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DoE United States Department of Energy — Division of Power Systems, Energy Technology Branch, Washington DC 20545

EPA United States Environmental Protection Agency — Industrial Environmental Research Laboratory, Research Triangle Park NC 27711 — EPA-600/ February

March 1993

Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement — Sites L1-L7

Interagency Energy/Environment R&D Program Report

Source Analysis Section, AMTB (MD-14)
Research Triangle Park, N. C. 27711

- ALL INDUSTRIAL BOILERS (@10-100 10^6 Btu/hr)
- UNDERFEED
  - MULTIPLE RETORT
  - SINGLE
- OVERFEED
  - TRAVELING GRATE
  - VIBRATING GRATE
- CONTROLLED + UNCONTROLLED (multiclones)
- all bituminous coal

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February 1981

Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement — Sites L1-L7

by

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R. D. Bessette	Island Creek Coal Company
T. Davis	Combustion Engineering
N. H. Johnson	Detroit Stoker
K. Luuri	Riley Stoker
D. McCoy	E. Keeler Company
J. Mullan	National Coal Association
E. A. Nelson	Zurn Industries
E. Poitras	The McBurney Corporation
P. E. Ralston	Babcock and Wilcox
D. C. Reschley	Detroit Stoker
R. A. Santos	Zurn Industries

Finally, our gratitude goes to the host boiler facilities which invited us to test their boiler. At their request, the facilities will remain anonymous to protect their own interests. Without their cooperation and assistance this program would not have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The objective of the Site L program is to produce information which will (1) enhance the ability of small industrial, commercial and institutional boiler users to install coal-fired steam generators, thereby significantly expanding the utilization of coal; (2) provide data for better designs to make the switch from oil and gas to coal usage less costly; (3) facilitate preparation of intelligent and reasonable national emission standards for smaller coal-fired boilers by the U.S. Environmental Protective Agency; (4) refine application of existing pollution control equipment and more closely control stack emissions under varied operating conditions through more accurate boiler outlet dust loading data; (5) contribute to the design of new and improved air pollution control equipment; and (6) facilitate planning for coal supply contracts by users of the boiler-stoker equipment.

The Site L program consists of a series of seven tests to determine particulate emission rate and particle size distribution of typical small institutional-type stoker-fired boilers firing Western Pennsylvania bituminous coals. Operational data were recorded during the test period to provide the necessary information to evaluate boiler emissions as a function of boiler load, heat release rates, coal size and characteristics, percent excess combustion air, and flue gas temperature.

All boilers were tested under normal operating conditions with coal supplied from the institution's contracted source. Test dates were selected to obtain average boiler loads of 50 to 75 percent of maximum boiler capacity. The types of stokers tested included single retort underfeed, multiple retort underfeed, traveling grate overfeed, and vibrating grate overfeed.

The test report contains a description of the seven boiler-stoker units, test port locations, test equipment and procedures, and a summary of test results and observations.

2.0 EXECUTIVE SUMMARY

Seven typical small institutional-type stoker-fired boilers were tested for particulate emission rate and particle size distribution. Emission rates were evaluated as they relate to stoker type, coal size and characteristics, operating conditions, and heat release rates. This section summarizes the results of these tests.

UNITS TESTED:

Test Site	Stoker Type	Capacity, lb/hr	Year Built
L1	Multiple Retort	34,500	1966
L2	Vibrating Grate	40,000	1960
L3	Single Retort	31,000	1951
L4	Traveling Grate	30,000	1969
L5	Multiple Retort	38,000	1950
L6	Multiple Retort	27,000	1957
L7	Multiple Retort	55,000	1968

COALS FIRED: Western Pennsylvania bituminous, double screened.

PARTICULATE EMISSION RATE TEST RESULTS

A relationship between mass emission rate and stack velocity was observed. The rate in pounds per hour emitted from sites having high stack velocities was greater than those sites with lower stack velocities. This was true whether or not a collector was in place. While the relationship was not strictly linear, the statistical correlation coefficient was 0.83 for sites with collectors and 0.98 for those without control devices. Lower velocities sweep fewer pounds of particle matter from a stack than higher velocities - not a surprising result.

It is instructive to examine the results from the site where the lowest emission rate was found - Site L5. The tables in Sections 4 and 5 list the analyses of the coals, coal sizing, boiler performance, and the emission rates. It is apparent that the performance at L5 had the following characteristics:

- the lowest percentage of volatiles (18.9% as compared to the average of 32.4%),
- the highest percent of fixed carbon (68.7% as compared to the average of 55.1%),
- the highest free swelling index (8),
- the largest percentage of fines in the coals of those coals screened (11% passed through # 16 screen as compared to the average of 6%),
- the second lowest percent excess air (33% as compared to the average of 81%).

In addition, the stack temperature was among the lowest, the smallest amount of sulfate was found in the impingers, and - in all fairness - it must be added that the percent of operating capacity was also among the lowest.

When the operating parameters at the site with the highest emission rate (L2) are examined, no characteristics that are significantly different from others are found. This would seem to indicate that the relationships are not linear but that there may be curves with break points. Clearly it would be helpful to establish such curves, but the present study was not designed to accomplish this. The factors which may affect the emission rate are:

1) type, sizing, and condition of the coal;
2) type and condition of the stoker grate;
3) air flow through the fuel bed;
4) firing rate and fuel bed thickness;
5) boiler operating parameters;
6) "caking" of the fuel bed and resulting high excess air and flue gas temperatures.

The boiler-stoker types tested are capable of operating at a steaming capacity of 50 to 75 percent with uncontrolled emission rates well below the emission factor of 5A (potential emission rate in pounds of particulate per ton of coal fired is equal to five times A - the weight percentage of ash in coal) as reported in the U.S. Environmental Protective Agency Publication AP 42, Compilation of Air Pollution Factors, Third Edition.

Two of the multiple retort stoker units had particularly low emission rates, while the other two multiple retort stoker units, plagued with caking fuel beds, had much higher rates. Emission rates of the traveling grate, vibrating grate, and single retort stoker units were progressively higher than those of the two best multiple retort units. The calculated emission factors, summarized in Table 5-7, indicate that the emission factor of 5A for underfeed and overfeed stokers in the size range tested might be reduced by a minimum of 50 percent.

PARTICLE SIZE DISTRIBUTION TEST RESULTS

The data obtained on particle size indicate that in all cases 50% of the mass at the boiler outlet is made up of particles less than 30 micrometers in diameter. In one extreme case 50% were less than 13 micrometers in diameter. It is safe to assume, therefore, that the collection or elimination of the finer particles is essential if control is to be achieved.

In two cases where collectors were installed (L1 and L7), the mean particle size was reduced by the collector to 7.4 at L1 and 2.9 at L7. Both were still in violation of the Pennsylvania regulations for emissions. The particle size distribution at the boiler outlet indicates a marked similarity in all five cases. There was a sizable fraction of particles less than 10 μm. At sites L1 and L7 the fraction of particles larger than 10 μm were measureably reduced while those at L2 and L4 were not significantly affected

In the case of large ducts with masonary stacks and no collectors, low velocities were the rule. At L5 and L6 the velocities were less than 5 ft/sec while at L3 it was 10.7 ft/sec. This latter velocity was apparently sufficient to carry larger particles through the system and up the stack. The mean particle size at L3 did not change between the boiler outlet and the stack and this is reflected in the emission rate. It would seem that if large ducts and stacks are to be used as an aid to particle control, the velocity must be very carefully chosen.

Not if emissions are normalized by ash content
See p 53 factors

COLLECTOR EFFICIENCY

The only collector operating near its design temperature and flowrate was the one at L7. It actually brought this unit within the regulation limit - provided the impinger catch was ignored. The other three flowrates were much less than the recommended value and the consequences are obvious. The efficiency of the collector on the fine particle fraction (< 10 m) is the crucial element in particle control.

The data presented in this report indicate that there is a relationship between collector efficiency and the coal used, the grate type and boiler operating parameters, and the collector operating parameters. The mechanical collectors on the boilers in this study were at best marginal and at worst totally ineffective. Large ducts through which the stack gas passed at low velocities proved almost as effective as the collectors. The high velocities required by the cyclonic control units kept particles airborne and, since these collectors were not operating at the design conditions, large amounts of particle matter passed through the duct work and mechanical collectors and into the atmosphere.

Proper installation, regular maintenance, and correct operating procedures are necessary if the type of collectors in use at the test sites are to have the desired effect. At small facilities where trained personnel are at a premium collector operation will often be a problem.

3.0 DESCRIPTION OF TEST SITES

This section provides a general description of the seven facilities tested, the operational characteristics and general arrangement of the boiler-stoker unit tested at each location, and the test port locations for each.

3.1 DESCRIPTION OF TEST FACILITIES

The facilities tested are central steam heating plants which are providing energy for space heating, space cooling, domestic water heating, dietary service, and laundry service for typical correctional, educational, rehabilitation, and hospital type institutions. The sizes of the institutions vary from approximately five to 25 million cubic feet of heated building space. The coal requirements vary from four to 15 thousand tons of bituminous coal annually, and the maximum steam requirements vary from 25,000 to 85,000 pounds per hour. The total installed capacities of the central heating plants vary from 80,000 to 200,000 pounds of steam per hour.

The facilities and boiler-stoker units tested are designated herein as Test Sites L1 through L7. The names of the facilities and equipment manufacturers have been omitted.

3.2 DESCRIPTION OF UNITS TESTED

The seven boiler-stoker units tested represent typical state-of-the art designs for bituminous coal fired units installed in central heating plants between 1950 and 1969. Maximum capacities of the units range from 27,000 to 55,000 pounds of steam per hour. The stokers installed in these units represent the most common type of underfeed and overfeed stokers available at the time.

Three of the units tested are not equipped with particulate matter emission control devices. Four of the units are equipped with multiple cyclone dust collectors. However, the three units that are not equipped with control devices discharge into expanded central breechings and tall masonary stacks which provide a degree of emission control.

Table 3-1 and Figure 3-1 provide a brief description and general arrangement of the boiler-stoker unit tested at each of the seven test sites. A Design Data Sheet for each site is also included for informational purposes.

Table 3-1

DESCRIPTION OF BOILERS TESTED

Test Site	Year Built	Type Stoker	Max. Capacity lb/hr	Schematic Arrangement of Units Reference Figure 3-1
L1	1966	MR	34,500	Figure 3-1 b
L2	1960	VG	40,000	Figure 3-1 c
L3	1951	SR	31,000	Figure 3-1 a
L4	1969	TG	30,000	Figure 3-1 c
L5	1950	MR	38,000	Figure 3-1 a
L6	1957	MR	27,000	Figure 3-1 a
L7	1968	MR	55,000	Figure 3-1 b

Nomenclature: MR - Multiple retort underfeed
SR - Single retort underfeed
TG - Traveling grate overfeed
VG - Vibrating grate overfeed

DESIGN DATA

TEST SITE: L1

BOILER:

Year Built ---------------------------------- 1966
Configuration ------------------------------ Multiple Pass
Rated Steaming Capacity -------------------- 34,500 lb/hr
Operating Pressure ------------------------- 125 psig
Feedwater Temperature ---------------------- 212°F
Steam Temperature -------------------------- Saturated

STOKER:

Classification ----------------------------- Multiple Retort Underfeed
Effective Grate Area ----------------------- 97.3 ft^2

HEATING SURFACES:

Furnace Volume ----------------------------- 1,225 ft^3
Water Wall --------------------------------- 717 ft^2
Boiler ------------------------------------- 4,283 ft^2

HEAT RATES:

Fuel Burning Rate -------------------------- 3,480 lb/hr
Furnace Liberation ------------------------- 37,000 Btu/hr - ft^3

EMISSION CONTROL EQUIPMENT:

Mechanical Collector

DESIGN DATA

TEST SITE: L2

BOILER:

Year Built	1965
Configuration	Multiple Pass
Rated Steaming Capacity	40,000 lb/hr
Operating Pressure	125 psig
Feedwater Temperature	212°F
Steam Temperature	Saturated

STOKER:

Classification	Vibrating Grate
Effective Grate Area	126 ft^2

HEATING SURFACES:

Furnace Volume	1,665 ft^3
Water Wall	1,641 ft^2
Boiler	4,514 ft^2

HEAT RATES:

Fuel Burning Rate	4,000 lb/hr
Furnace Liberation	30,000 Btu/hr - ft^3

EMISSION CONTROL EQUIPMENT:

Mechanical Collector

DESIGN DATA

TEST SITE: L3

BOILER:

Year Built	1951
Configuration	Multiple Pass
Rated Steaming Capacity	31,000 lb/hr
Operating Pressure	120 psig
Feedwater Temperature	212°F
Steam Temperature	Saturated

STOKER:

Classification	Single Retort Underfeed
Effective Grate Area	73 ft^2

HEATING:

Boiler	4,490 ft^2

HEAT RATES:

Fuel Burning Rate	3,100 lb/hr

DESIGN DATA

TEST SITE: L4

BOILER:

Year Built	1969
Configuration	Multiple Pass
Rated Steaming Capacity	30,000 lb/hr
Operating Pressure	150 psig
Feedwater Temperature	220°F
Steam Temperature	Saturated

STOKER:

Classification	Traveling Grate
Effective Grate Area	107 ft^2

HEATING SURFACES:

Furnace Volume	1,315 ft^3
Water Wall	920 ft^2
Boiler	2,930 ft^2

HEAT RATES:

Fuel Burning Rate	3,470 lb/hr
Furnace Liberation	30,300 Btu/hr - ft^3

EMISSION CONTROL EQUIPMENT:

Mechanical Collector

DESIGN DATA

TEST SITE: L5

BOILER:

Year Built	1950
Configuration	Multiple Pass
Rated Steaming Capacity	38,000 lb/hr
Operating Pressure	150 psig
Feedwater Temperature	212°F
Steam Temperature	Saturated

STOKER:

Classification	Multiple Retort Underfeed
Effective Grate Area	80.6 ft^2

HEATING SURFACES:

Furnace Volume	1,250 ft^3
Water Wall	1,050 ft^2
Boiler	4,440 ft^2

HEAT RATES:

Fuel Burning Rate	3,800 lb/hr
Furnace Liberation	40,000 Btu/ft^3 - hr

DESIGN DATA

TEST SITE: L6

BOILER:

Year Built	1957
Configuration	Multiple Pass
Rated Steaming Capacity	27,000 lb/hr
Operating Pressure	110 psig
Feedwater Temperature	212°F
Steam Temperature	Saturated

STOKER:

Classification	Multiple Retort Underfeed
Effective Grate Area	83.3 ft^2

HEATING SURFACES:

Furnace Volume	1,130 ft^3
Water Wall	720 ft^2
Boiler	3,280 ft^2

HEAT RATES:

Fuel Burning Rate	2,440 lb/hr
Furnace Liberation	30,000 Btu/hr - ft^3

DESIGN DATA

TEST SITE: L7

BOILER:

Year Built	1968
Configuration	Multiple Pass
Rated Steaming Capacity	55,000 lb/hr
Operating Pressure	150 psig
Feedwater Temperature	218°F
Steam Temperature	Saturated

STOKER:

Classification	Multiple Retort Underfeed
Effective Grate Area	161.1 ft^2

HEATING SURFACES:

Furnace Volume	2,300 ft^3
Water Wall	1,503 ft^2
Boiler	6,057 ft^2

HEAT RATES:

