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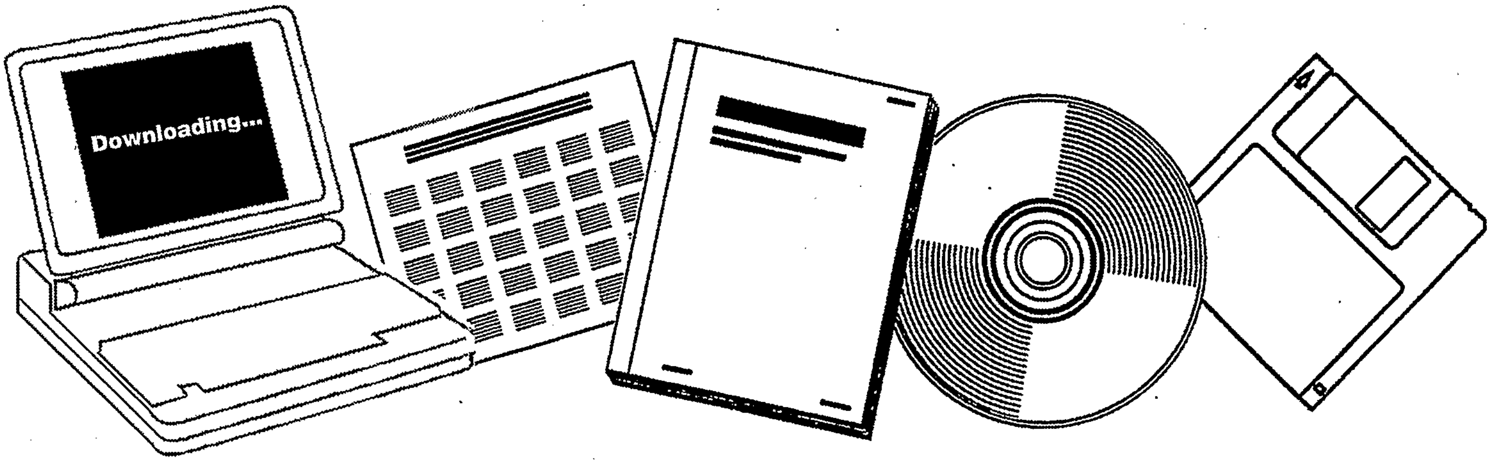
STUDY OF EBULLATED-BED FLUID DYNAMICS FOR H-COAL. QUARTERLY PROGRESS REPORT NO. 10, OCTOBER 1-DECEMBER 31, 1982

AMOCO RESEARCH CENTER
NAPERVILLE, IL

MAR 1983



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R. J. SCHAEFER, D. N. RUNDELL AND J. K. SHOU

DATE PUBLISHED: MARCH, 1983

CONTRACT DE-AC22-80PC30026

Research and Development Department
Amoco Oil Company
P. O. Box 400
Naperville, Illinois
60566

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PREPARED OR THE UNITED STATES
DEPARTMENT OF ENERGY
UNDER CONTRACT DE-AC22-80PC30026

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FOREWORD

The H-Coal process, developed by Hydrocarbon Research, Incorporated, (HRI) involves the direct hydroliquefaction of coal to low-sulfur boiler fuel or synthetic crude oil. The 200-600 ton-per-day H-Coal pilot plant is being operated next to the Ashland Oil, Incorporated, refinery at Catlettsburg, Kentucky, under DOE contract to Ashland Synthetic Fuels, Incorporated. The H-Coal ebullated bed reactor contains at least four discrete components: gas, liquid, catalyst, and unconverted coal and ash. Because of the complexity created by these four components, it is desirable to understand the fluid results of prior cold flow model experiments (1) to the operating H-Coal PDU reactor in Trenton, New Jersey. Studies are also planned to examine the coalescence behavior of gas bubbles in three-phase ebullated beds.

The work to be performed is divided into four parts: (1) fluid dynamics measurements on the PDU reactor, (2) gas bubble coalescence studies at Northwestern University, (3) cold flow and mixing tests at Amoco's Naperville Research Center, (4) and model implementation. The objective of this quarterly progress report is to outline progress in the first three areas.

SUMMARY

Task 1: H-Coal Reactor Fluid Dynamics

Carried out the cold-flow pilot plant Run 224 which used the Amocat-1A catalyst. The catalysts were fluidized by nitrogen and a slurry consisting of 25 wt% coal char fines in kerosene. Analysis of Run 224 data was started and preliminary results reported.

Task 2: Northwestern University/Gas Bubble Dynamics

Completed the construction of a remote-controlled traversing camera mount for the video camera and electronic devices necessary to improve the quality of the video image and to facilitate computer data acquisition. A holographic data analysis computer program was developed for calculating the Sauter mean bubble diameter.

Task 3: Liquid Mixing Study

Completed the experimental work for the liquid-phase mixing studies. The results have been used to develop a correlation between the liquid dispersion coefficient and the process variables. Performed the lateral gamma-ray scanning experiments across the reactor in order to evaluate the radial uniformity of phase holdups.

INTRODUCTION

The fluid dynamics of the H-Coal reactor have been previously studied in a cold flow unit. Reference 1 provides details of the construction of the unit and results of tests with a variety of gases, liquids, and catalyst sizes. A semi-theoretical model was developed to predict the volume fractions occupied by the gas, liquid, and catalyst phases. The aims of this new contract are fourfold:

1) The model developed using cold flow unit test results will be extended to apply to the operating H-Coal PDU reactor.

2) Because gas bubble dynamics are crucial in determining the nature of of flow, studies of bubble flow will be performed at Northwestern University using optically clear beds.

3) Liquid mixing tests will determine the residence time distribution of liquid in the reactor. Under the previous contract, it was determined that the coal char fines (simulating the unreacted coal and ash) were uniformly distributed throughout the bed. Hence, the measurement of liquid data is essential for modeling the residence time and kinetic parameters associated with the unreacted coal.

4) The model will be implemented into a readily usable format.

DATA COLLECTION

H-Coal Reactor Fluid Dynamics Study

Cold flow pilot plant fluidization experiments were performed this quarter in order to study the fluidization characteristics of Amocat-1A catalyst using nitrogen and a coal char/kerosene slurry.

Preparation of the Amocat 1A catalyst for the H-Coal fluid dynamics study was completed by soaking the fresh catalyst in kerosene for 15 days. The concentration of the coal char fines in kerosene was adjusted to 25 wt%. Thirty-eight fluidization tests were subsequently carried out. These tests consisted of bed expansion experiments run under various gas and slurry flow rates. The gas and slurry flow rates ranged from 0.0 to 0.15 ft/sec and 0.05 to 0.20 ft/sec, respectively. Bed expansions were measured using a travelling gamma-ray densitometer. Some gas and liquid velocities were selected to match those during the PDU-10 fluid dynamics experiments.

Northwestern University/Gas Bubble Dynamics

Construction of a remote-controlled traversing camera mount for the video camera was completed. Further work was done to improve this setup, including fitting the camera mount with a position-sensing device which will transfer the viewed position directly to the computer, and adding electronic devices which will improve the quality of the video image.

The helium-neon laser used to reconstruct the holograms needed a new plasma tube and was sent to the Spectra-Physics for repairs. Meanwhile, a Nd:YAG laser was used to reconstruct several holograms which appeared to have distinct bubble images.

A data processing computer program was developed. This program can measure the coordinates of several points on the edge of a bubble. By assuming the bubble is spherical and analyzing the data gathered on many bubbles, the program determines the Sauter mean bubble diameter for a given set of flow conditions.

Details are presented in the Northwestern University's monthly progress reports. The December monthly progress report is attached as Appendix A.

Liquid Mixing Tests

The remainder of the tests in the third series and the fourth series of liquid mixing experiments were carried out during this quarter. The total of four series of liquid mixing runs comprise the complete liquid mixing experimental plan.

Runs 490-14 through -16 in the third series of tests ~~were designed~~ to investigate the variation of liquid dispersion across the reactor diameter. These tests were carried out under the nominal H-Coal liquid velocity and zero gas flow conditions.

The fourth series of tests, consisting of Run 490-17 through -20 and Run 490-23, was carried out to investigate the effect of gas flow rate on liquid dispersion at the center of the reactor. The nitrogen gas flow was varied from 0 to 4.57 cm/sec (0-0.15 ft/sec), while the slurry flow rate was controlled at 3.05 cm/sec (0.10 ft/sec). Slurry samples were continuously drawn from the reactor for 4.8 sec/sample. In most cases, 25 samples were taken per tray.

Run 490-21 was a repeat of Run 490-4 in which the high gas velocity used may have caused the channeling near the reactor wall in the dense phase region. Run 490-21 was carried out in order to re-evaluate the high gas velocity effect. Run 490-22 was performed in order to obtain additional liquid dispersion data at a relatively higher liquid velocity.

Radial Uniformity of Phase Holdups

The lateral gamma-ray scanning experiments across the 6" ID cold flow fluidization column were carried out ion order to verify the previous assumption that bubbles are evenly distributed radially. The Amoco H-Coal cold flow pilot plant was modified so that the gamma-ray scanning could be performed at various radial positions. This involved remounting the gamma-ray source and the detector to a traversing support structure and realigning the gamma-ray instrument.

The lateral gamma-ray scan experiments were carried out using a 25 wt% coal char fines in kerosene slurry system. The nitrogen gas flow rates selected for these experiments were 0.08 and 0.10 ft/sec, while 0.10 and 0.125 ft/sec were selected for slurry flow rates. During each test, catalyst bed height data were also taken.

Lateral gamma-ray scans were conducted at 30, 50, 70, 90, and 110" reactor elevations. At each elevation, gamma-ray scanning data were taken manually at seven radial positions across the reactor column. A gamma-ray scan of the reactor filled with kerosene only was also carried out at zero gas and liquid flow. These data are necessary in order to calculate the various phase holdups.

DATA ANALYSIS

H-Coal Reactor Fluid Dynamics Study

Table I summarizes the physical properties (density and γ-ray mass absorption coefficient) of the liquid, fines, and catalyst phases for several cold-flow pilot plant runs with varying coal char fine concentrations. Properties of the AMOCAT-1A catalysts used in the HRI PDU 10(2) and in the cold flow pilot plant Run 224 are compared.

Catalyst bed expansions versus liquid and gas velocities are tabulated in Table II and plotted in Figure 1. At relatively high gas to liquid velocity ratios, the dense-dilute phase interfaces are not distinct, making bed expansion determination difficult. Examples of sharp interface and diffuse interfaces are illustrated in Figure 2 and 3, respectively. At the liquid velocities lower than 0.094 ft/sec, some evidence of bed contractions as gas flow rate increases is seen.

Dense-phase holdups and the Darton-Harrison drift flux (V_{CD}) are tabulated in Table III for various gas and liquid velocities. The drift flux is plotted as a function of gas holdup in Figure 4. The solid line represents the ideal bubbly region, while the dashed line represents bed behavior in a transition region between the ideal bubbly and churn turbulent states. Although the data are somewhat scattered, note the stabilizing effect of increasing liquid velocity upon bed behavior.

Liquid Mixing Tests

Experimental concentration-time distribution data are presented in Figures 5 through 14. Logarithmic probability plots showing cumulative areas under each C-curve versus sampling times are presented in Figures 15 through 24. The mean (first moment) and the standard deviation (second moment) of a normal distribution curve which plots as a straight line on probability paper are found at the fiftieth and eighty-fourth percentile points. Liquid mixing parameters (Peclet number and dispersion coefficient) are calculated from the values of these moments according to a plug flow axial dispersion model. Results are presented in Table IV.

The effect of various experimental techniques (liquid tracer quantity and injection mode) and data processing scheme (tracer RTD base line concentration and method of moment analysis) on calculating tracer material balance and Peclet number has been studied. The results of this study show that Peclet number is very sensitive to the selection of tracer base line concentration. The degree of axial mixing is estimated from the relative change of variance of the two RTD curves. Therefore, the Peclet number is extremely sensitive to the measured second moment which is affected by the base line selection. Other variables such as the means of RTD are not nearly as sensitive to base line concentration selection.

Liquid mixing data were analyzed by a linear least squares curve-fitting program. This data analysis was performed to correlate dispersion coefficient and Peclet number with operating conditions and to assess whether the dispersion has any radial position dependency. Preliminary results indicate that Peclet number correlates well with gas velocity but showed little dependency on radial position. Data analysis is continuing.

PLANS FOR NEXT PERIOD

Task 1 - H-Coal Reactor Fluid Dynamics

Compare HRI PDU fluid dynamics test results with those obtained from Amoco cold flow run 224. Apply the Bhatia-Epstein model to predict phase holdups for the HRI PDU tests.

Task 2 - Northwestern University/Gas Bubble Dynamics

Continue mechanical and optical development of the holographic instrument in order to improve its performance. Start reconstruction of the hologram of bubbles.

Task 3 - Liquid Mixing Tests

Start the development of the liquid-phase dispersion model. Analyze the lateral gamma-ray scan data in order to assess the radial uniformity of phase holdups in the reactor.

Task 4 - Model Implementation

The Bhatia-Epstein model will be implemented upon satisfactory completion of task 1 work.

REFERENCES

1) I. A. Vasalos, et al., Final Progress REport, "Study of Ebullated Bed Fluid Dynamics for H-Coal," Contract DE-AC05-77ET-10149, February, 1980.

2) Hydrocarbon Research Incorporated, "PDU Run 10" Contract DE-AC05-77ET-10152. Report FE-10152-67, September, 1981.

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R. D. Buttke; H-4
I. F. 94.300.3; H-6

TABLE I

Physical Properties of Gas, Liquid and Solid Phases in Amoco Cold Flow Runs and the HRI PDU 10

RUN	221	222	223	224	HRI PDU 10*
LIQUID	←	Kerosene		→	Coal/Oil
ρ, #/ft^3		49.3			
M.A.C. ft^2/#	.0424	.0424	.0417	.0425	
FINES					
ρ, #/ft^3	←	90.6		>	Wyodak
MAC, ft^2/#	.053	.0446	.0381	.0323	
FINES CONC. wt%	7.11	19.86	32.4	25.2	
CATALYST	←	HDS-2A	→	AMOCAT-IA	AMOCAT-IA
Dry ρ Bulk (ρ_B)		37.1		34.24	44.6
Dry ρ Particle (ρ_P)		67.3		59.1	74.1
$\varepsilon_{co} = \rho_B/\rho_P$		0.551		0.579	0.602
SOAKED ρ_P		107.9		86.89	97.1-106
length, inches	←	0.247	→	0.274 ± .061	0.1307
diameter		0.062		0.062 ± .002	0.0551
M.A.C. FT^2/#	.03484	.0360	.0357	.0433	--
ρ*MAC	--	3.884	--	3.806	--

M.A.C. = Mass Absorption Coefficient

*HRI report "PDU RUN 10", DOE Contract DE-AC05-77ET-10152 Report FE-10152-67, September, 1981.

