United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park, NC 27711

EPA-453/R-94-045a
July 1994

Air

EPA

Medical Waste Incinerators - Background Information for Proposed Standards and Guidelines:

Model Plant Description and Cost Report for New and Existing Facilities

Office of Air Quality Planning and Standards
Clean Air
OAQPS

EPA-453/R-94-045a

Medical Waste Incinerators-Background Information for Proposed Standards and Guidelines: Model Plant Description and Cost Report for New and Existing Facilities

July 1994

U. S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina

DISCLAIMER

This report is issued by the Emission Standards Division, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency. It presents technical data of interest to a limited number of readers. Mention of trade names and commercial products is not intended to constitute endorsement or recommendation for use. Copies of this report are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations--as supplies permit--from the Library Services Office (MD-35), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711 ([919] 541-2777) or, for a nominal fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 ([703]487-4650).

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

MODEL PLANT DESCRIPTION AND COST REPORT

1.0 INTRODUCTION

This report is one of a series of reports prepared to support the development of new source performance standards (NSPS) and emission guidelines for medical waste incinerators (MWI's) under Section 129 of the Clean Air Act. The other reports in the series provide background information on the medical waste incineration industry, the process description, the emission control technologies, and the environmental impacts associated with selected control technologies.

This report presents the design and operating parameters and costs for model plants that represent the MWI source category. These model plants will be used in the analysis of cost, economic, and environmental impacts for development of NSPS and emission guidelines. The source category consists of several industries, including (but not limited to): (1) hospitals, (2) commercial waste disposal facilities, (3) laboratories/research facilities, (4) veterinaries, and (5) nursing homes.

Model plants consist of model combustors in combination with air pollution control technologies. A total of 77 model plants were developed to represent new MWI's, and 84 model plants were developed to represent existing MWI's. The new model plants are based on the combination of 7 model combustors with 11 emission control technologies. The existing model plants are based on 7 model combustors and 12 emission control technologies.

The remainder of this report is divided into eight sections. Section 2.0 presents the design and operating parameters for the 7 model combustors and 11 control technologies that were developed to represent new MWI's. The model combustors characterize combustor designs, waste types, waste charging capacities, operating temperatures, operating hours, and gas residence time in the secondary chamber. The control technologies consist of combustion controls alone or in combination with add-on air pollution control devices (APCD's).

The specified parameters for each model combustor and control technology are based on typical or predominant valves for MWI's installed in the last 5 years. Section 3.0 presents the capital and annual costs for these model combustors and control technologies. All costs are presented in October 1989 dollars.

Section 4.0 presents the design and operating parameters for the 7 model combustors and 12 control technologies that represent existing MWI's. The model combustors are identical to those developed to represent new MWI's, except that the gas residence time in the secondary chamber is lower for most existing models. (This is the only parameter that is significantly different for all existing MWI's than for those installed in the last 5 years.) The control technologies are also identical for both new and existing models, but one additional combustion control technology has been evaluated for existing models. Section 5.0 presents the costs to retrofit existing model combustors with these control technologies.

Section 6.0 presents the distribution of both new and existing model combustors among the various industries. Section 7.0 presents the capital and annual costs for emission and process monitors, Section 8.0 presents estimated performance test costs, and Section 9.0 presents the references. Appendices A through D present algorithms for estimating total annual costs for the model combustors and three representative control technologies.

2.0 MODEL COMBUSTORS AND CONTROL TECHNOLOGIES FOR NEW FACILITIES

This section presents the design and operating parameters for the 7 model combustors and 11 control technologies developed to represent new MWI installations. Model combustor parameters are presented in Section 2.1. Control technology parameters are described in Section 2.2.

2.1 MODEL COMBUSTORS

A total of seven model combustors have been developed to represent the population of new MWI's. Table 1 summarizes the industries that typically use MWI's represented by each model. As shown in Table 1, most of the model combustors are generic in that they may represent MWI's in more than one industry. Knowledge about the types of combustors in some industries is not as complete as for other industries, but the models span the range of design capacities and options offered by MWI manufacturers. Therefore, a new MWI in any industry will be adequately represented by at least one of the seven models.

TABLE 1. SUMMARY OF MODEL COMBUSTORS

Combustor type	Model design capacity	Applicable industries
Intermittent	200 lb/hr 600 lb/hr 1,500 lb/hr	H, N, L, V[a] H, N, L, V H, N, L, V
Continuous	1,000 lb/hr 1,500 lb/hr	H, L C[b]
Batch	500 lb/batch	H
Pathological	200 lb/hr	H, N, L, V

[a]Codes represent hospitals, nursing homes, laboratories, and veterinaries.
[b]Code represents commercial facilities.

Most of the parameters considered in selecting the model combustors were determined from analysis of the existing MWI population. Information was provided by incinerator manufacturers, hospitals, and commercial facilities in response to U. S. Environmental Protection Agency (EPA) requests for information. Additional information was obtained from surveys of MWI's conducted by four States. Characteristics for new units are assumed to be similar to characteristics of those units recently installed to meet more stringent requirements for combustion temperatures and residence times.

2.1.1 Combustor Designs

The seven model combustors are based on four designs. Three of these designs (continuous, intermittent, and batch units) are used to burn mixed red bag and general waste. The fourth design is used to burn pathological waste (i.e., tissues, organs, body parts, blood, and body fluids removed during surgery, autopsy, and biopsy). The primary chambers in continuous, intermittent, and batch MWI's operate under substoichiometric air conditions, while pathological MWI's operate under excess-air conditions. Other distinguishing features of each design are described below.

2.1.1.1 Continuous. A continuous MWI is one that can accommodate waste charging for an unrestricted length of time because ash is automatically discharged from the incinerator on a periodic or continuous basis. The initial step in the operating cycle is to preheat the secondary chamber to operating temperature. Concurrently, the primary chamber is preheated, but it may not be preheated to the operating temperature. The air blowers are then turned on, and the unit is ready to receive waste. An automatic ram is used to charge relatively small quantities of waste at frequent, regulated time intervals--typically every 6 to 15 minutes. As the waste burns down to ash it travels through the primary chamber by one of several methods. In most continuous units, one or more internal transfer rams push the waste across a fixed hearth or a series of stepped hearths. The lowest ram pushes ash off the hearth at the discharge end of the chamber. A few continuous units are designed with a primary chamber that is an inclined rotary kiln. As the chamber rotates, the solids tumble within the chamber and slowly move down the incline toward the discharge end of the kiln.

2.1.1.2 Intermittent. An intermittent combustor, depending on its size, is designed to accept waste charges at periodic intervals for between 8 and 14 hours. Once ash builds up to an unacceptable level, the unit must be shut down and cooled so that ash can be removed. The operating procedure before charging is identical to that for continuous combustors. Intermittent combustors are designed to have waste charged either manually or with an automatic ram on a periodic basis--typically every 6 to 15 minutes. However, some intermittent MWI's are actually charged at uneven intervals, whenever waste is available. After the last load, the remaining waste in the primary chamber burns down to ash (with auxiliary fuel, as necessary) over 2 to 6 hours. The combustor is then allowed to cool before ash is either manually removed or discharged by an operator-activated ash ram. If the combustor operates for only a few hours, ash need not be removed at the end of each operating cycle.

2.1.1.3 Batch. A batch combustor is one that is designed to burn only one load of waste at a time. A single "batch" of waste is first charged (either manually or with a ram feeder) to a cold incinerator. Subsequent sequential steps in the operating cycle are to preheat the secondary chamber, ignite the primary chamber burner(s), burn the waste down to ash, allow the unit to cool, and manually remove the ash. Except for small batch MWI's, this is a 2-day procedure. If the incinerator is not fully loaded, ash need not be removed during each operating cycle.

2.1.1.4 Pathological. In comparison with the other combustor designs, pathological combustors are most similar to intermittent units. However, as noted above, pathological combustors are used to burn a different type of waste, and they are designed with higher combustion airflow rates in the primary chamber. Pathological combustors also have larger primary chamber burners than intermittent units that burn an equivalent amount of mixed medical waste. In addition, the burners in pathological combustors operate for a greater percentage of time to evaporate the high moisture levels in pathological waste. The waste charging and ash removal procedures for pathological MWI's are the same as those for intermittent MWI's.

Incinerator manufacturers also make batch pathological combustors. However, the only known use of such combustors is at crematories, which, if they are only burning human remains, are not considered to be MWI's. Therefore, batch pathological combustors are not considered in this analysis.

2.1.2 Design Waste Charging Capacity

The range of design waste charging capacities (design capacities) for existing MWI's represented by each of the four combustor types was divided into segments, and appropriate model capacities were chosen to represent each segment. This process resulted in a total of seven model combustors. Most of the specified model design capacities are approximately equal to the arithmetic mean of capacities in the range segment. The design capacity of an MWI depends on the heat release rate for which the unit was designed and the heating value of the waste. Typically, MWI manufacturers specify the design capacities for their units based on heating values of 8,500 British thermal units per pound (Btu/lb) for combinations of general/red bag waste and 1,000 Btu/lb for pathological waste.[1,2] The rationale for the specified design capacities for each model combustor is presented in the four subsections below.

2.1.2.1 Continuous Models. The continuous model combustors were developed with design capacities of 1,000 and 1,500 pounds per hour (lb/hr). Table 2 summarizes available information about existing continuous MWI's. This information indicates that almost all of these units are used by commercial facilities and hospitals.

TABLE 2. SUMMARY OF EXISTING CONTINUOUS COMBUSTORS[a]

Industry segment/capacity range, lb/hr	No. of units	Average capacity in range, lb/hr
Hospitals		
350-900	28	643
901-1,100	14	973
1,101-1,910	20	1,455
Total	62	960
Commercial		
500-1,000	5	713
1,001-2,000	31	1,566
2,001-6,588	3	4,696
Laboratories/research		
875-1,500	4	1,266

[a]The tabulated information was obtained from five incinerator manufacturers, responses to EPA information requests, and emissions test reports.[2-10]

Design capacities for existing continuous units at hospitals range from about 350 to 1,850 lb/hr. The 1,000 lb/hr model was selected to represent all continuous units at hospitals because it approximates the average size of all known continuous units at hospitals, and it is the most common size.[2,7-10]

Design capacities for existing or planned continuous units at commercial facilities range from 500 to 6,250 lb/hr. One model, with a design capacity of 1,500 lb/hr, was developed to represent these units. This model was developed because 20 of the 39 known commercial units are this size, and it is only slightly smaller than the average capacity of the 31 units with capacities in the range of 1,000 to 2,000 lb/hr.[2,7-10]

2.1.2.2 Intermittent Models. Three intermittent model combustors were developed with design capacities of 200, 600 and 1,500 lb/hr. The 200 lb/hr model represents combustors with design capacities of 50 to 400 lb/hr; the 600 lb/hr model represents combustors in the range of 401 to 1,000 lb/hr; and the 1,500 lb/hr model represents combustors larger than 1,000 lb/hr. Table 3 summarizes the information from incinerator manufacturers, hospitals, and State surveys that was used to determine range segments and design capacities. Some of these surveys show capacities for existing intermittent MWI's range from less than 50 lb/hr to 2,200 lb/hr. However, the smallest known MWI currently produced is 50 lb/hr.[11] This information also indicates that the design capacities of over two-thirds of existing the intermittent MWI's are less than or equal to 400 lb/hr. About 25 percent have design capacities between 401 lb/hr and 1,000 lb/hr. Only 6 percent of existing combustors are larger than 1,000 lb/hr. According to available information, this combustor type is used in all industry segments except commercial facilities.[2-4,7-8,12-14]

2.1.2.3 Batch Models. One batch model was developed with a design capacity of 500 pounds per batch (lb/batch). This size is equal to the design capacity of a combustor that is produced by the only known manufacturer of batch MWI's. It was selected because it is between the average size of all batch MWI's and the most common size. Sales information from the manufacturer of batch MWI's is summarized in Table 4. This information shows batch MWI's range in size from 150 to 3,800 lb/batch, and nearly all of them are installed at hospitals.[9]

TABLE 3. SUMMARY OF EXISTING INTERMITTENT COMBUSTORS[a]

Industry segment/capacity range, lb/hr	No. of units	Average capacity in range, lb/hr
Hospitals		
50-400	513	199
401-1,000	212	597
>1,000	50	1,484
Laboratories and research facilities		
50-400	46	218
401-1,000	21	743
>1,000	6	2,165
Nursing homes		
50-400	37	115
401-1,000	2	538
Veterinaries		
50-400	10	115
401-1,000	0	--
>1,000	0	--

[a]The tabulated information is from three incinerator manufacturers, three State surveys, hospitals that responded to EPA information requests, and emissions test reports.[2-4,7,8,12-14] Information from incinerator manufacturers has been limited to installations since 1980 because there is a trend toward larger sizes in recent years. Due to limitations in the data, several assumptions were made. Most incinerator manufacturers did not distinguish between pathological and mixed waste combustors. Because mixed waste combustors are more common, it was assumed that all of the incinerators that they reported are mixed waste units. Because the definitions of incinerator types used in this analysis are different than those used by the States, it was assumed that any incinerator permitted to burn waste other than Type 4 waste was an intermittent unit. No reported capacities below 50 lb/hr in the State surveys were included in the analysis because no evidence indicates that such small combustors are currently being produced. Veterinaries were distinguished from animal shelters on the basis of the facility name, but several facilities may be misrepresented because a clear distinction was rarely apparent. Finally, a few facilities may have been described by more than one respondent.

TABLE 4. SUMMARY OF EXISTING BATCH COMBUSTORS[a]

Industry segment/capacity range, lb/batch	No. of units	Average capacity in range, lb/batch
Hospitals		
150	22	150
340-970	77	605
1,620-3,800	16	2,070

[a]The tabulated information was obtained from one incinerator manufacturer.[9]

2.1.2.4 Pathological Model. One pathological model was developed with a design capacity of 200 lb/hr. The specified capacity is based primarily on information from the New York, New Jersey, and Washington State MWI surveys, which is summarized in Table 5. This information shows that the capacities of existing incinerators that burn pathological waste (i.e., MWI's that are permitted to burn only Type 4 waste) have design capacities ranging from 50 to 2,000 lb/hr. The majority of these pathological incinerators are small; more than 90 percent of the units have capacities less than or equal to 300 lb/hr.[12-14] Similar data were provided by hospitals in responses to EPA information requests; all of the pathological incinerators at these hospitals have capacities less than 300 lb/hr.[7]

2.1.3 Actual vs. Design Waste Charging Capacity

The actual waste charging capacity (actual capacity) is distinguished from the design capacity based on differences between the actual waste heating values and those typically used by manufacturers when expressing incinerator design capacities. As noted above, incinerator manufacturers typically use 8,500 Btu/lb as the heating value for general/red bag waste. Although measured waste heating values are not available, charging rates measured during emissions tests and other information show the average hourly general waste charging rates for intermittent and continuous units over an operating cycle are about two-thirds (67 percent) of the design rates specified by

TABLE 5. SUMMARY OF EXISTING PATHOLOGICAL COMBUSTORS

	No. of units in each range			Average capacity in each range, lb/hr		
Range, lb/hr	50-100	101-300	>300	50-100	101-300	300
Industry segment						
Hospitals	91	58	9	80	184	622
Laboratories/research	21	22	7	68	194	569
Nursing homes	11	3	0	56	198	--
Veterinaries	68	13	5	66	173	894

[a]The tabulated information was obtained from three State MWI surveys and from hospital responses to EPA information requests.[7,12-14] The State surveys identified the types of waste that each facility is permitted to burn. It was assumed that any facility permitted to burn only Type 4 waste has a pathological incinerator.

manufacturers.[15-20] Charging rates during the first few hours of an operating cycle may be at the design rate, but this rate cannot be sustained. Also, the actual charges to one batch unit during emissions tests were slightly higher than 67 percent of the design charge size.[21] Since the incinerators are designed for a specific, constant heat release rate, these average actual charging rates indicate the actual general waste heating value is about 12,750 Btu/lb. This value was used to develop the actual capacities for the continuous, intermittent, and batch models in Tables 6 and 7.

The actual capacity for the pathological model is the same as the design capacity, because the actual heating value of pathological waste is believed to be about 1,000 Btu/lb (as reported by manufacturers).

2.1.4 Design and Operating Parameters

The seven model combustor designs are further characterized by design and operating parameters. Each of the parameters is discussed in the subsections below, and Tables 6 through 8 present the parameter specifications for each model combustor. Recovery of heat from the stack gases was not specified for any of the models because the procedure is used with very few existing MWI's.