Fuel Burning Rate	5,650 lb/hr
Furnace Liberation	33,200 Btu/hr - ft^3

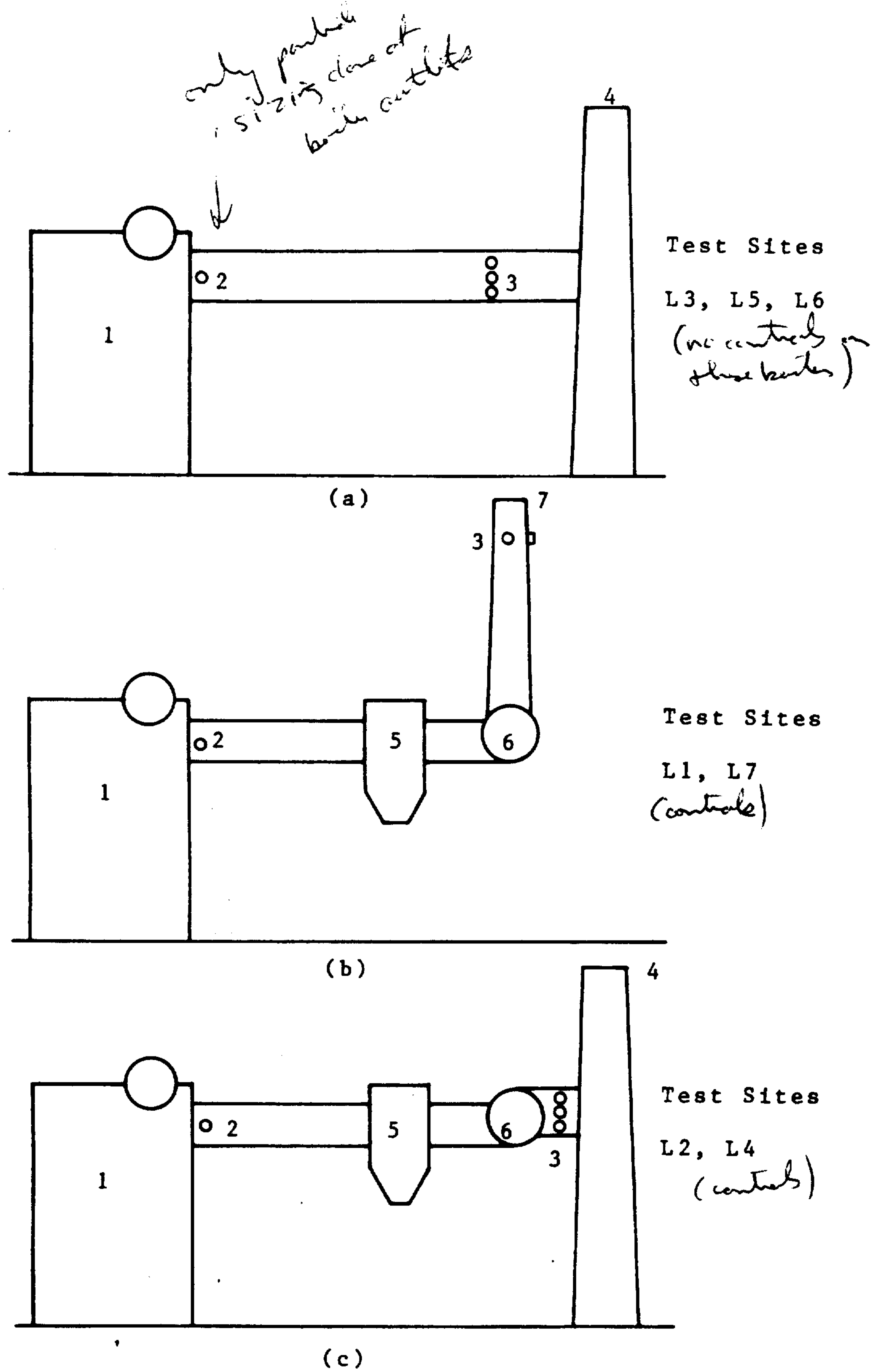
EMISSION CONTROL EQUIPMENT:

Mechanical Collector

3.3 TEST PORT LOCATIONS

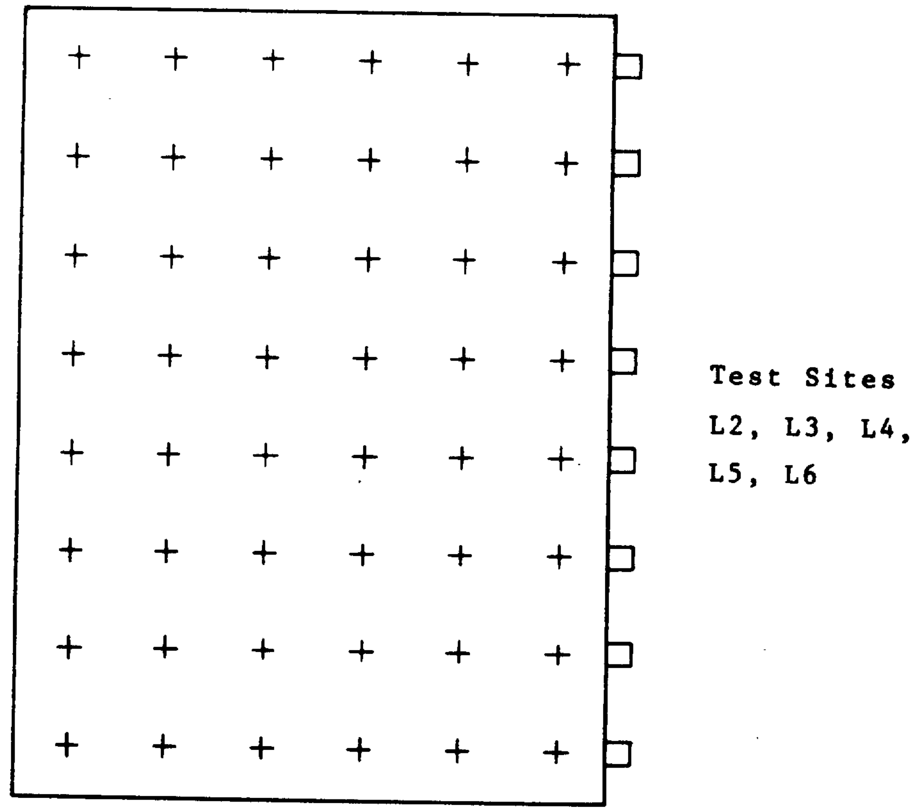
The particulate emission rate test was performed at the port locations shown in the schematic diagram, Figure 3-1. In each case preliminary tests were taken to establish the temperature-velocity profile, the moisture content of the stack gas, and the molecular weight of the gas. Figures 3-2 and 3-3 show - in representative form - the stack, duct, and boiler outlet configurations and relative port locations at all sites. By using Table 3-2 with the three figures, the actual stack dimensions and number of sampling points and ports as well as the relative location of the sampling points can be determined at each site. Results of the preliminary tests are recorded in Table 3-3. The locations at the seven sites were far from ideal relative to EPA testing procedure recommendations. Since physical limitations were encountered, ports were installed at points where easy access could be obtained. The number of sampling points was selected as specified in EPA Method 1.

Particle size measurements were taken at the same locations. Only impactor samples and samples for use with the Bahco were obtained at the boiler outlet. In two cases - L5 and L6 - boiler outlet measurements were not taken because access could not be obtained. Since isokinetic conditions were required, it was not possible to traverse with the impactor in the traditional way. Instead, grid points were selected in the stack where the velocities were similar and several impactor samples taken so that a representative sample could be collected.



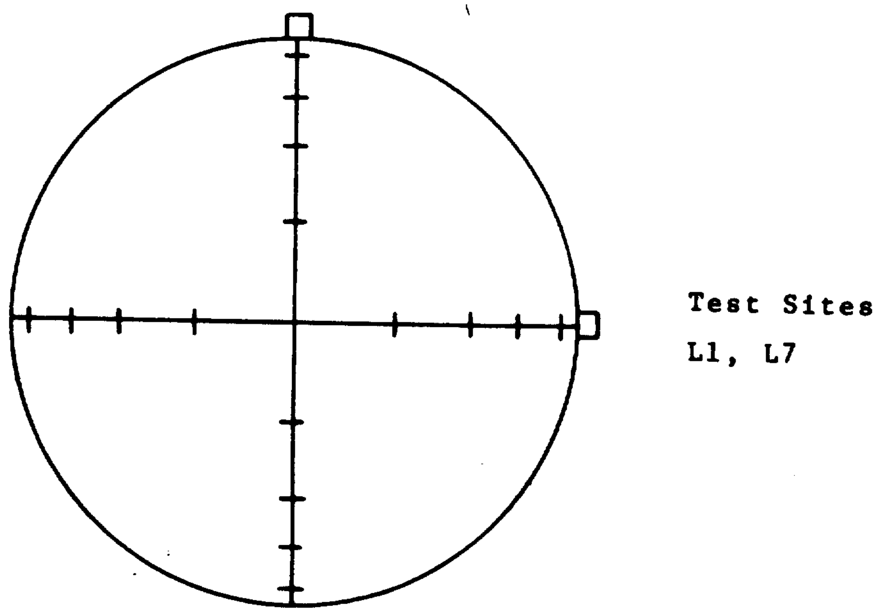
1. Boiler
2. Boiler Outlet Sampling Location
3. Stack or Duct Sampling Location
4. Stack
5. Collector
6. Induced Draft Fan
7. Stub Stack

FIGURE 3-1. BOILER SCHEMATICS



(a)

Rectangular Duct Divided Into Equal Areas
Sampling Points Located at the Centroid of Each Area



(b)

Circular Duct Divided Into Equal Areas
Sampling Points Located at the Centroid 6f Each Area

FIGURE 3-2. PORT LOCATIONS AND SAMPLING GRIDS

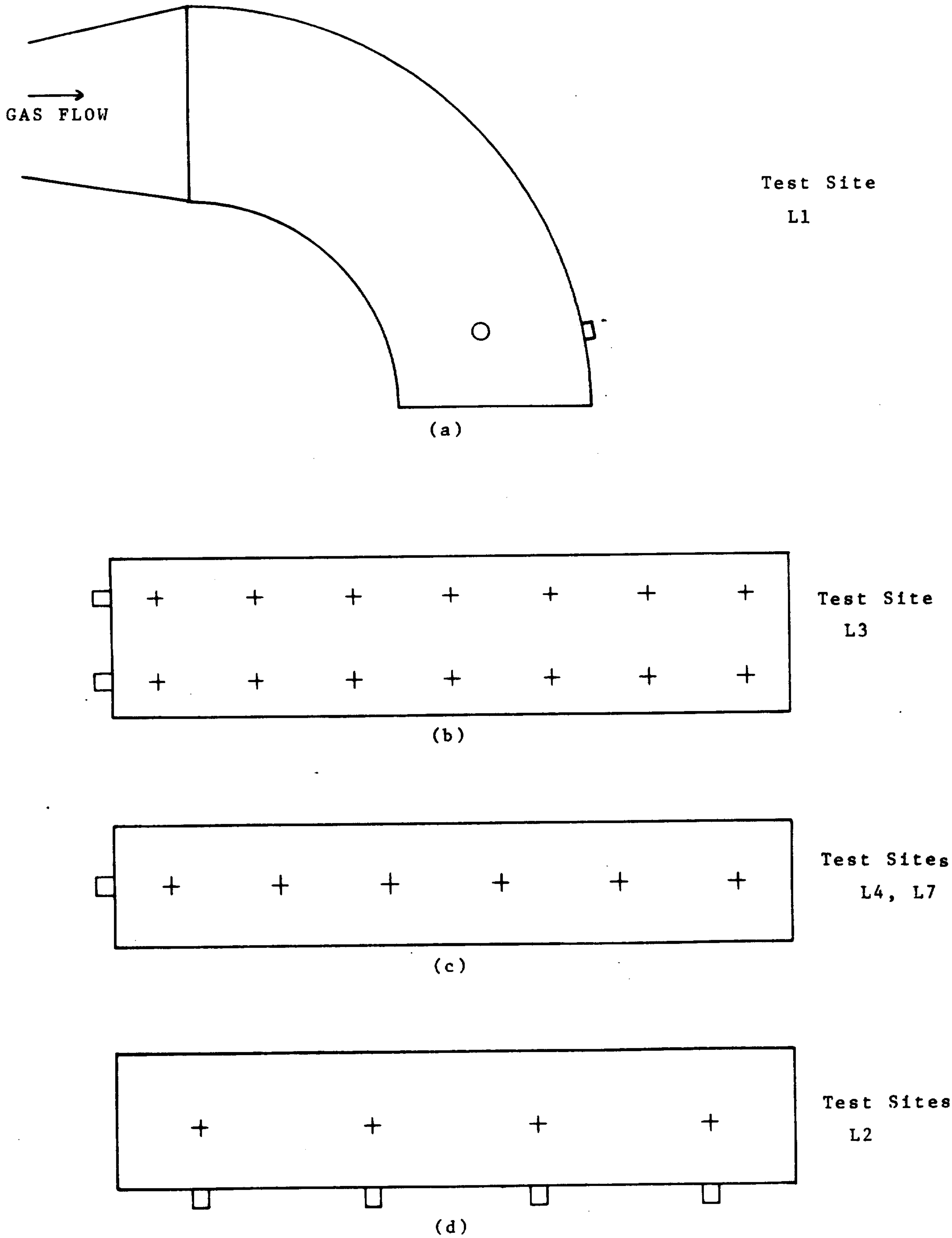


FIGURE 3-3. PORT LOCATIONS AT BOILER OUTLET

TABLE 3-2

Port Locations for Particulate Sampling

Test Site	Boiler Outlet				Stack Outlet			
	No. of Ports	Figure Ref.	No. of Sample Pts.	Stack Dimensions (in.)	No. of Ports	Figure Ref.	No. of Sample Pts.	Stack Dimensions (in.)
L1	2	3-3 a	24	36 D	2	3-2 b	32	37.25 D
L2	4	3-3 d	4	102 x 18	4	3-2 a	20	40 x 22
L3	2	3-3 b	16	96 x 24	8	3-2 a	48	96 x 48
L4	1	3-3 c	7	96 x 14.5	4	3-2 a	40	48 x 24
L5	No Data				8	3-2 a	48	96 x 64
L6	No Data				6	3-2 a	36	121 x 72
L7	1	3-3 c	2	120 x 24	2	3-2 b	24	46 D

TABLE 3-3

Preliminary Test Results

Test Site	Avg. Stack Velocity ft/sec @ STP	Avg. Stack Gas Temp. °F	Percent Water Vapor	Avg. Mol. Wt. Dry lb/lb-mole	Static Pressure "H_2O
L1	44.0	560	5.0	30.0	-3.3
L2	32.0	397	2.0	29.4	-0.6
L3	10.7	486	3.5	29.4	-0.6
L4	29.8	504	6.0	30.0	-0.6
L5	4.5	365	4.7	29.9	-0.6
L6	3.5	212	2.9	29.8	+0.5
L7	46.8	511	3.8	29.7	-0.1

4.0 TEST EQUIPMENT AND PROCEDURES

This section presents details of the test equipment and sampling procedures that were used to obtain accurate and reliable data.