TABLE II

(3/25/83)

% BED EXPANSION FOR RUN 224

CATALYST : AMOCAT 1
GAS : NITROGEN
LIQUID : KEROSENE
COAL CHAR CONC: 15.4 VOL %
TEMPERATURE : 68. DEG F

Run No.	Liquid Flow Rate, Ft/Sec	Gas Flow Rate Ft/Sec	Catalyst Bed Height (In.)	% Bed Expansion
224- 1	0.049	0.0	52.	16.
- 2	0.074	0.0	63.	40.
- 3	0.079	0.0	68.	51.
- 4	0.094	0.0	72.	60.
- 5	0.112	0.0	83.	84.
- 6	0.112	0.057	86.	91.
- 7	0.093	0.046	77.	71.
- 8	0.083	0.040	71.	58.
- 9	0.073	0.041	63.	40.
-10	0.047	0.043	48.	7.
-11	0.048	0.070	55.	22.
-12	0.072	0.069	62.	38.
-13	0.083	0.068	68.	51.
-14	0.094	0.067	78.	73.
-15	0.110	0.067	87.	93.
-16	0.045	0.090	50.	11.
-17	0.074	0.090	64.	42.
-18	0.083	0.090	67.	49.
-19	0.093	0.090	77.	71.
-20	0.112	0.089	87.	93.
-21	0.113	0.102	90.	100.
-22	0.094	0.101	77.	71.
-23	0.083	0.100	70.	56.
-24	0.073	0.100	62.	38.
-25	0.046	0.100	50.	11.
-26	0.046	0.148	48.	7.
-27	0.073	0.151	66.	47.
-28	0.083	0.152	66.	47.
-29	0.141	0.0	102.	127.
-30	0.173	0.0	130.	189.
-32	0.093	0.150	70.	56.
-33	0.112	0.152	76.	69.
-34	0.140	0.151	100.	122.
-35	0.140	0.096	112.	149.
-36	0.140	0.084	112.	149.
-37	0.143	0.067	110.	144.
-38	0.140	0.039	107.	138.

TABLE III

(3/25/83)

CALCULATED HOLDUPS, RUN 224: DENSE PHASE

CATALYST : AMOCAT 1
GAS : NITROGEN
LIQUID : KEROSENE
COAL CHAR CONC: 15.4 VOL %
TEMPERATURE : 68. DEG F

Run No.	Liquid Flow Rate, Ft/Sec	Gas Flow Rate, Ft/Sec	ECB	ELGB	Efgb	EGB	Vcd (Mm/Sec)
224- 1	0.049	0.0	0.501	0.414	0.075	0.0	0.0
- 2	0.074	0.0	0.414	0.511	0.093	0.0	0.0
- 3	0.079	0.0	0.383	0.529	0.096	0.0	0.0
- 4	0.094	0.0	0.362	0.541	0.098	0.0	0.0
- 5	0.112	0.0	0.314	0.580	0.105	0.0	0.0
- 6	0.112	0.057	0.303	0.525	0.095	0.076	12.1
- 7	0.093	0.046	0.338	0.506	0.092	0.064	10.4
- 8	0.083	0.040	0.367	0.491	0.089	0.053	9.5
- 9	0.073	0.041	0.414	0.450	0.082	0.055	9.8
-10	0.047	0.043	0.543	0.340	0.062	0.056	10.6
-11	0.048	0.070	0.474	0.418	0.076	0.033	19.8
-12	0.072	0.069	0.420	0.409	0.074	0.097	15.0
-13	0.083	0.068	0.383	0.452	0.082	0.082	15.5
-14	0.094	0.067	0.334	0.494	0.090	0.082	15.1
-15	0.110	0.067	0.300	0.515	0.093	0.092	14.0
-16	0.045	0.090	0.521	0.350	0.064	0.065	23.5
-17	0.074	0.090	0.407	0.424	0.077	0.092	21.1
-18	0.083	0.090	0.389	0.439	0.080	0.092	20.8
-19	0.093	0.090	0.338	0.469	0.085	0.108	19.5
-20	0.112	0.089	0.300	0.493	0.089	0.118	17.9
-21	0.113	0.102	0.290	0.495	0.090	0.126	20.9
-22	0.094	0.101	0.338	0.474	0.086	0.101	22.9
-23	0.083	0.100	0.372	0.459	0.083	0.086	24.3
-24	0.073	0.100	0.420	0.419	0.076	0.084	24.6
-25	0.046	0.100	0.521	0.344	0.062	0.072	26.0
-26	0.046	0.148	0.543	0.321	0.058	0.078	38.9
-27	0.073	0.151	0.395	0.425	0.077	0.103	37.3
-28	0.083	0.152	0.395	0.419	0.076	0.111	36.1
-29	0.141	0.0	0.256	0.630	0.114	0.0	0.0
-30	0.173	0.0	0.200	0.675	0.122	0.0	0.0
-32	0.093	0.150	0.372	0.430	0.078	0.119	34.5
-33	0.112	0.152	0.343	0.428	0.078	0.151	30.6
-34	0.140	0.151	0.261	0.465	0.088	0.167	28.0
-35	0.140	0.096	0.233	0.532	0.097	0.139	17.0
-36	0.140	0.084	0.233	0.547	0.099	0.121	15.6
-37	0.143	0.067	0.237	0.560	0.102	0.101	12.3
-38	0.140	0.039	0.244	0.588	0.107	0.062	7.5

TABLE IV

DENSE-PHASE LIQUID MIXING RESULTS
H-COAL PDU EBULLATED-BED REACTOR

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_o)
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	5.17	-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	6.83	0

R/R_o = 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

Figure 1

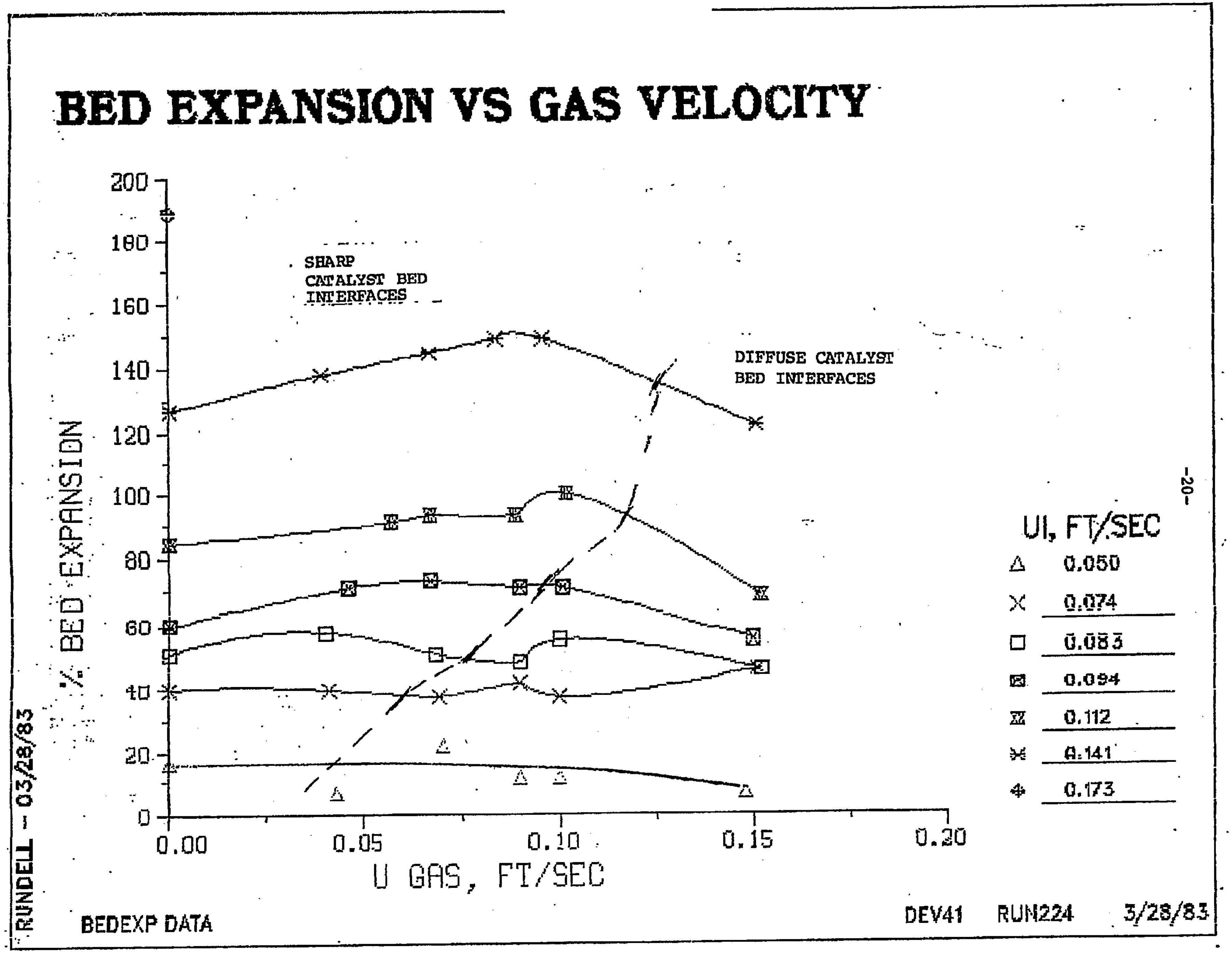
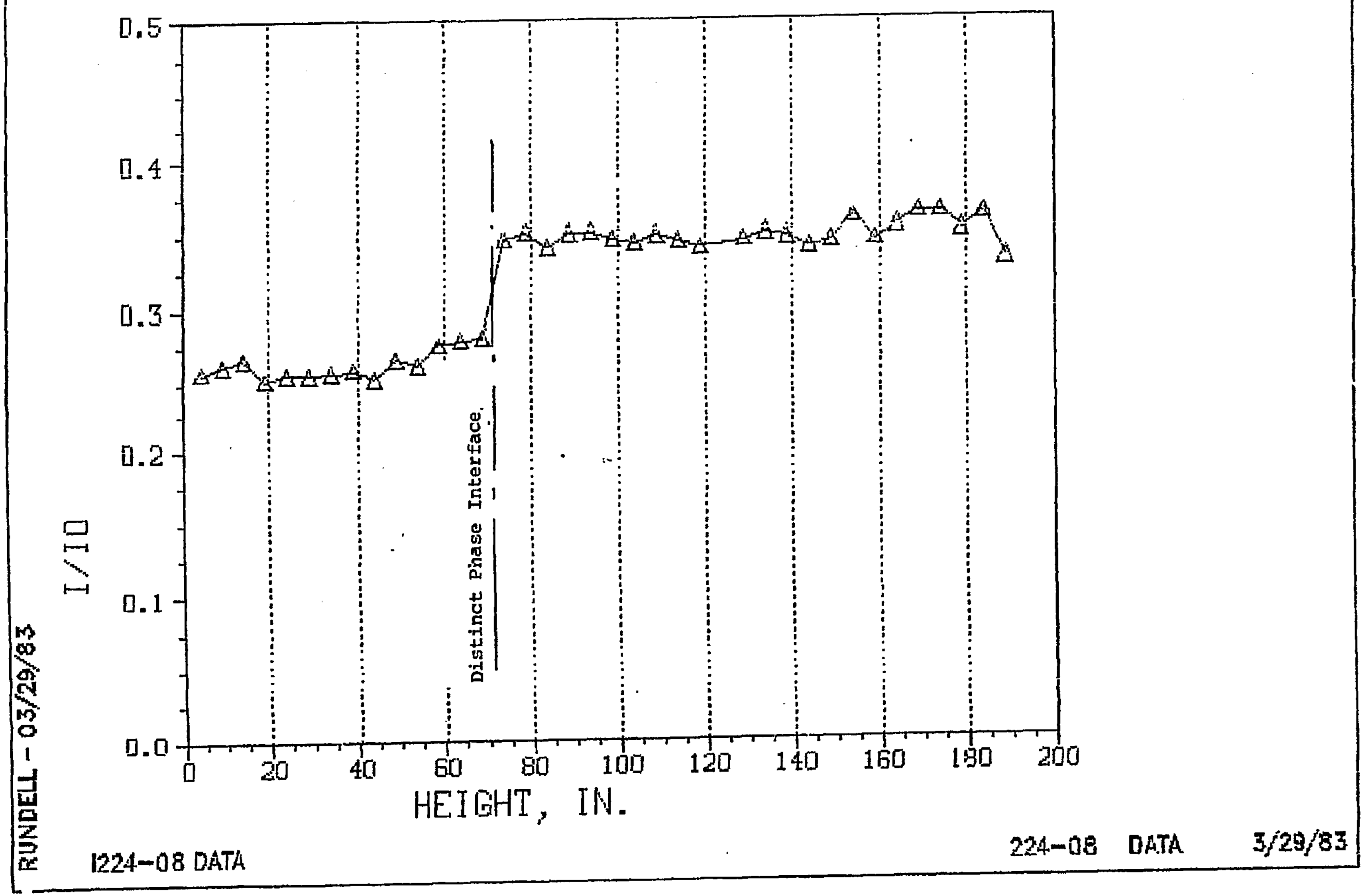

BED EXPANSION VS GAS VELOCITY
% BED EXPANSION
200
180
160
140
120
100
80
60
40
20
0
0.00
0.05
0.10
0.15
0.20
U GAS, FT/SEC
SHARP CATALYST BED INTERFACES
DIFFUSE CATALYST BED INTERFACES
UI, FT/SEC
△ 0.050
× 0.074
□ 0.083
⊠ 0.094
⌧ 0.112
✳ 0.141
✦ 0.173
RUNDELL - 03/28/83
BEDEXP DATA
DEV41
RUN224
3/28/83

