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LONE STAR STEEL STEAM-HYDRO AIR CLEANING SYSTEM EVALUATION

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LONE STAR STEEL STEAM-HYDRO AIR CLEANING SYSTEM EVALUATION

by

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ABSTRACT

This report presents the results of fractional and overall mass efficiency tests of the Lone Star Steel Steam-Hydro scrubber. The tests were performed on one of seven modules of a full scale scrubber used for controlling particulate emissions from an open hearth furnace. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes from about 0.3 μm to 5 μm, and on a number basis for sizes smaller than about 1 μm using optical and diffusional methods.

The text of this report includes brief descriptions of the open hearth process, the Lone Star Steel steam-hydro scrubber, economics of operating the scrubber, the measurement methods for calculating the fractional efficiency, a synthesized time history of the open hearth particulate emissions, and fractional efficiencies as measured for several scrubber operating conditions.

This report was submitted in fulfullment of a subcontract to Southern Research Institute per Task No. 11 of Contract 68-02-1308 by the M. W. Kellogg Company under the sponsorship of the Environmental Protection Agency. Work under the subcontract was completed as of February 15, 1974.

TABLE OF CONTENTS

Page

ABSTRACT.....iii

CONCLUSION..... 1

INTRODUCTION..... 2

DISCUSSION..... 5

APPDENDICES.....25

A - MANUFACTURER'S DESCRIPTION OF THE OPERATION OF THE SCRUBBER.....26

B - SCRUBBER OPERATING PARAMETERS DURING TESTS.....28

C^1- OPEN HEARTH FURNACE OPERATING SUMMARY.....30

C^2- OPEN HEARTH FURNACE MATERIALS SUMMARY.....31

D - ESTIMATED OPERATING COSTS OF THE STEAM HYDRO AIR CLEANING SYSTEM....32

E - CONVERSION FACTORS.....36

FIGURES

1 - The Lone Star Steel Steam-Hydro Air Cleaning System..... 4

2 - Optical and Diffusional Sizing System..... 8

3 - Condensation Nuclei Data Taken During the Oxygen Lance Cycle.....11

4 - Optical and Condensation Nuclei Counter Data Taken During the Charge Cycle.....12

TABLE OF CONTENTS
(Continued)

FIGURES
(Continued) Page

5 - Inlet and Outlet Particle Size Distributions Measured using Optical and Diffusion Techniques..... 14

6 - Fractional Efficiency of the Lone Star Steel Steam-Hydro Scrubber..... 15

7 - Time History of the Particulate Loading at the Inlet of the Steam-Hydro Scrubber..... 17

8 - Fractional Efficiency Calculated Using Impactor Data Only..... 21

TABLES

I - Optimization of Steam Hydro Scrubber Performance..... 9

II - Scrubber Outlet Loading by Size Interval..... 19

III - Scrubber Inlet Loading by Size Interval..... 20

IV - Mass Train Test Results, Lone Star Steel Steam-Hydro Air Cleaning System..... 22

V - Mass Train Test Results, Lone Star Steel Steam-Hydro Air Cleaning System..... 23

SECTION I
CONCLUSIONS

The collection efficiency of the Steam-Hydro air cleaning system is quite high. As measured using conventional (Method 5) techniques on a source producing particulate having a mass mean diameter of about 1 μm the efficiency was measured at 99.90 and 99.84% for two days of testing. Measured fractional efficiencies were about 90% at 0.01 μm, about 70% at 0.05 μm, 85% at 0.1 μm, 99.9% at 0.5 μm, 99.99% at 1 μm, and 99.6% at 5 μm. The minimum in the fractional efficiency at about 0.05 μm is probably real, but the actual value is somewhat uncertain because of difficulties in making diffusional measurements in the time variable open hearth process. The manufacturer's estimate of the energy requirements for achieving the efficiencies given above are approximately 8250 BTU/1000 SCF to 12,750 BTU/1000 SCF for system back pressures ranging from one to six inches of water.

SECTION II

INTRODUCTION

This report presents results of the tests conducted by Southern Research Institute to determine the capability of the Lone Star Steel Steam-Hydro scrubber to collect fine particulates. The goals of the tests were: (1) to determine optimum operating conditions of the scrubber, (2) to determine the overall mass efficiency and the fractional efficiency of the scrubber while operating under optimum conditions, and (3) to determine the fractional efficiency of the scrubber for some non-optimum operating conditions as time and circumstances permitted. Figure 1 is a schematic of the basic Lone Star Steam-Hydro scrubber showing the inlet and outlet sampling locations.

At the time tests were conducted four of five open hearth furnaces at this plant were operating continuously 24 hours per day. Each furnace producing three 300 ton batches of steel per day with the production time scheduled for each of the four furnaces staggered by about two hours for logistical purposes, although the actual timing for any one furnace varied somewhat from this schedule. The operations for any one batch were: (1) charging of the furnace with scrap metal, requiring about four hours, (2) addition of iron directly from a blast furnace, requiring about thirty minutes, (3) the refining phase (oxygen lance),

requiring about three hours, and finally (4) furnace tapping and pouring, requiring about thirty minutes. The highest sustained particulate emission rates occur during the oxygen lance portion of the operation, with the actual emission rate and size distribution of the particulate being quite variable throughout the cycle. This variability caused some difficulty in both measurement and interpretation of data as is described in the discussion section of this report.

The waste process gases, at temperatures of about 1500°F from the four furnaces, are carried through a series of flues, flow controllers, and ducts to three waste heat boilers, each of which supplies steam to drive seven of the scrubber modules shown in Figure 1. These are arranged in a semi-circle around the boilers. The gas temperature leaving the boilers is about 530°F. The draft for the entire furnace and scrubber system is provided by the steam ejectors in the scrubber modules. Because only three boiler/scrubber systems are used to control the emissions from four furnaces, each system treats the emissions from more than one furnace. The system on which the measurements were made was fed primarily by furnaces 3 and 4 with approximately 67% of the gas handled by the system coming from furnace No. 4. The fact that more than one furnace supplied the system being measured also added to the difficulty in interpreting some of the results and made it impractical to attempt to isolate certain portions of the overall furnace cycle for analysis. The manufacturers description of the operation of the scrubber is given in Appendix A.

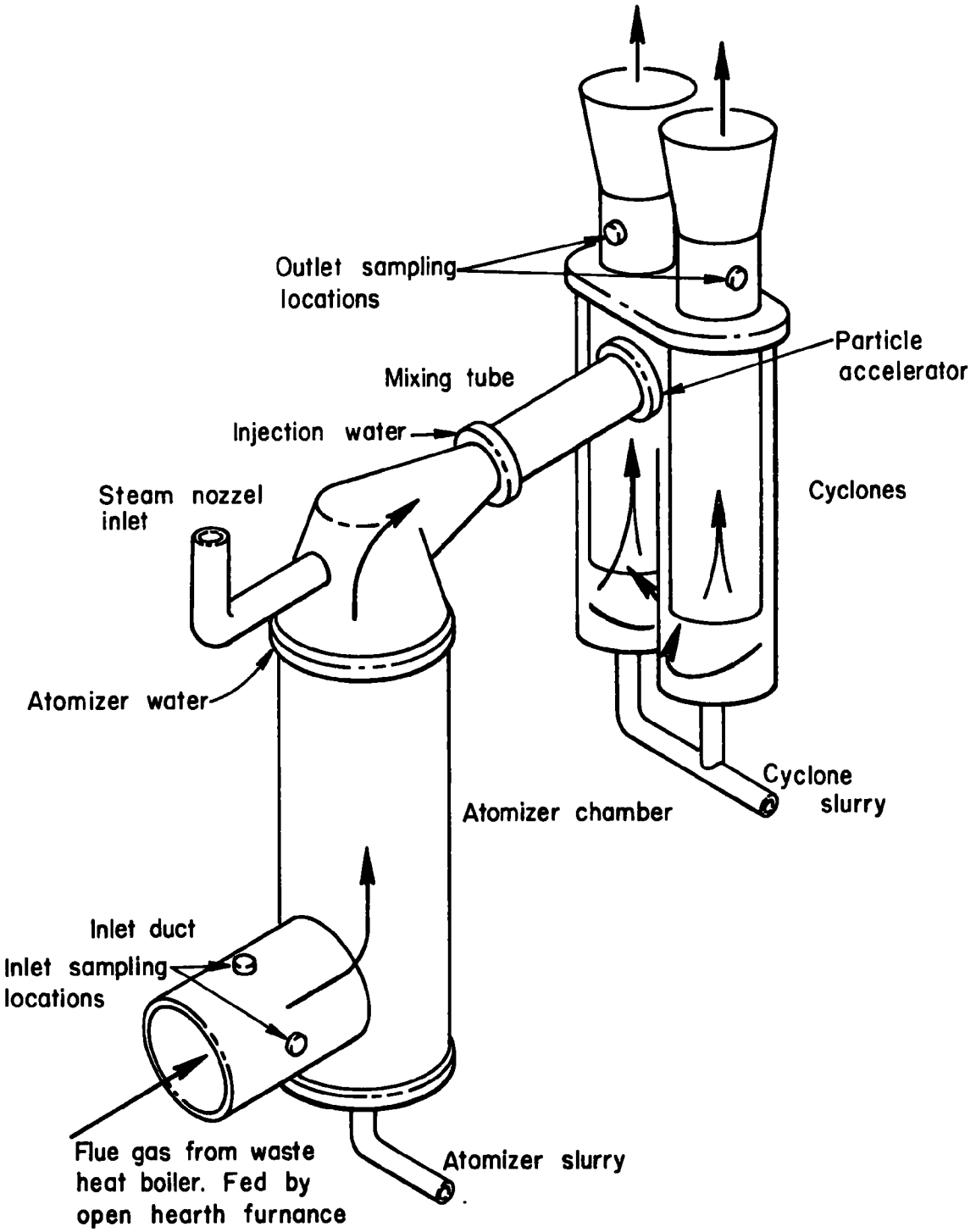

Figure 1. The Lone Star Steel Steam-Hydro Air Cleaning System.