TABLE 6. CONTINUOUS AND INTERMITTENT MODEL COMBUSTORS

Parameter\model combustor	Continuous models		Intermittent models		
	No. 1	No. 2	No. 3	No. 4	No. 5
Design thermal release rate, MMBtu/hr	13	9	12.8	5.1	1.7
Design capacity, lb/hr (based on 8,500 Btu/lb)	1,500	1,000	1,500	600	200
Actual capacity, lb/hr 67 % of design	1,000	667	1,000	400	133
Type of waste (general/red bag)	General and/or red bag				
Feed system	Automatic ram				
Design operating hours, hr/d					
Charging (maximum)	24	24	14	14	10
Burndown	N/A	N/A	4	4	4
Design d/yr (maximum)	340	340	340	340	340
Actual operating hours					
Preheat (a)	0.5	0.5	0.5	0.5	0.5
Charging, hr/d	24	9	7.5	7.5	5.5
Burndown (a)	2	2	4	4	4
Cooldown (b)	0	0	2	2	2
Actual d/yr	324	324	312	312	312
Actual hr/yr	7,776	3,726	4,368	4,368	3,744
Combustion air					
Overall, percent theoretical	300	300	300	300	300
Primary chamber, percent theoretical	50	50	50	50	50
Minimum operating temperature					
Primary chamber, F	1,200	1,200	1,200	1,200	1,200
Secondary chamber, F	1,700	1,700	1,700	1,700	1,700
Gas residence time in secondary chamber, s	1	1	1	1	1
Auxiliary fuel type	NG	NG	NG	NG	NG
Auxiliary fuel consumption, ft3/hr	2,576	1,717	2,576	1,030	343
Flue gas parameters					
Temperature, F (out of secondary chamber)	1,700	1,700	1,700	1,700	1,700
Oxygen concentration, percent (dry)	14	14	14	14	14
Volumetric flow rates					
dscfm	4,747	3,165	4,747	1,899	633
wscfm (assume 10 percent moisture)	5,275	3,516	5,275	2,110	703
acfm (out of secondary chamber)	21,578	14,385	21,578	8,631	2,877
Stack parameters					
Volumetric flow rate, acfm	19,580	13,053	19,580	7,832	2,611
Stack temperature, F	1,500	1,500	1,500	1,500	1,500
Stack height, ft	40	40	40	40	40
Stack diameter, ft	2.7	2.3	2.7	2	1.2

(a) Preheat and burndown times are given for each operating cycle; for the 1,500 lb/hr continuous unit, the operating cycle is two weeks, and for the 1,000 lb/hr continuous unit and the intermittent units, the operating cycle is one day.

(b) The cooldown hours represent the average number of hours during which the combustion airblowers remain on. The average is based on 6 hours for 1/3 of intermittent units and 0 hours for 2/3 of intermittent units.

TABLE 7. BATCH MODEL COMBUSTOR

Parameter\model combustor	No. 6
Thermal release rate, MMBtu/hr	4.3
Design capacity, lb/batch	500
(based on 8,500 Btu/lb)	
Size of primary chamber, ft3	112
Actual capacity, lb/batch	
67 % of design	333
Type of waste	General and/or red bag
Feed system	Manual
Design operating hours, hr/d	
"low air" phase hr/d	7
"high air" phase hr/d	5
Cooldown phase	10
Design d/yr (maximum)	340
Actual operating hours, hr/d	
Preheat phase	0.5
"low air" phase	7
"high air" phase	5
Cooldown	10
Actual d/yr	160
Actual hr/yr	3,600
Combustion air	
Overall, percent theoretical	300
Primary chamber, percent theoretical	50
Minimum operating temperatures	
Primary chamber, F	1,200
Secondary chamber, F	1,700
Gas residence time in secondary chamber, s	1
Auxiliary fuel type	NG
Auxiliary fuel consumption, ft3/hr	859
Flue gas parameters	
Temperature, F	1,700
Oxygen concentration, percent (dry)	14
Volumetric flow rates	
dscfm	455
wscfm (assume 10 percent moisture)	506
acfm	2,068
Stack parameters	
Volumetric flow rate, acfm	1,877
Stack temperature, F	1,500
Stack height, ft	28
Stack diameter, ft	1

TABLE 8. PATHOLOGICAL MODEL COMBUSTOR

Parameter\model combustor	No. 7
Design thermal release rate, MMBtu/hr	0.2
Design capacity, lb/hr (based on 1,000 Btu/lb)	200
Actual capacity, lb/hr 100 % of design	200
Type of waste	General and/or red bag
Feed system	Automatic ram
Design operating hours, hr/d	
Charging (maximum)	10
Burndown	4
Design d/yr (maximum)	340
Actual operating hours, hr/d	
Preheat	0.5
Charging	5.5
Burndown	4
Actual d/yr	312
Actual hr/yr	3,120
Combustion air	
Overall, percent excess	200
Primary chamber, percent excess	80
Minimum operating temperature	
Primary chamber, F	1,200
Secondary chamber, F	1,700
Gas residence time in secondary chamber, s	1
Auxiliary fuel type	NG
Auxiliary fuel consumption, ft3/hr	1,796
Flue gas parameters	
Temperature, F	1,700
Oxygen concentration, percent (dry)	14
Volumetric flow rates	
dscfm	730
wscfm (assume 10 percent moisture)	811
acfm	3,318
Stack parameters	
Volumetric flow rate, acfm	3,011
Stack temperature, F	1,500
Stack height, ft	20
Stack diameter, ft	1.0

2.1.4.1 Waste Charging System. Manual charging is specified for some of the models, and automatic charging systems are specified for other models. Typically, an automatic system consists of a charging ram.

Automatic charging is specified for all intermittent models. Responses to EPA information requests show that about 50 percent of the MWI's with capacities greater than 400 lb/hr have automatic charging equipment, and 33 percent of smaller MWI's have automatic charging systems.[7] However, two incinerator manufacturers indicated that automatic charging equipment is installed on nearly all of their new incinerators.[3,4] Another incinerator manufacturer indicated that automatic charging equipment is standard equipment for the larger models and an option for the smaller models.[2,22]

Automatic charging equipment is specified for both continuous models. This equipment is specified because it is used by all of the continuous MWI's for which information about the charging system is available.[7,8]

Manual charging is specified for the batch model because both the manufacturer's installation lists and responses to EPA information requests indicate that this approach is used by all existing facilities.[7,9]

The pathological model is specified with manual charging because most of the small pathological units described in responses to EPA information requests are charged manually.[7]

2.1.4.2 Combustion Air. According to several incinerator manufacturers, 50 percent of the air theoretically required for combustion is provided in the primary chamber of continuous and intermittent incinerators. Overall, 200 percent of the theoretical amount is introduced (i.e., 100 percent excess air if one considers total air for both the primary and secondary chambers).[3-5,23] However, the specified excess air levels for continuous, intermittent, and batch models are based on the actual results from emissions tests. These tests show the average oxygen concentration in the stack gas is about 14 percent, and the average overall excess-air level is about

200 percent (i.e., 300 percent of theoretical).[8,15-19,21] The specified airflow rate to the primary chamber is 50 percent of the theoretically required amount, as indicated by the manufacturers.

The overall excess air level for the pathological model also was assumed to be 200 percent. This value was selected because the oxygen (O_2) concentration in the exhaust gas and the overall excess air level were determined to be 15.7 percent and 270 percent, respectively, for one pathological MWI.[19] Both of these values are within the ranges of values for continuous and intermittent MWI's. The 200 percent value also has been reported as typical elsewhere.[24] Excess-air levels for the primary chamber are not available from emission tests and were assumed to be 80 percent.[24]

2.1.4.3 Gas Residence Time in the Secondary Chamber. Available data are insufficient to characterize the secondary chamber residence time for the existing MWI population. However, limited data show that older units typically have residence times that range from essentially 0 seconds up to about 1 second; most newer units have residence times of at least 1 second; and some may be as long as 2 to 3 seconds. A 1-second residence time has been assumed as baseline for all models representing new MWI's because it is a conservative estimate for determining cost impacts.

2.1.4.4 Minimum Primary and Secondary Chamber Operating Temperatures. The specified minimum operating temperatures for each model combustor type are 1200°F in the primary chamber and 1700°F in the secondary chamber. These temperatures are based on data provided by hospitals and commercial facilities in responses to EPA information requests. The responses indicated that operating temperatures vary widely, both at individual facilities and among facilities. Minimum operating temperatures were reported from 500° to 1950°F for the primary chamber and 1050° to 2150°F for the secondary chamber.[7]

2.1.4.5 Hours of Operation. Specified hours of operation are based on information from hospitals and commercial facilities that responded to EPA information requests, incinerator manufacturers, and State surveys. This information was used to develop hours of operation for MWI's at hospitals and commercial facilities. For each model, the hours of operation include the time for the preheat, burning (or charging), and burndown phases. Also included is the time while the combustion air blowers operate during the cooldown phase of intermittent and batch MWI's.

According to responses from hospitals and commercial facilities to EPA information requests, the most common preheat time for intermittent and batch combustors is about 0.5 hour.[7] Preheat times should be similar for other combustors. Therefore, this time has been specified for all of the models. The specified burning and burndown times, cooldown hours during which combustion air blowers operate, the total operating hours per year (hr/yr), and the basis for each are described in the subsections below.

2.1.4.5.1 Continuous models. Typically, commercial facilities operate for as much time as possible. Under ideal circumstances, the incinerators are only shut down an average of 1 day every other week for preventive maintenance and repairs. Adhering to this schedule would allow the incinerator to operate more than 8,100 hr/yr. However, according to the responses from commercial facilities to EPA information requests, commercial MWI's actually operate an average of about 7,776 hr/yr.[20] This utilization rate was specified for the 1,500 lb/hr continuous model. It was assumed that this operating rate can be characterized as 24 hours per day (hr/d) for 324 days per year (d/yr) (i.e., 26 2-week operating cycles per year with downtime of 1 day for preventive maintenance in every cycle and 2 or 3 additional days for corrective maintenance every 2 months). Included in the hours for the first and last days of the operating cycle are the hours for preheat and burndown, respectively. For continuous units, the burndown time is equivalent to the solids retention time. According to manufacturers, the average burndown time is about 2 hr.[2,4,23,25]

The 1,000 lb/hr continuous model combustor, which represents units at hospitals, is specified with 3,726 hr of operation per year. Responses from three hospitals to EPA information requests indicated that continuous units at hospitals operate about 11.5 hr/d for 340 d/yr.[7] However, based on the information from numerous commercial facilities, it was assumed that the 1,000 lb/hr continuous model would operate only 324 d/yr. The 11.5 hr/d includes 0.5 hr/d for preheat, 9 hr/d for burning, and 2 hr/d for burndown.

2.1.4.5.2 Intermittent models. The specified hours of operation for the 200 lb/hr model are 3,744 hr/yr, which can be characterized as 12 hr/d for 312 d/yr. For the larger models, the specified hours of operation are 4,368 hr/yr, or 14 hr/d for 312 d/yr.

The operating hours are based on responses from hospitals to EPA information requests, results of the New York survey, and information from incinerator manufacturers. The hourly rates provided in response to the EPA information requests include the preheat, burning, and burndown phases.[7] The hourly rates reported in the New York survey were assumed to be only for the burning phase.[12] In addition, all reported values less than 400 hr/yr in the New York survey were not included in the analysis. Most of the facilities that reported less than 400 hr/yr indicated that they operated their incinerator for 1 hr/d. Even if this operating time is correct for existing incinerators, it is reasonable to assume that new incinerators would not be operated for such a short amount of time. Based on information from incinerator manufacturers, the burndown hours for the New York facilities were estimated to be 4 hr/d. Preheat for the New York facilities was estimated to be 0.5 hr/d.

For all intermittent models, it was estimated that the primary chamber combustion air blower remains on for an average of 2 hours during the cooldown phase. This estimate is based on the cooldown operation of intermittent combustors from the three major MWI manufacturers. Combustion air blowers in combustors from two of these manufacturers are designed to shut off at the end of the burndown period. The combustors from the third manufacturer are designed to maintain the flow of combustion air for about 6 hours during the cooldown phase. Although the exact share of the intermittent combustor market held by each of these three manufacturers is not available, and the operation of the combustion air blower in combustors from most other manufacturers is not known, it was assumed that the combustion air blower remains on for 6 hours during the cooldown phase for one-third of intermittent combustors, while it is shut off at the end of the burndown phase in the other two-thirds of intermittent combustors.

2.1.4.5.3 Batch models. According to the manufacturer of batch combustors, it takes from 10 to 14 hr, depending on chamber capacity, to complete the burning and burndown phases of the operating cycle. Cooldown then takes another 10 hr. After the secondary chamber has been preheated and waste has been loaded into the primary chamber, the primary chamber burner is ignited. The waste then burns for 7 hr in a "low air" phase, in which the primary chamber is starved for combustion air. The combustor then enters a "high air" burndown phase, which lasts from 3 to 7 hr, depending on the size of the unit.[26] During cooldown, the burners are turned off, but the combustion air blower remains on and modulates between high and low flow, depending on the primary chamber temperature. After 10 hr, the blowers are turned off. Since the temperature is still 500° to 600°F in the primary chamber, several additional hours are required before the ash cleanout door can be opened.[21]

According to hospitals that responded to EPA information requests, about 47 percent of batch units are run 6 or 7 days per week (d/wk), and 33 percent run less than 3 d/wk.[7] However, these responses do not distinguish between the number of days when the incinerator is in use and the number of times waste is actually charged. Based on the information from the manufacturer and observations during an emissions test, the operating cycle of the 500 lb/batch model is more than 24 hr. For operator convenience that means the cycle lasts 2 days, and a weekly schedule consists of three operating cycles followed by one day off for preventive maintenance and repairs. This schedule results in 160 operating cycles per year.

As shown in Table 7, the 500 lb/batch model is specified with 3,600 hr/yr. These hours include the preheat, "low-air," "high-air," and cooldown phases of the operating cycles.

2.1.4.5.4 Pathological models. Data from the responses to EPA information requests and the results of the New York survey show operating hours for pathological combustors are less than 80 percent of the value for small intermittent units (i.e., MWI's that are represented by the 200 lb/hr intermittent model combustor burning mixed medical waste). However, the specified operating hours for the pathological model are the same as those for the 200 lb/hr intermittent model because (1) significantly less data are available on the operation of pathological combustors, (2) both combustor designs are used in the same industries, (3) the design hours of operation are the same for both combustors, and (4) it is likely that the utilization rates for both combustors need to be about the same to make it economical to operate them.

2.1.4.6 Flue Gas Parameters. Three of the flue gas parameters on which the design of add-on air pollution control equipment is based are temperature, moisture content, and volumetric flow rate. These parameters are discussed below.

The specified flue gas temperatures are based on the minimum secondary chamber temperature. As indicated above, responses from hospitals to EPA information requests indicate that the minimum secondary chamber temperatures for all combustor types is, on average, 1700°F. The average flue gas moisture content, based on data from the emission test reports, is about 10 percent.[8] This value was specified for all of the model combustors.

The volumetric flow rates for continuous and intermittent model combustors were calculated based on the flow rates monitored during emissions tests of similar MWI's. A plot of flow rate vs. actual charging rates during the tests was developed, and an equation for the best fit line through the data was used to calculate the flow rates for each model combustor.[27] The data from tests of both combustor designs are analyzed together because combustion air requirements are assumed to be the same for similar waste charging rates. As noted in Section 2.1.4.2, the exhaust gas streams that were monitored during the EPA and non-EPA emissions tests contained an average O_2 concentration of about 14 percent.[8]

Flow rates for batch model combustors were estimated from the average flow rates obtained during emission tests of four combustors and the assumption that the ratio of flow rate to charge rate is a constant. For the four tests, the ratio was 0.9 dry standard cubic feet per minute per pound (dscfm/lb) of waste charged.[8,21,27] Exhaust gas O_2 concentrations were assumed to be 14 percent.

For pathological incinerators, the gas stream flow rates were calculated based on assumed stoichiometric combustion air requirements, the total heat output from the incinerator, excess-air levels, and the gas stream moisture contents and temperatures.[27] The stoichiometric combustion air requirements were estimated to be 1.0 dscf/100 Btu. The total heat output in the gas stream from the incinerators was estimated by adding the heat content of pathological waste (1,000 Btu/lb) and the maximum capacities of the burners for pathological incinerators.[9] Heat losses were assumed to be zero. As indicated in Section 2.1.4.2, excess-air levels were assumed to be 200 percent. The applicable temperatures and moisture contents are presented earlier in this section.

2.1.4.7 Stack Parameters. The temperature and volumetric flow rate of the stack gas and stack dimensions are input parameters for dispersion modeling. According to responses to the EPA information request, the average stack gas temperature of MWI's without add-on APCD's or heat recovery was 1500°F.[8] The same stack gas temperature was assumed for all models because secondary chamber temperatures are similar and ductwork and stack configurations are similar for all combustor designs. The volumetric flow rates were calculated by applying a temperature correction factor to the flue gas flow rates. Stack heights for the models were based on responses to EPA information requests. The average heights were about 45 ft for intermittent and continuous units and 35 ft for pathological units. The typical height for batch units was about 30 ft. For most models, stack diameters were determined from the responses and from test reports.[7,8] Where data were not available, stack diameters were calculated assuming a gas velocity of 3,500 feet per minute.

2.2 CONTROL TECHNOLOGIES

Eleven control technologies were developed. One control technology consists of combustion controls; the other 10 consist of combustion controls in conjunction with an add-on APCD. The APCD's are based on variations of seven basic types of equipment: (1) venturi scrubber (VS), (2) packed bed (PB), (3) fabric filter (FF), (4) venturi scrubber/packed bed (VS/PB), (5) dry injection/fabric filter (DI/FF), (6) fabric filter/packed bed (FF/PB), and (7) spray dryer/fabric filter (SD/FF). All of the basic designs have been demonstrated to control emissions from one or more MWI's. Each of the APCD's with an FF were also evaluated with activated carbon injection. The specified design and operating parameters for combustion and add-on controls and the rationale for the specifications are presented in the following subsections.

2.2.1 Combustion Control

This control technology consists of incinerator design and operating parameters. For this analysis, these parameters are defined as (1) a minimum secondary chamber operating temperature of 1800°F whenever both the primary chamber combustion air blower is on and the primary chamber exhaust gas temperature is above 300°F, and (2) and a minimum secondary chamber gas residence time of 2 seconds when the gas is at 1800°F. The secondary chamber temperature requirement applies to the cooldown phase as well as the burning and burndown phases, as long as the primary chamber gas temperature and combustion air blower conditions are met. As noted in Section 2.1.4.5 and in Tables 6 and 7, the applicable cooldown time is an average of 2 hr/d for intermittent combustors and 10 hr/d for batch combustors.

