Liquid Khim i Tek Mas., No. 4, p. 36-39, April 1974	Air/Sunflower Oil, HCL Solution, Water/Glass Beads	Single Bubble Behavior
109	Viswanathan S., Kakar, A. S. and Murti, P. S. Effect of Dispersing Bubbles Into Liquid Fluidized Beds on Heat Transfer and Hold-up at Constant Bed Expansion CHEM Eng. Science, Vol. 20, pp. 903-910, 1964	Air/Water/Quartz Air/Water/Glass Beads	Three Phase Data

D. Gas-Solid Fluidization:

Reference No.	Reference	Systems Covered	Significance to Project
110	Batchelor, G. K. Low-Reynolds-Number Bubbles in Fluidized Beds Archives of Mechanics, Vol. 26, No. 3, pp. 339-351, 1974	Theoretical Study	Background
111	Chatterjee, S. Spout-Fluid Bed Technique Ind. Eng. Chem. Proc. Des. Devl., Vol. 9, No. 2, p. 340, 1970	Air/Sand Air/Coal	Background
112	Chiba, T. and Kobayashi, H. Gas Exchange Between the Bubble and Emulsion Phases in Gas-Solid Fluidized Beds Advances in Chem. Series, No. 109, p. 132	Air-Ozone/Glass Beads	Background
113	Clift, R. Bubble Interaction in Fluidized Beds Diss. Abstr. Int., B32 (1), p. 261-B, July 1971	Theoretical Study	Background
114	Collins, R. The Rise Velocity of Davidson's Fluidization Bubble Chem. Eng. Science, Vol. 20, pp. 788-789, 1964	Theoretical Study	Background
115	Davidson, J. F. Bubble Motion in Liquids and Fluidized Beds Proc. Roy. Inst., Vol. 45, pp. 161-167, 1972	No Experimental Data	Background
116	Fryer, C. and Potter, O. E. Bubble Size Variation in Two-Phase Models of Fluidized Bed Reactors Powder Technol., 6 (1972), p. 317	Theoretical Study	Background
117	Gibbs, B. M. and Perry, M. G. Paper 29D, Experimental Test of the Bubbling Bed Model for the Prediction of Residence Time Distributions 69th National Meeting, A.I.Ch.E., May 1971		Background

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Literature on The Hydrodynamics of Fluidization
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D. Gas-Solid Fluidization:

Reference No.	Reference	Systems Covered	Significance to Project
118	Grace, J. R. An Evaluation of Models for Fluidized-Bed Reactors A.I.Ch.E. Symp. Series, Vol. 67, No. 116, p. 159, 1971	Gas-Solid	Background
119	Mikula, O. and Havalda, I. Discussion on the Two-Phase Model of Non-Uniformly Fluidized Beds According to Pyle and Harrison Chem. Zvesti, Vol. 27, pp. 634-642, 1973	Air/Glass Ballotini	Background
120	Mori, S. and Wen, C. Y. Estimation of Bubble Diameter in Gaseous Fluidized Beds A.I.Ch.E. Journal, Vol. 21, No. 1, p. 109, 1975	Review of Various Systems	Background
121	Pyle, D. L. and Harrison, D. The Rising Velocity of Bubbles in Two-Dimensional Fluidized Beds Chem. Eng. Science, Vol. 22, pp. 531-535, 1967	Air/Solid Particles	Background
122	Pyle, D. L. Fluidized Bed Reactors: A Review Chem. Reaction Eng.. Ch. 3, p. 106, 1970	No Experimental Work	Review
123	Ravindram, M. Significance of Residence Time Distribution Studies in the Design of Fluidized Bed Reactors Chemical Aga India, Vol. 17, No. 6, p. 447-449, 1966		Background
124	Reuter, H. Fluid Particle Technology Chem. Eng. Progress Symp., Vol. 62, No. 62, 1966	Experimental Work	Background
125	Rieke, R. D. and Pigford, R. L. Behavior of Gas Bubbles in Fluidized Beds A.I.Ch.E. Journal, Vol. 17, No. 9, p. 1096, 1971.	Air/Glass Beads	Background
126	Rowe, P. N. and Partridge, B. A. An X-Ray Study of Bubbles in Fluidized Beds Trans. Instn. Ch. Eng., Vol. 43, p. T-157, 1965	Air/Ballotini Air/Sand	Background
127	Ruckenstein, E. and Muntean, O. On the Mechanism of Bubble Formation in a Fluidized Bed Canadian Journ. Ch. Eng., Vol. 45, p. 95, 1967	Theoretical Study	Background
128	Schuegerl, K. Mixing Processes in Multiphase Flow Systems Chem. Ingr. Tech., 38, Nov. 1966	Water/Soluble and Insol. Gases/ Small and Medium Particles	Background
129	Tigrel, A. Z. and Pyle, D. L. A Model for a Fluidized Bed Catalytic Cracker Chem. Eng. Science, Vol. 26, pp. 133-145, 1971	No Experimental Work	Background