4.1 MASS EMISSION MEASUREMENTS AND PROCEDURES

Particulate mass samples were taken at the sampling ports using an RAC STAKSAMPLER (Figure 4-1). This system meets the EPA design specifications for Test Method 5, Determination of Particulate Emissions from Stationary Sources (Federal Register, Volume 36, No. 27, page 24888, December 23, 1971). The initial velocity, temperature traverse, and the particulate sample collection were obtained using this device. Method 5 was followed in setting up and conducting all particulate emission tests.

This method calls for the probe to be attached to a cyclone collector and a filter holder. Four impingers, connected in series, follow the filter holder. The first, third and fourth are the modified Greenburg-Smith type while the second is a standard Greenburg-Smith. The control unit is equipped with a pump, a dry gas meter, an orifice meter, and two manometers. Temperatures were measured using both dial thermometers and chromel-alumel thermocouples. The pitot tube, the dry gas meter, and the orifice meter were calibrated prior to each series of tests in accordance with the procedures outlined in EPA bulletin No. APTD-0576 (Maintenance, Calibration, and Operation of Isokinetic Sampling Equipment by J. J. Rom).

Particle matter is collected by the cyclone and filter in a case heated to $\sim$ 120°C. The water vapor in the gas stream and the condensable particles condense out in the impinger train which is in an ice bath. The percent moisture in the stack gas is calculated from the increased water volume. Millipore filters are used to separate the insoluble condensables from the impinger water, and the soluble fraction is measured by driving off the water and weighing the residue.

The molecular weight of the stack gas was determined by withdrawing a sample from the gas stream and storing it in a teflon bag. The analysis was

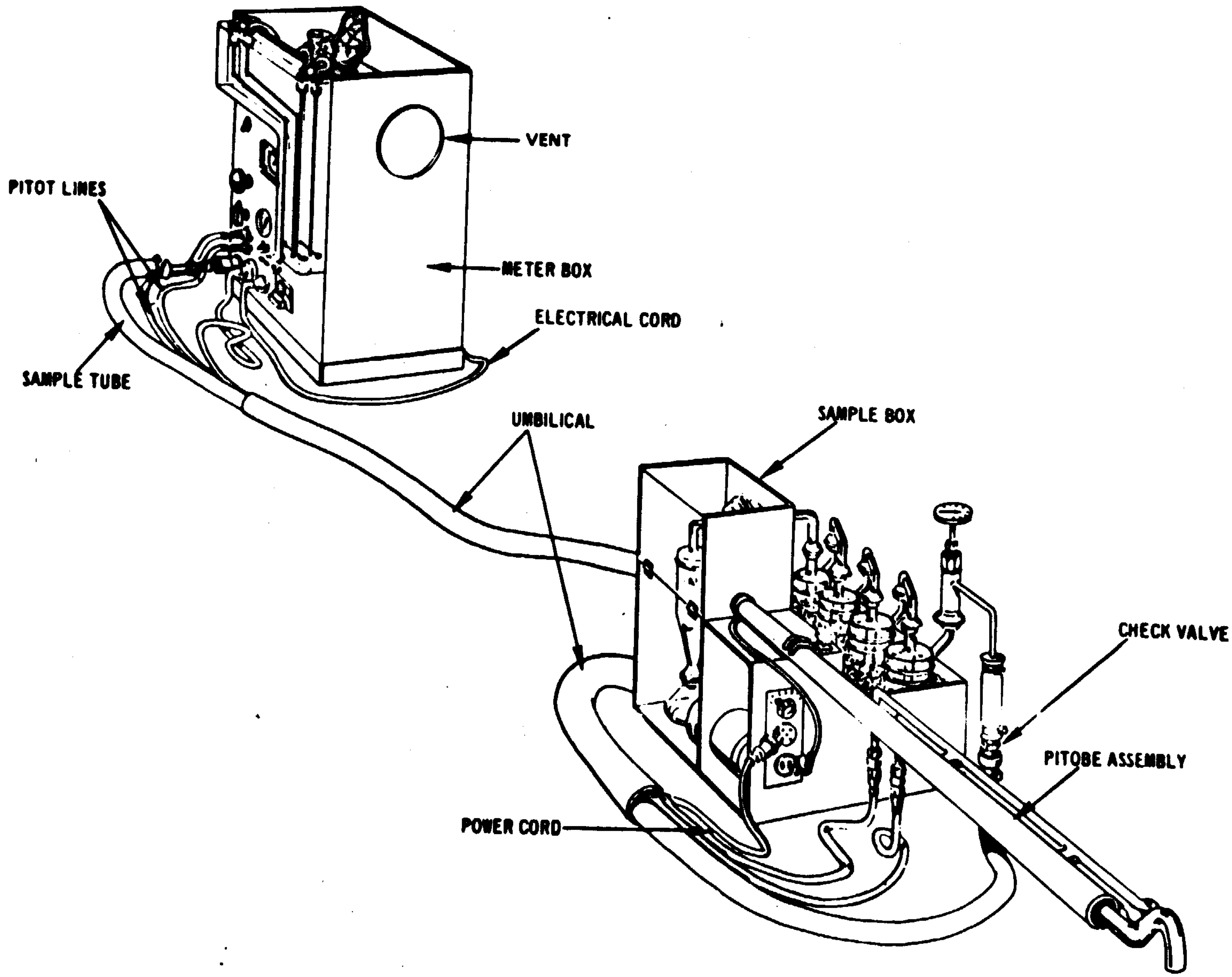


FIGURE 4-1. RAC STAKSAMPLER

performed on site using a standard orsat and was checked in the laboratory using infra-red analysis for CO and CO_2 and a micro-fuel cell (Teledyne Instrument) for O_2.

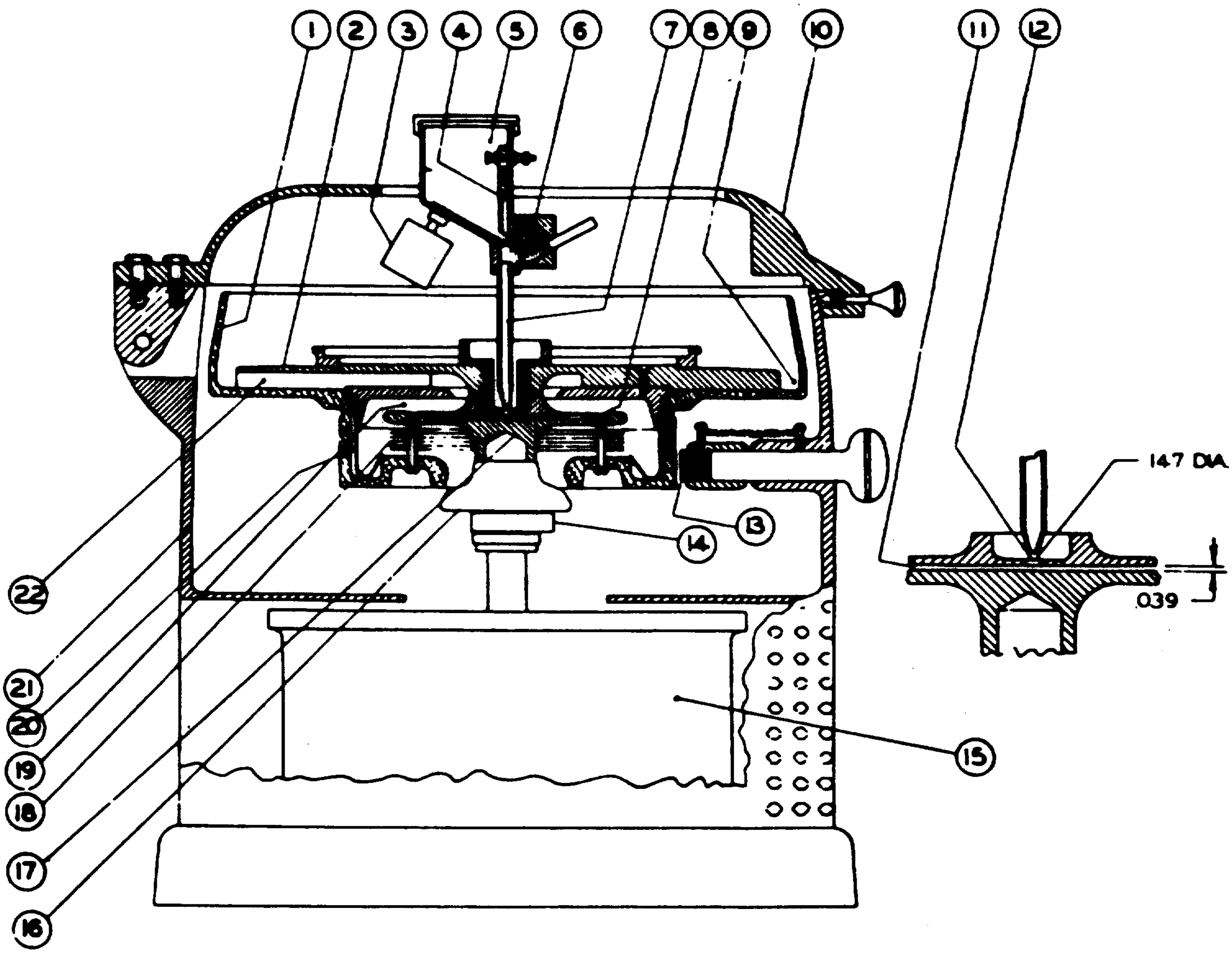
An on-site sampling van was used for sample train clean-up. All particle matter, filters, and liquid samples were stored in sealed containers for laboratory analysis. The clean-up and laboratory procedures were those specifed in the Federal methods and were performed in the particle laboratory at the Pennsylvania State University. Calculations were performed using the Method 5 equations.

4.2 PARTICLE SIZE DISTRIBUTION MEASUREMENT AND PROCEDURE

The Bahco centrifugal classifier and the Andersen in-stack impactor are devices used to obtain particle size information. Figures 4-2 and 4-3 are schematic diagrams of the two units. The method for using the Bahco is described in Power Test Code 28 distributed by the American Society of Mechanical Engineers. "Procedures for Cascade Impactor Calibration and Operation in Process Streams" (EPA-600/2-77-004) is the manual that details the use of impactors.

The centrifugal classifier requires that large samples (1 to 50 grams) be removed from the gas stream by some sampling technique prior to sizing. In the laboratory, the dust sample is introduced into a hopper in the center of the device. Particles are fed into an air flow pattern whose spiral current imparts velocities that carry the larger, heavier particles by centrifugal force to the periphery of the instrument while the smaller particles are swept toward the center of the wheel where they are deposited in a chamber. By varying the air flow, the particle matter can be separated into the size fractions. A complete description of the instrument, the method, and the operating principles can be found in the test code.

The cascade impactor operates directly in the gas stream. The Mark III Andersen device used in this work is shown disassembled in Figure 4-3. It is designed for use in gas streams with temperatures up to 815°C (1500°F). The preseparator at the intake end removes large particles (> 10 μm). Stack gas is drawn in through a nozzle (not shown), and passes through the preseparator and impactor cone to the plate section. There are eight plates (or stages)—each



1. ROTOR CASTING
2. FAN
3. VIBRATOR
4. ADJUSTABLE SLIDE
5. FEED HOPPER
6. REVOLVING BRUSH
7. FEED TUBE
8. FEED SLOT
9. FAN WHEEL OUTLET
10. COVER
11. ROTARY DUCT
12. FEED HOLE
13. BRAKE
14. THROTTLE SPACER
15. MOTOR-3520 RPM
16. GRADING MEMBER
17. THREADED SPINDLE
18. SYMMETRICAL DISC
19. SIFTING CHAMBER
20. CATCH BASIN
21. HOUSING
22. RADIAL VANES

FIGURE 4-2. BACHO CENTRIFUGAL CLASSIFIER

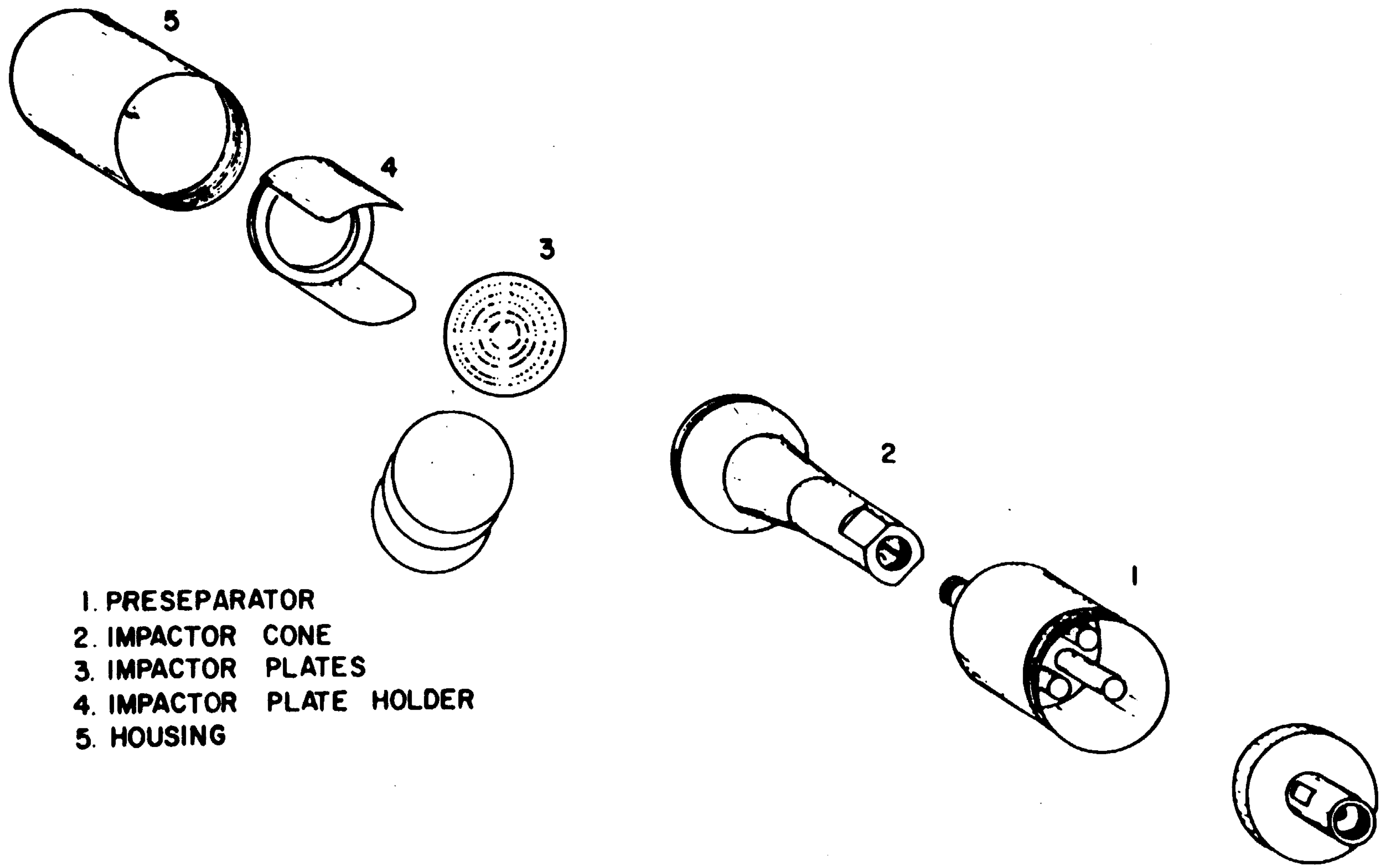


FIGURE 4-3. ANDERSEN MARK III IN-STACK IMPACTOR

with holes slightly smaller than those in the preceding plate. The holes in each plate are offset from the plate above and the plate below so that the air passing through a set of holes must impact on the surface of the lower plate and turn sharply in order to pass through the holes in that plate. Since the hole size decreases from plate to plate, the velocity increases and successively smaller particles are collected at each level. The eight stages are followed by an absolute back-up filter that captures the final particle fraction.