2.2.2 Add-On Control Equipment

The design and operating parameters for each of the seven basic APCD's are described in the subsections below and are summarized in Table 9 for all of the model combustors. Additional parameters needed for cost analyses are developed in Section 3.0. All parameters are based on typical values provided by vendors and on values from emission test reports.

2.2.2.1 Venturi Scrubber. The two parameters that describe VS operation are the pressure drop through the venturi throat and the L/G ratio (i.e., the combined liquid flow to the quench and venturi vs. the actual gas flow into the quench). According to two vendors, the typical pressure drop through the venturi is about 30 inches of water column (in. w.c.)[28,29] One vendor provided liquid flow rates that were used to calculate an L/G ratio of 6 gallons per 1,000 actual cubic feet per minute (gal/1,000 acfm). This vendor also indicated that hydrogen chloride (HCl) removal efficiency is nearly as good as that achieved with a VS/PB if caustic solution is used as the scrubbing liquid.[30]

2.2.2.2 Packed Bed. According to one vendor, at least two facilities use a quench followed by a PB to control emissions from MWI's.[28] Information is not available for these facilities. However, because the gas characteristics are essentially the same after the quench in both PB and VS/PB devices, it was assumed that the design and operating parameters and the HCl removal efficiencies for the PB system are the same as those for the VS/PB systems, which are described below.

2.2.2.3 Venturi Scrubber/Packed Bed. The pressure drop and L/G ratios for the VS in the VS/PB control device are the same as those for the VS control device alone. Important PB parameters are stoichiometric ratio (SR), L/G ratio, pressure drop, packing height, and absorber shell diameter. Typically, caustic solution is used as the scrubbing liquid. According to one vendor, the SR (the molar ratio of the amount of caustic added to the amount of

TABLE 9. CONTROL DEVICE OPERATING PARAMETERS

Model combustor no.	Continuous models No. 1	No. 2	Intermittent models No. 3	No. 4	No. 5	Batch model No. 6	Pathological model No. 7
Control device parameters							
1. **Venturi**							
a. pressure drop, in. w.c.	30	30	30	30	30	30	30
b. L/G (gal/1,000 acf)	6	6	6	6	6	6	6
2. **Fabric filter**							
a. bag type	FELT	FELT	FELT	FELT	FELT	FELT	FELT
b. G/C ratio, ft/min	7	7	7	7	7	7	7
c. cloth area, ft2	3,186	2,165	3,186	1,347	530	320	592
d. pressure drop, in. w.c.	3	3	3	3	3	3	3
3. **Packed bed absorber**							
a. packing height, ft	5	5	5	5	5	5	5
b. stoichiometric ratio	1:1	1:1	1:1	1:1	1:1	1:1	1:1
c. pressure drop, in. w.c.	4	4	4	4	4	4	4
d. L/G (gal/1,000 acf)	20	20	20	20	20	20	20
e. shell diameter, in	72	60	72	48	30	24	30
4. **Venturi/packed tower**							
a. venturi pressure drop, in. w.c.	30	30	30	30	30	30	30
b. packed bed pressure drop, in. w.c.	4	4	4	4	4	4	4
c. venturi L/G ratio	6	6	6	6	6	6	6
d. packed bed L/G ratio	20	20	20	20	20	20	20
e. stoichiometric ratio	1:1	1:1	1:1	1:1	1:1	1:1	1:1
f. packing height, ft	5	5	5	5	5	5	5
g. shell diameter, in	72	60	72	48	30	24	30
5. **Dry injection/fabric filter**							
a. bag type	FELT	FELT	FELT	FELT	FELT	FELT	FELT
b. G/C ratio, ft/min	3.5	3.5	3.5	3.5	3.5	3.5	3.5
c. cloth area, ft2	3,186	2,165	3,186	1,347	530	320	592
d. FF pressure drop, in. w.c.	5	5	5	5	5	5	5
e. stoichiometric ratio	2.5	2.5	2.5	2.5	2.5	2.5	2.5
f. makeup lime rate, lb/hr (a)	49.9	33.3	49.9	20.0	6.70	0.65	0.63
6. **Fabric filter/packed tower**							
a. bag type	FELT	FELT	FELT	FELT	FELT	FELT	FELT
b. G/C ratio	7	7	7	7	7	7	7
c. cloth area, ft2	3,186	2,165	3,186	1,347	530	320	592
d. FF pressure drop, in. w.c.	3	3	3	3	3	3	3
e. packed bed pressure drop, in. w.c.	4	4	4	4	4	4	4
f. L/G ratio	20	20	20	20	20	20	20
g. stoichiometric ratio	1:1	1:1	1:1	1:1	1:1	1:1	1:1
h. packing height, ft	5	5	5	5	5	5	5
i. shell diameter, in	72	60	72	48	30	24	30
7. **Spray dryer/fabric filter**							
a. gas residence time in SD, s	15	15	15	15	15	15	15
b. stoichiometric ratio	2.5	2.5	2.5	2.5	2.5	2.5	2.5
c. bag type	FELT	FELT	FELT	FELT	FELT	FELT	FELT
d. G/C ratio	3.5	3.5	3.5	3.5	3.5	3.5	3.5
e. cloth area, ft2	3,186	2,165	3,186	1,347	530	320	592
f. FF pressure drop, in. w.c.	5	5	5	5	5	5	5
g. makeup lime rate, lb/hr (a)	49.9	33.3	49.9	20.0	6.70	0.65	0.63

(a) The makeup rates are based on the stoichiometric ratio above and on the HCl concentration used in Table 23.

caustic required to exactly neutralize all acid gases) is about 1:1 or slightly less. This ratio is specified to maintain pH at or slightly below 7 to avoid scaling. The vendor also indicated that the L/G ratio at the inlet to the PB is about 20 gal/1,000 saturated acfm.[28] According to this vendor, the pressure drop across the packed tower is 4 in. w.c.[30] Two vendors indicated the packing height for their absorbers is 5 feet. One vendor indicated that the packing is plastic Intalox saddles; the other uses plastic Tellerette packing.[28,31] The absorber shell diameter is a function of the gas flow rate. The specified shell diameters for absorbers used with each model combustor are based on information from the vendor with larger absorbers.[28] The resulting shell diameters range from 24 in. for the smallest combustor to 72 in. for the largest combustor. A mist eliminator at the outlet of the PB minimizes salt carryover.

2.2.2.4 Fabric Filter. Although an FF has been used alone to control emissions from at least two MWI's, design and operating information for those installations is not available. However, because the inlet gas conditions for FF and FF/PB devices are identical, it was assumed that the parameters for an FF device alone are the same as those for the FF in the FF/PB device, which is described below. According to vendors, a range of PM emission levels can be achieved, depending on the type of bag. Membrane bags are more efficient than felt bags. For this analysis, the FF's are based on felt bags because they are used in most existing applications, and they are less expensive.

2.2.2.5 Dry Injection/Fabric Filter. For this control device, lime is injected into the duct between an evaporative cooler and the FF, and a retention chamber is placed between the injection point and the FF. Two of the four DI/FF equipment vendors that responded to EPA information requests indicated that lime is recycled, and the other two indicated that it is not. Three of the vendors use a retention chamber, and the fourth offers an FF with an extended housing that serves as a retention chamber.[32-35] All of the vendors specified a pulse-jet FF design. The parameters presented in Table 9 are for the most common variation of the DI/FF system, which includes a retention chamber but no recycle equipment.[32-37]

The vendors use either evaporative coolers, gas-to-air heat exchangers, or a combination of this equipment to reduce the gas temperatures to between 250° and 400°F before the alkaline reagent injection. According to the vendors, lower temperatures maximize control of metals and polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (CDD/CDF) as well as the acid gases. For the models, a temperature of 300°F has been assumed.

The makeup lime feed rate was based on an SR of 2.5:1, which is about the average of the values reported by two vendors that do not recycle lime.[34,35] The vendors specified this ratio for 95 and 75 percent removal of HCl and sulfur dioxide (SO_2), respectively, from a gas stream that contained HCl and SO_2 concentrations of 1,200 parts per million dry volume (ppmdv) and 60 ppmdv, respectively, corrected to a 7 percent O_2 concentration.[32-35] For different HCl and SO_2 concentrations, the lime makeup rate would be scaled up or down as necessary to maintain the 2.5:1 stoichiometric ratio.

An EPA-sponsored emission test of an MWI with a DI/FF control device showed the SR had to be about 5:1 to achieve a 95 percent HCl removal efficiency.[38] However, this DI/FF control device did not have a retention chamber. One vendor indicated that to achieve the same results, the lime feed rate in a device without a retention chamber might have to be two times higher than the rate in a device with a retention chamber. Therefore, an SR of 2.5:1 appears to be reasonable for the model DI/FF control device.

A range of PM emission levels can be achieved with this control device (just as for the FF alone), depending on whether felt or membrane bags are used. The net gas-to-cloth (G/C) ratio is specified as 3.5:1, which is about the midpoint of the range provided by vendors and is equal to the operating ratio at one hospital.[17,32-35] The models are based on felt bags because most existing FF's contain felt bags, and they are less expensive than membrane bags.

The specified pressure drop for the DI/FF control devices is 9 in. w.c. This value is based on information from vendors that the pressure drop across the FF is about 5 in. w.c. and on the assumption that the pressure drop is 4 in. w.c. through the combustor, evaporative cooler, and ductwork.

Data from an EPA-sponsored emissions test indicate that injecting activated carbon before the fabric filter improves the removal efficiency of both CDD/CDF and mercury (Hg). A carbon injection rate that produced a carbon concentration of 338 mg/dscm reduced CDD/CDF and Hg emissions by 98 percent and 90 percent, respectively, relative to inlet concentrations.[38] This carbon concentration was specified for the model DI/FF control technology with activated carbon injection.

2.2.2.6 Fabric Filter/Packed Bed. For this control device, as for all controls that include a FF, the gases must be cooled before entering the FF. One vendor that offers this type of control device uses a gas-to-gas heat exchanger before the FF. A water spray and dilution air are also included before the heat exchanger to provide additional cooling when needed. The exhaust gas could be cooled solely with a water quench, but no known FF/PB control device uses such cooling equipment. As for other FF technologies, the specified FF is a pulse jet design, it is assumed that felt bags are used, and the specified FF operating temperature is 300°F. According to the permit for one facility with this control equipment, the G/C ratio is 7:1, and the pressure drop across the FF is about 3 in. w.c.[39]

The gases are cooled to saturation by caustic solution spray in the duct between the FF and the PB. The PB parameters are assumed to be the same as those for the PB in the VS/PB control device. The gases leaving the PB are ducted to the gas-to-gas heat exchanger to cool the exhaust gases from the incinerator. The heat exchanger raises the temperature of the gases from the PB above the dew point, which eliminates a steam plume from the stack.

No FF/PB control device currently operates or has been tested with activated carbon injection. Consequently, the performance of carbon injection in a FF/PB control device is not known. For the model and the costing analyses, however, the carbon concentration for this control technology was assumed to be the same as that for the DI/FF control technology.

2.2.2.7 Spray Dryer/Fabric Filter. Parameters for this control device are based on information from one vendor that has installed an SD/FF control device for an MWI and from two other vendors that have produced SD/FF systems for other types of incinerators.[34,40-43] Each of these vendors indicated that lime slurry is injected into the spray dryer vessel by a rotary atomizer. According to two of the vendors, the gas residence time in the spray dryer vessel ranges from 10 seconds to 18 seconds; an average of 14 seconds was specified for the models.[40,43] Gases are cooled to about 300°F in the spray dryer.

Two of the vendors specified SR's that ranged from about 2.0:1 to 3.0:1 to achieve 95 percent removal of HCl and 75 percent removal of SO_2 from the gas stream described in Section 2.2.2.5.[34,42] During an EPA-sponsored emissions test, HCl removal efficiencies of about 99 percent were achieved with an SR of about 2.5:1.[41] Therefore, an SR of 2.5:1 was specified for the model.

Each of the vendors uses a pulse-jet FF, and two of them indicated that the FF parameters would be the same as those for DI/FF devices that they also make. Therefore, the G/C ratio for the model is 3.5:1, the pressure drops across the FF is 5 in. w.c., and felt bags are used in the FF.[34,41-43]

Data from the EPA-sponsored emissions test indicate that including activated carbon in the lime slurry improves the removal efficiency of CDD/CDF and Hg. Adding carbon at a concentration of 188 mg/dscm reduced CDD/CDF emissions by 98 percent and Hg emissions by 90 percent, relative to inlet levels.[41] This concentration was specified for the model.

3.0 COMBUSTOR AND CONTROL TECHNOLOGY COSTS FOR NEW FACILITIES

This section presents the capital and annual costs for the 7 model combustors and 11 control technologies developed in Section 2. All costs are in October 1989 dollars. Cost and design information was obtained from a total of nine incinerator and eight APCD vendors; some of the vendors also provided additional data in response to followup requests.[2-5,6,9,23,25,28,29,31-35,44-58] This information was used to develop the capital and annual cost algorithms that are discussed in this section.

Many of the vendors claimed their cost data (and some design data) to be confidential business information. Therefore, specific references regarding the number of information sources, design characteristics, or costs used to develop the algorithms are not provided in this section when they contain confidential business information. These details are presented in Reference 59.

The remainder of this section is divided into six subsections. Capital costs for the combustors and control technologies are discussed in Sections 3.1 and 3.2, respectively. Annual costs for the model combustors are presented in Section 3.3. Annual costs for each of the control technologies are estimated in Section 3.4. Activated carbon injection costs are discussed in Section 3.5. A summary of the total capital investment and total annual costs is presented in Section 3.6.

3.1 COMBUSTOR CAPITAL COSTS

The total capital investment (TCI) consists of purchased equipment costs (PEC) and installation costs. Purchased equipment costs for each combustor type are based on combustors with secondary chambers that are designed for operation at 1800°F or more with a gas residence time of 1 second. The model combustors are designed for 1800°F, but they are specified with an actual operating temperature of 1700°F because this is the typical temperature at facilities (including those with nearly new units) that responded to EPA requests for information.[2]

Installation costs were estimated to be equivalent to 48 percent of the PEC for all model combustors. This factor is the average of values obtained from manufacturers that indicated installation factors are between 33 and 60 percent. These manufacturers provided cost factors for intermittent and continuous combustors. It was assumed that installation costs for batch and pathological combustors fall in the same range.

The equations that were developed to estimate the model PEC's are shown in Table 10, and the TCI's for each model are presented in Table 11. The procedures by which the model PEC's were developed are described below.

3.1.1 Continuous Combustors

Purchased equipment costs for continuous combustors are presented in Figure 1. The data show considerable scatter. It is not known what design or fabrication factors account for the variation, but the data represent actual manufacturer costs. Therefore, the model combustor costs are based on the equation of a line that was determined by least-squares linear regression using all of the data.

The continuous combustor costs estimated from this equation are almost three times higher than the costs described in Section 3.1.2 for intermittent units that have the same design capacity. There are several design differences between continuous and intermittent units that account for the cost difference. Typically, the primary chamber of a continuous unit has at least two hearths, an ash transfer (or discharge) ram for each hearth, a water sump into which the ash is discharged, and an ash hoe or conveyor system to remove the ash from the sump. Also, the hydraulic system for continuous units is larger than that for intermittent units because it must power the ash transfer rams and the ash hoe as well as the ram feeder. Additional controls and instrumentation are also required for these continuous combustor components. The shell of the primary chamber is larger for continuous units because it encompasses the sump. Other differences between continuous and intermittent units are unique to individual manufacturers. For example, one manufacturer incorporates an underfire cooling system (recirculating water piping, pump, and water-to-air heat exchanger) in continuous units. Air shrouds on the primary and secondary chambers to preheat secondary chamber combustion air are included by one manufacturer. At least one manufacturer uses

TABLE 10. EQUATIONS TO ESTIMATE PURCHASED EQUIPMENT COSTS FOR MODEL COMBUSTORS

Combustor type	Purchased equipment cost equation[a]	Regression value, R^2
Intermittent	$\$ = 5,817 \times (lb/hr)^{0.4537}$	0.75
Continuous	$\$ = 174.2 \times (lb/hr) + 177,740$	0.44
Batch	$\$ = 31.3 \times (lb/batch) + 32,775$	0.98
Pathological	$\$ = 216 \times (lb/hr) + 21,898$	0.62

[a]The design capacities are used in these equations.

TABLE 11. SUMMARY OF MODEL COMBUSTOR CAPITAL COSTS

Combustor design	Combustor capacity	Model combustor	Model combustor costs	
			Purchased equipment cost, $	Total capital investment, $[a]
Continuous	1,500 lb/hr	1	439,040	650,000
	1,000 lb/hr	2	351,940	521,000
Intermittent	1,500 lb/hr	3	160,580	238,000
	600 lb/hr	4	105,961	157,000
	200 lb/hr	5	64,369	95,300
Batch	500 lb/batch	6	48,425	71,700
Pathological	200 lb/hr	7	65,098	96,300

[a]The PEC was multiplied by 1.48 to estimate the TCI. This factor accounts for the installation costs, and it is based on information from incineration manufacturers that estimated installation costs to be between 33 and 60 percent of the purchased equipment costs.