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D. Gas-Solid Fluidization:

Reference No.	Reference	Systems Covered	Significance to Project
130	Wen, C. Y. Research Needs for the Analysis, Design, and Scale-up of Fluidized Beds 67th Annual A.I.Ch.E., paper 41-A, Dec. 1974	No Experimental Work	Background
131	Werther, J. Bubble Chains in Large Diameter Gas Fluidized Beds Int. J. Multiphase Flow, Vol. 3, pp. 367-381, 1977	Air/Quartz Sand	Background
132	Yates, J. G. Fluidized Bed Reactors The Chem. Eng., No. 303, p. 671, Nov. 1975	No Experimental Work	Background

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TABLE D-II

Literature on Experimental or Analytical Techniques and Equipment

Reference No.	Reference	Technique	Application
133	Alonso, C. V. Comparative Study of Electrical Conductivity Probes Journal Hydraulic Res., Vol. 9, No. 1, p. 1, 1971	Conductivity Probes	Characterize Liquid Flow
134	Arunachalam, V., Hummel, R. L., and Smith, I. W. Flow Visualization Studies of a Turbulent Drag Reducing Solution Canadian Journ. Chem. Eng., Vol. 50, p. 337, 1972	Dye Tracers	Characterize Liquid Flow
135	Bartholomen, R. N. and Casagrande, R. M. Measuring Solids Concentration in Fluidized Systems by Gamma-Ray Absorption Ind. and Eng. Chem., Vol. 49, No. 3, p. 428, 1957	Gamma Ray Absorption	Algorithm for Establishing Point Densities from Gamma-Ray Measurement
136	Blasso, L. Flow Measurement Under Any Condition Inst. and Control Systems, p. 45, Feb. 1975	Survey of Flow Measurement Techniques	Background
137	Botton, R. J. Gas-Solid Contacting in Fluidized Beds A.I.Ch.E. Symp., Vol. 66, No. 101, p. 8, 1970	Gas Tracers	Background
138	Brown, A. E. Dual Path Ultrasonic Measurement of Fluid Flow Review of Scientific Inst., Vol. 37, No. 9, p. 1181, 1966	Ultrasonics	Flowmeter
139	Burgess, J. M. and Calderbank, P. H. The Measurement of Bubble Parameters in Two-Phase Dispersions Chem. Eng. Science, Vol. 30, pp. 743-750, 1975	Impedance Probe	Determine Bubble Characteristics
140	Calderbank, P. H., Evans, F., and Rennie, J. The Mass-Transfer Efficiency of Distillation and Gas-Absorption Plate Columns Inter. Symp. on Dist. (1960)	Gamma-Ray Absorption	Density Determination Using Gamma-Ray Scans
141	Cameron, J. F. Fluid Density Measurements in Enclosed Systems Int. Conf. on Radio Isotopes, Paper No. NS/Ric/195, p. 426	Radiation Detectors	Density Determination Using Gamma-Ray Scans
142	Chen, B. H. and Osberg, G. L. Radial Gas Dispersion in a Column Packed with Screen Cylinders Canadian Journ. Chem. Eng., Vol. 45, p. 46, 1967	Tracer Gas	Background
143	Crescitelli, S., Egiziano, L., and Macchiaroli, B. Glow Discharge Probes for Fluid Bed Applications Ing. Chim. Ital., Vol. 10, No. 2, p. 23, 1974	Glow Discharge	Background
144	Darton, R. C. and Harrison, D. Some Properties of Gas Bubbles in Three-Phase Fluidized Beds Inst. Ch. Eng. Symp. Series No. 38, Vol. 1, Paper B-1, 1974	Impedance Probe	Determine Bubble Characteristics