A glass fiber collecting media was used on each stage; the media were perforated to keep the holes clear and the collection surface covered. Before and after exposure, the media and the final filter were dried over Drierite for 24 hours and weighed. The difference in the weights was the mass in that size fraction. Calibration of the impactor, based on the assumption of spherical particles of 1.0 g/cc density, was accomplished in the laboratory prior to field tests.

The sampling train employed for both the centrifugal and impactor methods is shown in Figure 4-4. A preseparator was used on both trains to collect the large particles. This allowed these particles to be sized by sieving. Power Test Code 28 specifies that the particulate matter is to be removed directly from the gas stream by a sampling technique. A glass fiber filter was utilized in this case, and multiple samples were taken until about 2 grams of material were collected for particle size analysis in the centrifugal classifier. To strengthen confidence in the particle size distribution obtained by impaction, multiple samples were taken at different points within the duct or stack. A standardized laboratory procedure was instituted for the cleaning and handling of the collected particle matter.

4.3 COAL SAMPLING AND ANALYSIS

The coal storage and handling systems at Test Sites L1 through L7 are very similar. Each receive coal by truck delivery to a receiving hopper. From there the coal is transported to an in-plant overhead storage bunker. The coal is weighed and transported to individual boiler stoker coal hoppers by a suspended weigh larry. To obtain coal samples representative of the coal fired during the testing, incremental samples were

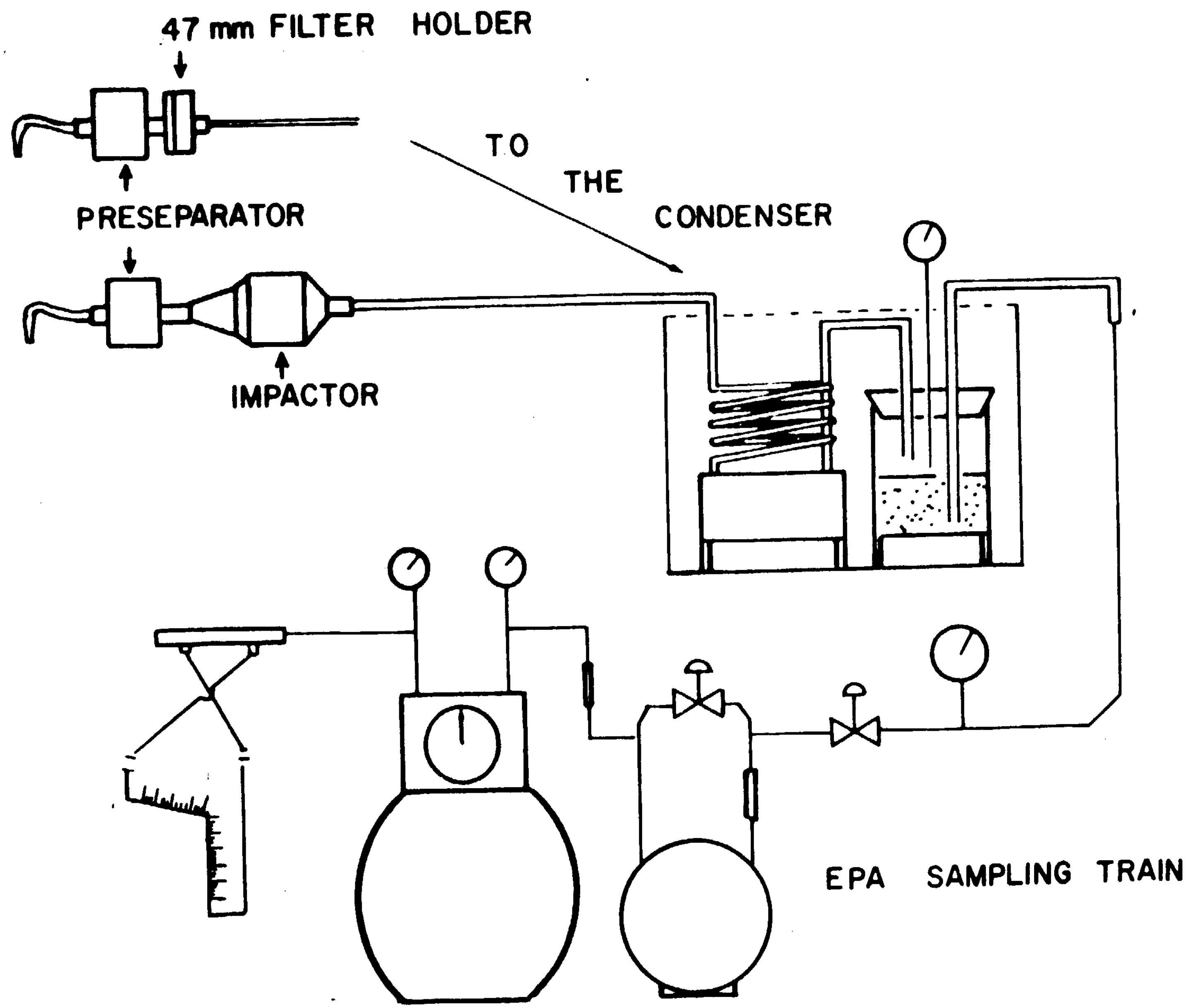


FIGURE 4-4. SCHEMATIC DIAGRAM OF THE SAMPLING TRAIN USED TO COLLECT PARTICLES FOR THE CENTRIFUGAL CLASSIFIER AND IMPACTOR ANALYSIS

obtained, using a standard coal shovel, from the weigh larry discharge at the stoker hopper. The frequency of sampling from the weigh larry load was varied in order to obtain a minimum 100 pound sample per test. As each incremental sample was collected, it was placed in a clean metal container with tight fitting cover.

The gross coal sample at each test site was prepared in a sample crushing machine provided with riffle buckets. The final riffling of the gross collection weighed approximately 12 pounds. This was placed in four standard metal sample cans having a capacity of three pounds each. The cans were sealed and delivered to an approved testing laboratory for analysis of moisture, heating value, ash, sulfur, volatile matter, fixed carbon, ash softening temperature, and free swelling index.

At Test Sites L5, L6, and L7 coal size data were obtained from a portion of the uncrushed samples. A Gilson Porta Screen Model PS-3, with Tyler square screens, was used to conduct these tests.

Test Results are shown in Tables 4-1 and 4-2.

Table 4-1

AS-FIRED ANALYSIS OF PENNSYLVANIA BITUMINOUS COALS FIRED AT EACH SITE

Test Site	L1	L2	L3	L4	L5	L6	L7
% Moisture	3.6	1.6	1.0	1.6	2.0	0.6	0.7
% Ash	13.0	13.0	11.0	8.5	12.0	12.7	12.5
% Volatile	32.0	32.7	41.4	37.5	18.9	32.0	32.2
% Fixed Carbon	54.2	53.6	47.0	53.0	68.7	54.7	54.6
% Sulfur	3.0	1.4	1.3	1.6	2.1	1.6	1.7
Heating Value, Btu/lb	13,100	13,100	13,400	13,500	13,500	13,200	13,000
Ash Softening Temp. °F	2,550	2,650	2,650	2,500	2,540	2,550	2,550
Free Swelling Index	6	6 1/2	6	6	8	7 1/5	7 1/2

Table 4-2

COAL SIZING DATA FOR
PENNSYLVANIA BITUMINOUS COALS
FIRED AT TEST SITES L5, L6, and L7

Test Site	Percent Passing Stated Screen Size 1 1/2"	3/4"	1/2"	1/4"	#16
L5	97	59	36	20	11
L6	89	24	15	9	5
L7	95	34	18	11	2
Average	94	39	23	13	6

4.4 ASH COLLECTION AND ANALYSIS

At each of the seven Sites L1 through L7 a bottom ash sample was collected from the stoker ash pit at completion of testing. The samples were manually crushed, mixed, quartered, and placed in a standard three-pound metal sample container.

At Test Sites L1, L2, L4, and L7 a fly ash sample was collected from a port near the base of the mechanical collectors. The samples were placed in a standard three-pound metal sample container.

All samples were delivered to an approved test laboratory for analysis of combustible content. The results of these tests are shown in Table 4-3.

Table 4-3

PERCENTAGE OF COMBUSTIBLE MATERIAL
IN BOILER BOTTOM ASH AND COLLECTOR FLYASH
AT TEST SITES

Test Site	L1	L2	L3	L4	L5	L6	L7
% Combustible, Bottom Ash	22.4	40.0	25.0	19.3	22.5	8.1	22.4
% Combustible, Collector Flyash	20.5	56.0	ND	21.8	ND	ND	20.2

Note: ND = No Data

4.5 BOILER PERFORMANCE DATA

Operating data from plant instruments were recorded every one-half hour to provide information necessary to evaluate coal burning rate, heat release rate, excess air, flue gas temperature, and boiler load during the stack testing. Coal scales, instruments, and controls at the seven test sites are checked and calibrated periodically by the manufacturer's service engineer. Special test equipment, other than an Orsat for boiler flue gas analysis, was not provided. Boiler efficiency testing was not included in the scope of Test Sites L1 and L7. Table 4-4 presents pertinent performance data.

Table 4-4

BOILER PERFORMANCE AND EFFICIENCY DATA

Test Site	L1	L2	L3	L4	L5	L6	L7
Coal Feed Rate, lb/hr	3,060	2,578	1,483	1,903	2,075	1,991	3,276
Coal Burning Rate, $lb/hr-ft_2$	31.4	20.5	20.3	17.8	25.7	23.9	20.3
Grate Heat Release, $10^3 Btu/hr-ft^2$	412	268	272	240	348	315	264
Furnace Heat Release, $10^3 Btu/hr-ft^3$	32.7	20.3	ND	19.5	22.4	23.3	18.5
Excess Air, % (by ASML formula)	71	26	186	72	33	61	116
Flue Gas Temperature, °F	564	520	484	556	497	475	599
Boiler Load, % of Capacity	75	65	60	70	55	65	50

NOTE: ND = No Data

5.0 TEST RESULTS AND OBSERVATIONS

This section presents the results of tests performed on seven boilers at seven different sites (L1-L7). The material includes information obtained on emission rates, particle size distributions, and collector efficiency.

Particulate mass loading was measured in each instance at a point just upstream of the point at which the emissions entered the atmosphere. Samples for particle size distribution measurements were taken at the same location and at the boiler outlet. At four of the seven sites a collector was in place, and the efficiency of each unit was determined by actual measurements. The techniques used to obtain all samples were described in section 4.0.

5.1 PARTICULATE MASS LOADING RESULTS

The test to determine the particulate emission rate at all seven facilities was carried out in accordance with the procedures specified in Chapter 139 of Title 25 of the Commonwealth of Pennsylvania Code. This code specifies the use of Federal Methods 1,2,3,4, and 5, but requires the inclusion of the soluble and insoluble fraction of the impinger catch in the calculation of the emission rate. The amount of sulfate in the impinger water also must be determined using a specified method. Since these tests were carried out in cooperation with the Department of Environmental Resources of the Commonwealth, their procedures were adopted. The results, however, are reported both with and without the impinger catch.

Table 5-1 is a summary of all the emission test results. There are a number of items that should be noted. The highest and the two lowest emission rates (in lbs/10^6 Btu), with or without the impinger catch, are on the boilers with no mechanical collectors. These three boilers also operated at the lowest stack velocities which allowed the longest settling times. In all three cases the stack gas concentrations are lower than those found in the gas streams following collectors. The significance of these results is discussed in section 2.0.

Table 5-1

Summary of Emission Test Data

Parameter	Test Site	L1	L2	L3	L4	L5	L6	L7
Emission Rate - With Impinger	lbs/10^6BTU	0.456	0.512	0.709	0.431	0.249	0.356	0.577
	lbs/hr	18.3	17.3	14.1	11.1	7.0	9.4	24.6
Pounds Emitted per Ton of Coal Used	lbs/ton	12.0	13.4	19.0	11.7	6.7	9.4	15.0
Concentration - With Impinger (corrected to 70°F, not corrected to 50% excess air)	gr/scf	0.19	0.29	0.13	0.18	0.15	0.08	0.17
Emission Rate - Without Impinger	lbs/10^6BTU	0.446	0.500	0.664	0.355	0.242	0.332	0.384
	lbs/hr	17.9	16.9	13.2	9.1	6.8	8.7	16.4
Pounds Emitted per Ton of Coal Used	lbs/ton	11.7	13.1	17.8	9.6	6.6	8.7	10.0
Concentration - Without Impinger (corrected to 70°F, not corrected to 50% excess air)	gr/scf	0.19	0.28	0.12	0.15	0.14	0.08	0.11
Sulfate	lbs/10^6BTU (x 10^{-2})	1.03	0.650	1.25	0.324	0.178	0.456	6.81
Stack Temperature	°F	549	482	382	505	365	286	553
Stack Velocity	ft/sec	51.0	38.7	11.6	29.9	3.8	5.0	49.5
Coal Heating Value	BTU/hr	13,100	13,100	13,400	13,500	13,500	13,200	13,000
Coal Feed Rate	lbs/hr	3,060	2,578	1,483	1,903	2,075	1,991	3,276
Heat Input	10^6BTU/hr	40.1	33.8	19.9	25.7	28.0	26.3	42.6
Collector		yes	yes	no	yes	no	no	yes

5.2 PARTICLE SIZE DISTRIBUTION RESULTS

The two methods used to obtain particle size information are described in section 4.2. This section deals with the results obtained from the Andersen in-stack impactor and the Bahco centrifugal classifier.

Particle size data are displayed in the Site L report in two ways. The log probability plot is useful in that one can determine the percentage of particles smaller than any given size, and the geometric mean or median of the distribution is the 50 percent cut point diameter. The geometric standard deviation is obtained by dividing the particle size at 84 percent by the particle size at 16 percent and taking the square root or, alternatively, dividing the particle size at 84 percent by the geometric mean size. The selection of the method is based on the shape of the distribution and it is assumed that the distribution can best be represented by a straight line on log-probability paper. The geometric standard deviation is, therefore, the slope of the line and provides a measure of the variation.

The second method of plotting the data gives additional information in a pictorial and graphical way. The particle size is plotted on a log scale on the abscissa, while a linear scale is used on the ordinate. This axis is labeled either d%M/dlog D or dC/dlog D. The area under the curve describes the change in particle mass or particle concentration with respect to the change in particle size. More simply, the area under the curve between any two selected particle sizes is the percentage of the mass or concentration between the two sizes. A display of this type is especially convenient in determining the efficiency of a collector with respect to particle size. To obtain the data on efficiency in the following section, the curves are carefully plotted from the impactor information and the areas under the curves are measured using a planimeter.