SECTION III

DISCUSSION

A total of four measurement techniques were used during the tests. These were: (1) diffusional techniques using condensation nuclei counters and diffusion batteries for determining concentration and size distribution on a number basis for particles having diameters less than approximately 0.2 μm, (2) optical techniques to determine concentrations and size distribution for particles having diameters between approximately 0.3 μm and 1.5 μm, (3) inertial techniques using cascade impactors for determining concentrations and size distributions on a mass basis for particles having diameters between approximately 0.25 μm and 5 μm, and (4) standard mass train measurements for determining total inlet and outlet mass loadings.

The useful concentration ranges of both the optical counter and the condensation nuclei counters are such that extensive dilution of the gas streams being sampled was required. Dilution factors of about 65:1 were used for the outlet measurements and about 500:1 for the inlet measurements. In order to insure that condensation effects were minimal and that the particles were dry as measured, the diluent air was dried and filtered, and diffusional driers were utilized in the lines carrying the diluted samples to the various instruments.

Because of the size and complexity of the optical and diffusional measuring systems, and the fact that only one set of equipment exists for measurements

of this type, it was not possible to obtain simultaneous inlet and outlet data with these methods. The system was first installed at the outlet sampling location, the scrubber was tuned, and all the outlet data were obtained. Subsequently, the equipment was moved to the inlet and the necessary inlet data were obtained. For the purposes of calculating the efficiency of the scrubber, the assumption was made that the open hearth process was sufficiently repetitive that the inlet data, as obtained above, were a valid representation of that which would have been obtained during the time the outlet measurements were made. Accuracy in the diffusional measurements was limited by process variations and the efficiencies derived from these data are rather uncertain. However, the trerds in the fractional efficiencies derived from the data are probably real and the fractions of the influent material that penetrate the scrubber are probably correct to within a factor of two to three. Similar tests on a source with less process variations (i.e., a Kraft recovery boiler, or a pulverized coal-fired power boiler) would be desirable in order to refine the efficiency data.

The optical data are presented on the basis of equivalent polystyrene latex sizes and the indicated sizes can differ from the true sizes by factors as large as two to three. Data obtained using this method were primarily intended as a means of real time monitoring of process changes and the results of changes in the scrubber operation, but also serve as rough checks on the data obtained with the cascade

impactors. The sampling system used for obtaining the optical and diffusional data is illustrated diagrammatically in Figure 2.

The tests took place on the dates of December 4 through December 11, 1973, with December 4 primarily used for instrumentation setup, checkout, and preliminary measurements. Optimization of the scrubber operating parameters was accomplished on December 5 using the optical and condensation nuclei counters. The results of these tests are given in Table I , which includes the three primary operating variables (cyclone accelerator position, steam pressure at the ejection nozzle inlet, and gas flow rate). Direct comparisons of data between some of the test conditions are not meaningful because of variations in the open hearth process. This is especially true of tests that are separated by periods of more than a few minutes. The operating condition chosen from the real time optical and CN data did appear to produce lower outlet loadings as later measured with the impactors when compared with two other conditions also used in the tests. The optimum conditions appeared to be accelerator position 3, steam pressure 250 lbs and 11,000 scfm flow rate. Other conditions tested were accelerator position 2, 250 lbs steam pressure and 15,000 scfm; and accelerator position 3, 300 lbs steam pressure, and 13,000 scfm.

Diffusional data for efficiencies below 0.3 μm were obtained only under the apparent optimum condition. A brief test using the condensation nuclei and

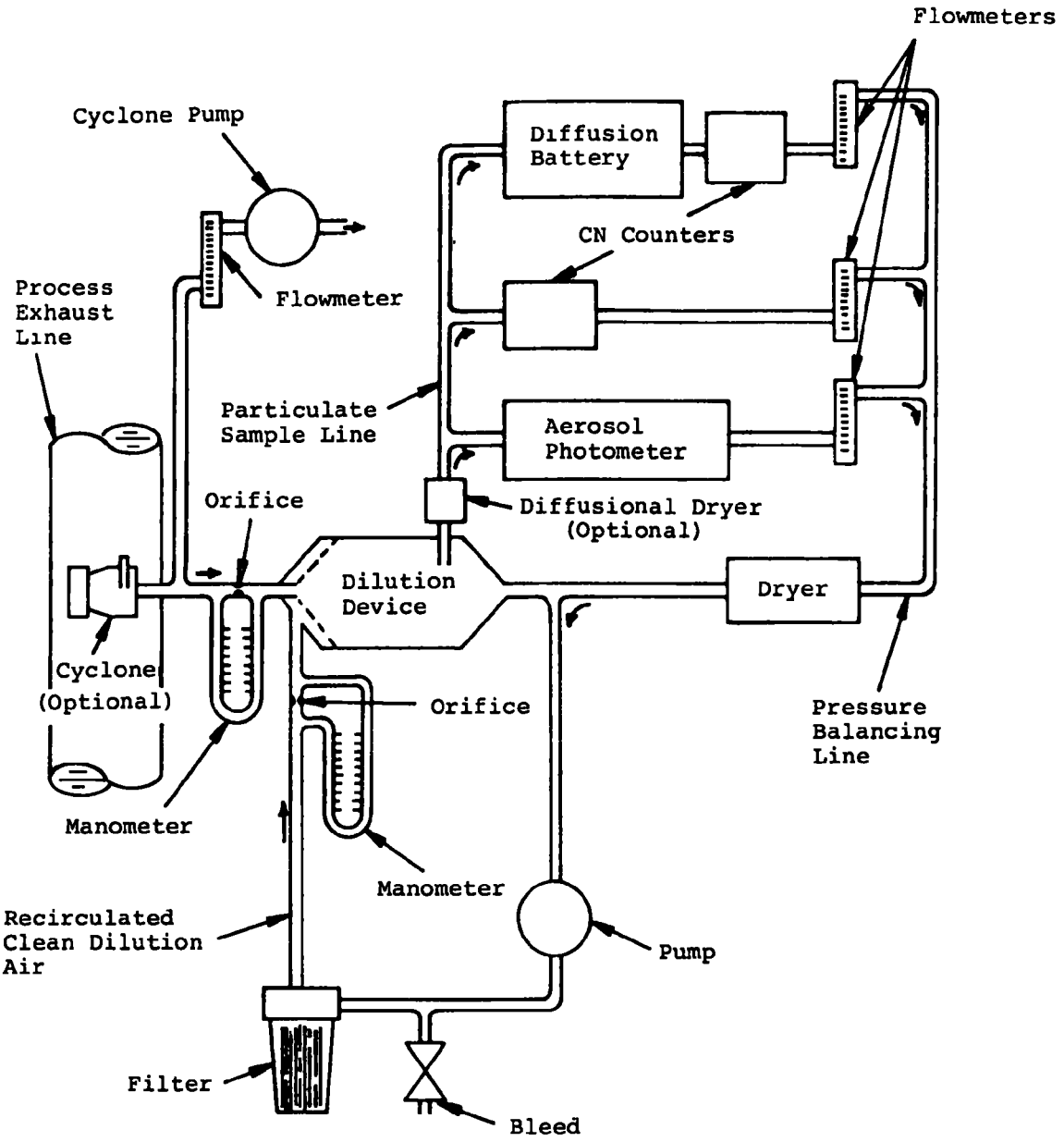

Figure 2. Optical and Diffusional Sizing System.

TABLE I

OPTIMIZATION OF STEAM HYDRO SCRUBBER PERFORMANCE

Time	Particle Acceleration Position	Steam Pressure psig	Gas Flow lbs/min	Particles/cm^3* Dia.≥0.06 µm	Particles/cm^3* Dia.≥0.45 µm	Particles/cm^3* Dia.≥1.0 µm	Particles/cm^3* Dia.≥1.6 µm
1130	2	250	1320	0.72×10^6	2.0×10^3	45	2
1140	2	300	1453	0.69	2.0	14	2
1150	2	350	1526	0.90	2.2	200	11
1225	1	250	1404	0.94	> 2.3	2100	105
1230	1	300	1498	1.51	> 2.3	2400	123
1240	1	350	1581	2.24	> 2.3	2400	248
1255	0	250	1510	0.93	> 2.4	> 2400	588
1300	0	300	1612	1.58	> 2.4	> 2400	235
1310	0	350	1702	1.47	> 2.4	1200	214
1330	2	250	1096	0.78	> 2.2	1.6	11
1340	2	300	1182	0.78	> 2.2	1.9	11
1730	3	350	1163	1.38	1.35	6.7	< 2
1740	3	300	1048	1.1	1.24	< 2	< 2
1750	3	250	916	0.79	1.17	< 2	< 2
1800	2	250	1283	0.85	> 2.1	15	< 2

* Concentration of particles larger than the stated size in the scrubber effluent gas stream.

optical techniques with the atomizer water turned off indicated a definite increase in the concentration of submicron particles with the atomizer water off. Insufficient data were obtained to fully quantify the effect.

Figures 3 and 4 are recordings made at the outlet using the optical and diffusional systems. Figure 3 is condensation nuclei data which corresponds to particulate concentrations over the range from 0.01 to 0.2 μm in particle diameter. This data was taken over a 25 minute period on December 7, during oxygen lance. It is evident from Figure 3 that even during lance, the most stable process, variations in the particulate concentration are large. Because of this, the accuracy of the diffusional results is limited. For example, when testing, the diffusional system operator may be looking for ten percent changes in concentration due to size related penetration differences in the diffusion batteries, while the open hearth process interjects concentration changes of almost an order of magnitude. In short, the "signal" to "noise" ratio was unfavorable when operating the diffusional system on the open hearth process.

