ABSTRACT

This study was carried out to design a system for the inexpensive treatment of ash pond effluent or leachate. Twelve different coals were burned in three different types of coal fired boilers to determine the influence of coal composition, ash fusion temperatures, boiler additives, combustion conditions and co-firing of natural gas or oil with the coal, on the composition of the fly ash and bottom ash as well as the leaching and sorbate characteristics of the fly ash produced.

The trace elemental analysis consisting of Ti, Cd, Sn, Ni, Pb, Mo, Cu, Cr. Zn, Mn, Ba, and V in the twelve coals and their respective fly and bottom ashes. In addition, the leaching characteristics of the fly ashes with respect to pH, Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn and Fe have been defined.

The results indicate that in the combustion of low ash fusion coals, the Sn, Ni, Mo, Cu, Cr and Mn tend to concentrate in the bottom ash, whereas the Ti, Zn and Ba tend to concentrate in the fly ash. For the high fusion coal, Sn, Cd, Pb, Mo, Cu, Cr, Ba and V in the parent coal concentrate in the bottom ash and Ti, Ni, Zn and Mn in the fly ash.

An increase in boiler temperatures were observed to favor lower concentrations of the above trace elements in fly ash particles produced from low ash fusion coals. Also, smaller fly ash particles were found to contain higher concentrations of the above trace elements when compared to that present in larger fly ash particles produced from the same coal.

The addition of the additive LPA-40 (which contains sulfur compounds to alter the sensitivity of the fly ash) to the combustion gases appears partially responsible for the amount of sulfur found on the surface of the fly ash particles.

Leaching of Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mu and Fe from the fly ash was found to be directly proportional to (1) the amount of these trace elements present in the fly ash, (2) decrease in pH, (3) decreases in boiler temperatures and (4) increases in ash fusion temperatures. Fly ash particles which in general leached the least amount of the above elements exhibited the best sorbate characteristics.

LEACHATE TREATMENT TECHNIQUE
UTILIZING FLY ASH AS A LOW COST SORBENT

by

TURAN A. RAMADAN

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DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
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APPROVAL OF THESIS

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CHAPTER I. INTRODUCTION

In this highly industrialized country, tremendous amounts of energy is consumed annually. With only 6% of the world's population, the United States accounts for about 35% of the worldwide energy consumption. In the past three decades, energy usage in this country has more than doubled (1). In order to deal with these increased energy requirements, coal is becoming more important as a source of energy, because of this country's large coal reserve. It is estimated that the United States has a reserve of coal of approximately 3.6 trillion tons (2) which is about a factor of 30 greater than that of petroleum and gas. By increasing the usage of coal, we could satisfy our energy needs for several centuries and could cut the dependence of our energy upon foreign oil to a minimum. However, the increased use of coal can result in increase in environmental problems due to the increased production of such waste products as fly ash.

Fly ash is a waste product of electric power plants. It is produced in large quantities during the burning of coal. It is generally collected with electrostatic precipitation from the flue gases before it escapes from the stacks. Fly ash consists of predominantly silt-size particles ranging from grey to tan to reddish brown. The individual particle size of this material ranges from 0.3 to 100 microns. The principal chemical constituents are silica, alumina, iron, sulfur trioxide, alkali and alkaline earth metals (3).

Increased reliance on coal combustion as an energy source can lead to significant waste management problems related to storage or disposal of fly ash generated as a result of this combustion. In 1972, 30 million tons of fly ash were produced and it is estimated that 40 million tons of fly ash will be produced in 1980. There is at present no commercially available process for the utilization of the large quantities of fly ash, Therefore, a need exists for an inexpensive waste management technology for the environmentally safe disposal or storage until such a process is developed.

Fly ash has been shown by a number of investigators (4,5,6,7) to leach boron, fluoride, molybdemum, selenium, arsenic, cadmium, chromium, copper, zinc, iron, mercury and nickel under batch conditions where s specific quantity of fly ash is mixed with a given volume of water at different pH's. Since most of the above cations and anions are considered toxic even in small quantitites, safe inexpensive waste management technology must be available to insure that ground and surface waters are not contaminated by the toxic cations and anions in the fly ash leachates.

Lining a disposal site or storage lagoon with impervious soil or synthetic membranes will prvent the leachate from contaminating surface or ground water. However, this approach creates a "batch tub without a drain" in areas where the rainfall exceeds evaporation unless facilities for treating the leachate are available. In 1974 (8), DiGioia, et al estimated that capital expenses alone for a leachate treatment system would be approximately $100,000.

The attenuation of the above cations and anions in the fly ash leachate by the natural clay components of soils surrounding a disposal or storage pond site has also been relied upon to prevent contamination of ground and surface waters. Here, the general approach is to minimize the leaching of such cations as inc, copper, nickel, lead, cadmium, etc. by the addition of lime to the fly ash. However, the resulting alkaline conditions significantly increased the solubilization of such anions as arsenic and fluoride (7,9) and resulted in unfavorable conditions for the attenuation of arsenic,^{V} selenium,^{IV} chromium,^{VI} and fluoride by the natural clay components in soils. However, these anions can be removed by the natural clay components present in soils under slightly acidic conditions with virtually no removals occurring under alkaline conditions (10,11).

For the past several years, investigations into the development of methods for the treatment of leachates from industrial sludges disposed of in landfills has been ongoing. It has established, on both the laboratory and pilot scale that the use of fly ash in combination with clay minerals provides an inexpensive, effective treatment of leachates from industrial sludges disposed of in landfills. These fly ash-clay combinations were also found to be an inexpensive means for the removal of heavy metals and toxic anions such as fluoride, cyanide, etc., from industrial waste stream effluents. Also, the combinations may be used for land reclamation since the spent sorbents retain the sorbed pollutants in the presence of rainwater.

During these investigations into the use of fly ash as a sorbent for waste treatment processes, two types of fly ash were repeatedly collected from the same electrostatic precipitator at the Public Service Electric and

Gas Company, Hudson Power Generating Station at different times. These fly ashes exhibited different leaching and sorbent characteristics. Analysis of the leachate produced by mixing the fly ash with water in the weight ratios of 1:2.5 for 24 hours on Burrell Shaker which was found to provide a saturated leachate, revealed that one type of fly ash produced an acidic leachate and the other a basic leachate. The acidic leachage contained greater concentrations of the cadions and anions than the basic leachate. However, when these two different fly ashes are placed in lysimeters and water is passed through the fly ash, leaching of the cations and anions occurs initially, but soon ceases as the pH of the effluent from the lysimeters approaches 7. In fact, when a neutral pH industrial sludge leachate which contained the same cation and anions found in the fly ash leachate passed through the lysimeters containing these fly ashes, the initial leaching of cations and anions is again observed until the effluent from the lysimeters approaches the neutral influent pH. Then, the cations and anions which were initially leached from the fly ash, are actually removed in greater quantities from the leachate by these same fly ash samples than was initially leached from the fly ash (9). For example (10), the fly ash whose effluent from the lysimeter was initially acidic exhibited leaching of copper and zinc that amounted to 0.69 micrograms of copper per gram of fly ash, and 0.32 micrograms of zinc per gram of fly ash. When the leachate from the lysimeters approaches neutral ph, the leaching ceased and both the copper and zinc were removed from the neutral pH industrial sludge leachate. The concentrations of the copper and zinc were reduced from about 2.5 mg/l and 0.4 mg/l respectively down to about 0.01 mg/l. The fly ash exhibited net removals, when the initial leaching is subtracted from the total removed, of 1.4 micrograms of copper removed per gram of fly ash and 1.7 micrograms of zinc removed per gram of fly ash. Remarkably, the fly ash which produced the initial acidic effluent and exhibited the greater initial leaching of cations and anions proved in general to be a better sorbent for the removal of the cations and anions in the neutral pH industrial sludge leachates than the fly ash which initially produced a basic effluent. However, a mixture of both types of fly ashes was required in the same lysimeter to effectively treat this neutral pH industrial sludge leachate since ach fly ash exhibits different sorbent characteristics.

pH adjustment of the fly ash by washing does not appear to improve the sorbent characteristics of the fly ash. Gangoli, et al.[10] reported that neutral or acid washed fly ash showed no improvement in the capacity of the fly ash for removing metal ions.

The above discussion indicates that inexpensive waste management technology can be developed for the environmentally safe disposal or storage of fly ash in landfills or the treatment of the effluent from power plant ash ponds provided that there is an adequate supply of the fly ashes with desired sorbent characteristics. This technology would require: (1) regulating the amount of the fly ashes with different sorbent characteristics that are mixed together; (2) collection of the leachate or effluent; (3) pH adjustment of the collected leachate or effluent; and, (4) recycling the leachate or effluent back through a mixed fly ash bed to remove the cations and anions originally leached from the fly ash.

The development of this technology necessitates that we know when fly ash with desired sorbent characteristics will be produced by the utilities in their coal fired boilers. This will insure that adequate supplies of the fly ashes with different sorbent characteristics will be available. However, the processes that controls these characteristics during the combustion of coal are not understood at this time. Thus, this investigation was undertaken to identify those parameters which control the sorbent characteristics of the fly ash produced. This investigation involved:

- Sampling of coal, fly ash and bottom ash samples and leachate from fly ash pond.
- Identification of leaching potentials on fly ash samples.
- Evaluation of the sorptive properties on the fly ash samples.
- Examination of the factors affecting sorbent behavior. These factors include pH, permeability, particle size distribution, boiler conditions, fusion temperatures, and the composition.

CHAPTER II: EXPERIMENTAL APPARATUS AND PROCEDURES

Boiler Type

Three different types of coal fired boilers (Hudson, Mercer, and the similarily designed Keystone and Connemaugh, located in Bergen County, New Jersey, Mercer County, New Jersey and in the Pittsburgh, Pennsylvania area, respectively were utilized for this study. These boilers were operated when power demand permitted at full, intermediate and minimum power output following planned test procedures to produce the fly ash being investigated. The test procedure for the Hudson coal fired boiler is enclosed (see appendicies). It is representative of that which was followed during the test burns at the Mercer boiler. The Hudson and Mercer coal fired boilers differ in that the Hudson boiler burns a high ash fusion coal and the Mercer boiler burns a low ash fusion coal. Keystone and Connemaugh are both tangentially fired boilers that burn a high ash fusion coal that is mined on site.

Coal Sources

Coal from eight mines located in Pennsylvania, West Virginia and Virginia (see Table 1) were delivered directly unblended to P.S.E. & G. Hudson's and Mercer's coal fired boilers. Two separate deliveries of Wellmore Cactus coal were made to the Mercer plant at different times. The coal from these mines for the Mercer and Hudson boilers were selected for this study because they provided the Hudson and Mercer generating stations with sufficient quantities of coal to carry out the planned test burns. Coal for the Keystone and Connemaugh boilers are in general mined on site.

TABLE 1

Coal Burned Under Test Conditions

Mine	Location
Hudson's coal fired boiler (high fusion coal)	
Militant	Clearfield County, Pa.
Deep Hollow	Preston County, W. Va.
Upshur	Upshure County, W. Va.
Badger	Barbour County, W. Va.
Mercer's coal fired boiler (low fusion coal)	
Wellmore Cactus	Buchanan County, Va.
Wellmore Ackiss	Buchanan County, Va.
Ellsworth	Washington County, Pa.
Nora	Dickerson County, Va.
Other coal fired boiler (high fusion coal)	
Keystone	Keystone, Pa.
Connemaugh	Connemaugh, Pa.

Test Procedures for Coal Combustion

The primary objective of this plan is to provide a uniform procedure to evaluate test coals for Hudson No. 2. The following conditions should exist prior to the test burn:

1. Minimum of 3 barges or 7,000 tons of test coal available.
2. Minimum of four pulverizers available.
3. Two days notice prior to coal receipt.
4. Supplemental fuel, oil or gas, available.
5. Condition of furnace, burners, registers, and igniters should be normal.
6. Coal flow on three burner mills will be limited to 80%.
7. Test to start with a normal deslagging load drop.
8. Steady load conditions for high load test period (maximum of 42 hours).

The following test schedule shall be followed:

1. Two days prior to arrival of the test coal barges, burn down completely a minimum of four reclaim hoppers.
2. Unload and place the test coal over the four empty hoppers.
3. Any remaining test coal should be left in the barge and used to top off the hoppers after the test begins.
4. Set the plow so that only test coal will be supplied to the silos.
5. Begin supplying test coal to the silos 5 hours prior to the deslagging load drop. This will be 2300 hours for a deslagging load period to start at 0400 hours and end at 0600 hours.
6. Blow soot during load drop to 275 Mw net with 4 or 5 miles in service.

7. Hold 275 Mw net load for 2 hours with flue gas oxygen between 6 to 8%, windbox differential at approximately 1 inch H_2O, registers in full load position, igniters out of service, and furnace televisions in service. Observe furnace wall conditions for complete deslagging as well as burner and furnace flame stability.

8. Increase load to maximum coal burning capability with no supplemental fuel being fired and hold for two hours for observations.

9. Raise load to maximum attainable by firing supplemental fuel to replace unavailable pulverizers, adjust registers for optimum position, hold flue gas oxygen at 4%, and stabilize main and reheat steam temperatures. Sootblowing is to be done twice per shift.

10. Hold load for duration of test coal supply, record operating data, and continue to observe furnace conditions every two hours paying particular attention to slagging conditions on front and rear walls as well as the slope. Total estimated time period that unit will be at full load will depend upon mill availability:

42 hours for 4 mill operation
38 hours for 5 mill operation
31 hours for 6 mill operation

11. If furnace conditions are satisfactory, reduce the flue gas oxygen to 3% when the reclaim hoppers begin to run out of test coal. Continue to hold load, record data, and observe furnace conditions until test coal is exhausted.

12. While sootblowing, reduce load to 300 Mw and hold normal conditions for a deslagging period. Observe furnace wall conditions for complete deslagging.

13. All data should be noted on the attached data sheet and comments made on the appropriate form.

Monitoring of Boiler Conditions and Collection of Samples for Analysis

According to test procedures previously outlined in the appendicies, the temperature profile encountered in the boilers along with coal, natural gas, and oil feed rates when co-fired, or relative power outputs when the coal feed rate is unavailable, boiler additive feed rates, percent excess air, ambient air temperature and barometric pressure were monitored during the generation of maximum, intermediate and minimum power (see Table 2). The limited results on the boiler temperatures monitored during the combustion of the Deep Hollow and Militant coal at the Hudson generating station was due to the fact that our water cooled thermocouple probes were unavailable because they were being modified during the time these samples were collected to fit the access ports in the boilers.

All temperatures were measured just prior to and after the collection of the coal samples and their respective fly ashes since it was physically impractical to collect the samples and measure the temperatures at the same times. In all cases, the temperatures remained essentially constant.

During the combustion of the test coal, coal samples are collected at the entrance to each pulverizer that was in operation. The collection of fly ash and bottom ash samples are timed to correspond to the coal being burned. Different size distributions of the fly ash were obtained by the collection of samples from both the front and back row of electrostatic precipitator hoppers. Bottom ash samples could only be collected at the Mercer and Keystone generation station. The bottom ash from the Hudson coal fired boiler was not collected because direct access to the bottom ash produced from a given coal that is

TABLE 2

Mercer coal fired boiler

Coal Combustion Conditions

Coal	Relative Power output %	Pressure (mmHg)	% Excess O_2	Additives Feed Rates LPA-40 gal/hr	Additives Feed Rates Control M lbs/hr	#11 Boiler Temp. Flame	#11 Boiler Temp. Above Flame Basket	#11 Boiler Temp. Arch	#12 Reheater Temp. Flame	#12 Reheater Temp. Above Flame Basket	#12 Reheater Temp. Arch	Economizer Temperature of #11 Boiler Gas in	#11 Boiler Gas out	#11 Boiler Air in	#11 Boiler Air out	#12 Reheater Gas in	#12 Reheater Gas out	#12 Reheater Air in	#12 Reheater Air out	Amb. Int. Temp.
Wellmore Cactus	100	27.8	3.3	28	0	3125	1400	1680	2970	1400	1320	710	253	135	628	720	305	85	610	33
Wellmore Cactus	89	—	3.8	32	0	3150	1620	2080	3150	1530	1480	665	315	151	581	673	240	180	525	62
Blend	95	27.8	3.4	28	0	3100	1815	2250	3100	1737	1835	705	238	126	620	700	290	74	605	24
Ellsworth	98	27.7	3.5	0	0	3100	1815	2240	3100	1740	1820	700	264	127	625	706	295	104	594	46
Wellmore	94	27.8		15	0	3050	1900	2180	2950	1725	1590	690	253	116	510	698	263	79	698	56
Ackiss	50	27.8	5.0	16	0	2870	1590	1780	2950	1620	1500	582	245	161	529	576	248	78	505	56
Nora	97	-	3.5	28	0	3100	1850	2175	3250	1700	1700	655	223	120	573	635	270	65	555	34

Hudson coal fired boiler

Coal	Coal (TPH)	Oil %	Gas (MCF)	Pressure (MM/S)	Excess O_2 %	Additive Feed Rate LPH-40 Gal/hr	Additive Feed Rate CTRL M Lbs/hr	Power	Boiler Temperature (F) Flame	Boiler Temperature (F) Above Basket	Boiler Temperature (F) Super Heater	Economizer Temperature (F) Gas Inlet	Gas Outlet	Gas Inlet	Gas Outlet	Ambient Air
Militant	110	0	2900	30.8	5.4	18	25	full	-	-	-	747	292	78	640	55
Militant	108	0	400	30.5	8.0	18	25	min.	-	-	-	669	292	63	525	66
Militant	102	0	1125	30.5	6.6	18	25	int.	-	-	-	673	296	66	525	66
Militant	110	0	3145	30.5	3.9	17.5	25	full	-	-	-	742	297	71	600	51
Deep Hollow	140	32	0	29.65	5.4	14	25	full	-	-	-	755	279	54	630	35
Deep Hollow	114	0	0	29.65	8.0	14	25	low	-	1450	-	653	283	44	490	37
Deep Hollow	142	0	0	29.65	6.8	16	20	int.	-	1550	-	685	273	45	506	37
Upshur	138	0	0	29.8	4.7	18	0	full	2470	1590	1565	775	286	59	580	45
Badger	138	0	0	29.3	3.1	18	25	full	2550	1750	1440	743	290	54	600	61

Keystone and Connemaugh coal fired boilers

Coal	Coal (TPH)	Pressure (mmHg)	% Excess O2	Additives Feed Rate LPA-40 gal/hr	Additives Feed Rate Control M lbs/hr	Boiler Temperature Power	Boiler Temperature Flame	Boiler Temperature Above Flame Basket	Boiler Temperature Arch	Economizer Temperature Gas in	Gas out	Air in	Air out	Gas in	Gas out	Air in	Air out	Amb. Int. Temp.
Keystone	313	—	4.2	0	0	full	-	2600	-	621	274	77	503	618	272	75	563	70
Connemaugh	303	--	4.7	0	0	full	2650	2700	2700	654	315	77	577	622	246	75	499	70

being sampled and burned was unavailable.

Analysis of Samples

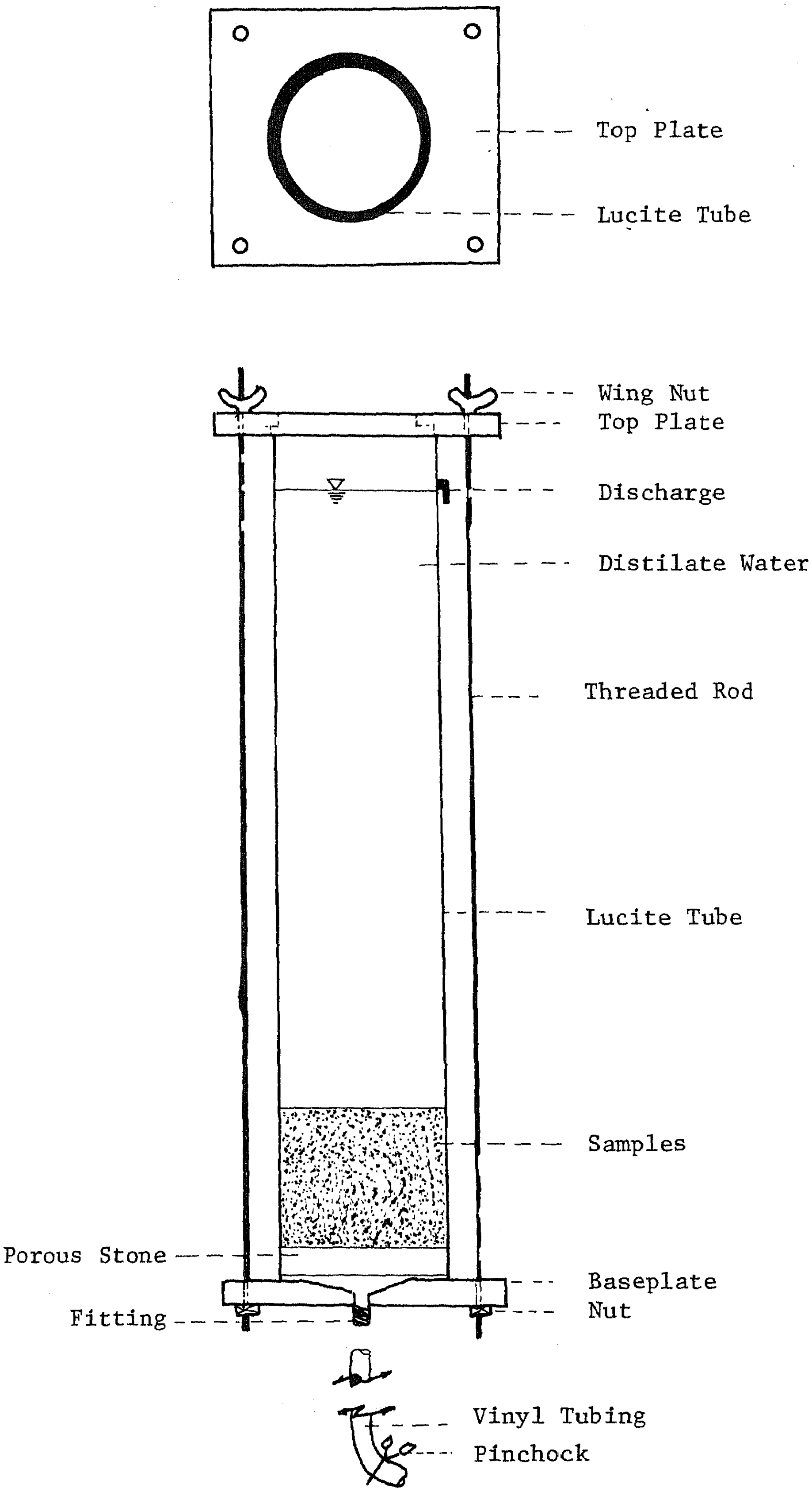
Coal, Fly Ash and Bottom Ash Samples

The coal samples were analyzed for %C, %S, %SiO_2, %Al_2O_3, %Fe_2O_3, %CaO, %K_2O, %Na_2O, %MgO, %TiO_2, and ppm of Cd, Cu, Cr, Pb, Zn, Sn, Ni and Mn, ash content, sulfur and ash fusion temperatures according to ASTM Methods. The ash fusion temperatures were measured to determine how the sorbent characteristics of the fly ash particles are influenced by their being either in the fluid or solid state in the Mercer and Hudson coal fired boilers, respectively. The Mercer coal fired boiler requires that the ash be in the fluid state whereas the Hudson coal fired boiler requires that the remains in a solid state. The fly ash and bottom ash samples have been analyzed for the same above elements as found in the ashed coal samples.

Lysimeter Design

The lysimeter tests performed in this study were essentially based on a variable head gravity forced filtration system. Two cylindrical columns were constructed from a 6- inch diameter lucite tube (see Figure 1). The columns could be easily disassembled and were conveniently clamped to a portion of "unistrut" structure centrally located in the laboratory. Water and vacuum lines were run to the area. The fly ash sample when placed in the column had to be supported by a special support media. It was imperative that this media actually supported the sample, yet have no effect on the permeability and removal efficiency of the fly ash. Glass wool was originally tried but due to channeling in the preliminary tests, it was found unsuitable. A porous, carborundum stone, cut to size, was

FIGURE 1. Lysimeter Design



Scale: 1/6

finally constructed and employed as the support media which worked satisfactorily. Silicone-rubber was used to seal the stone to the lucite tubing, and as such proved to work adequately.

A perforated plastic 1/4 inch thick filter plate was installed under the porous stone to allow for unhindered fluid flow. The bottom of the column was slightly beveled to allow the fluid to flow to a center drain hole. A 1/2 inch 90 degree fitting and a piece of plastic tubing was used to direct the filtrate to a waste container so that samples could be easily obtained. Four external rods were used to support the base plate and the entire column could be taken down by simply unscrewing four wing nuts.

Leaching and Sorbent Characteristics of Fly Ash

The leaching properties from the fly ash of different sizes, collected in the Hudson facility and in parallel in the Mercer facility were determined. These determinations were carried out by passing water through the lysimeter containing the fly ash sample and collecting and analyzing successive samples of effluent for pH and Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn, and Fe. Once the leaching of these elements have ceased, actual fly ash pond effluent was passed through these fly ash samples in the lysimters to determine their ability to remove each of the above elements. This is determined by analyzing the fly ash pond effluent before and after specific volumes of this effluent has been passed through the fly ash samples.

pH Measurement

The pH of the samples was measured by means of an Orion Model 701 Digital pH/Mv meter using an Orion combination pH electrode Model 91-02.

Determination of Metals

The concentration of the various metals identified were determined using a Varian Techtron Emission Spectrometer Argon Plasma (Spectraspan 3 (SMI 3)) according to P.S.E. & G. Maplewood (12,13).

Sieve Analysis

A sieve analysis consists of passing a sample through a set of sieves and weighing the amount of material retained on each sieve. The sieves used in this analysis were (1) 0.420 mm (#40), (2) 0.210 mm (#70), (3) 0.116 mm (#130), (4) 0.074 mm (#200), (5) 0.050 (#300), (6) bottom. These sieves are all specified according to ASTM Methods (14, 15).

Permeability Studies

The permeability of leachate through the sorbent lysimeters was monitored until breakthrough occurred. In certain cases, where the flowthrough in lysimeters was very low, the studies were discontinued even though leachate analysis indicated that the sorptive capacity of the column was not exhausted. This was done because the resultants long detention time would not lend itself to an economically feasible system. The permeability coefficient K, was determined by means of the following equation (14)

$$K = (Q\ L)/aht$$

a = cross-sectional area of lysimeter (in cm^2)

Q = total volume of flowthrough the lysimeter sorbent for elapsed time (in cm^3)

h = hydraulic head (in cm)

L = length of sorbent sample in the lysimeter (in cm)

t = total elapsed time (in seconds)

CHAPTER III. RESULTS AND DISCUSSION

Elemental Analysis of Coals and Their Respective Ashes

The results of the analysis for Ti, Cd, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn, Ba and V in the coals and their respective fly ash and bottom ashes produced at different boiler temperatures and levels of power generation are presented in Tables 3 through 14.

An examination of these Tables reveals that Sn, Ni, Mo, Cu, Cr, and Mn tend to concentrate in the bottom ash as apposed to the fly ash for the low ash fusion Mercer coals. The elements Ti, Zn and Ba tend to concentrate in the fly ash and the Cd, Pb and V do not exhibit any preferential concentration either in the fly ash or bottom ash. The analysis of the high ash fusion Keystone fly ash and bottom ash shows that the majority of the above elements tend to concentrate in the bottom ash rather than the fly ash. The elements Ti, Ni, Zn and Mn were found to concentrate in the fly ash. Examination of the Hudson and Connemaugh ashes could not be carried out because the bottom ash produced by a specific coal could not be collected from the boiler.

The boiler temperatures appear to regulate the amount of the above elements that occur within a fly ash. The outlet fly ashes were produced at boiler temperatures some 400°F lower than the inlet fly ashes. A comparison of the analysis of the fly ashes, produced from the same coal and collected from the inlet and outlet precipitator at the Mercer facility show in general for all the elements, with the exception of cadmium, that the outlet fly ashes contain the greater amounts of the above elements.

The amount of cadmium present in the inlet and outlet fly ashes show no clear trend. Of the 12 fly ashes examined, the Wellmore

TABLE 3

Ti concentration (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	7731-8253	7893	8651	-	-	6320	-
Wellmore Cactus #2	8838-9257	9073	9723	-	-	-	-
Mercer Blend	7604-9951	8662	8950	-	-	6407	-
Ellsworth	7354-9048	9064	9645	-	-	8054	-
Wellmore Ackiss	7702-9538	10065	10036	9652	10664	7794	7970
Nora	6422-6853	8355	9778	-	-	7608	

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	8065-10350	9854	12563	9510	10781	9423	12176
Deep Hollow	10100-14200	12933	13205	12235	13832	12604	13014
Upshur	13612-14398	13565	12039	-	-	-	-
Badger	10092-10432	12788	12326	-	-		

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	7628-7958	8585	7955
Connemaugh	7622-8878	10971	

TABLE 4

Cd (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

		Fly Ash				Bottom Ash	
Source	Coal	Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	1.5-2.0	2.1	1.8	-	-	2.2	-
Wellmore Cactus #2	4.1-6.0	7.2	5.4	-	-	-	-
Mercer Blend	0.5-0.8	0.92	0.71	-	-	-	-
Ellsworth	2.1-2.4	2.4	2.4	-	-	0.73	-
Wellmore Ackiss	0.29-0.65	0.34	0.48	0.51	0.21	0.44	0.38
Nora	0.20-0.65	0.10	0.72	-	-	-	-

Hudson coal fired boiler

				Fly Ash			
Source	Coal	Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	2.4-3.8	3.8	5.1	3.0	4.8	3.6	7.8
Deep Hollow	3.2-5.5	5.0	5.8	4.6	6.2	4.8	5.4
Upshur	0.21-0.23	0.20	0.25	-	-	-	-
Badger	0.75-0.90	0.90	0.65	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	1.3-1.4	1.5	1.7
Connemaugh	0.35-0.43	0.42	-

TABLE 5

Sn (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	1091-1164	1514	1635			2587	
Wellmore Cactus #2	251-341	257	269			-	
Mercer Blend	863-1027	1144	1207			2383	
Ellsworth	51.0-67.9	55.7	59.3			306	
Wellmore Ackiss	51.6-78.3	64.4	69.2	69.1	74.2	253	190
Nora	45-70	76.4	69.8			226	

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
ilitant	505-778	745	856	776	798	802	893
eep Hollow	284-348	342	348	363	385	376	392
pshur	164-207	109	132				
adger	211-282	174	215				

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	208-266	127	233
Connemaugh	217-226	169	-

TABLE 6

Ni (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	271-496	231	246	-	-	2477	-
Wellmore Cactus #2	219-895	241	256	-	-	-	-
Mercer Blend	229-283	219	227	-	-	1872	-
Ellsworth	494-885	255	259	-	-	2713	-
Wellmore Ackiss	330-422	231	243	220	218	2298	2190
Nora	305-371	186	248	-	-	2939	-

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	278-350	268	286	262	316	246	278
Deep Hollow	225-296	268	257	277	289	263	260
Upshur	213-233	253	226	-	-	-	-
Badger	360-380	240	247	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Bull
Keystone	152-196	181	153
Connemaugh	195-235	210	-

TABLE 7

Pb (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
ellmore Cactus #1	567-642	405	509	-	-	445	-
ellmore Cactus #2	447-495	377	507	-	-	-	-
ercer Blend	256-507	321	442	-	-	251	-
lsworth	397-579	1154	1015	-	-	1082	-
llmore ckiss	335-1280	922	1056	1123	1054	892	1005
ra	880-994	271	359	-	-	453	-

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Litant	565-668	529	831	482	779	425	787
ep Hollow	348-541	379	413	-	501	378	485
hur	293-491	353	392	-	-	-	-
lger	226-523	436	513	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	247-254	217	254
Connemaugh	204-230	144	-

TABLE 8

Mo (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	115-154	178	212			309	
Wellmore Cactus #2	116-138	113	128			-	
Mercer Blend	94-169	179	190			238	
Ellsworth	87-124	121	135			238	
Wellmore Ackiss	75-146	131	123	122	149	178	211
Nora	98.7-125	97	118			227	

Hudson coal fired boiler

Source	Coal			Fly Ash			
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	158-248	152	181	134	98	109	134
Deep Hollow	99-163	157	162	-	164	131	164
Upshur	81.0-116	84.8	77.8				
Badger	122-144	113	134				

Keystone and Connemaugh coal fired boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	76.9-93.2	51.9	59.7
Connemaugh	68.4-88.0	48.1	-

TABLE 9

Cu (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	361-515	243	325	-	-	339	-
Wellmore Cactus #2	763-897	268	281	-	-	-	-
Mercer Blend	361-434	284	381	-	-	303	
Ellsworth	640-1160	156	207	-	-	932	-
Wellmore Ackiss	968-1746	250	248	246	242	466	372
Nora	419-706	211	217	-	-	537	-

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	273-421	242	302	279	319	261	304
Deep Hollow	226-388	345	296	318	359	308	322
Upshur	386-520	223	162	-	-	-	-
Badger	466-779	206	209	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	489-507	217	156
Connemaugh	200-281	185	-

TABLE 10

Cr (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	592-832	225	289	-	-	5113	-
Wellmore Cactus #2	298-479	222	275	-	-	-	-
Mercer Blend	219-284	268	247	-	-	3738	-
Ellsworth	990-1441	319	315	-	-	5611	-
Wellmore Ackiss	258-560	288	288	270	295	4310	-
Nora	211-534	180	257	-	-	5820	-

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	287-466	286	317	245	304	259	281
Deep Hollow	321-363	325	278	-	319	265	286
Upshur	343-386	279	319	-	-	-	-
Badger	317-530	300	340	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	208-217	178	186
Connemaugh	228-240	244	-

TABLE 11

Zn (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	184-251	159	235	-	-	84	-
Wellmore Cactus #2	314-502	280	308	-	-	-	-
Mercer Blend	194-319	219	236	-	-	102	-
Ellsworth	435-729	187	305	-	-	295	-
Wellmore Ackiss	387-672	242	357	241	382	206	873
Nora	193-238	212	347	-	-	154	-

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	287-585	355	479	325	453	298	496
Deep Hollow	297-362	264	307	301	396	258	266
Upshur	252-258	282	209	-	-	-	-
Badger	343-412	223	247	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	314-439	238	91
Connemaugh	217-327	237	-

TABLE 12

Mn (Mg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	323-483	300	316	-	-	803	-
Wellmore Cactus #2	319-380	271	250	-	-	-	-
Mercer Blend	298-351	364	379	-	-	701	-
Ellsworth	314-424	233	265	-	-	841	-
Wellmore Ackiss	288-403	237	296	242	313	737	700
Nora	314-360	289	268	-	-	856	-

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	304-377	230	252	221	240	197	214
Deep Hollow	195-227	155	153	120	165	143	147
Upshur	76.8-103	166	59.2	-	-	-	-
Badger	154-213	108	138	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	209-232	170	149
Connemaugh	147-278	189	-

TABLE 13

Ba (μg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash Full Inlet	Fly Ash Full Outlet	Fly Ash Minimum Inlet	Fly Ash Minimum Outlet	Bottom Ash Full	Bottom Ash Minimum
Wellmore Cactus #1	1847-2679	1849	2326	-	-	1437	-
Wellmore Cactus #2	2531-2625	1751	2321	-	-	-	-
Mercer Blend	1904-2341	1895	1969	-	-	1272	
Ellsworth	1767-1826	1269	1400	-	-	1478	
Wellmore Ackiss	1899-2154	1858	1853	1659	2020	1293	
Nora	1795-2345	2124	2044	-	-	1147	

Hudson coal fired boiler

Source	Coal	Fly Ash Full Front	Fly Ash Full Back	Fly Ash Intermediate Front	Fly Ash Intermediate Back	Fly Ash Minimum Front	Fly Ash Minimum Back
Militant	1801-2415	1407	1343	-	1809	1768	-
Deep Hollow	866-1024	765	725	-	786	765	711
Upshur	743-981	760	1149	-	-	-	-
Badger	993-1225	865	1124	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash Full	Bottom Ash Bull
Keystone	613-673	674	794
Connemaugh	869-979	877	

TABLE 14

V (μg/g) in the coal and its respective ashes generated under different power requirements

Mercer coal fired boiler

Source	Coal	Fly Ash				Bottom Ash	
		Full		Minimum		Full	Minimum
		Inlet	Outlet	Inlet	Outlet		
Wellmore Cactus #1	405-451	392	552	-	-	409	-
Wellmore Cactus #2	605-667	539	654	-	-	-	-
Mercer Blend	352-417	336	413	-	-	295	-
Ellsworth	445-510	646	723	-	-	537	-
Wellmore Ackiss	491-733	627	663	658	713	458	529
Nora	426-551	405	615	-	-	451	-

Hudson coal fired boiler

Source	Coal	Fly Ash					
		Full		Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	403-546	464	582	379	566	362	550
Deep Hollow	297-417	423	440	-	494	441	449
Upshur	633-711	568	609	-	-	-	-
Badger	500-759	641	704	-	-	-	-

Keystone and Connemaugh coal fire boilers

Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Keystone	379-454	339	384
Connemaugh	446-465	449	-

Cactus #1, Wellmore Cactus #2 and Mercer Blend showed a greater concentration of cadmium in the inlet fly ash than their respective outlet fly ashes. The amount of cadmium in the inlet and outlet Ellsworth fly ash was the same and the amount of cadmium in the outlet Wellmore Ackiss and Nora fly ashes was greater than the cadmium in their respective inlet fly ashes (see Table 4).

The analysis of the fly ashes collected from the front and back precipitators at the Hudson facilities revealed that the particles collected from the back precipitators contained the greater amounts of the above elements (see Tables 3 through 14). Only the barium was found to be in greater amounts in the larger particles (collected from the front precipitators) than in the smaller particles (collected from the back precipitators).

These results are in agreement with the results reported by Davison et al., (Davison, R.L., David, R.S., Natusch, F.S. and Wallce, J.R., Env. Sci. & Tech., 13, 1107-1103 (1974). In this article, it was shown that the concentration of the elements Pb, Ti, Sb, Cd, Se, As, Zn, Ni, Cr and S are greater in the smaller particles than in the larger particles.

A reduction in power output does not appear to influence the elemental composition of the fly ashes. Analysis of the Wellmore Ackiss, Militant and Deep Hollow fly ashes produced in those test runs where power output as varied show no correlation between power output and the elemental composition of these fly ashes (see Tables 3 through 14). The reasons for these results are not clear at this time since a reduction in power is generally accompanied by a decrease in boiler temperatures. It was expected that the reduction in power output from full to intermediate or to minimum would produce fly ashes that would also contain greater amounts of the above elements than that present in the fly ashes produced at full power.

Relation of Fly Ash Leaching Characteristics to Combustion Condition, Boiler Type, Elemental Fly Ash Composition and Coal Ash Fusion Temp.

The leaching characteristics of the fly ashes generated under the various combustion conditions were evaluated as to the extent that each fly ash leaches Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn and Fe. Deionized water was added to the lysimeters containing 500 grams of the fly ash and specific volumes of effluent leachate were collected and analyzed for the above elements until 5 liters of effluent was passed through each ash sample. It was observed that 500 grams of fly ash generally ceases to leach after 5 liters of water was passed through the fly ash.

The results of these experiments generated over 200 curves which correlates the concentration of each element in a specific volume leachate collected from the fly ash samples in the lysimeters with this specific volume of leachate.

A matrix representing the leaching of each element from a specific fly ash was prepared to compare it with the leaching of this element from other fly ashes. This matrix was used to evaluate the leaching characteristics of each fly ash as influenced by (1) boiler temperature, (2) ash fusion temperature, (3) elemental composition of the ash, (4) pH, (5) sulfur content and (6) particle size of the fly ash.

Boiler temperature appear to be one of the most important parameters that influence the leaching properties of fly ash. For the same coal burned, the fly ash produced at higher boiler temperatures exhibited less leaching than the fly ash produced at lower boiler temperatures. As an example, the Mercer fly ashes which were collected in the inlet hopper (corresponding to the #11 coal fired boiler) exhibited less leaching of trace elements than the fly ashes collected in the outlet hopper (#12 coal fired boiler) (see Table 15). The fly ash produced in the #11 coal fired boiler encountered significantly higher boiler temperatures than that produced in the #12 boiler.

This temperature effect on the fly ash leaching can also be observed from a comparison of the leaching from the Wellmore Ackiss coal ash under minimum anf full power firing conditions. The fly ash obtained at full power was generated at boiler temperatures 400°F higher than the minimum. The fly ash collected under full power exhibited significantly less leaching for all of the trace elements than that collected under minimum power (see the Ackiss coal "Full" and "Min" in Table 16). The same phenomenon was also observed in fly ashes produced from Keystone and Connemaugh power plant (see Table 17). The temperatures measured above the flame basket in Connemaugh boiler were higher than those measured in Keystone boiler, and the results showed less leaching for the Connemaugh fly ash. However, a reduction in power generation for the Hudson coals does not appear to influence the leaching characteristics of their respective fly ashes. The fly ashes produced at the different power levels all exhibit similar leaching (see Table 18). Apparently, the absence of melting by the Hudson coals for the different power levels is responsible for these results.

A comparison of fly ashes produced from the three different coal fired boilers also show that an increase in the boiler temperature is accompanied by a decrease in the number of elements and the amounts leached by the fly ash. The Mercer Blend fly ashes encountered the highest boiler temperature (flame) followed by the Connemaugh and Deep Hollow fly ashes in decreasing order, respectively (see Table 19). The Mercer Blend fly ash produced the least number of elements that leached followed by Connemaugh and Deep Hollow in increasing order, respectively (see Table 19).

There appears to be a correlation between the coal ash fusion temperatures and leaching properties of fly ash. In many cases, the fly ash produced from the low ash fusion coals exhibited less leaching than the fly ash produced from the high ash fusion coals. The ash fusion temperatures for the Nora coal was the lowest. Its inlet fly ash leached only three elements Sn, Mo and Cr when compared to the other fly ashes (see Table 16). Apparently, the melting of the fly ash in the coal fired boilers favors a decrease in the leaching characteristics of the fly ash.

The results also indicates that the elemental composition of fly ash is also an important factor in the leaching characteristics of the fly ash. For example, the outlet fly ashes in general contain greater amounts of each element than their corresponding inlet fly ashes. For each element, all the outlet fly ashes exhibit more leaching than the inlet fly ashes.

These results can also be observed in general by comparing the leaching of a specific element such as Cd, Ni and Zn by the Mercer inlet fly ashes and the amount of each specific element in the fly ash. For example, the Nora and Wellmore Ackiss inlet fly ashes contain only 0.10 μg/g and 0.34 μg/g of cadmium, respectively. Analysis of the leachate from both fly ashes revealed no cadmium. The inlet Mercer Blend fly ash contained 0.92 μg/g of cadmium and when compared to the

TABLE 15

Matrix comparing leaching characteristics for inlet-outlet fly ash from Mercer coals

Parameters		Ackiss		Cactus		Ellsworth		Nora		Cactus		Blend	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Cd	Leaching conc. in fly ash (μg/g)	− 0.34	− 0.48	+ 2.1	+ 1.8	+ 2.4	+ 2.4	− 0.10	+ 0.72	+ 7.2	+ 5.4	+ 0.92	+ 0.71
B	Leaching conc. in fly ash (μg/g)		+		+		+		+		+		+
Sn	Leaching conc. in fly ash (μg/g)	64.4	+ 69.2	1514	+ 1635	+ 55.4	+ 59.3	69.8	+ N.A.	+ 257	+ 269	1144	+ 1207
Ni	Leaching conc. in fly ash (μg/g)	231	+ 243	+ 231	+ 246								
Pb	Leaching conc. in fly ash (μg/g)	+ 922	+ 1056	405	+ 509	+ 1154	+ 1015	− 271	+ 359	+ 377	+ 507	+ 321	+ 442
Mo	Leaching conc. in fly ash (μg/g)	+ 131	+ 123	178	+ 212	+ 121	+ 135	97	+ 118	+ 113	+ 128	+ 179	+ 190
Cu	Leaching conc. in fly ash (μg/g)	− 256	+ 248	− 243	+ 325	− 156	+ 207	− 211	+ 217	+ 268	+ 281	− 284	− 381
Cr	Leaching conc. in fly ash (μg/g)	− 254	+ 288	+ 225	289	+ 319	+ 315	+ 180	− 257	+ 222	+ 279	+ 268	247

\+ : greatest leaching of the element
− : no leaching of the element
blank : leaching of the element but less than +

(continued)

TABLE 15 - continued

Matrix comparing leaching characteristics for inlet-outlet fly ash from Mercer coals

	Ackiss		Cactus		Ellsworth		Nora		Cactus		Blend	
Parameters	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Zn Leaching		+	-	+	-	+	+	+	+	+	-	+
conc. in fly ash (μg/g)	242	357	159	235	187	305	212	257	280	308	219	236
Mn Leaching		+	-	+	-	+	+	+	+	+	-	+
conc. in fly ash (μg/g)	237	296	300	316	233	265	289	268	371	250	364	379
Fe Leaching	-	-	+	+	+	+	-	+	+	+	+	+
conc. in fly ash (Fe_2O_3,%)	17.4	15.2	13.8	14.6	15.4	13.4	15.6	14.3	11.8	12.9	13.5	13.3
Boiler Temp. ^oF												
Flame	3050	950	3123	2970	3100	3100	3100	3250	3150	3150	3100	3100
Above Flame bskt	1900	1725	1400	1400	1815	1740	1850	1700	1620	1530	1815	1737
Arch	2180	1500	1680	1320	2240	1820	2175	1700	2080	1480	2250	1835
Ash Fusion Temp. ^oF												
In. Def.	2135	2110	2120	2135	2150	2155	2130	2145	2190	2155	2143	2188
Soft	2330	2265	2285	2310	2235	2275	2230	2265	2400	2215	2325	2353
Fluid	2625	2440	2570	2555	2445	2470	2330	2480	2695	2510	2665	2325
pH	8.7-8	5.1-6.8	8.5-9	7.9-7.2	10.5	9	9.2-9.8	4.6-5	11.5-9.8	9-8.3	7.3-9.5	7.5-7.3
S,%	1.07	2.47	0.71	1.57	1.07	1.82	1.37	2.20	0.77	1.32	N.A.	N.A.