Purchased Equipment Costs
Continuous Combustors

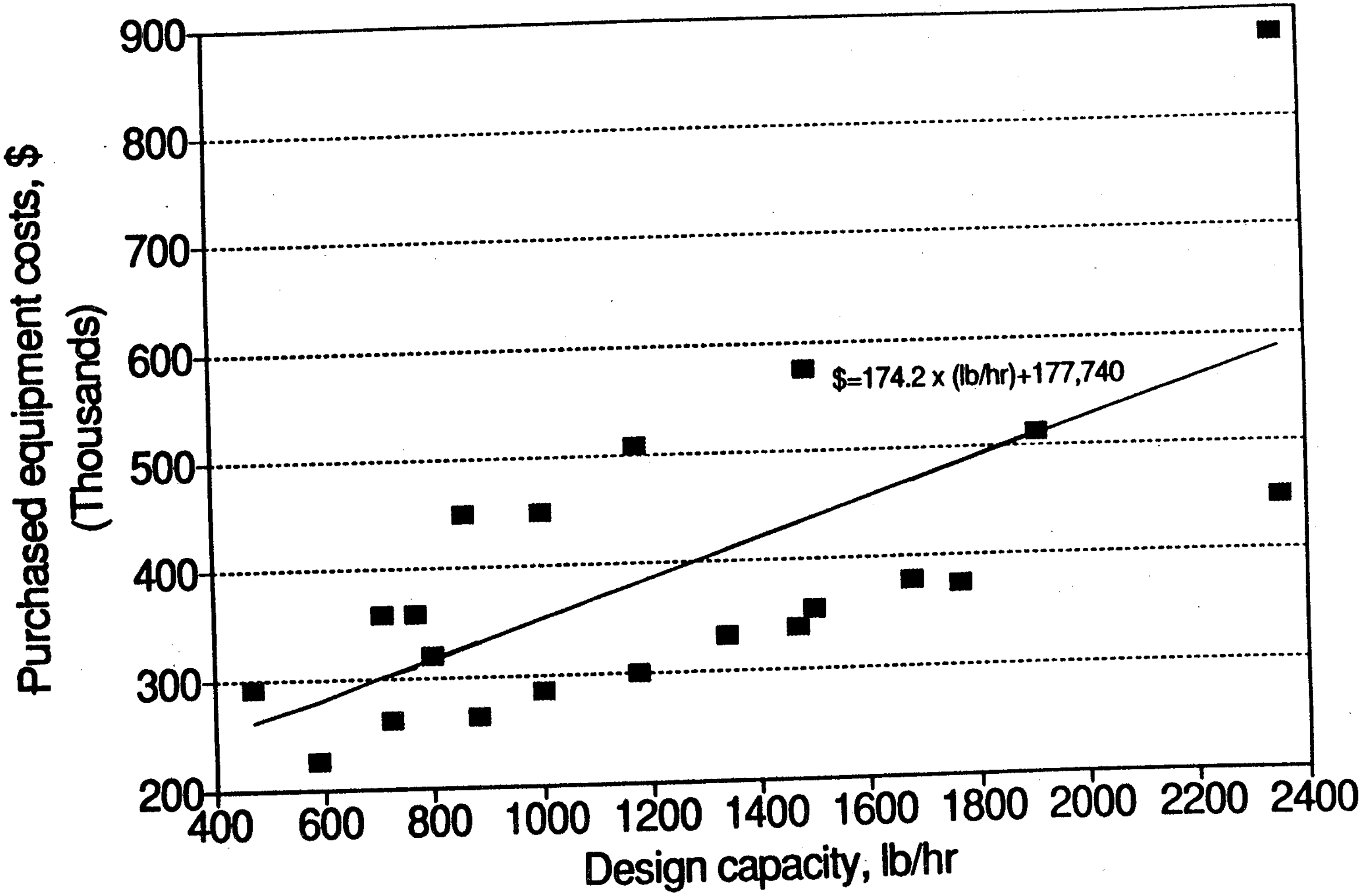

Figure 1. Purchased equipment costs for continuous combustors.

thicker and/or different refractory and insulation in continuous units. One manufacturer includes temperature zone controls only in the primary chamber of continuous units. One manufacturer designs a continuous unit with a Pulse-Hearth™ primary chamber.

3.1.2 Intermittent Combustors

Purchased equipment costs for intermittent combustors are presented in Figure 2. Except for three of the small combustors, the cost for an automatic feed mechanism is included in the costs that were obtained from the manufacturers. Since the models include automatic charging equipment, ram feeder costs were estimated for the three small units based on information from other manufacturers. One manufacturer indicated that one unit has a top loading mechanism, and the cost for this equipment is about the same as a ram feeder.[47] The model combustor costs are estimated from the equation for the best-fit curve, which was determined from a power function through the data.

The costs for two combustors (385 lb/hr and 765 lb/hr units) appear to be extreme outliers. The sizes for the these combustors are based on the actual burn rate rather than the maximum charge rate, which other manufacturers have used. Accounting for this difference would increase the sizes of these units by 20 percent, but that is not enough to bring their costs into line with the others. Other factors that could explain why these two units cost significantly more than other combustors are not known. Since a majority of the costs are much lower, these two data points are not included in the analysis.

3.1.3 Batch Combustors

Purchased equipment costs for three batch combustors are presented in Figure 3. The costs do not include an automatic ram feeder because a ram is not available on the small and midsize units, and it is only an option on the large unit. The model combustor PEC's are based on a least-squares linear regression line through the data.

3.1.4 Pathological Combustors

The manufacturers provided information for two types of pathological combustors: "hot-hearth" and "dual-purpose"

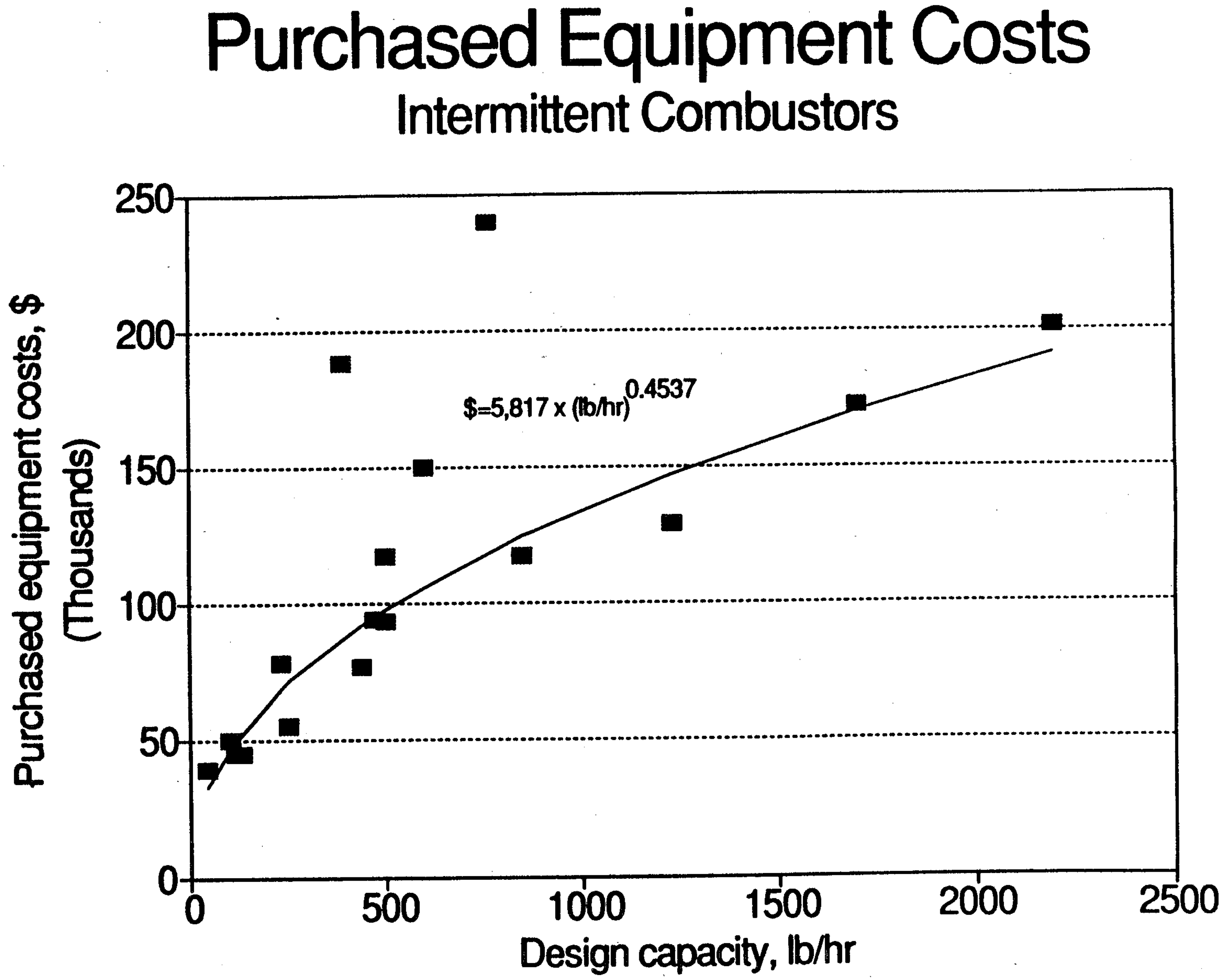

Figure 2. Purchased equipment costs for intermittent combustors.

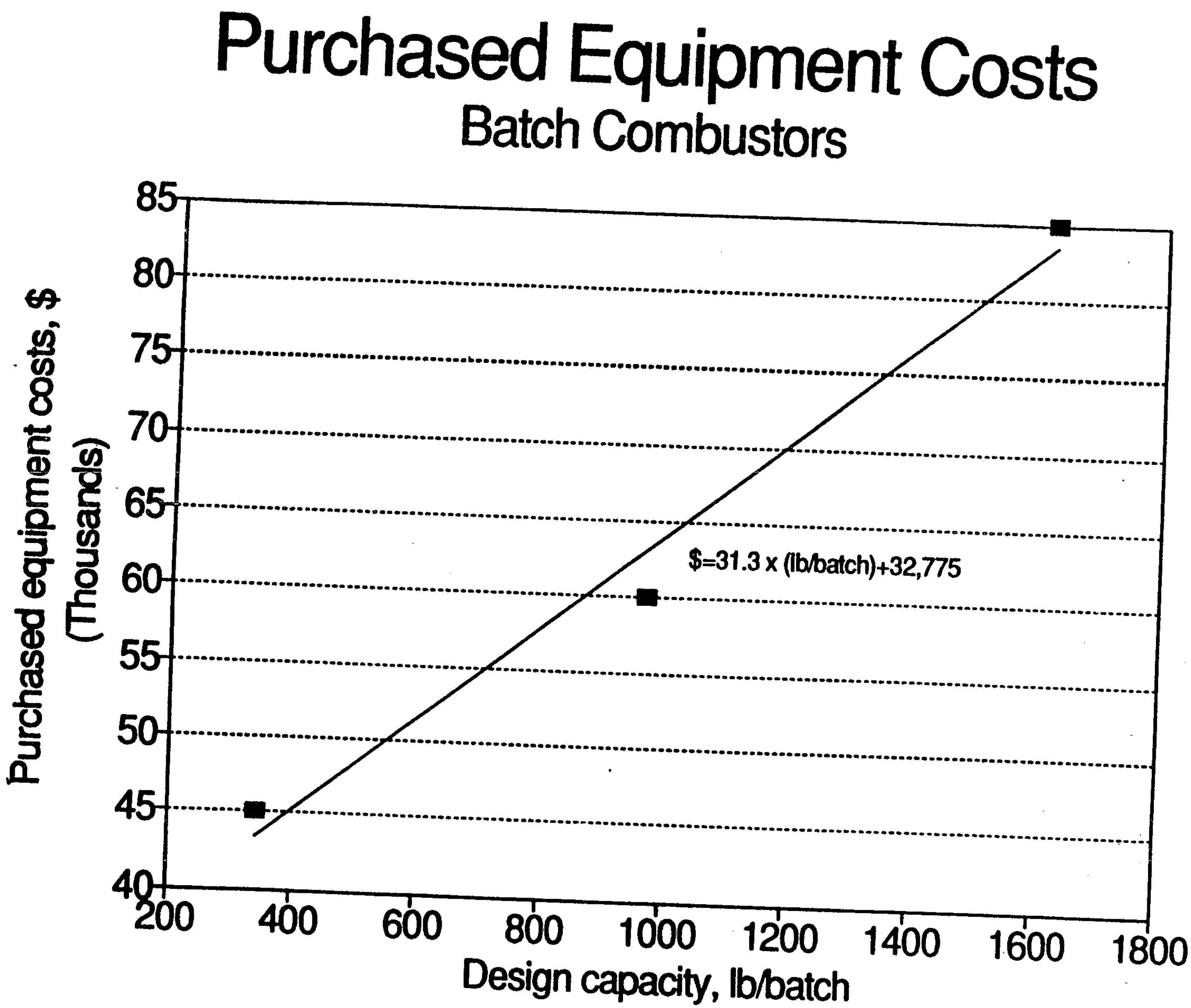

Figure 3. Purchased equipment costs for batch combustors.

designs. Purchased equipment costs for both designs are shown in Figure 4. Some of the costs for dual-purpose units designed for pathological waste were estimated from costs that the manufacturers provided for the intermittent version and from estimates that some of the manufacturers provided for the cost difference between the two designs. Most of the cost difference is for larger, or additional burners in the pathological design. Purchased equipment costs for the model pathological combustors were estimated from the equation for a least-squares linear regression line drawn through the data.

3.2 CONTROL TECHNOLOGY CAPITAL COSTS

This section presents costs for the combustion control technology described in Section 2.2.1 and for the seven add-on control technologies without activated carbon injection that are described in Section 2.2.2. Costs for the three FF-based control technologies that incorporate activated carbon injection are described in Section 3.5.

3.2.1 Combustion Control Costs

All of the combustor manufacturers that responded to EPA information requests indicated that the design operating temperatures are 1800°F or more. Therefore, it was assumed that an 1800°F control parameter would not result in higher PEC's.

Most of the combustor manufacturers that responded to EPA information requests also provided costs both for combustors with secondary chambers that have a 2-second residence time and for combustors that have a 1-second residence time. Most of the data are for intermittent and continuous combustors. The data for these two combustor designs were evaluated in a single analysis, and the results were used to estimate combustion control costs for all of the model combustors. A single approach was used to simplify the analysis. Also, the secondary chamber costs should be the same for any combustor type assuming similar gas stream temperatures and moisture contents (and similar secondary chamber designs). The model combustors are based on these assumptions.

The first step in the analysis was to estimate gas flow rates for the combustors that were identified by the

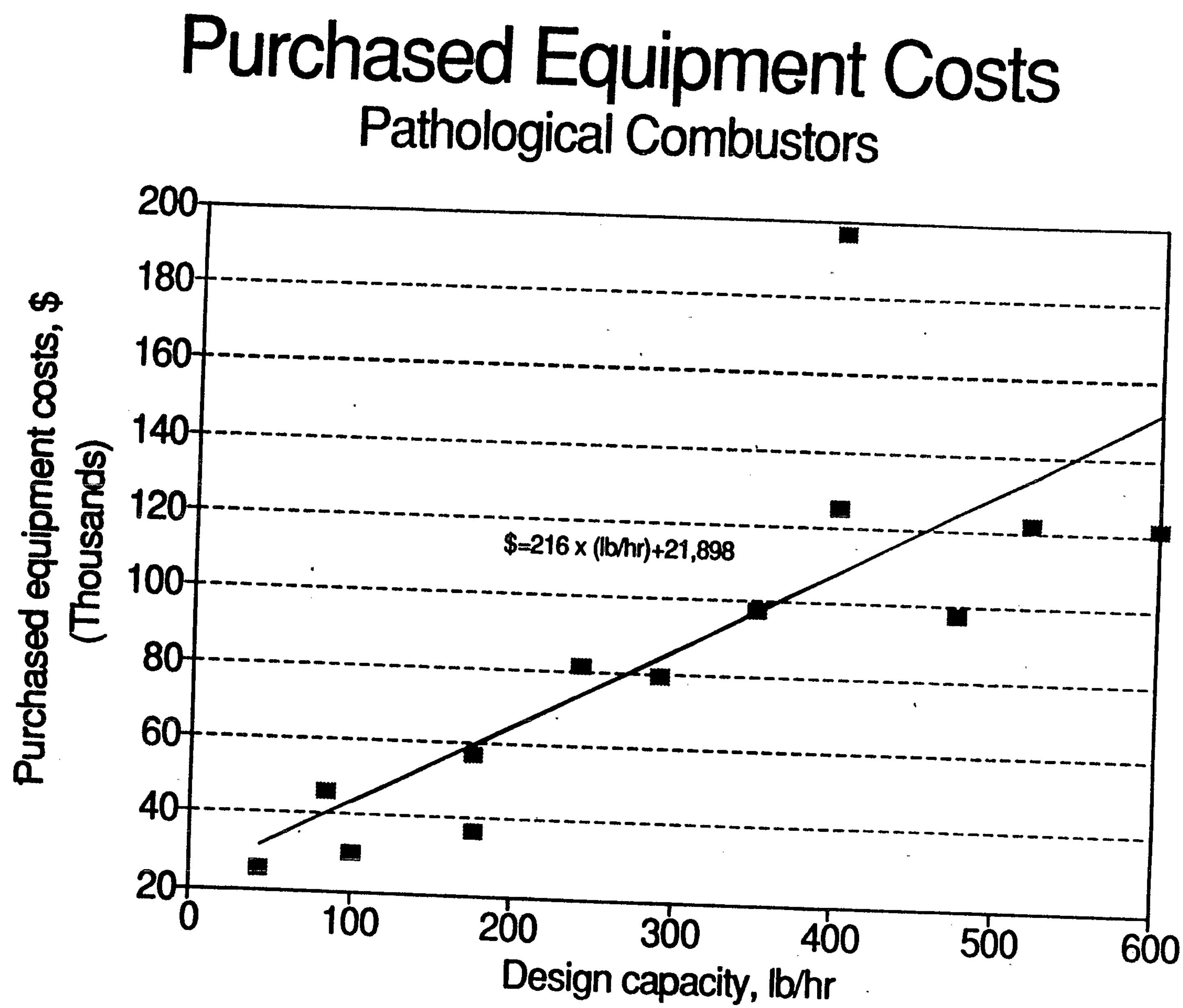

Figure 4. Purchased equipment costs for pathological combustors.

manufacturers. These flow rates were estimated by the same procedure described in Section 2.1.4.6. Figure 5 shows the resulting flow rates in dry standard cubic feet per minute (dscfm) plotted versus the additional PEC's for the larger secondary chambers. The best-fit line through the data was determined by linear regression. The line and the equation for it are also shown in Figure 5. Installation costs are assumed to be equal to 48 percent of the PEC--the same factor as that used to estimate installation costs for the complete combustors. The PEC, installation cost, and TCI for all of the model combustors are shown in Table 12.