Figure 4 shows optical and diffusional data taken December 7, during a charging cycle. The variations in particulate concentration are quite large, and periodic. The periodicity may be related to the charge operations or to the furnace draft direction

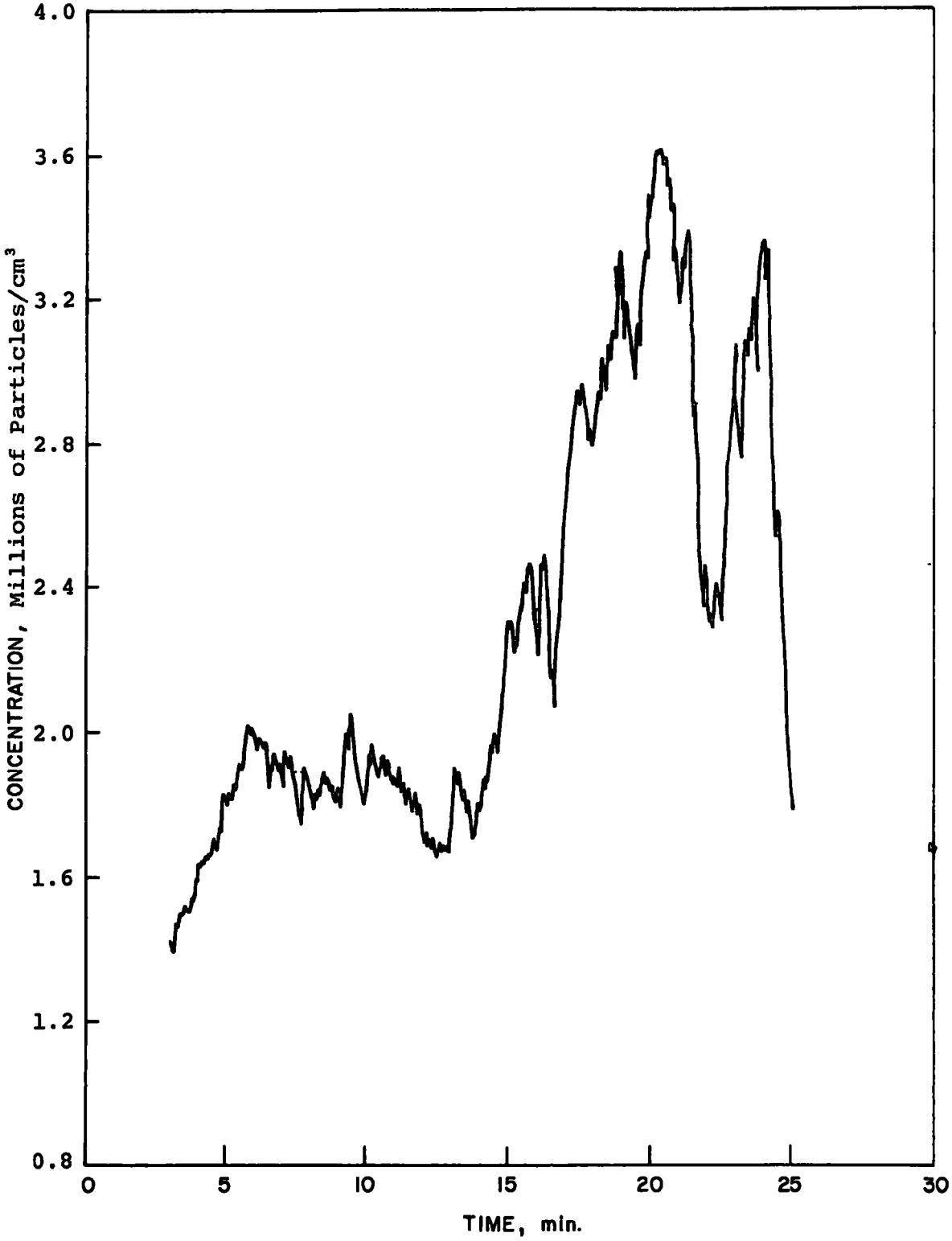

Figure 3. Condensation Nuclei Data Taken During the Oxygen Lance Cycle.

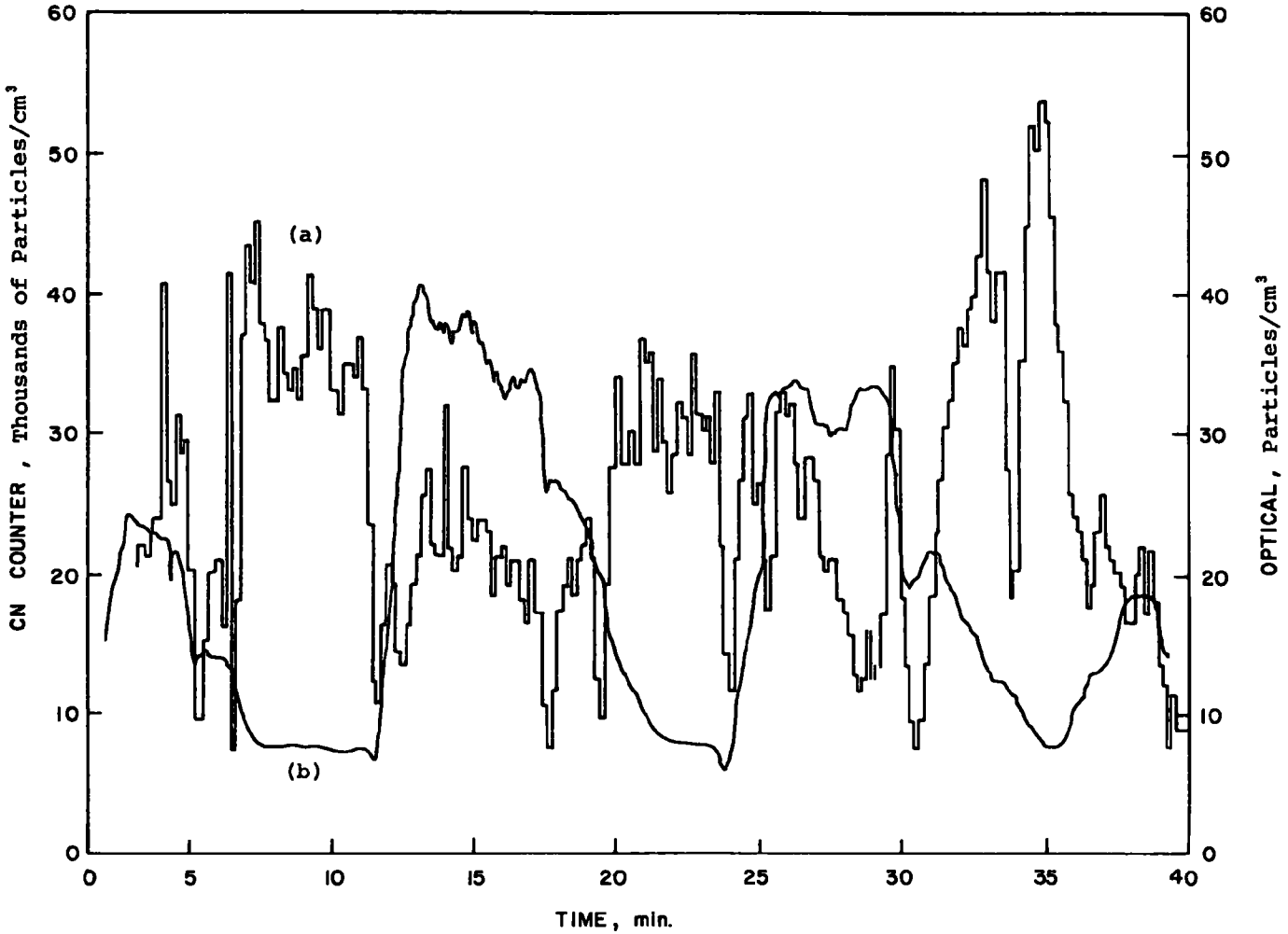

Figure 4. Optical and Condensation Nuclei Counter Data Taken During the Charge Cycle. (a) Optical Data (0.3 - 2 μm Diameter), (b) Diffusional Data (0.01 - 2 μm Diameter). Concentrations are those obtained after dilution by a factor of 1:65.

changes. Curve (a) is optical data and corresponds to the particle concentration from about 0.3 to 2 μm diameter. Curve (b) is condensation nuclei data corresponding to the concentration within the size range from 0.01 to 0.1 μm diameter.

Notice that when the large particle concentration curve (a) increases, the small particle concentration curve (b) decreases. This probably occurs as a result of a higher loss rate by agglomeration resulting from changes in the surface area to which the ultrafine particles may diffuse.

Figure 5 shows typical inlet and outlet size distributions as obtained by optical and diffusional methods during oxygen lance, the most stable process during the heat cycle (see Figure 7). Figure 6 shows the fractional efficiencies calculated from these data together with a set of typical results from the impactor measurements.