+ : greatest leaching of the element

- : no leaching of the element

blank : leaching of the element but less than +

TABLE 16

Matrix comparing leaching characteristics for Mercer fly ashes

Parameters		Ackiss	Cactus	Ackiss	Ellsworth	Ackiss	Nora	Ackiss	Blend	Blend	Cactus	Ackiss	Coal
		Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Full	Minimum
Cd	Leaching conc. in fly ash (μg/g)	– 0.34	+ 2.1	– 0.34	+ 2.4	– 0.34	– 0.10	– 0.34	+ 0.92	0.92	+ 7.2	– 0.34	–
B	Leaching conc. in fly ash (μg/g)	+			+	+		+			+	+	+
Sn	Leaching conc. in fly ash (μg/g)	+ 64.4	+ 1514	+ 64.4	+ 55.4	+ 64.4	+ 69.8	+ 64.4	1144	1144	+ 257	64.4	+
Ni	Leaching conc. in fly ash (μg/g)	+ 231	+ 231	+ 231	+ 255	+ 231	– 186	+ 231	– 219	– 219	+ 241	231	+
Pb	Leaching conc. in fly ash (μg/g)	335	+ 405	335	397	335	– 880	335	+ 321	321	+ 377	335	+
Mo	Leaching conc. in fly ash (μg/g)	+ 131	+ 178	+ 131	+ 121	+ 131	+ 97	131	+ 179	179	+ 113	131	+
Cu	Leaching conc. in fly ash (μg/g)	– 256	– 243	– 256	– 156	– 256	– 211	– 256	– 284	– 284	+ 268	– 256	+
Cr	Leaching conc. in fly ash (μg/g)	– 254	+ 225	– 254	+ 319	– 254	+ 180	– 254	+ 268	268	+ 222	– 254	+

+ : greatest leaching of the element
– : no leaching of the lement
blank : leaching of the element but less than +

(continued)

TABLE 16 - continued

Matrix comparing leaching characteristics for Mercer fly ashes

Parameters	Ackiss Cactus		Ackiss Ellsworth		Ackiss Nora		Ackiss Blend		Blend Cactus		Ackiss Coal	
	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Full	Minimum
Zn Leaching conc. in fly ash ($\mu g/g$)	+ 242	- 159	+ 242	- 187	+ 242	212	+ 242	- 219	- 219	+ 280	242	+
Mn Leaching conc. in fly ash ($\mu g/g$)	+ 237	- 300	+ 237	233	+ 237	- 289	+ 237	- 364	- 364	+ 371	237	+
Fe Leaching conc. in fly ash (Fe_2O_3,%)	- 17.4	+ 13.8	- 17.4	+ 15.4	- 17.4	- 15.6	- 17.4	+ 13.5	13.5	+ 11.8	- 17.4	+ 16.1
Boiler Temp., °F												
Flame	3050	3125	3050	3100	3050	3100	3050	3100	3100	3150	3050	2870
Above Flame bskt	1900	1400	1900	1815	1900	1850	1900	1815	1815	1620	1900	1590
Arch	2180	1680	2180	2240	2180	2175	2180	2250	2250	2080	2180	1780
Ash Fusion Temp., °F												
In. Def.	2135	2120	2135	2150	2135	2130	2135	2143	2143	2190	2135	-
Soft.	2330	2285	2330	2235	2330	2230	2330	2325	2325	2400	2330	-
Fluid	2625	2570	2625	2445	2625	2330	2625	2665	2665	2695	2625	-
pH	8.7-8	8.5-9	8.7-8	10.5	8.7-8	9.2-9.8	8.7-8	7.3-9.3	7.3-9.5	11.5-9.8	8.7-8	7.2-7.5
s,%	1.07	0.71	1.07	1.07	1.07	1.37	1.07	-	-	0.77	1.07	-

\+ : greatest leaching of the element

\- : no leaching of the element

blank : leaching of the element but less than +

TABLE 17

Comparison of specific element leaching for Hudson, Connemaugh and Keysteon fly ashes

Parameter		Militant - Deep Hollow		Militant - Upshur		Upshur - Badger		Keystone - Connemaugh	
Cd	Leaching conc. in fly ash ($\mu g/g$)	+ 3.8	+ 5.0	+ 3.8	0.20	+ 0.20	+ 0.90	+ 1.5	− 0.42
B	Leaching conc. in fly ash ($\mu g/g$)	+ N.A.	+ N.A.	+ N.A.	+ N.A.	+ N.A.	+ N.A.	+ N.A.	N.A.
Sn	Leaching conc. in fly ash ($\mu g/g$)	745	+ 342	+ 745	109	+ 109	+ 174	+ 127	169
Ni	Leaching conc. in fly ash ($\mu g/g$)	+ 268	268	+ 268	253	+ 253	+ 340	+ 181	210
Pb	Leaching conc. in fly ash ($\mu g/g$)	529	+ 379	+ 529	− 353	− 353	− 436	+ 217	+ 144
Mo	Leaching conc. in fly ash ($\mu g/g$)	+ 152	+ 157	+ 152	+ 84.8	84.8	+ 113	+ 51.9	48.1
Cu	Leaching conc. in fly ash ($\mu g/g$)	+ 242	345	+ 242	223	+ 223	+ 206	+ 147	185
Cr	Leaching conc. in fly ash ($\mu g/g$)	+ 286	325	+ 286	279	+ 279	− 300	+ 178	244

+ : greatest leaching of the element
− : no leaching of the element
blank : leaching of the element but less than +

(continued)

TABLE 17 - continued

Comparison of specific element leaching for Hudson, Connemaugh and Keystone fly ashes

Parameter	Militant - Deep Hollow		Militant - Upshur		Upshur - Badger		Keystone - Connemaugh	
Zn Leaching conc. in fly ash (μg/g)	+ 355	+ 264	+ 355	282	+ 282	+ 223	+ 238	+ 237
Mn Leaching conc. in fly ash (μg/g)	+ 230	+ 155	+ 230	+ 166	+ 166	+ 108	+ 170	+ 189
Fe Leaching conc. in fly ash (Fe_2O_3,%)	+ 12.4	12.9	+ 12.4	+ 8.90	+ 8.9	+ 11.8	+ 11.5	+ 18.3
Boiler Temp., ^{o}F Flame	N.A.	N.A.	N.A.	2470	2470	2550	N.A.	2650
Above Flame bskt	N.A.	1450-1550	N.A.	1590	1590	1750	2600	2700
Arch	N.A.	N.A.	N.A.	1565	1565	1440	N.A.	2700
Ash Fusion Temp., ^{o}F								
In. Def.	2555	2575	2555	2700+	2700+	2700+	2183	2125
Soft	2700+	2700+	2700+	2700+	2700+	2700+	2520	2503
Fluid	2700+	2700+	2700+	2700+	2700+	2700+	2700+	2700+
pH	3.6-7	3.8-7	2.6-7	2.5-4.5	2.5-4.5	3.6-4.1	6.5-7.5	7-8.5
S,%	0.37	0.34	0.37	0.18	0.18	0.25	0.27	0.20

+ : greatest leaching of the element

- : no leaching of the element

blank : leaching of the element but less than +

TABLE 18

Comparison of specific element leaching between different coal fired boilers

Parameter	Mercer Blend - Connemaugh		Connemaugh - Deep Hollow	
Cd Leaching conc. in fly ash (μg/g)	+ 0.92	- 0.42	- 0.42	+ 5.0
B Leaching conc. in fly ash (μg/g)	+ N.A.	+ N.A.	N.A.	+ N.A.
Sn Leaching conc. in fly ash (μg/g)	+ 1144	+ 169	169	+ 342
Ni Leaching conc. in fly ash (μg/g)	- 219	+ 210	210	+ 268
Pb Leaching conc. in fly ash (μg/g)	+ 321	144	144	+ 379
Mo Leaching conc. in fly ash (μg/g)	+ 179	+ 48.1	+ 48.1	+ 157
Cu Leaching conc. in fly ash (μg/g)	- 284	+ 185	185	+ 345
Cr Leaching conc. in fly ash (μg/g)	+ 268	+ 244	+ 244	+ 325
Zn Leaching conc. in fly ash (μg/g)	- 219	- 237	237	+ 264
Mn Leaching conc. in fly ash (μg/g)	- 364	+ 189	189	+ 155
Fe Leaching conc. in fly ash (Fe_2O_3, %)	13.5	+ 18.3	+ 18.3	12.9
Boiler Temp., ^{o}F				
Flame	3100	2650	2650	N.A.
Above Flame bskt	1815	2700	2700	1450-1550
Arch	2250	2700	2700	N.A.
Ash Fusion Temp., ^{o}F				
In. Def.	2143	2125	2125	2575
Soft	2325	2503	2503	2700+
Fluid	2665	2690	2690	2700+
pH	7.3-9.3	7-8.5	7-8.5	3.8-7
S,%	N.A.	0.20	0.30	0.34

+ : greatest leaching of the element
- : no leaching of the element
blank : leaching of the element but less than +

Wellmore Ackiss inlet fly ash is observed to leach cadmium (see Table 16).

It should be noted that in general the pH measured in the effluent leachate of fly ash is another important factor affecting the leaching characteristics. A high pH leachate usually is accompanied by less leaching of trace elements than a low pH leachate. This was observed in all of the fly ashes leachates with the exception of Wellmore Cactus #2 fly ash whose leachate exhibits the highest pH and also leaches the highest concentration of all the trace elements when compared to the other fly ashes. The Wellmore Cactus #2 inlet and outlet fly ashes leachate pH was 11.5 and 9, respectively (see Table 29) and leaches the greatest amounts of the elements of Zn, Ni, Cr, Pb, Cd, Mn, Fe, Mo, and Sn when compared to the other fly ashes (see Table 16).

Relation of Fly Ash Sorbate Characteristics to Combustion Condition, Boiler Type, Elemental Fly Ash Composition and Coal Ash Fusion Temperatures

A variety of combustion conditions were encountered during the firing of the test coals in the Mercer and Hudson coal fired boilers. These included combustion of the same coal at different boiler temperatures, the use of different amounts of excess air, combustion with and without additives, co-firing the coal with oil or natural gas.

The sorbate characteristics of the fly ashes generated under the above combustion conditions were evaluated from the extent that each ash reduced the concentration of Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn and Fe in an actual ash pond effluent whose composition is listed in Table 19. The ash pond effluent was added to lysimeters containing 500 grams of the fly ash and specific volumes of treated effluent collected and analyzed from the above elements until 5 liters of ash

TABLE 19

Elemental concentration of actual ash pond effluent used in fly ash sorbate characterization

Element	Concentration mg/l
Cadmium	0.02
Boron	2.79
Tin	1.01
Nickel	0.09
Lead	0.62
Molybdenum	0.41
Copper	0.09
Chromium	0.09
Zinc	1.48
Manganese	0.40
Iron	0.10

pond effluent was passed through each ash sample. The results of these experiments generated over 200 curves which correlates the removal of each of the above elements achieved with each of the fly ashes samples with the volume of ash pond effluent treated.

A matrix which compares each curve representing the treatment achieved by a specific fly ash with that obtained for each of the other fly ashes has been designed. The matrix was utilized to screen the performance of each of the fly ashes as influenced by (1) boiler temperatures, ash fusion temperatures and elemental composition of the ash; (2) presence of the additives LPA-40 and Control M; (3) co-firing with oil or natural gas; (4) excess oxygen, and (5) particle size of the fly ash to effectively treat the concentration of Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn and Fe encountered in the ash pond effluent.

Boiler temperatures were observed to influence the sorbate properties of the fly ashes. The Mercer fly ashes that were produced in the #11 coal fired boiler which encountered the higher boiler temperatures exhibited better sorbate characteristics with the exception of the Ellsworth ash than the fly ashes produced in the #12 boiler eventhough both furnaces were burning the same coal at comparable flame temperatures. The number of elements removed by the fly ashes collected from the inlet precipitators exceeded the number of those removed by the fly ashes collected from the outlet precipitator (see Table 20). Both the Ellsworth inlet and outlet fly ash removed consistantly the same number of elements in the ash pond effluent.

The effect of boiler temperatures on the sorbate characteristics of the fly ashes can also be observed from a comparison of the sorbent

TABLE 20

Matrix comparing sorbate characteristics for inlet/outlet fly ashes from Mercer coals

Element	Ackiss		Cactus #1		Ellsworth		Nora		Cactus #2		Blend	
	inlet/outlet		inlet/outlet		inlet/outlet		inlet/outlet		inlet/outlet		inlet/outlet	
Cd	+	-	+	+	-	-	+	+	+	+	+	+
B	-	-	-	-	-	-	-	-	+		+	
Sn	-	-	-	-	+	+	+		+	+	+	+
Ni	+		+	+		+	+	+	+	+	+	
Pb	+		+		-	-		+	+		+	
Mo	-	-	-	-	-	-	-	-	+	+	+	+
Cu	+		+	+	+	+	+		+		+	+
Cr	+	+	+		-	-	-	-	+	+	+	+
Zn	+		+	+	+		+		+		+	+
Mn	+		+		+	+	+		+	+	+	+
Fe	+		-	-	-	-	+		+		+	

+ represents best removal of specific ion
+ + in inlet and outlet columns, respectively, represents same removal
- represents no removal for that element

performance of the Connemaugh and Mercer Blend fly ashes whose ash in the coals exhibit approximately the same ash softening temperatures (see Table 21). The Connemaugh fly ash which was formed at boiler temperatures over 400°F higher than the Mercer Blend fly ashes significantly treats more elements than the Mercer Blend fly ash (see Table 24). This is also the case for the fly ashes produced from the Wellmore Ackiss coal under minimum and full power. The fly ash produced under full power at higher boiler temperatures removes significantly more elements than the ash produced at lower temperatures and at minimum power (see Table 22). The temperatures measured at the arch at full power were some 400°F hotter than those measured under minimum power (see Table 2).

There also, appears to be some correlation between the coal ash fusion temperatures and the sorbate characteristics of the fly ash produced from this coal. Low ash fusion temperatures appear to favor the sorbate characteristics of the fly ashes. A comparison of the number of elements removed from the ash pond effluent by the fly ashes produced at the Mercer coal fired boiler indicates that the inlet fly ash from the Nora coal exhibits the best sorbate characteristics followed by the inlet fly ashes produced from the Wellmore Ackiss, Mercer Blend, Wellmore Cactus #2, Wellmore Cactus #1 and the Ellsworth coals in decreasing order (see Table 22). The ash fusion temperatures for the Nora coal is the lowest followed by the Wellmore Ackiss in increasing order (see Table 21). However, the ash softening temperatures exhibited by the Mercer Blend and Wellmore Cactus #2 coals indicate that their fly ashes should remove less elements from the ash pond effluent than Wellmore Cactus #1 fly ash. The ash softening

TABLE 21

Average coal ash fusion temperatures for test coals

Boiler	Source	Init. Def.	Soft.	Fluid
Mercer	Nora	2119	2276	2489
	Wellmore Ackiss	2123	2371	2591
	Mercer Blend	2130	2505	2637
	Wellmore Cactus #1	2149	2481	2618
	Wellmore Cactus #2	2220	1510	2700+
	Ellsworth	2268	2461	2625
Connemaugh	Connemaugh	2125	2503	2690
Keystone	Keystone	2183	2520	2700+
Hudson	Militant	2114	2436	2590
	Deep Hollow	2423	2574	2700
	Upshur	2700+	2700+	2700+
	Badger	2700+	2700+	2700+

TABLE 22

Comparison of specific element removal between Mercer fly ashes

Element	Ackiss vs Cactus #1		Ackiss vs Ellsworth		Ackiss vs Nora		Ackiss vs Blend		Blend vs Cactus #2		Ackiss	
	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	full vs min.	
Cd	+	+	+		+	+	+	+	+	+	+	+
B	-	-	-	-	-	-		+	+	+	-	-
Sn	-	-		+		+		+	+	+	-	-
Ni	+	+	+		+	+	+		+		+	
Pb	+	+	+		+		+		+		+	
Mo	-	-	-	-	-	-	-	-		+	-	-
Cu	+		+	+		+		+	+	+	+	
Cr	+		+		+		+		+	+	+	
Zn	+		+	+		+	+			+	+	+
Mn	+	+	+		+	+	+	+	+	+	+	+
Fe	+		+			+	+	+	+		+	

\+ represents best removal of specific ion

\+ + in inlet and outlet columns, respectively, represents same removal

\- represents no removal for that element

blank represents some removal

temperatures for the Wellmore Cactus #1 coals occurs at some 25°F and 40°F lower than the Blend and Wellmore Cactus #2 (see Table 21). However, it should be noted that the temperatures measured at the arch during the combustion of the Mercer Blend and Wellmore Cactus #2 is some 600°F and 400°F higher than those measured during the combustion of the Wellmore Cactus #1 coal (see Table 2). The higher boiler temperatures encountered by the Mercer Blend and Wellmore Cactus #2 fly ashes resulted in these ashes being in the fluid state for longer periods of time than the Wellmore Cactus #1 fly ash which could account for their exhibiting better sorbate characteristics.

The period that the fly ash particles remain in the molten or softened state apparently favors the sorbate characteristics of the fly ashes. Flame temperatures of greater than 3100°F in both Mercer boiler insures that the ash is in the fluid state in the flame. However, the ash probably remains longer in the fluid state in boiler #11 than boiler #12, because of the higher arch temperatures measured in boiler #11. The temperatures in boiler #11 measured at the arch which is located near the top of the boiler was only 100°F higher than the ash softening temperature for the Nora coal and 200°F higher for the Wellmore Ackiss coal (compare Table 2 with Table 21). In comparison, the temperatures at the arch for the combustion of these two coals in boiler #12 was some 600°F and 800°F lower than their respective ash softening temperatures.

It should be noted that the boiler temperatures measured during the combustion of the Ellsworth coal was comparable to that measured during the combustion of the Mercer Blend while its ash softening temperatures is significantly lower than that of the Mercer Blend.

Yet, the Mercer Blend fly ash exhibits better sorbate characteristics than the Ellsworth inlet fly ash. The reasons for the Ellsworth inlet fly ash exhibiting the poorest sorbate characteristics of all the Mercer inlet fly ashes is not understood at this time.

A comparison of the sorbate characteristics for the fly ashes produced from the Hudson coals reveals that the Militant fly ash removes the most elements followed by the Deep Hollow, Upshur and Badger fly ashes in decreasing order (see Table 23). The latter two fly ashes exhibit similar number of removals of the elements measured in the ash pond effluent. An examination of the ash softening temperature followed by the Deep Hollow in increasing order with Upshur and Badger exhibiting ash fusion temperatures greater than 2700°F.

The correlation between the ash fusion temperatures and sorbate characteristics is also observed for the fly ashes produced from the Keystone and Connemaugh coals. The Connemaugh fly ash which has the lower ash fusion temperatures removes significantly more elements than the Keystone fly ash (see Table 23). In addition, a comparison of the sorbate characteristic of the Connemaugh fly ash with the Deep Hollow fly ash whose coal has the higher ash fusion temperatures shows the Connemaugh fly ash to remove significantly more elements from the ash pond effluent than the Deep Hollow fly ash (see Table 24).

Conditions that would be expected to favor higher combustion temperatures also appear to favor the sorbate characteristics of the fly ashes produced. A comparison of the sorbate characteristics of the Militant fly ashes produced where the percent excess O_2 is reduced while the amount of natural gas co-fired with the coal is increased (see Table 2) shows a progressive improvement in the sorbate characteristic. The Militant fly ash produced under full power with 3.9% excess O_2 and a 3145 MCF feed rate of natural gas co-fired with the coal removed the largest amount of elements from the ash pond effluent followed by the fly ash produced at intermediate and minimum power, respectively (see Table 25). Minimum power generation at a 400 MCF natural gas feed rate and 8 percent excess air produced the fly ash with the poorest sorbate characteristics.

Similar results are encountered in a comparison of the sorbate characteristics of Deep Hollow fly ashes produced under full and intermediate power generation. A reduction in the excess oxygen from 6.8 percent down to 5.4 percent with an increase in oil co-fired with the coal from 0 percent up to 32 percent (see Table 2) resulted in a fly ash that removes more elements from the ash pond effluent than the fly ash produced at intermediate power (see Table 25).

The addition of the additive Appollo Control M which neutralizes the SO_2 in the flue gas does not appear to improve the sorbate characteristics of the fly ash. A comparison of the sorbate characteristic of the Upshur and Badger fly ashes produced with and without the addition of Control M to the flue gas (see Table 2) shows no improvement in their sorbate characteristics. Both the Upshur and Badger fly ashes removed the same number of elements from the ash pond effluent (see Table 24).

The presence of absence of the sulfur containing additive LPA-40, which is added to the flue gas after the superheated to improve the resistency of the fly ash particles also does not appear to influence the sorbate characteristics of the fly ash. The Ellsworth fly ash received no LPA-40, whereas the Wellmore Ackiss and Wellmore Cactus #1

TABLE 23

Comparison of specific element removal for Hudson, Connemaugh and Keystone

Element	Militant vs Deep Hollow		Militant vs Upshur		Upshur vs Badger		Keystone vs Connemaugh	
Cd	+		+	+	+	+	+	+
B	+	+	+	-	-	-		+
Sn	+		+	-	-	-	+	+
Ni	-	+	-	-	-	-	+	+
Pb	+			+		+		+
Mo	-	-	-	-	-	-		+
Cu	-	+	-	+	+	-	+	+
Cr	+			+	+	+	+	+
Zn	+		+		+			+
Mn	+	+	+		-	-	+	+
Fe	+		+			+		+

+	represents best removal of specific ion
+ +	in inlet and outlet columns, respectively, represents same removal
-	represents no removal for that element
blank	represents some removal

TABLE 24

Comparison of specific element removal between different coal fired boilers

Element	Mercer Blend vs Connemaugh		Connemaugh vs Deep Hollow	
Cd	+	+	+	+
B	+	+	+	
Sn	+	+	+	
Ni		+	+	
Pb		+	+	
Mo		+	+	
Cu	+	+	+	+
Cr		+	+	
Zn		+	+	
Mn		+	+	
Fe	+	+	+	

\+ represents best removal of specific ion
\+ + in inlet and outlet columns, respectively, represents same removal
\- represents no removal for that element
blank represents some removal

TABLE 25

Comparison of specific element removal between Hudson fly ashes for different power generation

Element	Militant		Militant		Deep Hollow	
	full vs intermediate		minimum vs intermediate		intermediate vs full	
Cd	+	+	+	+	+	+
B	+	+		+	+	+
Sn	+	+	+	+	-	-
Ni	+			+	-	-
Pb	+	+		+	-	-
Mo	-	-	-	-	-	+
Cu	+		+		+	+
Cr	+	+	+	+	+	+
Zn	+			+	-	-
Mn	+			+	-	+
Fe	+	+	+		+	

+ represents best removal of specific ion

+ + in inlet and outlet columns, respectively, represents same removal

– represents no removal for that element

blank represents some removal

fly ashes were produced using LPA-40 feed rates of 16 gal/hr. and 28 gal/hr., respectively. Yet, the Ackiss fly ash as was shown earlier removed the most elements from the ash pond effluent followed by the Cactus #1 and the Ellsworth fly ashes in decreasing order.

Combinations of different fly ashes produced by each coal fired boiler have been identified that could be used to essentially treat all the elements measured in the ash pond effluent. The inlet Nora fly ash in combination with the inlet Wellmore Ackiss and Wellmore Cactus #2 can be used to treat all the elements in the ash pond effluent (see Table 22). Similarly, the Militant fly ash in combination with the Deep Hollow fly ash appear capable of treating all the elements in the ash pond effluent with the exception of Molybdenum (see Table 23). The Connemaugh fly ash appears to exhibit excellent sorbate characteristics. An examination of Table 23 reveals that the Connemaugh fly ash alone appears capable of treating all the elements measured in the ash pond effluent.

Comparison of Leaching and Sorbate Characteristics of the Fly Ashes.

There appears to be a correlation between the leaching characteristics and sorbate characteristics of the fly ashes. The fly ash which leaches the least amount of elements when compared to other fly ashes also removes the largest amount of these elements from ash pond effluent. A comparison of the leaching characteristics of the inlet and outlet fly ashes reveal that the inlet fly ashes leaches less elements than the outlet fly ashes (see Table 15). The inlet fly ashes were shown to be better sorbents than the outlet fly ashes. Similarly, a comparison of the leaching of different elements by the different inlet fly ashes reveals that Nora inlet fly ash leaches the least amount of elements followed by Wellmore Ackiss, Mercer Blend, Wellmore Cactus #1, Ellsworth and Cactus #2 in increasing order, respectively (see Table 16). The Nora inlet fly ash was found to exhibit the best sorbate characteristics followed by the Wellmore Ackiss, Mercer Blend, Wellmore Cactus #2, Wellmore Cactus #1 and Ellsworth. The only apparent disagreement between the orders of least leaching characteristics is the Wellmore Cactus #2.

Similar results can be observed for the Keystone and Connemaugh fly ashes. The Connemaugh fly ash which was found to exhibit the best sorbate characteristics, leaches the least amount of elements when compared to the Keystone fly ash (see Table 17).

The exception to the above correlation between the leaching and sorbate characteristics is encountered with the Hudson fly ashes. The Upshur and Badger fly ashes were found to leach the fewest elements followed by the Deep Hollow and Militant fly ashes in increasing order, respectively (see Table 17). The order for the best to poorest sorbate characteristic of the Hudson fly ashes is reversed. The Militant fly ash was found to exhibit the best sorbate characteristics followed by Deep Hollow, Badger and Upshur in decreasing order, respectively. The reason for this discrepancy is not yet clear at this time.

RESULTS OF GRAIN SIZE DISTRIBUTION AND PERMEABILITY OF SORBENTS

The grain size distribution of sorbent, using the combined sieve and hydrometer analysis, were analyzed for the identification and classification. The results showed that in general the fly ash sorbents collected in the Hudson plant (high fusion coals) have larger particle sizes than the collected in the Mercer plant (low fusion coals). The Hudson fly ash have an average of eighty percent particles, smaller than 0.10 mm. In addition, the fly ash particle sizes were also found different between inlet and outlet hoppers in the Mercer plant as well as between front and back hoppers in the Hudson plant. In all cases, the inlet hopper in the Mercer plant has fly ash particles greater than that of the outlet hopper, while the front hopper in the Hudson plant has fly ash particles greater than that of the back hopper.

This phenomenon also showed true for the permeability results. The permeabilities of the inlet hopper collected in the Mercer fly ash were found to be greater than that of the outlet fly ash (see Fig. 20 to 23 and the permeabilities of the front hopper fly ash were found to be greater than that of the back fly ash (see Fig. 16 to 19).

CHAPTER IV. CONCLUSIONS

The purpose of this study is to identify the leaching and the absorption characteristics of fly ash samples collected from a selected number of different sources, and the develop an inexpensive treatment system using fly ash as the sorbents to remove the hazardous ion leached from the fly ash disposal landfill, or the fly ash pond effluent.

The sorbate characteristics of fly ash is a function of its leaching potential, combustion condition, types of boiler, elemental composition, coal fusion temperature, and pH.

Actual fly ash pond effluent was passed through fly ash samples in the lysimeters to determine their ability to remove each of the elements. This was determined by analyzing the fly ash pond effluent before and after specific volumes of the effluent has been passed through the fly ash samples. A fly ash that leaches the least amount of elements is the best sorbent for thos elements.

Boiler temperature appears to be one of the most important parameters that influences the leaching properties of the fly ash. For the same coal burned, the fly ash produced at higher boiler temperatures exhibited less leaching than the fly ash produced at lower boiler temperatures.

A comparison of fly ashes produced from the three different coal fired boilers also show that an increase in the boiler temperature is accompanied by a decrease in the number of elements and the amounts leached by the fly ash.

These results also indicate that the elemental composition of fly ash is an important factor to influence its leaching characteristics of the fly ash. The fly ash which contains greater amounts of elements appears more leaching and less absorption capabilities for those elements.

There also, appears to be some correlation between the coal ash fusion temperature and the sorbate characteristics of fly ash produced from its coal. The ash generated from low fusion coals exhibits less leaching of elements than that fly ash from high fusion coals, and thus shows better sorbate property.

It should also be noted, that in general the pH measured in the effluent leachate of fly ash is another important factor effecting the leaching characteristics. A high pH leachate usually is accompanied by less leaching of trace elements than a low pH leachate. This was observed in all of the fly ashes leached with the exception of Wellmore Cactus #2 fly ash whose leachate exhibits the highest pH and also leachates the highest concentration of all the trace elements when compared to the other fly ashes. An increase in pH results in a less leaching and better sorbate property.

CHAPTER V. RECOMMENDATIONS

While this study has identified the parameters that influence the leaching and sorbate parameters of the fly ash, the application of this information to develop an effective fly ash sorbent treatment process of controlling hazardous leachate from fly ash pond must be carried out. The future study should be included to achieve this goal. There are still many other areas which need further investigations to assist in further developing a fully commercial scale system based on this sorbent system.

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APPENDICES

FIGURE 2.1

pH - Profile of Fly Ash
Hudson Boiler
Militant Coal

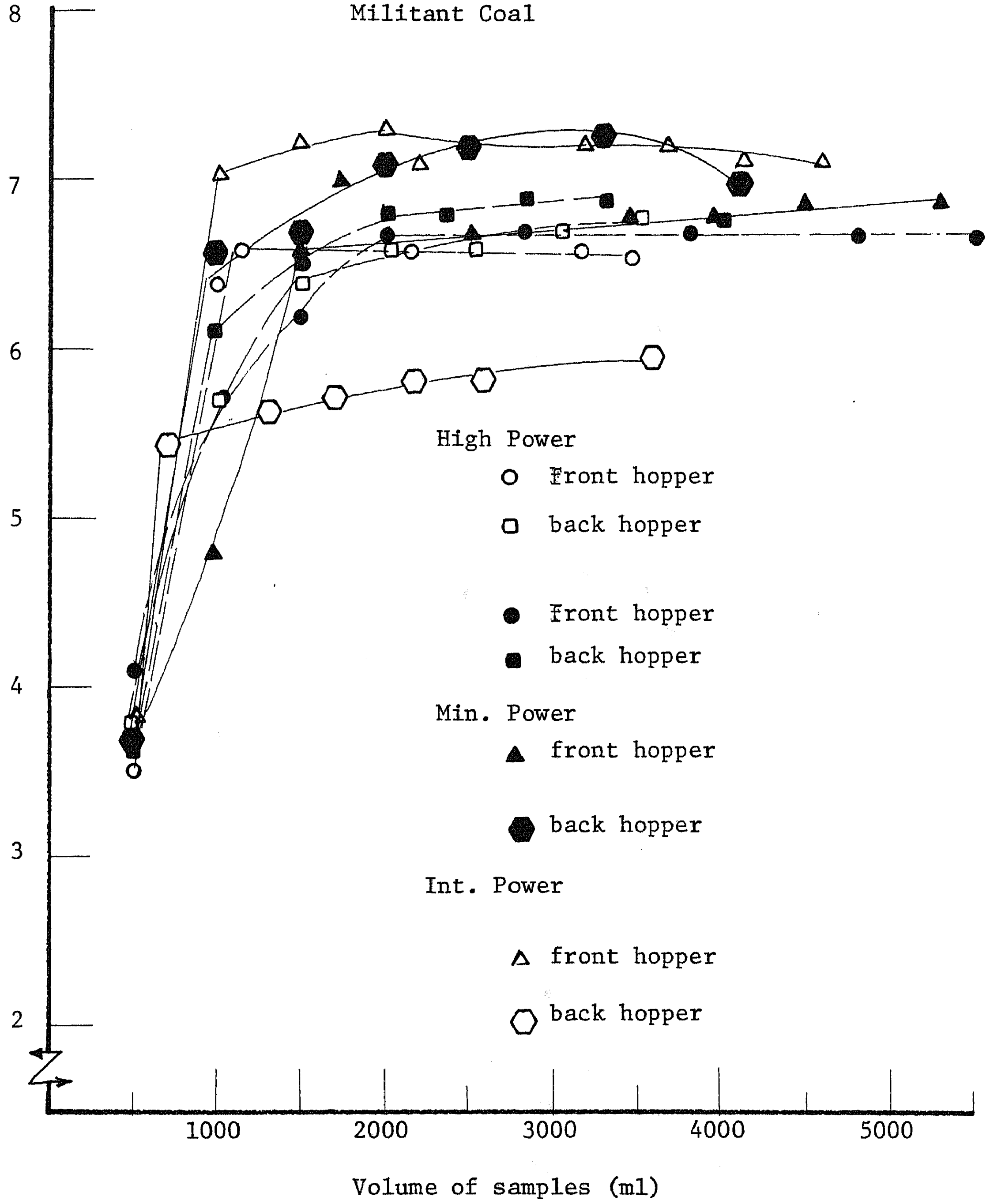


FIGURE 2.2

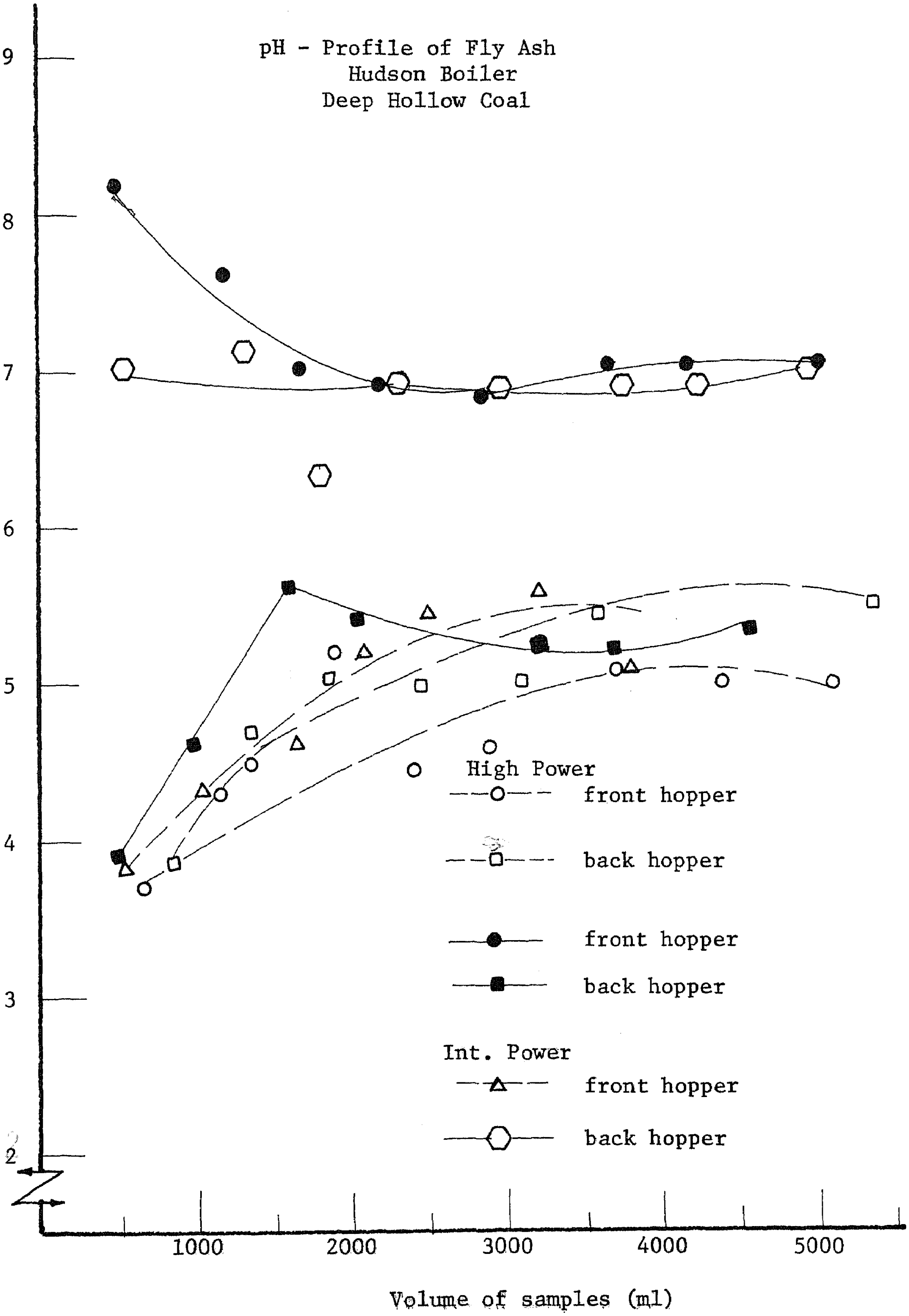

pH - Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal
9
8
7
6
5
4
3
2
1000
2000
3000
4000
5000
Volume of samples (ml)
High Power
front hopper
back hopper
front hopper
back hopper
Int. Power
front hopper
back hopper

FIGURE 2.3

pH - Profile of Fly Ash
High Power
Hudson Boiler

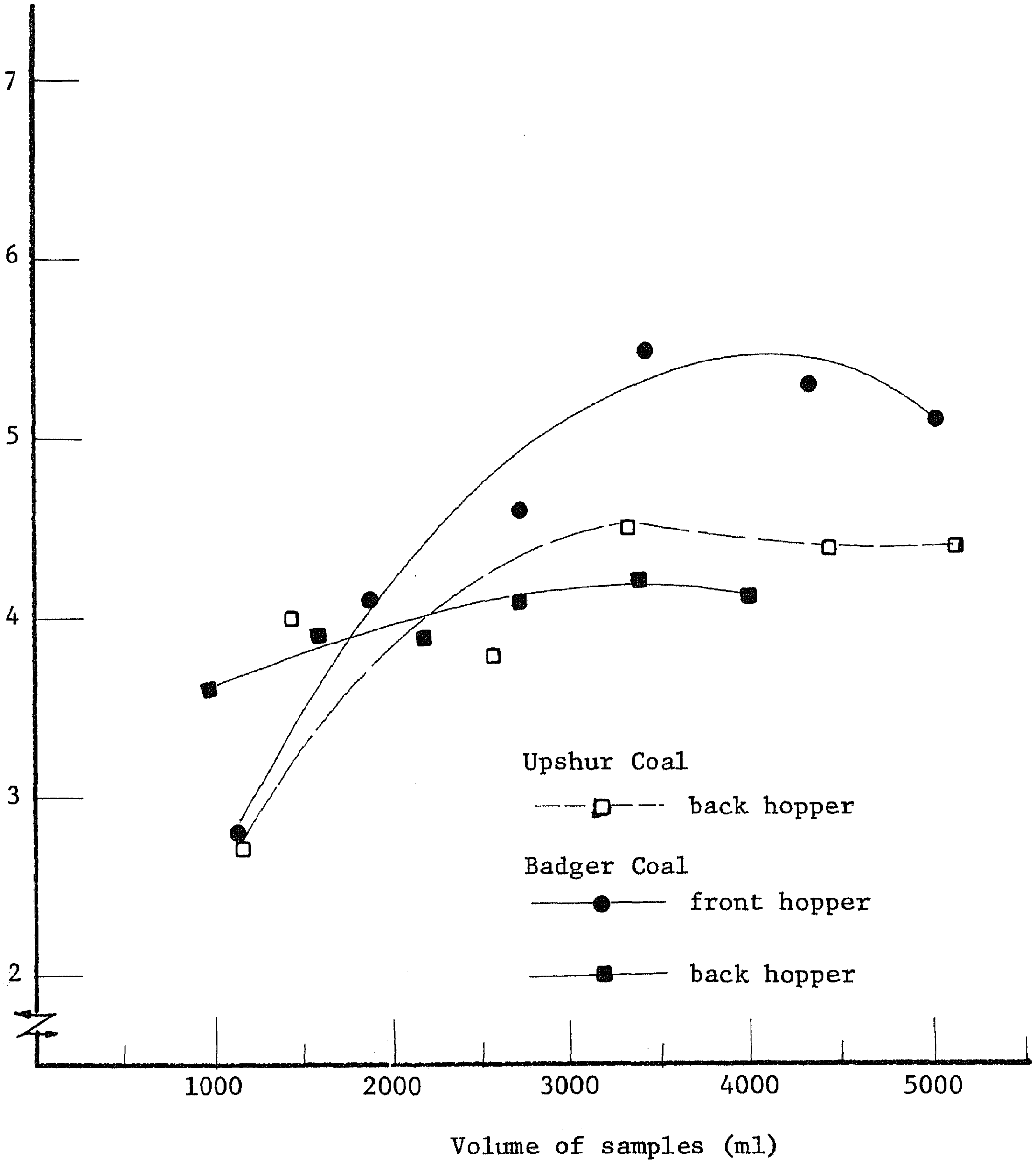


FIGURE 3.1

pH - Profile of Fly Ash
High Power
Mercer Blend

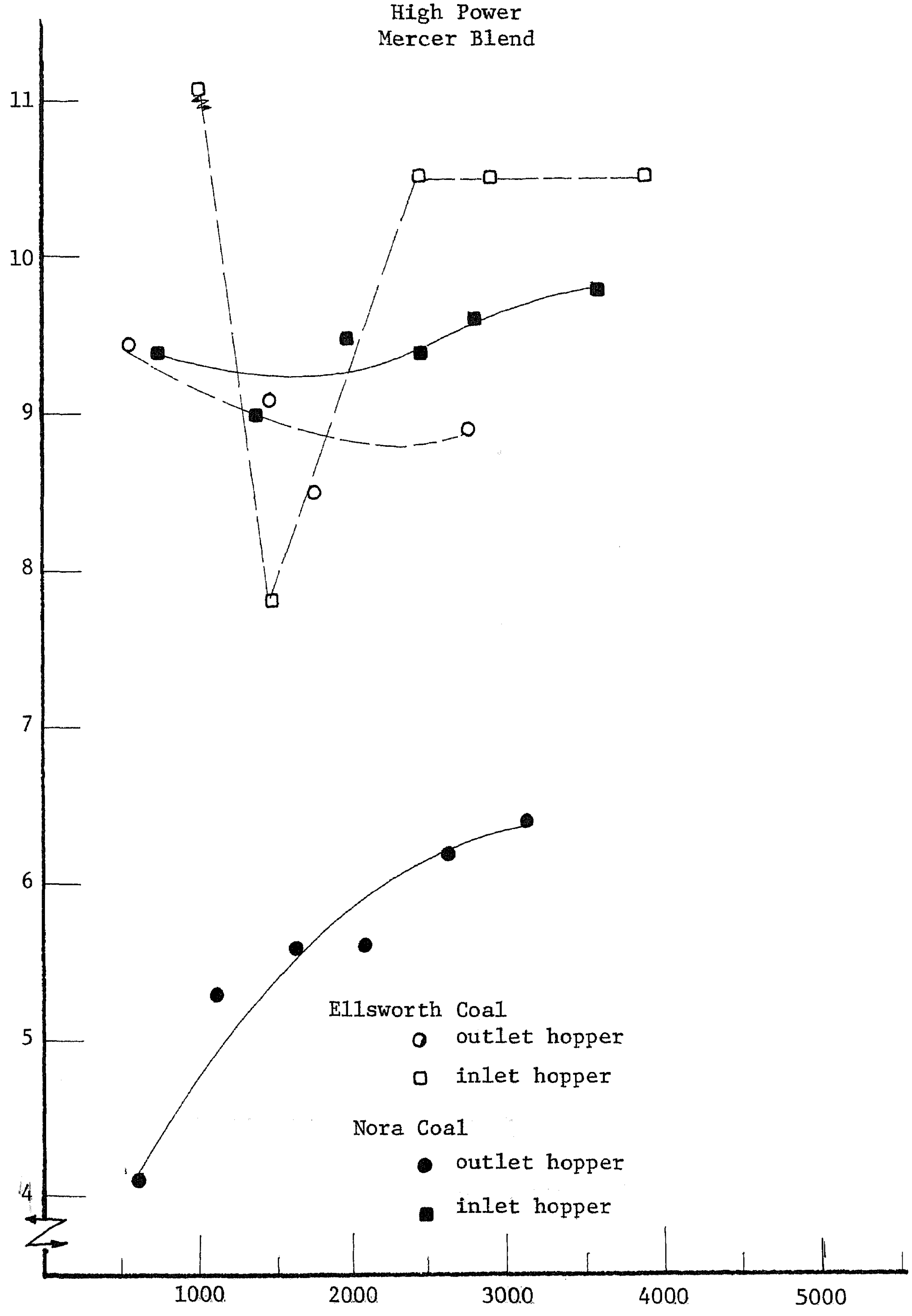
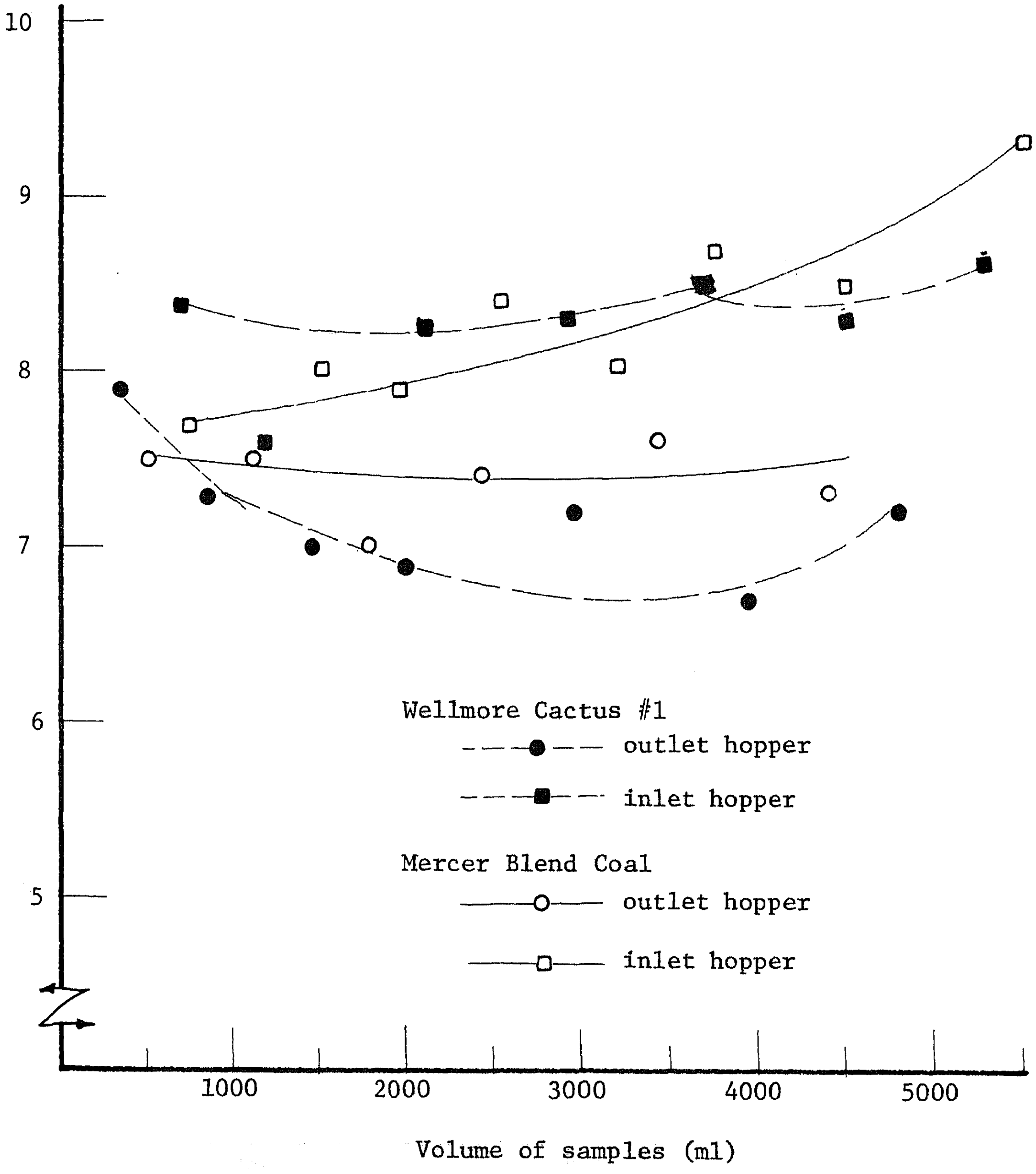