Figure 2

GAMMA RAY I?IO RATIO VS. BED HEIGHT, RUN 224-08



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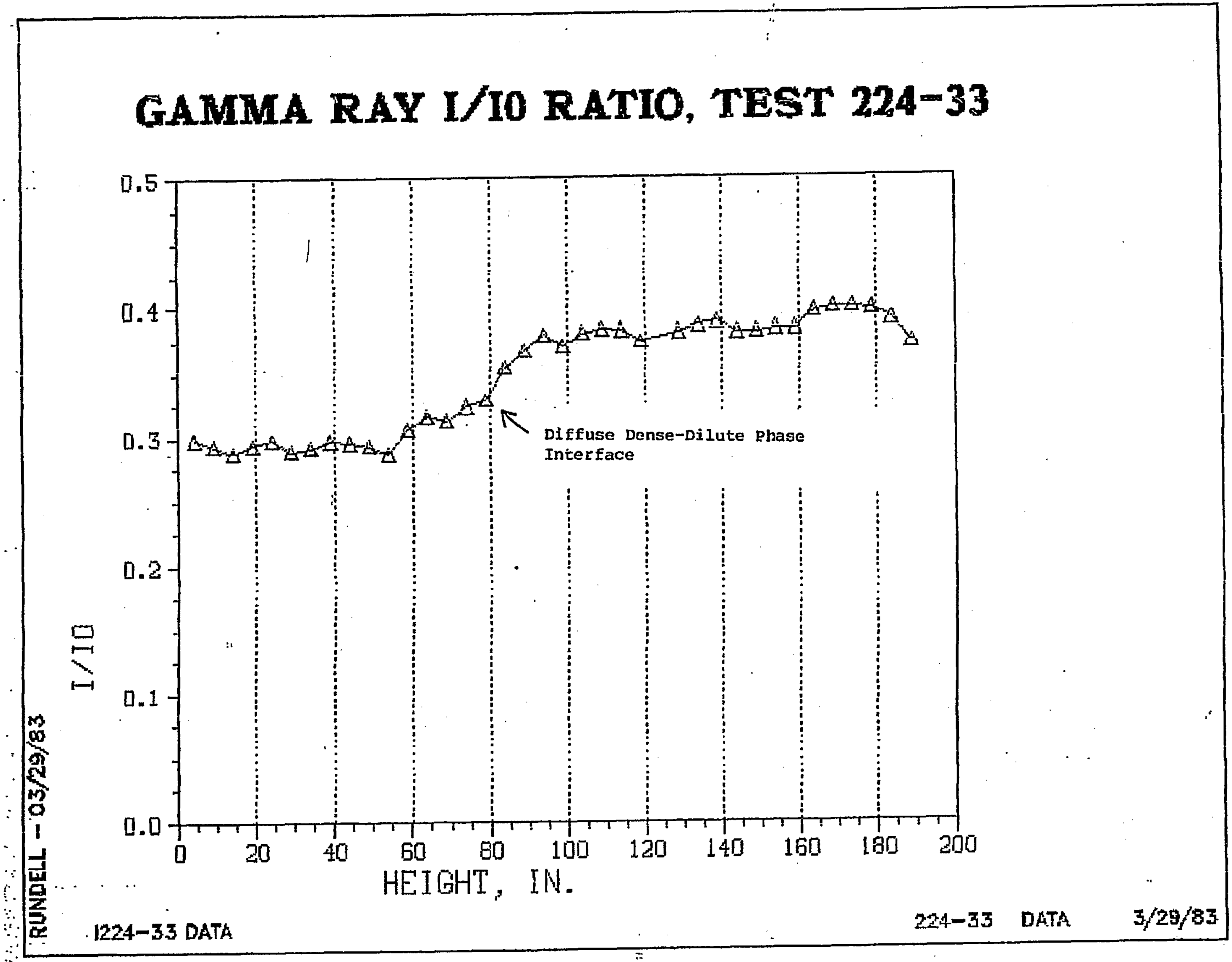
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I/I0
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0.1
0.2
0.3
0.4
0.5
HEIGHT, IN.
0
20
40
60
80
100
120
140
160
180
200
Diffuse Dense-Dilute Phase Interface
RUNDELL - 03/29/83
I224-33 DATA
224-33 DATA
3/29/83

Figure 4

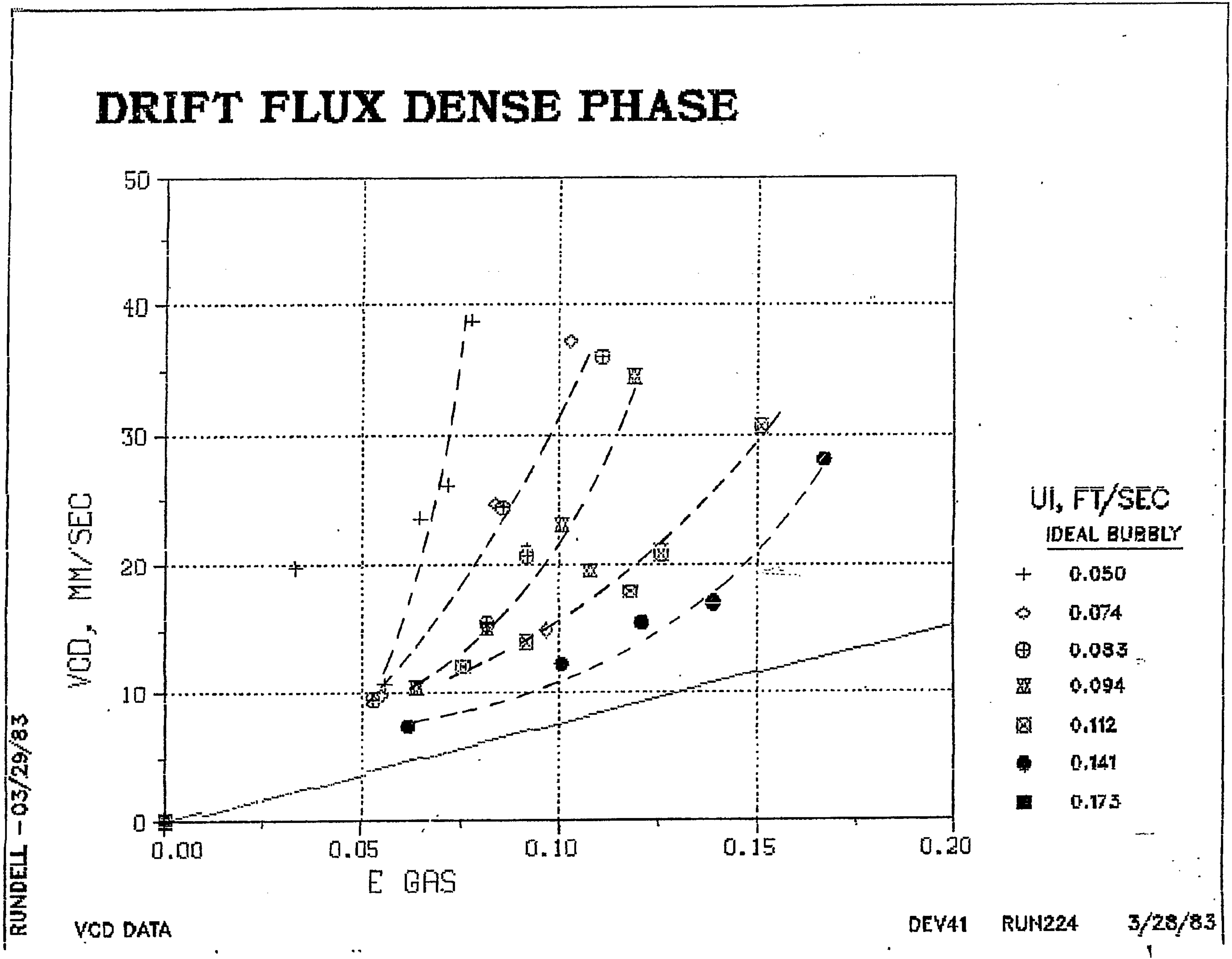
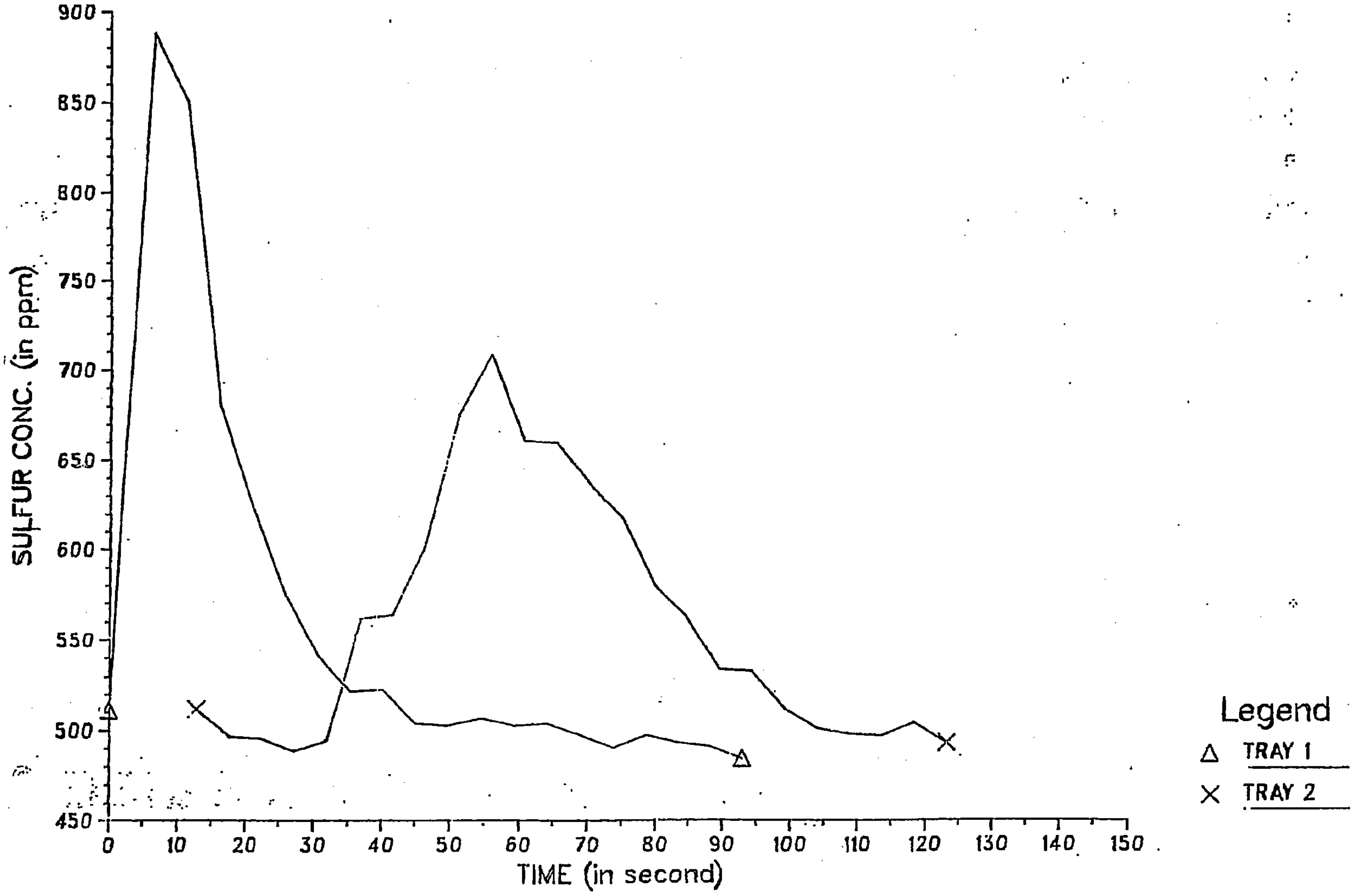

DRIFT FLUX DENSE PHASE
VCD, MM/SEC
0
10
20
30
40
50
0.00
0.05
0.10
0.15
0.20
E GAS
UI, FT/SEC
IDEAL BUBBLY
+ 0.050
◇ 0.074
⊕ 0.083
⧖ 0.094
⊠ 0.112
● 0.141
■ 0.173
RUNDELL – 03/29/83
VCD DATA
DEV41
RUN224
3/28/83