Inertial sizing was accomplished using Brink cascade impactors for inlet measurements and Andersen impactors for outlet measurements. Sampling was done at near isokinetic rates. Errors due to deviations from isokinetic sampling should be of little consequence for particles having aerodynamic diameters smaller than 5 μm or physical diameters smaller than 2 μm for an assumed density of 5.2 gm/cm^3. Further, because the sampling was at near isokinetic rates, the calculated collection efficiencies for larger particles are

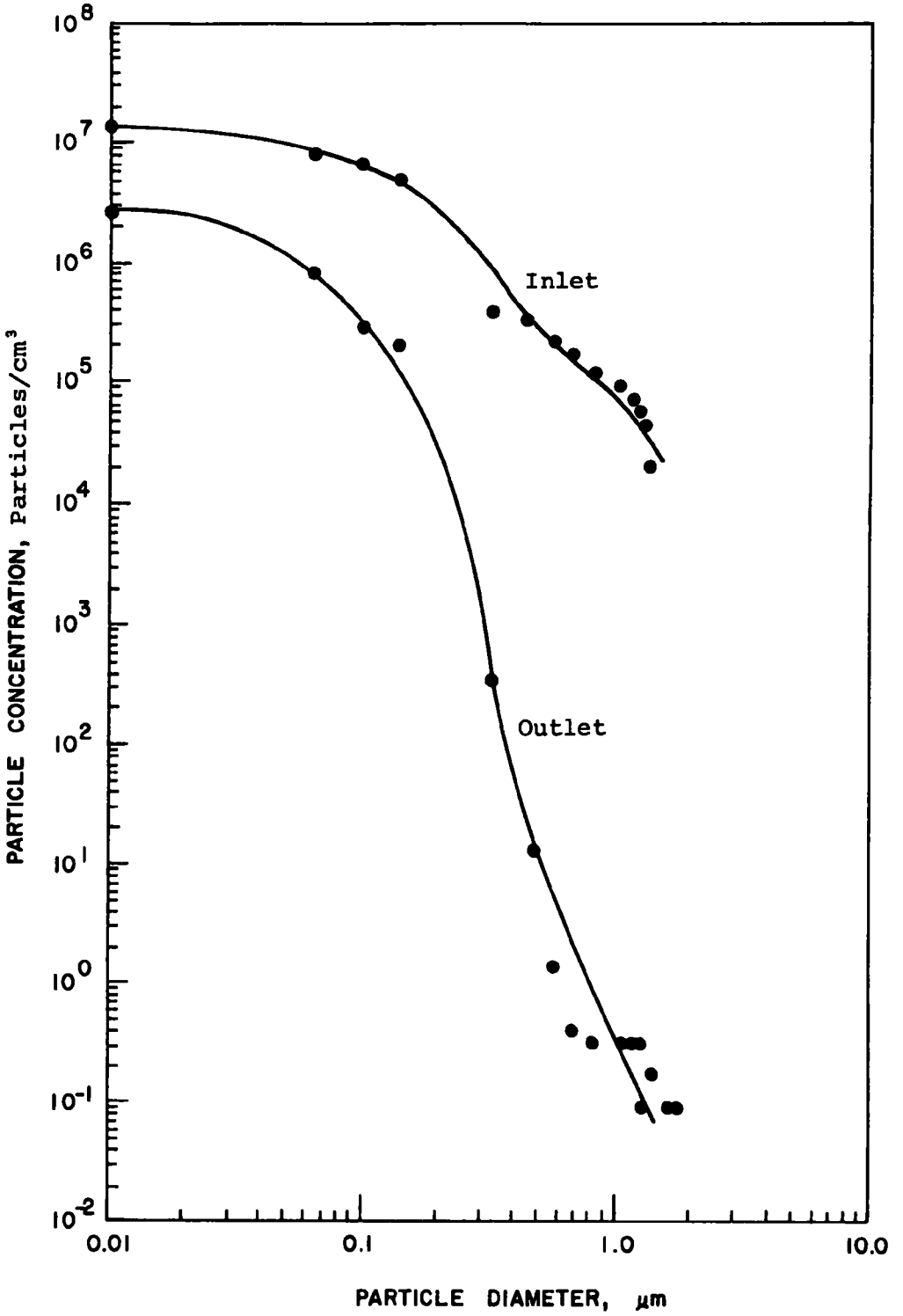

Figure 5. Inlet and Outlet Particle Size Distributions Measured using Optical and Diffusional Techniques.

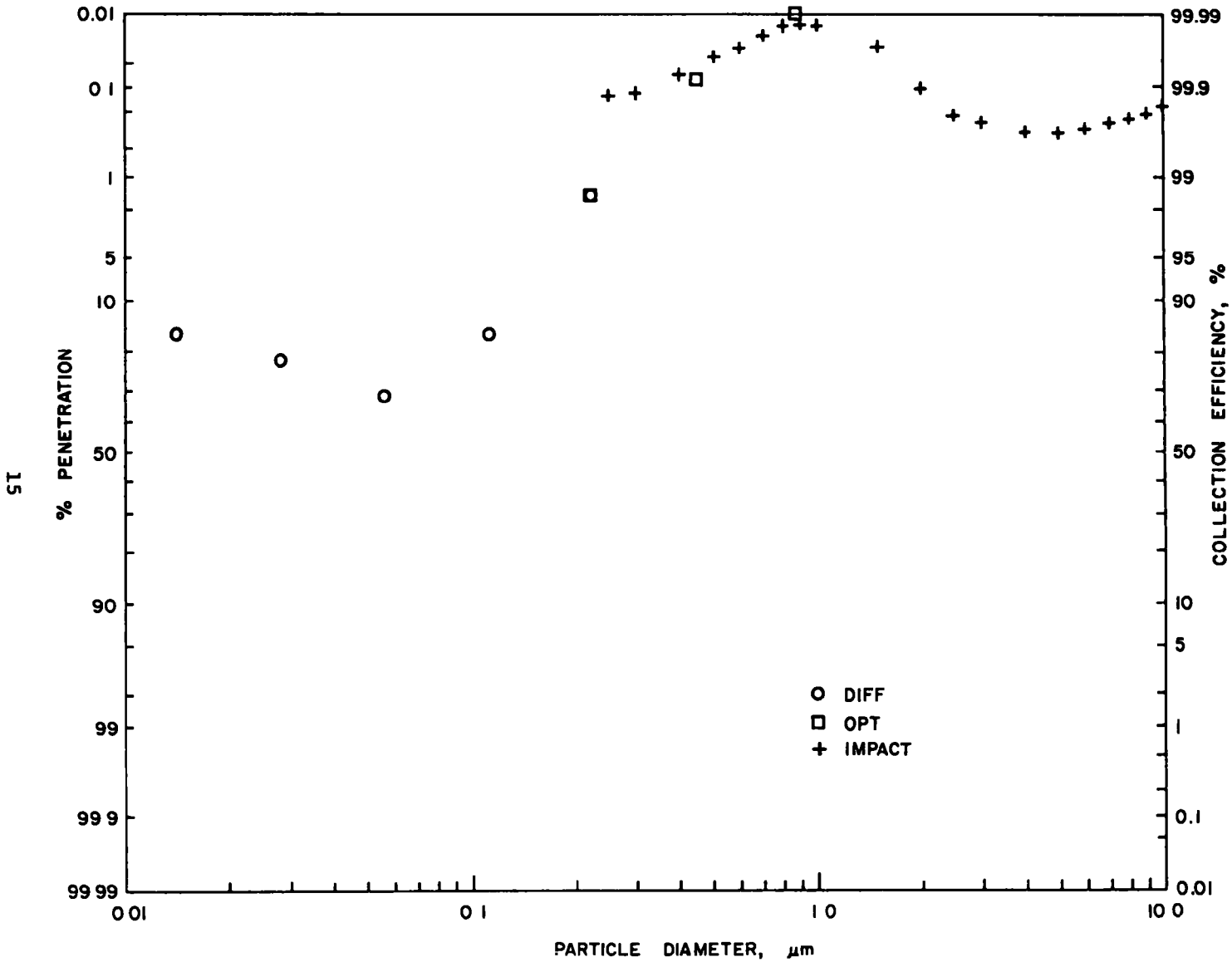

Figure 6. Fractional Efficiency of the Lone Star Steel Steam-Hydro Scrubber.

probably reasonably close to the true values. Because of the relatively small duct dimensions as compared to the sizes of the impactors, single point sampling was used in the ducts with the inlet impactors at flue gas temperature (∿515°F). The outlet impactors were heated to about 40° above flue gas temperature to insure that no condensation took place within the impactor. Such condensation might cause operational difficulties or lead to incorrect sizing.

Because of the wide disparity in the inlet and outlet mass loadings (inlet ∿1 - 2 grains/cf, and outlet ∿0.001 grain/cf) complete simultaneity in the inlet and outlet sampling was not possible. Outlet samples were generally of about 6 hours duration while inlet samples were of about 6 minutes duration. Because of the very low outlet loading and the consequent length of the outlet sampling time, it was found to be impractical to attempt to isolate individual portions of the overall furnace cycle for analysis. A secondary consideration in omitting the furnace operation breakdown in the outlet measurements was the fact that the scrubber was being fed from two furnaces, approximately 67% from number four and 33% from number three, with the phase relations between the two furnace cycles being quite variable. Since the inlet sampling could not correspond directly with the outlet sampling, an inlet mass loading history for one complete furnace cycle was synthesized for each size interval covered by the inlet impaction stages. Examples of these synthesized histories are shown in Figure 7.