FIGURE 3.2

pH - Profile of Fly Ash
High Power
Mercer Boiler



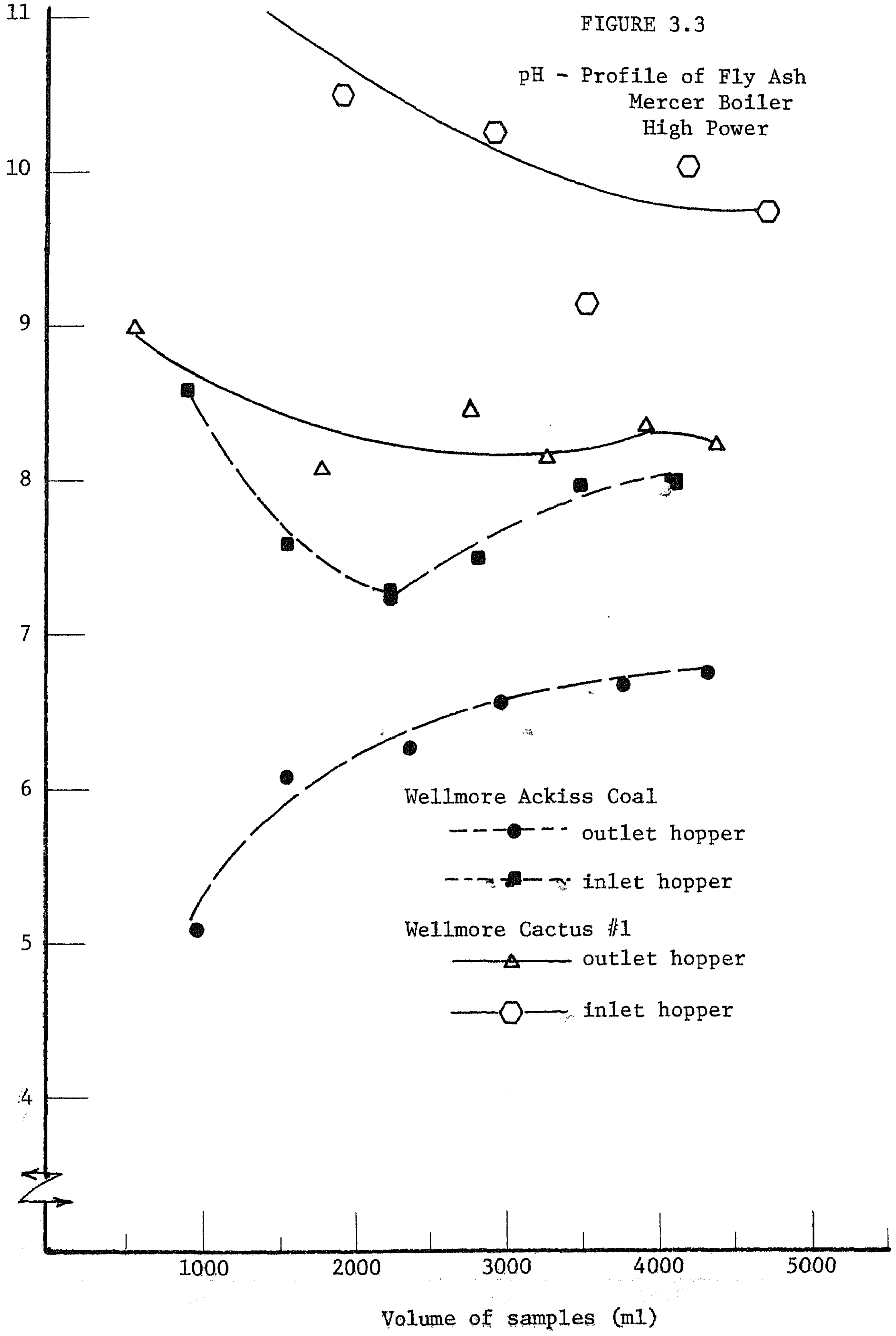


FIGURE 3.3

pH - Profile of Fly Ash
Mercer Boiler
High Power

FIGURE 4

pH - Profile of Fly Ash

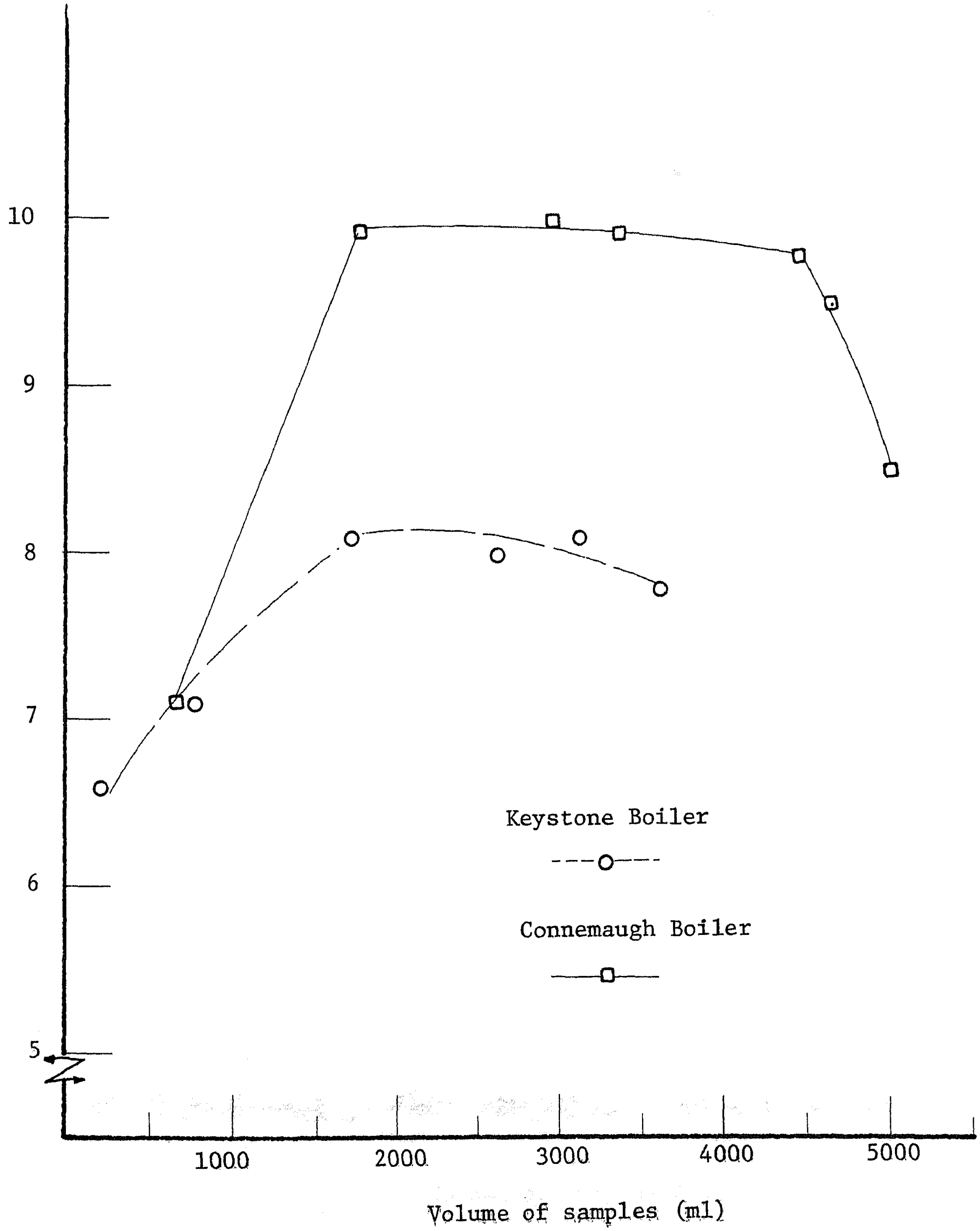


FIGURE 5.1

Cd - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

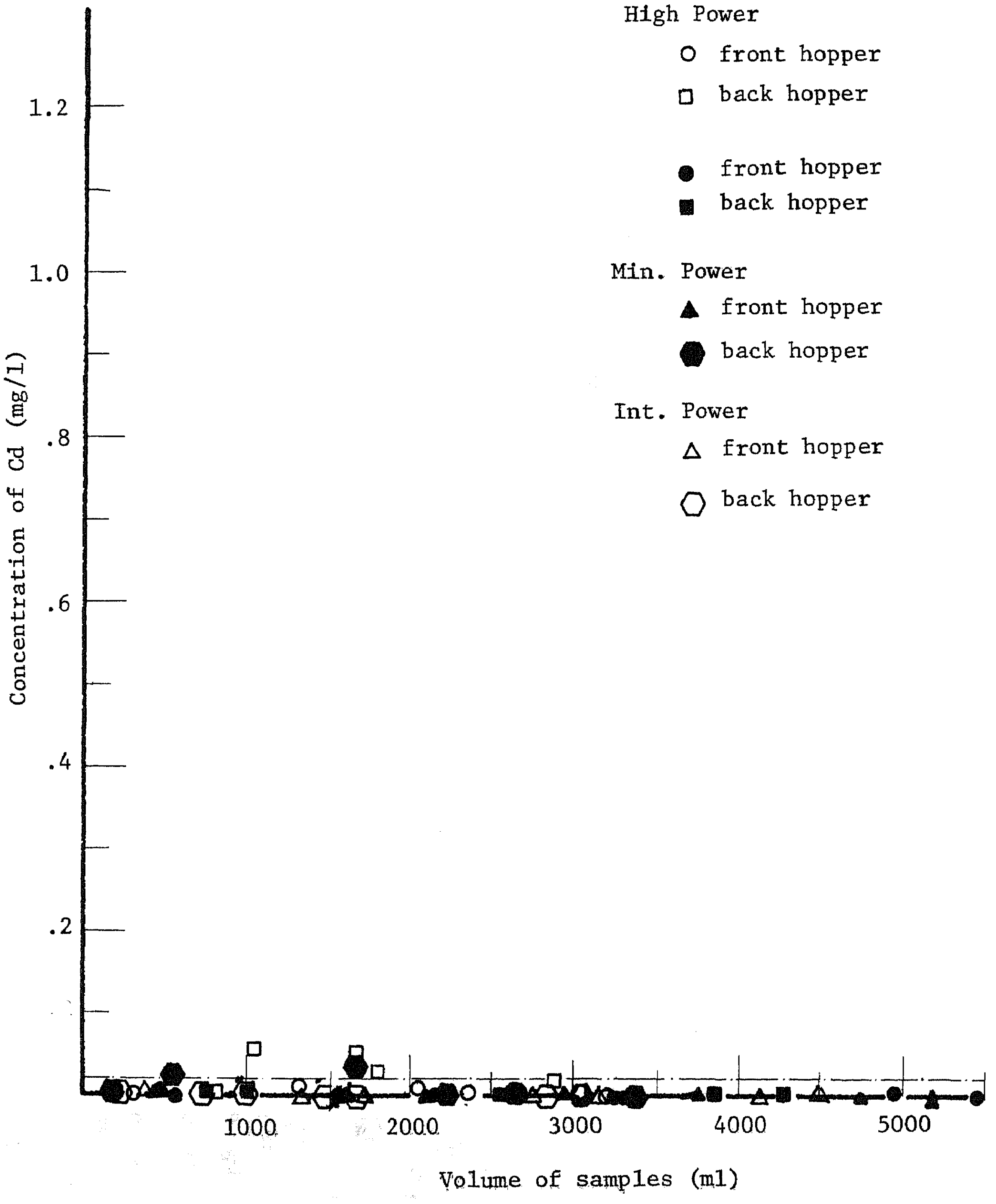


FIGURE 5.2

Cd - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

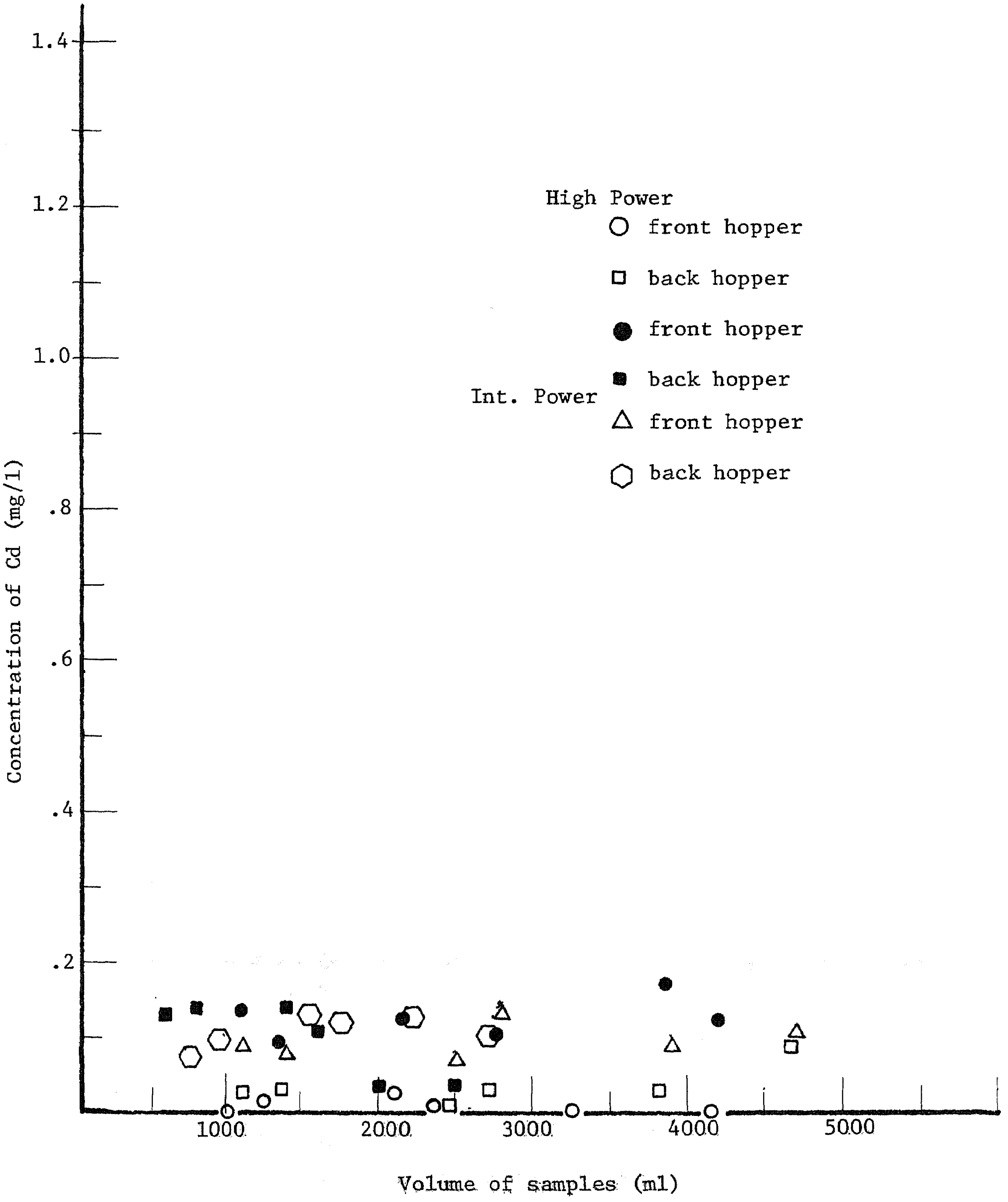


FIGURE 5.3

Cd - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

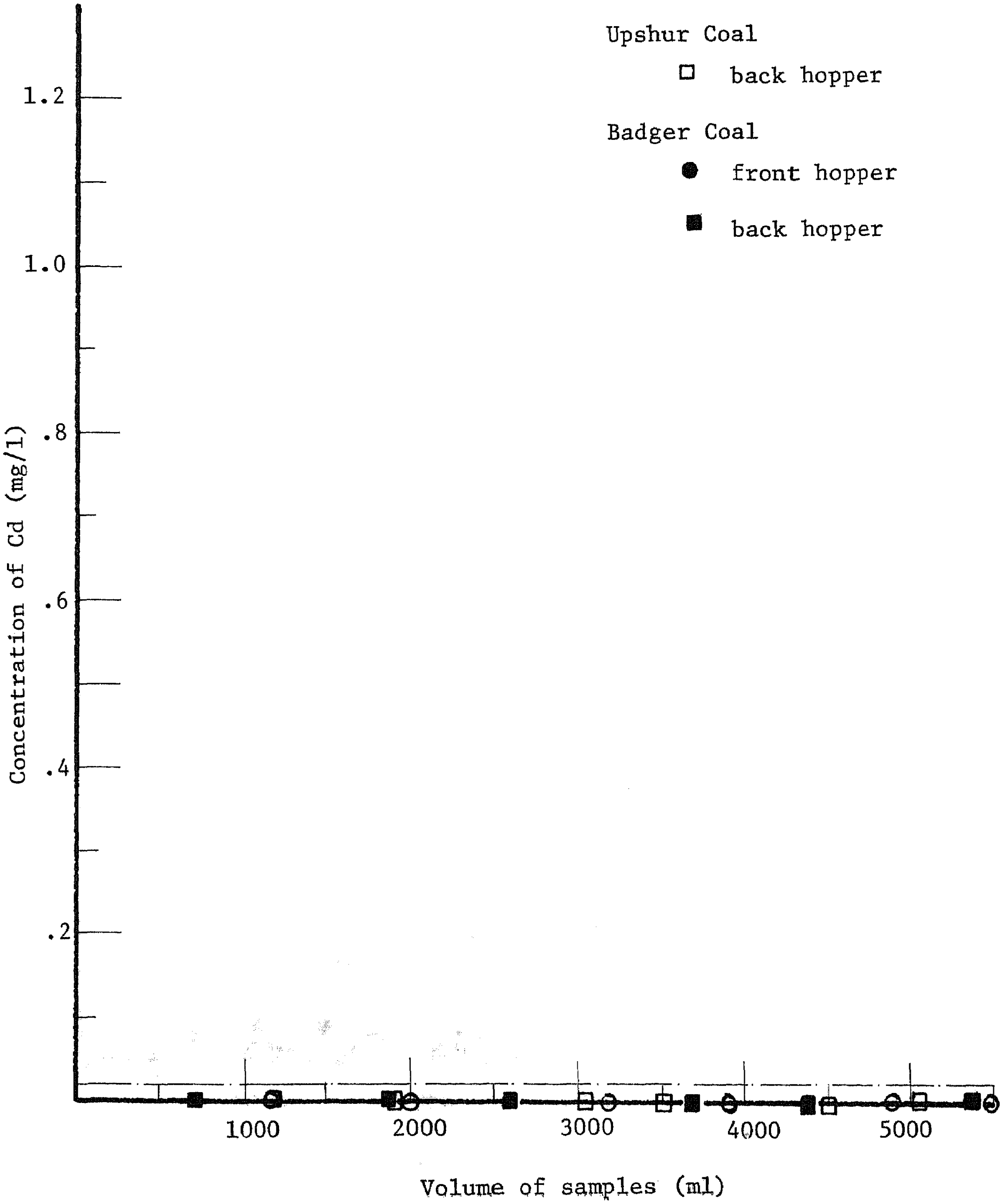


FIGURE 5.4

Cd - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

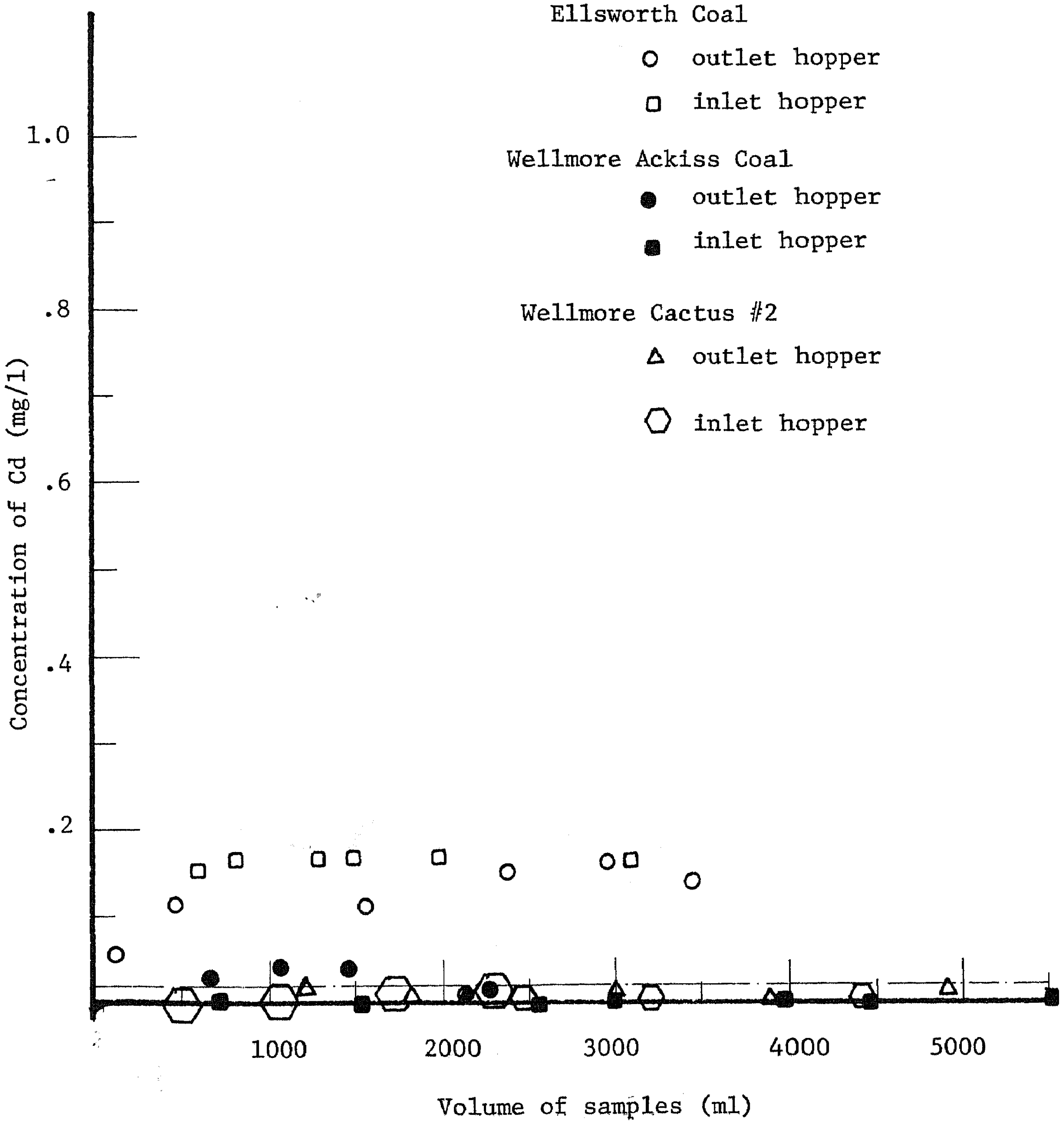


FIGURE 5.5

Cd - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

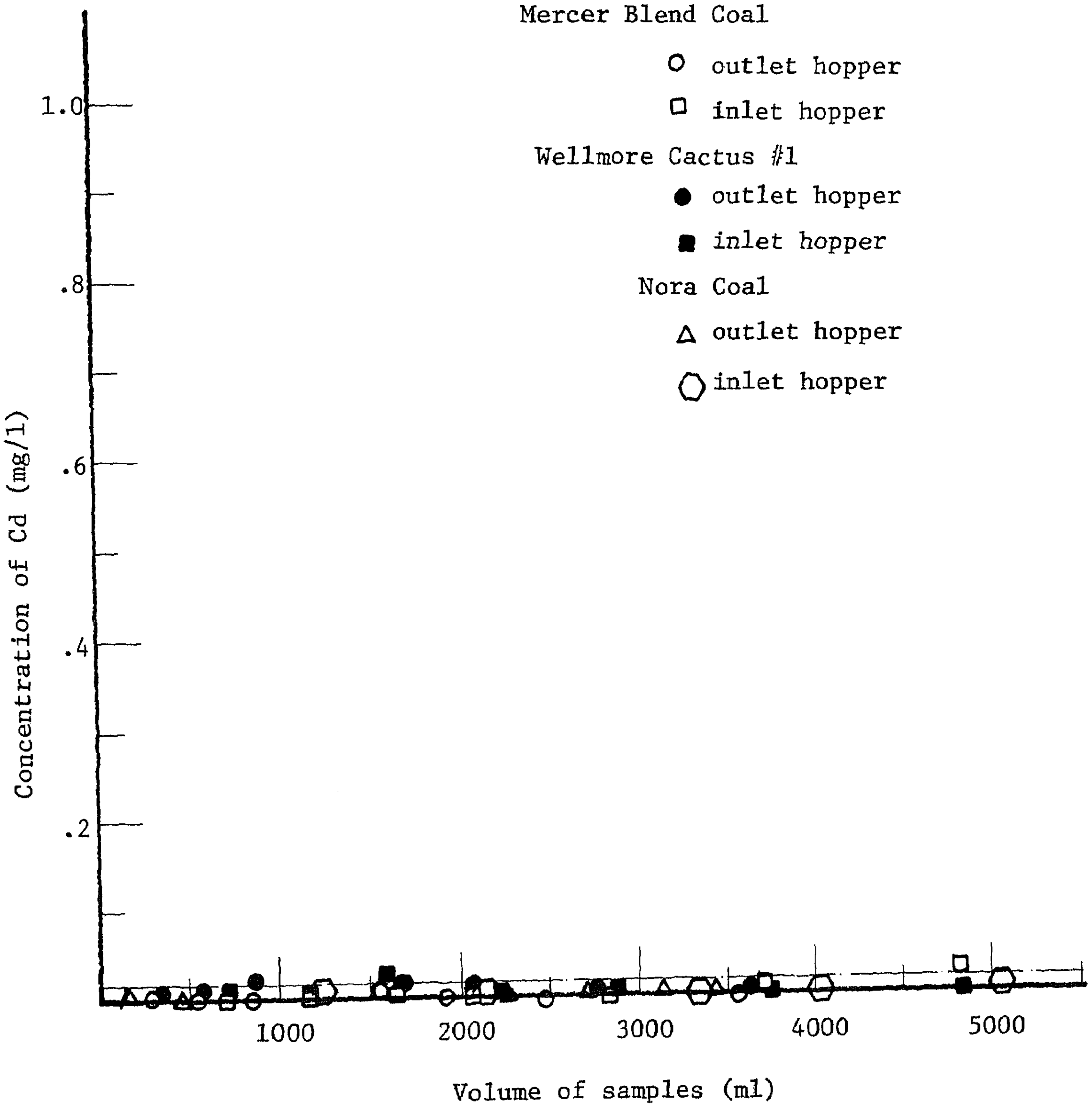


FIGURE 5.6

Cd - Absorbent Profile of Fly Ash
High Power

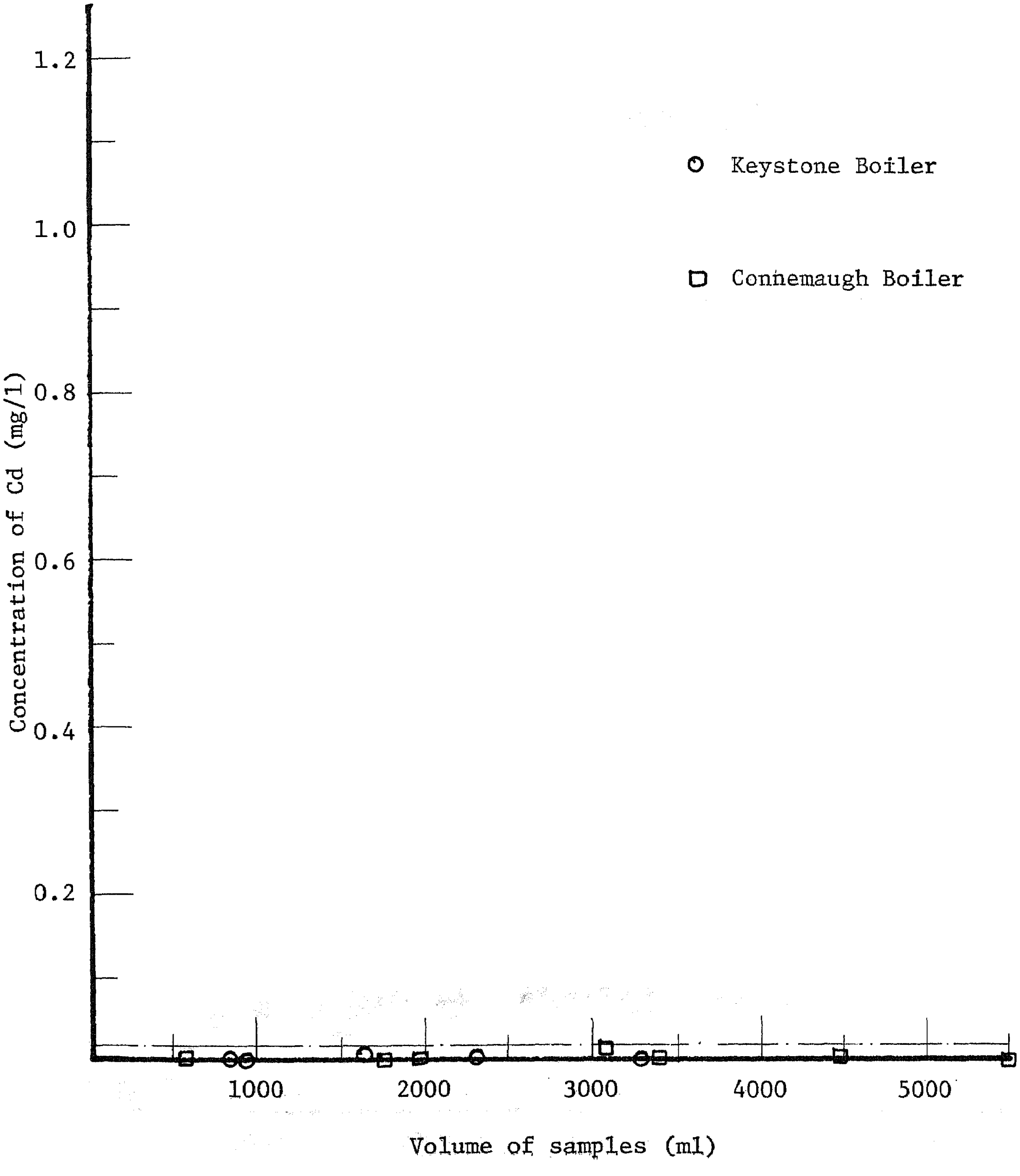


FIGURE 6.1

B - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

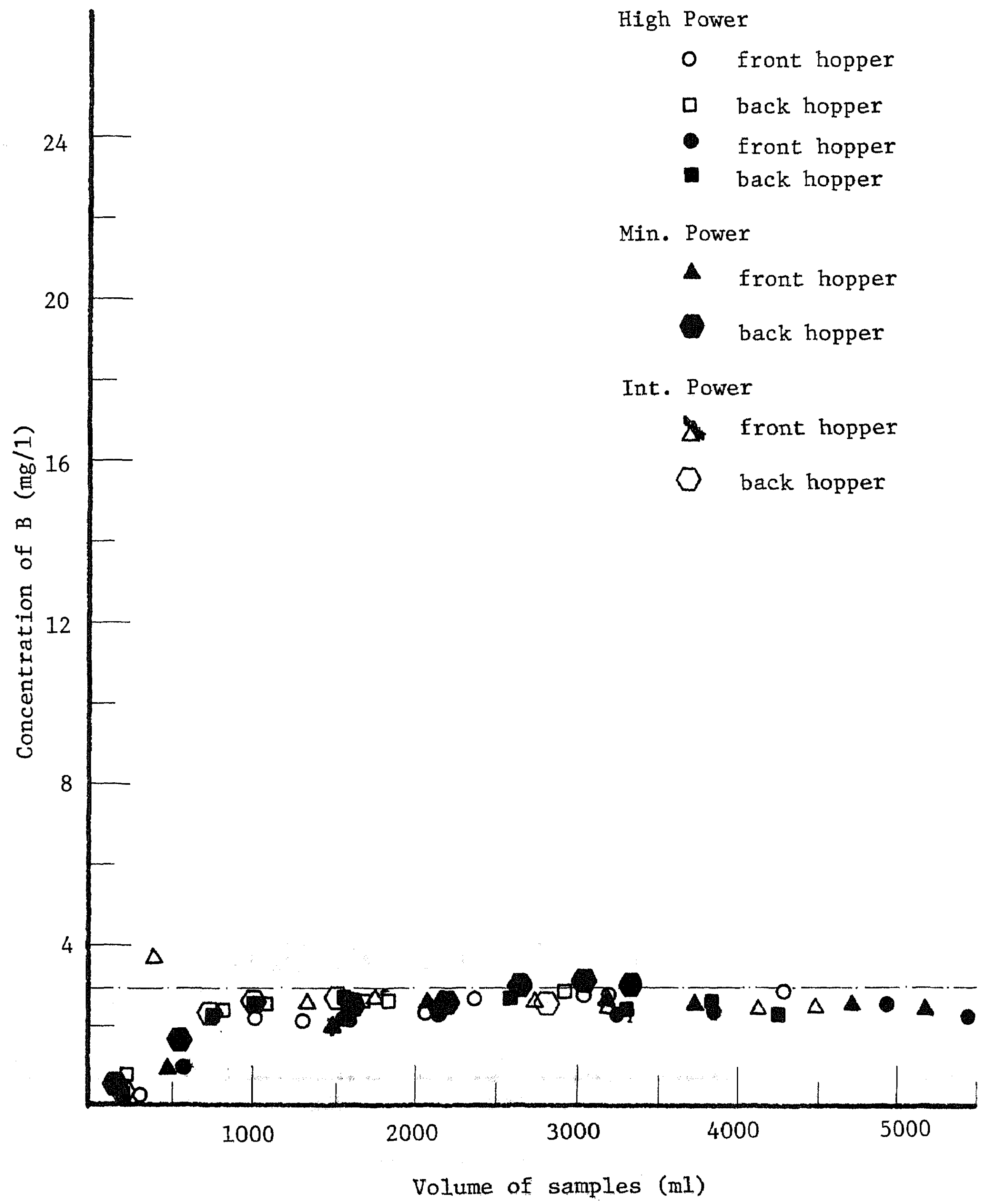


FIGURE 6.2

B - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

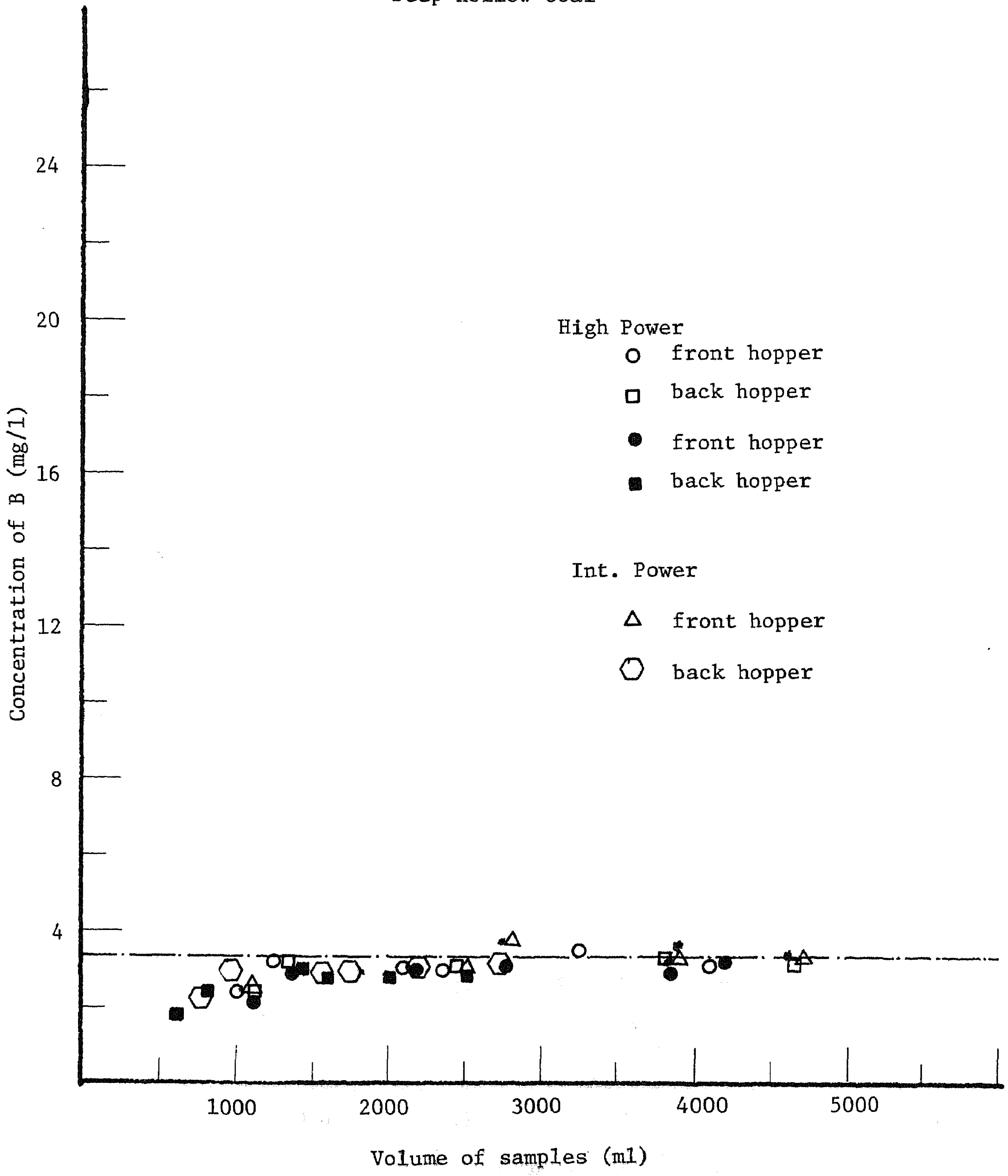


FIGURE 6.3

B - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

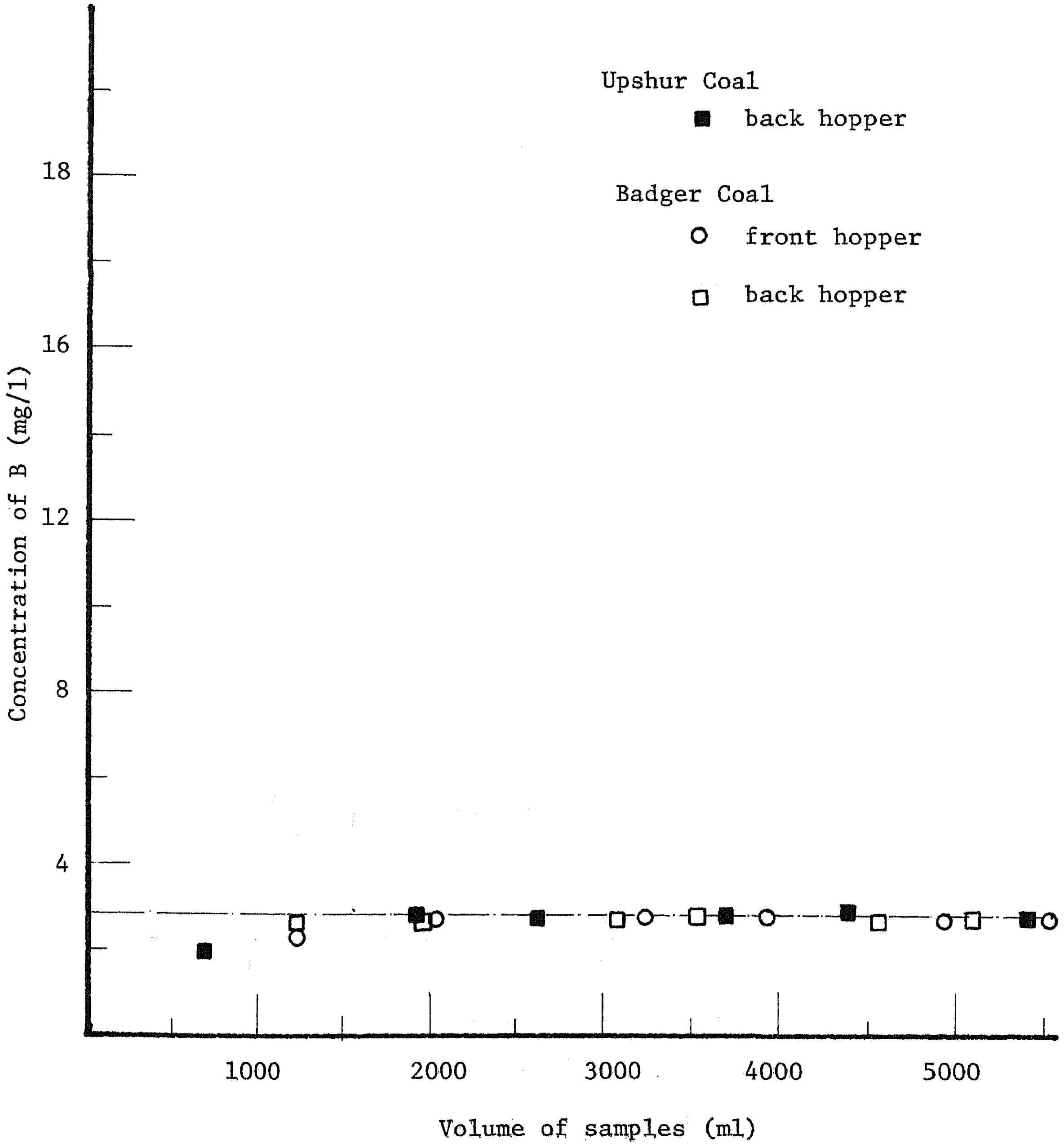


FIGURE 6.4

B - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

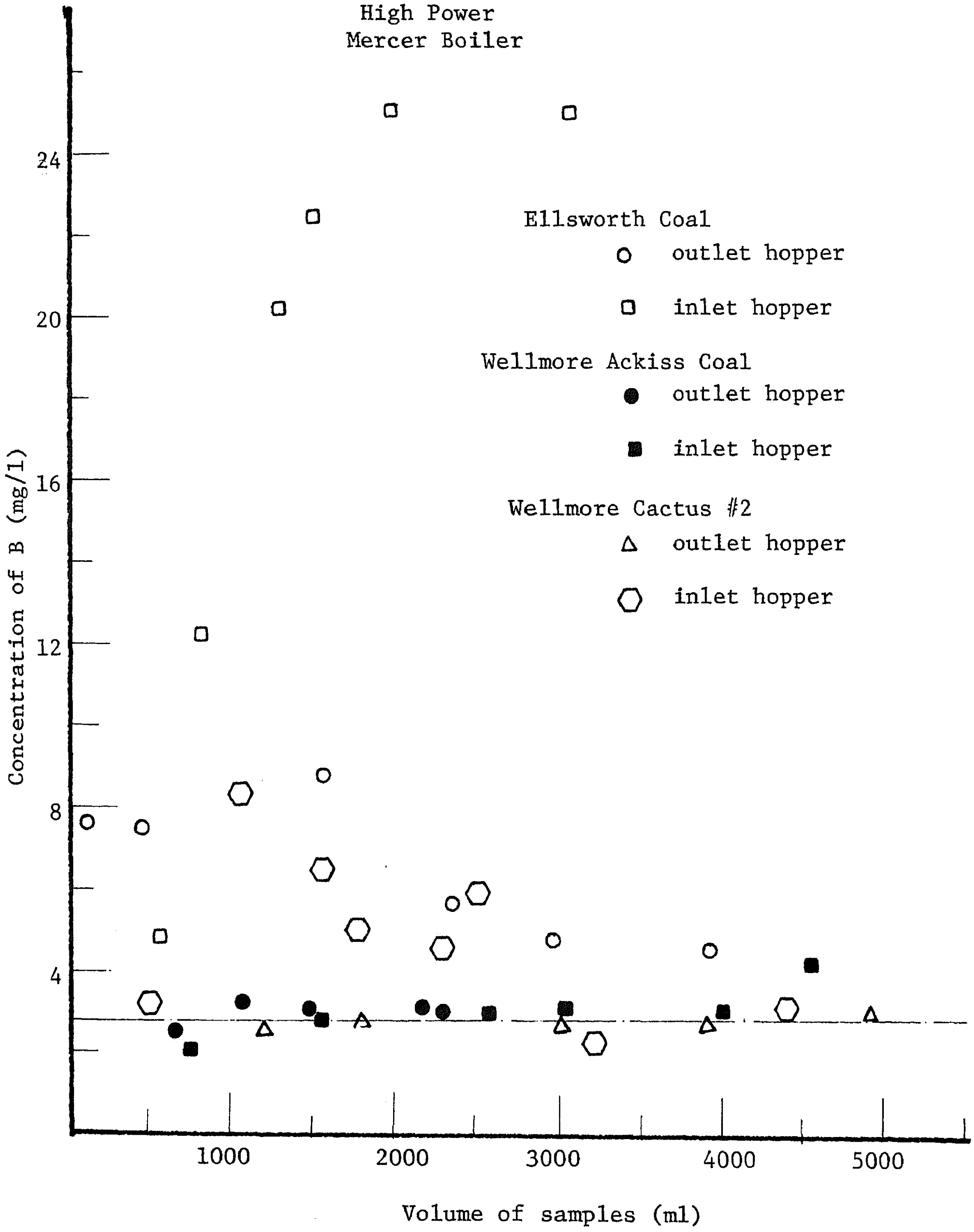


FIGURE 6.5

B - Absorbent Profile of Fly ASh
High Power
Mercer Boiler

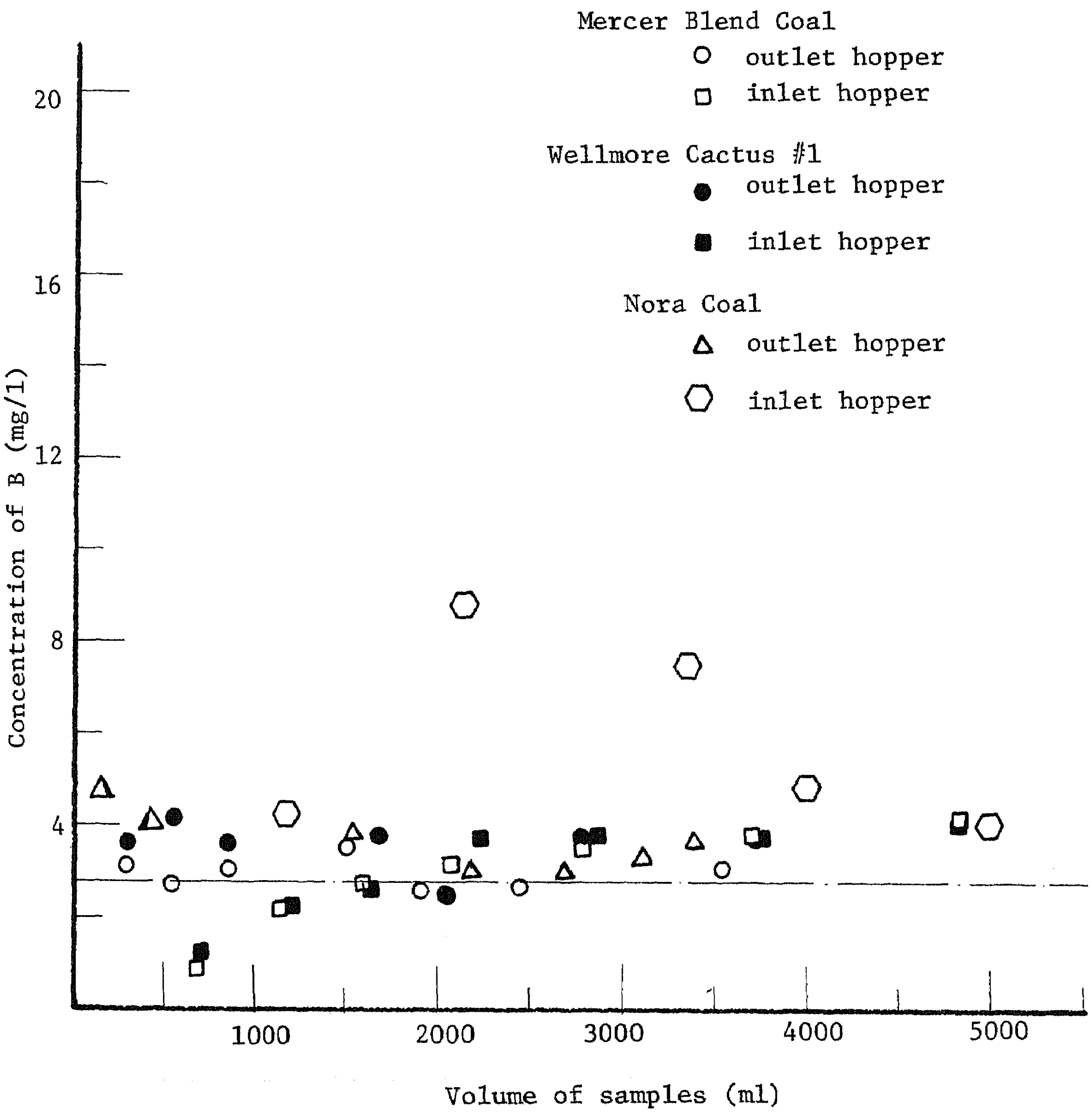


FIGURE 6.6

B - Absorbent Profile of Fly Ash
High Power