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Literature on Experimental or Analytical Techniques and Equipment
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Reference No.	Reference	Technique	Application
145	Delhaye, J. M. and Jones, O. C., Jr. Measurement Techniques for Transient and Statistical Studies of Two-Phase, Gas-Liquid Flows Paper, Heat Transfer Conf., A.S.M.E., San Francisco, Calif., Aug. 1975	Review of All Techniques: Light Probe	Determination of Gas and Liquid Hold-up
146	Delhaye, J. M., Semeria, R., and Flamand, J. C. Void Fraction and Vapor and Liquid Temperatures: Local Measurements in Two-Phase Flow Using a Micro Thermocouple Journ. of Heat Transfer, p. 365, Aug. 1973	Phase Measurement by Thermocouple	Background
147	Farley, R. and Ray, D. J. Gamma Radiation Absorption Measurement of Density and Gas Hold-up in a Three-Phase Catalytic Reactor British Ch. Eng., Vol. 9, No. 12, p. 830, 1964	Gamma-Ray Scanning	Density Determination
148	Fries, B. A. Chemical Engineering Progress Symposium Series Nuclear Engineering, Part XXII, Vol. 66, No. 106, p. 1, 1970	Radioactive Tracer	Background
149	Geake, J. E. Linear Refractometers for Liquid Concentration Measurement Chem. Eng., Vol. 297, p. 305, May 1975	Light Probe Measurement	Background
150	Gilliland, E. R. and Mason, E. A. Gas Mixing in Beds of Fluidized Solids Ind. Eng. Chem., Vol. 44, p. 218, Jan. 1952	Tracer Gas	Background
151	Hancox, W. T., Forrest, C. F., and Harms, A. A. Void Determination in Two-Phase Systems Employing Neutron Transmission Paper, A.I.Ch.E.-A.S.M.E. Heat Transfer Conf., Aug. 1972	Neutron Transmission	Background Applied to Gamma-Ray Scans
152	Hancox, W. T. and Harms, A. A. Discrete-Time Neutron Interrogation of Liquid Flow Systems Trans. Am. Nuclear Soc., Vol. 14, p. 1, 1971	Neutron Scanning	Background
153	Hull, R. L. and Von Rosenberg, A. E. Industrial and Engineering Chemistry, Vol. 52, No. 12, p. 989, 1960	Radioactive Tracer	Externally Detected Tagged Catalyst
154	Hunt, R. H., Biles, W. R., and Reed, C. O. Find Catalyst Density With Isotopes Petr. Refiner, Vol. 36, No. 4, p. 179, 1957	Gamma-Ray Absorption	Algorithm for Establishing Point Densities from Gamma-Ray Measurement
155	Jones, Jr., O. C. and Delhaye, J. M. Transient and Statistical Measurement Techniques for Two-Phase Flows Int. J. Multiphase Flow, Vol. 3, No. 2A, p. 89, 1976	Review of Measuring Techniques	Optical Probes
156	Keeler, R. N., Petersen, E. E. and Prausnitz, J. M. Mixing and Chemical Reaction in Turbulent Flow Reactors A.I.Ch.E. Journal, Vol. 11, No. 2, p. 221, 1965	Conductivity Probe	Background