Figure 5

J K S
9/28/82

CONCENTRATION—TIME DISTRIBUTION CURVE FOR LIQUID MIXING RUN 490–14



J K S
9/30/82

CONCENTRATION–TIME DISTRIBUTION CURVE
FOR LIQUID MIXING RUN 490–15

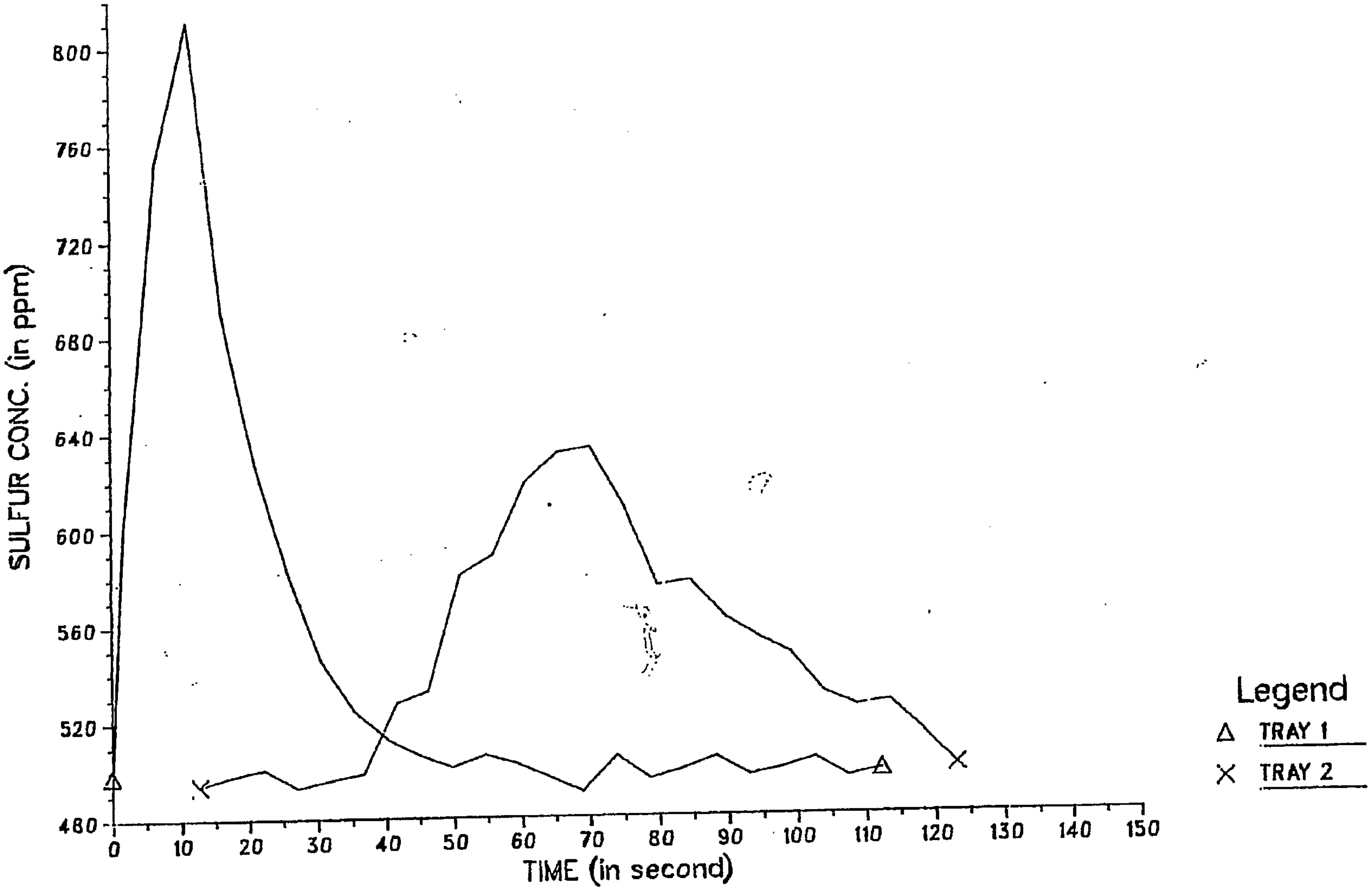
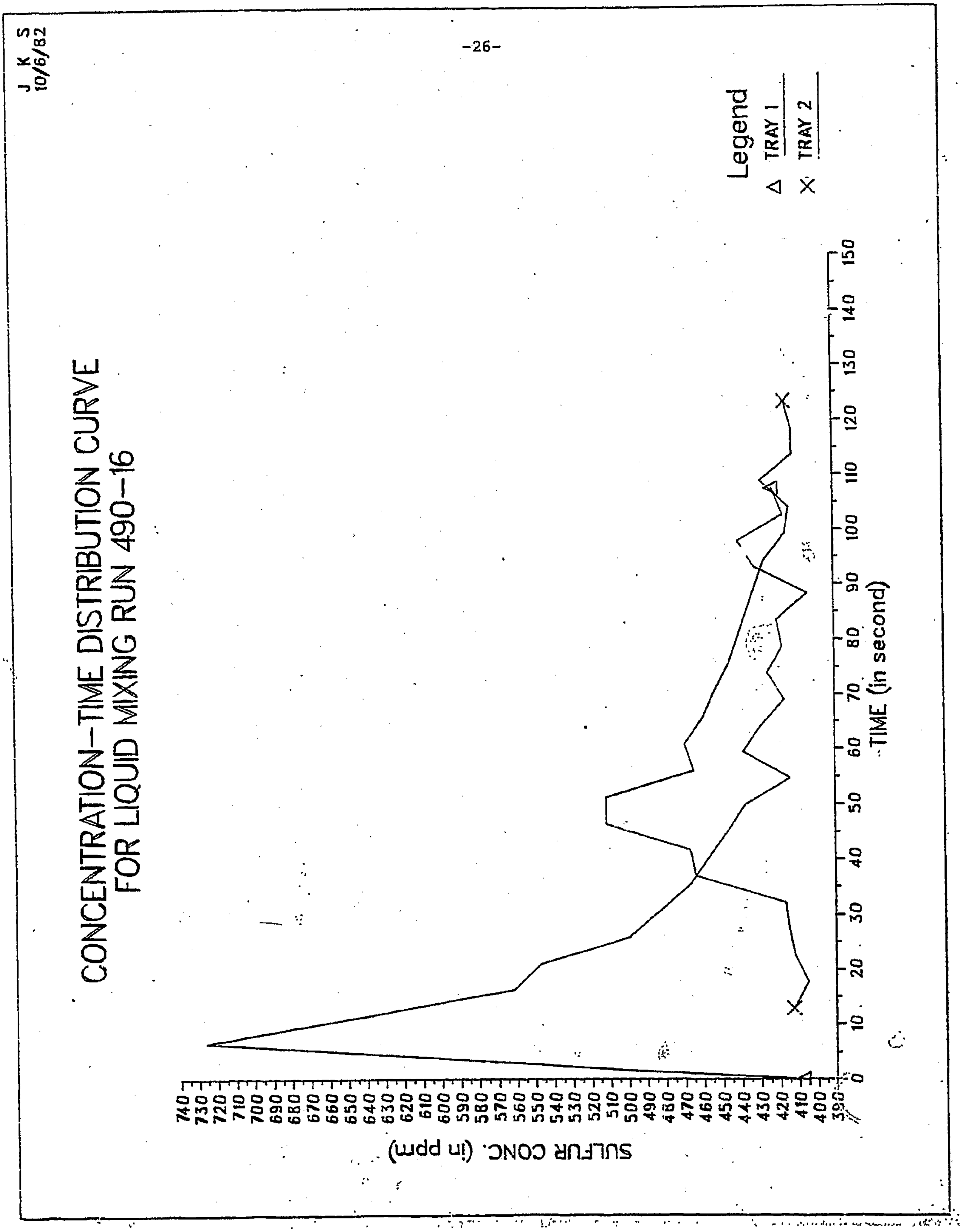


Figure 6

Figure 7



J K S
10/6/82

Figure 6

J K S
10/15/82

CONCENTRATION—TIME DISTRIBUTION CURVE
FOR LIQUID MIXING RUN 490—17

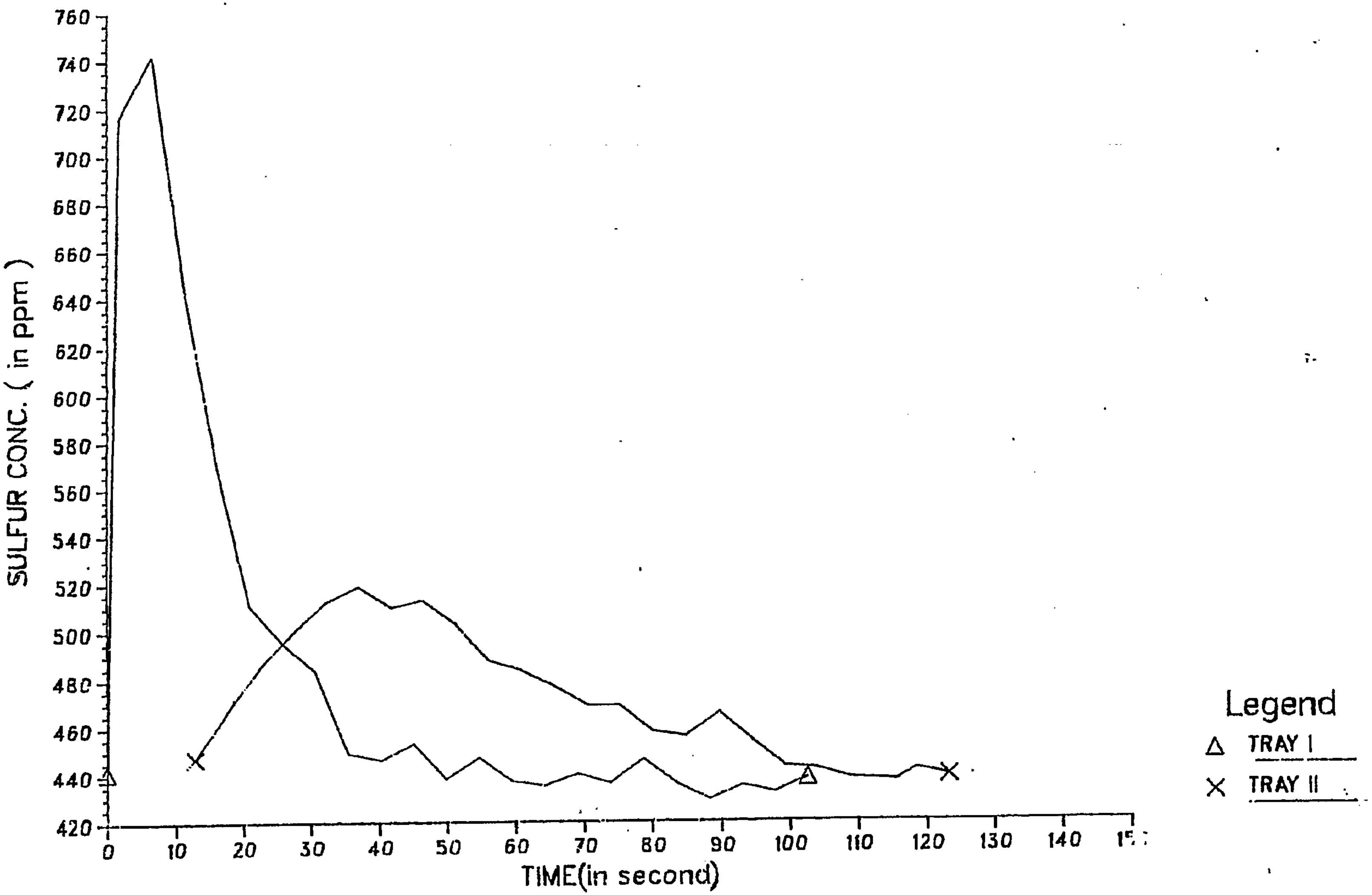


Figure 9

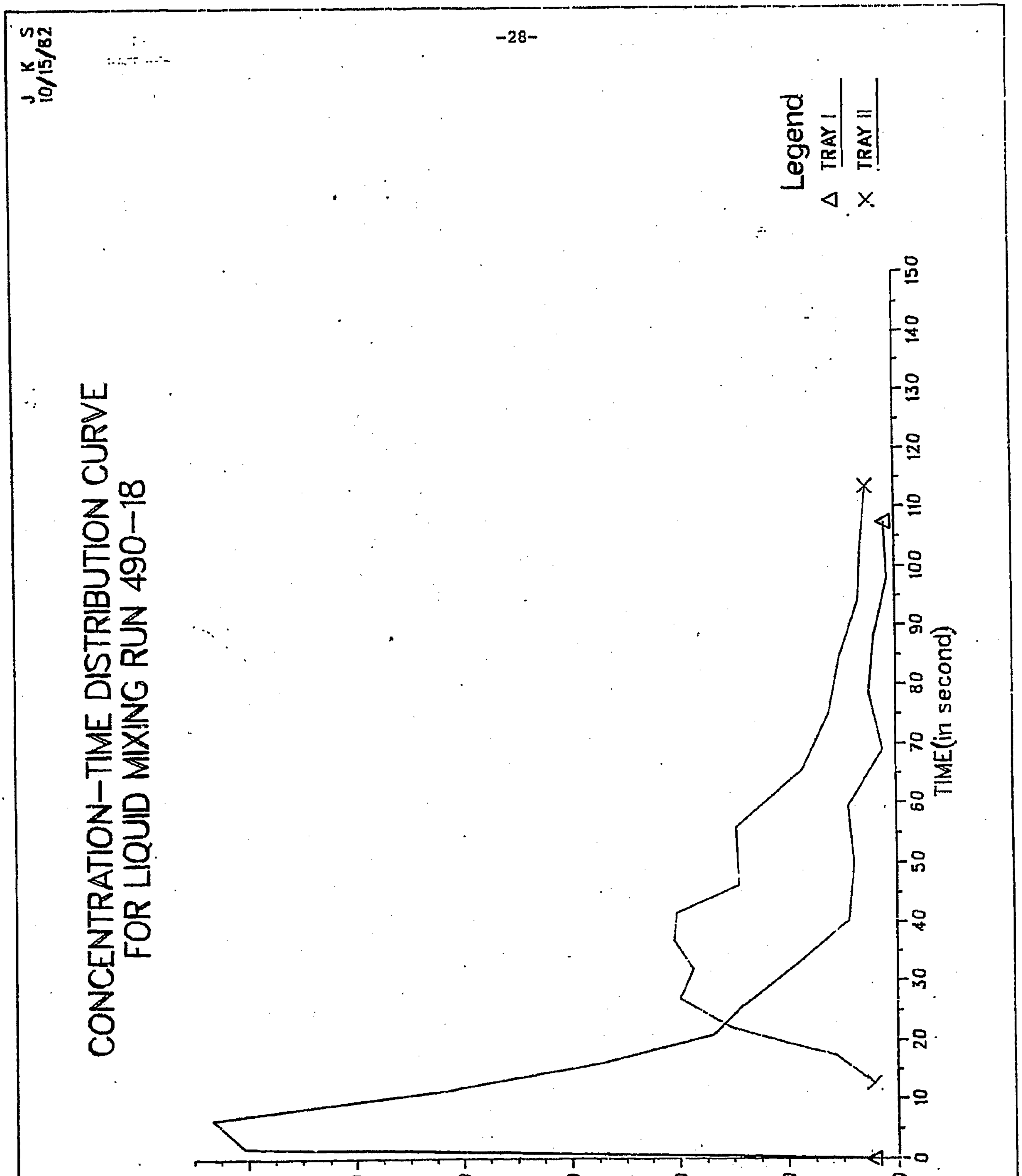

J K S
10/15/82
CONCENTRATION–TIME DISTRIBUTION CURVE
FOR LIQUID MIXING RUN 490–18
SULFUR CONC. (in ppm)
640
600
560
520
480
440
400
TIME(in second)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Legend
△ TRAY I
× TRAY II