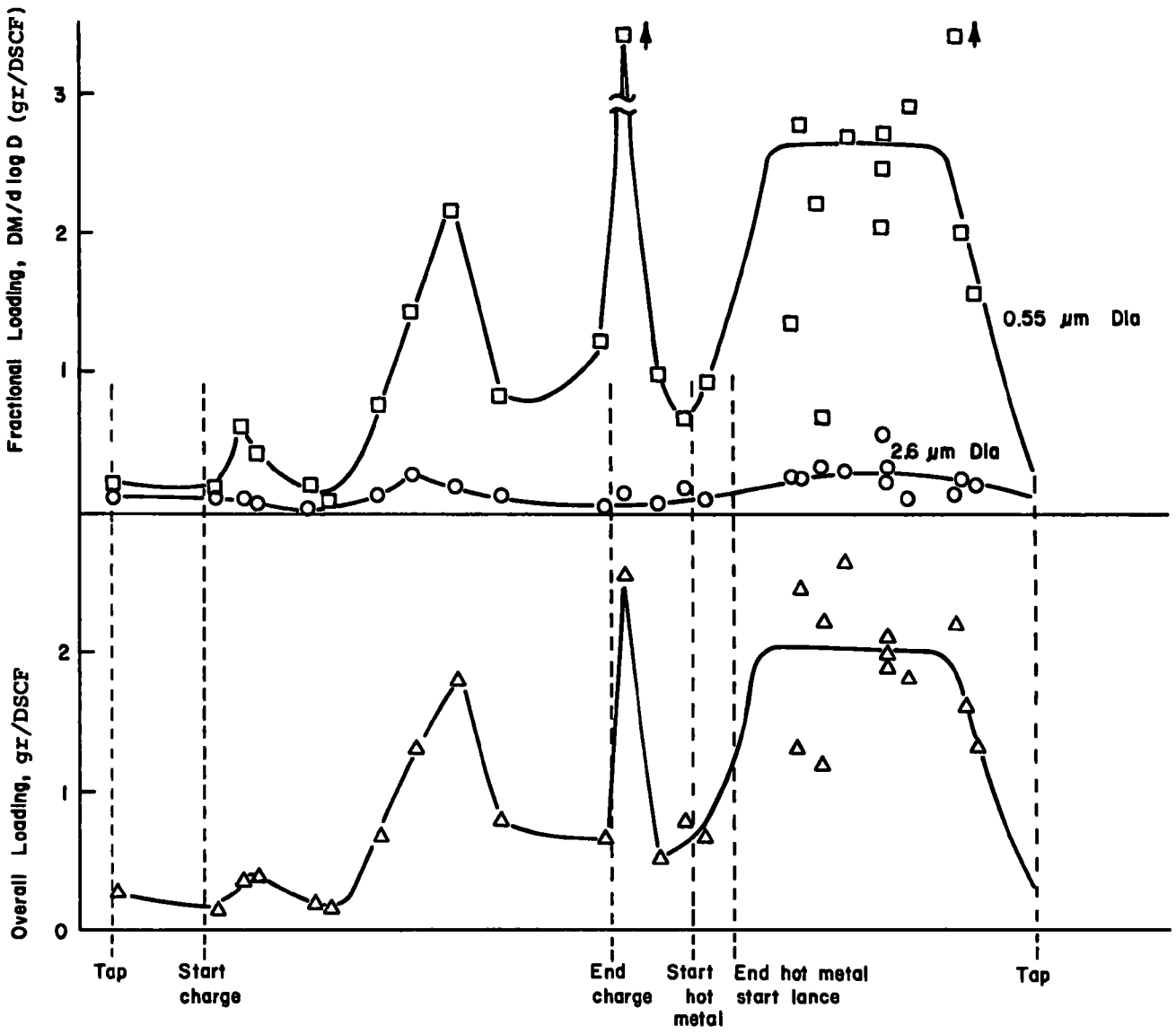

Figure 7. Time History of the Particulate Loading at the Inlet of the Steam-Hydro Scrubber. The Time Period Shown is About Eight Hours.

Appropriate time averages from the synthesized complete cycle was used in computing the fractional efficiencies from the impactor data.

The sizes reported here for the inertial data are based on an assumed particle density of 5.2 gm/cm^3. If the true particle densities are lower than this value, the sizes as given should be increased by a factor equal to the square root of ratio of the assumed density to true density. The impactor data are summarized in Tables II and III and the fractional efficiencies as calculated from these data are shown in Figure 8.

Mass train measurements were obtained by Guardian Systems, Inc., of Anniston, Alabama, under subcontract to Southern Research Institute on December 10 and 11, and the results of these measurements are shown in Tables IV and V. The overall efficiencies, by mass, based on these results are included in Table V.

Appendices are included which contain summaries of furnace and scrubber operations during the time intervals over which data were obtained, and cost-estimates for the operation of the scrubber.

With regard to the scrubber energy requirements, it should be noted that the steam flow is that which is required to pump and clean a gas stream with approximately five to seven inches of water back pressure. According to the manufacturer, the amount of steam used is a function of this back pressure.

TABLE II

SCRUBBER OUTLET LOADING BY SIZE INTERVAL

DATE(S) & TIME(S)	12/6 12:03/ 13:33	12/6 17:45/ 19:15 12/7 11:45/ 13:32	12/7* 10:03/ 11:33 13:35/ 14:00	12/8 10:30/ 16:30	12/9 09:30/ 10:25 10:55/ 16:00	12/10 10:15/ 19:15	12/11 09:45/ 16:10
Acc. Position	3	3	3	3	2	3	3
Steam Pres.	250	250	250	300	250	300	300
Scrubber Flow Rate	11,000	11,000	11,000	13,000	15,000	13,000	13,000
#4 Furnace Operations During Measurement	Lance	Lance	Non-Lance	60% NL 40% L	60% NL 40% L	60% Lance 40% NL	60% Lance 40% NL
Overall Loading (gr/dscf)	0.0012	0.0012	0.0014	0.00086	0.0016	0.00009	0.0017
Size Interval/Loading Microns/(gr/dscf)							
>6.04	0.00009	0.00013			0.00007	0.00004	0.00015
3.75-6.04	0.00002	0.00005			0.00006	0.00004	0.00010
2.53-3.75	0.00000	0.00006			0.00004	0.00004	0.00009
1.71-2.53	0.00008	0.00004			0.00003	0.00002	0.00012
1.09-1.71	0.00001	0.00001		0.00003**	0.00002	0.00002	0.00009
0.52-1.09	0.00008	0.00007		0.00007	0.00006	0.00005	0.00012
0.30-0.52	0.00018	0.00015	0.00040**	0.00014	0.00016	0.00014	0.00023
0.18-0.30	0.00017	0.00017	0.00018	0.00012	0.00020	0.00011	0.00017
<0.18	0.00053	0.00052	0.00081	0.00049	0.00091	0.00042	0.00060

* Heater failed resulting in large amount of water condensing in impactor.

** Value represents the total loading for all particle sizes larger than the minimum size shown for this impactor stage. All impactor stages were not used for these runs.

TABLE III

SCRUBBER INLET LOADING BY SIZE INTERVAL *

Date	Time	#4 Oper.	Time After Op. Start.	Total Load	Dia. (ρ=5.2	Loading in Size Interval, grains/sdcf									
						>6.0	>3.4	3.4-6.0	2.0-3.4	1.3-2.0	0.70-1.3	0.43-0.70	0.23-0.43	<0.43	<0.23)
12/11	10:23	Charge	3	0.157		0.024		0.021	0.029	0.012	0.021	0.036		0.014	
12/09	13:07		10	0.346		0.064		0.005	0.016	0.029	0.096	0.128		0.007	
12/07	14:44		15	0.385			0.048		0.013	0.018	0.084	0.088	0.100		0.033
12/08	15:03		35	0.182		0.029		0.008	0.003	0.014	0.020	0.043		0.065	
12/05	15:00		40	0.129			0.048		0.017	0.008	0.005	0.013	0.029		0.008
12/08	09:48		60	0.656		0.088		0.010	0.027	0.057	0.207	0.158		0.110	
12/11	11:33		75	1.29			0.250		0.062	0.045	0.210	0.312	0.319		0.091
12/08	16:01		90	1.81			0.299		0.042	0.123	0.290	0.459	0.471		0.123
12/05	15:57		100	0.784		0.176		0.010	0.027	0.080	0.225	0.171		0.094	
12/10	16:12		160	0.656		0.075		0.000	0.002	0.016	0.152	0.252		0.159	
12/07	10:46		180	2.55			0.109		0.028	0.139	0.430	1.066	0.735		0.049
12/09	09:54	End of Charge to Hot Metal	15	0.507		0.063		0.006	0.009	0.035	0.118	0.205		0.070	
12/08	11:45		45	0.768			0.203		0.038	0.070	0.161	0.142	0.125		0.029
12/09	16:10	Hot Metal	0	0.616			0.077		0.019	0.014	0.112	0.197	0.149		0.048
12/11	13:34	Lance	19	1.30		0.238		0.048	0.057	0.152	0.403	0.274		0.125	
12/06	17:52		22	2.46			0.230		0.060	0.218	0.797	0.589	0.356		0.214
12/06	12:18		30	2.20			0.346		0.066	0.180	0.678	0.469	0.273		0.188
12/07	11:57		30	1.18		0.337		0.035	0.079	0.266	0.206	0.141		0.156	
12/05	11:46		40	2.63			0.444		0.068	0.230	0.866	0.569	0.205		0.251
12/05	11:55		50	2.11		0.472		0.050	0.127	0.196	0.679	0.425		0.156	
12/09	11:13		55	1.87			0.433		0.052	0.138	0.379	0.527	0.304		0.042
12/10	18:15		55	2.02			0.134		0.075	0.170	0.622	0.572	0.248		0.200
12/10	11:38		63	1.82		0.148		0.009	0.022	0.031	0.390	0.612		0.605	
12/06	18:49		80	2.18		0.154		0.029	0.032	0.050	0.202	0.967		0.747	
12/11	14:37		82	1.61			0.274		0.059	0.143	0.367	0.428	0.256		0.082
12/06	13:16		86	1.32		0.209		0.031	0.047	0.209	0.205	0.324		0.294	
12/10	12:32	Tap	7	0.267			0.113		0.022	0.006	0.012	0.041	0.056		0.016
					(Dia. (ρ=1.	>14	>7.9	7.9-14	4.7-7.9	3.2-4.7	1.8-3.2	1.1-1.8	0.69-1.1		<0.69)

* Samples are ordered to synthesize one complete furnace cycle.