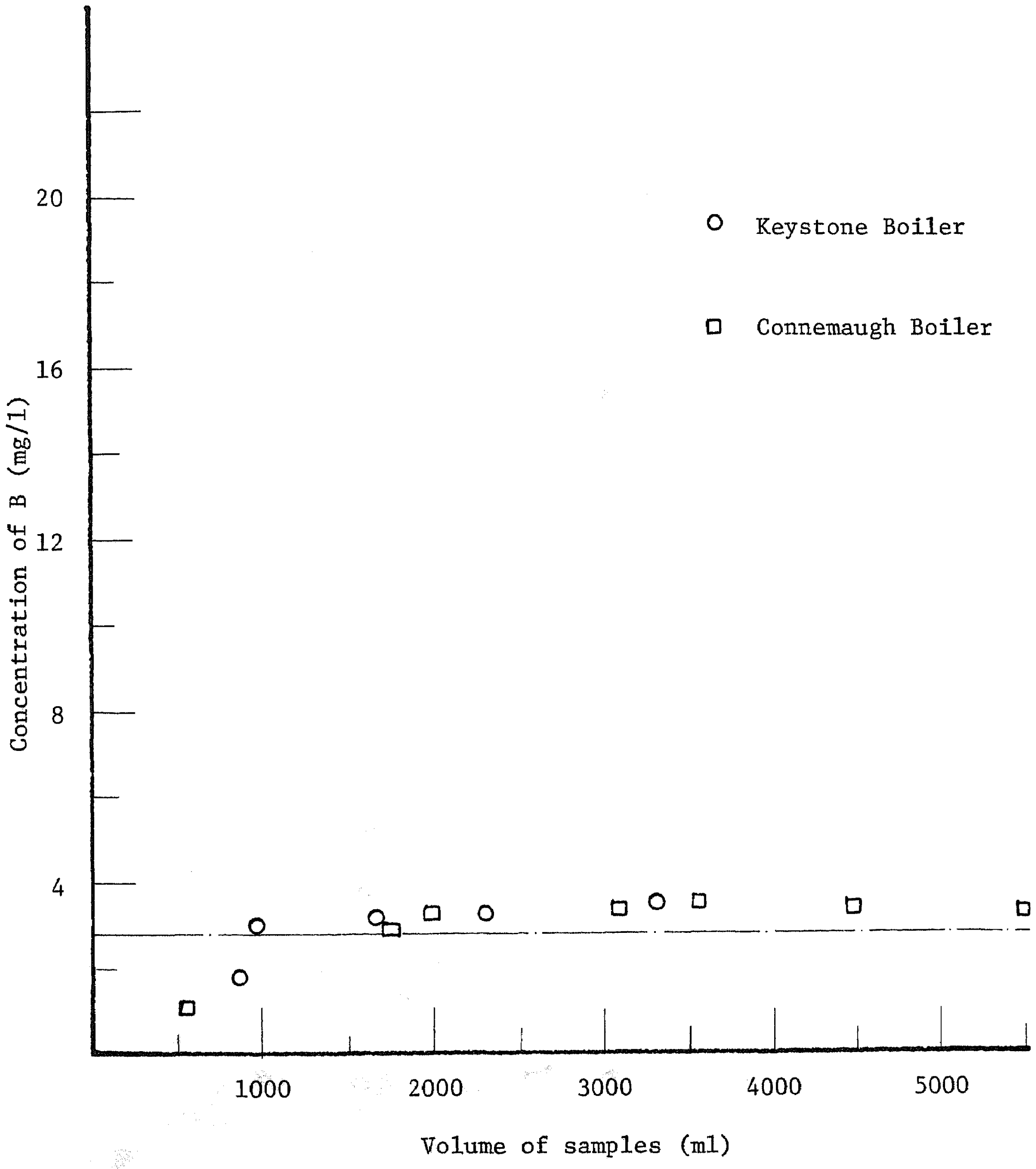


FIGURE 7.1

Sn - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

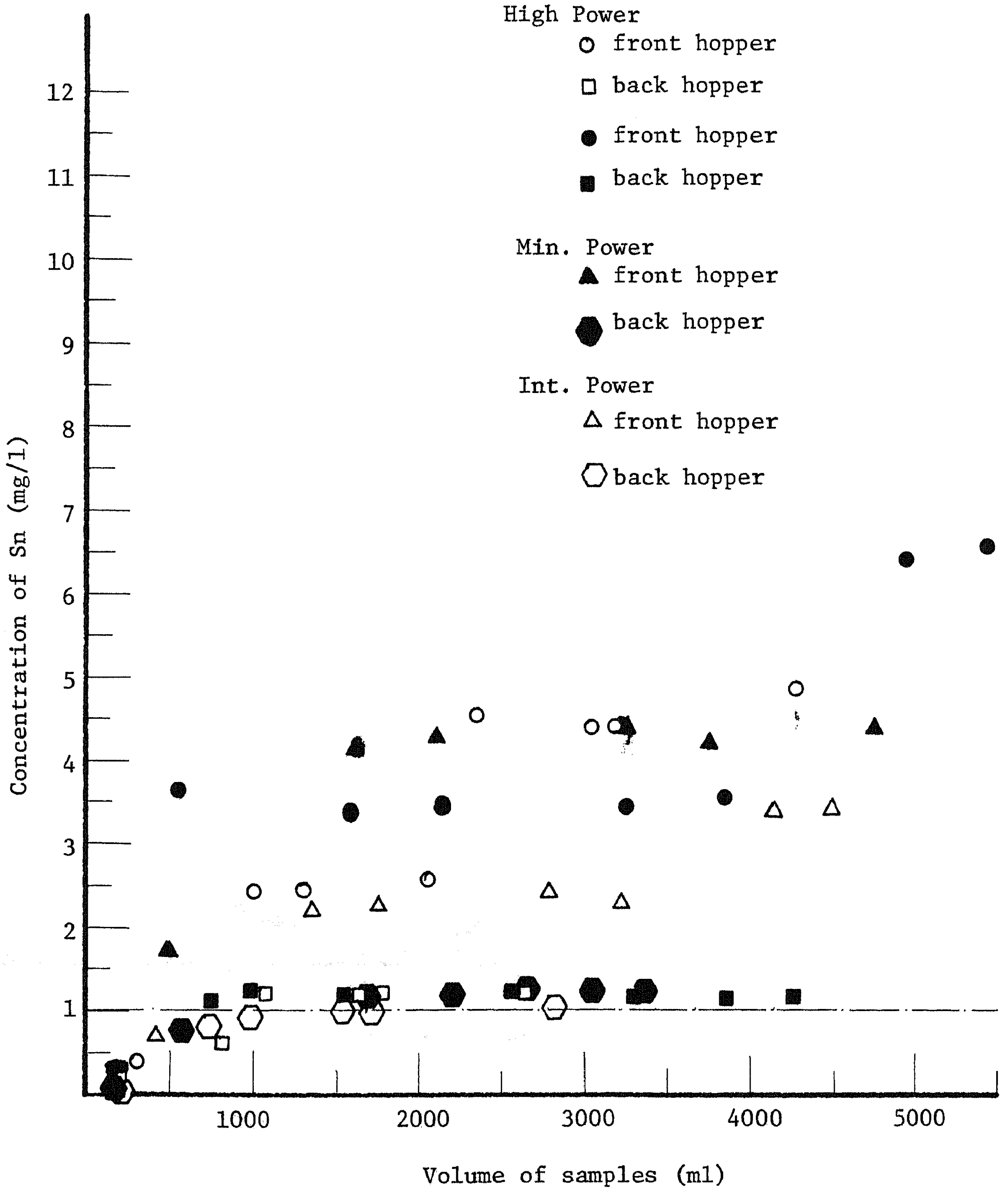


FIGURE 7.2

Sn - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

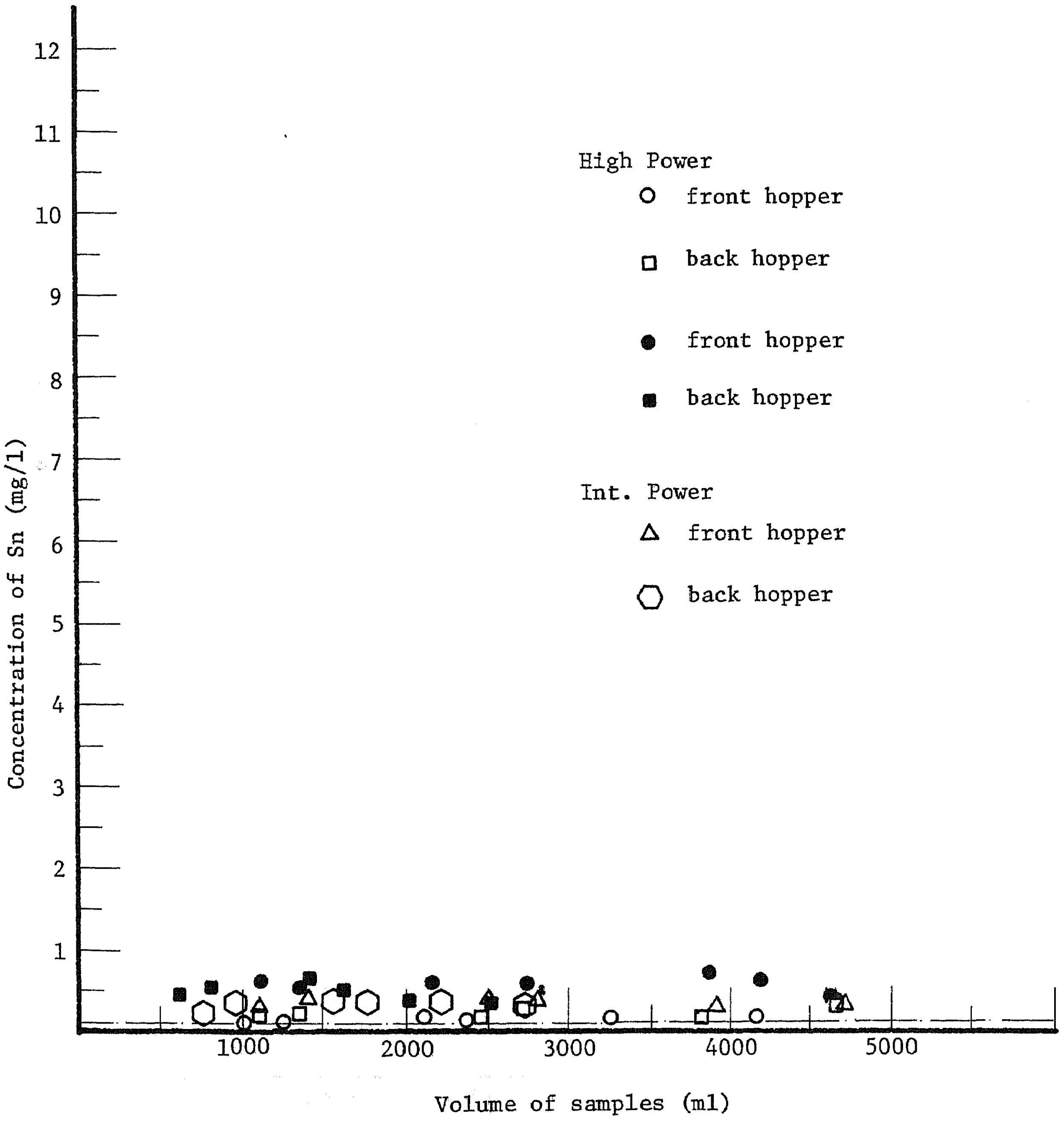


FIGURE 7.3

Sn - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

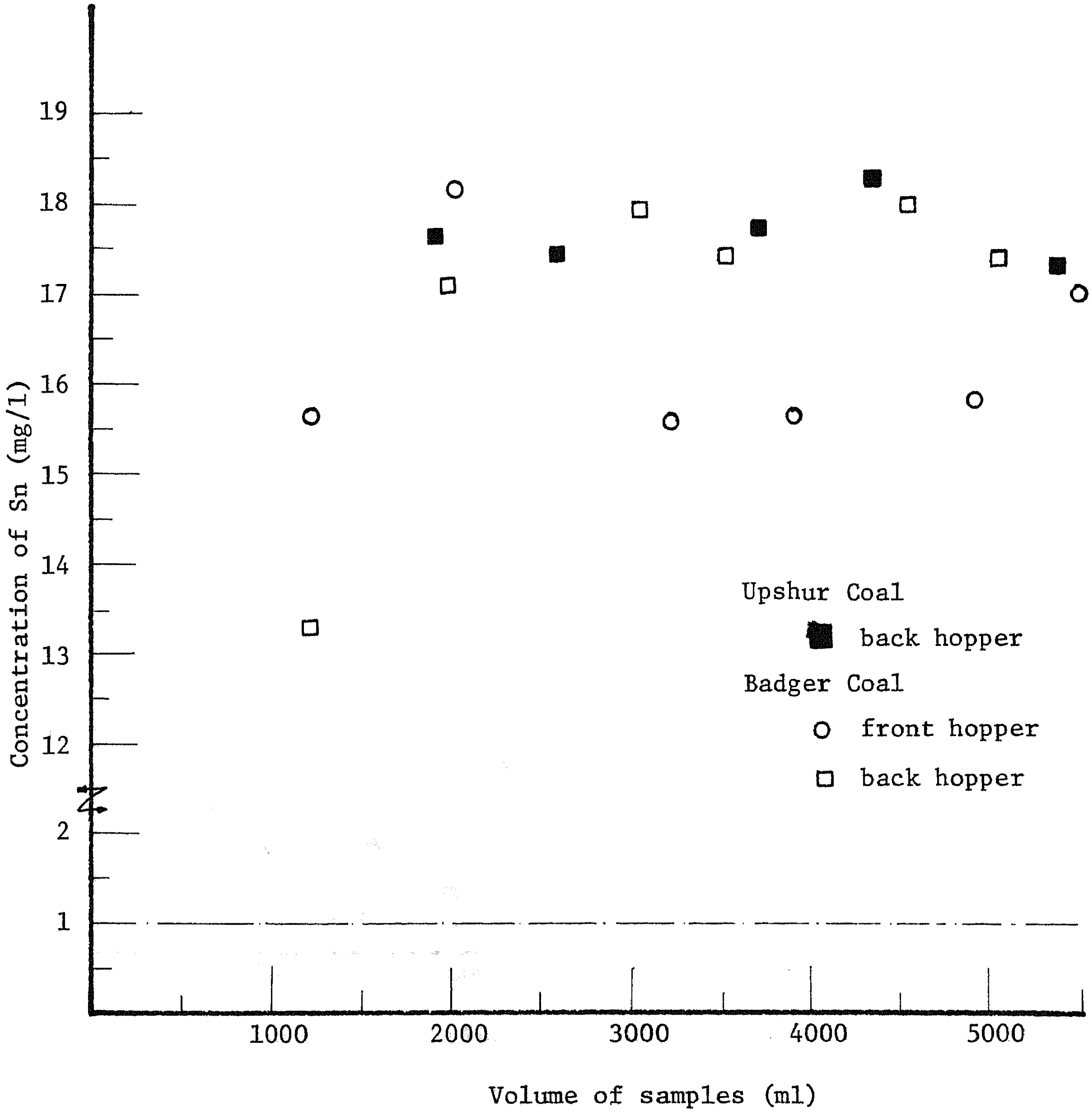


FIGURE 7.4

Sn - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

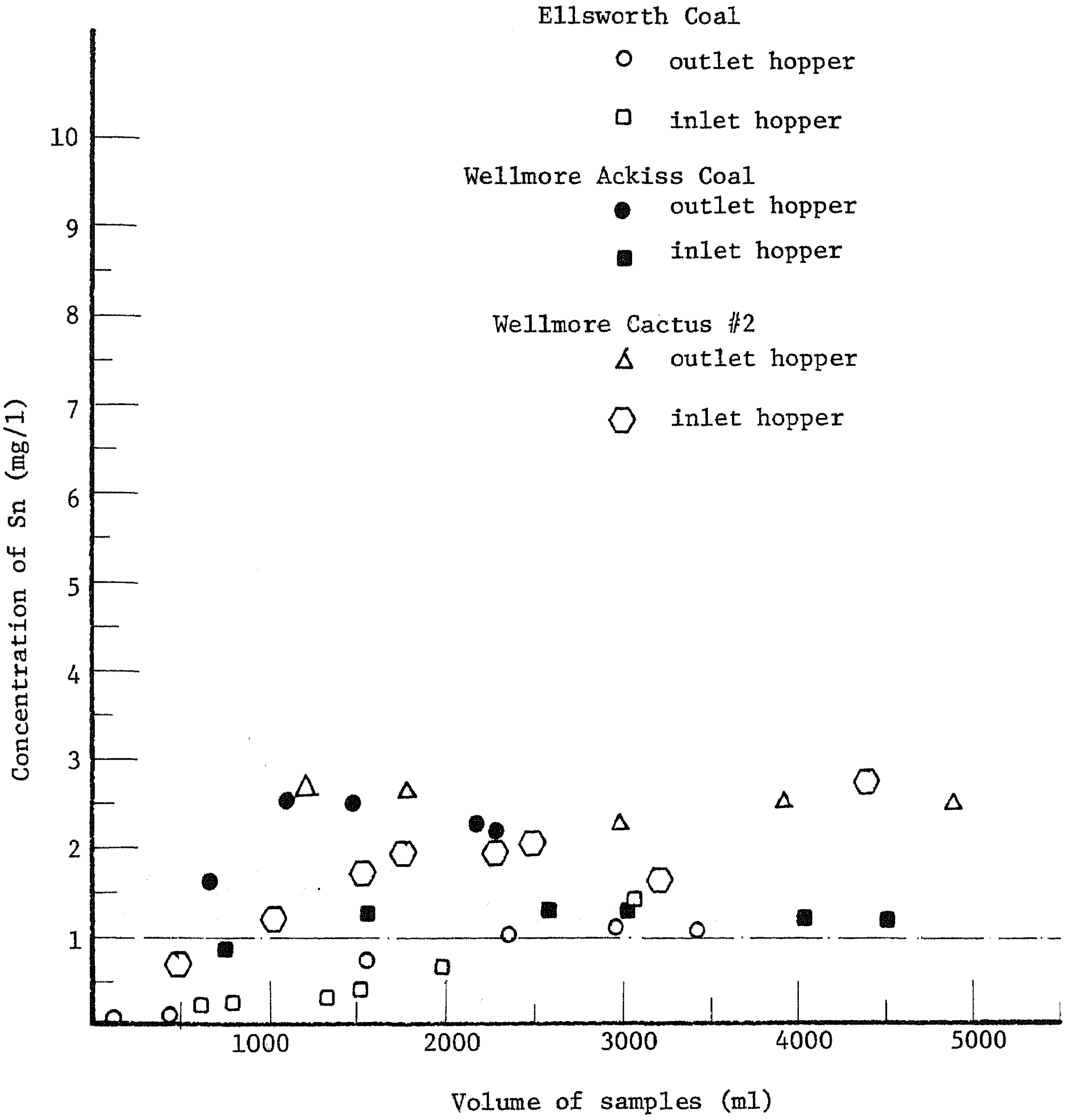


FIGURE 7.5

Sn - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

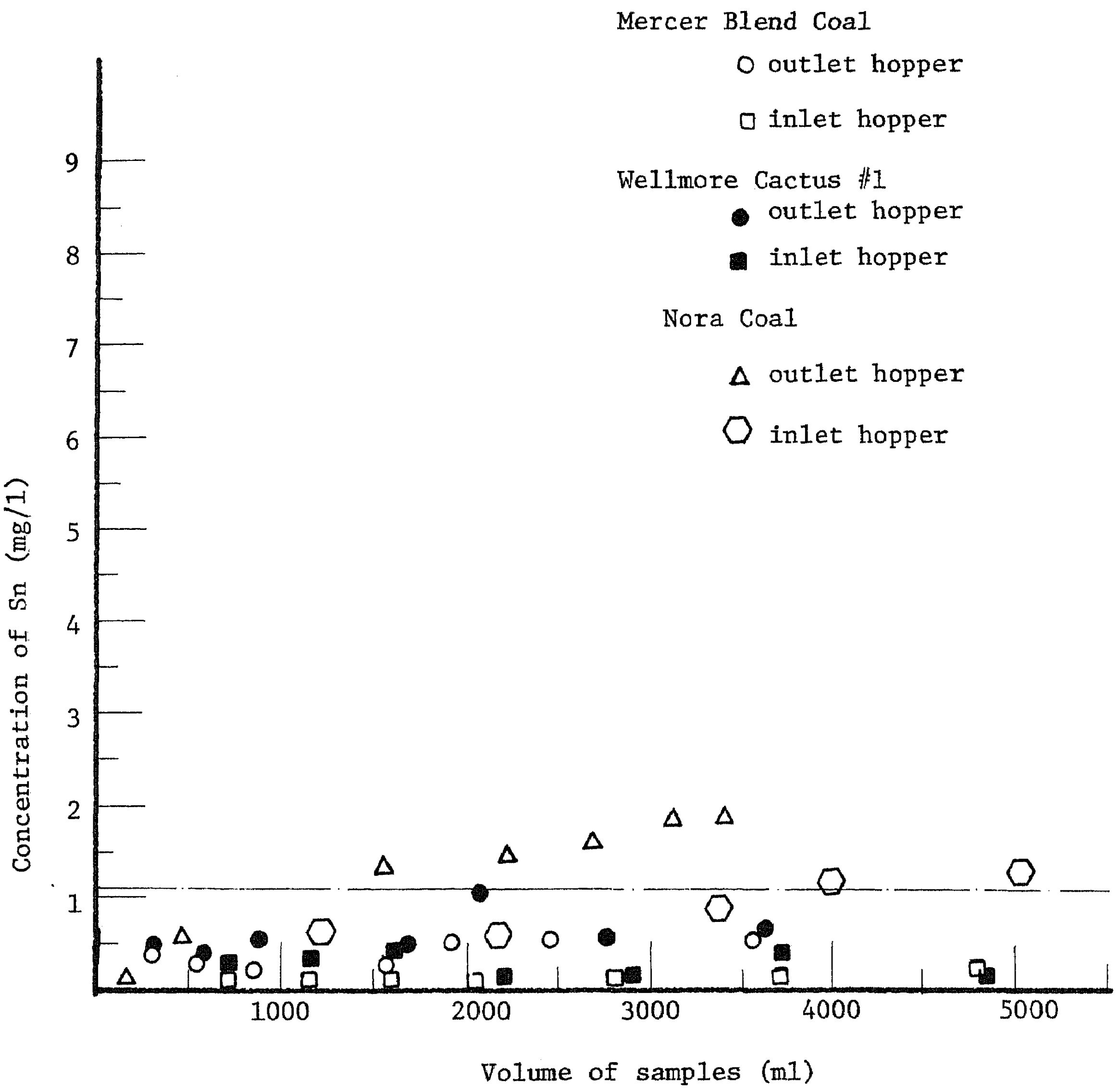


FIGURE 7.6

Sn - Absorbent Profile of Fly Ash
High Power

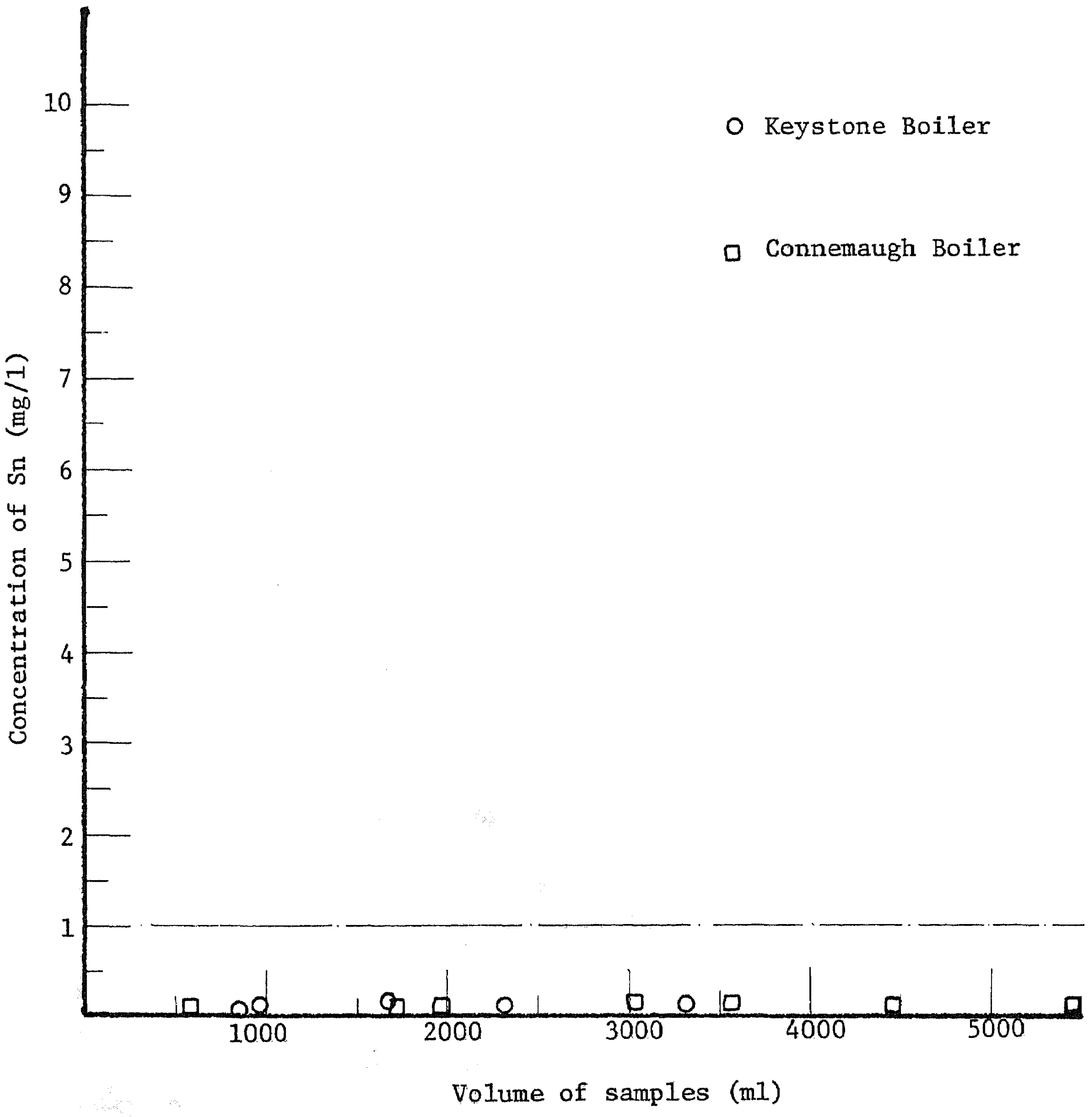


FIGURE 8.1

Ni - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

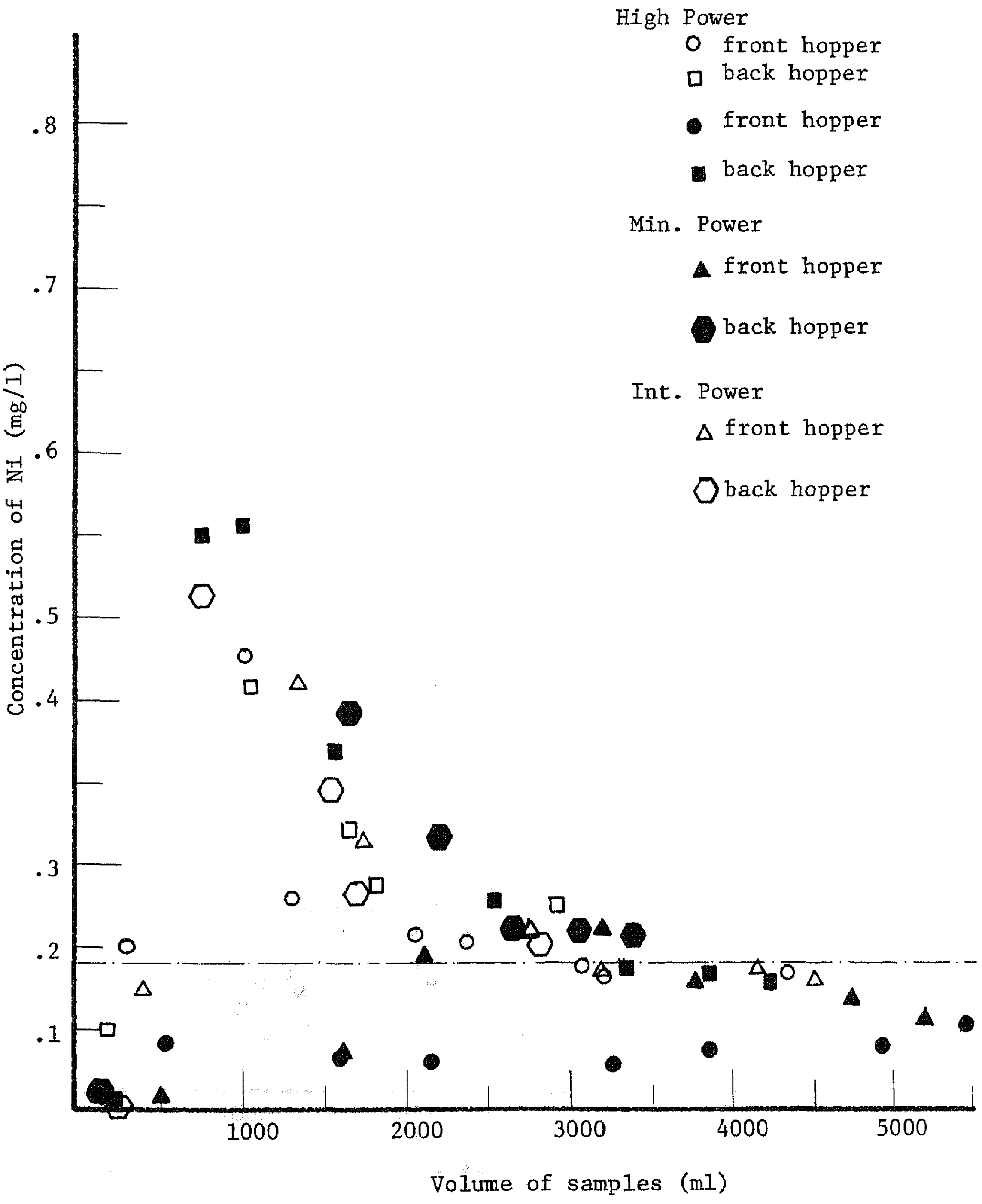


FIGURE 8.2

Ni - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow

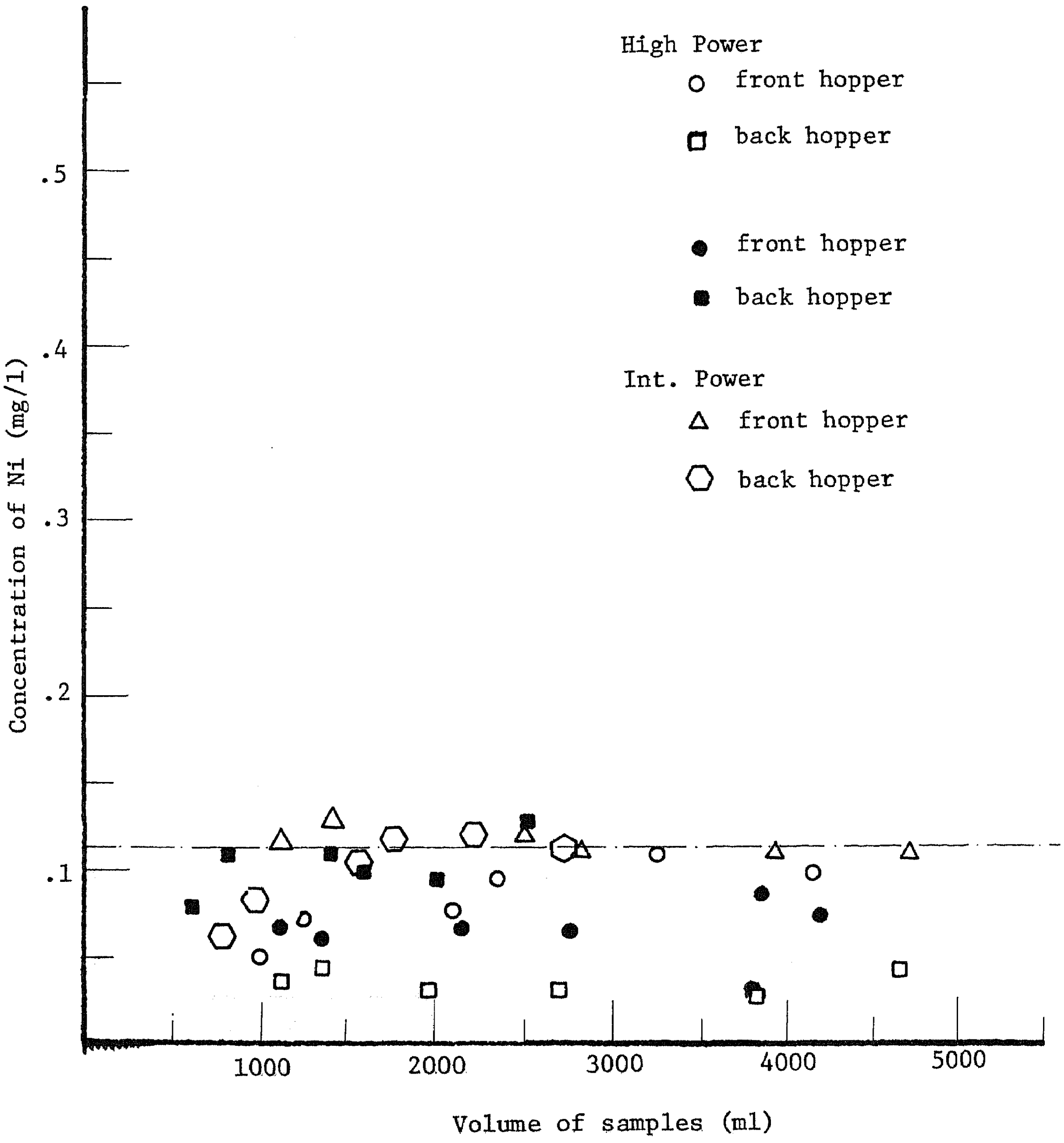


FIGURE 8.3

Ni - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

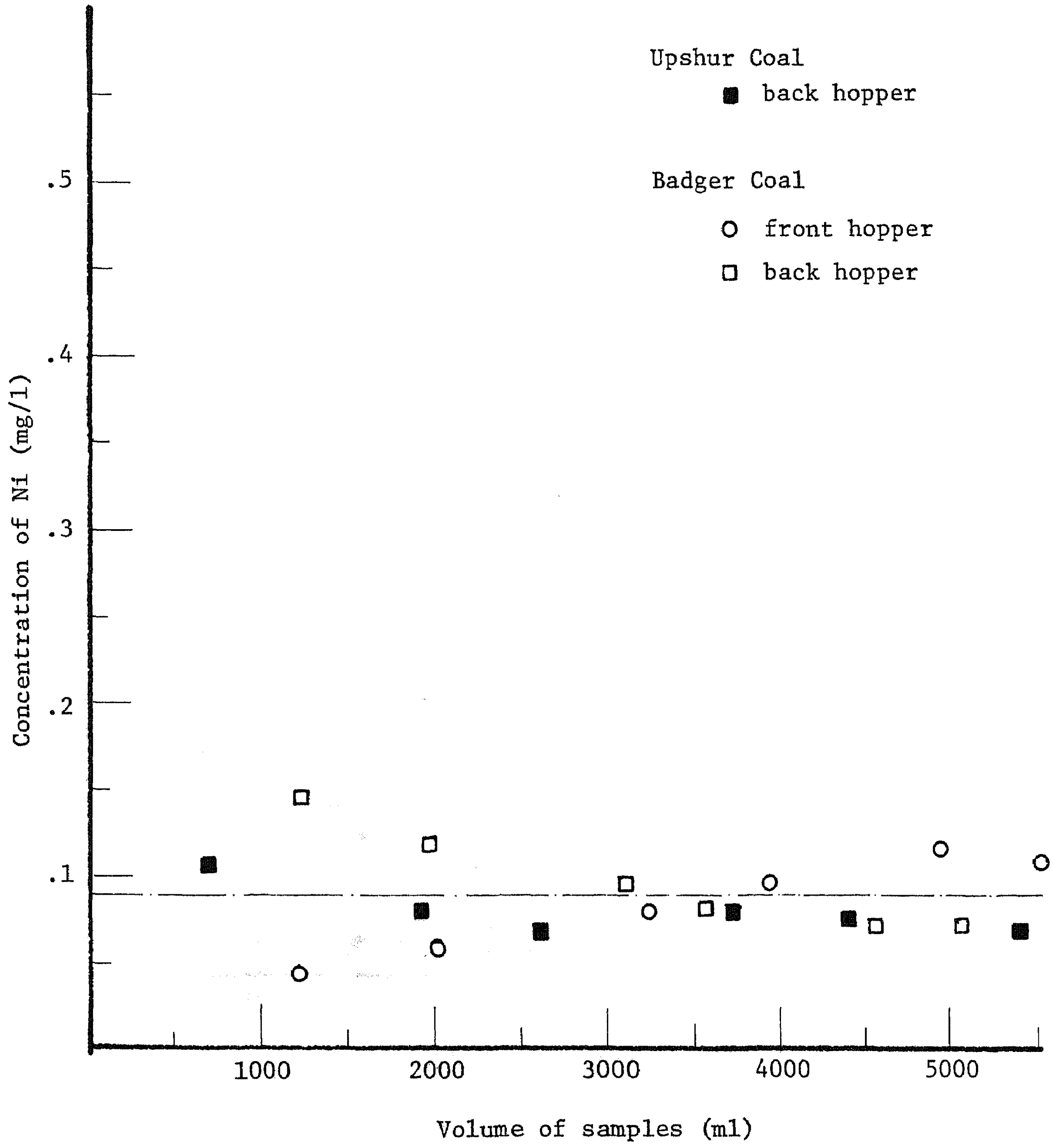


FIGURE 8.4

Ni - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

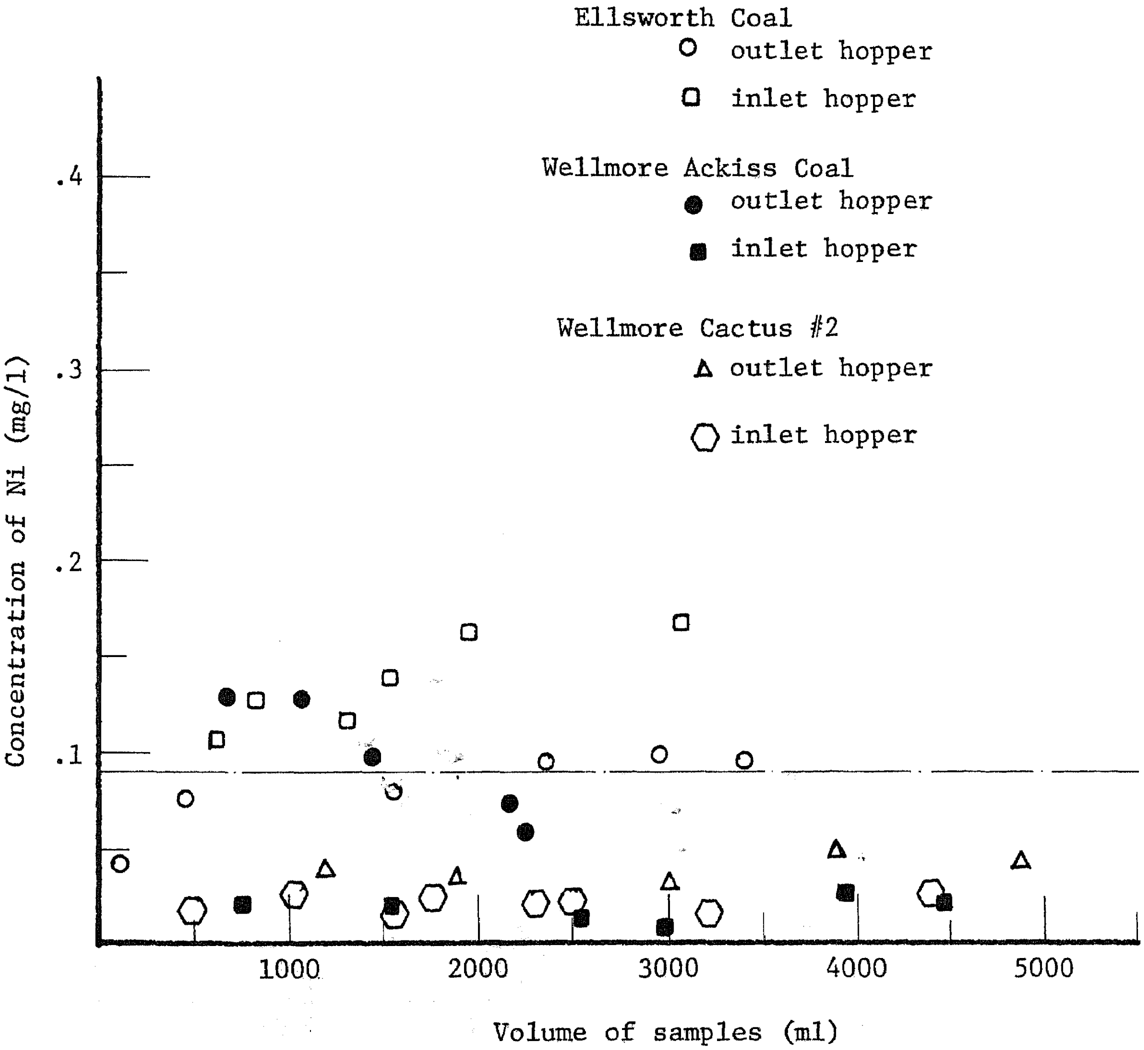


FIGURE 8.5

Ni - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

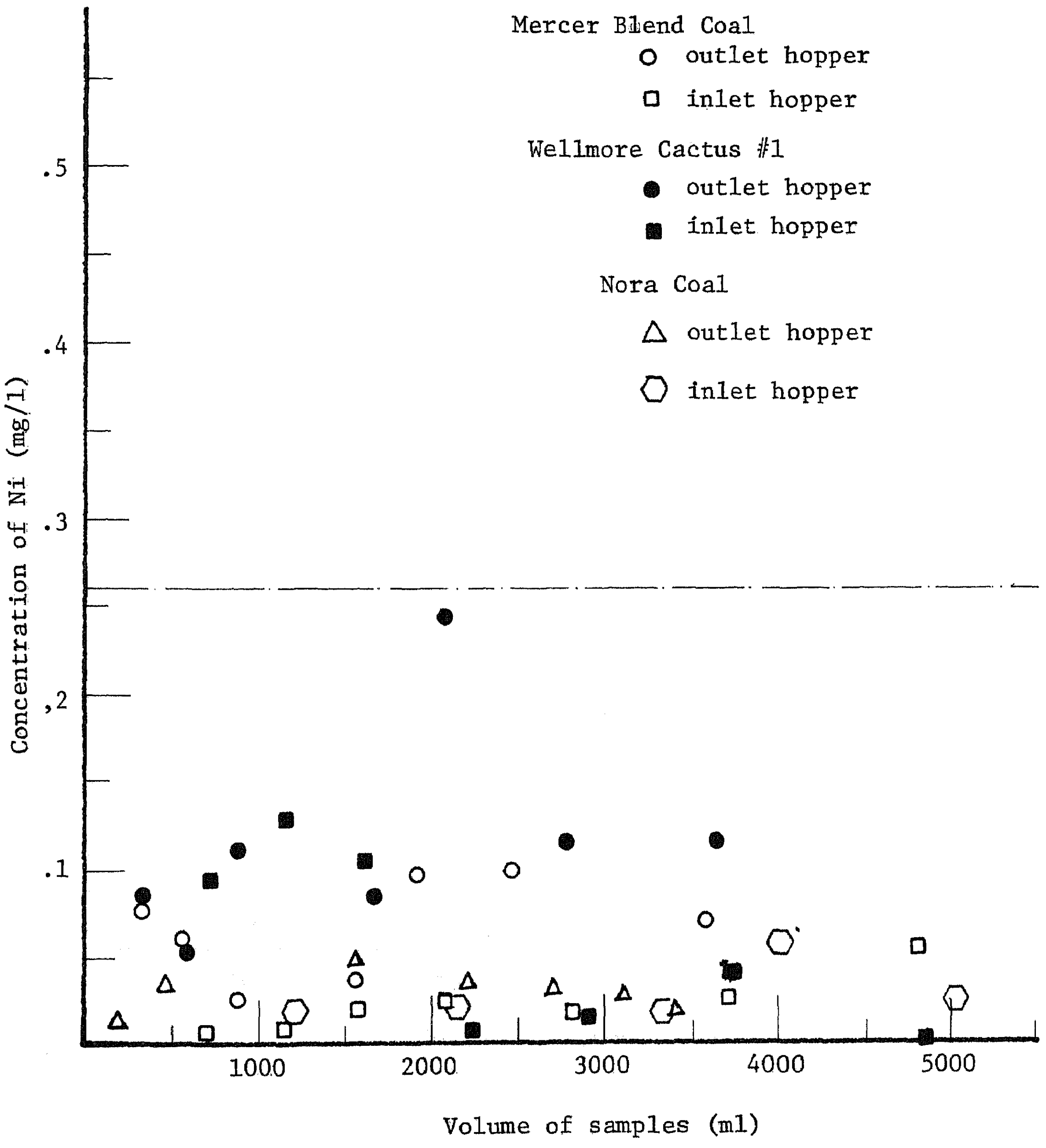


FIGURE 8.6

Ni - Absorbent Profile of Fly Ash
High Power

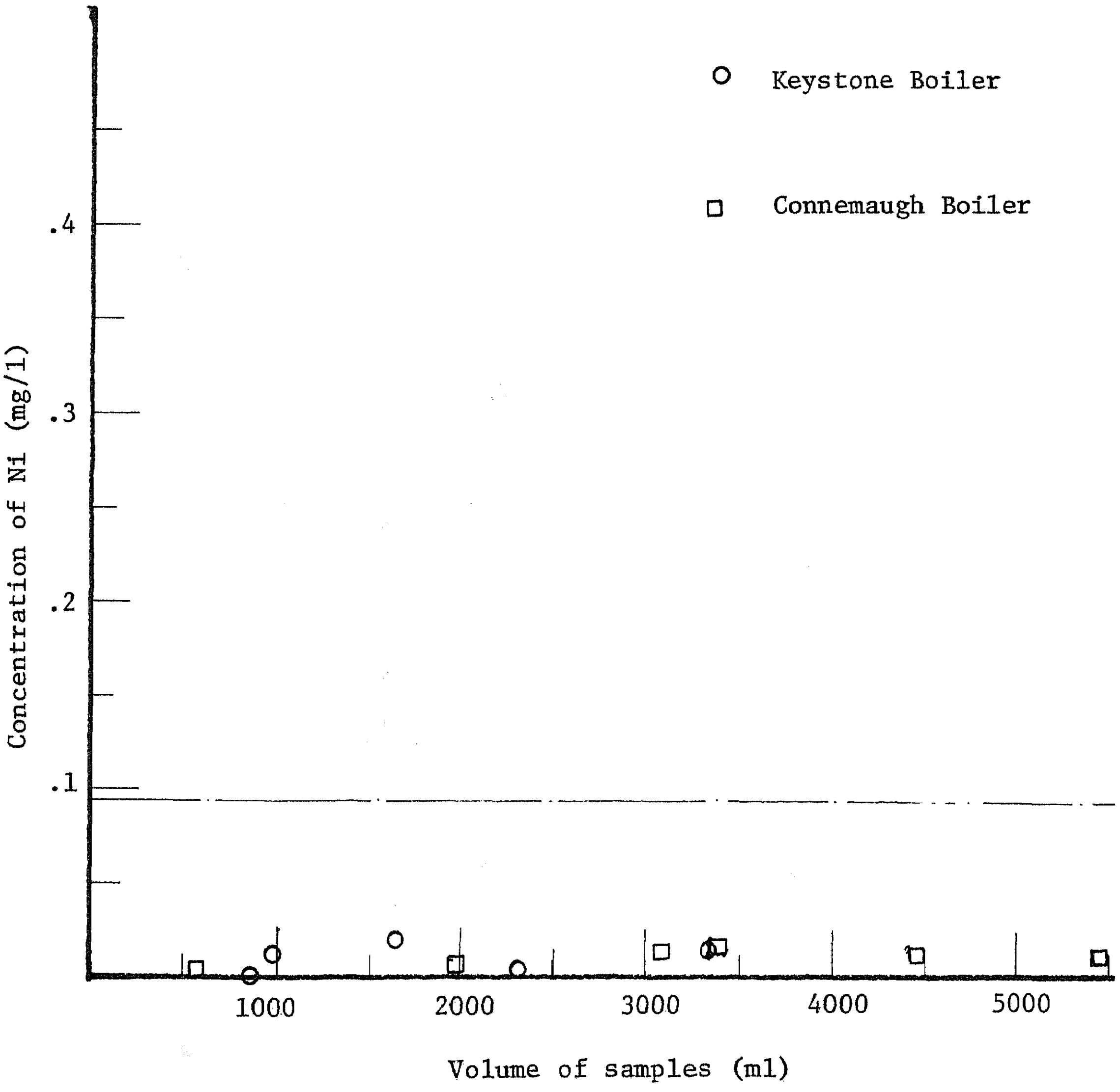


FIGURE 9.1

Pb - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

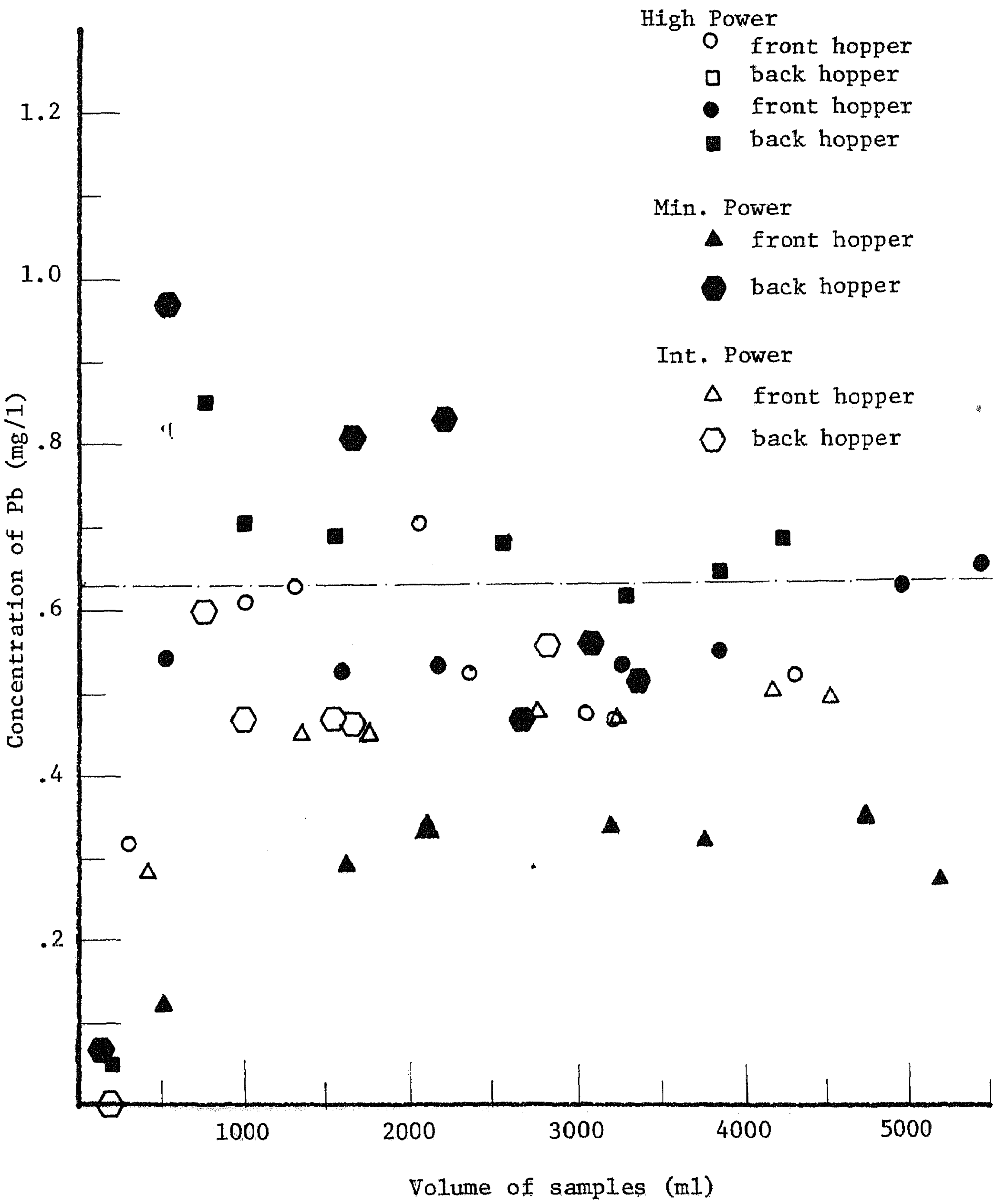


FIGURE 9.2

Pb - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow

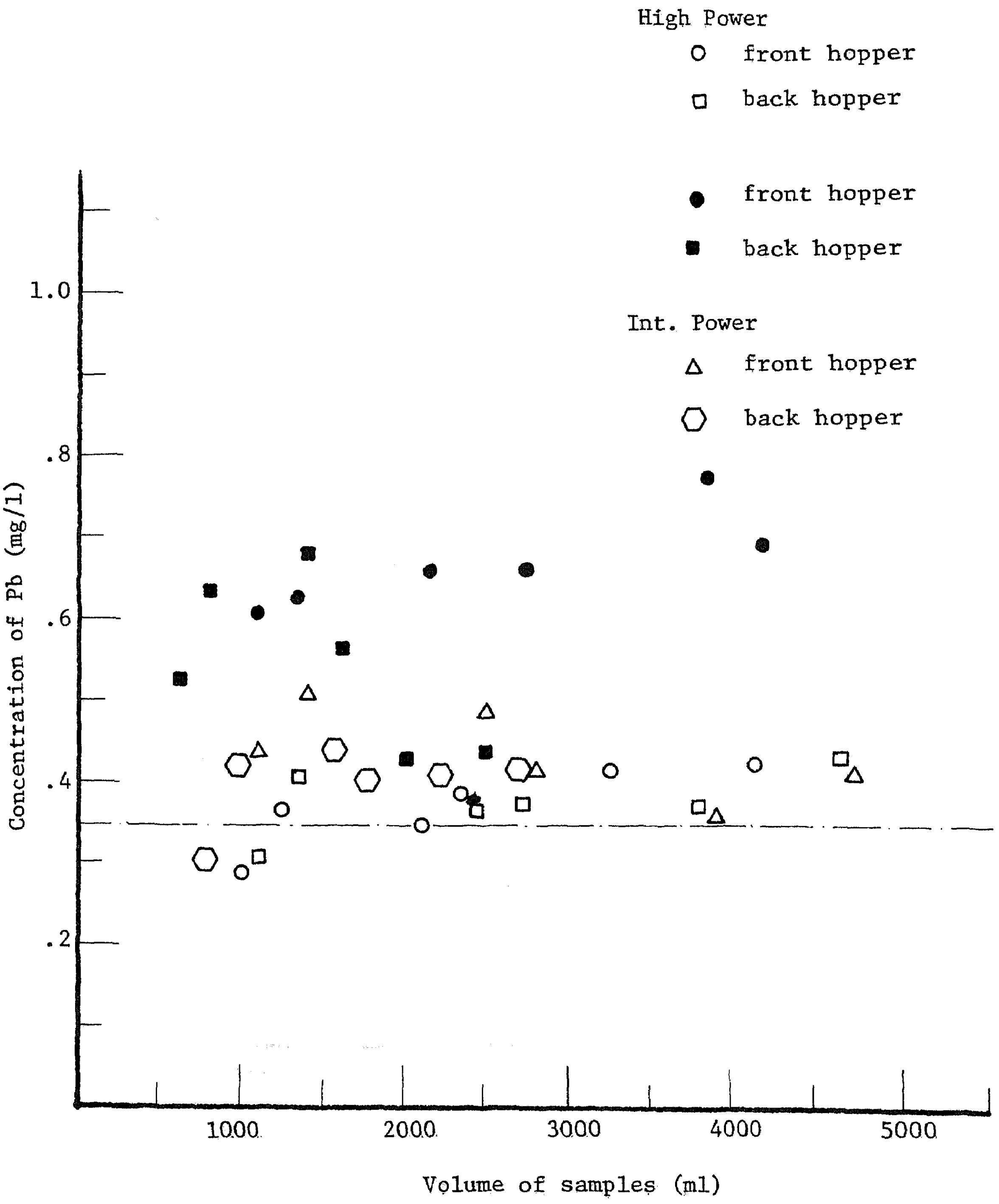


FIGURE 9.3

Pb - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

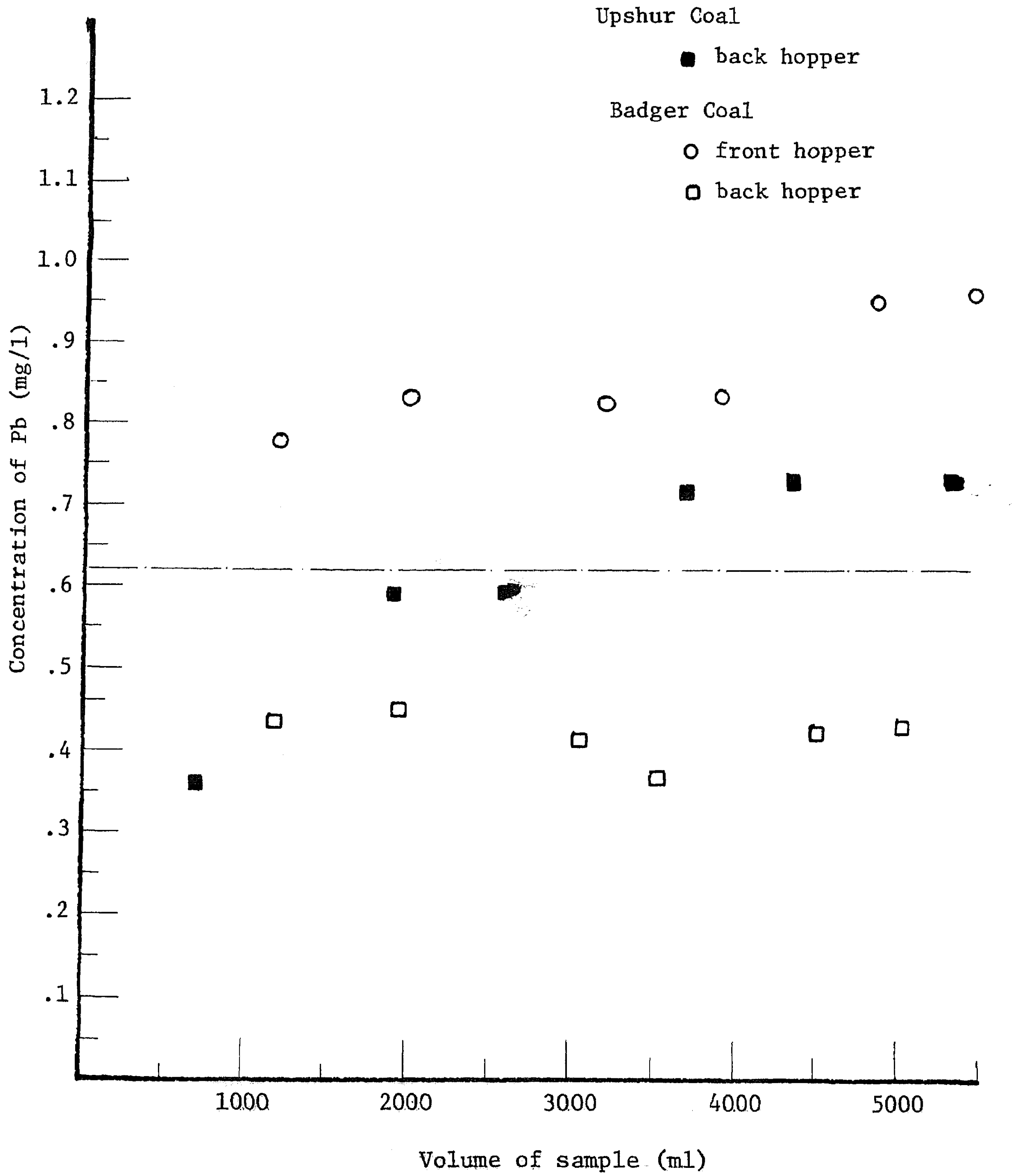


FIGURE 9.4

Pb - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

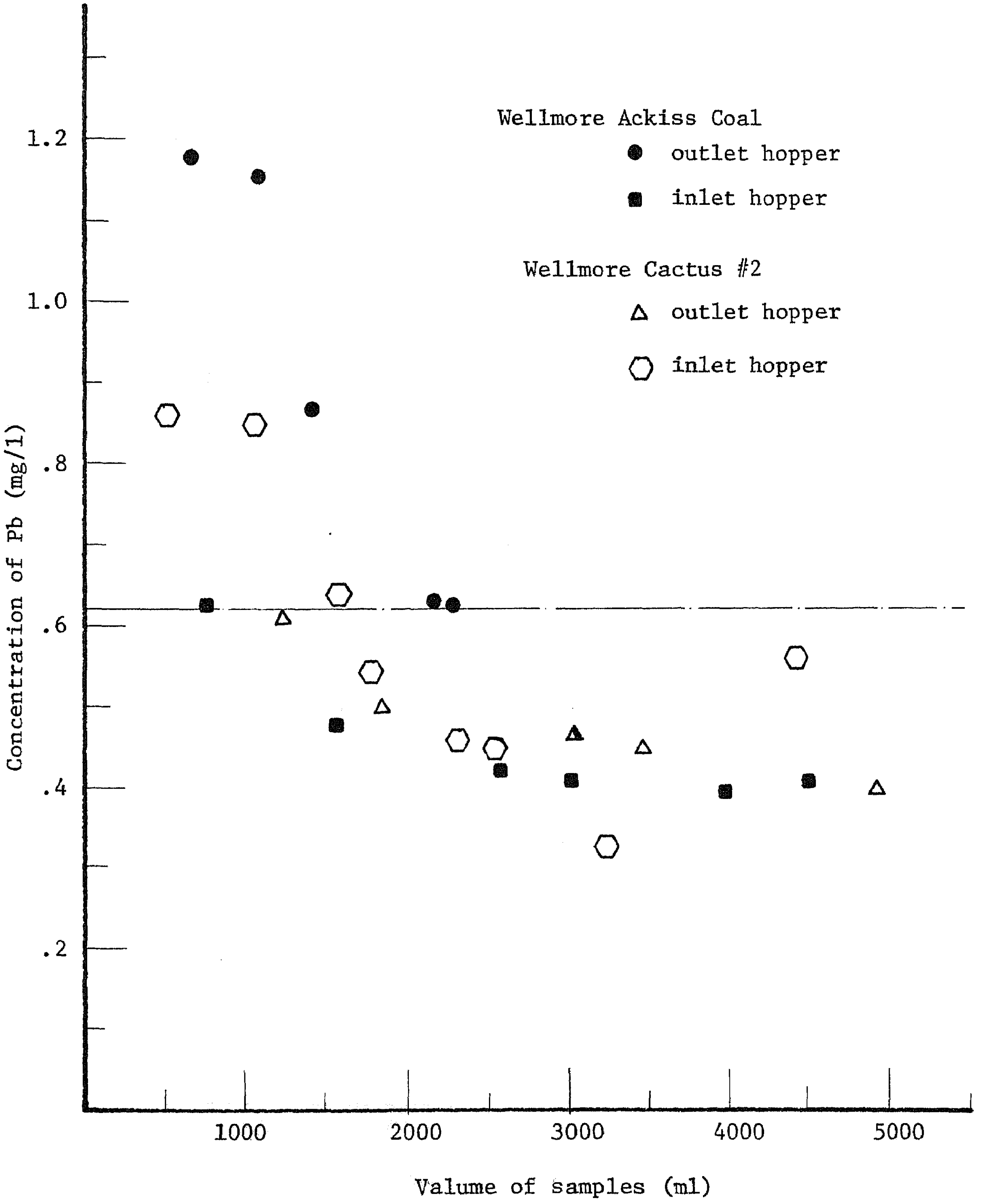


FIGURE 9.5

Pb – Absorbent Profile of Fly Ash
High Power
Mercer Boiler

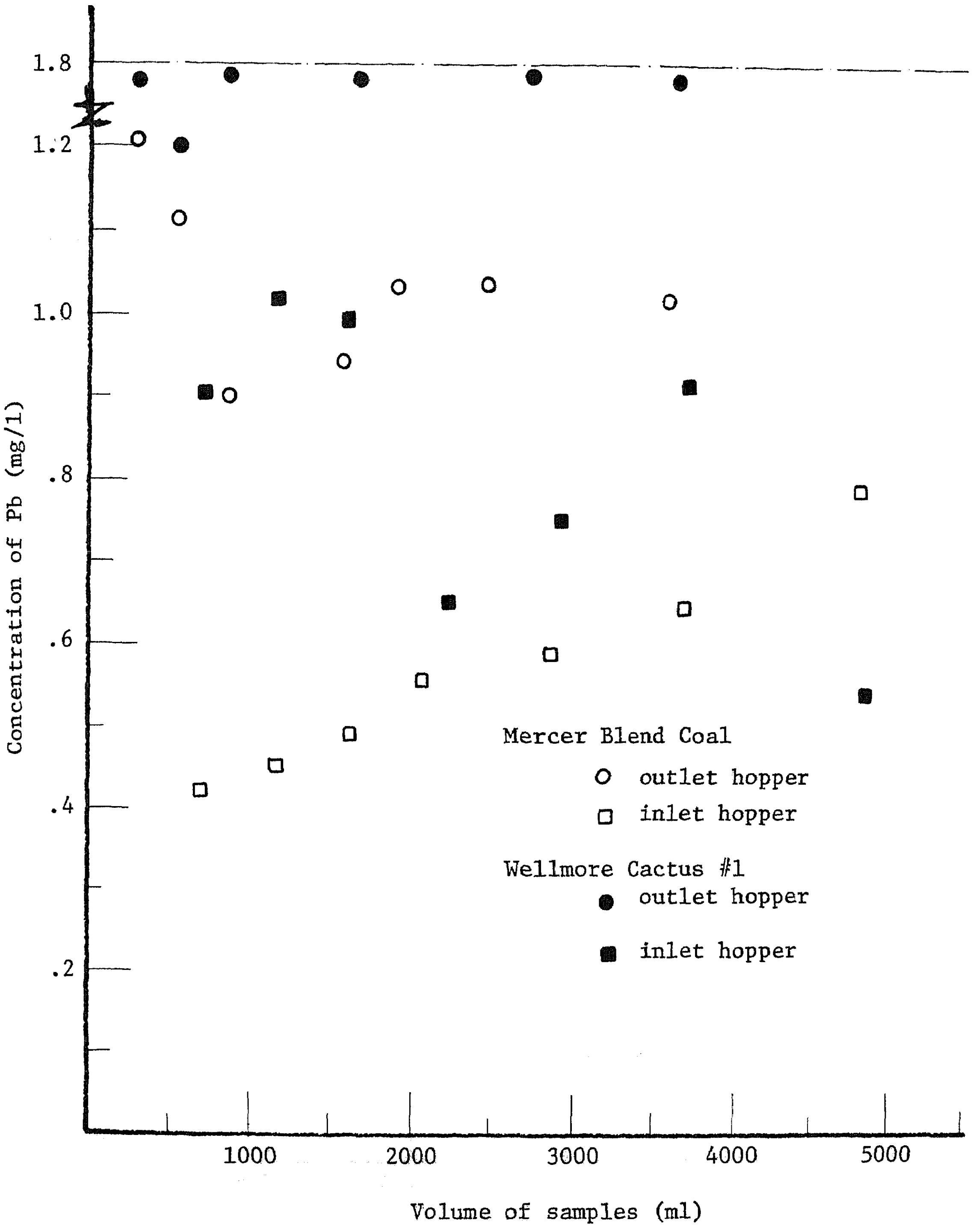


FIGURE 9.6

Pb - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

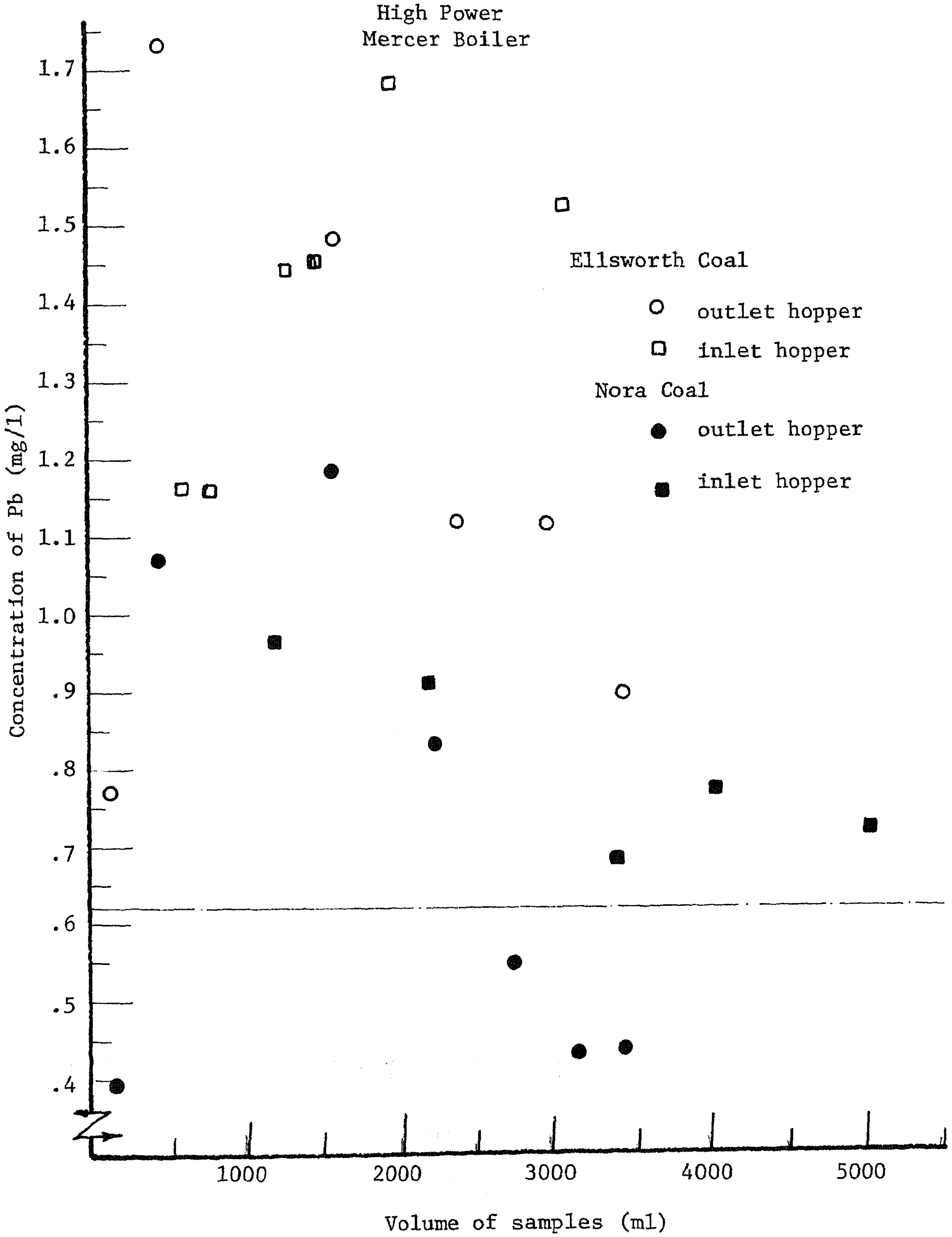


FIGURE 9.7

Pb - Absorbent Profile of Fly Ash
High Power

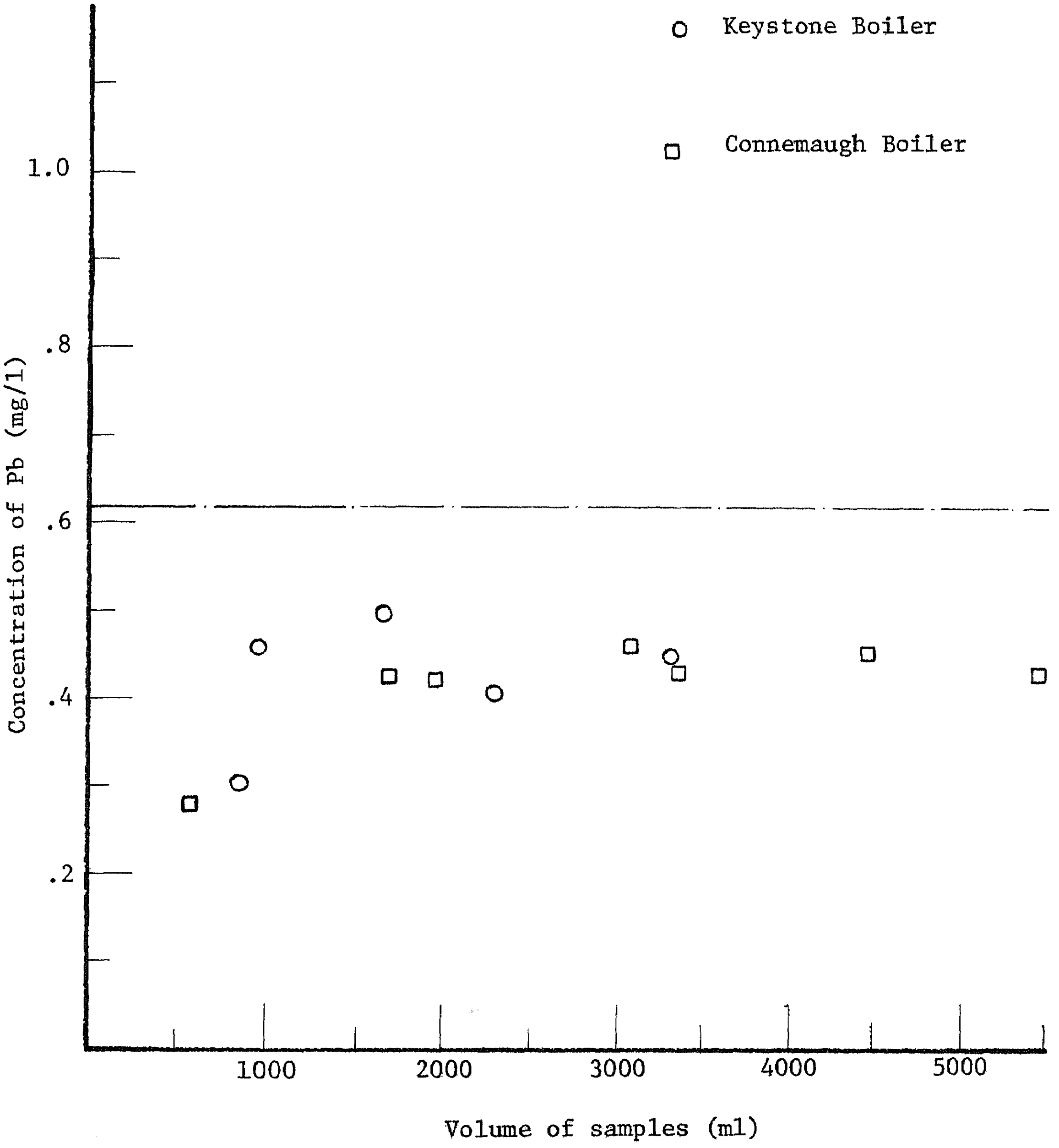


FIGURE 10.1 Mo - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

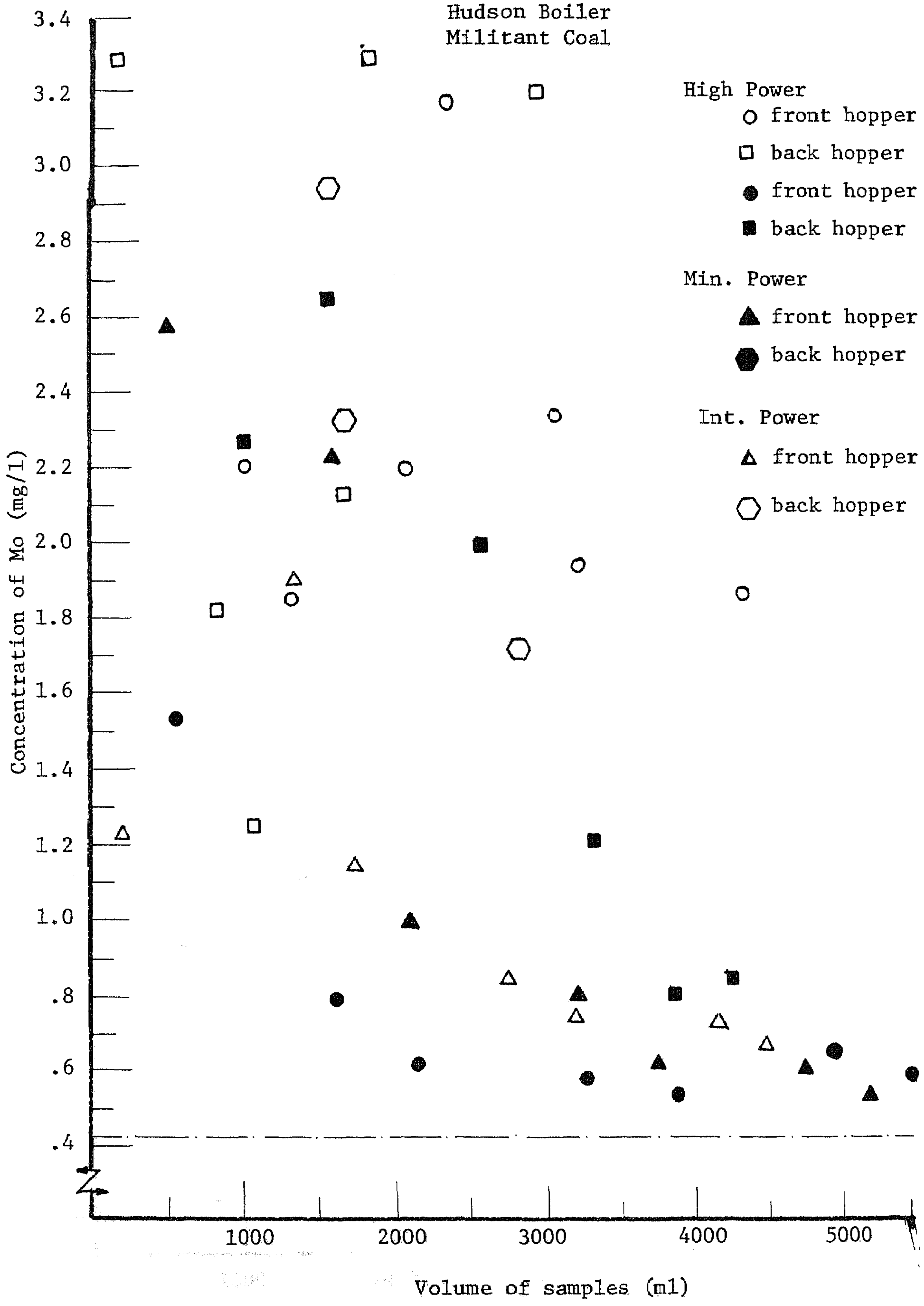


FIGURE 10.2

Mo - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

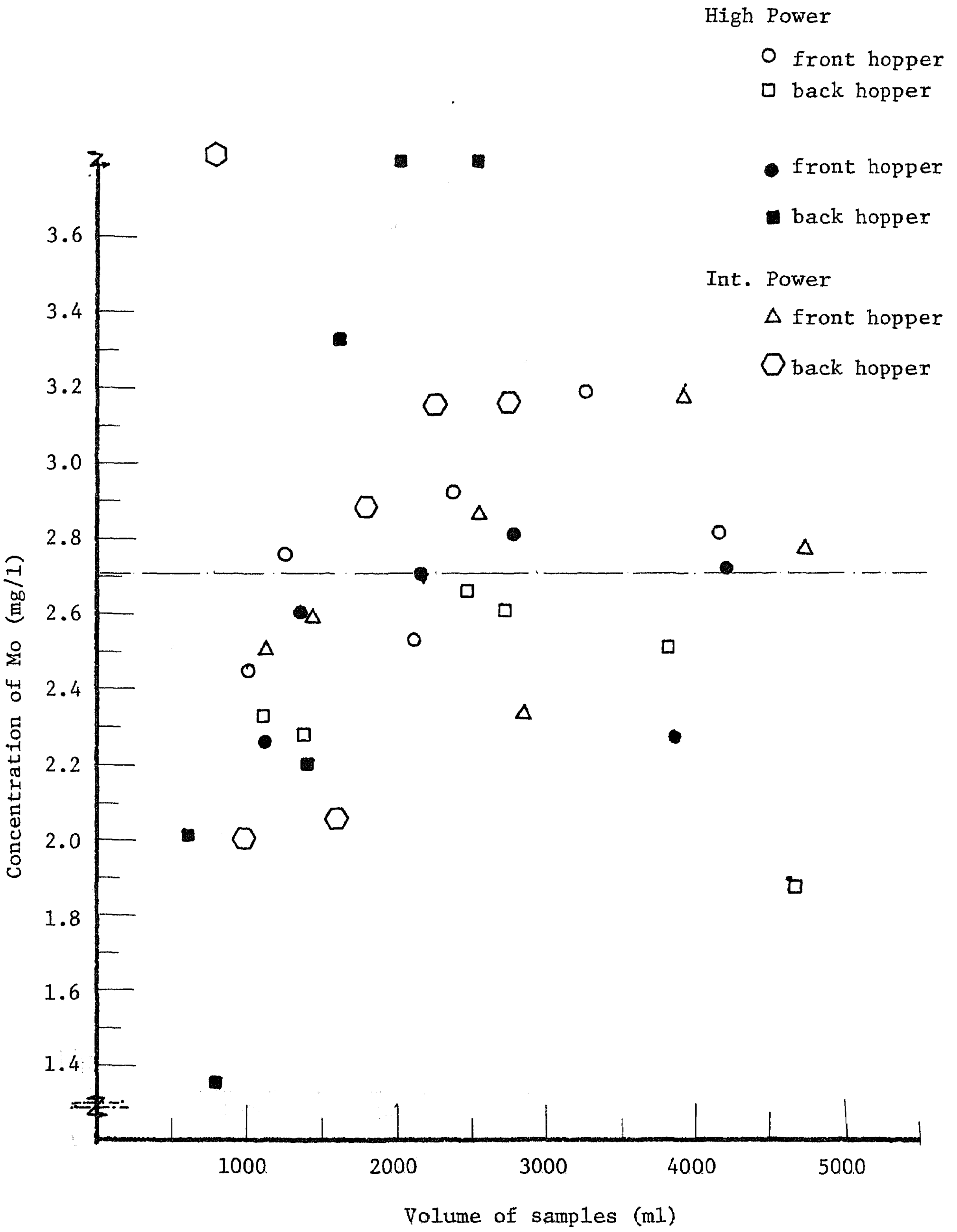


FIGURE 10.3

Mo - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

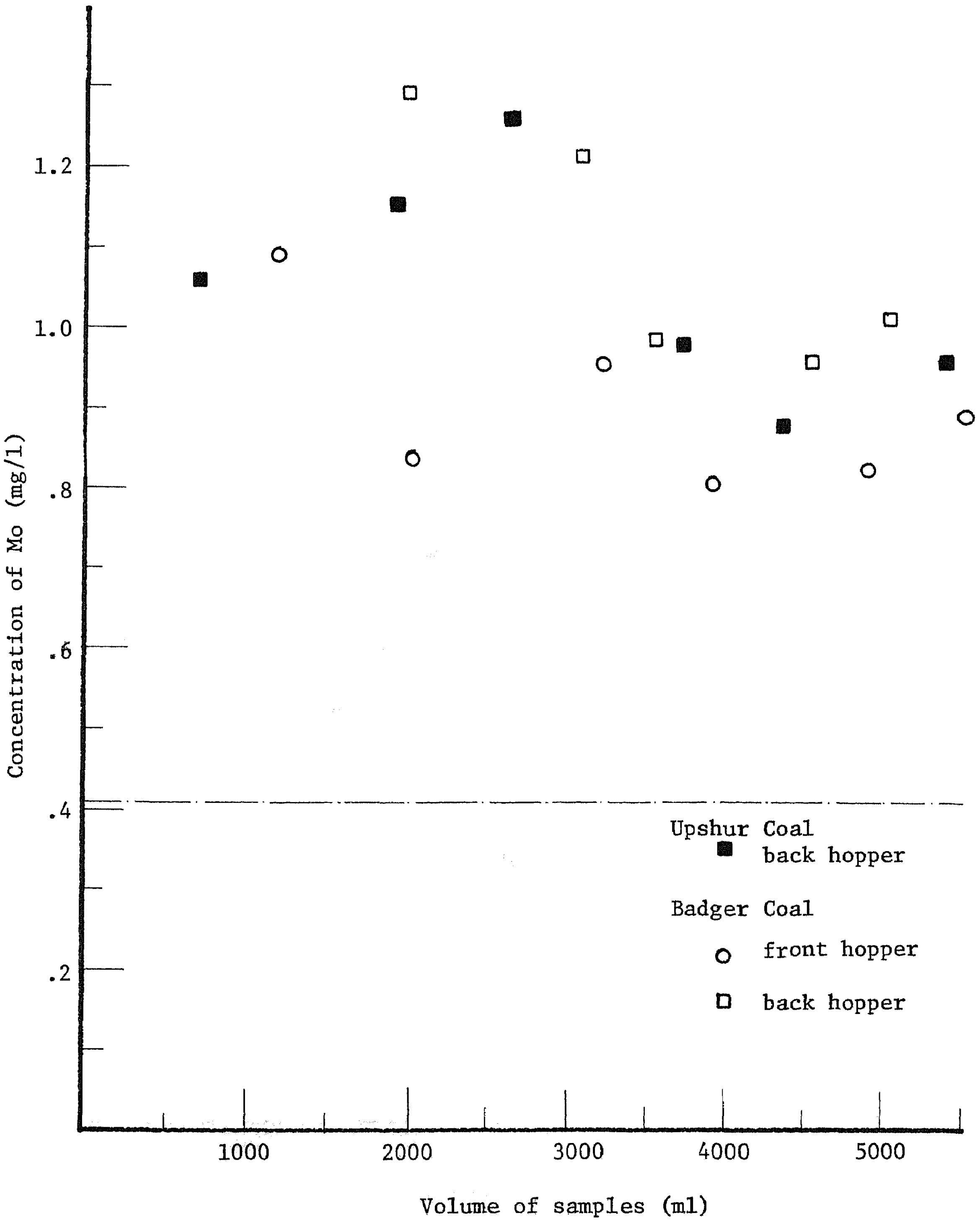


FIGURE 10.4

Mo - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

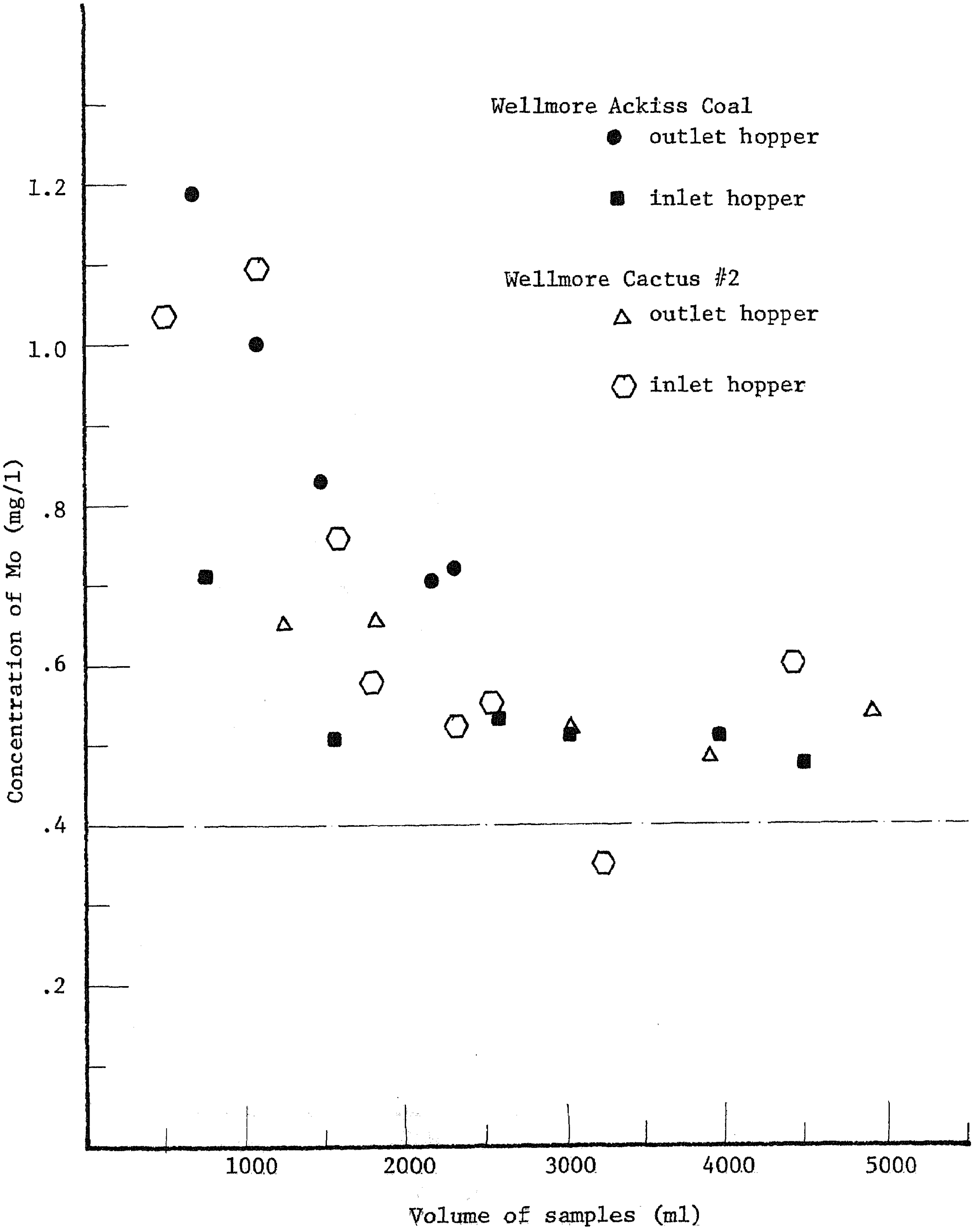


FIGURE 10.5

Mo - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

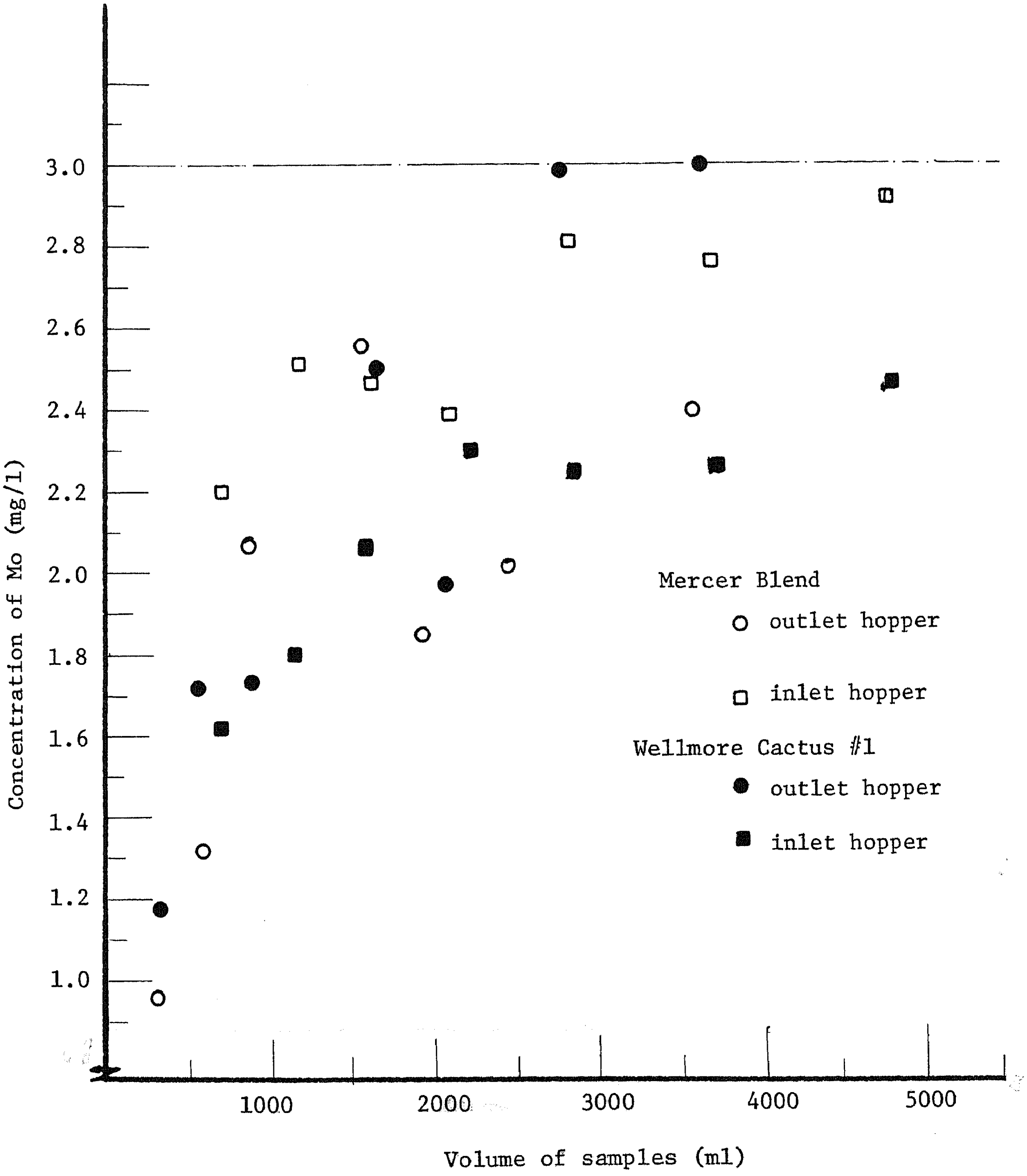


FIGURE 10. 6

Mo - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

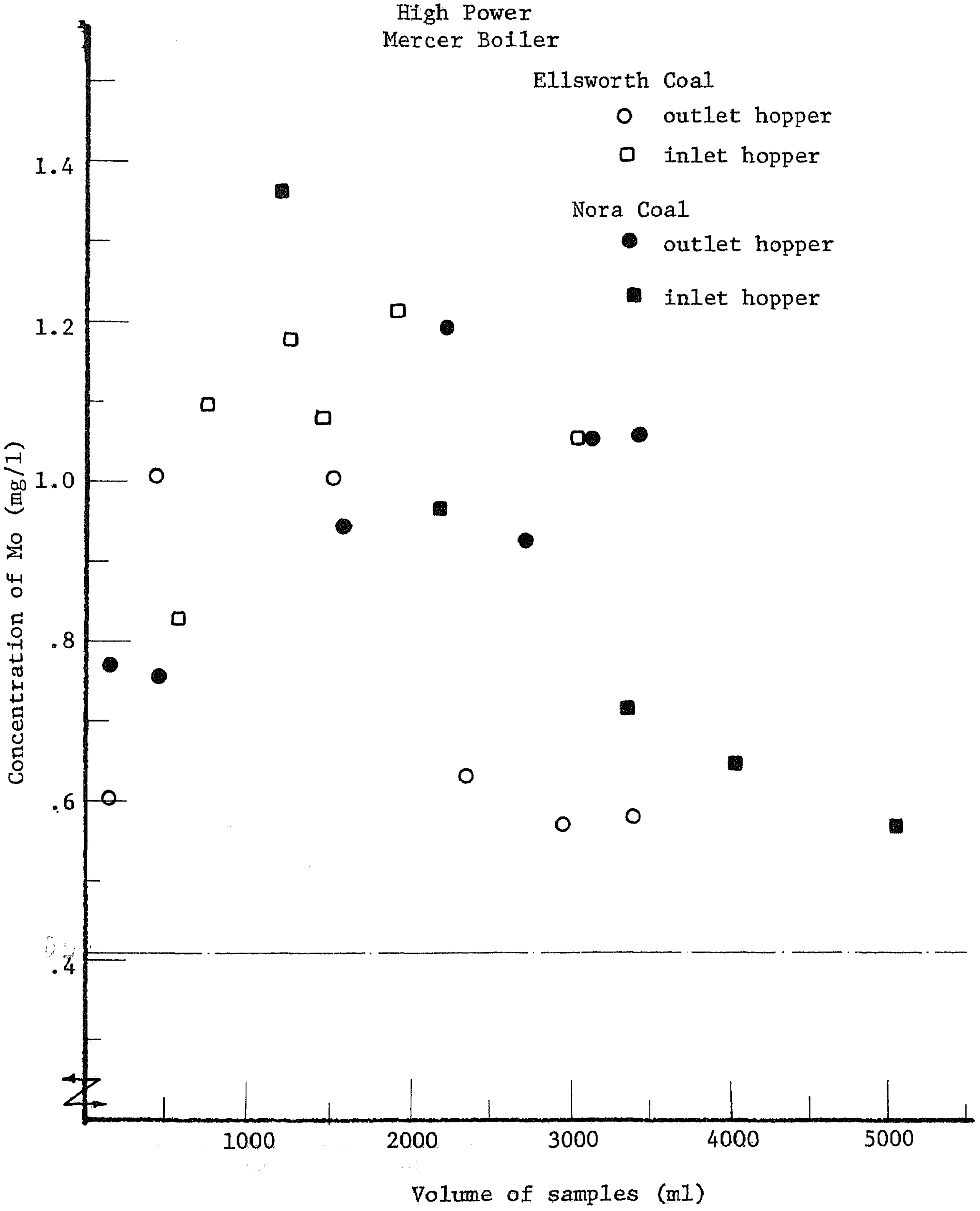


FIGURE 10.7

Mo - Absorbent Profile of Fly Ash
High Power

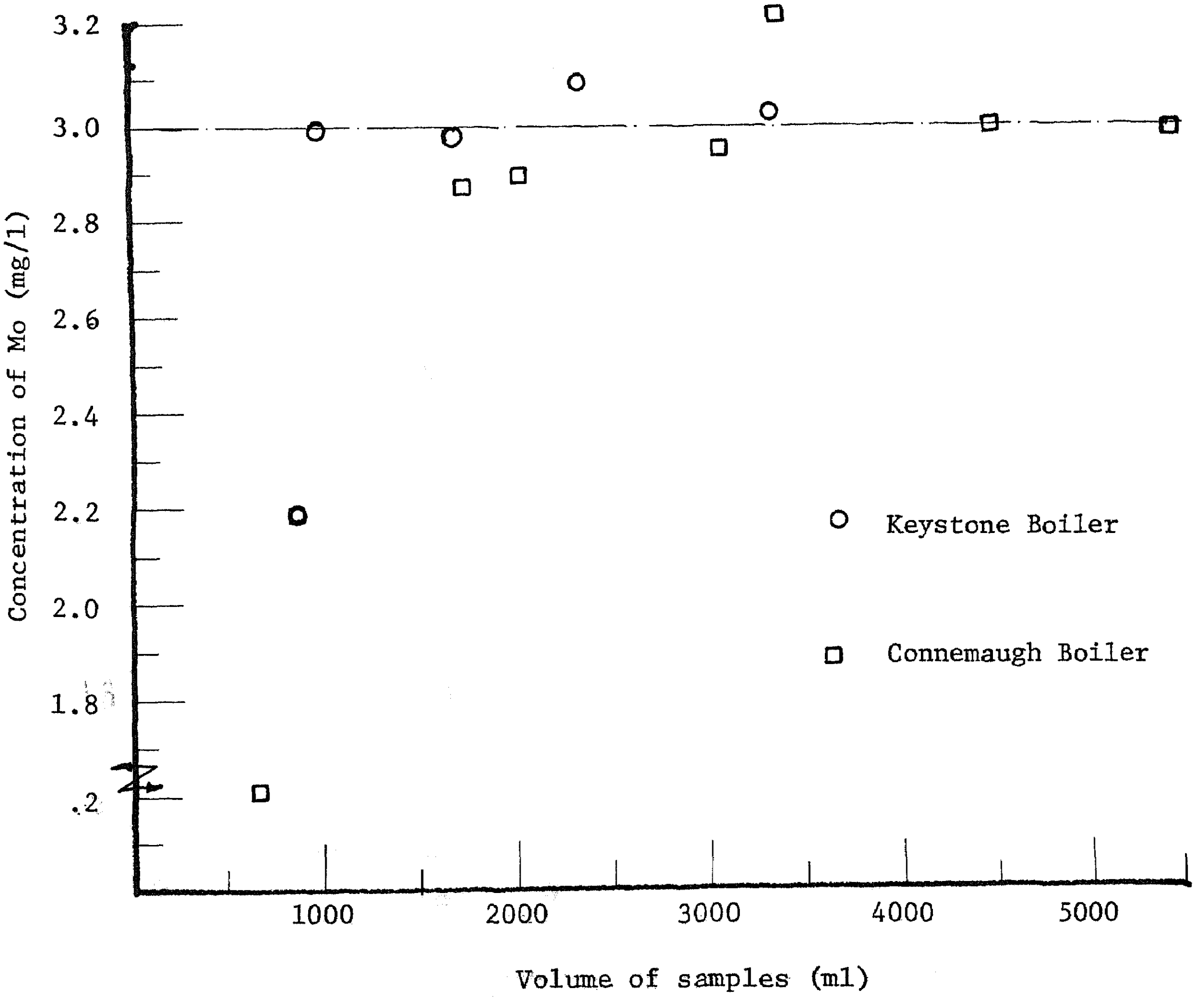


FIGURE 11.1

Cu - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

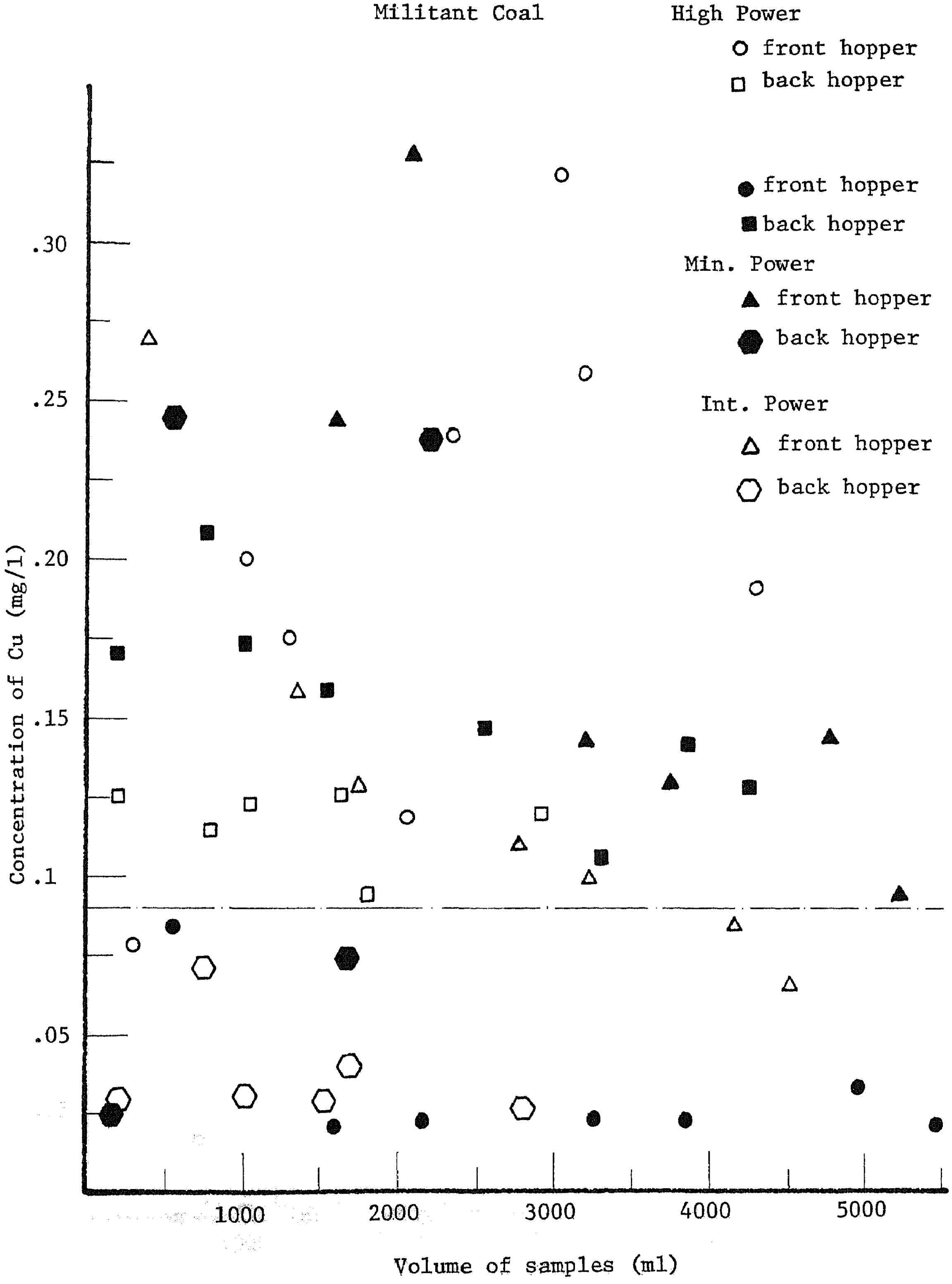


FIGURE 11.2

Cu - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