Figures 5-1 to 5-4 show the data:

a) from each site where samples were taken;

b) at the boiler outlet and in the stack prior to emission to the atmosphere; and

c) for both the impactor and the centrifugal classifier.

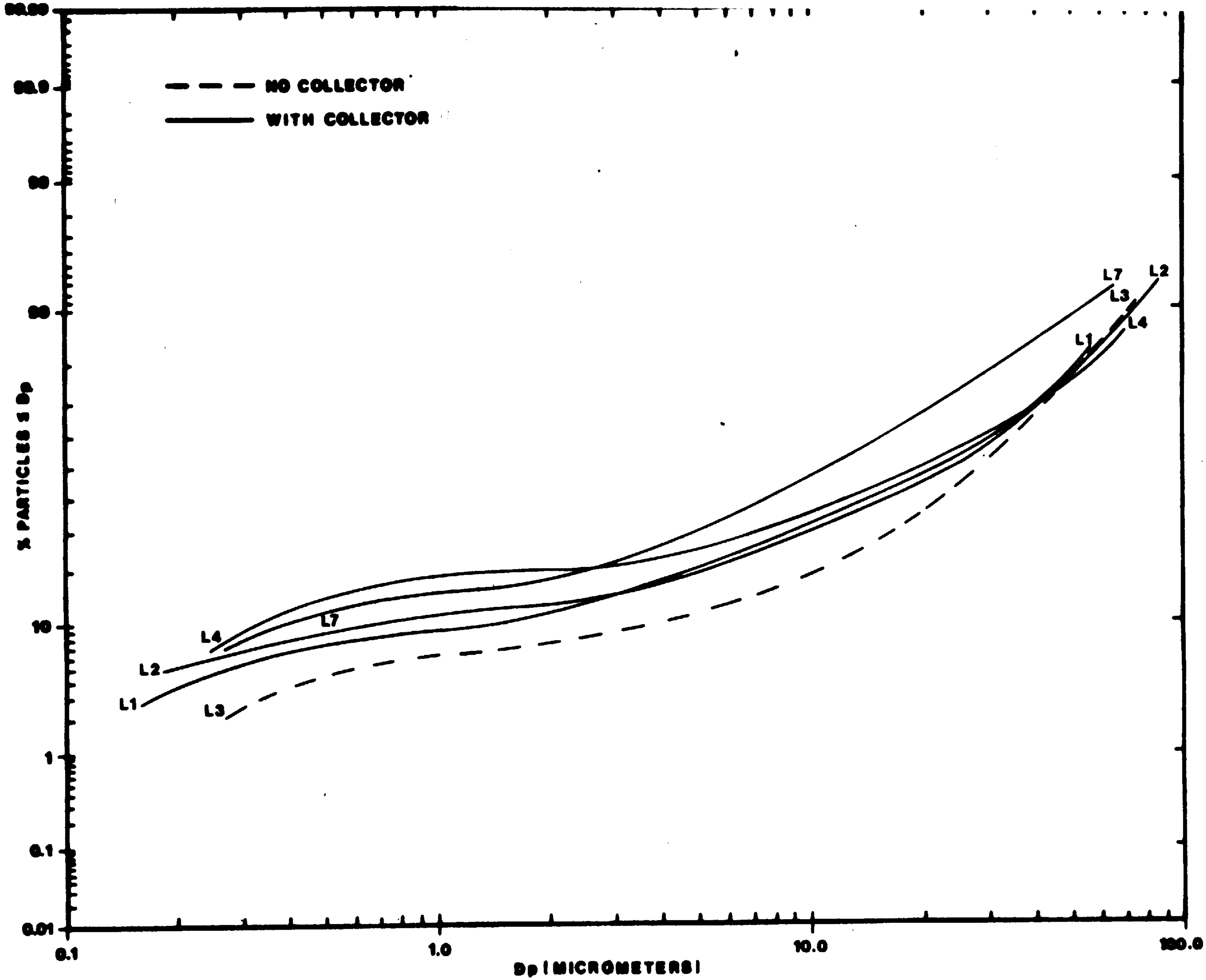


FIGURE 5-1 LOG PROBABILITY PLOTS OF PARTICLE SIZE DISTRIBUTION OF PARTICLE MATTEF AT BOILER OUTLET BY IMPACTION

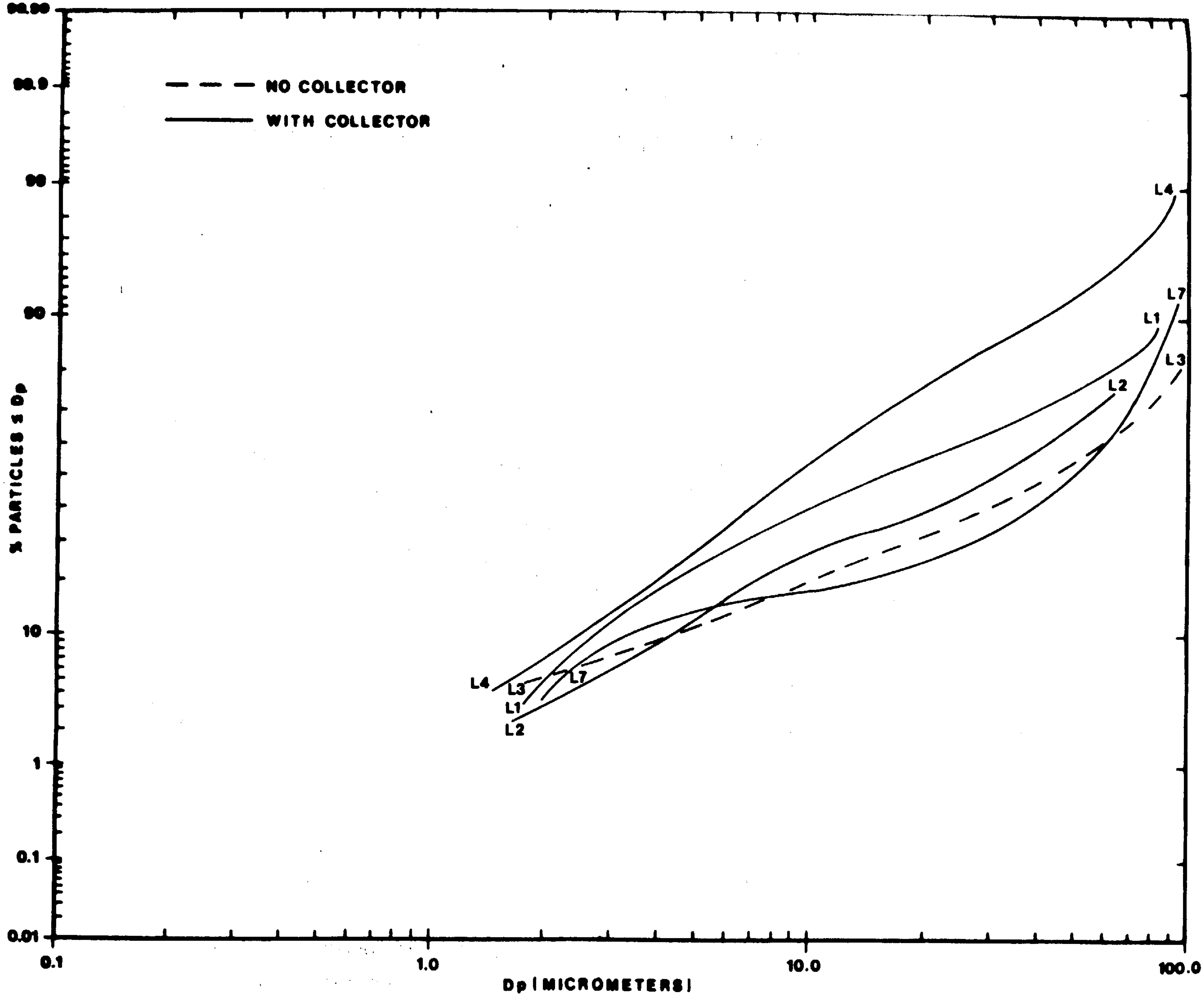


FIGURE 5-2 LOG PROBABILITY PLOTS OF PARTICLE SIZE DISTRIBUTION OF PARTICLE MATTER AT BOILER OUTLET BY CENTRIFUGAL CLASSIFIER

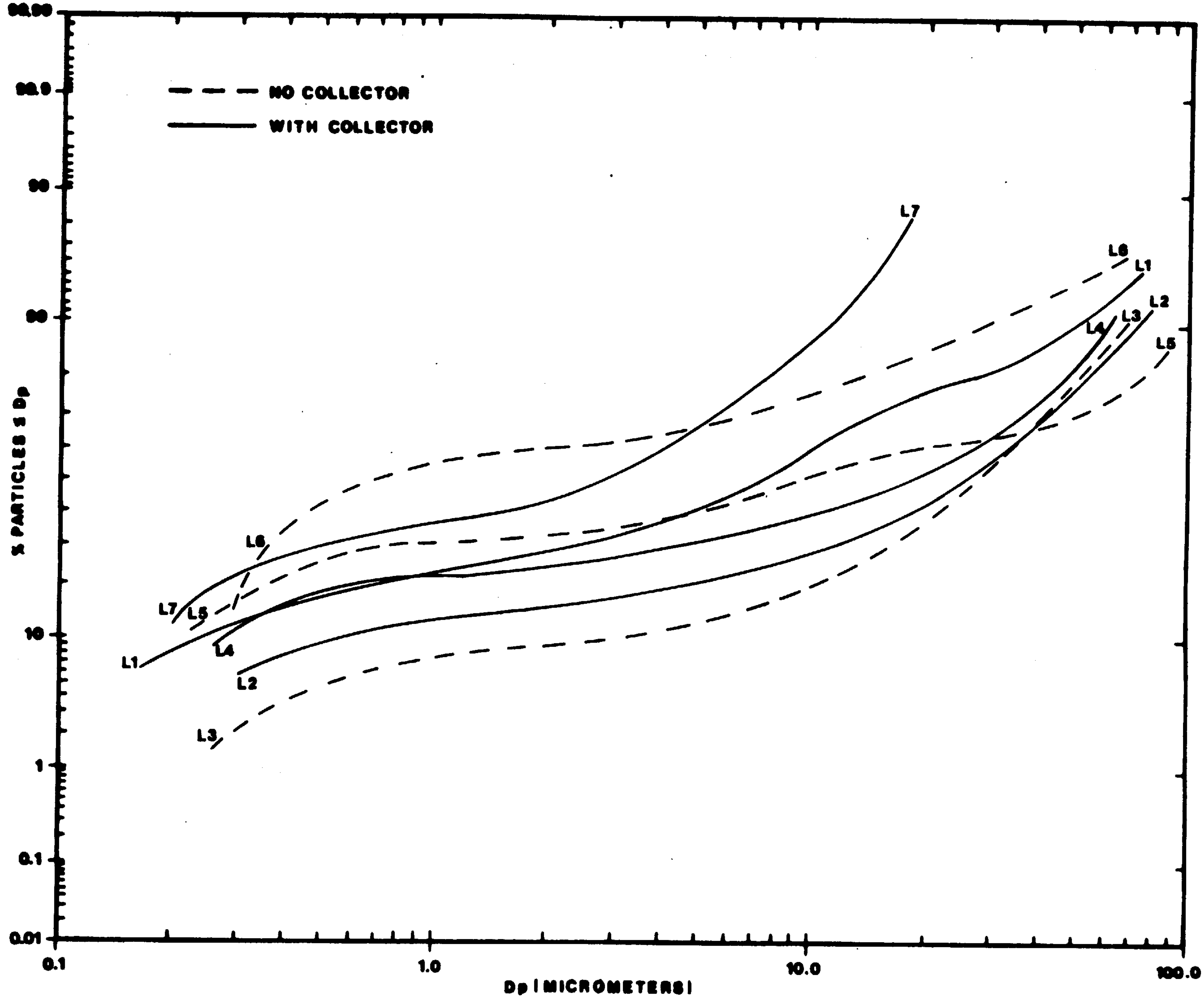


FIGURE 5-3 LOG PROBABILITY PLOTS OF PARTICLE SIZE DISTRIBUTION AT STACK OUTLET BY IMPACTION

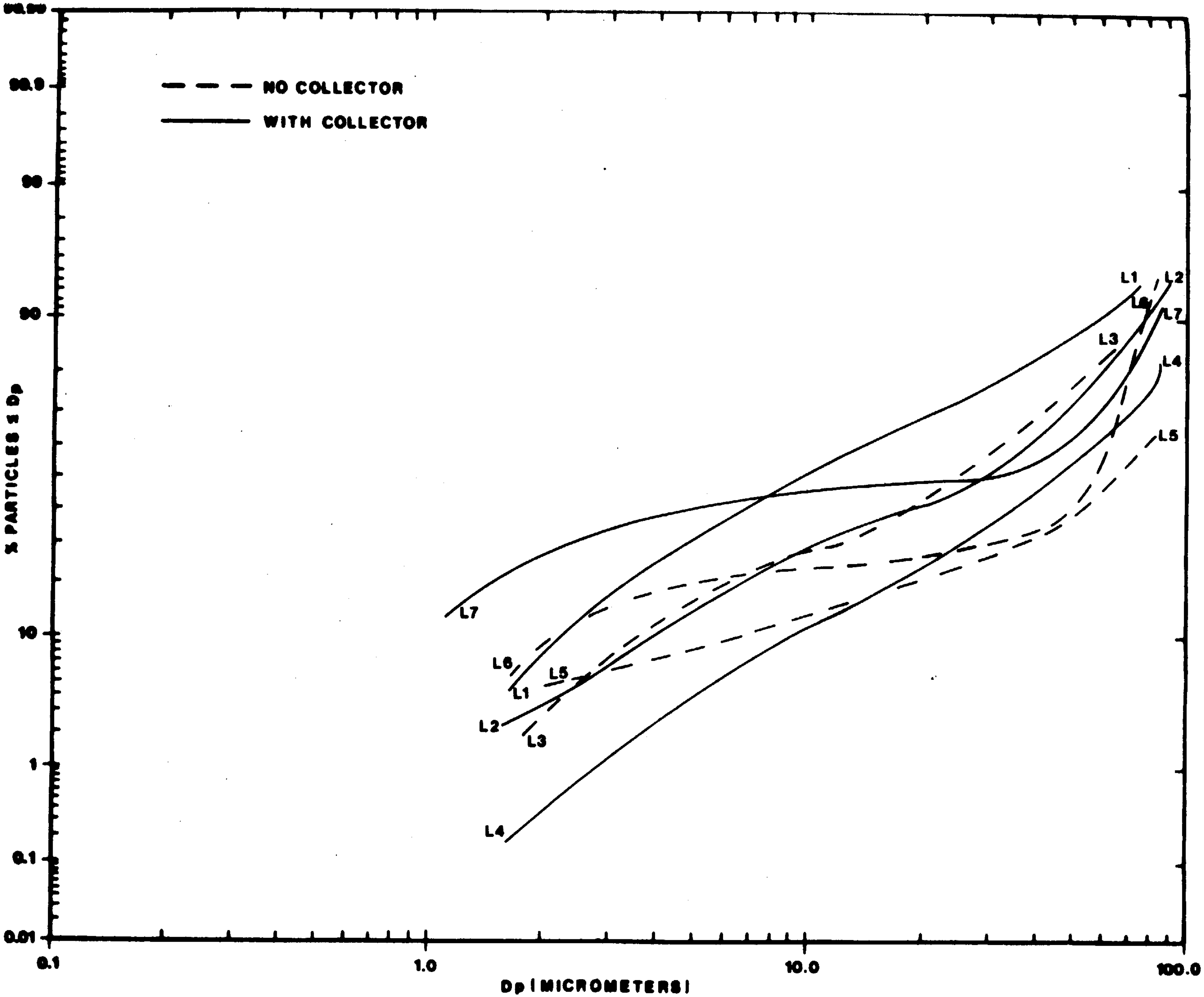


FIGURE 5-4 LOG PROBABILITY PLOTS AT PARTICLE SIZE DISTRIBUTION AT STACK OUTLET BY CENTRIFUGAL CLASSIFIER

The data from the centrifugal classifier are somewhat different from the impactor results particularly for particles less than 10 micrometers in diameter. The lower cut off for the centrifugal device is about 2.5 μm while the impactor can classify particles down into the submicrometer range. This lack of definition in the lower size ranges distorts the distribution shifting it toward larger mean particle sizes. Table 5-2 shows the geometric means and standard deviations based on the log-probability plots. The differences between the methods are obvious. Given the fact that the impactor withdraws the sample directly from the gas stream and has a finer definition across the entire size distribution, the data from this sampling device are used in the extended analysis.