TABLE D-II

Literature on Experimental or Analytical Techniques and Equipment

-3-

Reference No.	Reference	Technique	Application
157	Kim, B. O. and Harris, T. R. The Experimental Measurement and Theoretical Analysis of Flow-System Tracer Curves by a Line-Sampling Method Chem. Eng. Science, Vol. 28, pp. 1653-1659, 1973	Conductivity Probe	Background
158	Kohl, J., Zentner, R. D., and Lukens, H. R. Radioisotope Applications Engineering D. Van Nostrand Co., Princeton, New Jersey, 1961	Gamma-Ray Scans and Radioactive Tracers	Radioactive Experiments
159	Magrini, U. Flowmeter for Measurement of Low Velocities in Liquids with Weak Electrical Conductance Review of Scientific Inst., Vol. 37, No. 35, p. 627, 1966	Conductance Probe	Background
160	Manieh, A. A. Sensing the Height of a Gas-Fluidized Bed Chem. Eng., p. 112, Aug. 1973	Conductivity Measurement	Background
161	Mann, U. and Crosby, E. J. Cycle Time Distribution in Circulating Systems Chem. Eng. Science, Vol. 28, pp. 623-627, 1973	Use of Gas Tracers to Determine Cycle Time Distribution	Background
162	McDonald, D. P. Ultrasonics are Moving Into Unconventional Processing Applications Process Eng., p. 82, June 1973	Ultrasonics	Background
163	McShane, J. L. and Geil, F. G. Measuring Flow Res./Devl., Vol. 26, No. 2, p. 30, 1975	Survey of Measurement Devices	Flow Rate of Coal Slurries
164	Metcalfe, T. B. Chemical Engineering Progress Vol. 60, No. 2, p. 71, 1964	Radioactive Tracer	Sampled Tagged Catalyst
165	Morikawa, S., Lanz, O., and Johnson, C. C. Laser Doppler Measurements of Localized Pulsatile Fluid Velocity I.E.E.E. Trans. on Bio-Medical Eng., Vol. BM1-18, No. 6, p. 46, Nov. 1971	Optical Doppler Meter	Background
166	Nakatani, N., Fujiwara, K., Matsumoto, M., and Yamada, T. Measurement of Flow Velocity Distributions by Pulse Luminescence Method Journ. Physics E: Scientific Instr., Vol. 8, p. 1042, 1975	Pulse Luminescence	Liquid Flow Visualization
167	Nam-Koong, S. and Sae-Ki, M. A Dynamic Response Study of Gas Residence Time in a Fluidized Bed Int. Chem. Eng., Vol. 6, No. 4, p. 668, Oct. 1966	Adsorbing Tracer Gases	Background
168	Nauman, E. B. and Collinge, C. N. Measurement of Contact Time Distributions in Gas Fluidized Beds Chem. Eng. Science, Vol. 23, pp. 1317-1326, 1968	Weakly Absorbing Tracers	Background

TABLE D-II

Literature on Experimental or Analytical Techniques and Equipment

-4-

Reference No.	Reference	Technique	Application
169	Noble, F. W. Dual Frequency Ultrasonic Fluid Flowmeter Review of Scientific Inst., Vol. 39, No. 9, p. 1327, Sept. 1968	Ultrasonics	Background
170	Nye, J. O. and Brodkey, R. S. Light Probe for Measurement of Turbulent Concentration Fluctuations Rev. Sc. Inst., Vol. 38, No. 1, p. 26, Jan. 1967	Light Probes	Background
171	Singer, E., Todd, D. B., and Guinn, V. P. Industrial and Engineering Chemistry Vol. 49, No. 1, p. 11, 1957	Radioactive Tracer	Sampled Tagged Catalyst
172	Sorrentino, C. D. F.C.U. Radioactive Tracer Studies N77-10, Amoco Oil Co., Feb. 1977	Radioactive Tracers	Experimental Techniques
173	Tiley, P. F. Opening New Windows to On-Stream Analysis Process Eng., p. 89, Nov. 1974	Orifices: Fluid Jet Measurements	Background
174	Yasui, G. and Johanson, L. N. Characteristics of Gas Pockets in Fluidized Beds A.I.Ch.E. Journal, Vol. 4, No. 4, p. 445, 1958	Light Probe	Background
175	Zientara, D. E. Measuring Process Variables Chem. Eng., Deskbook Issue, p. 19, Sept. 11, 1972	Review of Techniques to Measure Process Variables	Background