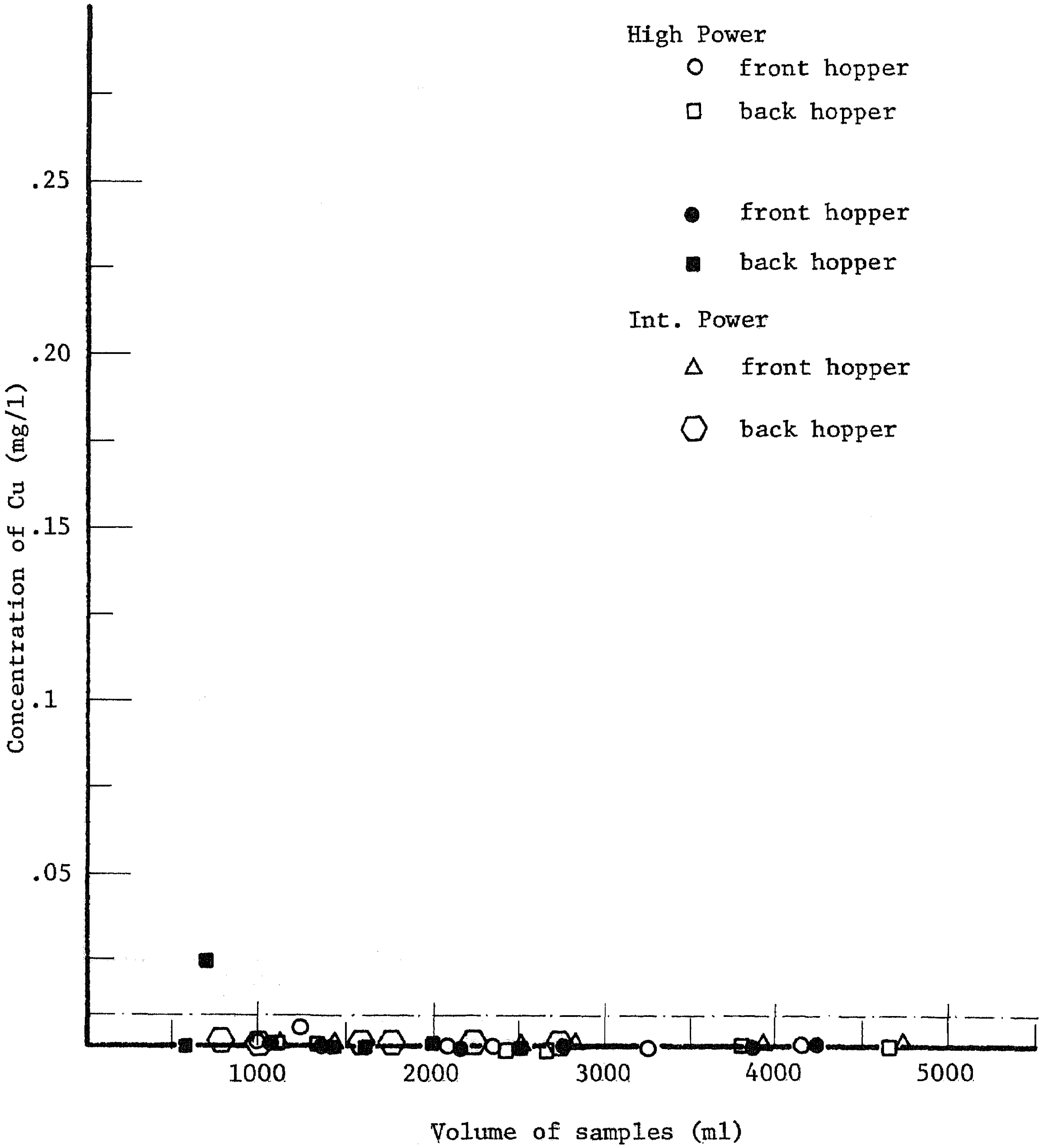


FIGURE 11.3

Cu - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

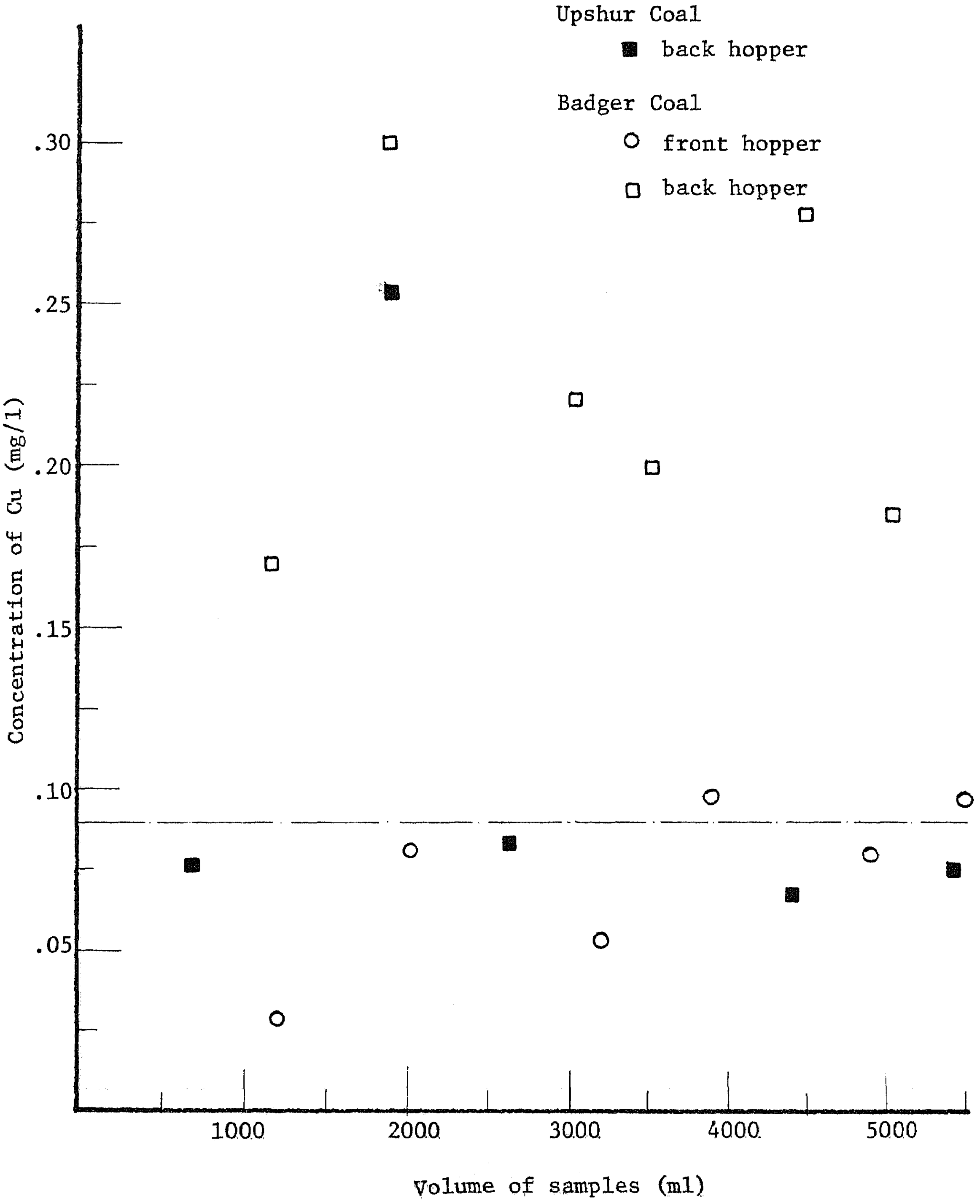


FIGURE 11.4

Cu - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

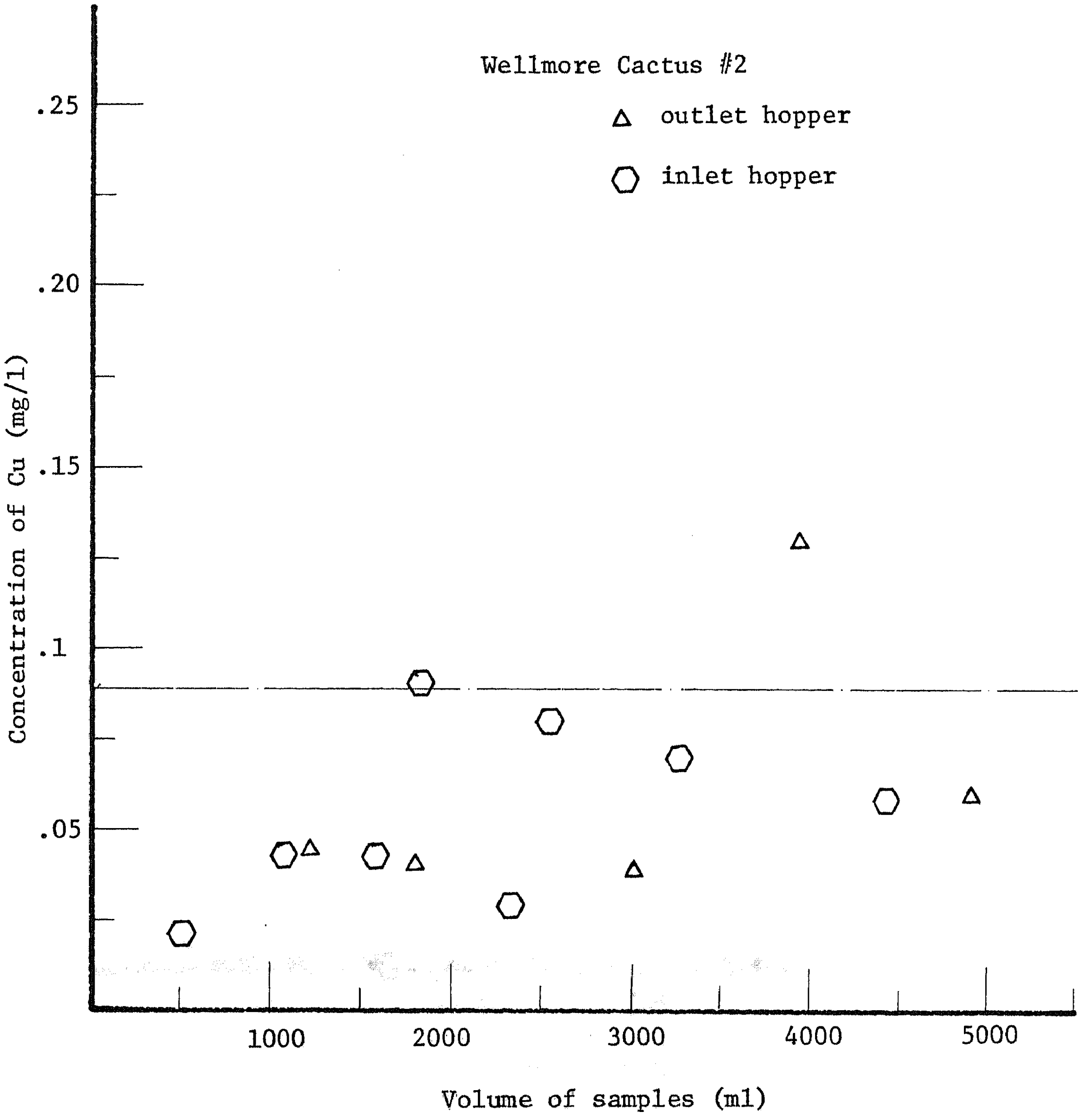


FIGURE 11.5

Cu - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

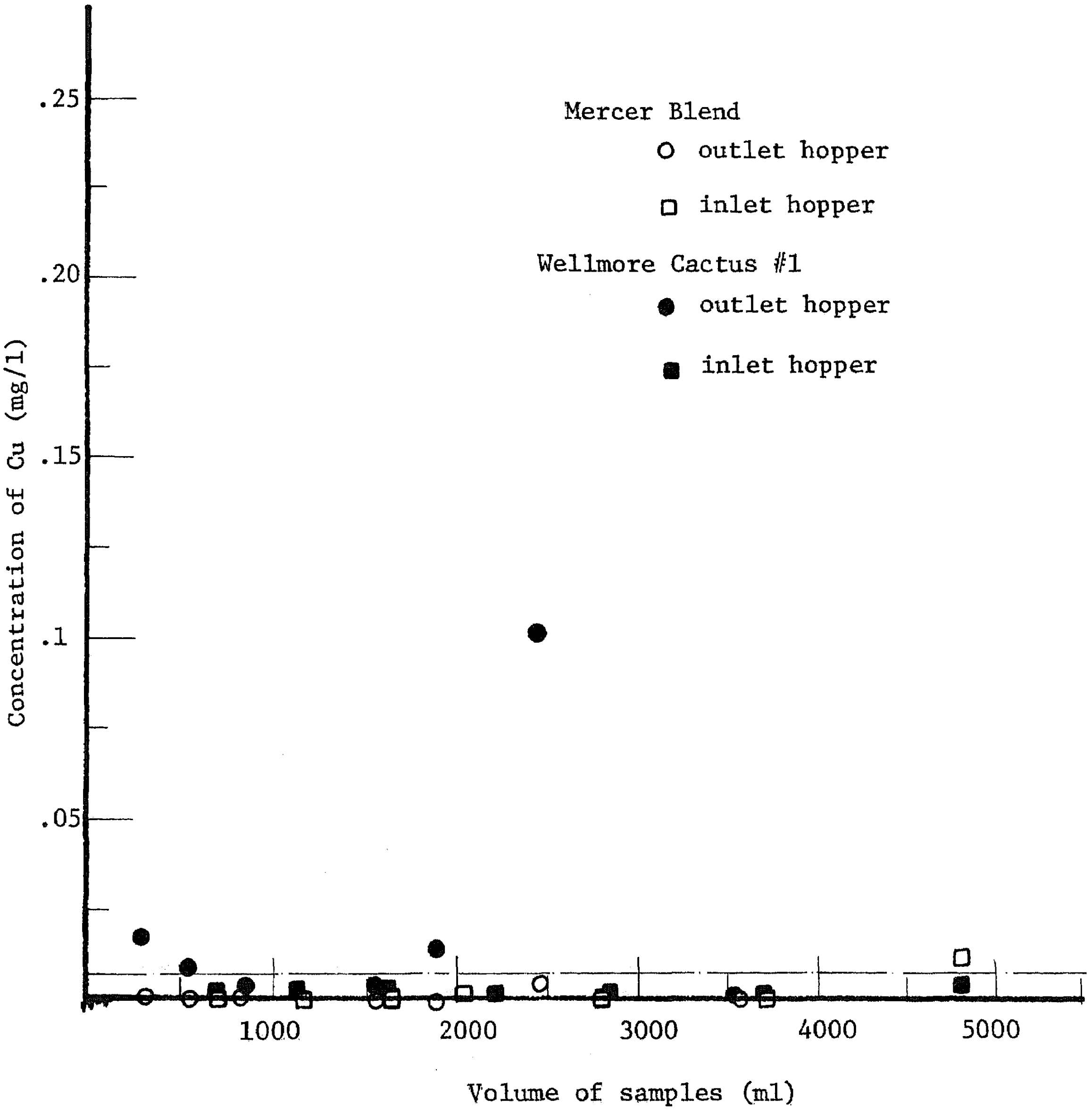


FIGURE 11.6

Cu - Absorbent Profile of Fly Ash
High Power
Mercer Coal

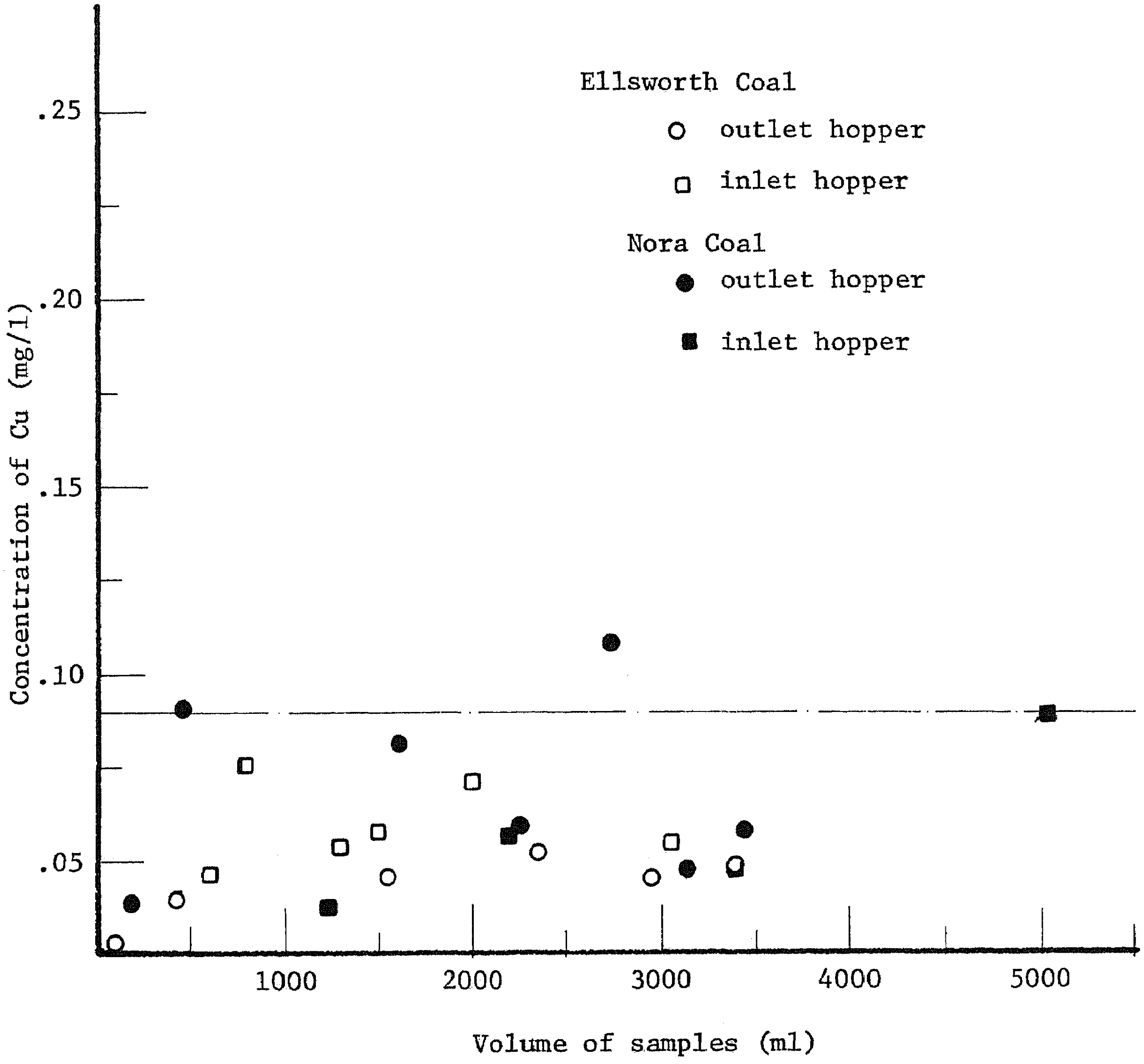


FIGURE 11.7

Cu - Absorbent Profile of Fly Ash
High Power

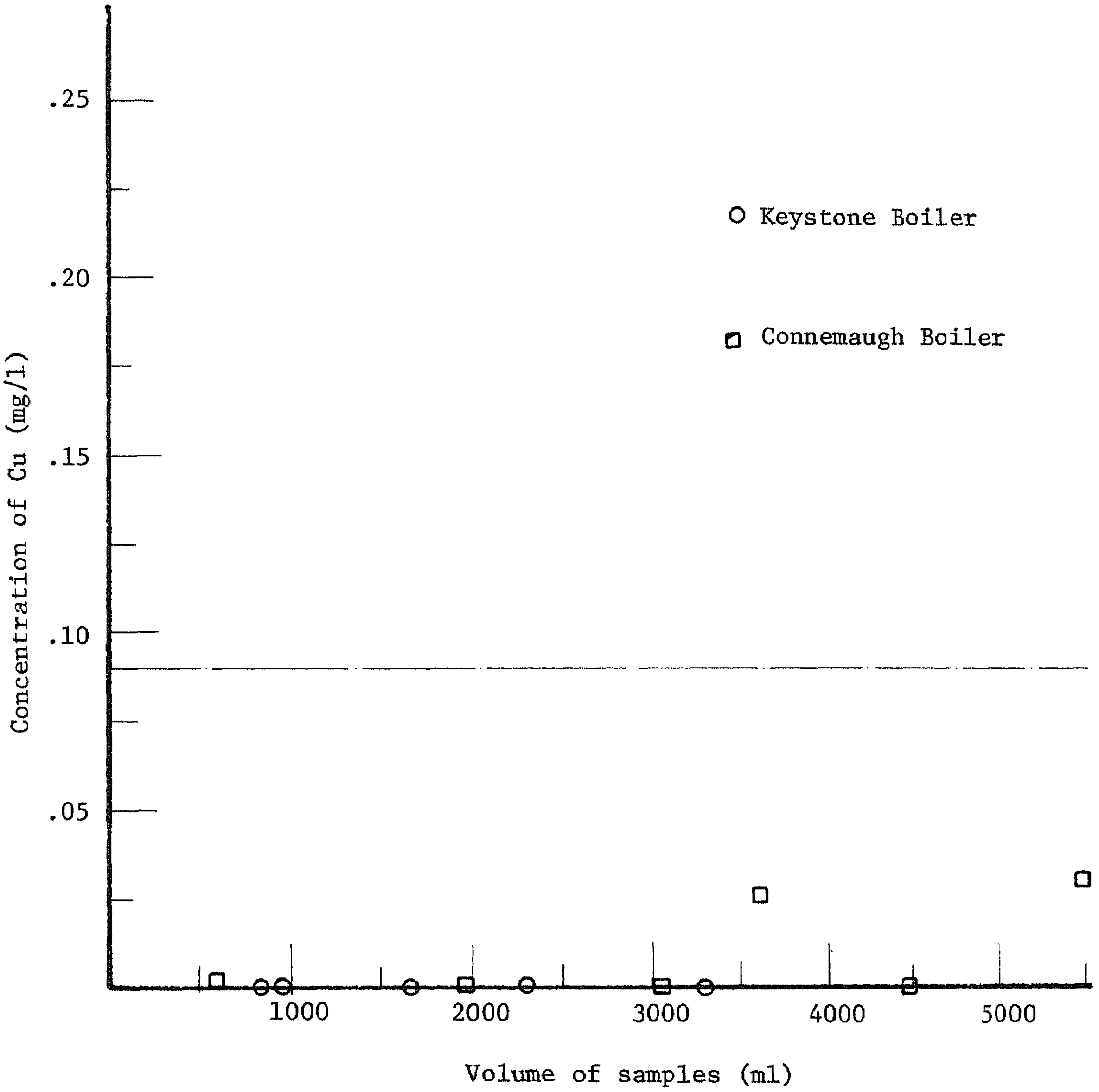


FIGURE 12.1

Cr - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

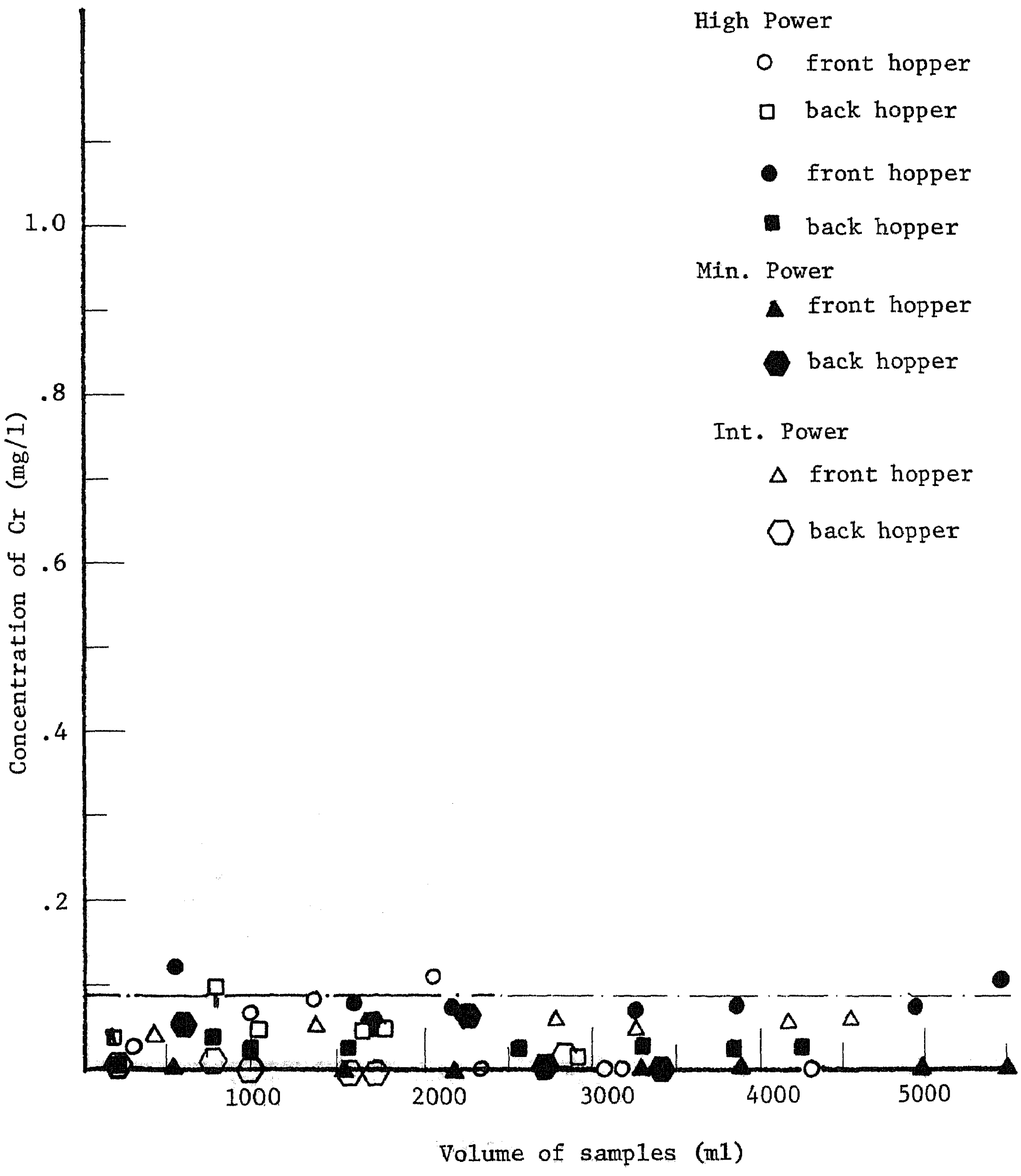


FIGURE 12.2

Cr - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

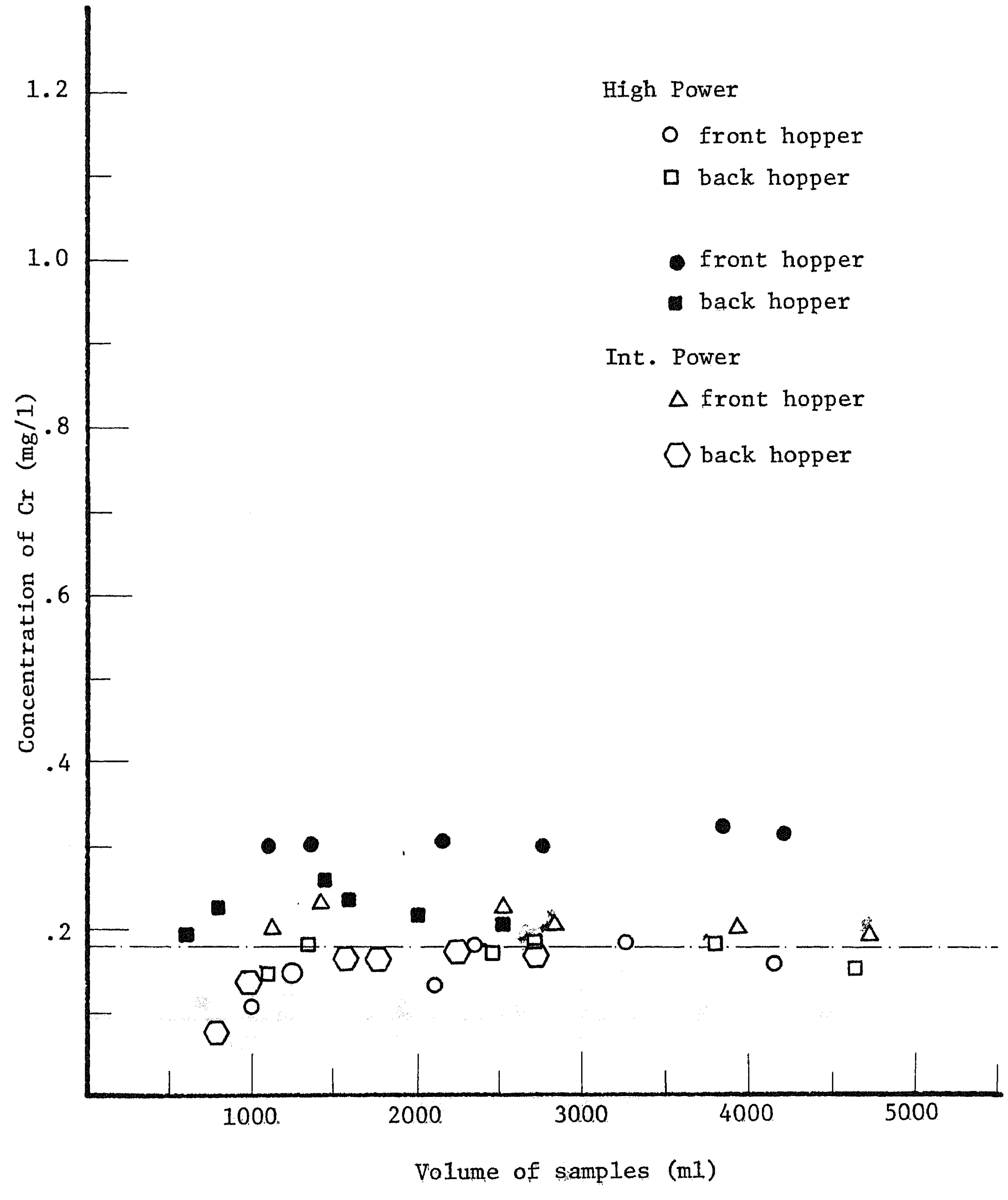


FIGURE 12.3

Cr - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

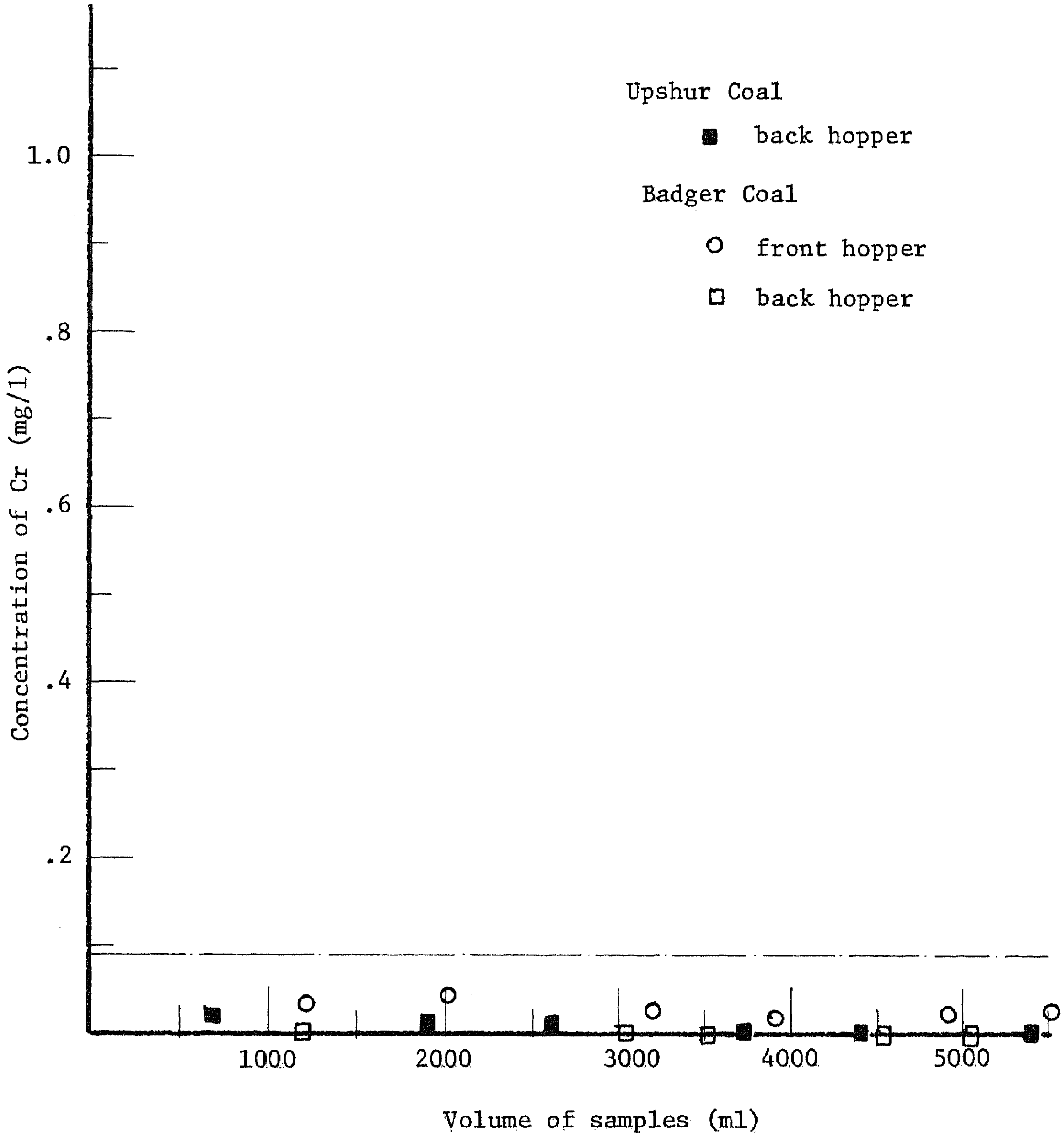


FIGURE 12.4

Cr - Absorbent Profile of Fly Ash
High Power
Mercer Coal

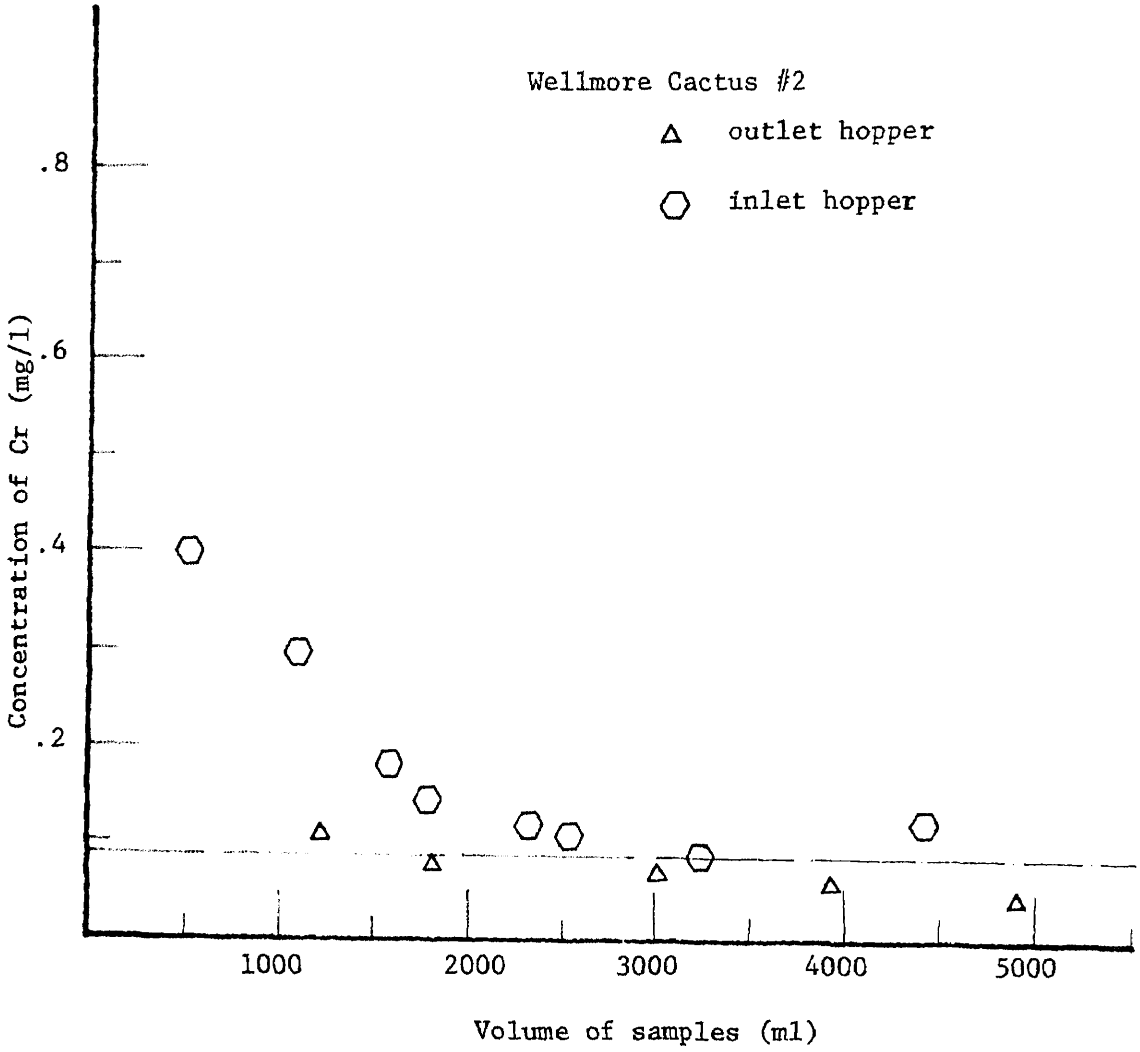


FIGURE 12.5

Cr - Absorbent Profile of Fly Ash
High Power
Mercer Coal

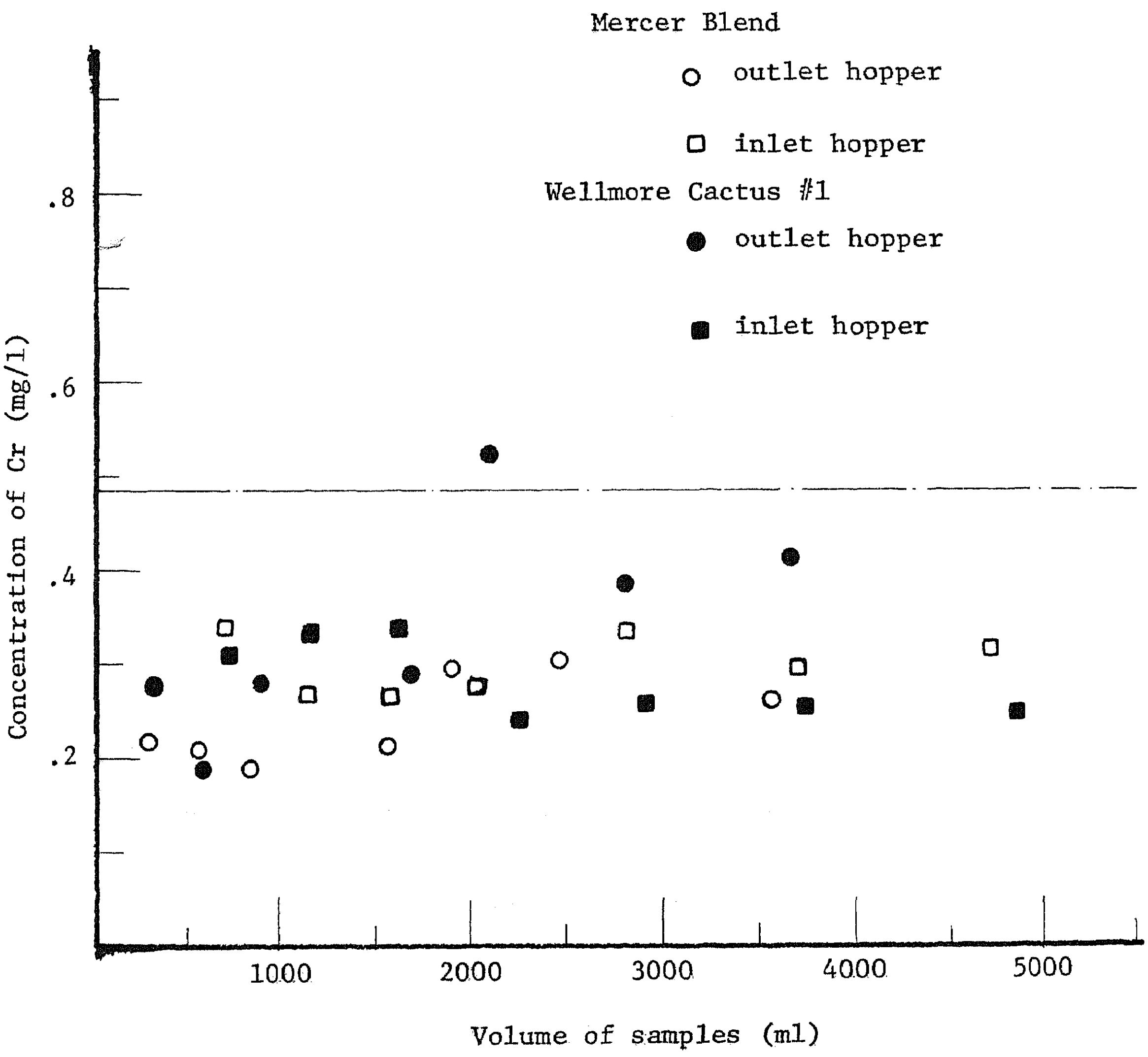


FIGURE 12.6

Cr - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

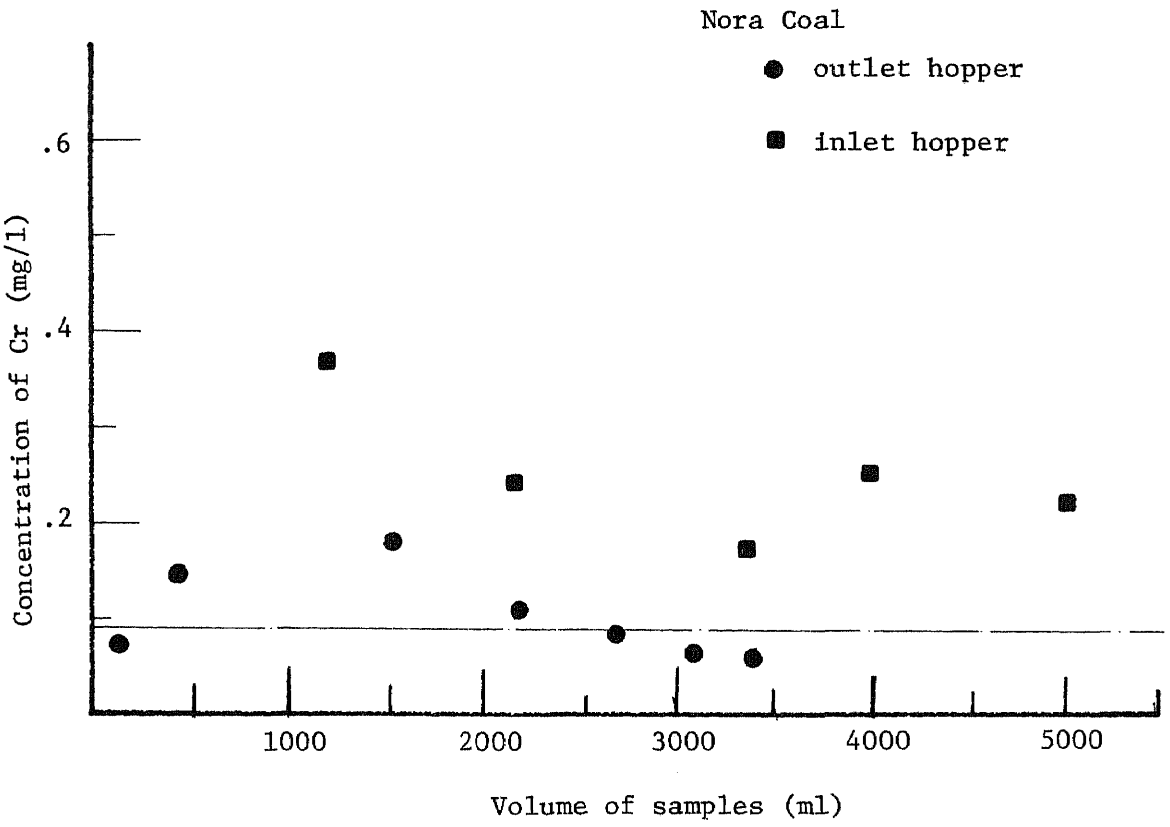


FIGURE 12.7

Cr - Absorbent Profile of Fly Ash
High Power

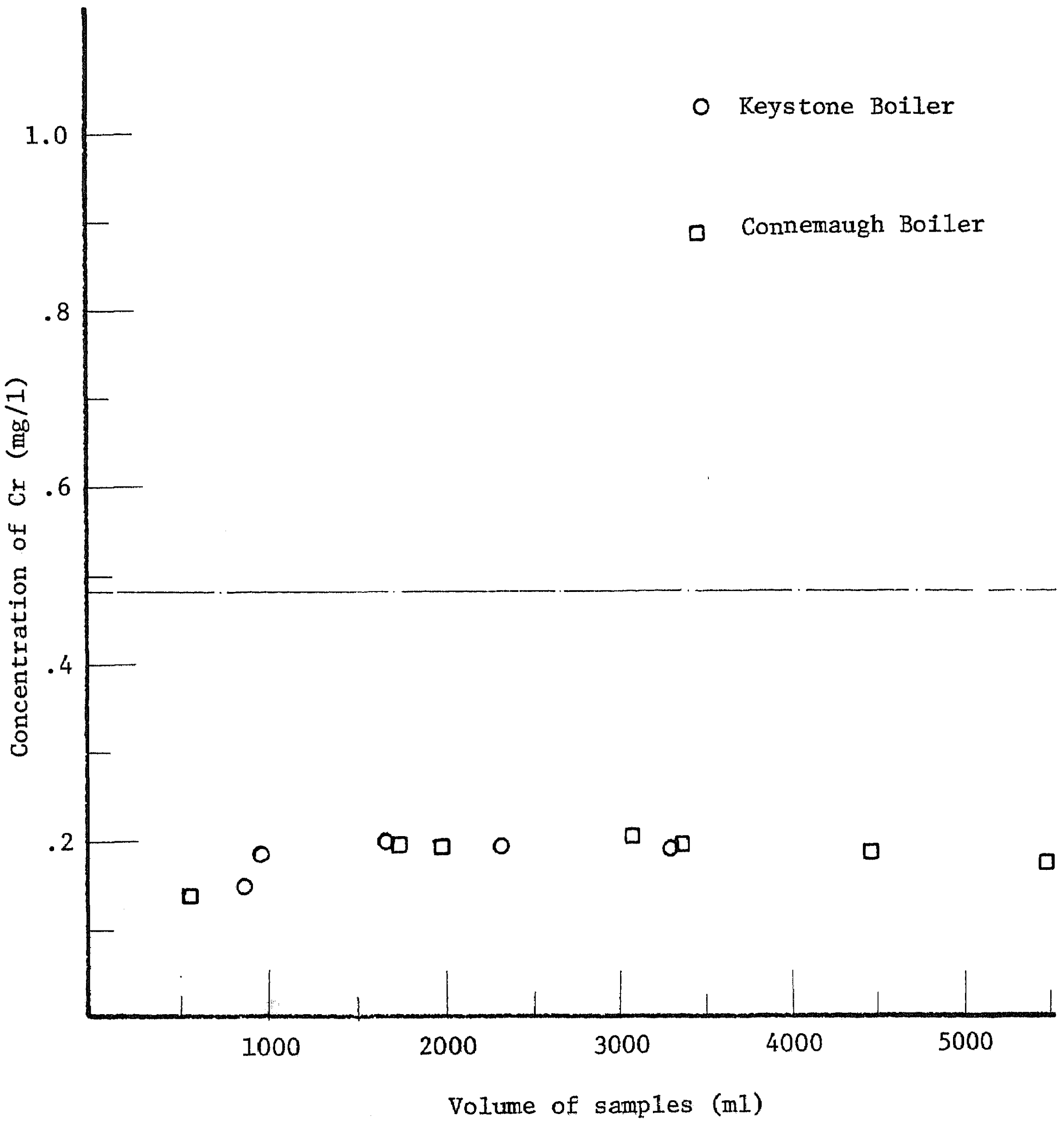


FIGURE 13.1

Zn - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

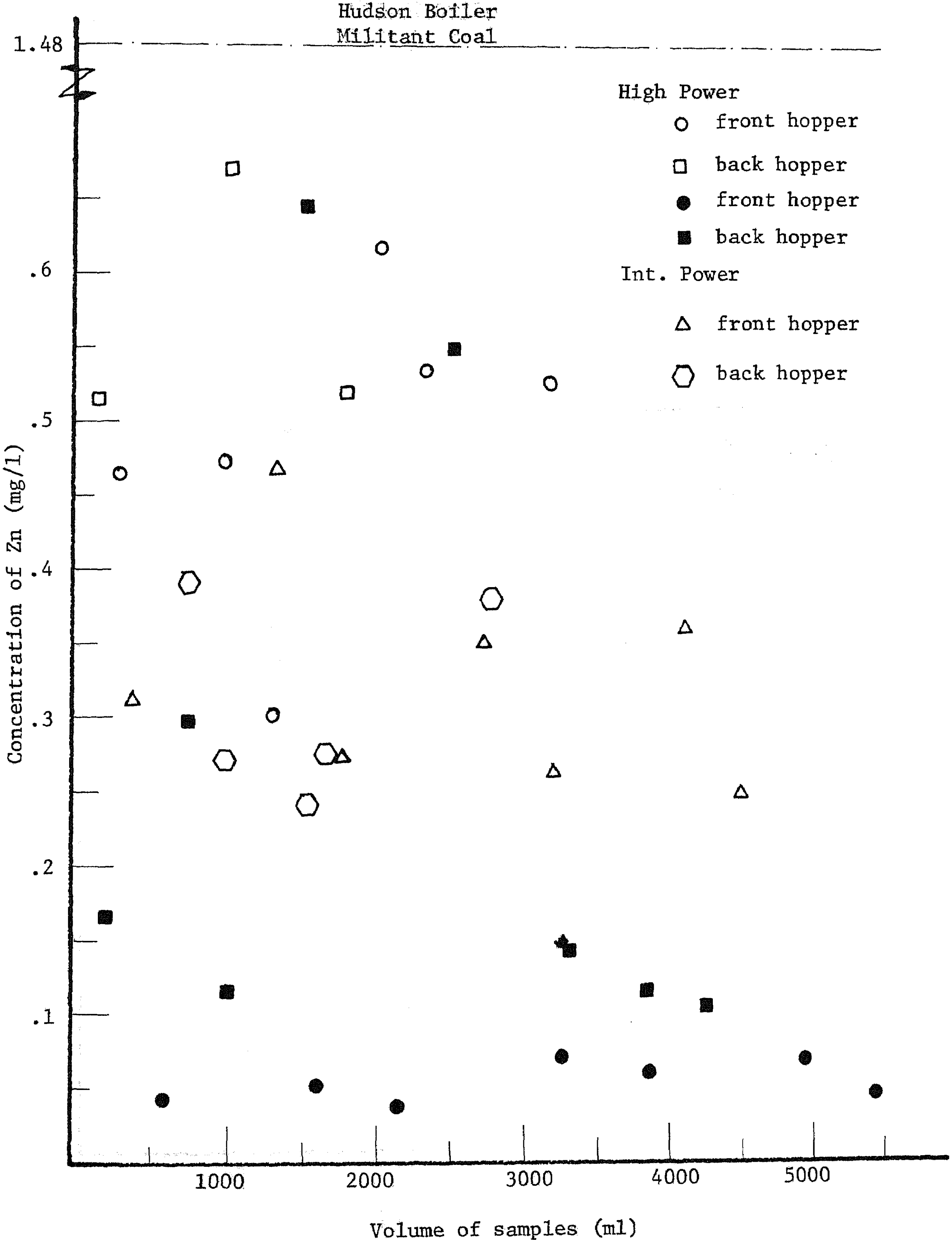


FIGURE 13.2