Figure 10

J K S 10/20/82

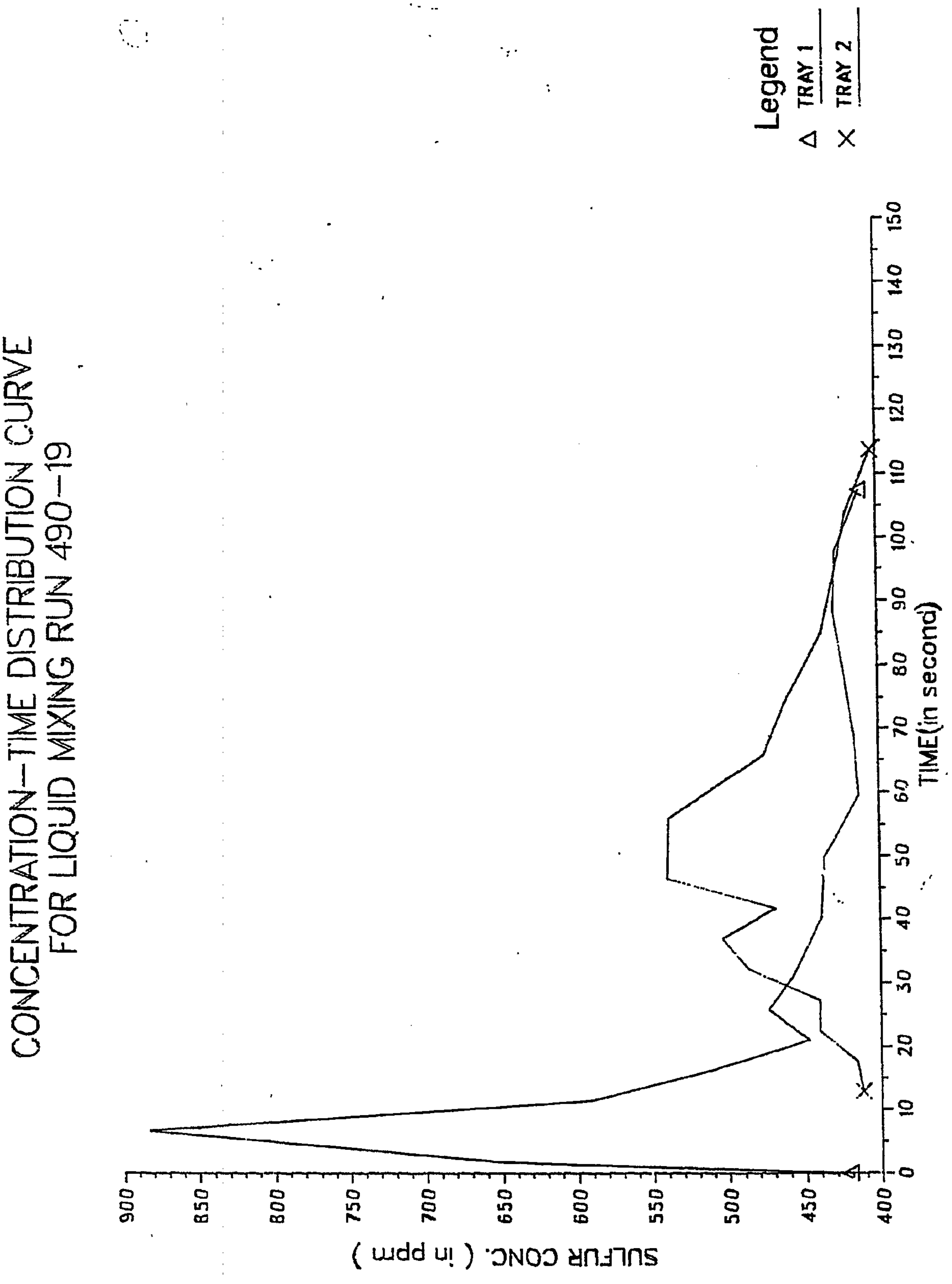


Figure 11

J K S
11/03/82

CONCENTRATION—TIME DISTRIBUTION CURVE
FOR LIQUID MIXING RUN 490—20

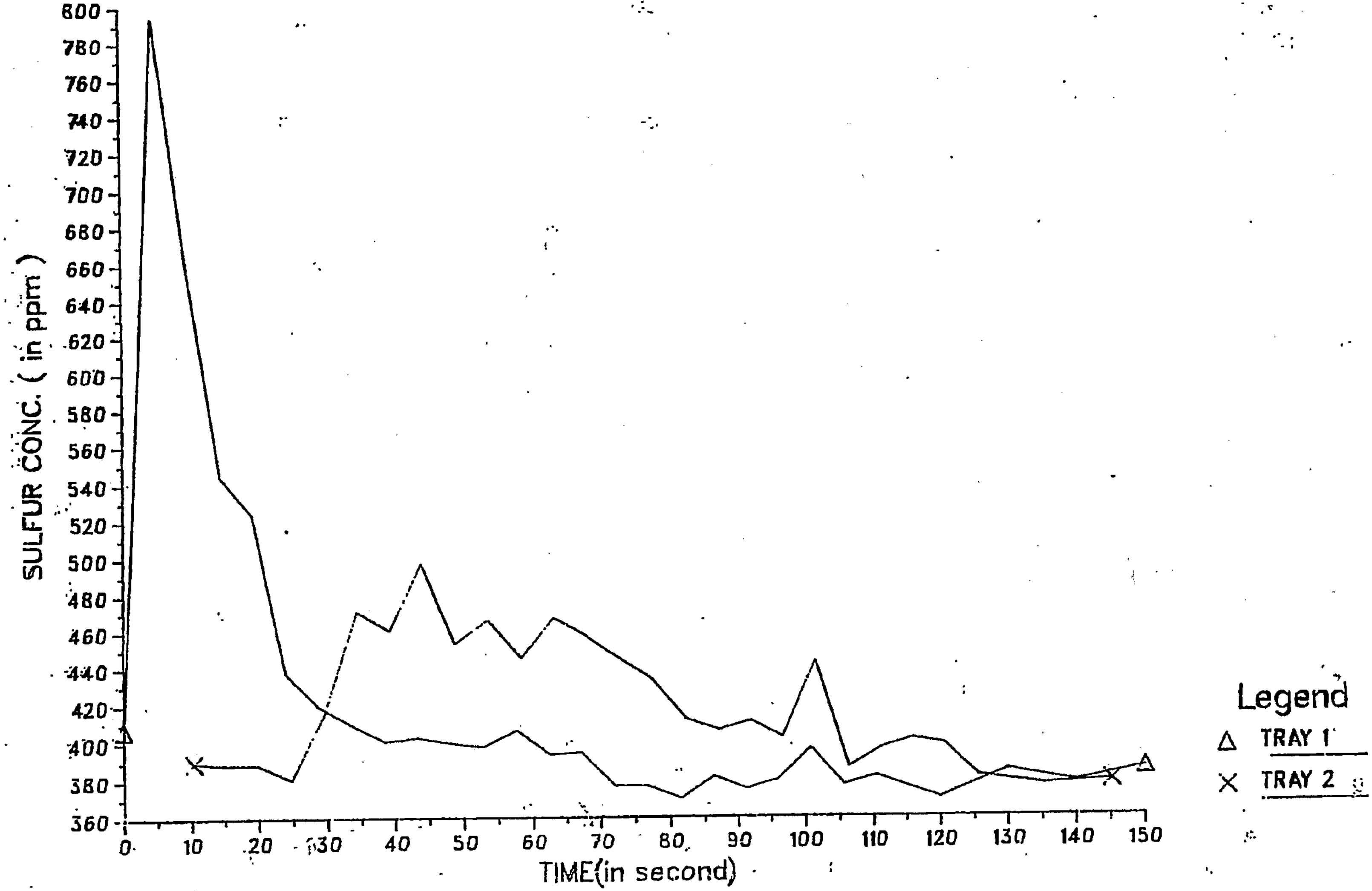


Figure 12

J K S
11/23/82

CONCENTRATION—TIME DISTRIBUTION CURVE FOR LIQUID MIXING RUN 490—21

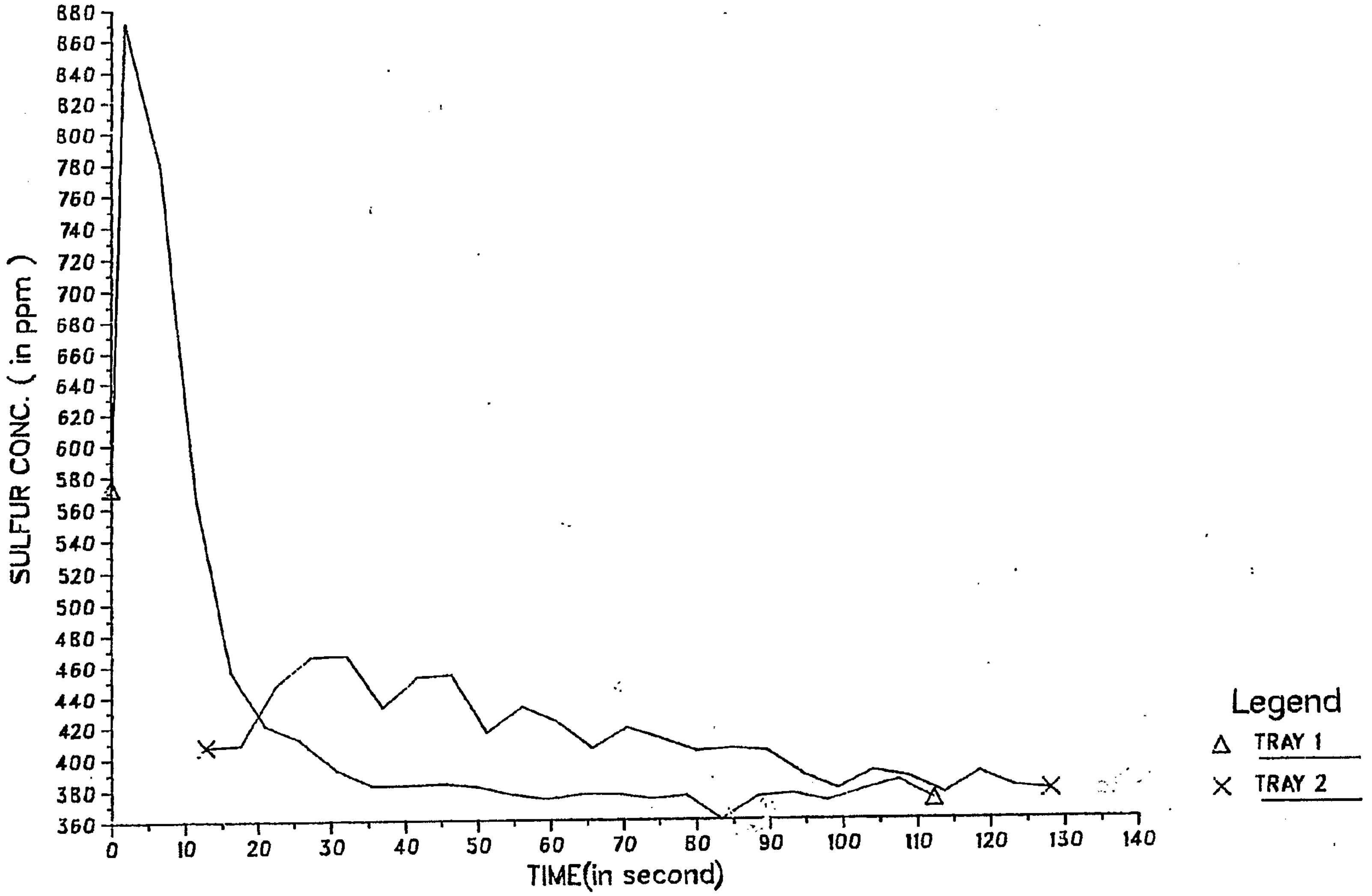
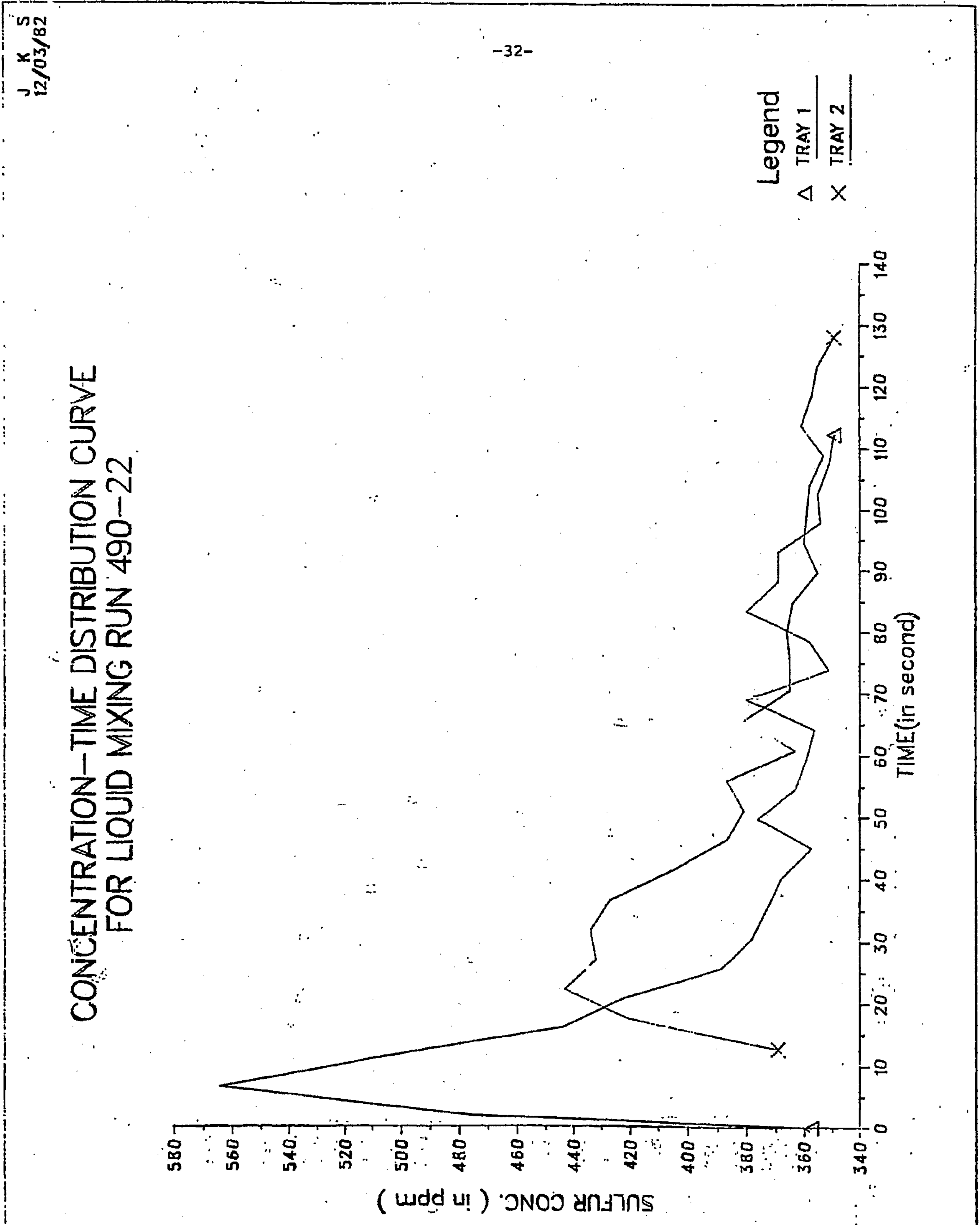


Figure 13


J K S
12/03/82
CONCENTRATION—TIME DISTRIBUTION CURVE
FOR LIQUID MIXING RUN 490—22
Legend
Δ TRAY 1
X TRAY 2
SULFUR CONC. (in ppm)
580
560
540
520
500
480
460
440
420
400
380
360
340
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
TIME(in second)