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TABLE D-III

Literature on Physical Properties of Coal-Oil Mixtures

Reference No.	Reference	Coal Concentration	Significance to Project
176	Barrett, D. and Sergeant, G.D. Coal-Oil Mixtures Pace, 27, No. 4, April 1974	0 - 40%, 40 - 60%	Background
177	Droege, J.W., Hassell, J.A., Kleinschmidt, W.W., and Chauhan, S.P. Final Technical Report on Physical Properties of Synthoil Products ERDA, Contract No. E (46-1)-8009 Battelle Laboratories, Columbus, Ohio, July 6, 1977		Viscosity Measurement Technique
178	Petrolite Corp. - (News Report) Chemical Additive Keeps Crushed Coal in Slurries on the Move Coal Age, p. 140, Dec. 1974	0 - 65%	Experimental Operation
179	Rudzki, E.M., Pease, B.K. and Weidner, T.H. Use of Coal-In-Oil Mixtures to Improve Open-Hearth Furnace Performance Journal of the Institute of Fuel, p. 154, April, 1965	0 - 60%	Viscosity of Coal-Oil Mixtures

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TABLE D-IV

General Literature Related to Fluidization

Reference No.	Reference	Significance to Project
180	Bankoff, S.G. A Variable Density Single-Fluid Model for Two-Phase Flow With Particular Reference to Steam-Water Flow Journ. of Heat Transfer, p. 265, Nov. 1960	Background
181	Brown, R.A.S. and Jensen, E.J. The Pipeline Flow of Paste Slugs Part II. Pressure Gradients and Velocities of Trains of Slugs Canadian Journ. of Ch. Eng., Vol. 46, p. 157, June 1968	Background
182	Cole, R, and Shulman, H.L. Bubble Growth Rates at High Jakob Numbers Int. J. Heat Mass Transfer, Vol. 9, p. 1377, Pergamon 1966	Theory on Bubble Growth
183	Dwivedi, P.N. and Upadhyay, S.N. Particle - Fluid Mass Transfer in Fixed and Fluidized Beds Ind. Eng. Chem. Des. Dev'l., Vol. 16, No. 2, p. 157, 1977	Background
184	Gill, W.N., Cole, R., Estrin, J., Nunge, R.J., and Littman, H. Fluid Dynamics Ind. Eng. Chem., Vol. 61, No. 1, p. 41, Jan. 1969	Thorough Review of 1967 Literature
185	Froment, G.F. Model Discrimination and Parameter Estimation in Heterogeneous Catalysis A.I.Ch.E. Journal, Vol. 21, No. 6, p. 1041, Nov. 1975	Background
186	Francis, R.C. and Berg, J.C. The Effect of Surfactants on a Packed Distillation Column Ch. Eng. Science, Vol. 22, p. 685, 1967	Bubble Coalescence
187	Heywood, H. J. Imp. College Chem. Eng. Soc., Vol. 4, p 17, 1948	Particle Shape Factor
188	Jeffrey, D.J., and Acrivos, A. AIChE Journ., Vol. 22, No. 3, p. 417, 1976	Review of Methods for Analysis of Viscosity Data of Suspensions
189	Kolbel, H., Klotzer, I.D., and Hammer, I.H. Reaction Technology of Bubble Column Reactors With Suspended Catalyst at Elevated Pressure Ch. Eng. Tech. 43, No. 3, p. 103, Jan. 1971	Background