Zn - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

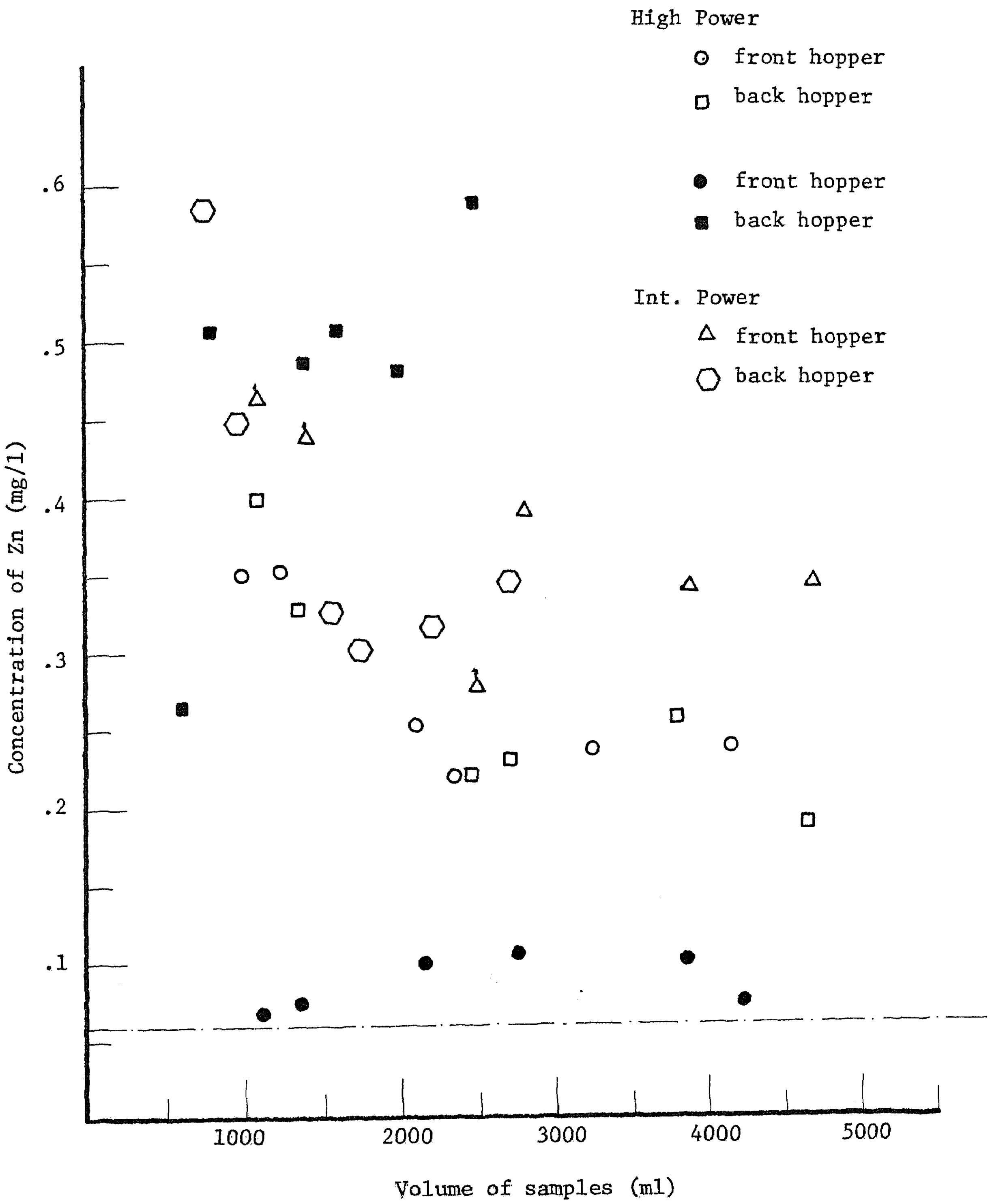


FIGURE 13.3

Zn - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

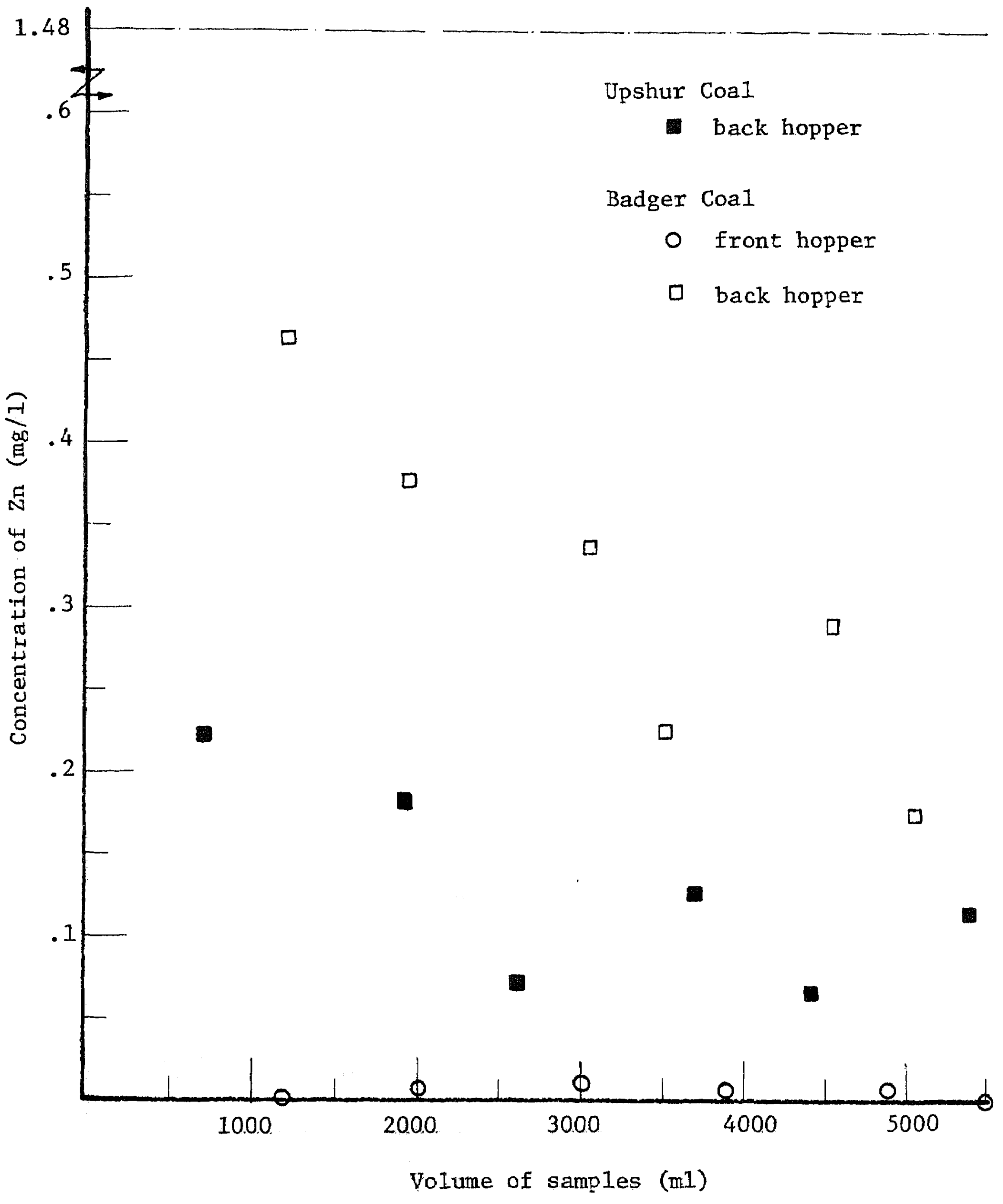


FIGURE 13.4

Zn - Absorbent Profile of Fly Ash
High Power
Mercer Coal

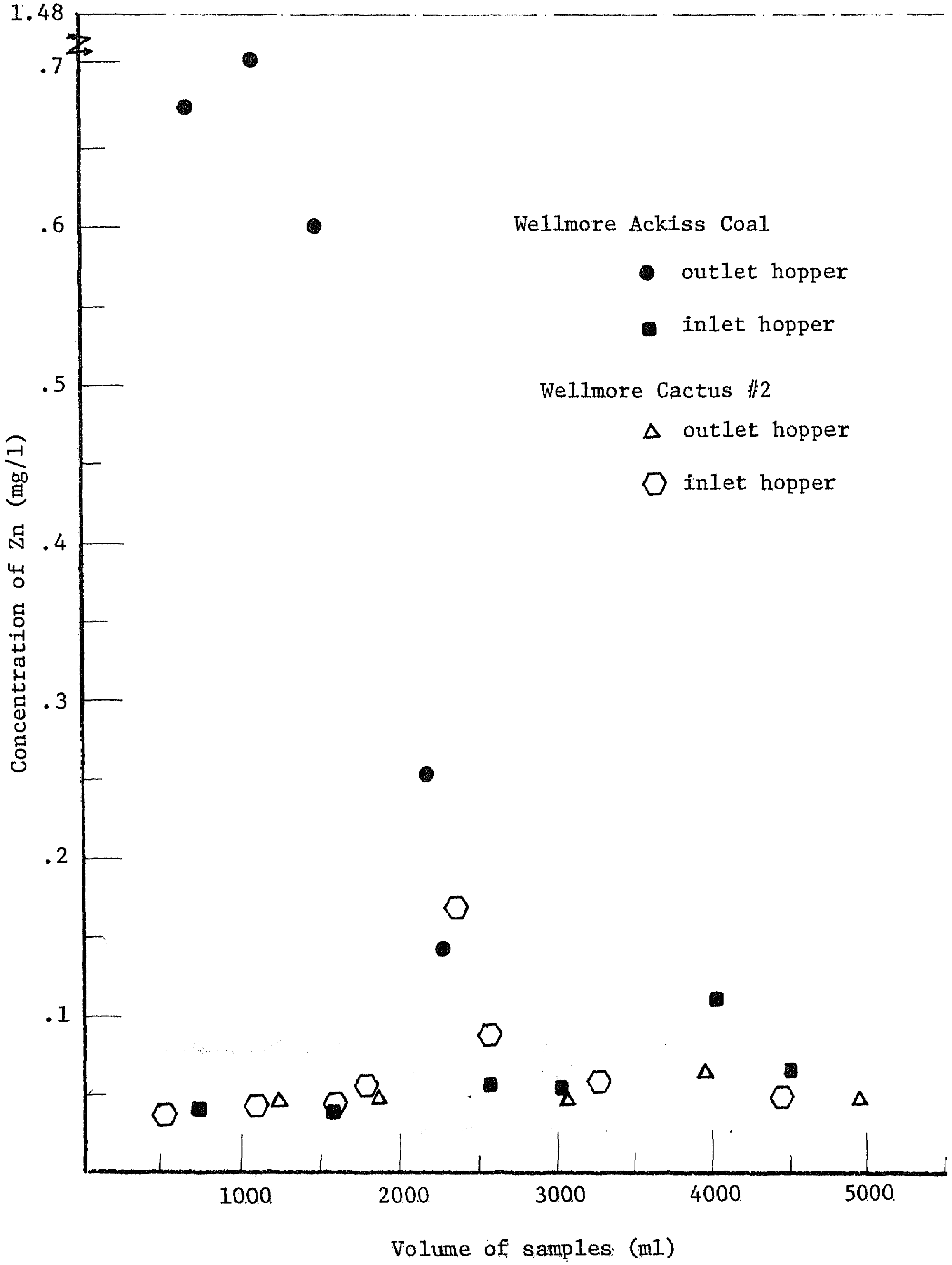


FIGURE 13.5

Zn - Absorbent Profile of Fly Ash
High Power
Mercer Coal

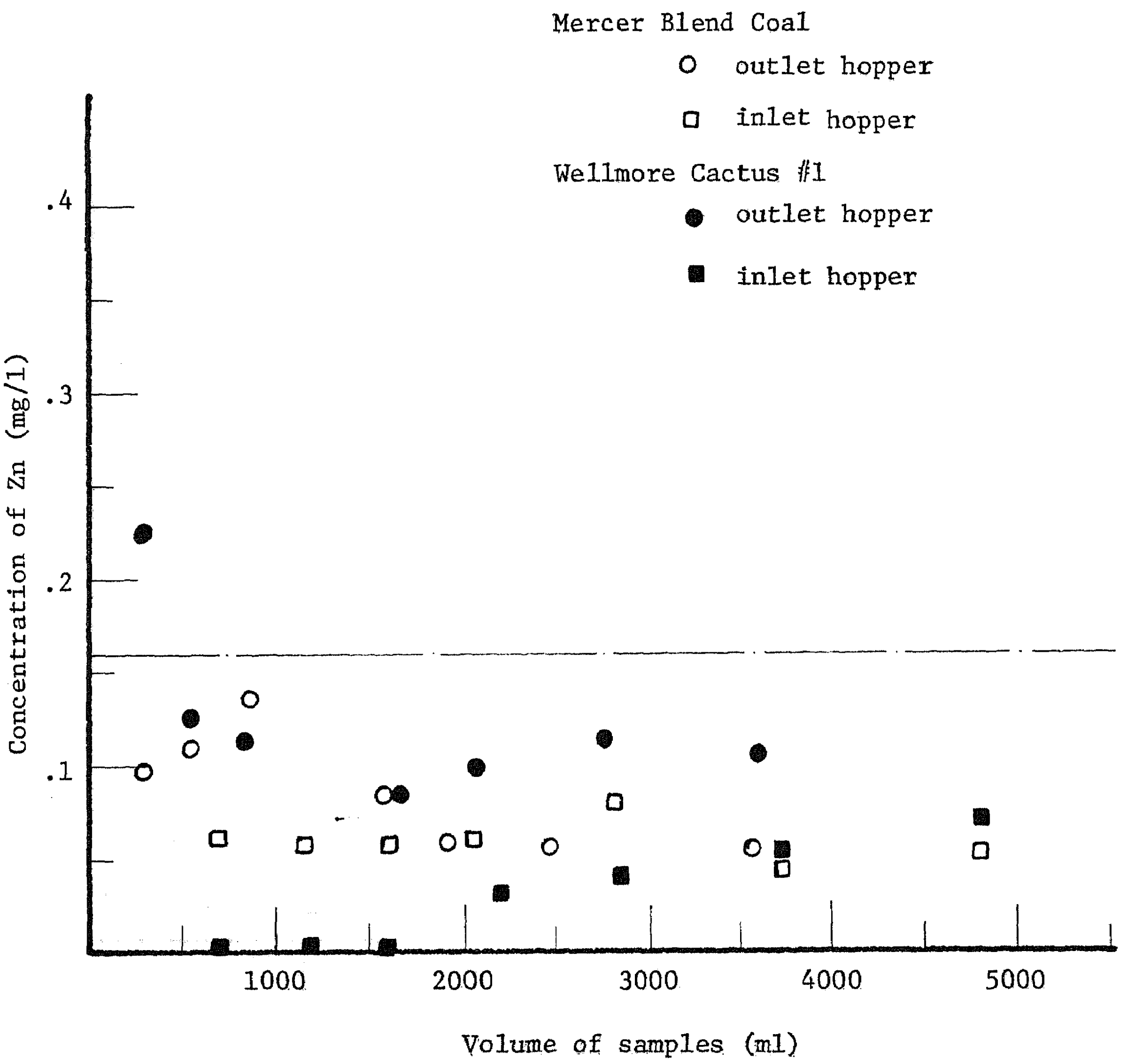


FIGURE 13.6

Zn - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

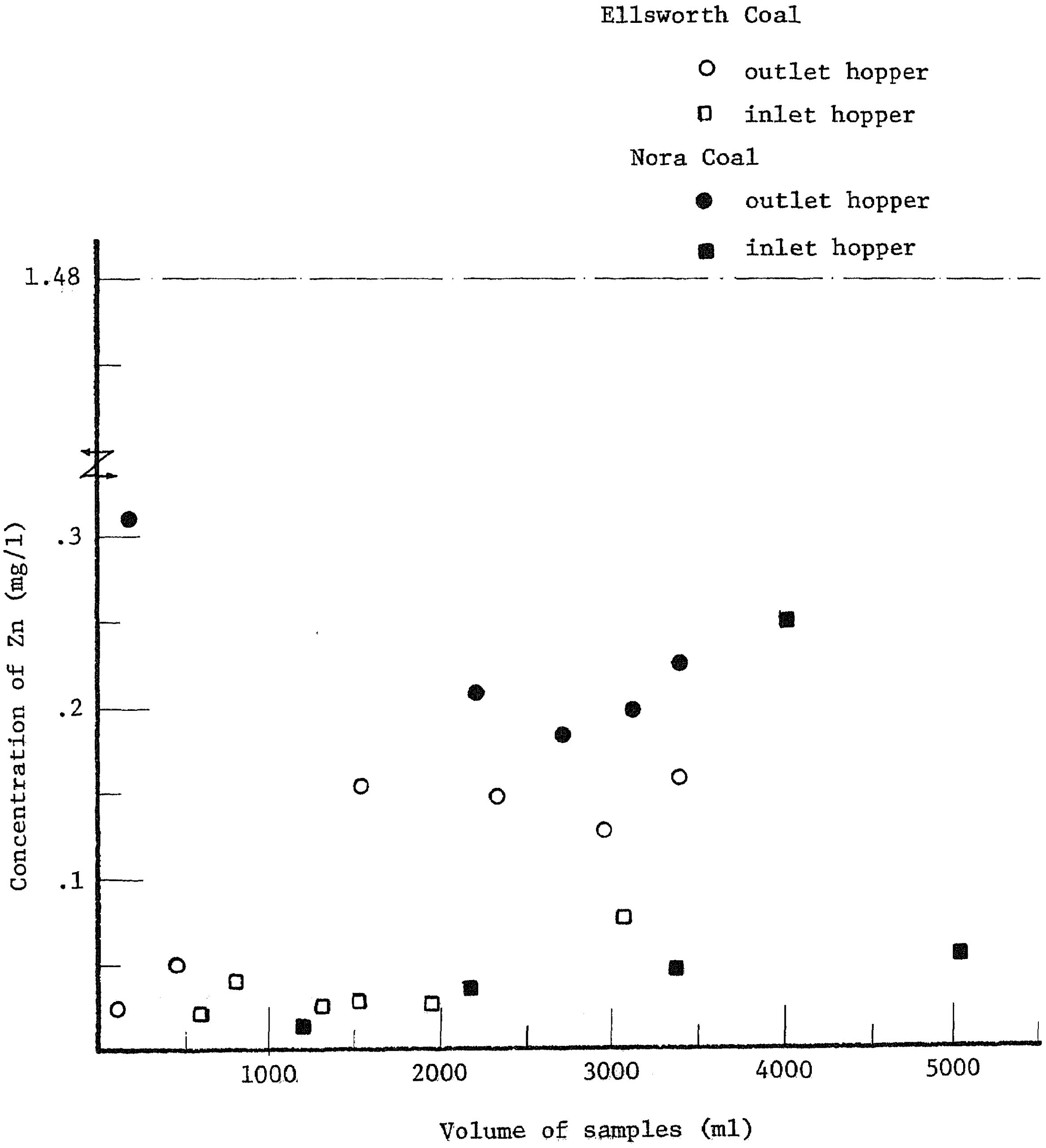


FIGURE 13.7

Zn - Absorbent Profile of Fly Ash
High Power

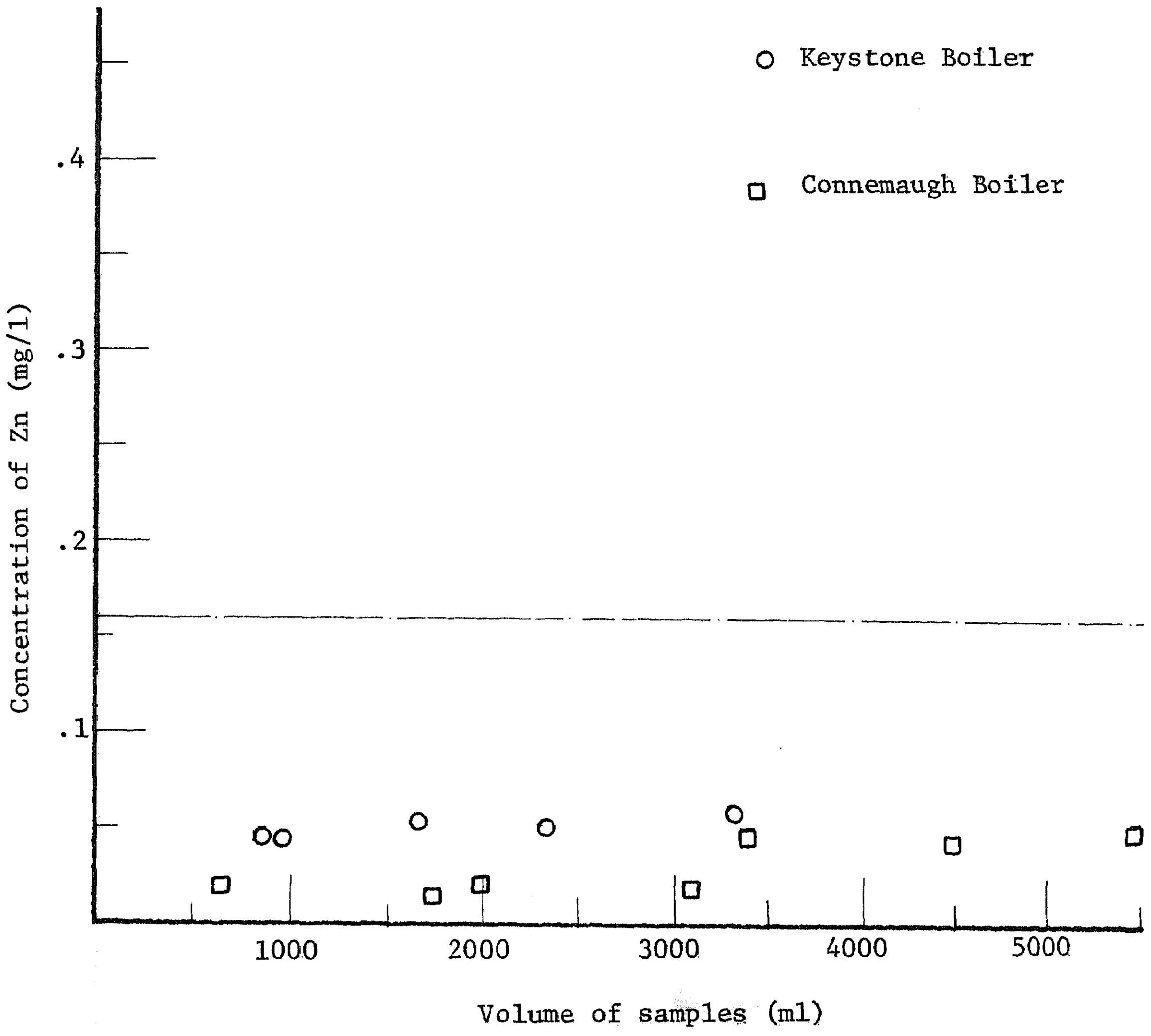


FIGURE 14.1

Mn - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

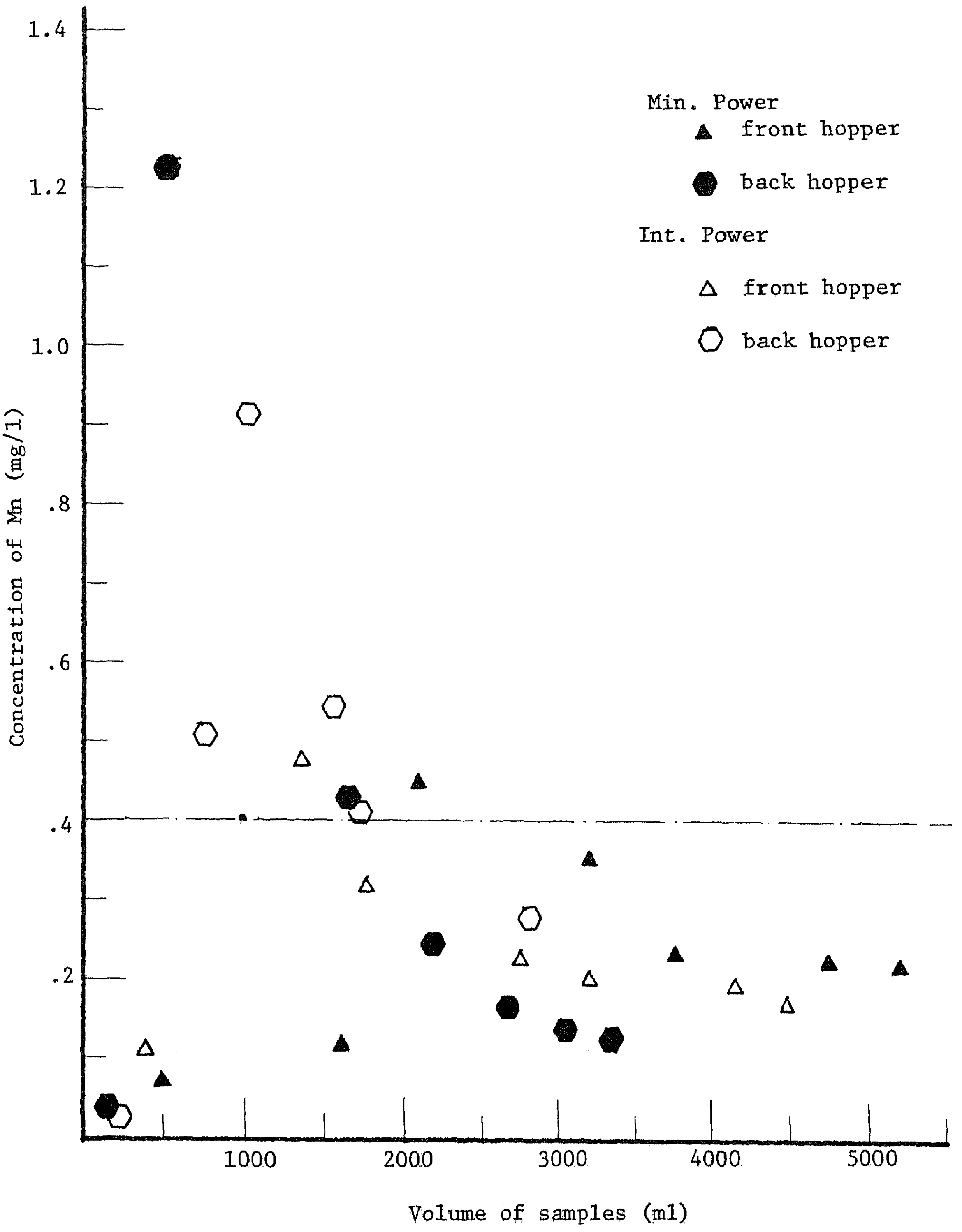


FIGURE 14.2 Mn - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

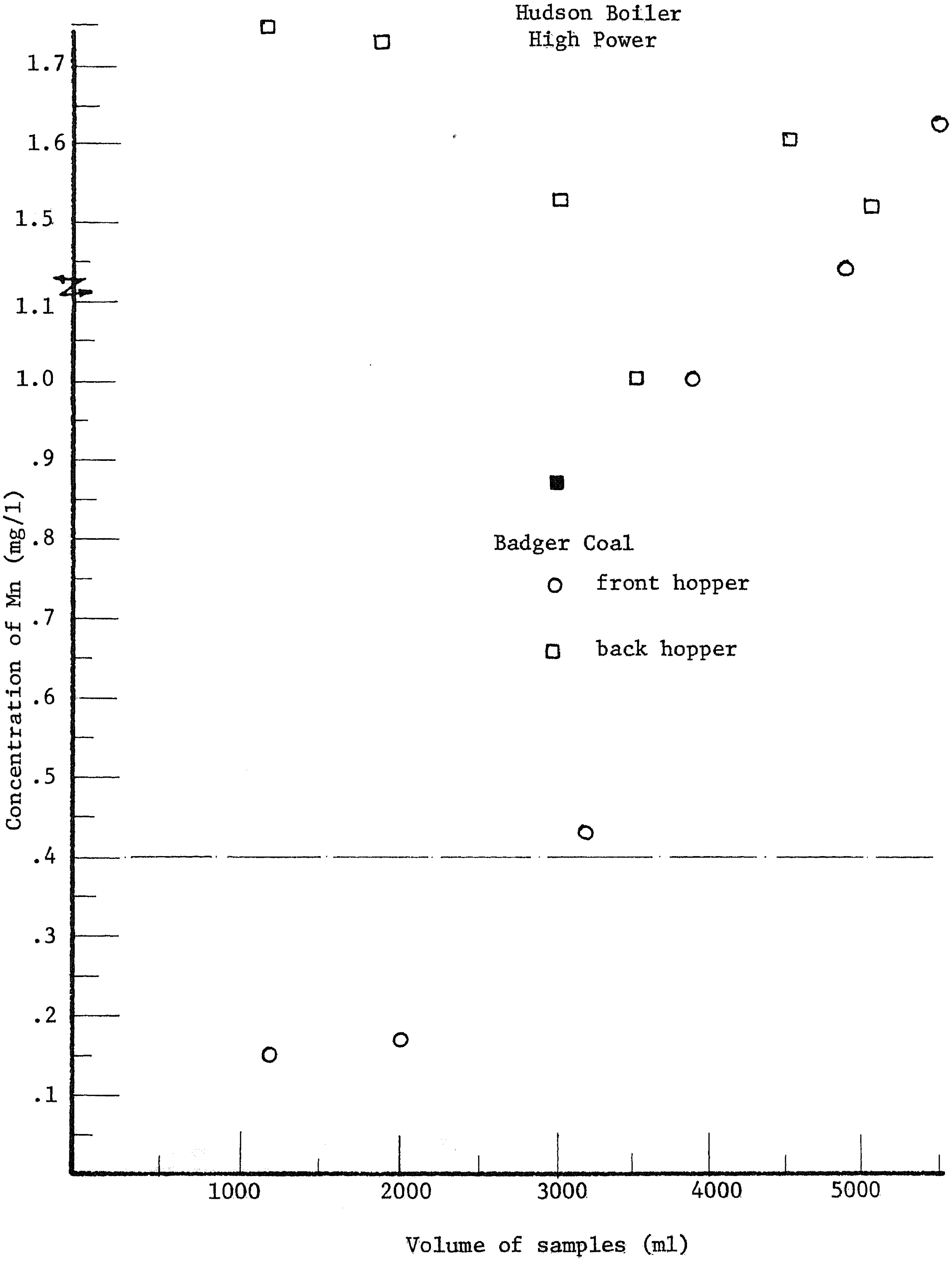


FIGURE 14.3

Mn - Absorbent Profile of Fly Ash
High Power
Mercer Coal

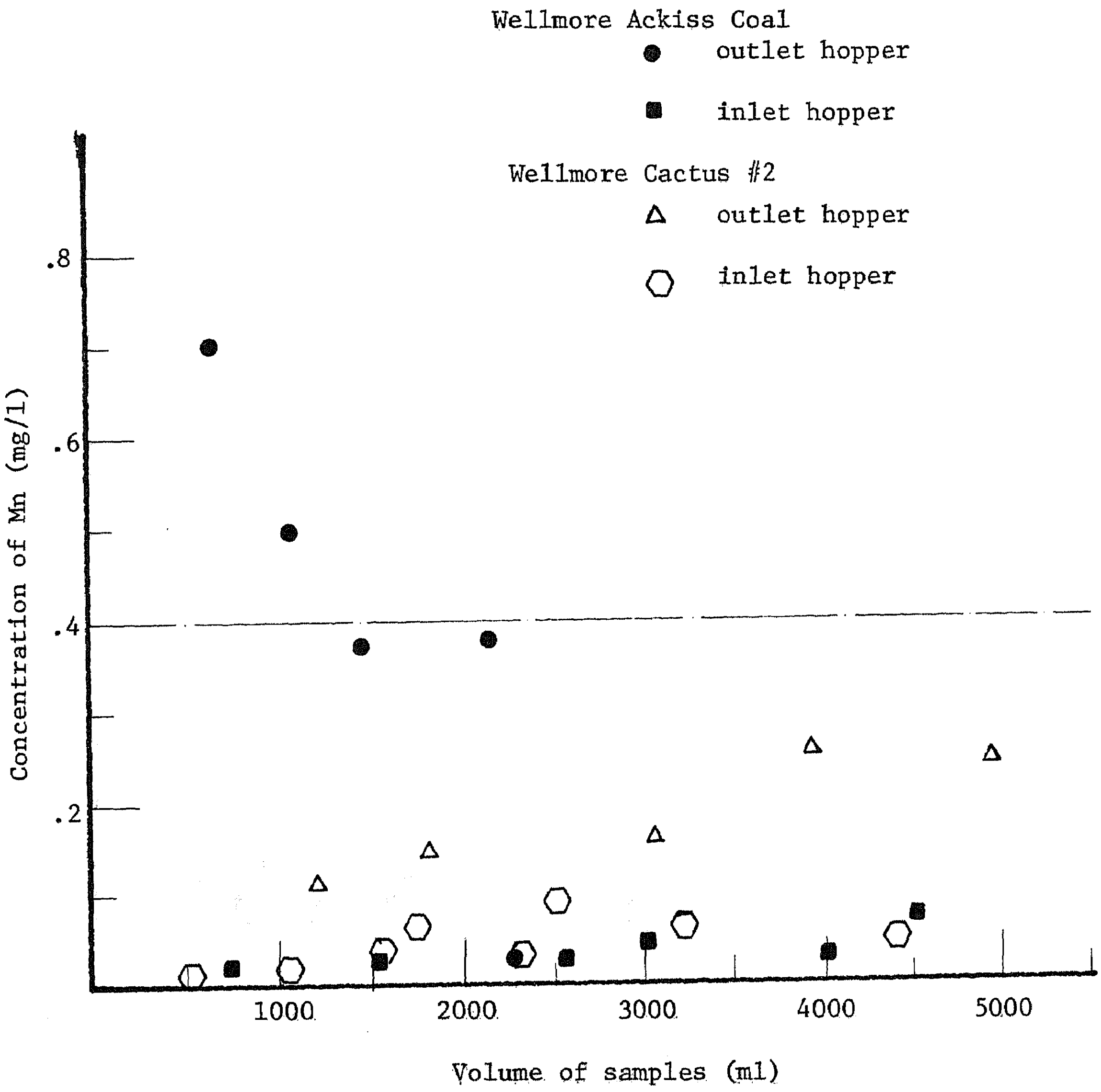


FIGURE 14.4

Mn - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

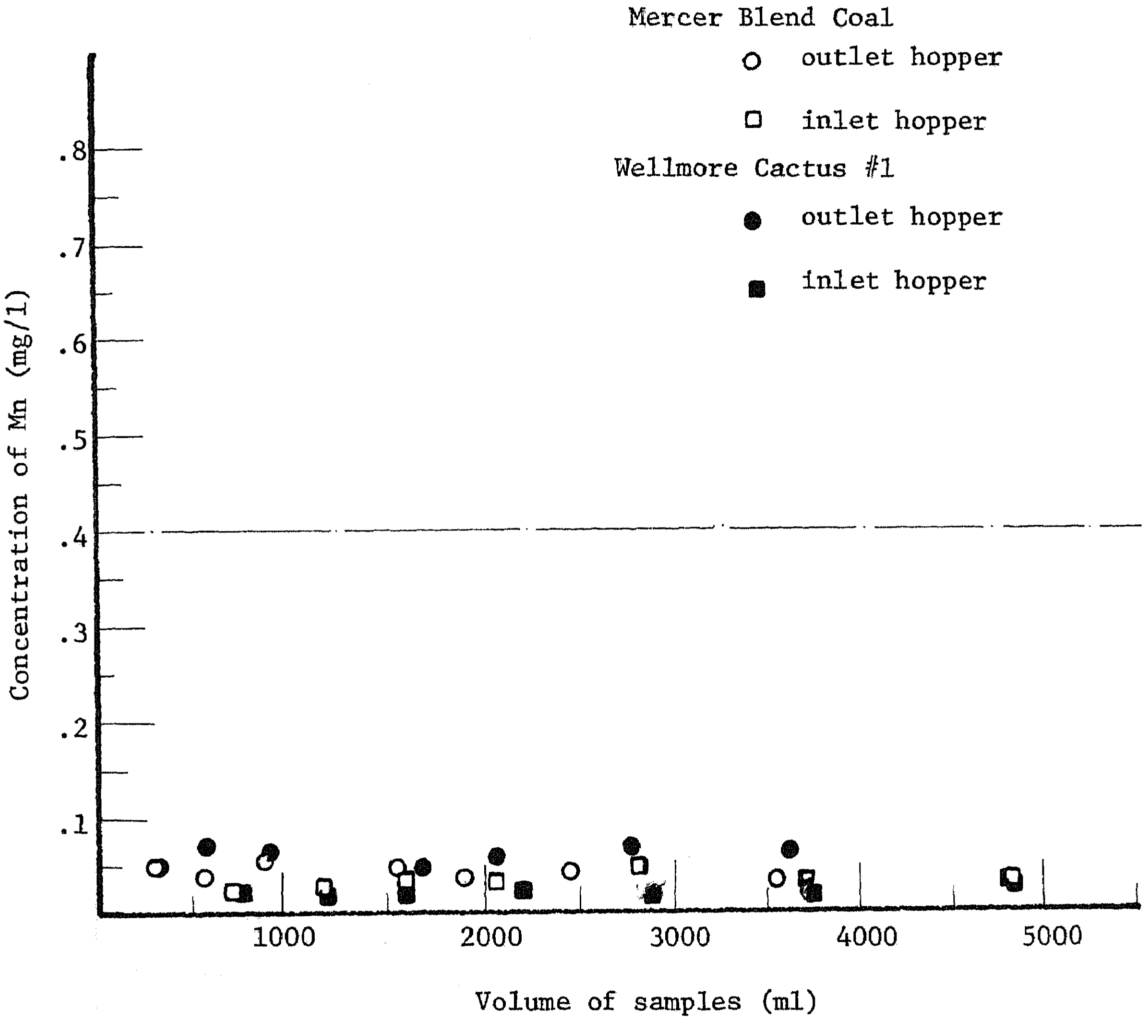


FIGURE 14.5

Mn - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

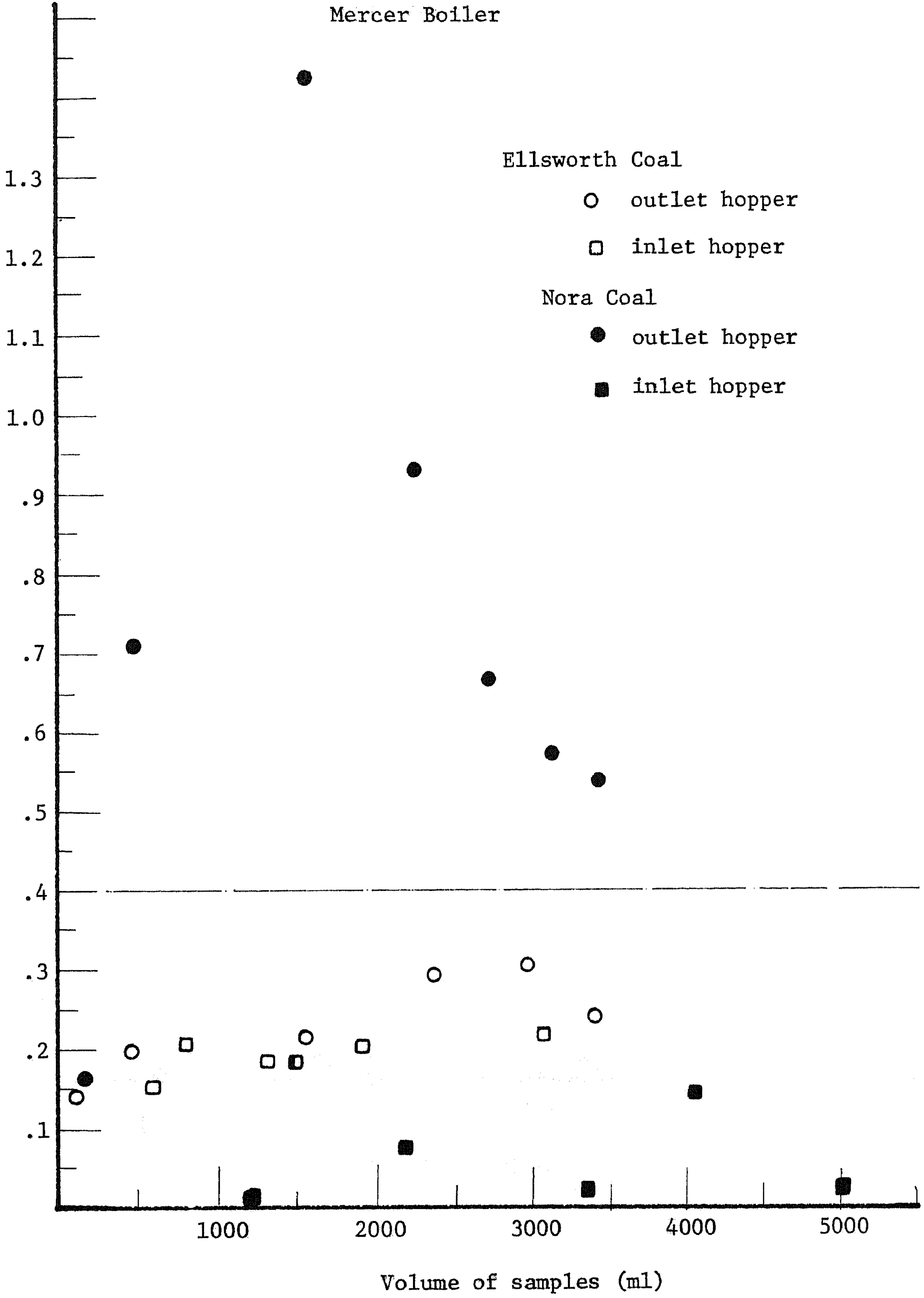


FIGURE 14.6

Mn - Absorbent Profile of Fly Ash
High Power

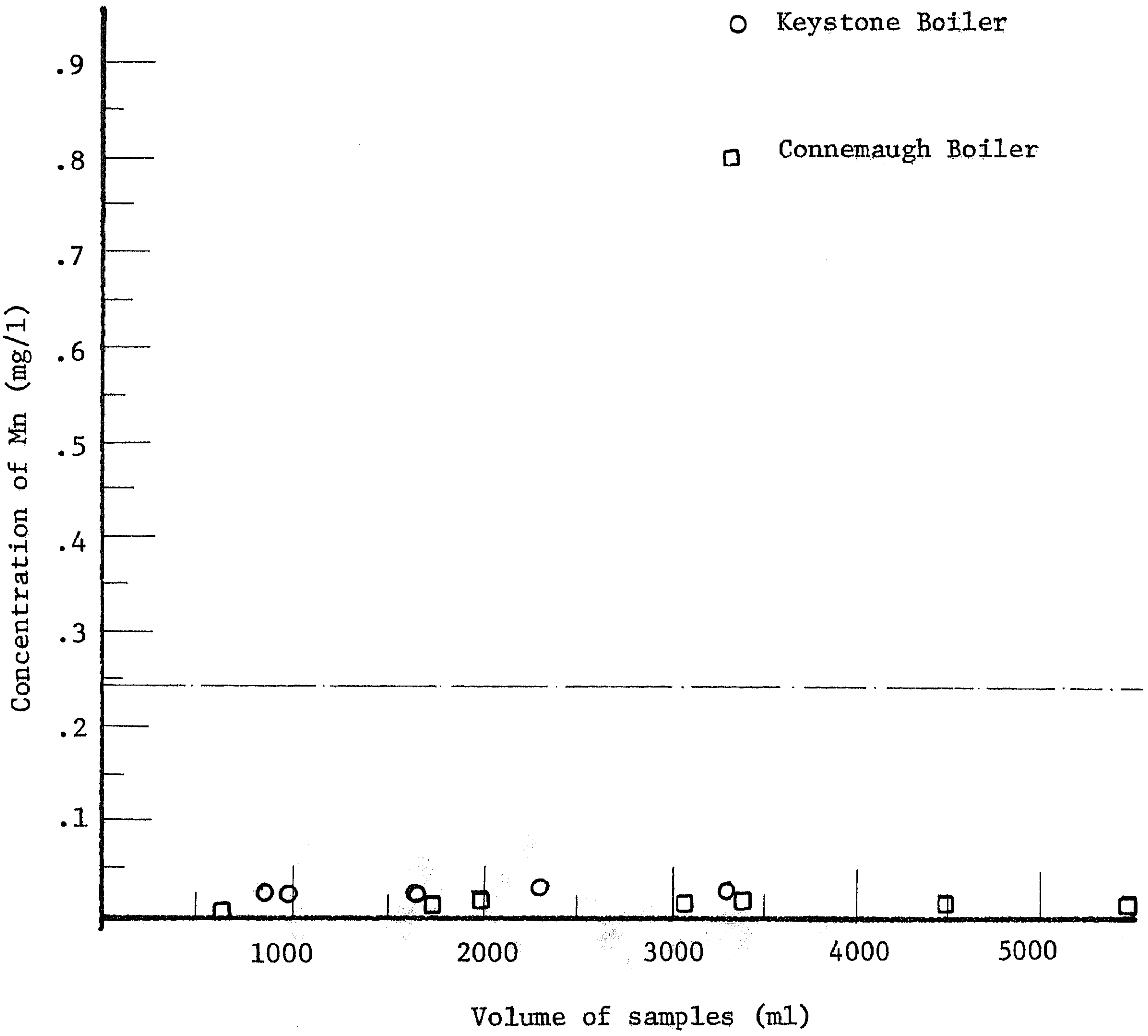


FIGURE 15.1

Fe - Absorbent Profile of Fly Ash
Hudson Boiler
Militant Coal

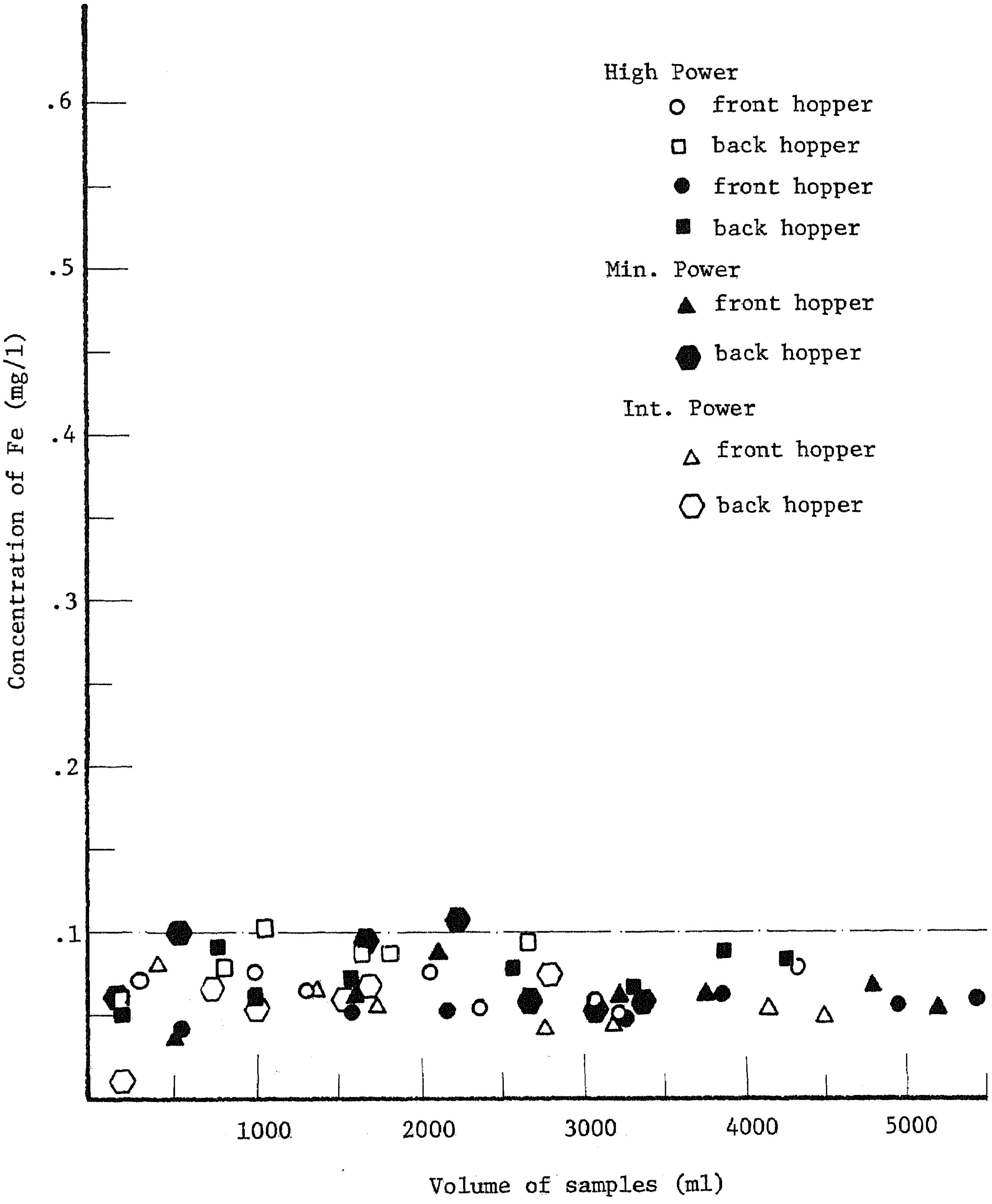


FIGURE 15.2

Fe - Absorbent Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal

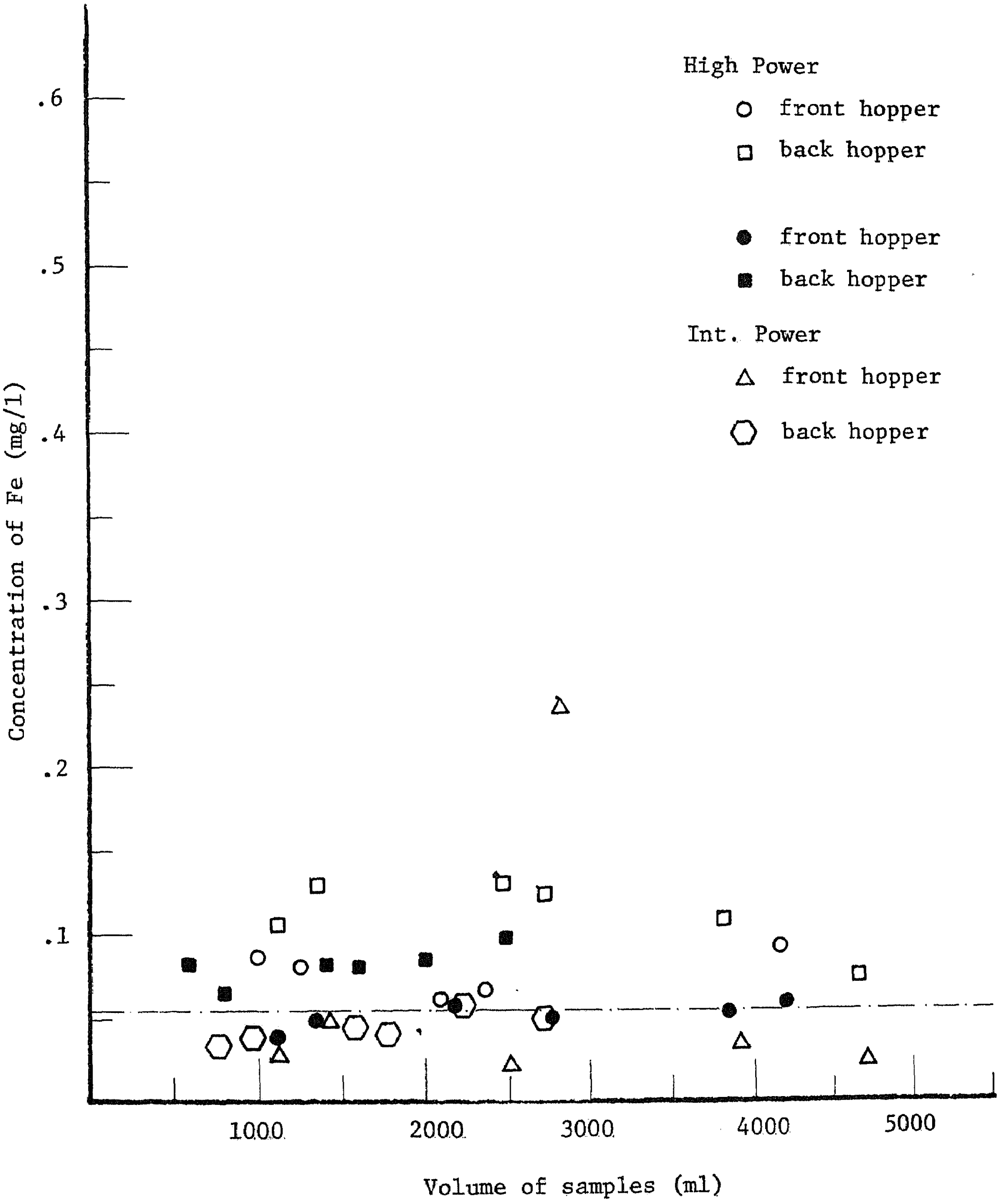