TABLE 12. COMBUSTION CONTROL COSTS FOR MODEL COMBUSTORS

Model combustor	Purchased equipment cost, $	Combustion control capital costs[a]	
		Installation cost, $	Total capital investment, $
1	43,433	20,848	64,300
2	31,812	15,270	47,100
3	43,433	20,848	64,300
4	22,512	10,806	33,300
5	13,213	6,342	19,600
6	11,905	5,715	17,600
7	13,925	6,684	20,600

[a]Combustion control capital costs are equal to the difference between costs for combustors that have secondary chambers with 2-second residence times and costs for combustors that have secondary chambers with 1-sec residence times.

3.2.2 APCD Control Costs

The TCI's for most of the APCD technologies were estimated by a two-step procedure. First, algorithms were developed to estimate TCI's for two or three different sizes of control devices from each vendor (vendor algorithms). Second, the results of the vendor algorithms were averaged to develop a generic algorithm for any size of the control device. Differences from this approach are described in the appropriate subsections below.

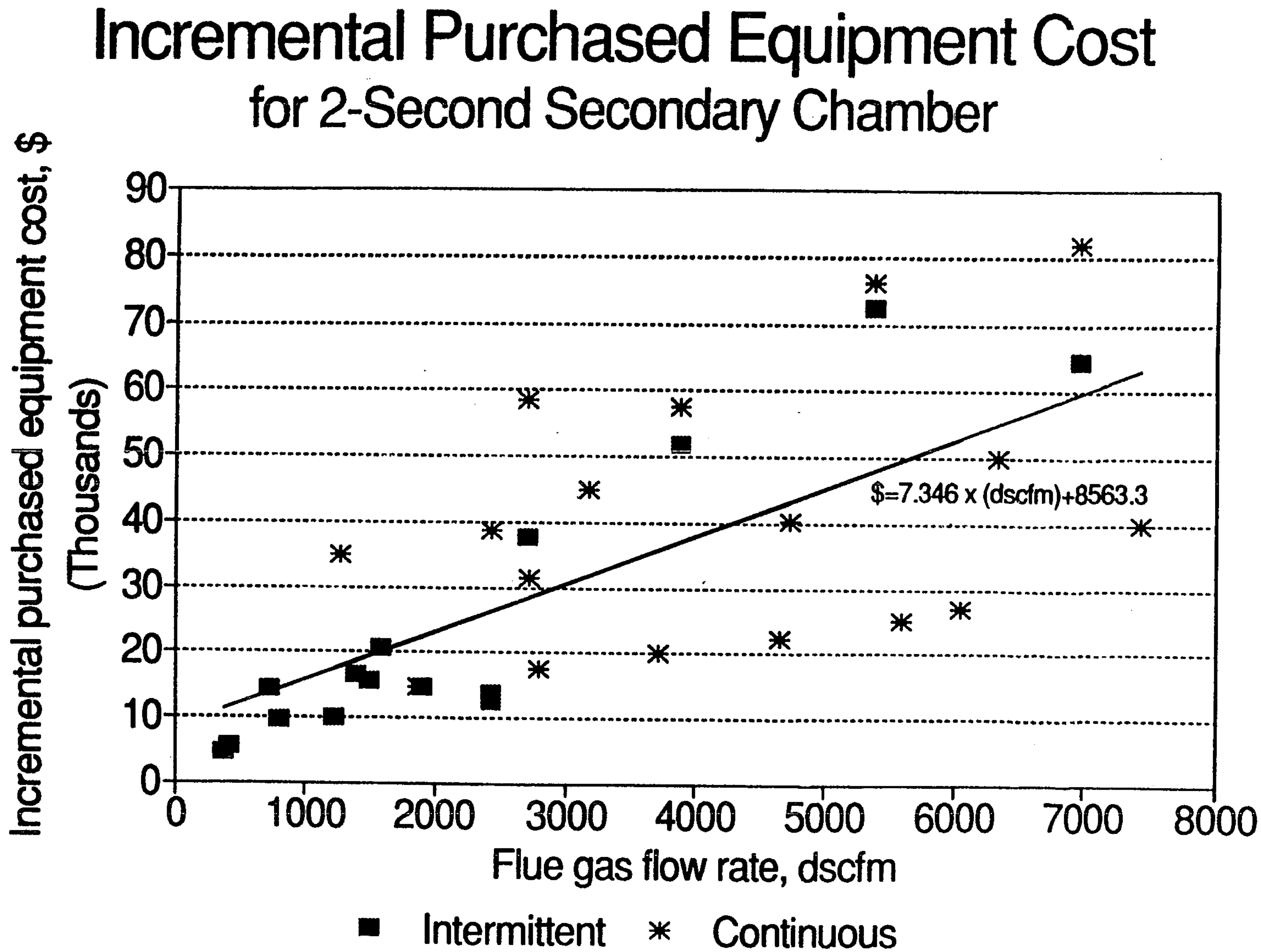

Figure 5. Incremental purchased equipment cost for secondary chamber with 2-second residence time.

The vendor algorithms are based on the quoted costs from vendors in response to EPA information requests and estimated costs for additional items the vendors do not provide or for which they neglected to provide costs. The EPA information requests specified the composition of three MWI gas streams (the flow rates varied, but the temperature and pollutant concentrations were identical) and asked for the design and cost of APCD's that the vendors produce to control emissions from such MWI gas streams. The vendors quoted costs for five of the seven control devices evaluated in this analysis. These five APCD designs are the DI/FF, FF, VS/PB, PB and SD/FF devices. Equipment component costs and installation costs were also obtained from some vendors. Costs for the VS and FF/PB control devices were estimated by eliminating, reducing, or combining component costs from the first five APCD's.

To develop the TCI for each control device, the vendor algorithms also include procedures to estimate costs for a bypass damper in the stack, ductwork between the incinerator and the control equipment, foundations, taxes, and (in most cases) freight. Costs for items like startup and contingencies also were estimated when vendors did not provide them. All of these estimated costs were based on standard procedures found in the OAQPS Control Cost Manual and on some assumptions.

Assumptions used in ductwork calculations for all control devices are (1) 20 ft of carbon steel duct with one elbow are necessary, (2) the duct is lined with 6 in. of refractory, and (3) the gas velocity is 4,000 ft/min. Based on data limitations in the OAQPS Control Cost Manual, it was assumed that both the dump stack and the bypass damper costs would be constant (independent of diameter) for diameters up to 24 in. even though the ductwork was estimated to be as small as 8 in. for small MWI gas streams.[60] The costs for these components are the same for each control device applied to a particular model combustor.

Taxes and freight costs were estimated to be 3 and 5 percent, respectively, of the equipment costs. Foundations were estimated to be 2 percent of PEC's for DI/FF and FF control devices, 5 percent for wet control devices, and 4 percent for FF/PB and SD/FF control devices. Before these costs were estimated, it was necessary to estimate the equipment costs. When equipment costs were not available separate from instrumentation and installation costs, the OAQPS procedures were used to estimate the percentage of the total costs comprised by equipment costs.

For convenience, the TCI is used instead of the PEC in the vendor algorithms. Vendors often provided costs that varied with the size of the equipment, and other times the installation costs had to be estimated from the total costs (as described above). Therefore, it was easier to evaluate installation costs as part of the individual control device TCI in each vendor algorithm, rather than trying to develop an average installation factor to apply to the results of a generic PEC algorithm.

The generic algorithms are based on linear regression analyses of the TCI data from the vendor algorithm plotted vs. gas flow rate in dscfm at the inlet to the APCD. The results are shown in Figures 6 through 12. The figures for the VS/PB, VS, DI/FF, FF, and SD/FF control devices show a shaded area that represents the range of costs from the vendor algorithms. The bounds of the shaded area have been extrapolated linearly on figures that have only one data point for the smallest control device. The line bisecting the shaded area shows the best fit line through the data as determined by least-squares linear regression analysis. The figures for the PB and FF/PB control devices show only individual points and the regression line because the costs for these devices were estimated from the regression analyses of other control devices. The equations for the regression lines are shown on each figure and in Table 13. These equations were used to estimate the costs of the control devices as applied to the model combustors.

3.2.2.1 Wet Control Devices. Vendors that responded to EPA requests for information about wet control devices provided costs for the VS/PB and PB control devices. Most of these vendors produce packed bed absorbers, but one produces a tray tower

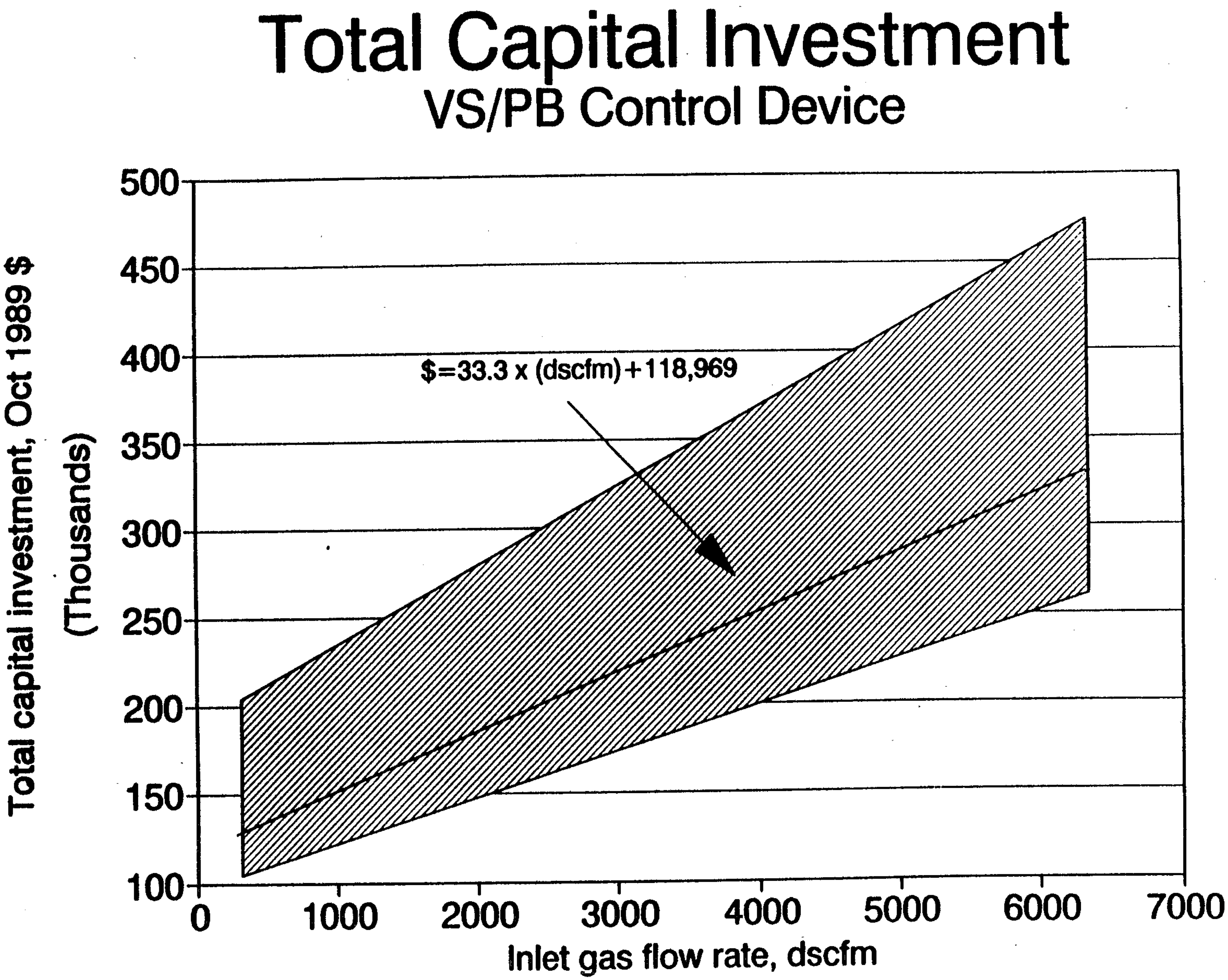

Figure 6. Total capital investment for VS/PB control device.

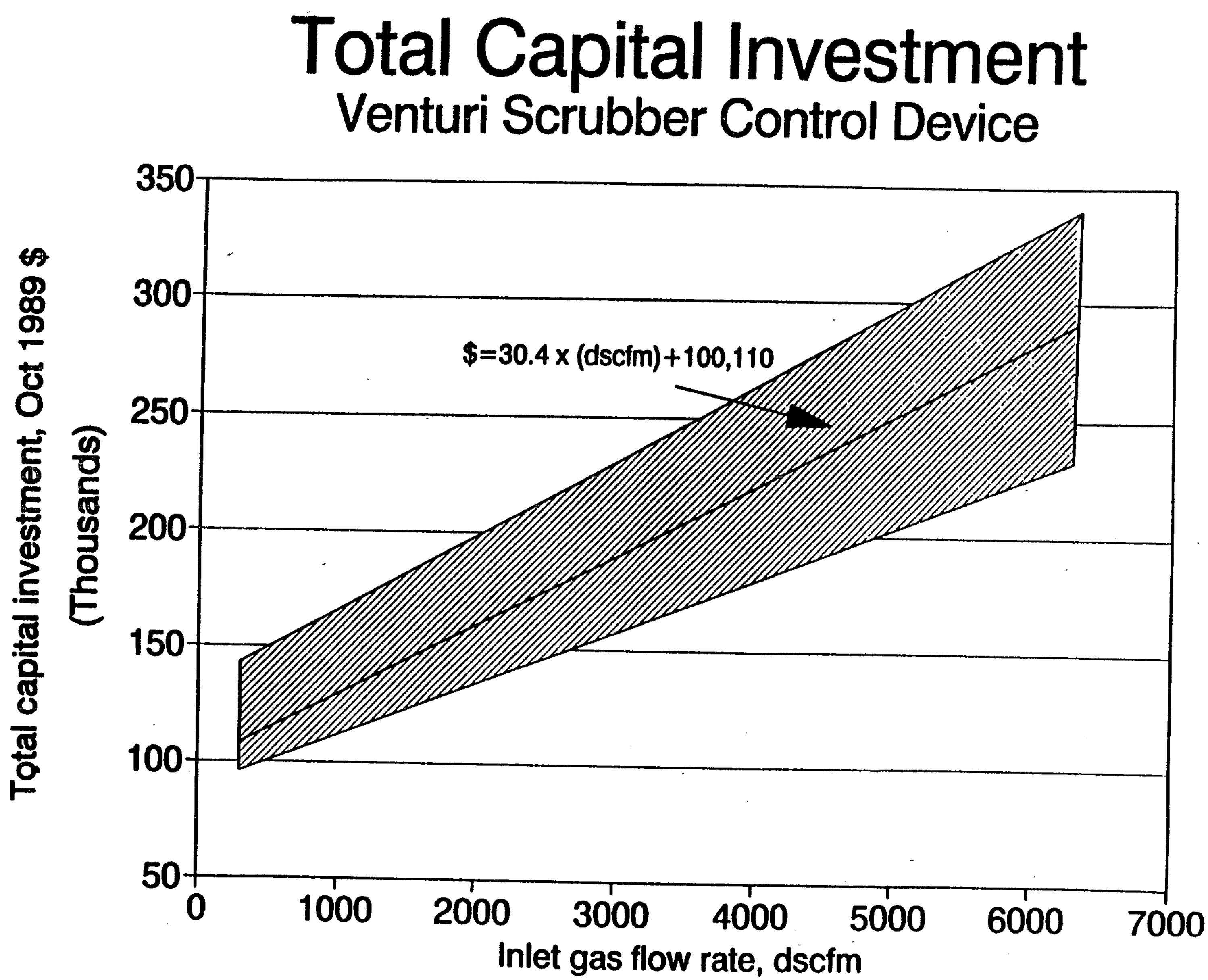

Figure 7. Total capital investment for VS control device.