Using the second method of plotting provides a better understanding of what the particle distribution looks like. The d%M/dlog D and dC/dlog D plots for the boiler outlet (Figures 5-5 and 5-6) indicate that the material coming from the boiler has very similar characteristics. Only Site L7 deviates markedly from the others and then only in the region above 10 micrometers. It appears that the lack of particles in this region is accurate since it is also reflected at the stack outlet shown in Figure 5-7 and 5-8. Once the particles pass through the collectors and the long ducts, the distributions are changed as shown in the latter two figures. It is clear from these data that the largest percentage of particles emitted from boilers are larger than 10 micrometers and that there is a significant fraction between 2 and 10 μm. Collectors that have little efficiency below 10 μm will probably not be able to provide sufficient control for compliance purposes. On the basis of these data, it would seem necessary to reduce the 2 to 10 μm fraction in order to achieve compliance with regulations.

The irregular curves in Figure 5-7 are caused by the reduction of the large particle fraction through settling and multiclone collection. The major percentage of the mass is thus shifted into the 1 to 10 μm range, indicating that the largest fraction of the emitted particles are small in size. Figure 5-8 which shows particle concentration with respect to size is less irregular, but the effect of the cyclones at sites L1 and L7 is quite apparent. The concentration of larger particles is reduced and, in the case of L7, fewer particles are to be found even in the 1 to 10 μm range. It is this fine particle fraction that must be reduced to achieve control.

Table 5-2

Particle Size Distribution

Comparison

	Test Site	Impaction Boiler Outlet $\bar{x}$	Impaction Boiler Outlet Sg	Impaction Stack Outlet $\bar{x}$	Impaction Stack Outlet Sg	Centrifugal Classification Boiler Outlet $\bar{x}$	Centrifugal Classification Boiler Outlet Sg	Centrifugal Classification Stack Outlet $\bar{x}$	Centrifugal Classification Stack Outlet Sg
Controlled	L1	21.0	4.5	7.4	8.1	15.0	4.0	8.8	3.4
"	L2	23.0	4.6	23.0	4.0	32.0	3.7	25.0	3.8
No controls	L3	28.0	2.3	28.0	2.5	44.0	3.7	22.0	3.5
Controlled	L4	25.0	9.0	18.0	10.9	44.0	2.5	9.0	2.9
No controls	L5	ND		9.3	16.9	ND		70.0	2.9
No controls	L6	ND		0.7	7.7	ND		60.0	5.5
Controlled	L7	13.0	7.3	2.9	6.6	54.0	3.2	15.0	8.1

$\bar{x}$ = Geometric Mean Diameter in Micrometers

Sg = Geometric Standard Deviation

NOTE: ND = No Data

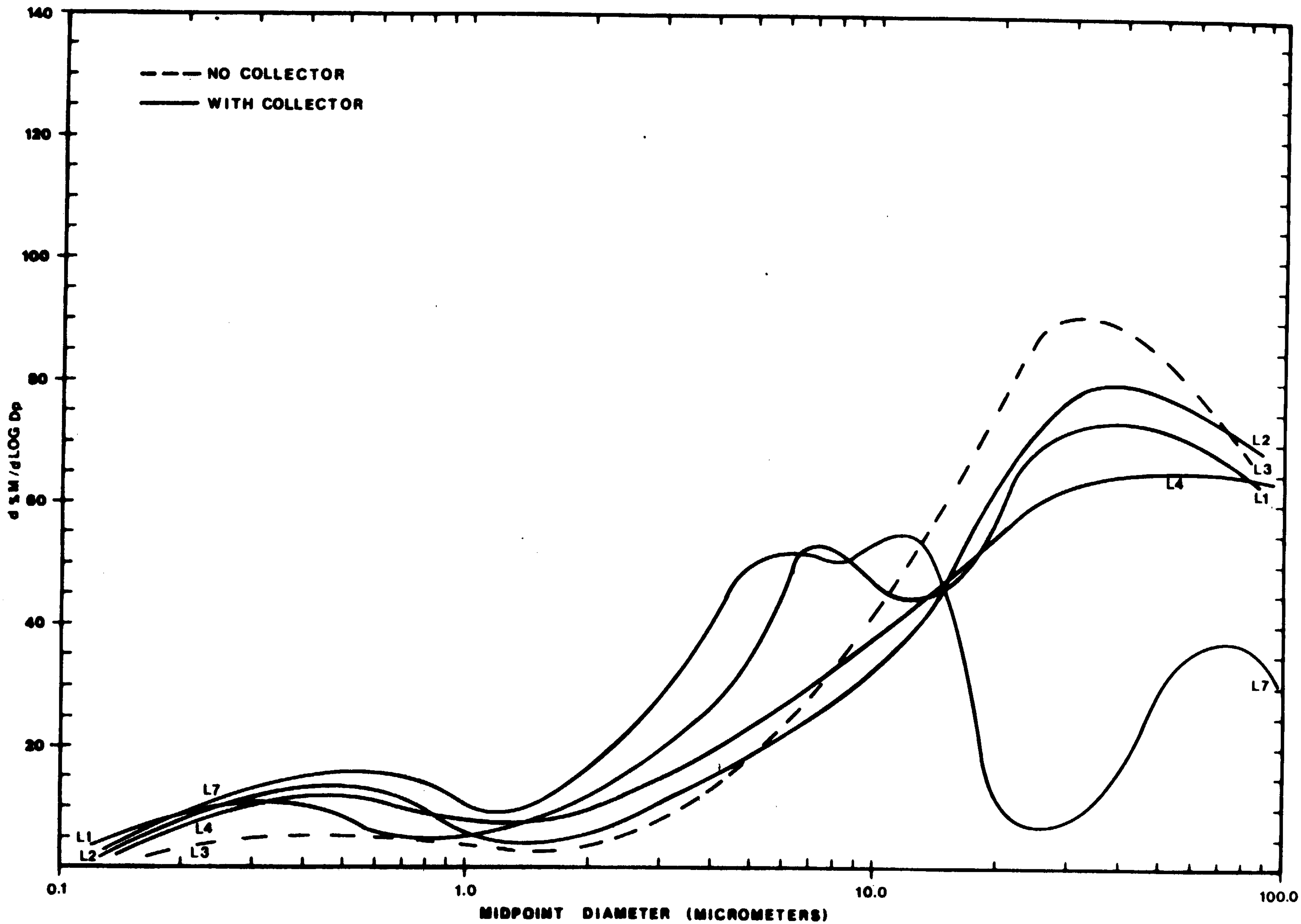


FIGURE 5-5 - DIFFERENTIAL PERCENT MASS PLOTS OF PARTICLE SIZE DISTRIBUTION AT THE BOILER OUTLET BY IMPACTION AT SITES L1, L2, L3, L4, L7

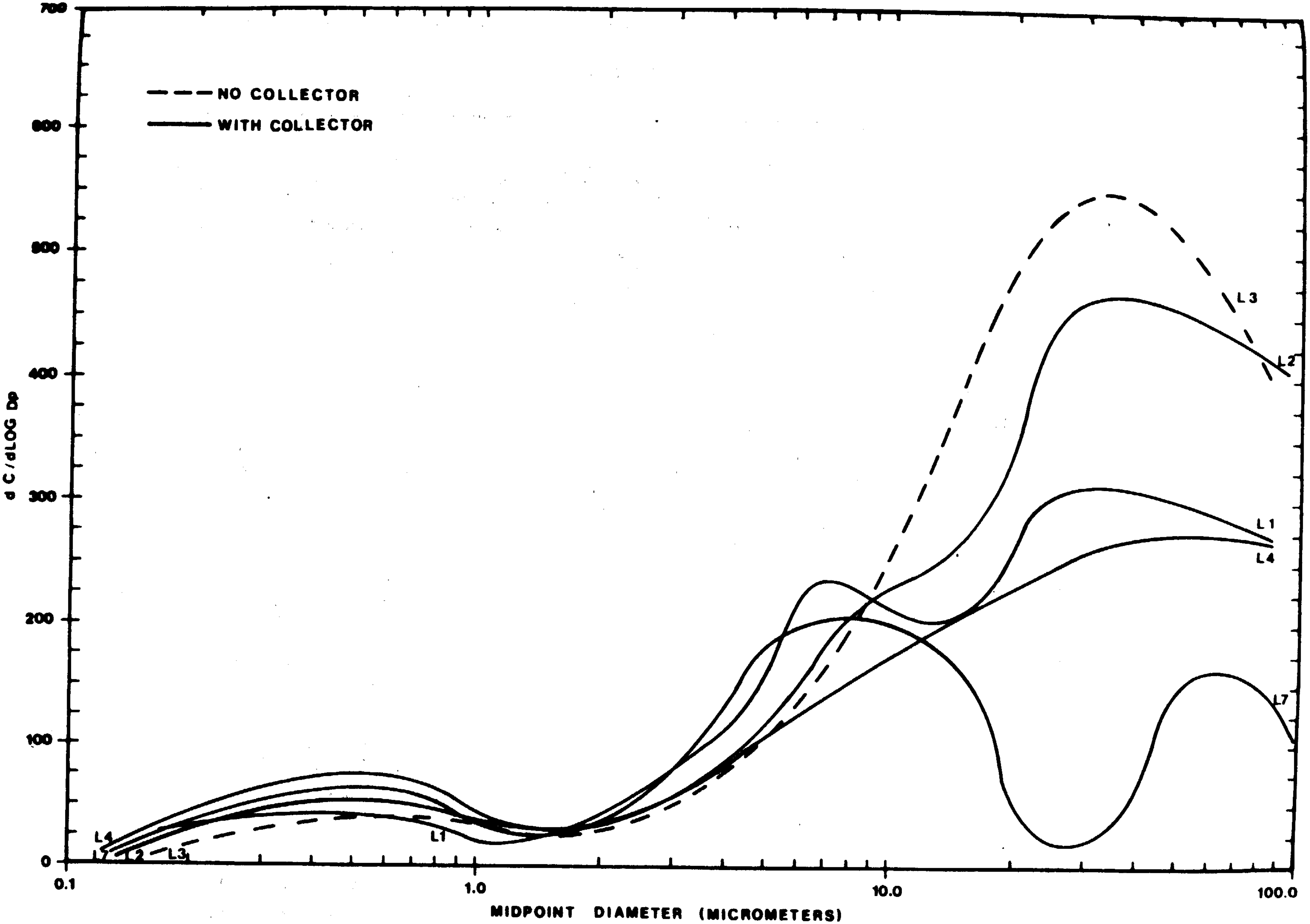


FIGURE 5-6 - DIFFERENTIAL PERCENT CONCENTRATION PLOTS OF PARTICLE SIZE DISTRIBUTION AT THE BOILER OUTLET BY IMPACTION AT SITES L1, L2, L3, L4, & L7