FIGURE 15.3

Fe - Absorbent Profile of Fly Ash
Hudson Boiler
High Power

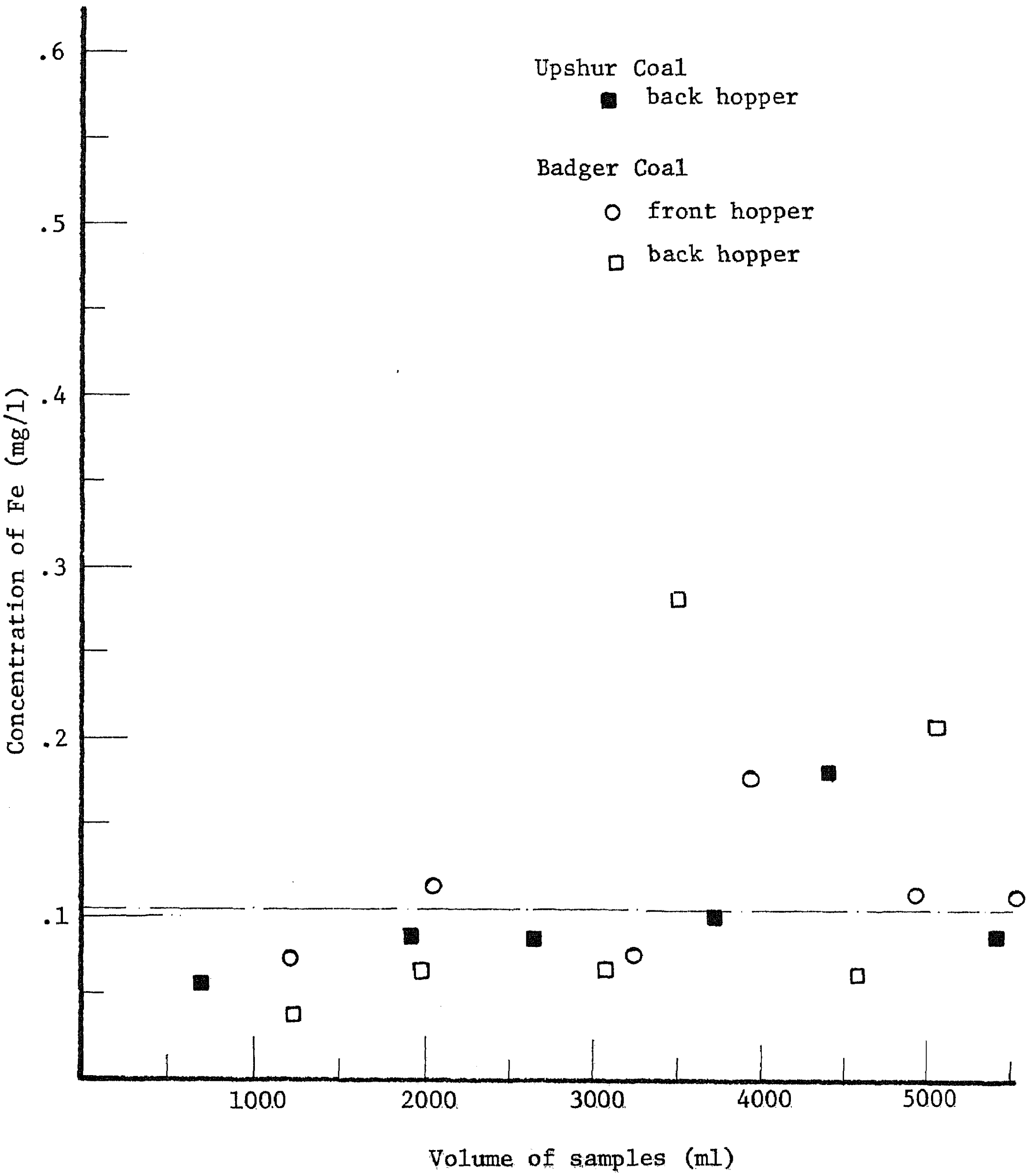


FIGURE 15.4

Fe - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

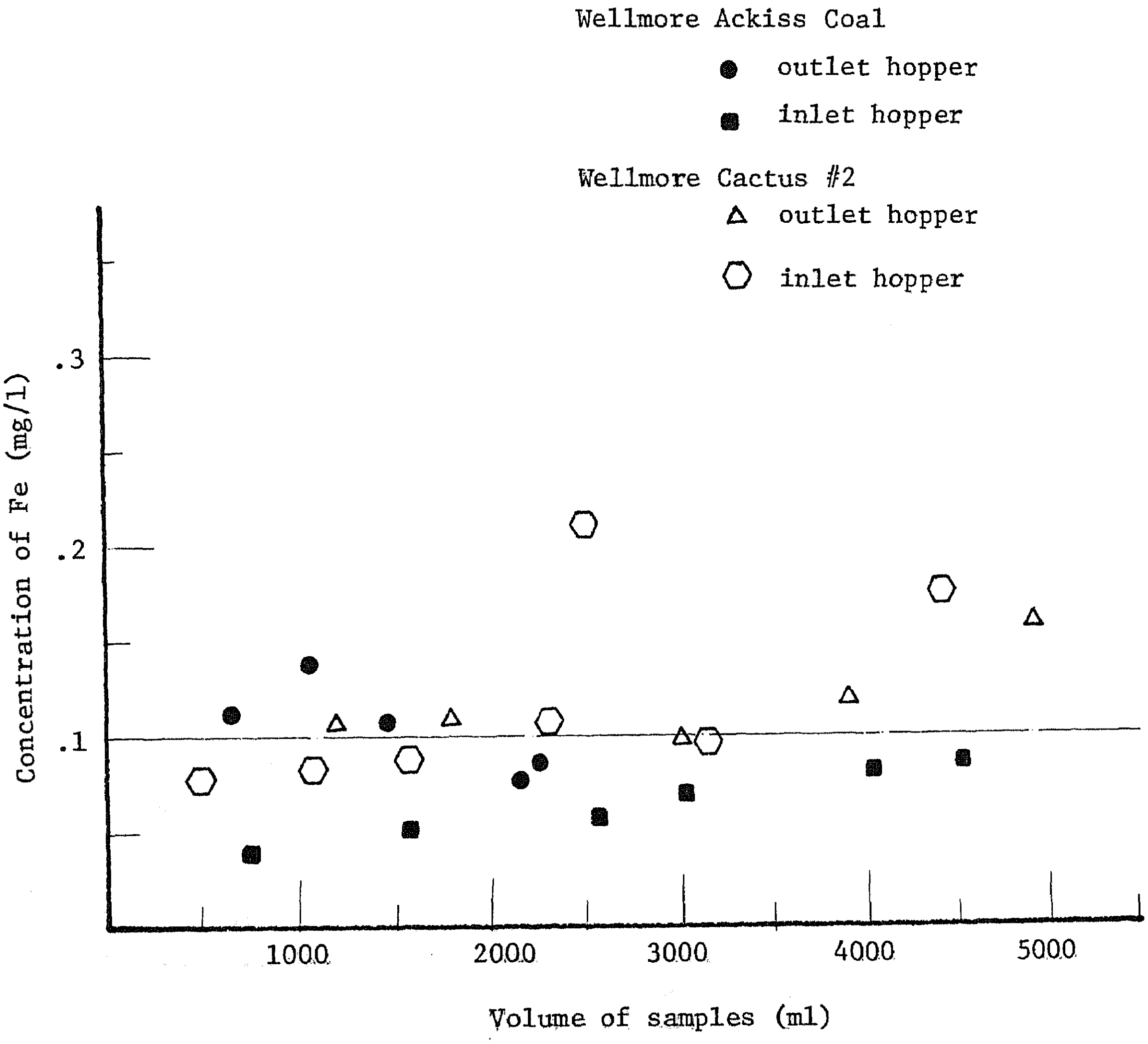


FIGURE 15.5

Fe - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

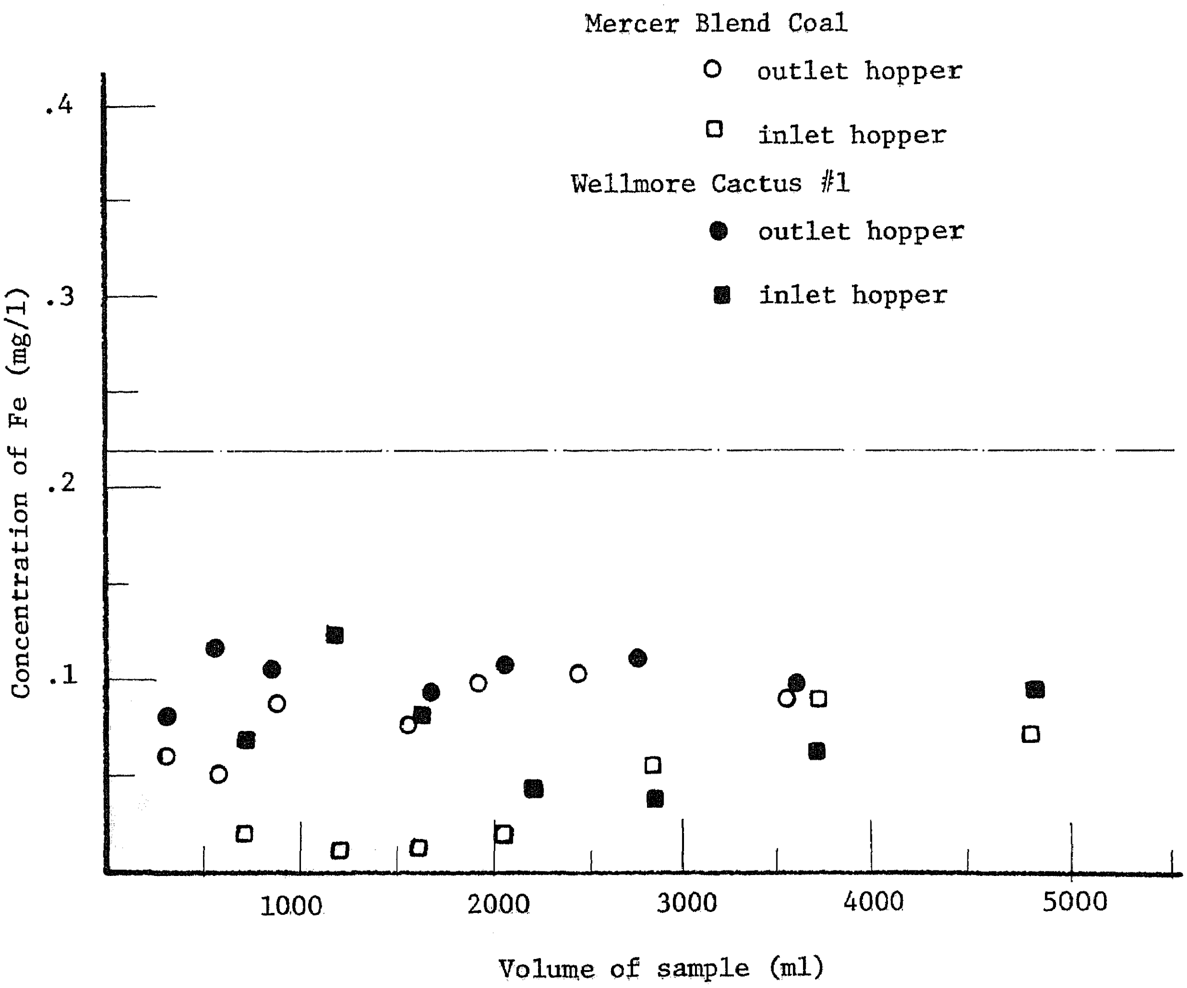


FIGURE 15.6

Fe - Absorbent Profile of Fly Ash
High Power
Mercer Boiler

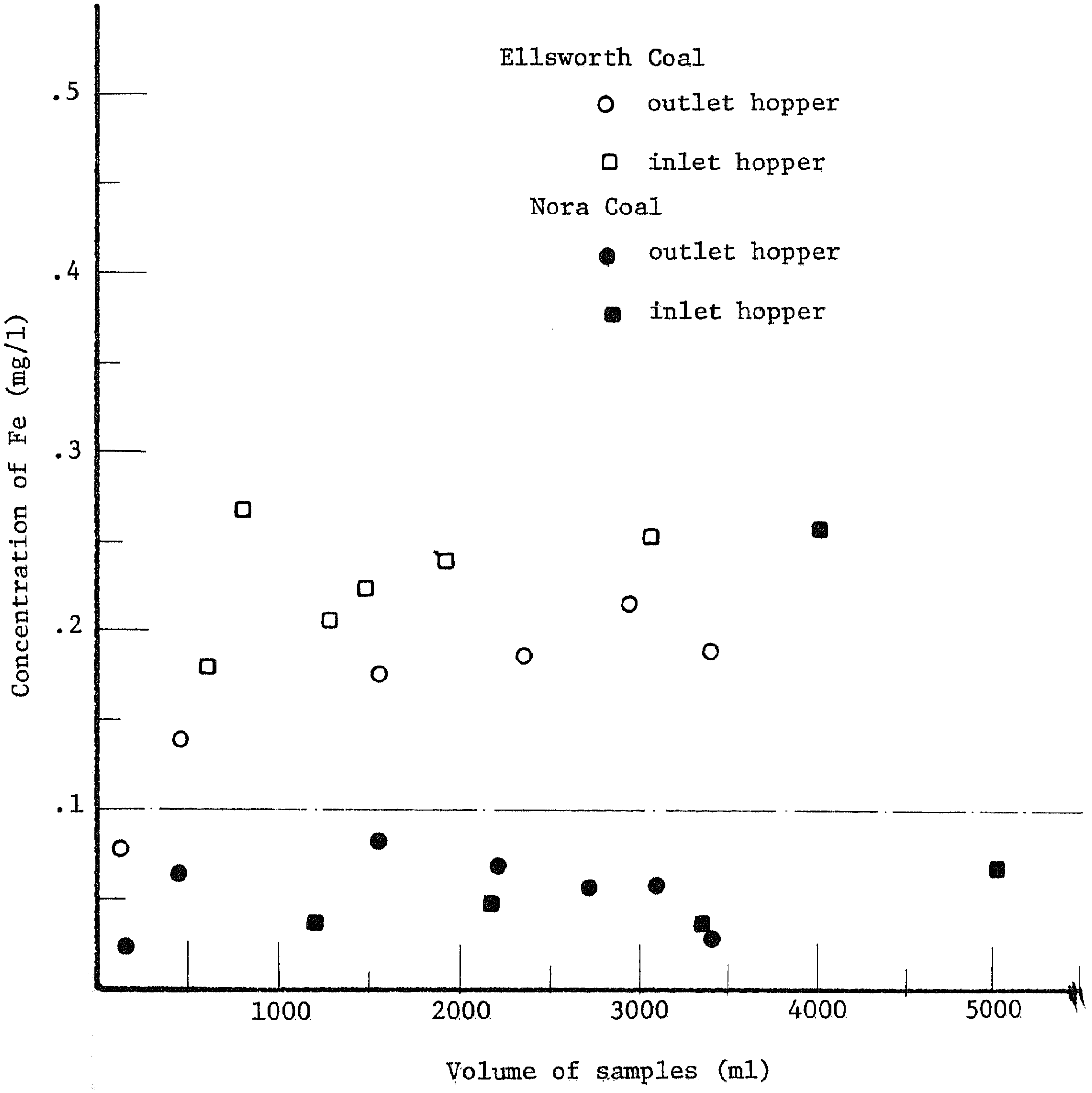


FIGURE 15.7

Fe - Absorbent Profile of Fly Ash
High Power

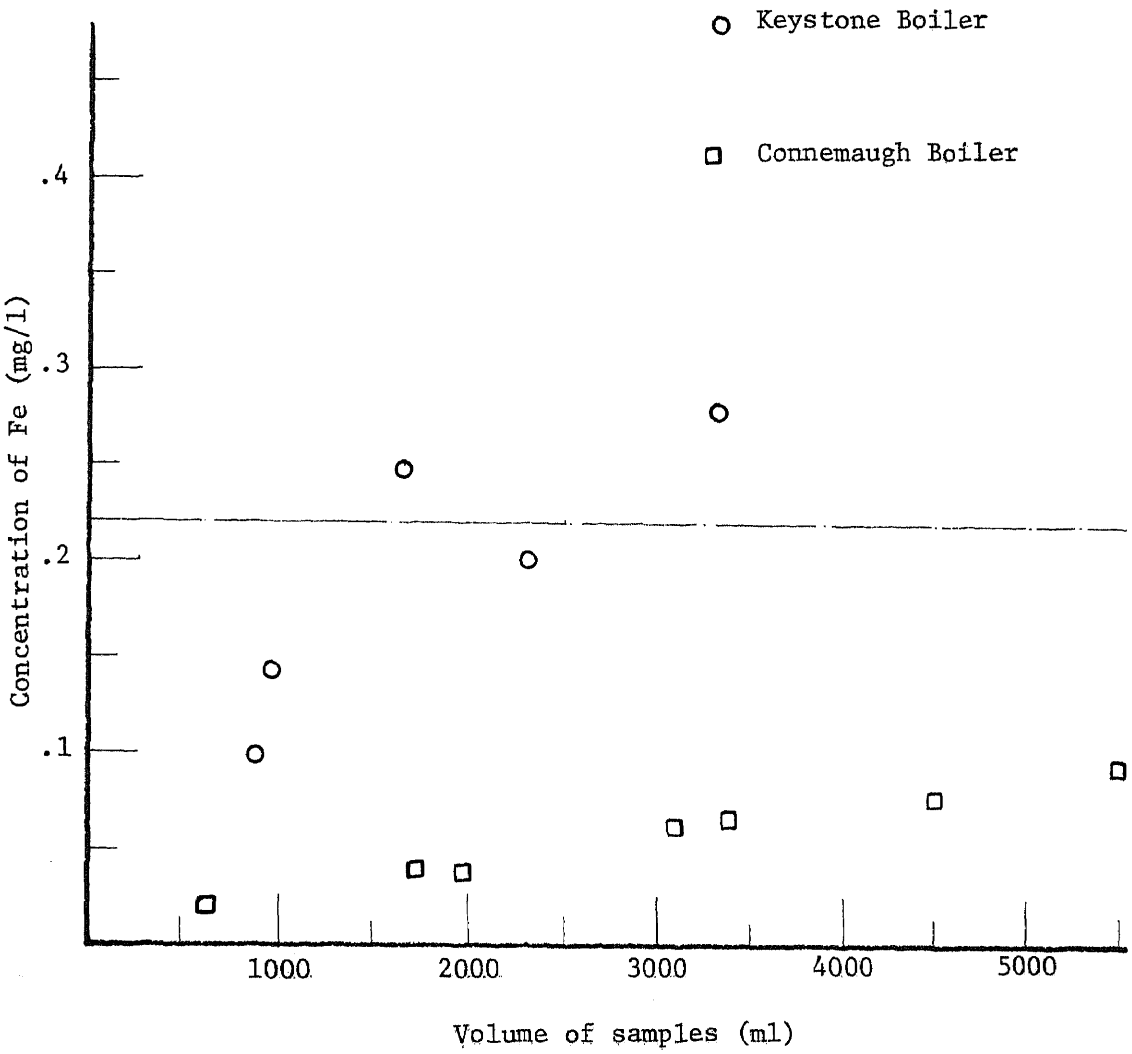


FIGURE 16

Permeability Profile of Fly Ash
Hudson Boiler
Militant Coal
Min. Power

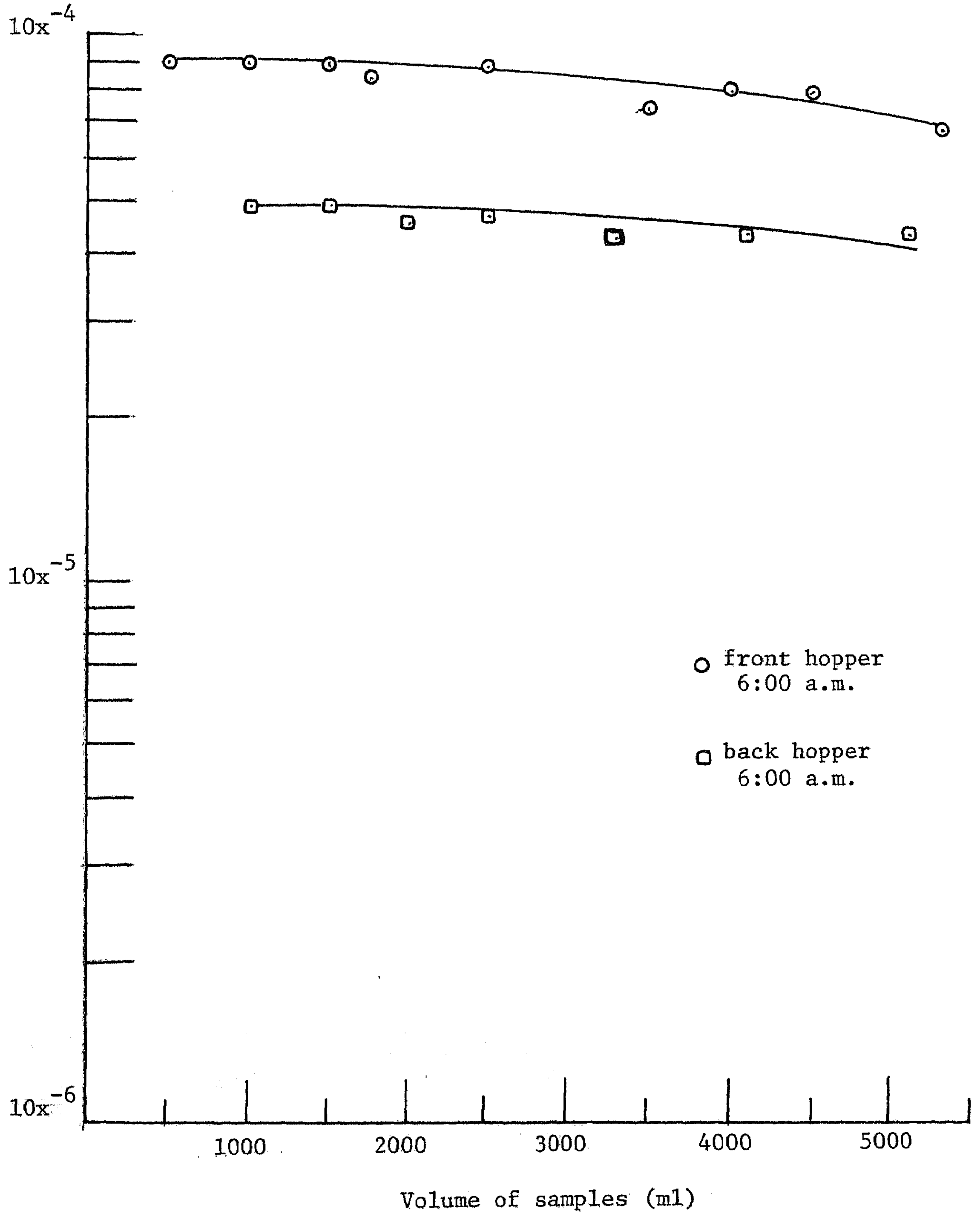


FIGURE 17

Permeability Profile of Fly Ash
Hudson Boiler
Int. Power
Deep Hollow Coal

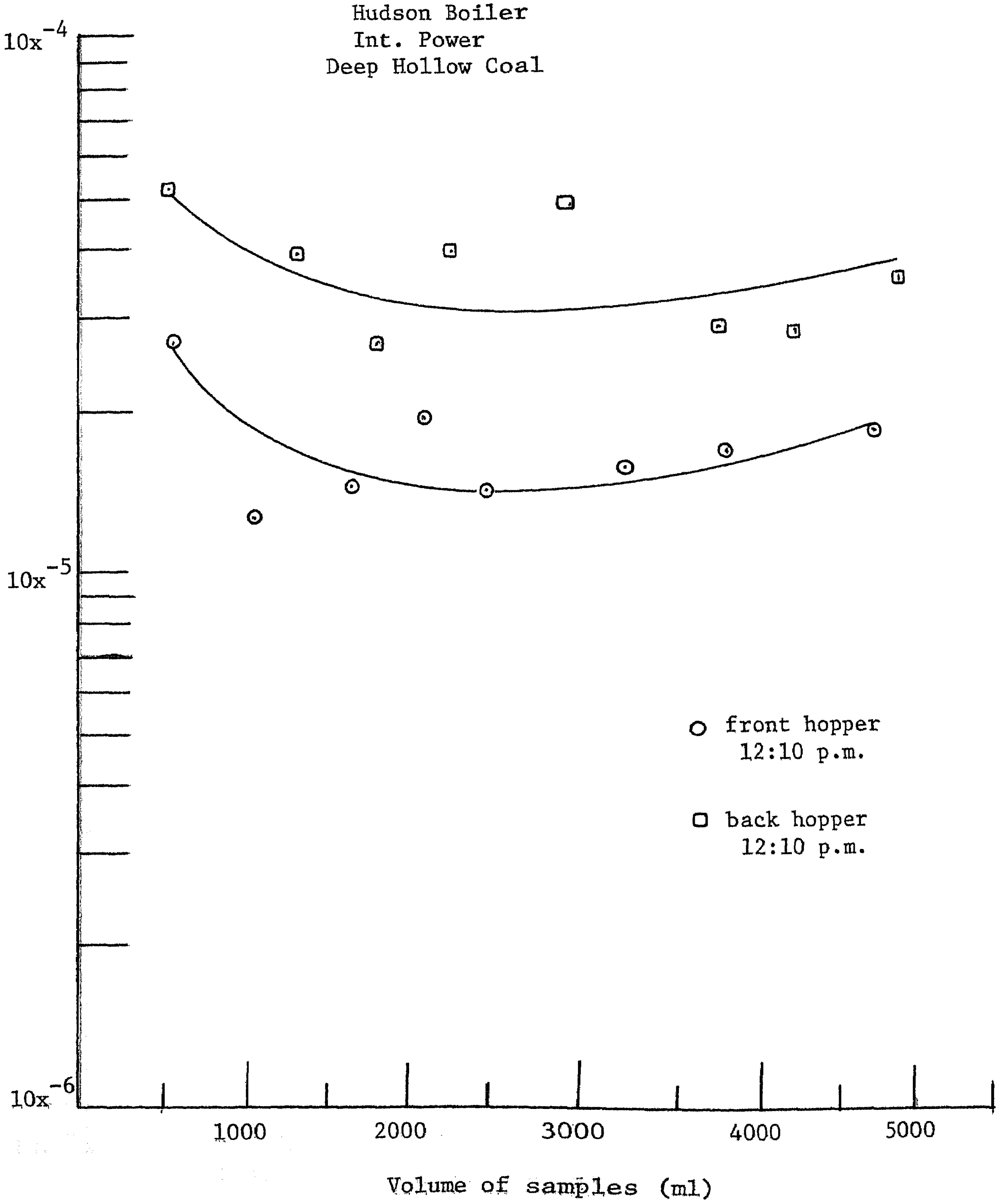


FIGURE 18

Permeability Profile of Fly Ash
Hudson Boiler
Deep Hollow Coal
Min.Power

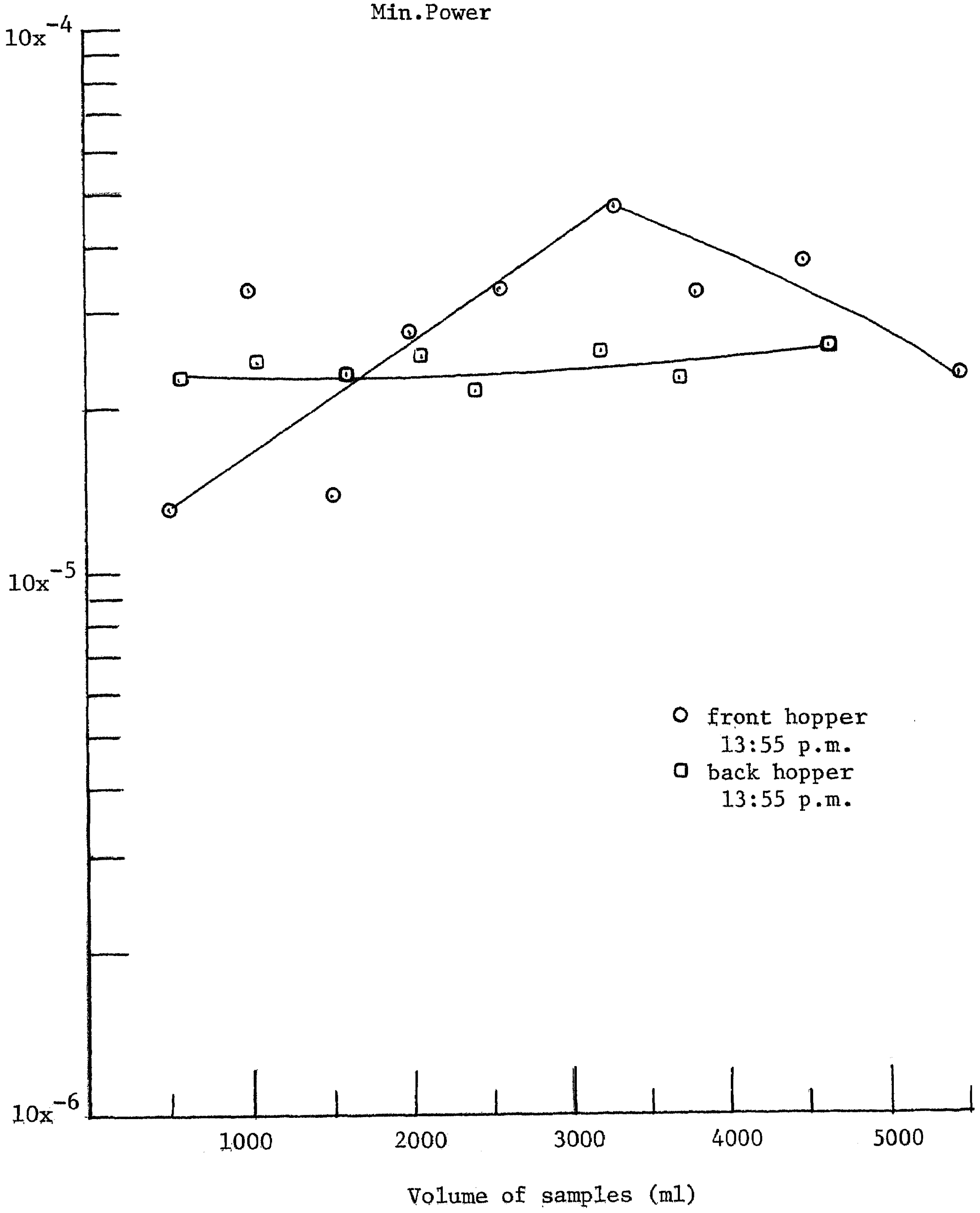


FIGURE 19

Permeability Profile of Fly Ash
Hudson Boiler
Badger Coal
Full Power

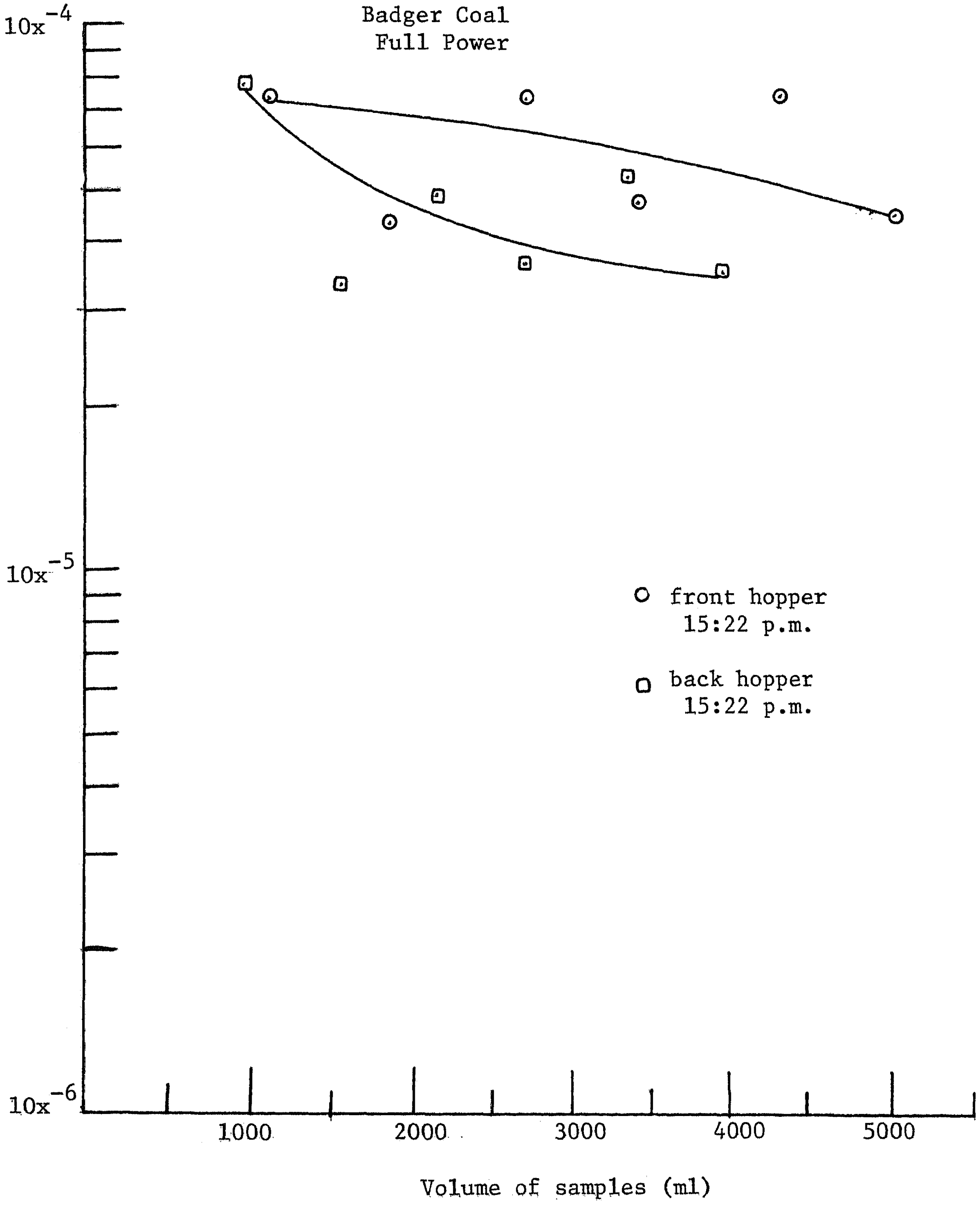
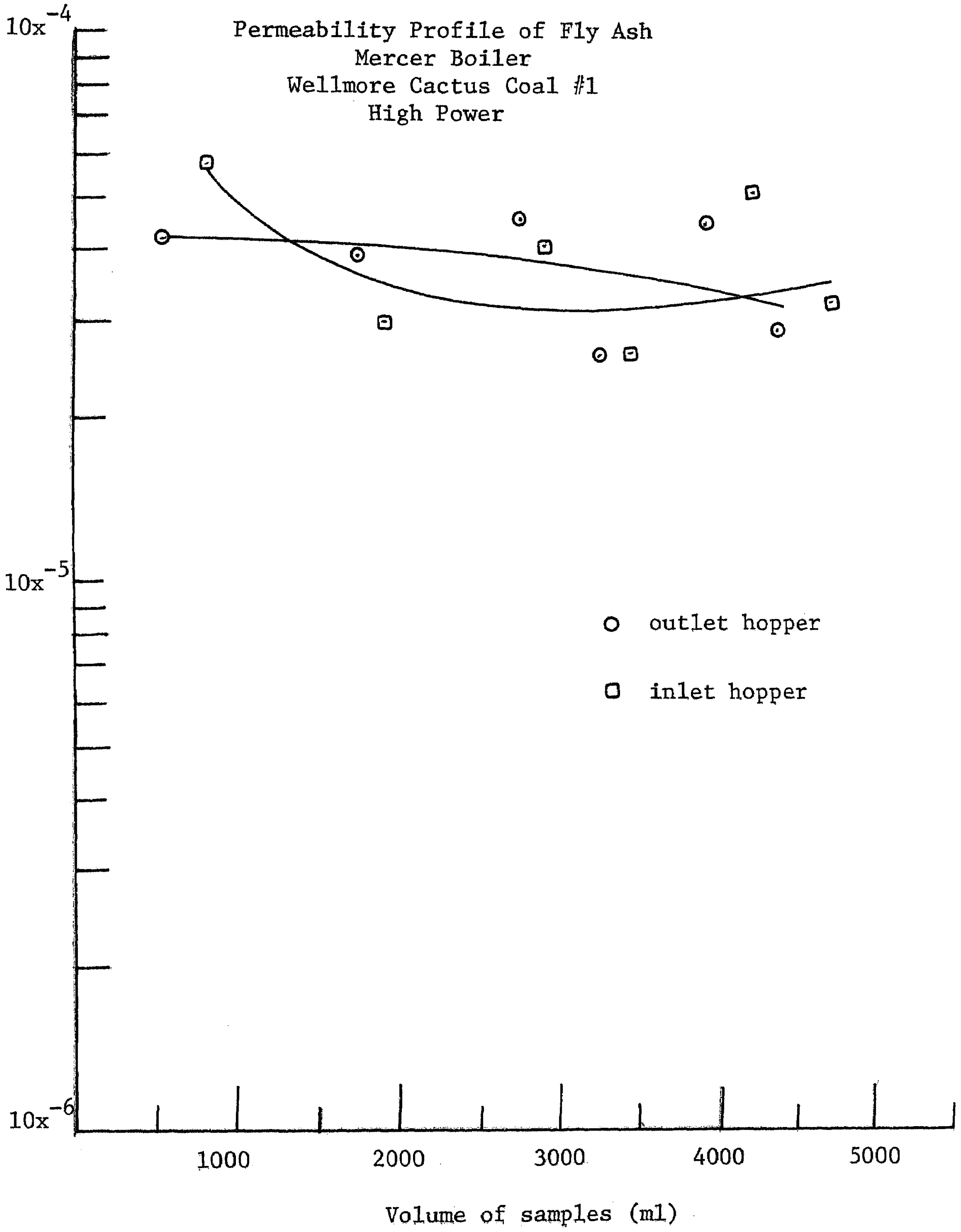


FIGURE 20



Permeability Profile of Fly Ash
Mercer Boiler
Wellmore Cactus Coal #1
High Power

FIGURE 21

Permeability Profile of Fly Ash
Mercer Boiler
Ellsworth Coal
High Power

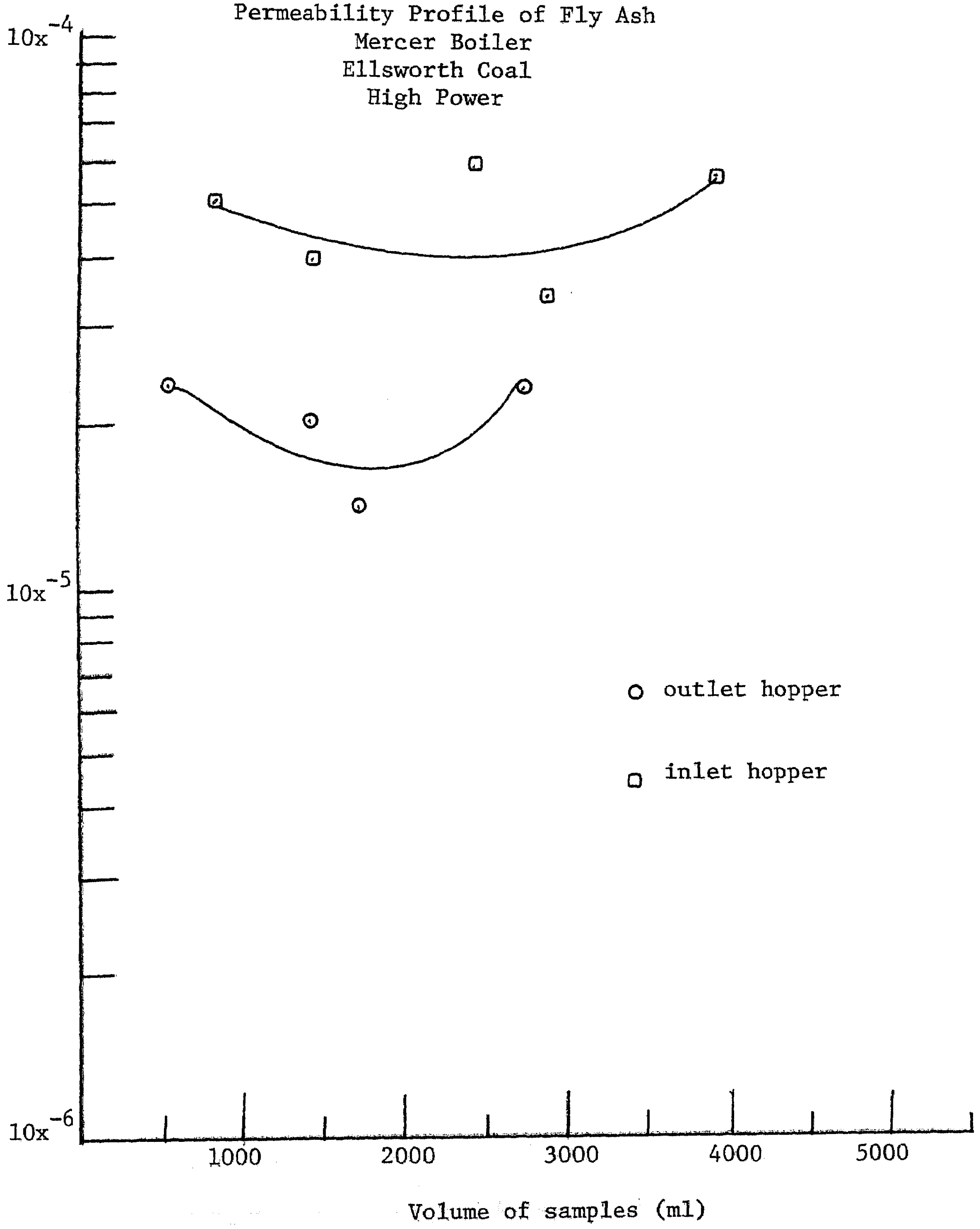


FIGURE 22

Permeability Profile of Fly Ash
Mercer Boiler
Wellmore Ackiss Coal
Low Power

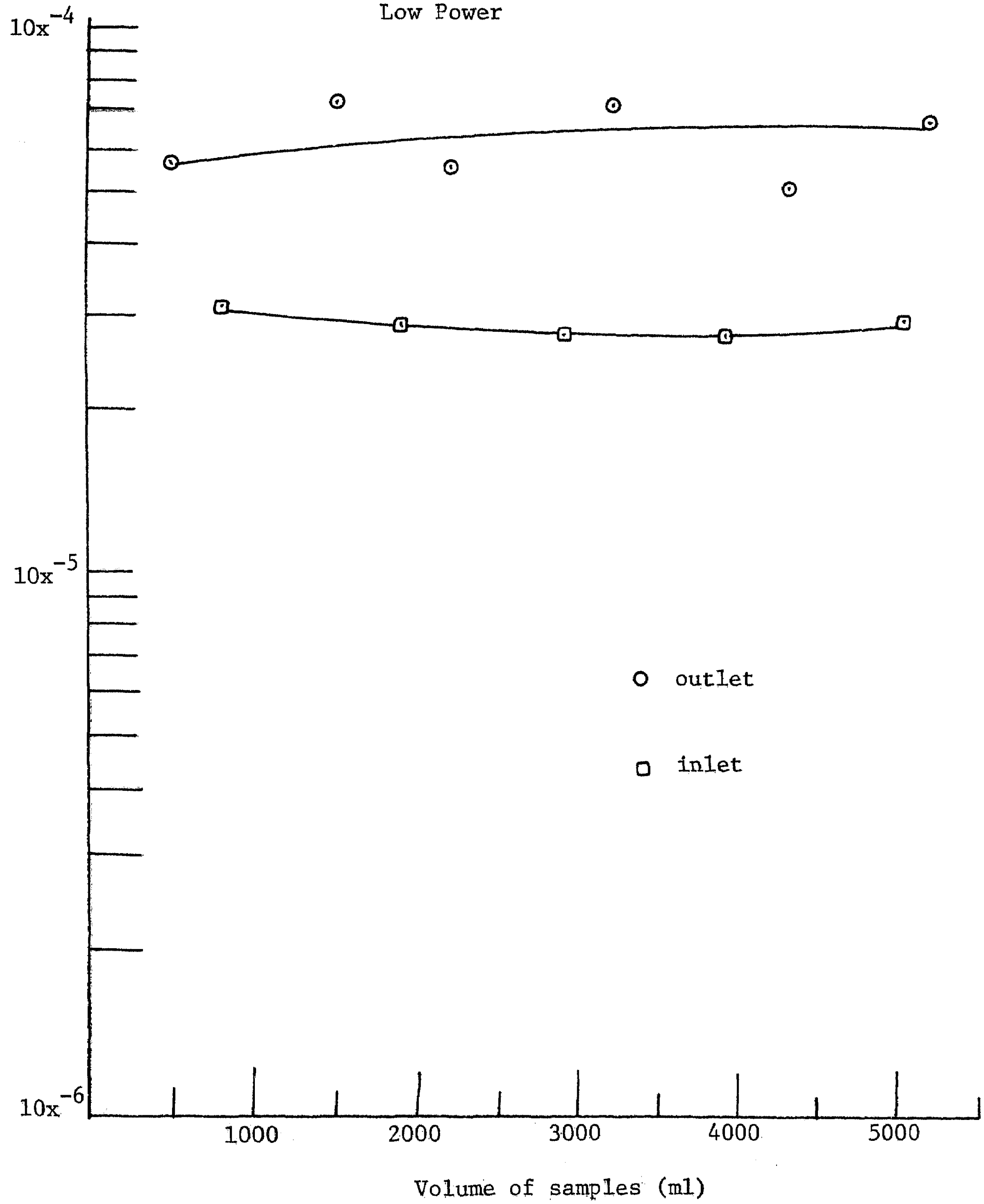


FIGURE 23

Permeability Profile of Fly Ash
Mercer Boiler
Wellmore Cactus Coal #2
High Power