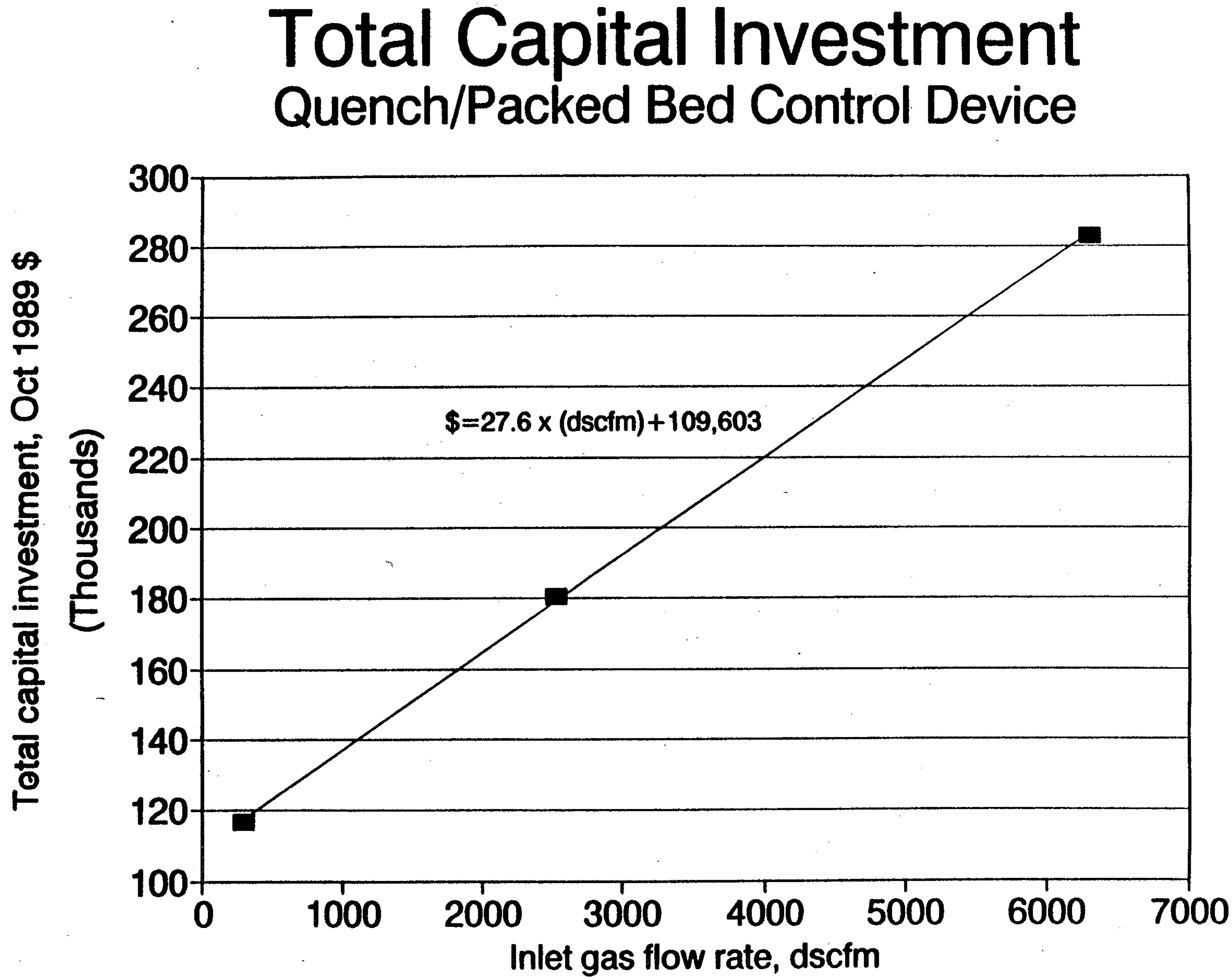

Figure 8. Total capital investment for PB control device.

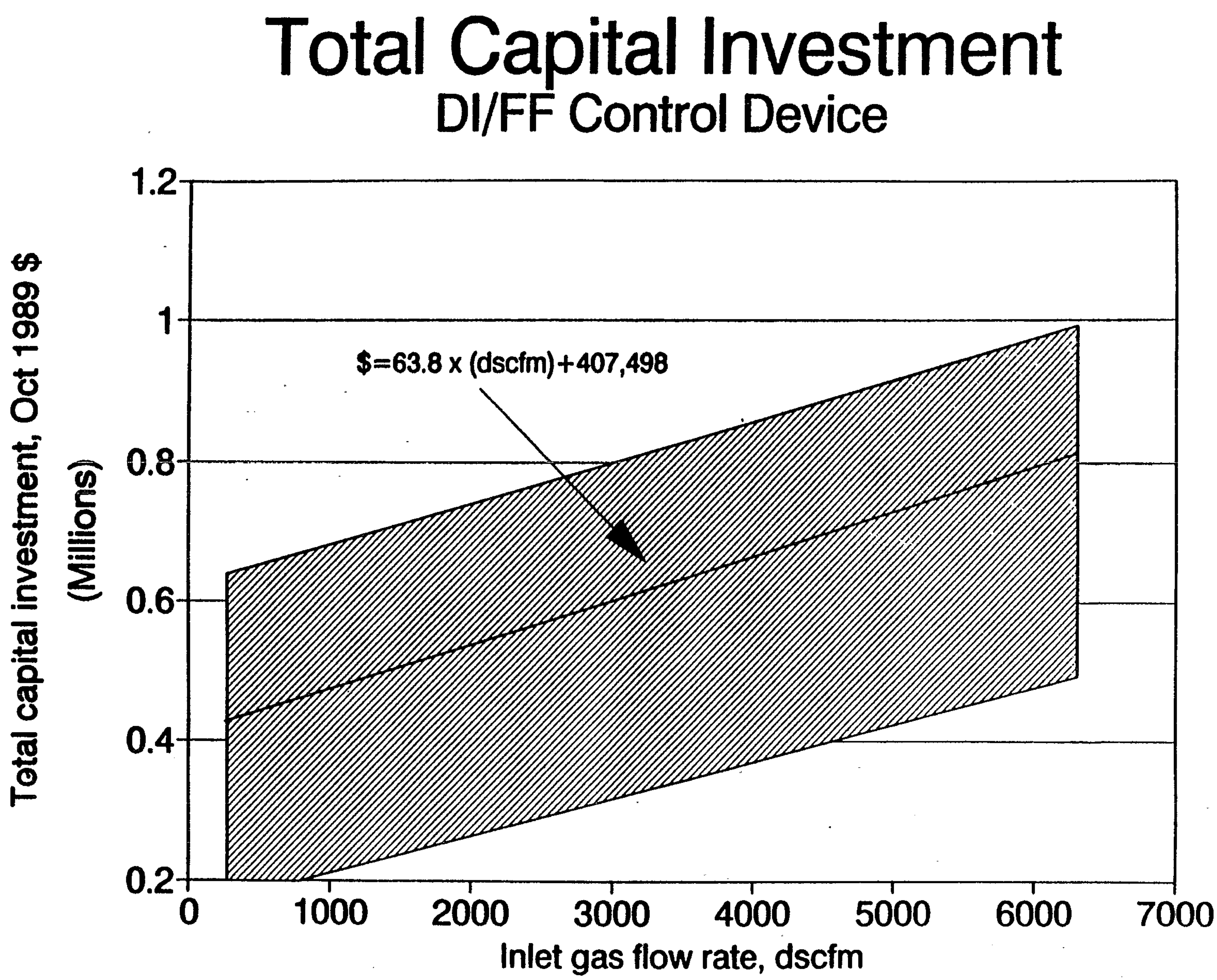

Figure 9. Total capital investment for DI/FF control device.

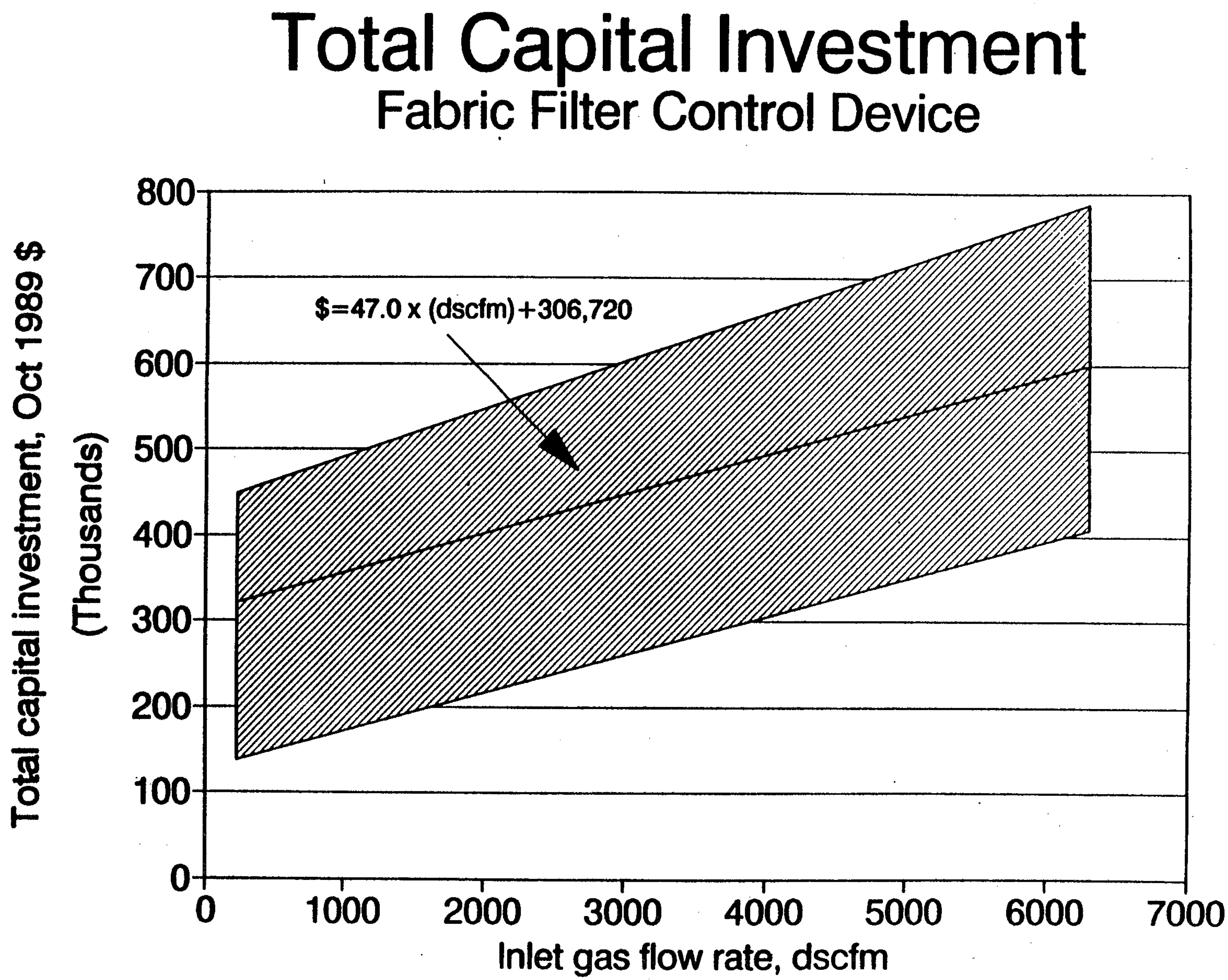

Figure 10. Total capital investment for FF control device.

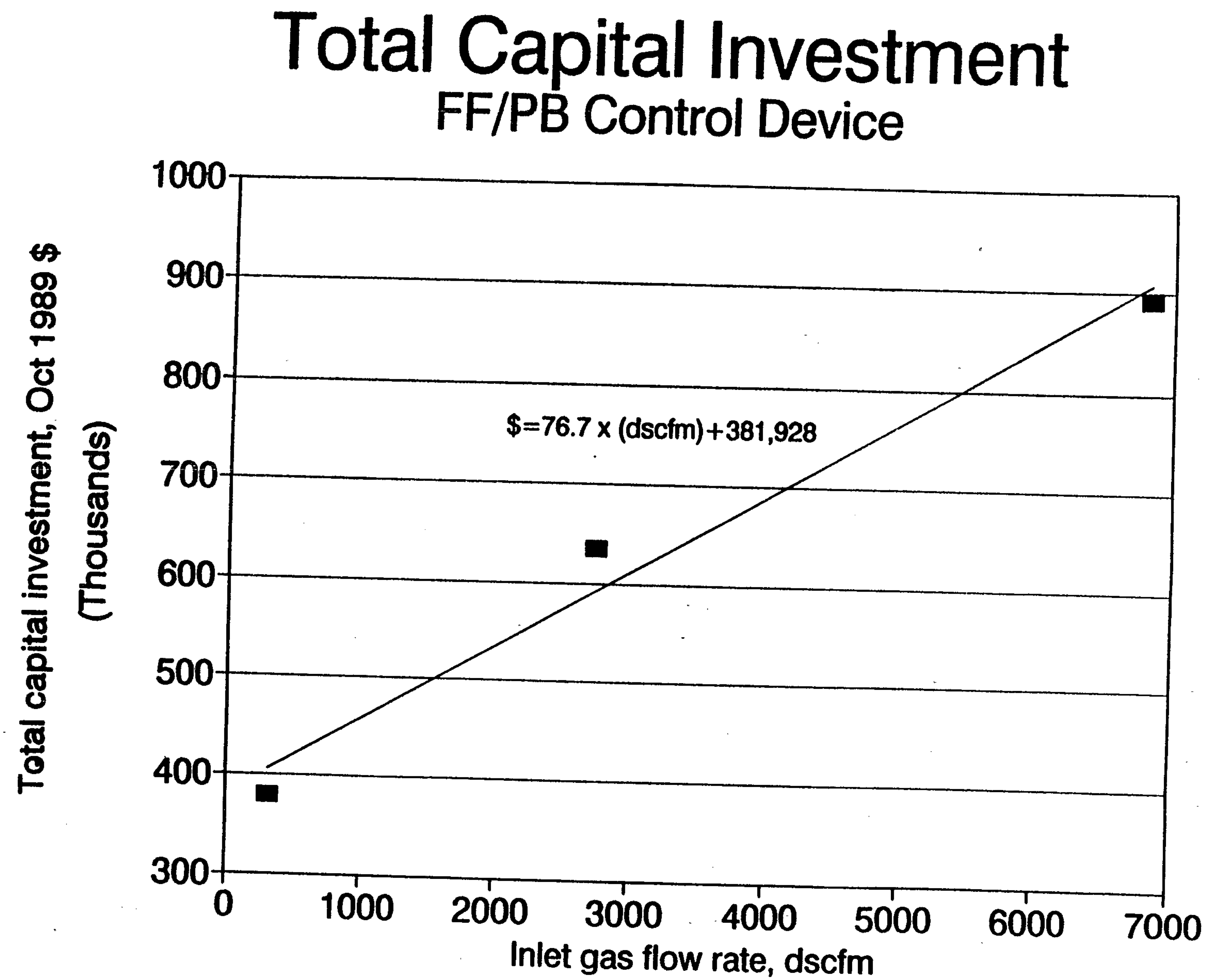

Figure 11. Total capital investment for FF/PB control device.

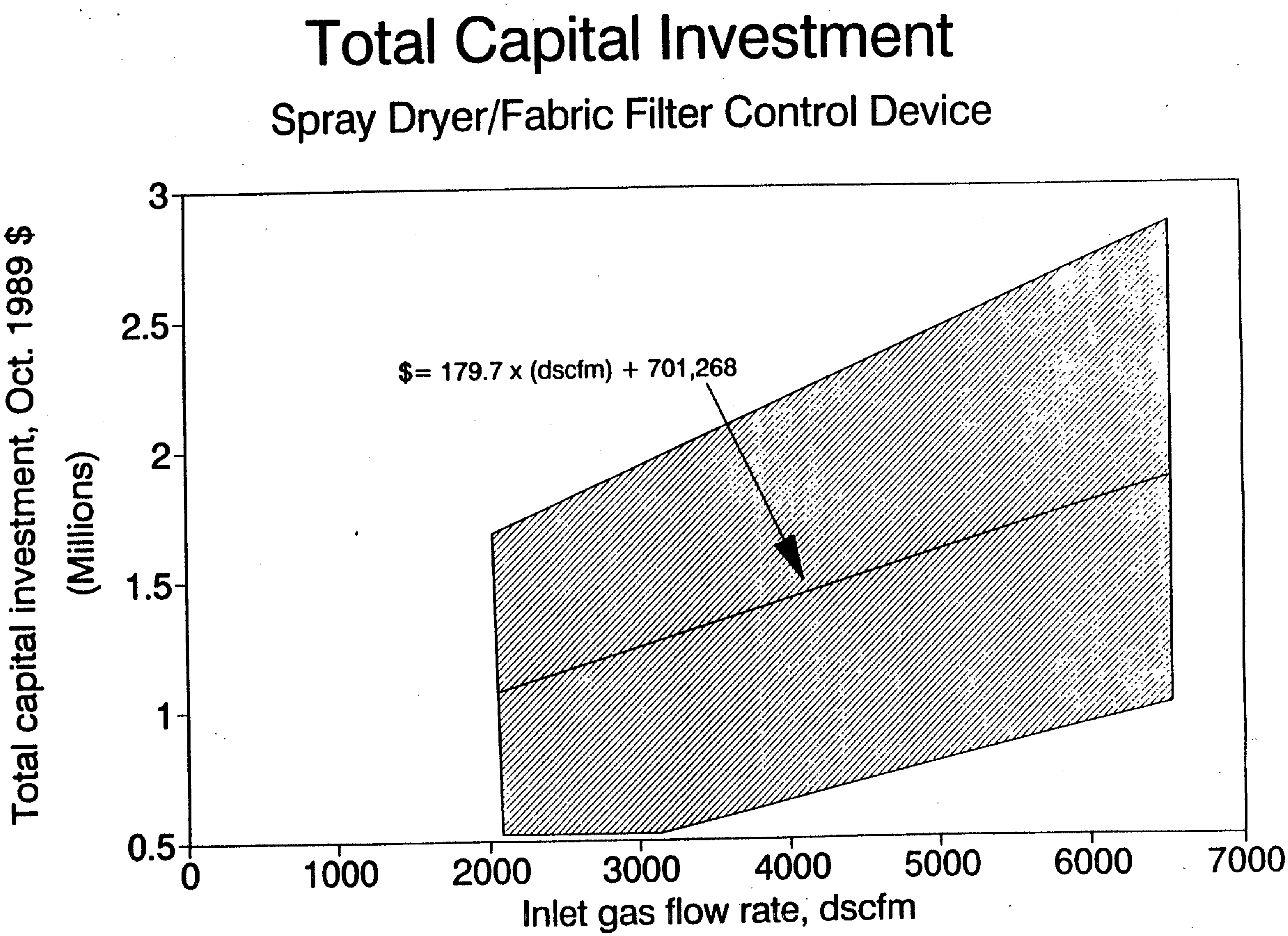

Figure 12. Total capital investment for SD/FF control device.