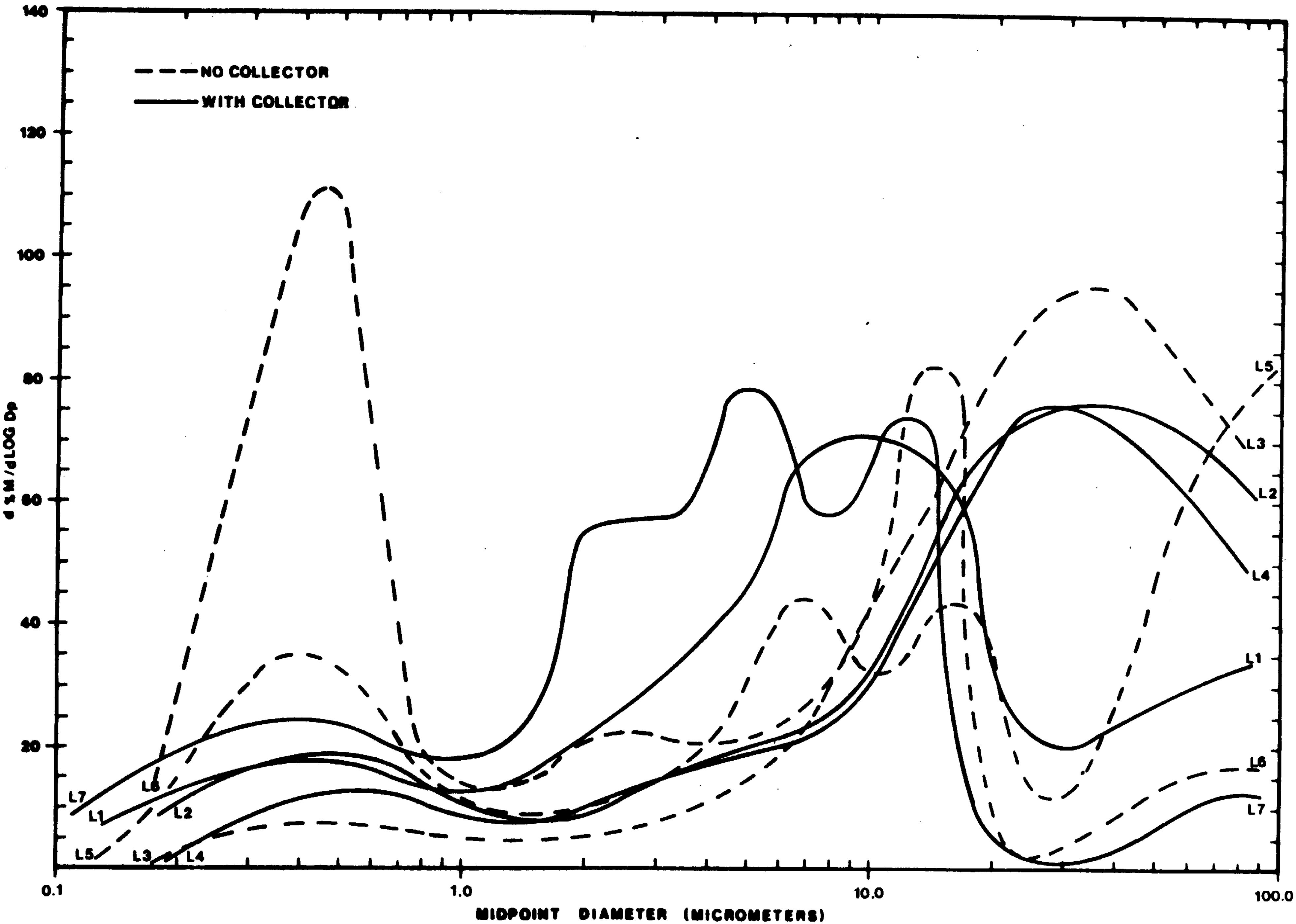


FIGURE 5-7 - DIFFERENTIAL PERCENT MASS PLOTS OF PARTICLE SIZE DISTRIBUTION AT THE STACK OUTLET BY IMPACTION

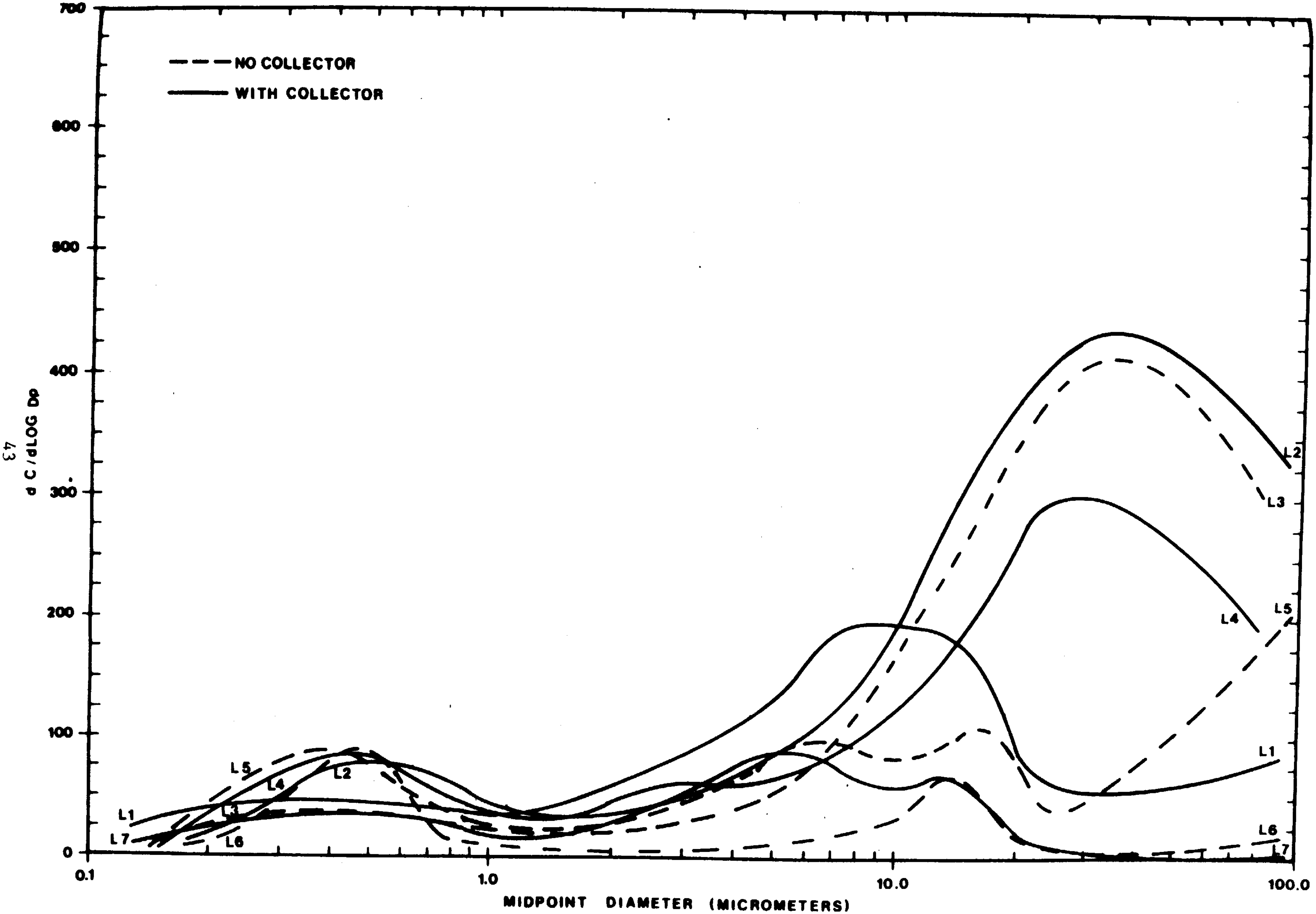


FIGURE 5-8 - DIFFERENTIAL PERCENT CONCENTRATION PLOTS OF PARTICLE SIZE DISTRIBUTION AT THE STACK OUTLET BY IMPACTION

5.3 COLLECTOR EFFICIENCY

Collector efficiency can be estimated in two ways. First, the lbs/hr measured by the standard emission test can be used in conjunction with the actual material collected per hour in the collector. In order to make this estimate the collector is cleaned prior to the initiation of the stack test. After the test is over the particle matter is removed and weighed. The second method uses the total concentration from the samples taken at the collector inlet and outlet. This latter technique utilizes the fact that the mass concentration of particle matter in each cubic meter of gas can be calculated from the samples obtained by impactors and from centrifugal classification. By comparing the concentration before and after the collector, the efficiency can be estimated. The following example taken from Site L1 results is illustrative:

Method 1 - Based on Stack Test and Mass in Collector

Emission Rate = 18.29 lbs/hr. Collector Rate = 6.65 lbs/hr.

Total material generated per hour = 24.94 lbs/hr.

$$\text{Efficiency} = \frac{24.94 - 18.29}{24.94} \times 100 = 26.6\%$$

Method 2 - Based on concentrations as measured by the Impactor (or Centrifugal Classifier)

Before collector = 427.7 mg/NCM

After collector = 271.1 mg/NCM

$$\text{Efficiency} = \frac{427.7 - 271.1}{427.7} \times 100 = 36.6\%$$

Since it is quite difficult to remove all the material from the collector and since there would be losses in the breaching, it is not surprising that the methods do not yield identical results. In the four cases where efficiency was measured by these methods, the outcome was similar to that shown above.

The collector efficiency information is shown in Table 5-3. Methods 1 and 2 are discussed above. The similarity of the results is quite striking. Only at site L4 do the values differ by significant amounts and, even in this case, it is still apparent that the efficiency is quite low.

There is not a single instance in which the collector was operated at the design flowrate (see Table 5-4). When design flowrates differ by large amounts (Sites L2 and L4) the penalty is quite severe and leads to collector efficiencies that are extremely low. The device operating closest to design conditions (Site L7) has the most reasonable efficiency, but this is not reflected in the overall emission rate when the rate includes condensables. About 33% of the particle matter was found in the impingers. If the impinger catch is excluded, the particle concentration at site L7 is the next to the lowest recorded (See Table 5-1, Concentration Without Impinger Catch).

The sulfate concentration in Table 5-1 should also be noted. The sulfate is determined using the barium sulfate turbidity method* as specified by the Commonwealth of Pennsylvania. It is performed on the impinger water. The only number that is quite different from the others is the 6.81×10^{-2} lbs/10^{6} Btu at site L7. It appears that the soluble fraction collected in the impingers at site L7 contains a considerable amount of sulfate. The reason for this is not clear but may be related to the coal used.

Table 5-3

Collector Efficiency Comparisons

Test Site	Method 1	Method 2: Impactor Measurement	Method 2: Centrifugal Classifier Measurement
L-1	26.6%	36.6%	36.0%
L-2	10.9%	10.9%	7.2%
L-4	22.8%	2.8%	12.6%
L-7	42.9%	66.3%	65.4%

note: The higher %'s from Method 2 may result from extra collection in breeching.

*The method is described in Standard Methods for the Examination of Water and Wastewater prepared and published by the American Public Health Association, the American Water Works Association, and The Water Pollution Control Federation (pgs 334-335) 13th Edition, 1971

i.e., method 1 does not account for material deposited in breeching before control device

TABLE 5-4

Collector Efficiency Performance Information

Test Site	Collector Efficiency From Impactor (%)	Efficiency with Respect to Particle Size Eff.>10	Efficiency with Respect to Particle Size Eff.<10	Design Flowrate (cfm) & Temp. °F	Nominal Design Flowrate @ Std. Temp. (NDF)	Operating Flowrate (cfm) & Temp. °F	Nominal Operating Flowrate @ Std. Temp. (NOF)
L1	36.6	59.8	0.4	28,000 @ 600°F	14,000	21,200 @ 540°F	11,240
L2	8.9	9.0	8.0	22,000 @ 580°F	11,200	12,400 @ 480°F	6,990
L4	2.8	2.8	0.0	19,270 @ 615°F	9,500	13,200 @ 500°F	7,290
L7	66.3	82.3	56.6	35,400 @ 580°F	18,040	32,000 @ 530°F	17,130

Facility	NOF/NDF
L1	0.80
L2	0.62
L4	0.77
L7	0.95

The collection efficiency curves based on the impactor data are shown in Figure 5-9. On the basis of these results one could assume that the collectors at sites L1 and L7 are performing near the design criteria while the collectors at the other two sites are not removing even the larger particles with reasonable efficiency. This is born out more directly by examining the data as presented in Table 5-5. These data are obtained by measuring the area under the curve in Figures 5-6 and 5-8. Note that at site L1 the efficiency drops off dramatically below 20 micrometers while at site L7 the multiclone appears to have a 50% cut point diameter of about 10 micrometers. At sites L2 and L4 the collectors have rather low efficiency values across the whole operating spectrum.

Figure 5-10 is a plot of the emission rate from the stack in lbs per hour versus the stack velocity in feet per second. The sites with collectors and without are grouped for analysis. Note that in both cases the statistical correlation coefficient is relatively high--0.83 for the sites with collectors and 0.98 for those without control devices. The lines shown are based on a least squares fit to the data on the graph. The results are not surprising; the higher velocity gas streams tend to carry more particles out into the atmosphere even in cases where a collector is in place. and where operation of that collector is not per design specs for airflow rate

5.4 PARTICULATE LOADING VERSUS OPERATING PARAMETERS

The Site L test program did not provide for the testing of individual boilers at various loads and operating conditions, or with coals other than those supplied from the contracted source. However, a comparison of the types of stokers, fuels fired, and performance data versus uncontrolled emission rates downstream of the boiler outlet as listed in Table 5-6 provides some interesting observations.

Type of Stoker

Two multiple retort stoker units (L5 and L6), not equipped with emission control devices, had the two lowest emission rates. The other two multiple retort stoker units (L1 and L7), equipped with multiple cyclone collectors, ranked fifth and seventh with

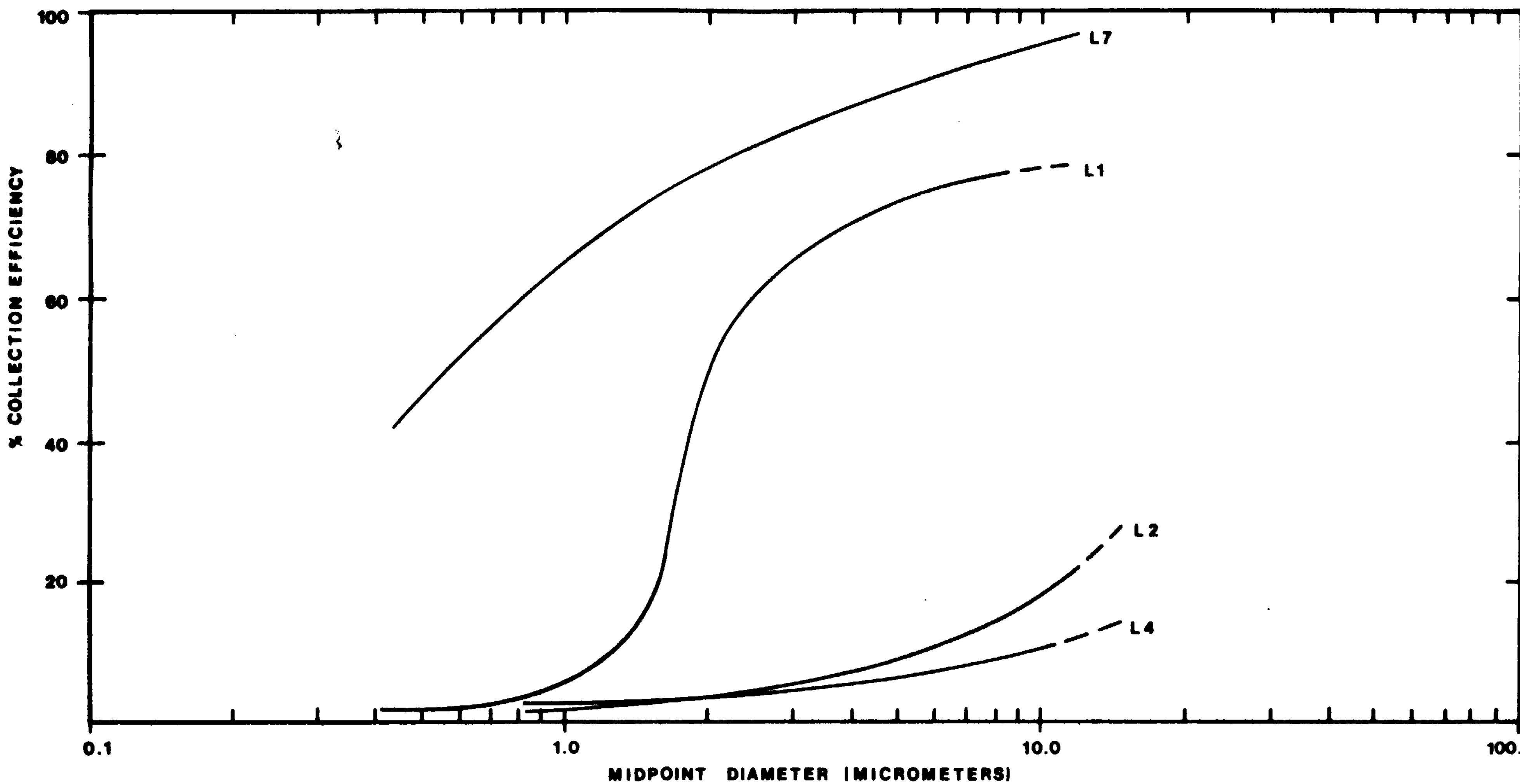


FIGURE 5-9. COLLECTOR EFFICIENCY CURVES

TABLE 5-5

Efficiency with Respect to Particle Size Calculated from Impactor Results

Test Site	Particle Size Range (Micrometers)	Boiler Outlet Concentration mg/NCM	Stack Concentration mg/NCM	Collector Efficiency %
L1	125-30	183.7	51.6	71.9
	30-20	47.9	12.6	73.8
	20-10	63.7	54.9	13.9
	<10	108.4	107.9	0.4
L2	125-30	280.5	243.4	13.2
	30-20	75.2	71.1	5.6
	20-10	86.7	93.0	0.0
	<10	95.6	86.2	9.8
L4	125-30	173.8	165.1	5.0
	30-20	57.7	55.7	3.5
	20-10	63.5	62.2	2.0
	<10	111.1	111.8	0.0
L7	125-30	85.2	5.9	93.1
	30-20	6.7	1.7	74.3
	20-10	65.9	20.3	69.2
	<10	140.6	61.0	56.6