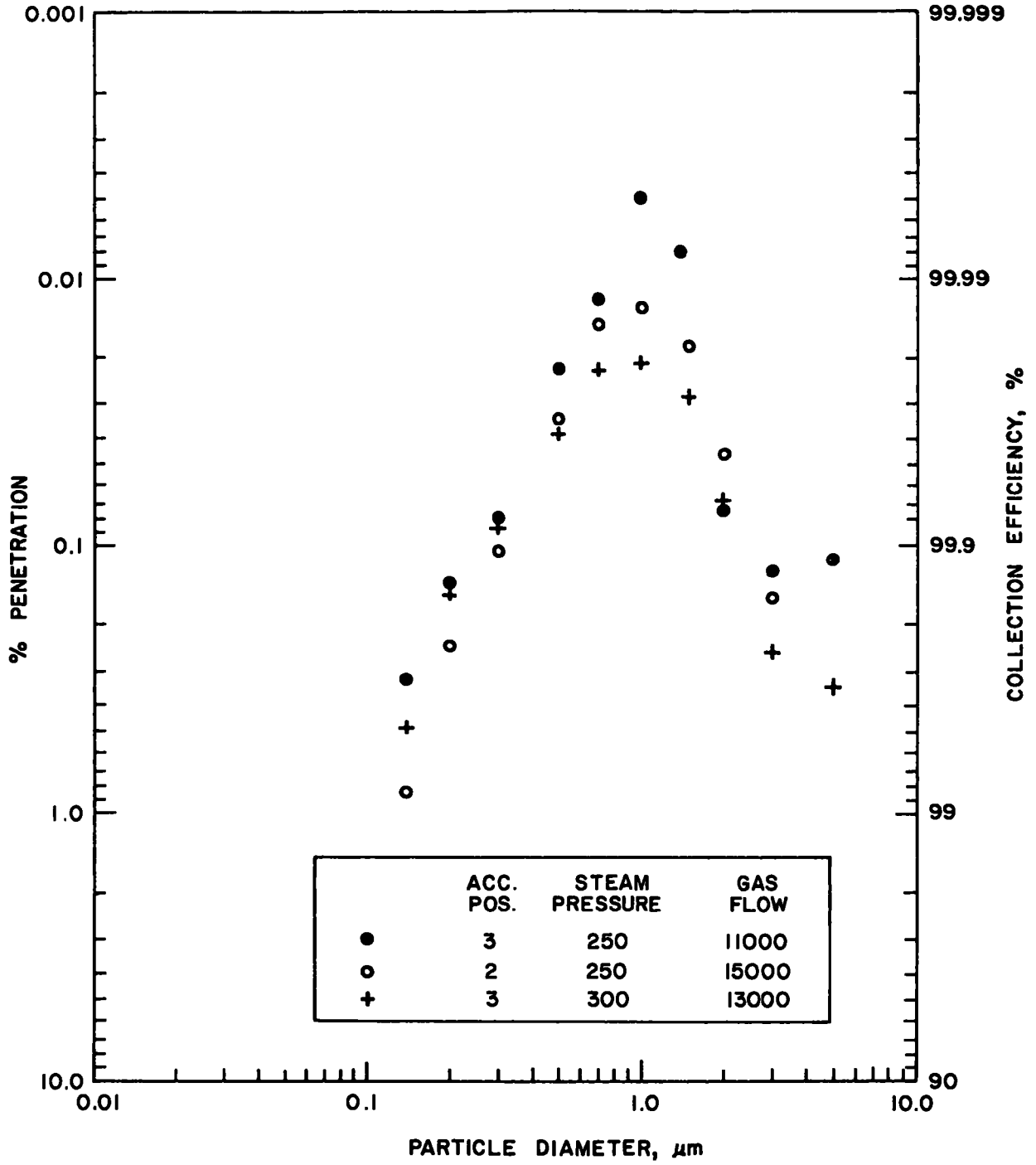

Figure 8. Fractional Efficiency Calculated Using Impactor Data Only.

TABLE IV

MASS TRAIN TEST RESULTS
Lone Star Steel
Steam-Hydro Air Cleaning System

Position:	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet
Date:	12/10	12/10	12/10	12/10	12/11	12/11
Test No.:	1	2	3	4	1	2
Stack Temp:°R	965	965	970	965	995	995
Moisture, %	5.42	4.68	8.50	4.04	3.63	3.44
Avg. Velocity, fpm	1428	1613	1780	1835	1398	1718
Flow, ACFM	17939	20261	22350	23047	17561	21582
Flow, DSCFM	9110	10476	11036	11996	8849	10940
Grains/ACF	0.306	0.132	0.259	0.627	0.157	0.467
Grains/DSCF	0.597	0.255	0.525	1.205	0.312	0.921
Run Duration (min)	60	120	40	120	160	165
Time:	11:15	12:35	15:30	17:15	09:00	13:20

TABLE V

MASS TRAIN TEST RESULTS
Lone Star Steel
Steam-Hydro Air Cleaning System

Position:	Outlet	Outlet	Outlet	Outlet	Outlet	Outlet	Outlet	Outlet	Outlet
Date:	12/10	12/10	12/10	12/10	12/11	12/11	12/11	12/11	12/11
Time:	11:30	13:00	15:00	17:00	09:00	10:30	12:00	13:30	15:00
Test No.:	1	2	3	4	1	2	3	4	5
Stack Temp.:°R	620	623	621	621	624	622	624	625	625
Moisture, %	29.31	34.21	28.78	20.71	29.21	33.00	36.44	38.44	34.43
Grains/ACF	0.0002	0.0003	0.0003	0.0006	0.0004	0.0004	0.0004	0.0004	0.0004
Grains/DSCF	0.0003	0.0005	0.0005	0.0008	0.0007	0.0007	0.0007	0.0007	0.0007
Run Duration (min)	70	60	60	60	60	60	60	60	60
Scrubber Eff.	99.95	99.80	99.90	99.93	99.78	99.78	99.78	99.92	99.92

For example, the amount of steam required to pump and clean a system with two inches of water back pressure is approximately one third that required at five to seven inches. (Excessive back pressure is caused in the case of the Lone Star Steel system by dirty waste heat boilers).

SECTION IV

APPENDICES

A MANUFACTURER'S DESCRIPTION OF THE OPERATION OF THE SCRUBBER

B SCRUBBER OPERATING PARAMETERS DURING TESTS

C^1 OPEN HEARTH FURNACE OPERATING SUMMARY

C^2 OPEN HEARTH FURNACE MATERIALS SUMMARY

D ESTIMATED OPERATING COSTS OF THE STEAM HYDRO AIR CLEANING SYSTEM

E CONVERSION FACTORS

APPENDIX A

MANUFACTURER'S DESCRIPTION OF THE OPERATION OF THE SCRUBBER

The system utilizes a high-speed steam drive with injected water to perform an extremely efficient scrubbing action. The heart of the system, which contains no moving parts, consists of a steam nozzle, water injector, mixing tube and twin cyclones. System operation is simple and easily controlled.

Normally, the system operates on energy produced by waste heat captured from the process being controlled. The heat is used to generate steam in a waste heat boiler. In installations where heat energy is low, supplemental heat may be provided. In many cases, a package steam boiler may supply all the energy.

In addition to driving the system, the steam nozzle creates draft which draws contaminated gases into the system.

Atomizer Chamber

First stage of cleaning is done in an optional atomizing chamber with water sprays that may be employed to cool the gas stream and remove heavy particulate. Most processes do not require this chamber but it can be installed as a first-phase cleaner for certain difficult effluents. A negative pressure is

maintained in this chamber. A process occurs where steam joins small particulate for second-phase removal in the mixing tube.

Mixing Tube

Collision between injected water droplets and the particulate, (including acidic gases if present) encapsulation, nucleation, and droplet growth take place in the mixing tube. Collisions occur between particulate and billions of high-speed water droplets. Particulate is encapsulated and a growth process begins to bring submicron particulate to manageable size for disposal through low-pressure-drop cyclones. To insure positive capture of all particulate, a shock wave pattern is created in the mixing tube. Massive turbulence created by the shock wave pattern subjects encapsulated particulate to a sudden and violent scrubbing action.

Cyclones

Separation of particulate from the gas is achieved by entering low-pressure-drop cyclones with appropriate velocities and particulate which has grown to a size matched to the system. Centrifugal energy in the cyclones is maintained by force imparted from the mixing tube.