J K S
12/03/82

CONCENTRATION—TIME DISTRIBUTION CURVE
FOR LIQUID MIXING RUN 490—23

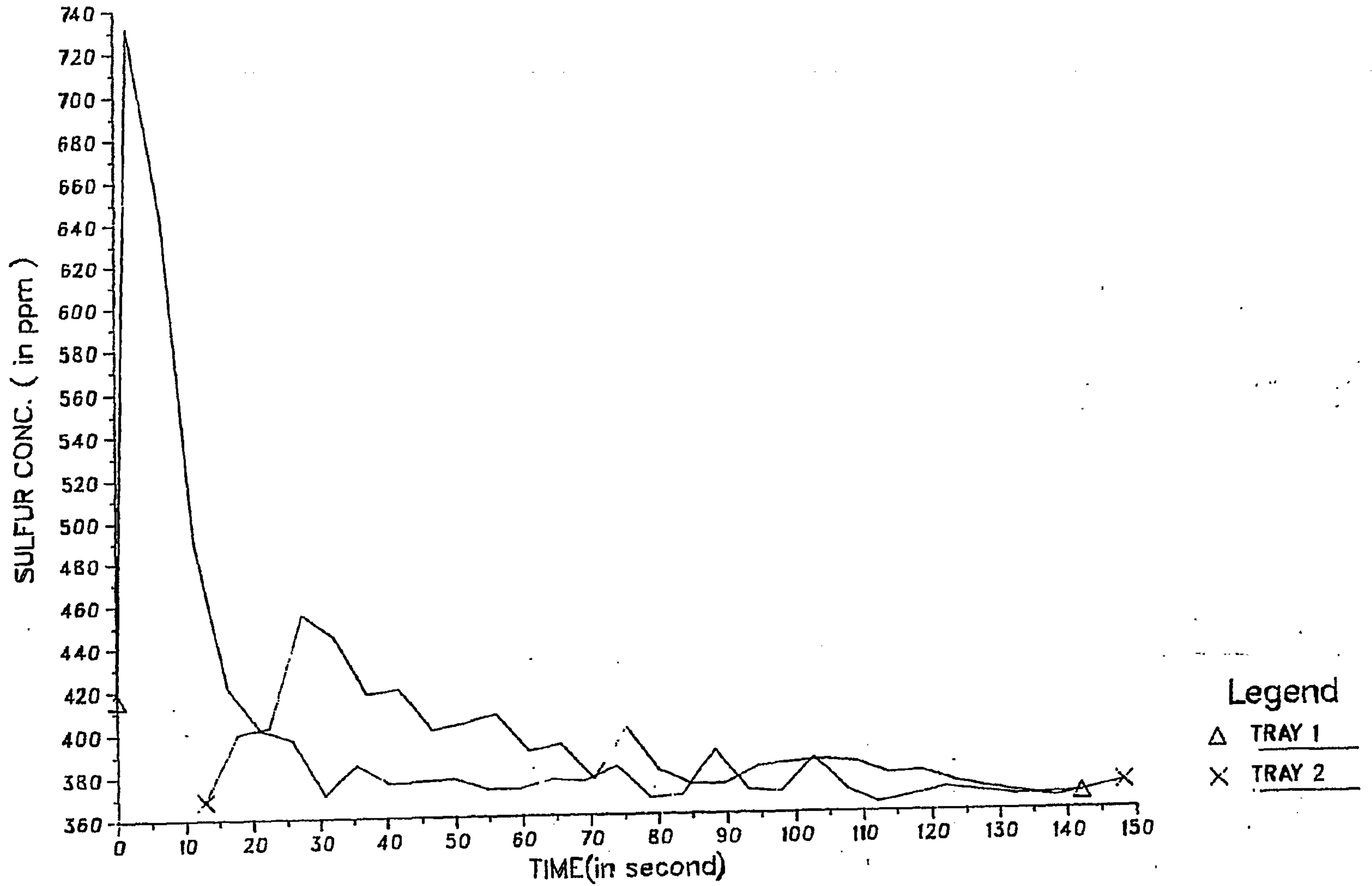


Figure 14

Figure 15

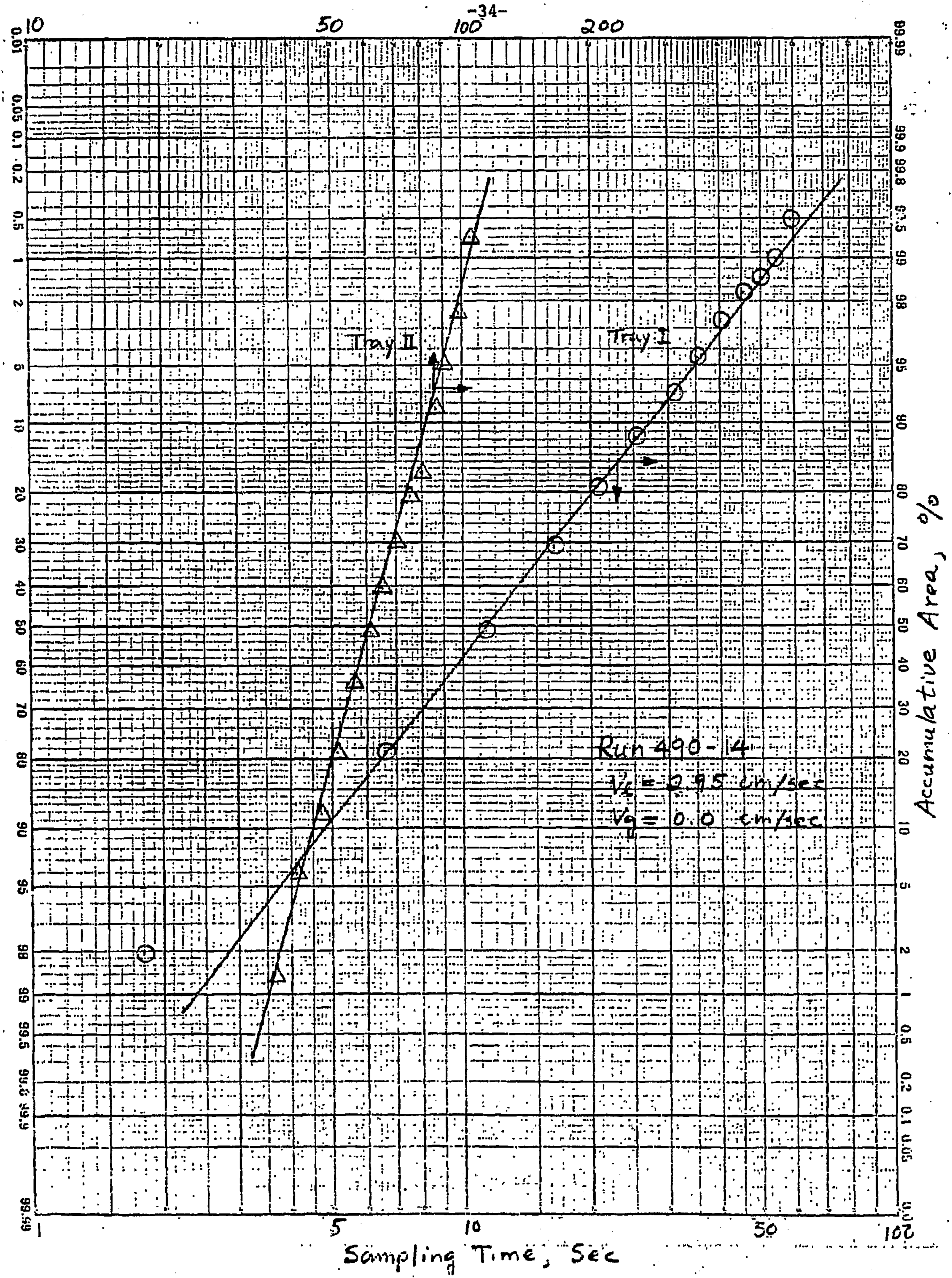

10
50
100
200
Tray II
Tray I
Run 490-14
V_ℓ = 2.95 cm/sec
V_g = 0.0 cm/sec
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
1
5
10
50
100
Sampling Time, Sec
Accumulative Area, %

Figure 16

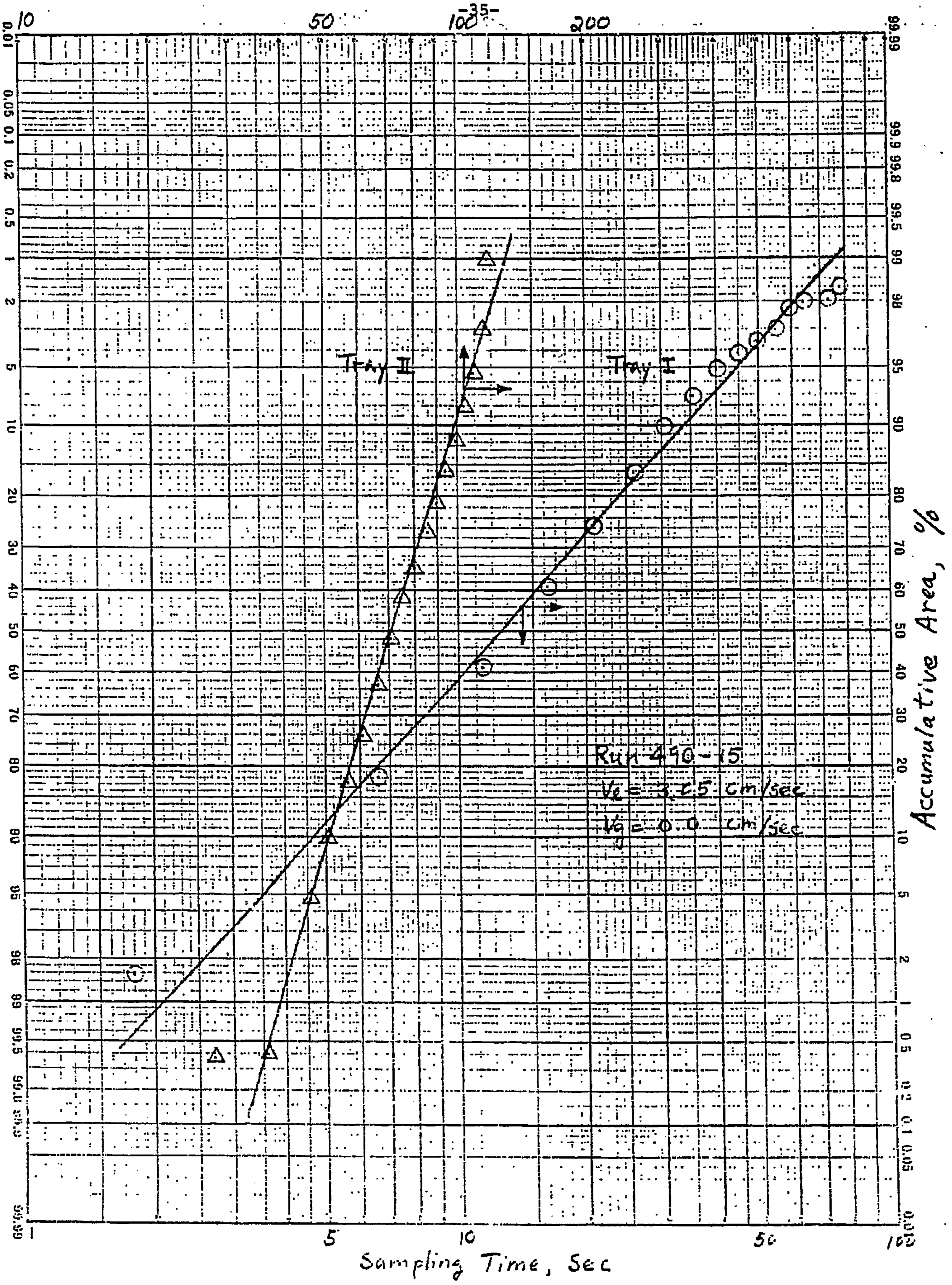

10
50
100
200
Tray II
Tray I
Run 490-15
V_ℓ = 3.25 cm/sec
V_g = 0.0 cm/sec
Accumulative Area, %
1
5
10
50
100
Sampling Time, Sec
0.01
0.05 0.1 0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8 99.9
99.99
99.99
99.9 99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2 0.1 0.05
0.01

Figure 17

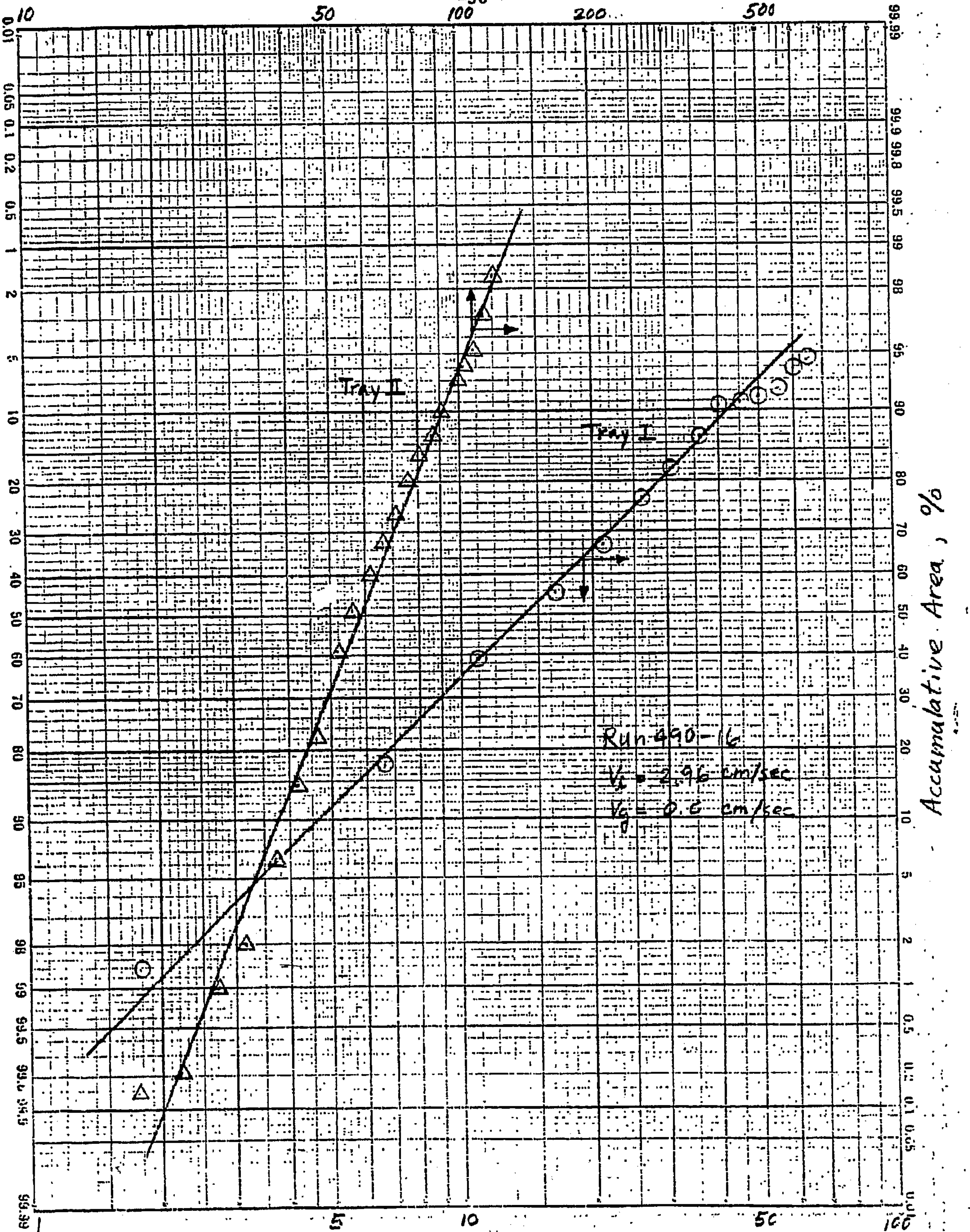

10
50
100
200
500
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
Tray II
Tray I
Run 490-16
Vl = 2.96 cm/sec
Vg = 0.6 cm/sec
Accumulative Area, %
1
5
10
50
100
Sampling Time, Sec