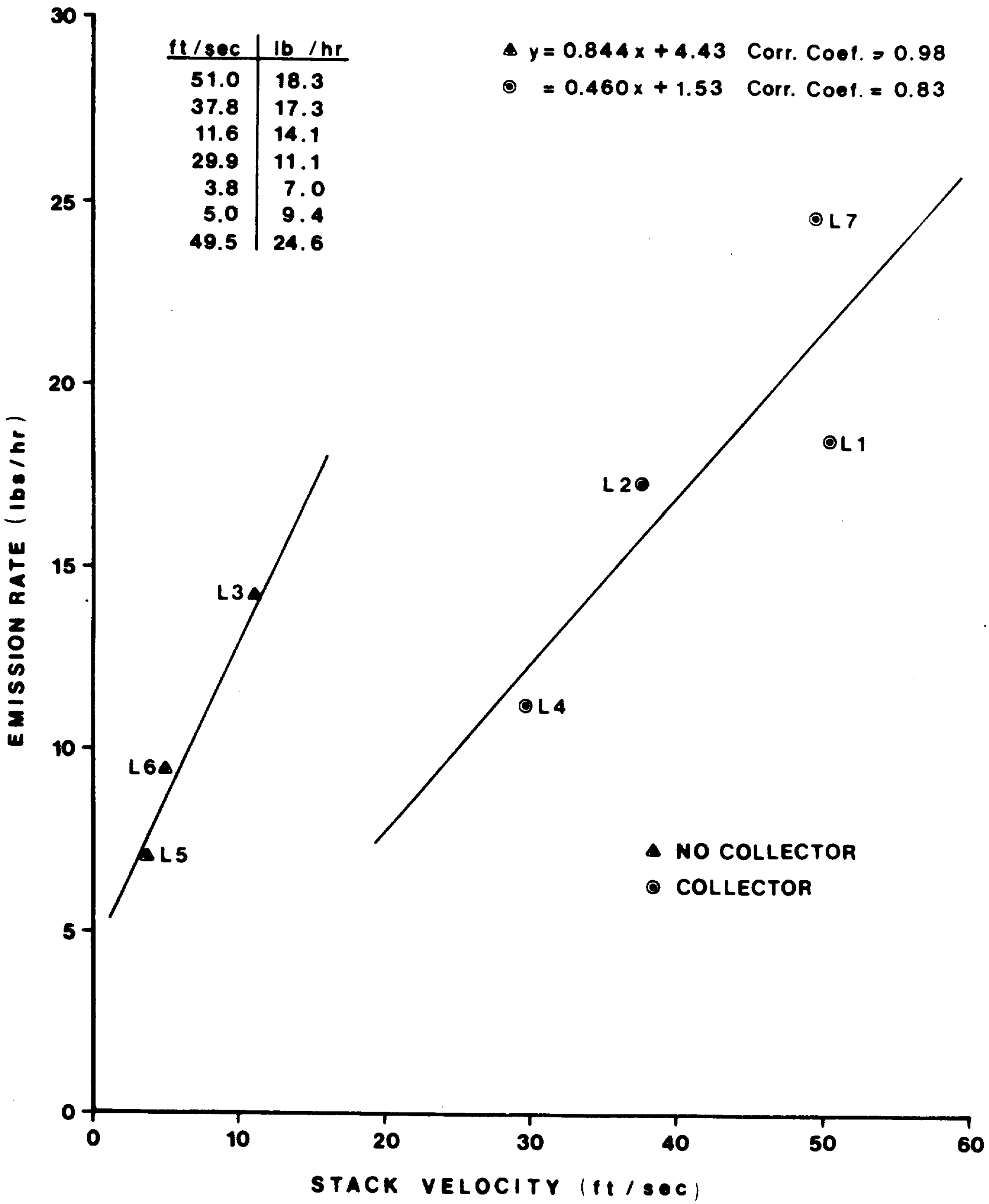


FIGURE 5-10. STACK VELOCITY vs EMISSION RATE

respect to increasing emission rate. The higher emission rates from the latter two units may be attributed to "caking" fuel bed problems resulting in high excess air and high flue gas temperature. Higher gas velocity in the flue gas discharge systems of the latter two units also contribute to the higher emission rates.

The traveling grate stoker (L4), vibrating grate stoker (L2), and single retort stoker (L3), units ranked third, fourth and sixth with respect to increasing emission rate. The high emission rate from the single retort stoker unit also may be attributed to "caking" fuel bed problems.

Coal Sizing and Characteristics

Coal size data (Table 4-2) was obtained at Test Sites L5, L6, and L7 only. These data do not indicate any particular relationship to the emission rates. There also was no apparent relationship between the various coal characteristics listed in Table 4-1 and the emission rates.

Excess Air/Flue Gas Temperature

A good relationship is indicated, for multiple retort stoker units, between emission rate and the inter-related variables of excess air and flue gas temperature listed in Table 4-4. Emission rates increased as excess air and flue gas temperatures increased.

Boiler Capacity, Coal Feed Rate, and Heat Release Rate

A good relationship is indicated, for multiple retort stoker units, between emission rate and the coal feed rate listed in Table 4-4. However, no relationship can be established between emission rate and the boiler design capacity, boiler load in percent of steaming capacity, or heat release rate.

Particulate emission test results are listed in Table 5-1. However, the results shown for Test Sites L3, L5 and L6 represent uncontrolled boiler emissions, and results shown for Test Sites L1, L2, L4 and L7 represent controlled emissions downstream of multiple cyclone collectors. To provide a means of comparing uncontrolled emission rates of all sites, uncontrolled boiler emissions from units equipped with collectors were calculated by applying the collector efficiencies, shown in Table 5-3, to the controlled emission rate. A summary of the test and calculated uncontrolled boiler emission rates are listed in Table 5-6.

Table 5-6

UNCONTROLLED EMISSION RATE, LB/10^6 BTU

include impinger catch

Test Site	By Test	By Calculation Average	High	Low
L1	--	0.684 (.67)	0.719	0.621
L2	--	0.563 (.55)	0.575	0.552
L3	0.709	--	--	--
L4	--	0.498 (.41)	0.588	0.433
L5	0.249	--	--	--
L6	0.356	--	--	--
L7	--	1.464	1.712	1.011

excluding impinger catch

The particulate emission factor for coal combustion without control devices for all stoker types except spreaders, as reported in the U.S. Environmental Protective Agency Publication AP-42, Compilation of Air Pollution Factors, Third Edition, is 5A (potential emission rate in pounds of particulate per ton of coal fired is equal to five times the weight percentage of ash in the coal). The uncontrolled emission rates shown in Table 5-6 were converted to equivalent particulate emission factors provided by this publication. A summary of the calculated factors are listed in Table 5-7.

Table 5-7

UNCONTROLLED EMISSION FACTORS, LB/TON — including impinger catch

	Test Site	By Test	By Calculation (using method 2) Average	High	Low	Avg (excluding impinger)
UNDERFEED, MR	L1	--	1.4A	1.4A	1.3A	1.4 A or 18 lb/ton
VIBRATING GRATE	L2	--	1.1A	1.2A	1.1A	1.1 A 14 lb/ton
UNDERFEED, SR	L3	1.6A	--	--	--	1.6A 18.8 lb/ton
OVERFEED, TRAV. GRATE	L4	--	1.6A	1.8A	1.4A	1.3A 11 lb/ton
UNDERFEED, MR	L5	0.6A	--	--	--	.6A 7.2 lb/ton
UNDERFEED, MR	L6	0.8A	--	--	--	.7A 8.9 lb/ton
" "	L7	--	2.9A	3.6A	2.1A	2A 25 lb/ton
	~~AP-42~~	~~5A~~				

~~AVG = 1.9A~~

Avg = 1.3A or 14.7 lb/t

AVG (overfeed) = 1.2A or 12.5 lb/t

AVG (underfeed) = 1.3A or 16 lb/t

overall averages, excluding impinger catch

MR = MULTIPLE RETORT

SR = SINGLE RETORT

Method 2 gives an estimate of emissions directly at the boiler outlet

Note: by using method 1 measured collector efficiencies the factor represents emissions after fallout in breaching

Avg (before control, based method 1 ~~measured~~ efficiency)

uncontrolled units

L1	1.2A,	15.2 lb/ton
L2	1.1A,	14 lb/ton
L3	———	(1.7A, 18.8 lb/ton)
L4	1.4A,	12 lb/ton
L5	———	(.6A, 7.2 lb/ton)
L6	———	(.7A, 8.9 lb/ton)
L7	1.4A,	17.5 lb/ton

53 Overall average (1.2A, 13.2 lb/ton)

Avg (overfeed) 1.3A, 13 lb/ton

Avg (underfeed) 1.1A, 13 lb/ton

APPENDICES

APPENDIX A

CONVERSION FACTORS

ENGLISH AND METRIC UNITS TO SI UNITS

To Convert From	To	Multiply By
in	cm	2.540
in^2	cm^2	6.452
ft	m	0.3048
ft^2	m^2	0.09290
ft^3	m^3	0.02832
lb	Kg	0.4536
lb/hr	Mg/s	0.1260
$lb/10^6 BTU$	ng/J	430
g/Mcal	ng/J	239
BTU	J	1054
BTU/lb	J	1054
BTU/lb	J/kg	2324
BTU/hr	w	0.2929
J/sec	W	1.000
J/hr	W	3600
BTU/ft/hr	W/m	0.9609
BTU/ft/hr	J/hr/m	3459
$BTU/ft^2/hr$	W/m^2	3.152
$BTU/ft^2/hr$	$J/hr/m^2$	11349
$BTU/ft^3/hr$	W/m^3	10.34
$BTU/ft^3/hr$	$J/hr/m^3$	37234
psia	Pa	6895
"H_2O	Pa	249.1
Rankine	Celsius	C = 5/9R-273
Fahrenheit	Celsius	C = 5/9(F-32)
Celsius	Kelvin	K = C+273
Rankine	Kelvin	K = 5/9R

APPENDIX B

CONVERSION FACTORS

SI UNITS TO ENGLISH AND METRIC UNITS

To Convert From	To	Multiply By
cm	in	0.3937
cm^2	in^2	0.1550
m	ft	3.281
m^2	ft^2	10.764
m^3	ft^3	35.315
Kg	lb	2.205
Mg/s	lb/hr	7.937
ng/J	$lb/10^6$BTU	0.00233
ng/J	g/Mcal	0.00418
J	BTU	0.000948
J/kg	BTU/lb	0.000430
J/hr/m	BTU/ft/hr	0.000289
$J/hr/m^2$	BTU/ft^2hr	0.0000881
$J/hr/m^3$	$BTU/ft^3/hr$	0.0000269
W	BTU/hr	3.414
W	J/hr	0.000278
W/m	BTU/ft/hr	1.041
W/m^2	$BTU/ft^2/hr$	0.317
W/m^3	$BTU/ft^3/hr$	0.0967
Pa	psia	0.000145
Pa	"H_2O	0.004014
Kelvin	Fahrenheit	F = 1.8K-460
Celsius	Fahrenheit	F = 1.8C+32
Fahrenheit	Rankine	R = F+460
Kelvin	Rankine	R = 1.8K

APPENDIX C

SI PREFIXES

Multiplication Factor	Prefix	SI Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto*	h
10^{1}	deka*	da
10^{-1}	deci*	d
10^{-2}	centi*	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

*Not recommended but occasionally used

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15. SUPPLEMENTARY NOTES IERL-RTP project officer is R. Hall. (*) Cosponsors are DoE(W. Harvey Jr.) and the American Boiler Manufacturers Assn. Reports are available for Sites A-K.

16. ABSTRACT The report gives results of field measurements to determine particulate emission rate and particle size distribution for seven institutional-type stoker-fired boilers firing bituminous coals. Operational data were recorded during the tests to provide information for evaluating boiler emissions as a function of boiler load, heat release rates, coal size and characteristics, percent excess combustion air, and flue gas temperature. All boilers were tested under normal operating conditions at loads of 50-75% of maximum boiler capacity. The types of stokers tested included single retort underfeed, multiple retort underfeed, traveling grate overfeed, and vibrating grate overfeed. The report describes the seven boiler-stoker units, test port locations, and test equipment and procedures, and summarizes test results and operations. The particulate mass emission rate from high stack velocity sites was greater than from lower stack velocity sites, whether or not a collector was used: the statistical correlation coefficient was 0.83 with collectors and 0.98 without. The units tested can operate at 50-75% load with uncontrolled particulate emission rates, well below the calculated value of five times the weight percentage of ash in coal recommended in 'Compilation of Air Pollution Factors,' AP-42. Data indicate that 50% of the mass at the boiler outlet consists of <30 micrometer diameter particles.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Measuring	Pollution Control	13B	
Field Tests	Dust	Stationary Sources	14B	11G
Boilers	Emission	Particulate	13A	14F
Bituminous Coal	Particle Size Distribution		21D	
Stokers				
Combustion	Efficiency		21B	

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Site L (note: in all cases, impinger catch excluded)

1 - Multiple retort underfeed (53×10^6 Btu/hr)
- Testing in stack after collector (multiple cyclone)
- Particulate loading, after multiclone, was 0.446 lb/10^6 Btu or 11.7 lb/ton (0.9 A) - excluding impinger catch
- ~~Particulate ...~~
- Particulate before controls is ~~...~~ calculated at 0.68 lb/10^6 Btu, or about 1.2 A, or about 15 lb/ton, based on measured collector efficiency by Method 1.

2 Vibrating grate overfeed (52×10^6 Btu/hr)
- Testing in duct after controls (multiple cyclone)
- Particulate loading, after multiple cyclone, was 0.5 lb/10^6 Btu, or 13 lb/ton (1A).
- Particulate calculated before controls is about 0.55 lb/10^6 Btu or 14.3 lb/ton or about 1.1A.

3 Single retort underfeed (42×10^6 Btu/hr)
- Testing in duct, no controls; testing done after ~~...~~ flue gas has traversed the length of the duct
- Particulate loading (uncontrolled) is 0.664 lb/10^6 Btu, or 17.8 lb/ton, or 1.6A.

4 Traveling grate overfeed (47×10^6 Btu/hr)
- Testing in duct downstream of multiple cyclone
- Particulate loading, after controls, is 0.355 lb/10^6 Btu or 9.6 lb/ton, or 1.1A.
- Particulate calculated before controls, based on measured collection efficiency (Method 1), is 1.4A, or 12 lb/ton

L5 Multiple retort underfeed (51×10^6 Btu/hr)
No controls
Testing in duct downstream from boiler outlet
Particulate loading (uncontrolled) is 0.242 lb/10^6 Btu, or 6.6 lb/ton, or 0.6A

-6 Multiple retort underfeed (32×10^6 Btu/hr)
No control
Testing in duct downstream from boiler outlet
Particulate loading (uncontrolled) is 0.332 lb/10^6 Btu or 8.7 lb/ton, or 0.7A

7 Multiple retort underfeed (42×10^6 Btu/hr)
Testing in stack after multiple cyclone
-Particulate loading after control is 0.384 lb/10^6 Btu, or 10 lb/ton or 0.8A.

-Calculated particulate upstream of collector (based on Method 1 measured efficiency) is 17.5 lb/ton, or 1.4A

(See page 53 of report for emission summary for all tests)

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