APPENDIX B

SCRUBBER OPERATING PARAMETERS DURING TESTS

Date	24 Hour Time	Furnace	Condition	Steam Flow Lbs/hr	Gas Flow SCFM	Injection Water GPM	Atomizer Water GPM	Atomizer Slurry GPM	Cyclone Slurry GPM	Particle Accrl. Position	Nozzle Steam Pres psig	Steam Temp °F	Emission GR/SCF
12/05/73	11 05-13:40	4	Lance	8379	18,441	30	27.2	23.3	29.8	Varied 1-3	Varied 250-350	590-620	
	12 20-12.35	3	Hot Metal	7851	18,449	30	27 6	22 2	30 7	1-3	250-350	590-620	
	12·35-13 40	3	Lance	8519	18,562	30	27 5	24.4	28.4	1-3	250-350	590-620	
	17·30-18 33	4	Lance	8108	14,362	31 5	25.7	26 9	28 3	1-3	250-350	590-620	
	17.30-18:15	3	Charge	7932	13,887	31 6	26.1	27 4	28 5	1-3	250-350	590-620	
12/06/73	12 00-13 41	4	Lance	7357	10,926	33 6	26 2	23 7	28 1	03	250	545	0 0012
	12 20-12:35	3	Hot Metal	7357	11,116	33.6	26.2	23.5	28.1	03	250	545	0 0012
	12.35-14:50	3	Charge	7357	10,741	33.6	26.2	23.9	28 1	03	250	545	0 0012
	14:20-16:20	4	Charge	7357	10,659	33.6	24 6	23.9	28.1	03	250	545	0.0012
	15 05-15.15	3	Hot Metal	7357	10,674	33 6	24.3	23.9	28 1	03	250	545	0.0012
	15.15-17.25	3	Lance	7357	10,761	33.6	23.6	24.1	28.6	03	250	545	0.0012
	17:15-17:30	4	Hot Metal	7357	11,065	33 1	0	0	24.1	03	250	545	0 0012
	17.30-19:30	4	Lance	7560	10,782	32.6	26.4	23.9	28 8	03	250	545	0.0012
	18.05-19.30	3	Charge	7560	10,782	32.6	26.4	23.9	28.8	03	250	545	0 0012
12/07/73	09.00-10 09	3	Lance	7270	10,937	33.6	25.9	23.6	30 1	03	250	550	0 0012
	09.00-10.50	4	Charge	7270	10,919	33.2	25.9	23.6	29 6	03	250	550	0 0012
	10·50-12 45	3	Charge	7357	10,722	32.7	26.3	24.4	27.6	03	250	550	0 0012
	11:15-11 30	4	Hot Metal	7357	10,638	32.6	26.6	25.6	28.1	03	250	550	0.0012
	11.30-13:05	4	Lance	7386	10,770	32 7	26.1	23.8	28 1	03	250	550	0.0012
	13.25-13·55	3	Hot Metal	7328	10,817	33.1	26 0	25.7	27.4	03	250	550	0 0012
	13.55-15 38	3	Lance	7299	10,954	32.6	26.3	25 8	28.5	03	250	550	0.0012
	14:30-15 38	4	Lance	7328	10,949	32.6	26.4	25.9	28.6	03	250	550	0 0012
12/08/73	10 30-11:00	4	Charge	8695	12,999	33.4	26.0	23 0	31.4	03	300	560	0.00082
	11.05-12.55	3	Charge	8840	12,933	33 5	26.0	22.6	31.3	03	300	560	0 00082
	12.10-12:25	4	Hot Metal	9202	12,904	33.6	25.9	22.4	31.3	03	300	560	0.00082
	12:25-13 50	4	Lance	8811	13,036	33.6	25.8	22 5	31.6	03	300	560	0.00082
	13.30-13 45	3	Hot Metal	8695	13,200	33.6	25.8	23.3	31.6	03	300	560	0.00082
	13 45-15.40	3	Lance	8724	13,011	33 6	25 9	22.3	31.5	03	300	560	0 00082
	14.30-16 30	4	Charge	8666	12,967	33 4	25 9	22.2	31 4	03	300	560	0 00082

*Time intervals are shown to cover the individual furnace operation of furnaces 3 and 4.

APPENDIX B
(Continued)

Date	24 Hour Time	Furnace	Condition	Steam Flow Lbs/hr.	Gas Flow SCFM	Injection Water GPM	Atomizer Water GPM	Atomizer Slurry GPM	Cyclone Slurry GPM	Particle Accrl. Position	Nozzle Steam Pres psig	Steam Temp. °F	Emission GR/SCF
12/09/73	08 30-09.40	3	Lance	7287	15,094	35.5	25.9	22.5	32.5	02	250	540	0.0015
	08 30-09:40	4	Charge	7287	15,094	35.5	25.9	22.5	32.5	02	250	540	0.0015
	10 05-10 20	4	Hot Metal	7299	15,146	35.5	25.6	24.0	32.0	02	250	540	0.0015
	10:20-12:20	4	Lance	7317	15,022	35.6	24.9	22.7	32.0	02	250	540	0.0015
	10:20-12:40	3	Charge	7317	15,059	35.6	24.9	22.6	32.1	02	250	540	0.0015
	12:40-13:10	3	Hot Metal	7328	15,020	35.0	24.7	21.7	33.5	02	250	540	0.0015
	13 00-15:35	4	Charge	7328	14,996	35.0	24.8	21.5	33.7	02	250	540	0.0015
	13.20-15:35	3	Lance	7328	15,065	35.1	24.8	21.5	33.7	02	250	540	0.0015
	16:10-16:25	4	Hot Metal	7386	14,933	35.0	24.5	19.9	34.8	02	250	540	0.0015
	16:20-16:30*	3	Charge	7386	14,933	35.0	24.5	19.9	34.8	02	250	540	0.0015
	16:25-16:30*	4	Lance	7386	14,933	35.0	24.5	19.9	34.8	03	250	540	0.0015
12/10/73	09:00-09:30	4	Charge	8834	12,834	34.6	25.9	21.9	33.4	03	300	555	0.00089
	09:00-11:04	3	Lance	8753	13,042	34.4	26.6	23.1	32.7	03	300	555	0.00089
	10:20-10:35	4	Hot Metal	8561	13,149	34.1	27.3	24.9	32.4	03	300	555	0.00089
	10:35-12:25	4	Lance	8666	13,060	34.1	26.8	23.5	32.3	03	300	555	0.00089
	11:45-13:45	3	Charge	8753	13,021	34.1	26.7	23.0	32.0	03	300	555	0.00089
	13:30-16:25	4	Charge	8736	12,985	33.7	26.7	22.6	32.2	03	300	555	0.00089
	14:30-14:45	3	Hot Metal	8724	13,088	33.6	27.1	22.3	32.2	03	300	555	0 00089
	14:45-16:40	3	Lance	8753	13,064	33.6	26.7	22.5	32.3	03	300	555	0.00089
	17:00-17:20	4	Hot Metal	8637	13,355	34.1	26.6	23.1	32.9	03	300	555	0.00089
	17:20-19.10	4	Lance	8637	12,909	33.0	26.5	22.7	32.1	03	300	555	0.00089
	17:20-19.10	3	Charge	8637	12,909	33.0	26.5	22.7	32.1	03	300	555	0.00089
12/11/73	08:30-09:15	3	Charge	8724	13,026	34.1	26.2	24.1	32.0	03	300	555	0.00089
	09:15-09:30	3	Hot Metal	8724	12,927	34.1	26.4	23.9	31.8	03	300	555	0.00089
	09:30-12:15	3	Lance	8695	12,877	33.4	26.5	24.2	31.6	03	300	555	0.00089
	10:20-13:00	4	Charge	8737	12,852	33.2	26.5	24.1	31.3	03	300	555	0.00089
	13:00-13:20	4	Hot Metal	8753	12,894	33.1	26.4	24.7	30.9	03	300	555	0.00089
	13:10-16:05	3	Charge	8782	13,040	33.6	26.3	23.8	32.0	03	300	555	0.00089
	13:20-16:05	4	Lance	8782	13,040	33.6	26.3	23.8	32.0	03	300	555	0.00089

*Stopped Sampling at 16:30

APPENDIX C1

OPEN HEARTH FURNACE OPERATING SUMMARY

		TIME					
Number *	Date	Previous Heat Tapped	Began Charging	Finish Charging	Begin Hot Metal Addition	End Hot Metal Addition	Heat Tapped
37770	12/05/73	0830	0910	1010	1220	1235	1450
47657	12/05/73	0705	0745	1015	1050	1105	1340
37771	12/05/73	1450	1600	1815	1850	1900	2130
47658	12/05/73	1340	1420	1645	1715	1730	1916
37774	12/06/73	0840	1125	1400	1505	1515	1727
47661	12/06/73	0700	0740	1035	1120	1150	1341
37775	12/06/73	1727	1805	2020	2050	2100	2250
47662	12/06/73	1340	1420	1620	1715	1730	1934
37777	12/07/73	0500	0540	0740	0815	0830	1009
47665	12/07/73	0710	0750	1050	1115	1130	1305
37778	12/07/73	1010	1050	1245	1325	1355	1538
47666	12/07/73	1310	1430	1710	1750	1800	1944
37782	12/08/73	1010	1105	1255	1330	1345	1541
47669	12/08/73	0810	0850	1100	1210	1225	1350
37783	12/08/73	1540	1645	1915	1955	2005	2209
47670	12/08/73	1350	1430	1710	1745	1800	2007
37785	12/09/73	0335	0415	0625	0710	0725	0939
47673	12/09/73	0700	0740	0940	1005	1020	1219
37786	12/09/73	0940	1020	1240	1310	1320	1536
47674	12/09/73	1220	1300	1535	1610	1625	1819
37787	12/09/73	1535	1620	1805			
37789	12/10/73	0330	0610	0755	0830	0845	1104
47677	12/10/73	0630	0755	0930	1020	1035	1225
37790	12/10/73	1105	1145	1345	1430	1445	1640
47678	12/10/73	1225	1330	1625	1700	1720	1910
37791	12/10/73	1640	1720	1925	1945	2010	2210
37793	12/11/73	0425	0545	0840	0915	0930	1214
47681	12/11/73	0800	1020	1230	1300	1315	1602
37794	12/11/73	1215	1315	1600	1643	1700	1935

* The first digit identifies the furnace, the remaining four identify the batch number.

APPENDIX C2

OPEN HEARTH FURNACE MATERIALS SUMMARY

Heat Number	Cold Iron Charge*	Steel Charge	Non Metallic Charge	Hot Metal Charge (Direct)	Extra Hot Metal Addition	Metallic Addition	Non Metallic Addition
47657	38200	317100	27200	217000	---------	9000	--------
47658	40000	311300	28000	216500	---------	5000	--------
47661	0	314000	25200	258000	---------	14100	--------
47662	0	285800	27000	286000	---------	11000	--------
47665	49000	311800	20500	213900	---------	8800	--------
47666	42000	310300	23500	224200	---------	5800	--------
47669	34000	314200	23500	216700	---------	7700	--------
47670	34200	314200	22300	203000	---------	15800	--------
47673	0	314800	21700	261000	---------	10800	--------
47674	55000	314000	22300	201000	---------	5000	--------
47677	0	314800	23100	259900	---------	5700	--------
47678	54200	308100	23700	200000	---------	7900	--------
47681	25000	311400	23900	227900	---------	8500	4500
37770	41200	319200	25200	212000	8000	13300	--------
37771	58800	314800	25100	197800	---------	13300	--------
37774	0	286600	35400	283300	---------	13100	--------
37775	0	285100	21300	284700	---------	5800	--------
37777	35600	311000	24500	219200	---------	6300	4000
37778	49000	310800	23500	212800	---------	7600	4000
37782	24400	314800	22300	231800	---------	7700	--------
37783	54400	314000	21700	202000	---------	7700	--------
37785	0	315600	22900	258000	---------	17000	--------
37786	57000	314200	22500	202000	---------	8100	4000
37787	67200	313400	20900	197000	---------	14800	4500
37789	0	312200	22700	260900	---------	15300	4000
37790	23000	314200	23500	234500	---------	6200	--------
37791	65300	316800	21900	196000	---------	5000	--------
37793	61000	314400	23900	199000	15000	11500	--------
37794	35000	312800	23500	220000	---------	13300	--------

* All charges and additions are weights of material in pounds.