Figure 18

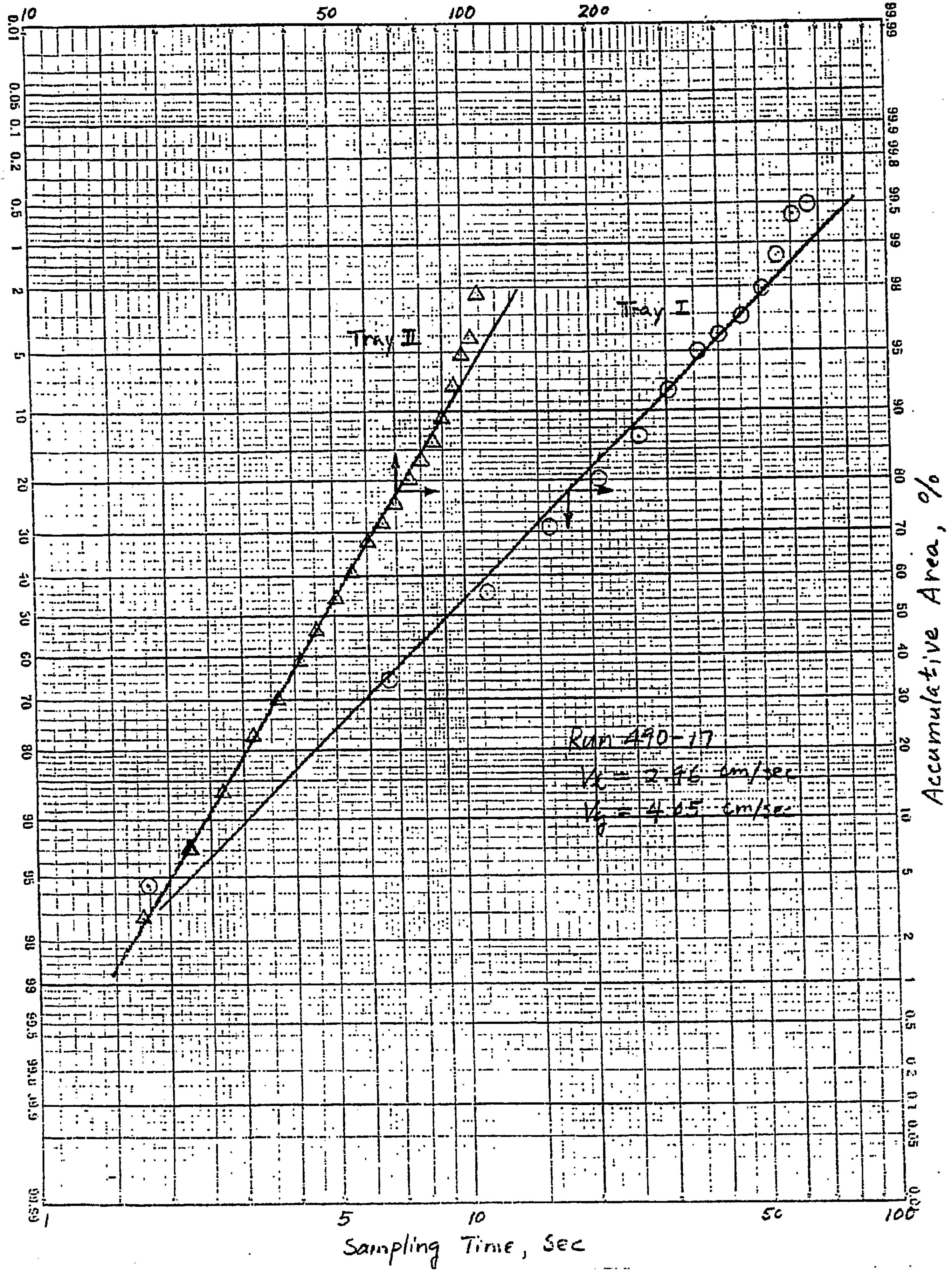

10
50
100
200
Tray II
Tray I
Run 490-17
V_L = 2.46 cm/sec
V_g = 4.65 cm/sec
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
Accumulative Area, %
1
5
10
50
100
Sampling Time, Sec

Figure 19

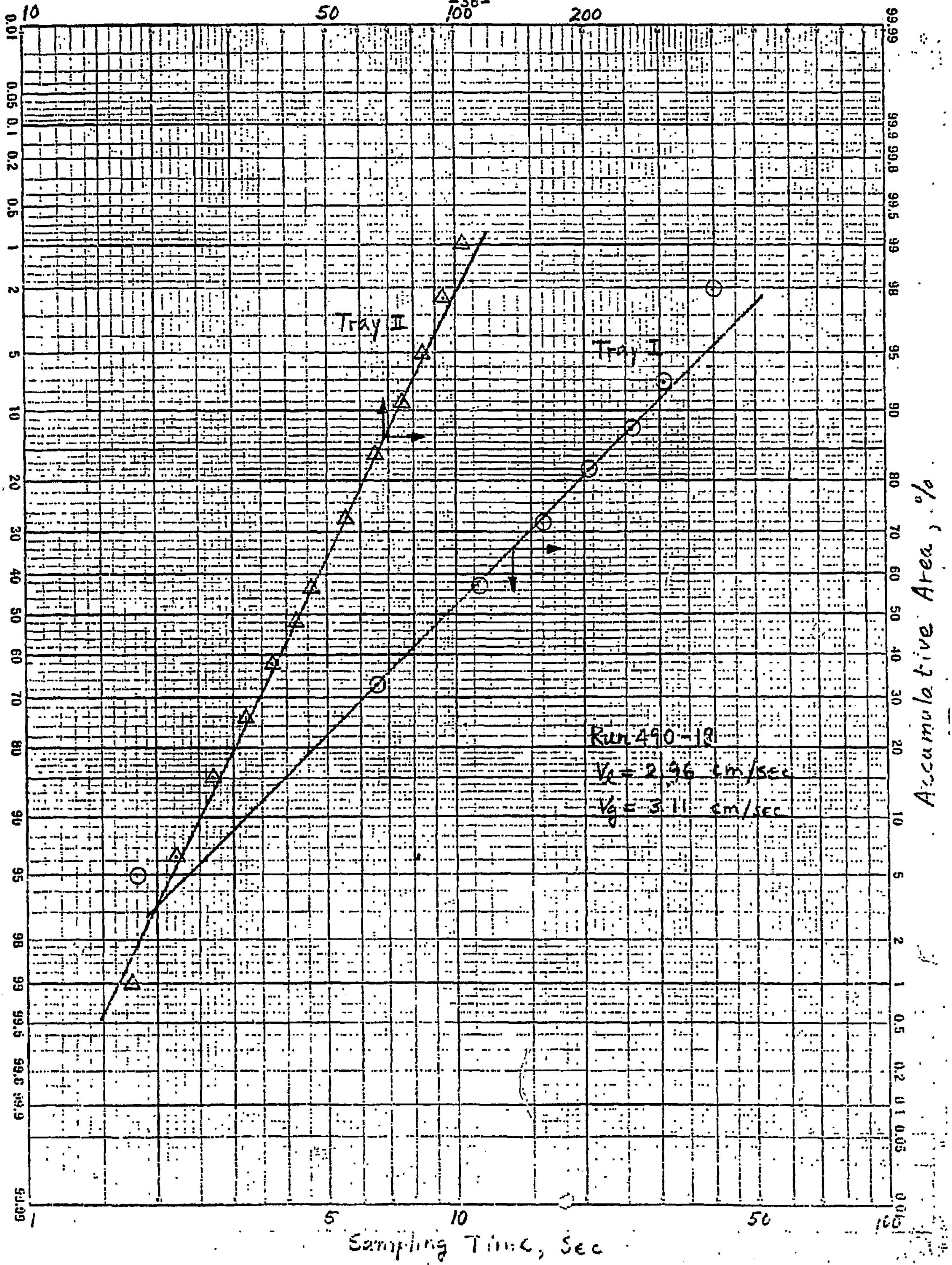

10
50
100
200
Tray II
Tray I
Run 490-13
V_L = 2.96 cm/sec
V_g = 3.11 cm/sec
Accumulative Area, %
1
5
10
50
100
Sampling Time, Sec
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

Figure 20

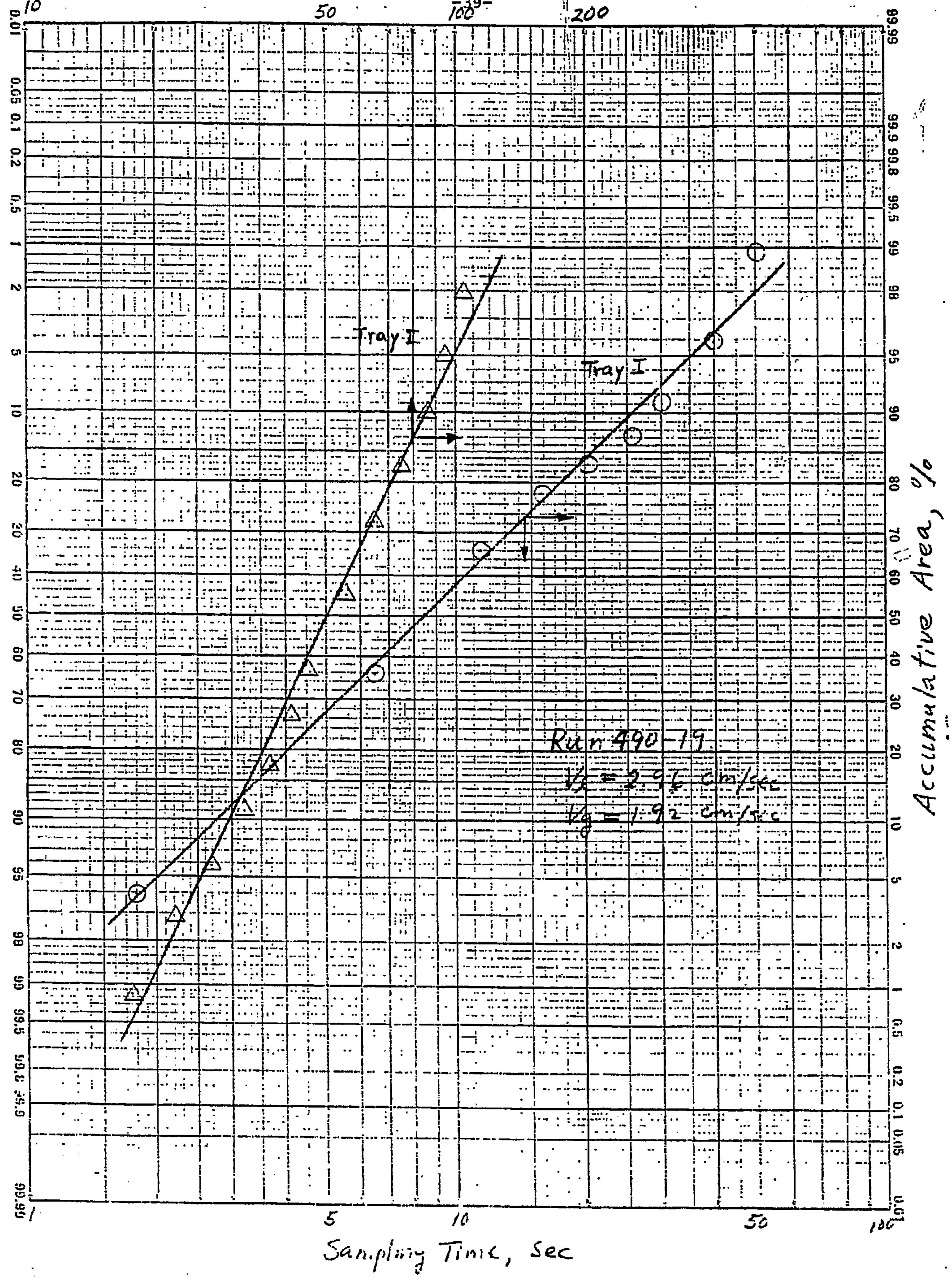

10
50
100
200
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
Tray II
Tray I
Run 490-19
V_L = 2.96 cm/sec
V_g = 1.92 cm/sec
Accumulative Area, %
1
5
10
50
100
Sampling Time, Sec

Figure 21

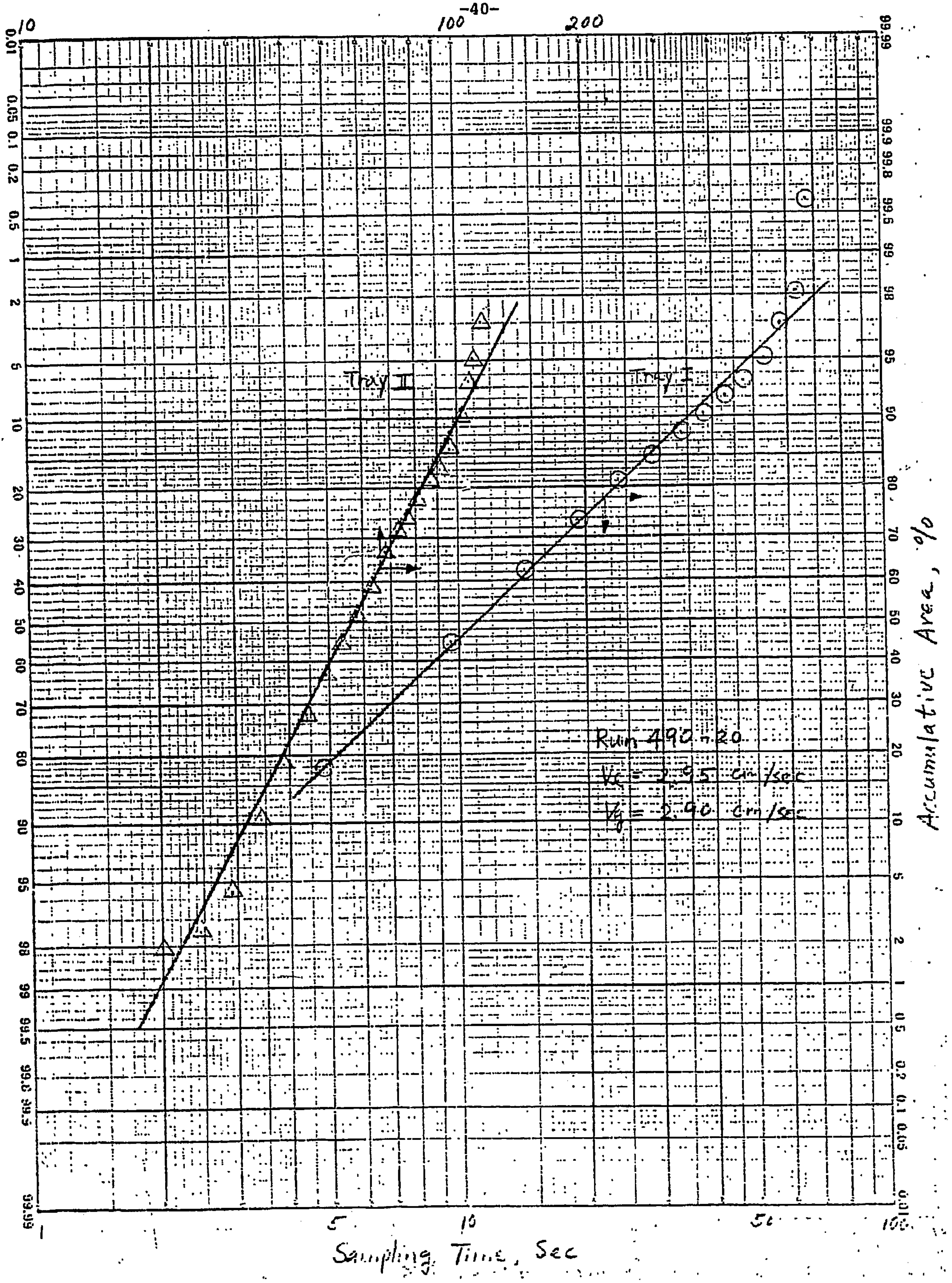

10
100
200
Tray II
Tray I
Run 490-20
Vc = 2.95 cm/sec
Vg = 2.90 cm/sec
Accumulative Area, %
1
5
10
50
100
Sampling Time, Sec
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99