TABLE 13. EQUATIONS TO ESTIMATE TOTAL CAPITAL INVESTMENT FOR APCD'S

APCD	Total capital investment cost equation	Regression value, R^2
DI/FF	$ = 63.8 x (dscfm) + 407,498	0.33
FF	$ = 47.0 x (dscfm) + 306,720	0.37
VS/PB	$ = 33.3 x (dscfm) + 118,969	0.60
VS	$ = 30.4 x (dscfm) + 100,110	0.81
PB	$ = 27.6 x (dscfm) + 109,603	a
FF/PB	$ = 76.7 x (dscfm) + 381,928	0.98
SD/FF	$ = 179.7 x (dscfm) + 701,268	0.19
DI/FF w/carbon	$ = 63.8 x (dscfm) + 407,498 + 4,500 x $(dscfm/1,976)^{0.6}$	
FF/PB w/carbon	$ = 76.7 x (dscfm) + 381,928 + 4,500 x $(dscfm)/1,976)^{0.6}$	
SD/FF w/carbon[b]	$ = 179.7 x (dscfm) + 701,268	

[a]The PB costs are estimated as a percentage reduction from the regression line for VS/PB costs.
[b]No additional capital costs are incurred when using carbon in a SD/FF system.

absorber. The two devices are analyzed together because both are designed primarily to remove acid gases, and it was assumed that the pollutant removal efficiencies are similar for the two devices. Most of the vendors that responded provided the TCI for the devices that they produce. Some vendors also provided installation costs and some component equipment costs. Missing equipment costs and installation costs for any of the vendors were estimated based on standard factors in the OAQPS Control Cost Manual and/or on component costs from other vendors. These VS/PB control device costs were used as the starting point for estimating capital costs for all wet control options.

Two of the vendors identified design (maximum) inlet gas flow rate capacities for "off-the-shelf" control devices that they would use for the gas streams specified in the EPA information requests. Therefore, when costs from these vendors are used in this analysis, they are associated with the control device flow rates rather than the gas stream flow rates from the information requests.

3.2.2.1.1 Venturi Scrubber/Packed Bed. The range of VS/PB control device costs are shown in Figure 6. The equation of the line through these data was determined by linear least-squares regression, and it is also shown in Figure 6.

At least some of the costs differences in Figure 6 are due to known design differences. The costs at the upper bound of the range are for systems with a higher horsepower (hp) fan, more corrosion resistant construction materials in some components, redundancy (e.g., backup pumps), and the more extensive use of automatic controllers. Also, one vendor indicated that additional packing in the PB (in the same shell) would be required to increase the removal efficiency from the 90 percent specified in the EPA information request to the 99 percent that other vendors claimed. All costs were used in the analysis because available data do not show any of these systems to be either over or under designed.

3.2.2.1.2 Venturi Scrubber. Estimated costs for VS control devices are presented in Figure 7. The control device costs were estimated by eliminating or reducing component costs from the costs for the VS/PB control device (see Section 3.2.2.1.1). The main cost savings were realized by subtracting the absorber costs. The cost of caustic solution circulation equipment was reduced based on the eliminated flow to the absorber. Instrumentation and installation costs were also reduced. A small cost was added for a 4-pass, chevron-blade mist eliminator to minimize salt carryover.

3.2.2.1.3 Packed Bed. Estimated costs for PB control devices are presented in Figure 8. Some of the vendors that provided VS/PB system costs also provided PB device costs. The differences between VS/PB and PB costs (in percent) from these vendors were plotted vs. the inlet gas flow rate (in dscfm), and an equation for the line through these data was determined by linear regression. The differences range from about 9 percent for small systems, to 11 percent for medium systems and 14.5 percent for large systems. The PB costs were then estimated by applying these percentages to the linear regression equation for the VS/PB costs.

3.2.2.2 Control Devices with an FF.

3.2.2.2.1 Dry injection/fabric filter. Vendors that responded to EPA information requests provided TCI costs for two DI/FF configurations. One group of vendors described systems with lime recycling; others did not. These vendors also estimated costs for at least some of the components in their DI/FF control devices. The system components on which the costs are based include equipment to reduce the gas stream temperature, dry lime injection into the ductwork, a reaction or retention chamber after the injection point to increase contact time between the lime and the acid gases, a pulse-jet FF, lime recycling equipment, an I.D. fan, and a stack.

Even though the vendors produce equipment based on the same basic design, many features are unique to each system. For example, gas cooling is accomplished with evaporative coolers, gas-to-air heat exchangers, and a combination of an evaporative cooler with a gas-to-air heat exchanger. The cooled gas stream temperatures range from 250°F for one vendor to 400°F for another vendor. The G/C ratios range from 2.6 for one vendor to 4.3 for another. A few of the large and midsize systems have multi-compartmented FF's; all other FF's have a single compartment. Some vendors specified lime recycling equipment. Three of the vendors included a retention chamber, and a fourth vendor offered an FF with an extended housing, which was assumed to serve the same function as a retention chamber.

The range of DI/FF costs and the equation of the line through the data that was determined by linear least-squares regression are shown in Figure 9. This analysis is based on DI/FF systems without lime recycle because lime is not recycled in most of the existing DI/FF control devices. Therefore, costs for lime recycling equipment were estimated and subtracted from the total costs provided by vendors that use such equipment. According to one vendor, lime recycling equipment costs comprise about 4 percent of the TCI for the large and midsize models and 1 percent for the small model. The lime recycling equipment costs comprise a smaller percentage of the TCI for the small model because a simpler design can be used. It was assumed that the same percentages are valid for estimating lime recycling equipment for other vendors.

The costs from one vendor are not included in the graphical analysis because gas cooling is accomplished in the APCD with a gas-to-air heat exchanger and a flue gas recirculation system that are not employed by other vendors. The designs from other vendors can achieve this same gas cooling, apparently at a much lower cost. Furthermore, even though the vendor claims higher HCl removal efficiencies, it is believed that the other vendors can also achieve these efficiencies by increasing the lime makeup feed rates (i.e., by increasing the stoichiometric ratio). As Figure 9 shows, the costs from the other vendors also vary significantly. The unique features described earlier in this section account for some, if not all, of the variation. However, available data do not show any of these systems to be either over or underdesigned.

3.2.2.2.2 Fabric filter. Costs for FF control devices are presented in Figure 10. The costs were estimated by subtracting DI equipment costs from the total DI/FF equipment costs. If the vendor provided DI equipment costs, they were subtracted directly from that vendor's DI/FF costs. Otherwise, the DI equipment costs were estimated by assuming they comprise the same percentage of the total equipment cost as for other vendors. For each vendor, the ratio of installation-to-equipment costs was assumed to be the same for the FF control option as for the DI/FF control option.

3.2.2.2.3 Fabric filter/packed bed. The FF/PB control device consists of gas-cooling equipment (a gas-to-gas heat exchanger with water spray and dilution air) that reduces the gas temperatures to 300°F, FF, in-line quench that further reduces the gas temperature to saturation (about 132°F), PB, recirculating liquid and neutralization systems, I.D. fan, and stack.

No vendor provided costs for a FF/PB control device. Therefore, component costs from other control devices were combined to estimate the FF/PB costs. The costs for the PB and all auxiliary equipment except the FF and heat exchanger were estimated by using the following simplified two step process. First, costs were developed for VS/PB control devices that would be used for lower flow rates (i.e., the flow rate out of the heat exchanger that is used in the FF/PB control device is less than that out of the evaporative quench that is used in the VS/PB control device). The second step was to subtract estimated VS and related auxiliary equipment, instrumentation, and installation costs from the new VS/PB costs.

Fabric filter costs were estimated based on FF costs from one of the DI/FF vendors. Since costs for the unique gas cooling equipment described above were not available, the costs were assumed to be similar to those for a gas-to-air heat exchanger used by one of the DI/FF vendors to cool exhaust gas from 1800° to 300°F. Instrumentation and installation costs were also estimated for the heat exchangers and FF's based on the installation cost factors provided by the respective vendors for their complete DI/FF system. The resulting FF/PB costs are shown in Figure 11.

3.2.2.2.4 Spray dryer/fabric filter. The range of SD/FF costs and the equation of the line through the data that was determined by linear least-squares regression are shown in Figure 12. These costs are for SD/FF systems that consist of a spray dryer absorber vessel, lime slurry mixing tank(s), slurry piping, rotary atomizer, pulse-jet FF, I.D. fan, and stack. In each system, the spray dryer reduces the gas temperature to about 300°F, but the residence times range from 10 to 18 seconds. The G/C ratios range from 2.8:1 to 4.2:1. These design differences account for at least some of the range in costs.

3.3 COMBUSTOR ANNUAL COSTS

Estimated annual costs for the model combustors are shown in Table 14. The costs are based on the operating hours for each model combustor as described in Tables 6 through 8. Other information that was used to develop each of the costs is described in the subsections below. A copy of the algorithm for intermittent combustors is presented in Appendix A.

3.3.1 Electricity

Three combustor manufacturers provided connected horsepower ratings for intermittent and continuous combustors, although most of the data were obtained from one manufacturer. These ratings were for combustion and burner air blowers, the feed ram motor, and, where applicable, the ash ram motor. Least-squares linear regression analyses were performed with both complete data sets, and the resulting equations were used to estimate the horsepower requirements for the model combustors. Figure 13 shows the data and equations. A similar analysis was performed with data for the combustion and burner air blowers that were obtained from one batch combustor manufacturer. These data and the resulting equation are shown in Figure 14. Horsepower requirements for pathological combustors were assumed to be the same as those for intermittent combustors.

TABLE 14. ANNUAL COSTS FOR NEW COMBUSTORS

Cost parameters\model combustors	Continuous models 1	Continuous models 2	Intermittent models 3	Intermittent models 4	Intermittent models 5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity							
(1) lb/hr	1,500	1,000	1,500	600	200		200
(2) lb/batch						500	
b. Operating hours, hr/yr							
(1) preheat phase	13	162	156	156	156	80	156
(2) burning phase	7,711	2,916	2,340	2,340	1,716	1,120	1,716
(3) burndown phase	52	648	1,248	1,248	1,248	800	1,248
(4) cooldown with blower on	0	0	624	624	624	1,600	0
c. Volumetric flow rate out of SC, dscfm	4,747	3,165	4,747	1,899	633	455	730
2. Total capital investment, $	649,779	520,871	237,659	156,822	95,266	71,669	96,345
3. Combustor annual costs, $/yr							
a. Electricity	10,414	3,906	2,820	1,297	516	164	516
b. Auxiliary fuel	36,156	17,980	20,524	10,128	4,901	7,564	9,284
c. Water	356	135	108	54	0	0	0
d. Operating labor	46,176	17,496	17,784	16,848	12,168	2,880	12,168
e. Supervisory labor	6,926	2,624	2,668	2,527	1,825	432	1,825
f. Maintenance labor	6,415	3,074	3,089	3,089	2,574	2,970	2,574
g. Maintenance materials	12,996	10,417	4,753	3,136	1,905	1,433	1,927
h. Ash disposal	20,779	5,249	6,318	2,527	618	144	618
i. Refractory replacement	8,052	6,329	7,029	3,992	2,141	2,180	2,226
j. Overhead	43,508	20,167	16,976	15,360	11,084	4,629	11,096
k. Property tax, insurance, and administration	25,991	20,835	9,506	6,273	3,811	2,867	3,854
l. Capital recovery (a)	75,935	60,883	27,528	18,206	11,083	8,332	11,200
4. Total annual cost, $/yr	293,704	169,095	119,103	83,437	52,626	33,595	57,288

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

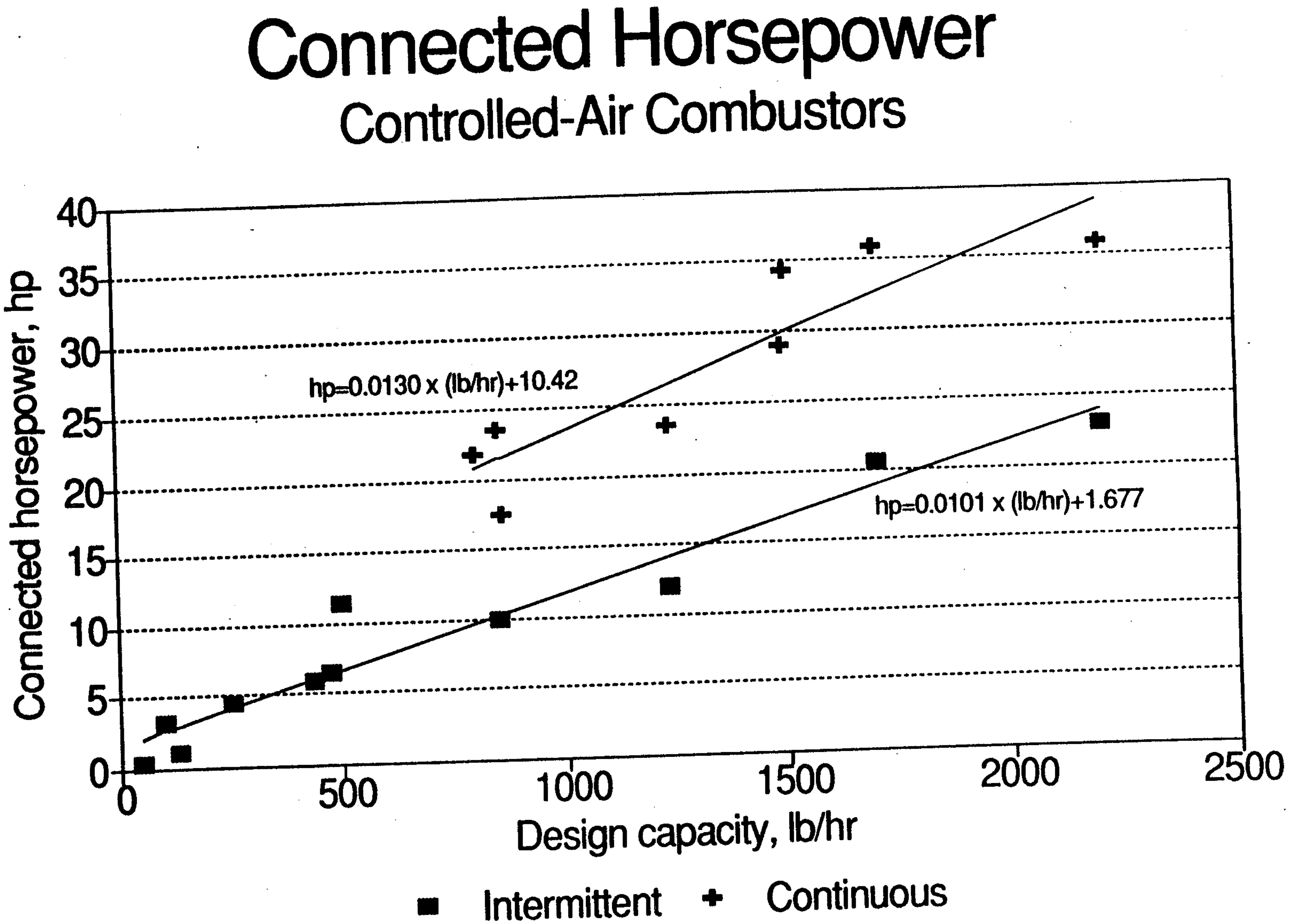

Figure 13. Connected horsepower requirements for intermittent and continuous combustors.