APPENDIX D

ESTIMATED OPERATING COSTS OF THE STEAM HYDRO AIR CLEANING SYSTEM

Data for these cost estimates were taken from Peters and Timmerhans, Plant Design and Economies For Chemical Engineers, 2nd edition, 1968 and are based on cost data for the year 1967.

Steam	Cost
500 PSIG	$0.60 - $1.20/1000 lb
100 PSIG	0.50 - 1.00/1000 lb
Water	
Well	0.03 - 0.15/1000 gal
River	0.02 - 0.06/1000 gal
Fuel Oil	0.05 - 0.15/gal

Figure D1 shows estimated energy requirements as furnished by Lone Star Steel for achieving various levels or grain loadings when operating on the open hearth process. Note that as the backdraft increases, the steam requirement increases. In the case of waste heat boilers - if these are not designed so that they can be kept clean, the steam requirement is higher than for a clean system. Attention is also invited to the fact that on installations such as cupolas and sinter

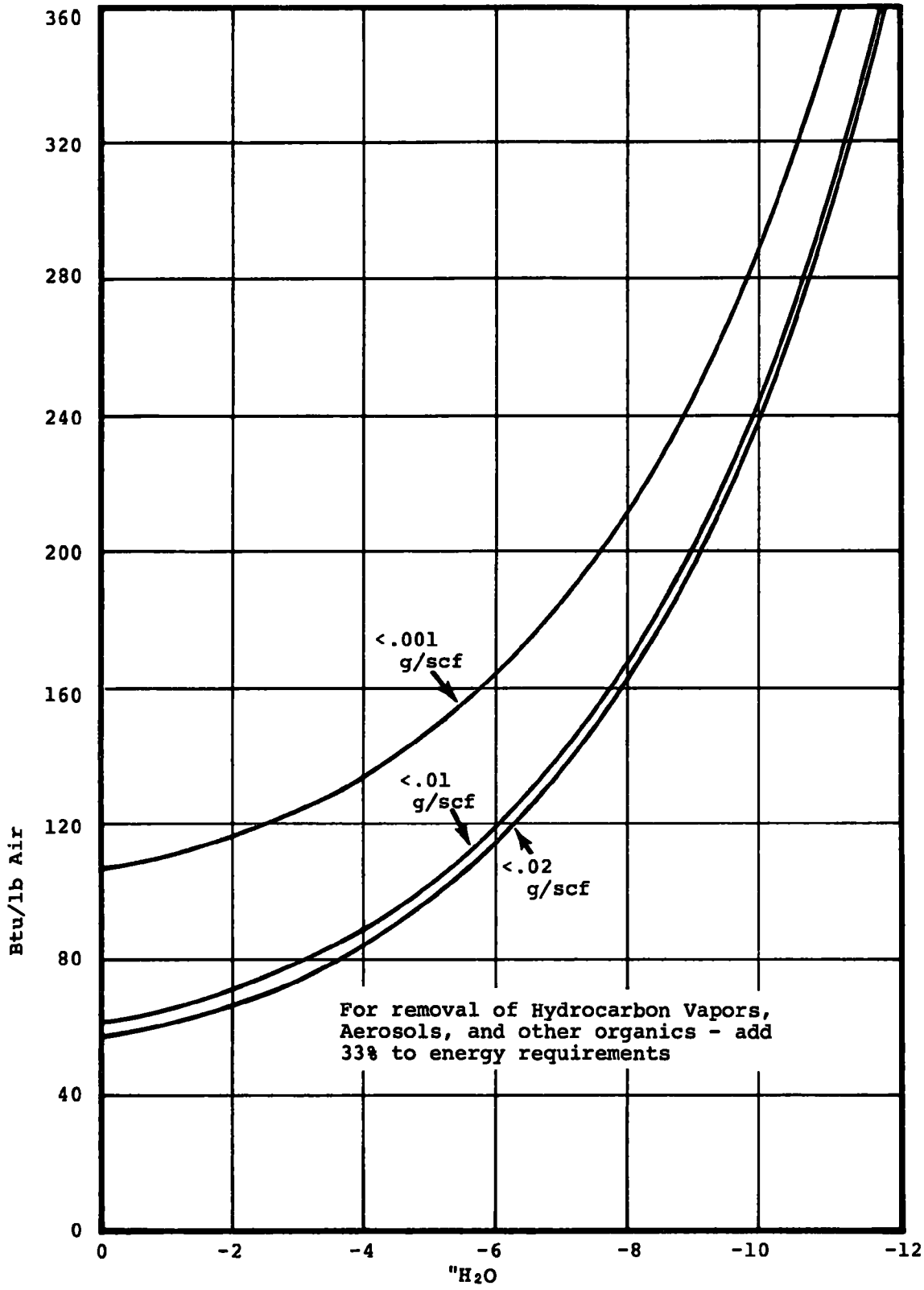

Figure D1. Steam Hydro Steam Requirements Necessary for Producing the Indicated Outlet Loadings When Handling Open Hearth Emissions.

plants, the energy to remove hydrocarbon vapors, aerosols, and other organics is approximately 1/3 higher than for the removal of inorganics, i.e., particulate. The level of cleaning can be readily changed by a change in the energy to the system. Once the Steam-Hydro is installed, capital costs are not involved in increasing the cleaning level, simply the operating costs. The operating costs described here are based on two conditions---one in which the system energy is derived solely from process waste heat and one for which fuel oil supplies the energy. These figures are estimates only and do not include such things as savings deriving from the fact that the system provides its own draft as well as that for the furnaces, consequently eliminating I.D. and F.D. fans, blowers, etc.

The conditions of the tests were:

Steam usage: 7300 lb/hr at 250 PSIG

Water usage: 61 gal/min (of which 55 gal/min is recovered)

Air flow: 13000 SCFM with a system back pressure of 6" H_2O.

Outlet particulate loading: 0.0007 gr/DSCR

Note that in this application the system back pressure was anomalously high as a result of fouling of the waste heat boiler which was installed with tube rappers but without soot blowers. Figure D1 indicates that this back pressure would lead to a 50% increase in the system energy requirements as compared to the requirements at a back pressure of 1 inch of water.

Assuming nominal values for costs of $0.85/1000 lb for steam (including the cost of fuel), 0.04/1000 gal for water, and 0.08/gal for fuel oil, the operating cost per thousand SCF when running with a back pressure of 6" W.G. are $0.007977 for steam production, which includes a fuel cost of $0.00671, and a water cost of $0.000188. With a system back pressure of 1" W.G. the steam cost is reduced to $0.00532 of which $0.00474 represents the cost of fuel. Thus where waste heat is available for steam production, eliminating the fuel cost, the operating cost per 1000 SCF are $0.00145 and $0.00077 respectively for operating at 6" W.G. and 1" W.G. back pressures. For applications where waste heat is not available for steam production and fuel must be supplied the costs rise to $0.00817 and $0.00551 per thousand SCF at the afore mentioned back pressures. For operation at 1" W.G. back pressure the annual operating costs per SCFM are $0.403 in the waste heat case and $2.89 for the case in which fuel must be purchased. For the purposes of the preceeding operating cost estimates amortization of capital costs were not included. Inclusion of capital cost amortization would result in substantial increases in the above figures.

APPENDIX E

TABLE OF CONVERSION FACTORS

To Convert From	To	Multiply By
lbs	Kg	0.454
grains/cf	grains/m^3	2.288
cfm	m^3/sec	0.000472
lbs/in^2	Kg/m^2	703.1
°F	°K	(°F + 460) x 5/9
°R	°K	0.556
inches w.g.	mm Hg	1.8682
gallon	liter	3.785
Btu	Joules	1054.8
feet/min	m/sec	0.00508

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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EPA-650/2-74-028		

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	6 PERFORMING ORGANIZATION CODE
7 AUTHOR(S) J. D. McCain and W. B. Smith, Southern Research Institute, Birmingham, Ala. 35205	8 PERFORMING ORGANIZATION REPORT NO
9 PERFORMING ORGANIZATION NAME AND ADDRESS M. W. Kellogg Co. 1300 Three Greenway Plaza Houston, Texas 77046	10 PROGRAM ELEMENT NO 1AB012; ROAP 21ADL-04 11 CONTRACT/GRANT NO 68-02-1308 (Task 11)
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15 SUPPLEMENTARY NOTES	

16 ABSTRACT The report gives results of fractional and overall mass efficiency tests of the Lone Star Steel steam-hydro scrubber. The tests were performed on one of seven modules of a full scale scrubber used for controlling particulate emissions from an open hearth furnace. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes from about 0.3 to 5 μm, and on the number basis for sizes smaller than about 1 μm using optical and diffusional methods. The report includes brief descriptions of the open hearth process, the Lone Star Steel steam-hydro scrubber, economics of operating the scrubber, measurement methods for calculating fractional efficiency, a synthesized time history of the open hearth particulate emissions, and fractional efficiencies as measured for several scrubber operating conditions.

17 KEY WORDS AND DOCUMENT ANALYSIS

a DESCRIPTORS	b IDENTIFIERS/OPEN ENDED TERMS	c COSATI Field/Group
Air Pollution Economic Analysis Soot Scrubbers Measurement Openhearth Furnaces Flue Dust	Air Pollution Control Stationary Sources Particulates Steam-Hydro Scrubber	13B, 14A 21B 07A 13A

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