Figure 22

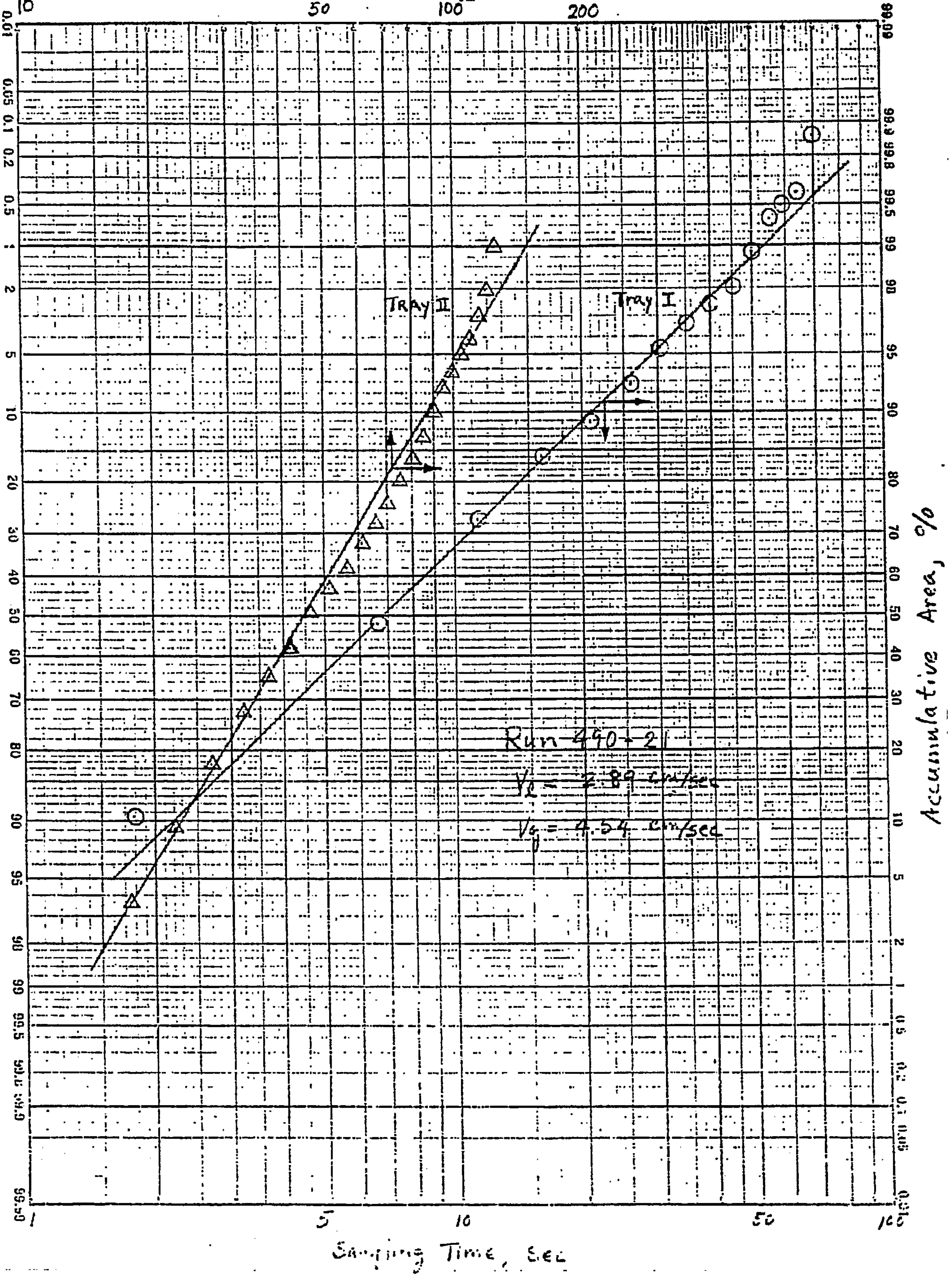

10
50
100
200
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
Tray II
Tray I
Run 490-21
V_L = 2.89 cm/sec
V_G = 4.54 cm/sec
Accumulative Area, %
1
5
10
50
100
Sampling Time, sec

Figure 23

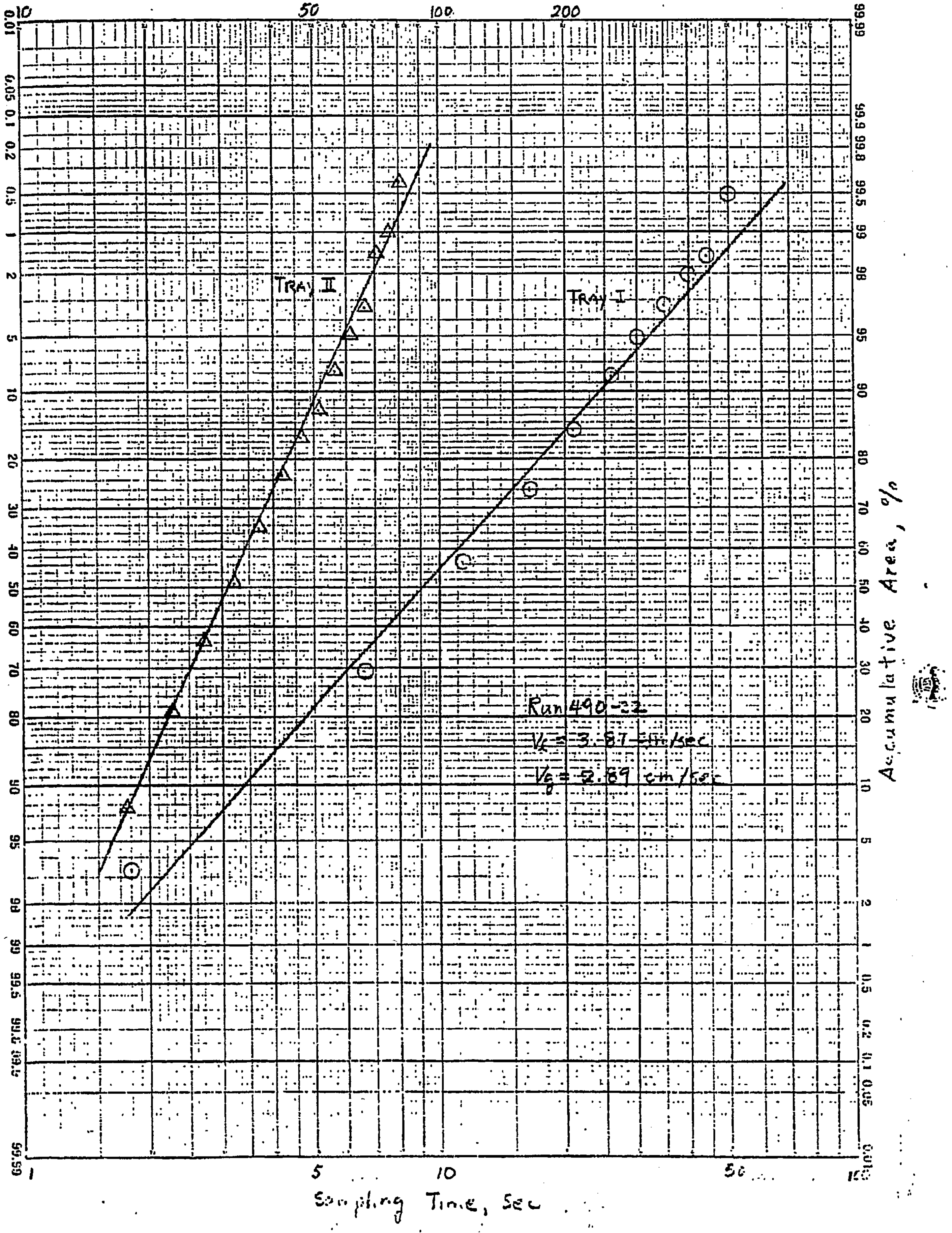
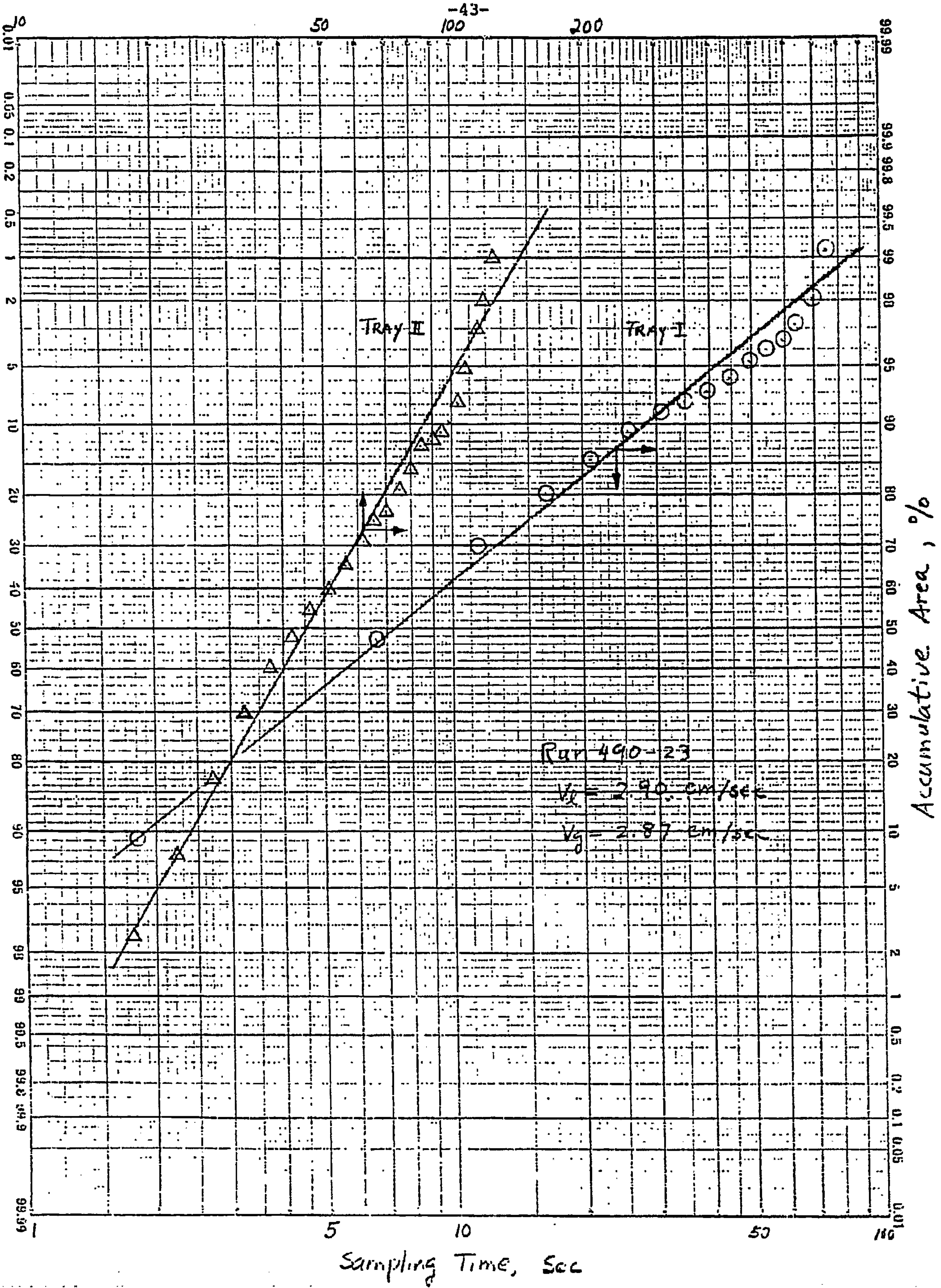

10
50
100
200
1
5
10
50
100
Sampling Time, Sec
Accumulative Area, %
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
TRAY II
TRAY I
Run 490-22
V_L = 3.87 cm/sec
V_g = 2.89 cm/sec

Figure 24


10
50
100
200
Tray II
Tray I
Run 490-23
V_l = 2.90 cm/sec
V_g = 2.87 cm/sec
Accumulative Area, %
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
1
5
10
50
100
Sampling Time, Sec

APPENDIX A

MONTHLY (DECEMBER 1982) PROGRESS REPORT ON AMOCO DOE CONTRACT "ON H-COAL DYNAMICS"

Holographic Technique

During the past month it was found that the helium-neon laser used to reconstruct the holograms needed to be repaired. The intensity of the laser light had decreased below useful levels, rendering it ineffective for our purposes. Upon consultation with the manufacturer it was determined the plasma tube needed to be replaced. Although unexpected, this problem was bound to occur eventually since the plasma tube had a limited lifetime and was several years old. The laser has since been sent to Spectra-Physics for repairs which will cost approximately $1500. Until its return, work will continue in the laboratory while sharing a similar helium-neon laser belonging to the mechanical engineering department.

The larger Nd:YAG laser used to construct the holograms was also inoperative for several weeks. It too suffered from a decrease in output energy to such a degree that holograms could not be formed. Fortunately, the problem was corrected by realigning the harmonic generator crystal ourselves, thereby saving the expense of a repairman. Since then several holograms have been taken which appear to have good clarity and distinct bubble images.

The laboratory has been recently equiped with darkroom supplies to facilitate the developing of holograms. This makes the developing process more convenient since earlier holograms were developed in a separate darkroom shared by others in the mechanical engineering department. Now the holograms can be developed at any time and more quickly.