TABLE D-IV

General Literature Related to Fluidization
-2-

Reference No.	Reference	Significance to Project
190	Krieger, I.M., and Dougherty, T.J., A Mechanism for Non-Newtonian Flow in Suspensions of Rigid Spheres Trans. Soc. Rheol, Vol. 3, pp. 137-152, 1959	Correlation for Viscosity of Suspensions
191	Maxwell, J.B. Data Book on Hydrocarbons Van Nostrand, New York, pp. 163-165, 1950	Viscosity of Crude Fractions
192	Melcher, J.R. and Hurwitz, M. Gradient Stabilization of Electrohydrodynamically Oriented Liquids J. Spacecraft Rockets, Vol. 4, p. 864, 1967	Stability of Interfaces
193	Mooney, M. The Viscosity of a Concentrated Suspension of Spherical Particles Journal Colloid. Science, Vol. 6, p. 162, 1951	Viscosity Relationships in Suspensions
194	Pritchard, D.J. and Bacon, D.W. Statistical Assessment of Chemical Kinetic Models Ch. Eng. Science, Vol. 30, p. 567, 1975	Background
195	Ross, S. Mechanisms of Foam Stabilization and Antifoaming Action Ch. Eng. Progress, Vol. 63, p. 41, Sept. 1967	Bubble Coalescence
196	Shakhova, N.A. and Lastovtseva, G.N. The Problem of Interface Heat Transfer in a Fluidized Bed Int. Chem. Eng., Vol. 14, No. 3, p. 527, July 1974	Background
197	Turner, R. Fluidization in the Petroleum Industry Proc. Chem. Eng. Group, Soc. Chem. Ind., p. 47, 1963	Background
198	Weekman Jr., V.W. Laboratory Reactors and Their Limitations A.I.Ch.E. Journal, Vol. 20, No. 5, p. 833, Sept. 1974	Background
199	Yeheskel, J. and Kehat, Ephraim The Size and Rate of Shedding of Wakes of Single Drops Rising in a Continuous Medium Ch. Eng. Science, Vol. 26, p. 1223, 1971	Liquid - Liquid Wake Behavior
200	Zighanshin, G.K., Stefoglo, E.F. and Ermakova, A. A Model Reaction for Determination of the Parameters for Mathematical Description of a Reactor With a Three-Phase Pseudo-Liquified Bed Kinet. Katal., Vol. 14 (2), p. 530, March-April 1973	Background

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TABLE D-V

Literature Provided by H-Coal Participants

Reference No.	Reference	Significance to Project
201	Volk, W. and Weber, C. HRI Report: Catalyst Concentration Measurements in Heptane Nitrogen Ebullated Bed Studies January 24, 1967	Background
202	Wolk, R. HRI Report: Variables Affecting the Performance of an Ebullated Bed May 4, 1961	Two and Three-Phase Data
203	Wolk, R. MRI Report: Gas-Liquid-Solid Fluidization June 18, 1962	Two and Three-Phase Data
204	Zenz, F. A. Private Communication to H. H. Stotler June 3, 1976	Correlation of Three-Phase Data
205	Consolidation Coal Company OCR Research and Development, Report No. 39, Vol. II, Book 2, Prepilot Plant Research on the CSF Process, Section VI, pp. 46-49 June 1968	Two and Three-Phase Data
206	Consolidation Coal Company OCR Research and Development, Report No. 39, Vol. IV, Book 3, "Pilot Scale Development of the CSF Process," Section IV, E, pp. 193-198	Two and Three-Phase Data
207	Hydrocarbon Research, Inc. Report to Atlantic-Richfield Company ARCO-HRI Joint H-Coal Development Program, Feb. 14, 1971, pp. 149-158	Viscosity of H-Coal Products
208	de Looper, H., Lehman, L. M., "The Importance of the Kentucky H-Coal Pilot Plant," HRI Engineering, Inc.	Background

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TABLE D-VI

ADDITIONAL REFERENCES

Reference No.	Reference	Significance to Project
209	Exxon Research and Engineering Company Quarterly Technical Progress Report, January 1-June 30, 1976, "EDS Coal Liquefaction Process Development," FE-2353-2, Contract E (49-18)-2353, October, 1977	Measurement of the viscosity of coal slurries
210	Lewis, E., and Bowerman, E. W., "Fluidization of Solid Particles in Liquids," Chem Eng Progr, Vol 48, p-603-610, 1952.	Liquid-solid fluidization
211	Wen, C. Y., and Fan, L. S., "Some Remarks on the Correlation of Bed Expansion in Liquid-Solid Fluidized Beds," Ind Eng Chem, Proc Des Devel, Vol 13, p 194, 1974.	Liquid-solid fluidization
212	Zenz, F. A., and Othmer, D. F., Fluidization and Fluid-Particle Systems, Chapter 7, Reinhold Publishing Corporation, 1960.	Background
213	Gartsman, A. N., Eimakova, A., Bakhbalova, V. P., and Rassadnikova, "Mass Transfer with Chemical Reaction in the Three-Phase System Gas-Liquid-Solid Catalyst," International Chemical Engineering, Vol 17, p. 697, 1977.	Background

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