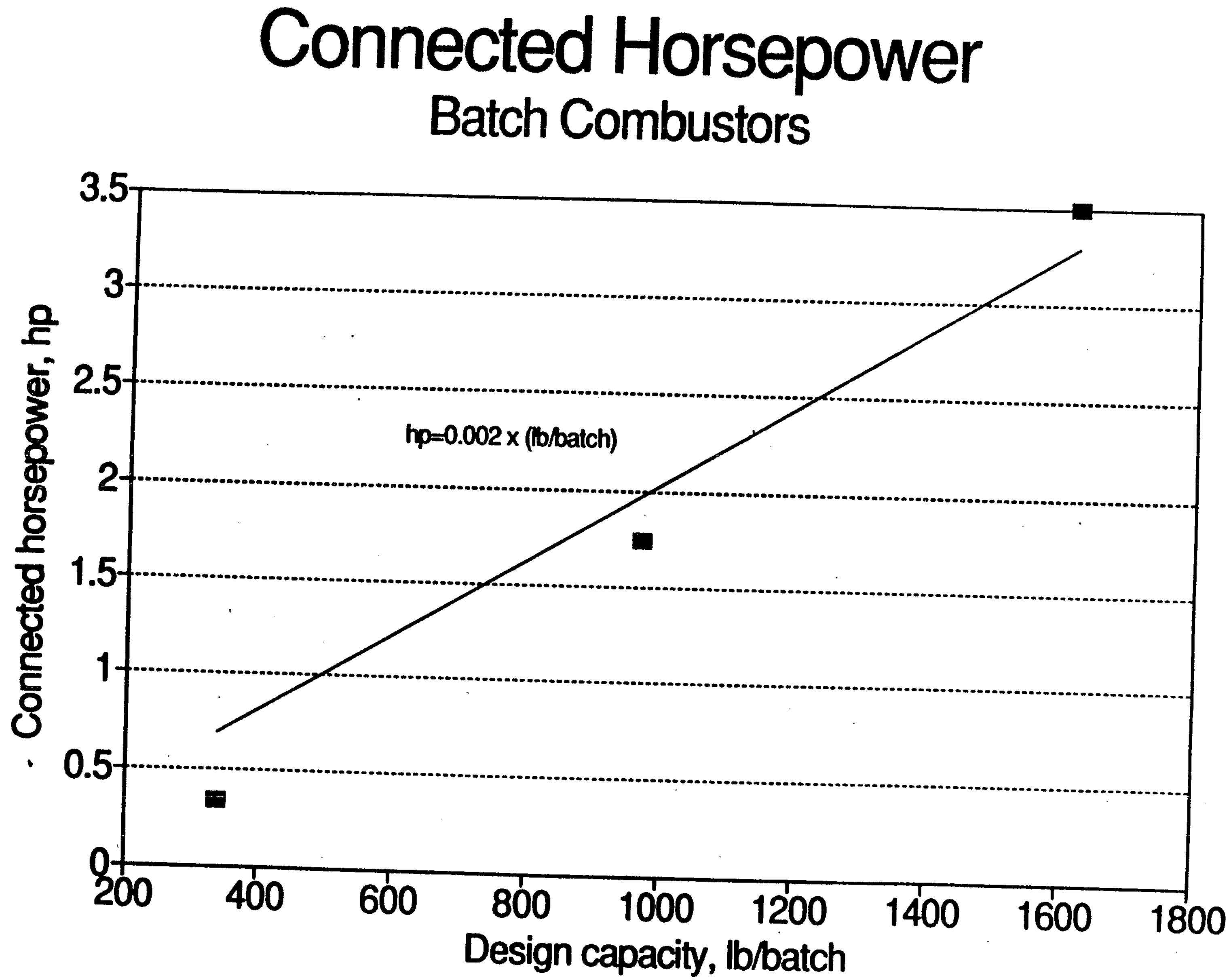

Figure 14. Connected horsepower requirements for batch combustors.

Electricity costs were estimated by assuming all of the motors were running continuously during all operating hours (including 2 hr of cooldown for intermittent units and 10 hr of cooldown for batch units). This assumption overestimates the cost because the feed and ash rams do not operate continuously. Electricity costs were assumed to be $0.06 per kilowatt-hour (Kwh).[28,32,33]

3.3.2 Auxiliary Fuel

Auxiliary fuel costs are based on the type of fuel, the burner capacities, and the burner utilization rates. Natural gas was specified as the auxiliary fuel for all of the models because it is used in nearly all existing MWI's.[7,12,13,22] Natural gas costs were assumed to be $0.35/therm, which is $3.5/1,000,000 Btu.[25]

Burner capacities for all combustor designs were obtained from one manufacturer each. The equation for the best-fit line through each data set as determined by least-squares linear regression was used to estimate burner capacities for the model combustors.

During the preheat phase, the secondary chamber burner is on continuously in all combustors. Because of its lower setpoint temperature, the primary chamber preheat for intermittent, continuous, and pathological combustors may be completed before the secondary chamber preheat. If so, the primary chamber burner will cycle on and off to maintain the setpoint temperature until the first charge is introduced. The primary chamber is not preheated in batch combustors.

After the first few charges during the burning phase, the primary chamber burner is typically off in intermittent and continuous combustors, as long as waste is charged regularly (although it can be significantly below the design rate). For batch combustors, the primary chamber burner fires for a preset time period (about 60 seconds) to ignite the waste; it then turns off. In pathological incinerators, the primary chamber burner cycles on and off as necessary. During the burning phase, the secondary chamber burners in all combustors cycle on and off or between high-fire and low-fire as necessary to maintain the setpoint temperature.

During burndown, burners in the primary chamber of intermittent, continuous, and pathological combustors may also cycle on and off or between high-fire and low-fire as needed to maintain setpoint temperatures. In batch combustors, the primary chamber burner remains off. The secondary chamber burner cycles in all combustors.

Fuel consumption rates during preheat were estimated by assuming the secondary chamber burners for all combustor types are on 100 percent of the time; the primary chamber burner was also assumed to be on 100 percent of the time, except in batch units, where it is off. During the burning phase (or the "low-air" phase for batch units), the secondary chamber burner was assumed to be on 50 percent of the time in all combustor types; the primary chamber burner was assumed to be on 50 percent of the time in pathological units, and it was assumed to be off in the others. During burndown (or the high-air" phase for batch models), the primary chamber burner was assumed to be on 75 percent of the time in all except batch units, where it is off. The secondary chamber burner was assumed to be on 90 percent of the time during burndown in all combustors.

3.3.3 Water

Three manufacturers indicated the water injection rates for cooling the primary chamber in intermittent and continuous combustors. The highest of the three flow rates was used in the analysis. Even so, the annual water cost is minor. Water costs were estimated to be $0.77/1,000 gallons.[61]

3.3.4 Operating Labor

Based on observation of operators at several facilities, it was estimated that, for all combustor types except batch units, operators spend about 50 percent of their time tending to the incinerator during the burning phase. For the batch model, it was assumed that operators spend about 1 hour to start the unit, add the waste, and monitor the process. For both intermittent and batch combustors, an additional 0.25 to 1 hour was allocated for ash removal, depending on the combustor size. Operator wage rates were assumed to be $12/hr--the same as the rate for MWC operators.[62]

3.3.5 Supervisory Labor

According to the OAQPS Control Cost Manual, the cost for supervisory labor is about 15 percent of the operating labor cost.[63]

3.3.6 Maintenance Labor

According to the OAQPS Control Cost Manual, maintenance labor requirements for air pollution control incinerators are about 0.5 hr/8-hr shift, and the wage rate is 10 percent higher than the operator wage rate.[64] The maintenance labor requirements were assumed to be the same for MWI's.

3.3.7 Maintenance Materials

Annual maintenance materials costs are assumed to be equal to 2 percent of the TCI.

3.3.8 Ash Disposal

Based on information from EPA-sponsored emissions tests, the weight of the ash that is removed from the combustor is 9 percent of the waste charged.[15,17] The costs to dispose of ash in a municipal waste landfill were estimated to be $40/ton in October 1989 dollars. This cost is based on an estimated cost in June 1991 of $43/ton and an assumed inflation rate of 5 percent per year.[65]

3.3.9 Refractory Replacement

Equations to estimate the annual costs for replacing the primary and secondary chamber refractory were developed from the installed refractory cost and the capital recovery factor (CRF). The installed refractory costs are a function of the volume and configuration of the chambers, the thickness of the refractory, and the unit cost to purchase and install 1 cubic foot (ft^3) material. Each of these parameters is discussed below.

Typically, the walls of the primary and secondary chambers are lined with either high-strength, castable refractory or high-heat-duty firebrick. Most manufacturers also add an insulating mineral wool block and/or ceramic fiber mat on top of the refractory; one manufacturer, however, circulates air between the primary chamber refractory, which is attached to an inner shell, and the outer shell. The refractory thickness in both chambers ranges from 3 to 6 in., depending on the manufacturer and the capacity of the combustor. Insulation thickness ranges from 1.5 to 3.0 in. For this analysis, it was assumed that the refractory and insulation thicknesses in both chambers are 4.5 and 2.0 in., respectively, for all models.

Primary and secondary chamber volumes are based on information from manufacturers, other model combustor parameters, and assumptions. The model primary chamber volumes are based on information from manufacturers of batch, intermittent, and continuous combustors. This information is shown, along with the equations that were determined by linear regression, in Figures 15 through 17. It was assumed that primary chamber volumes for pathological model combustors are similar to those for intermittent combustors because dual-purpose units are more common than hot-hearth designs. Secondary chamber volumes for all model combustors are based on the gas stream flow rate and the 1-second residence time.

The interior dimensions of the primary and secondary chambers are based on information from one manufacturer, observations of existing units, and assumptions. Typically, both chambers are enclosed in cylindrical shells. According to one manufacturer, the internal length-to-diameter (L/D) ratio is about 1.5 for horizontal primary chambers.[66] Based on observations of vertical primary chambers, the height is about 1.5 times the diameter. It was assumed that the L/D ratio is 2:1 for all secondary chambers. Although designs are unique to each manufacturer, the refractory volumes for both chambers in all of the model combustors were estimated based on the chamber volumes and this dimensional information.

Unit costs for refractory and insulation (material plus installation costs) were obtained from the <u>OAQPS Control Cost Manual</u> and updated from December 1977 to October 1989 costs using the CE plant cost indexes.[67,68] The resulting costs are $\$127/ft^3$

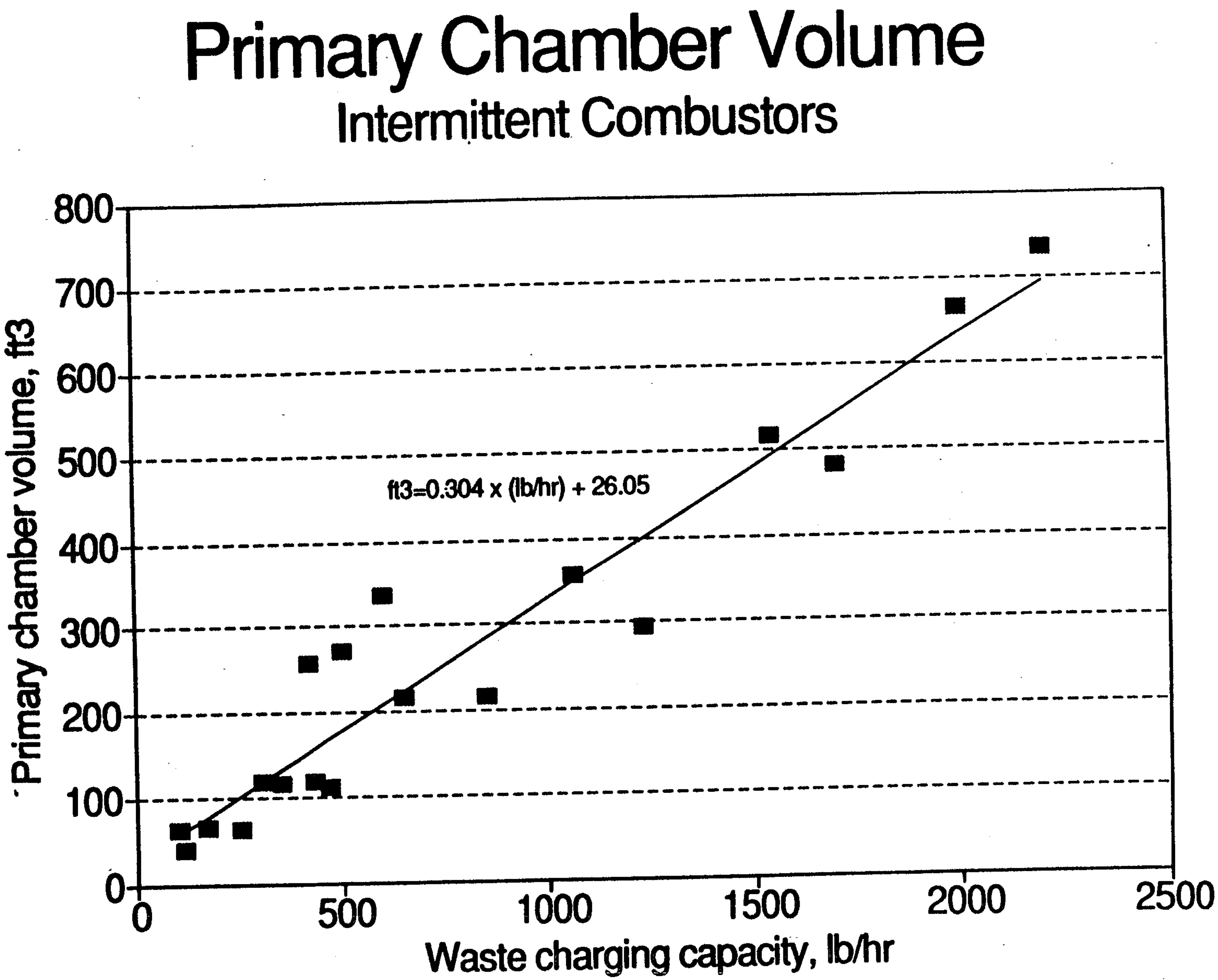

Figure 15. Primary chamber volume for intermittent combustors.

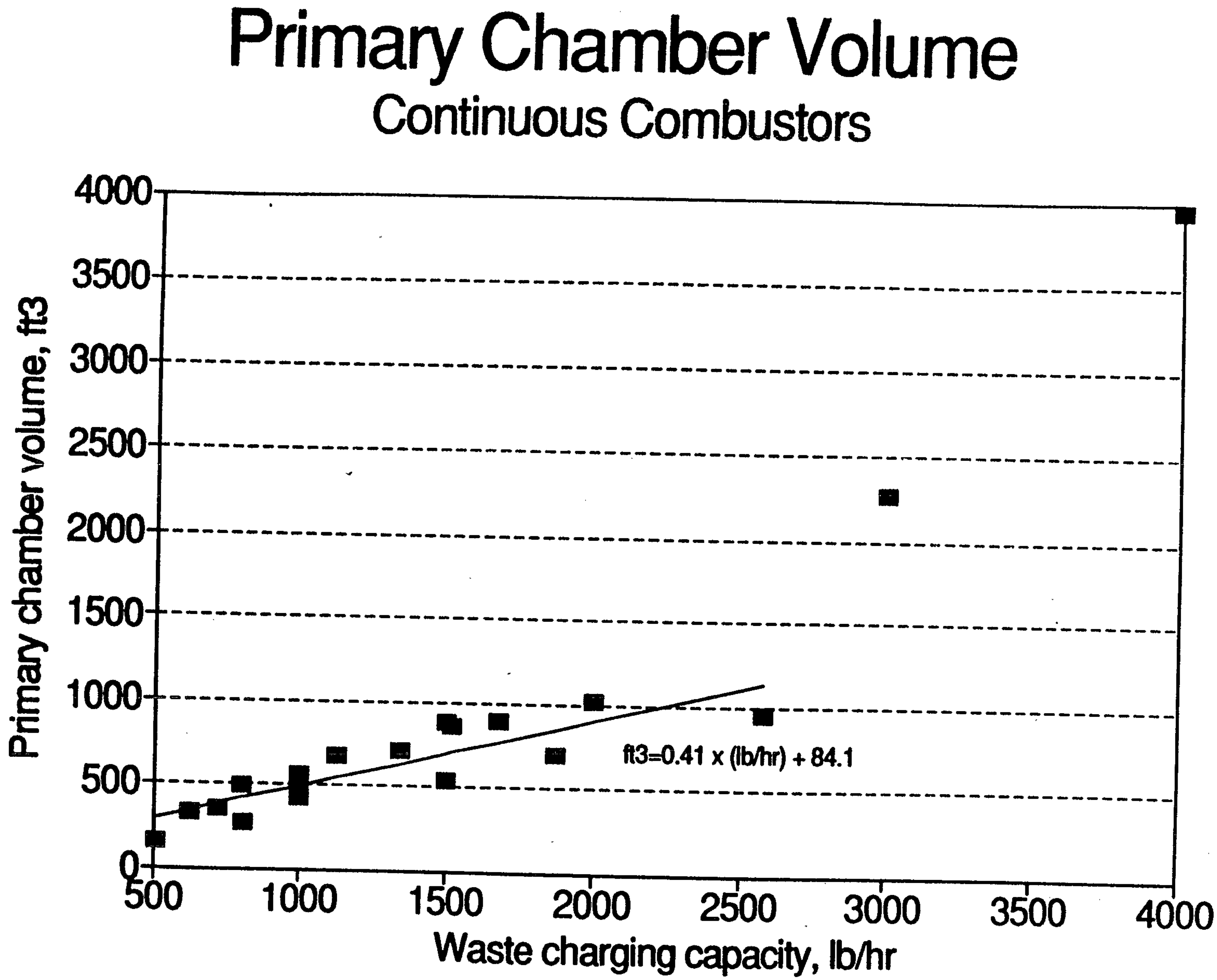

Figure 16. Primary chamber volume for continuous combustors.

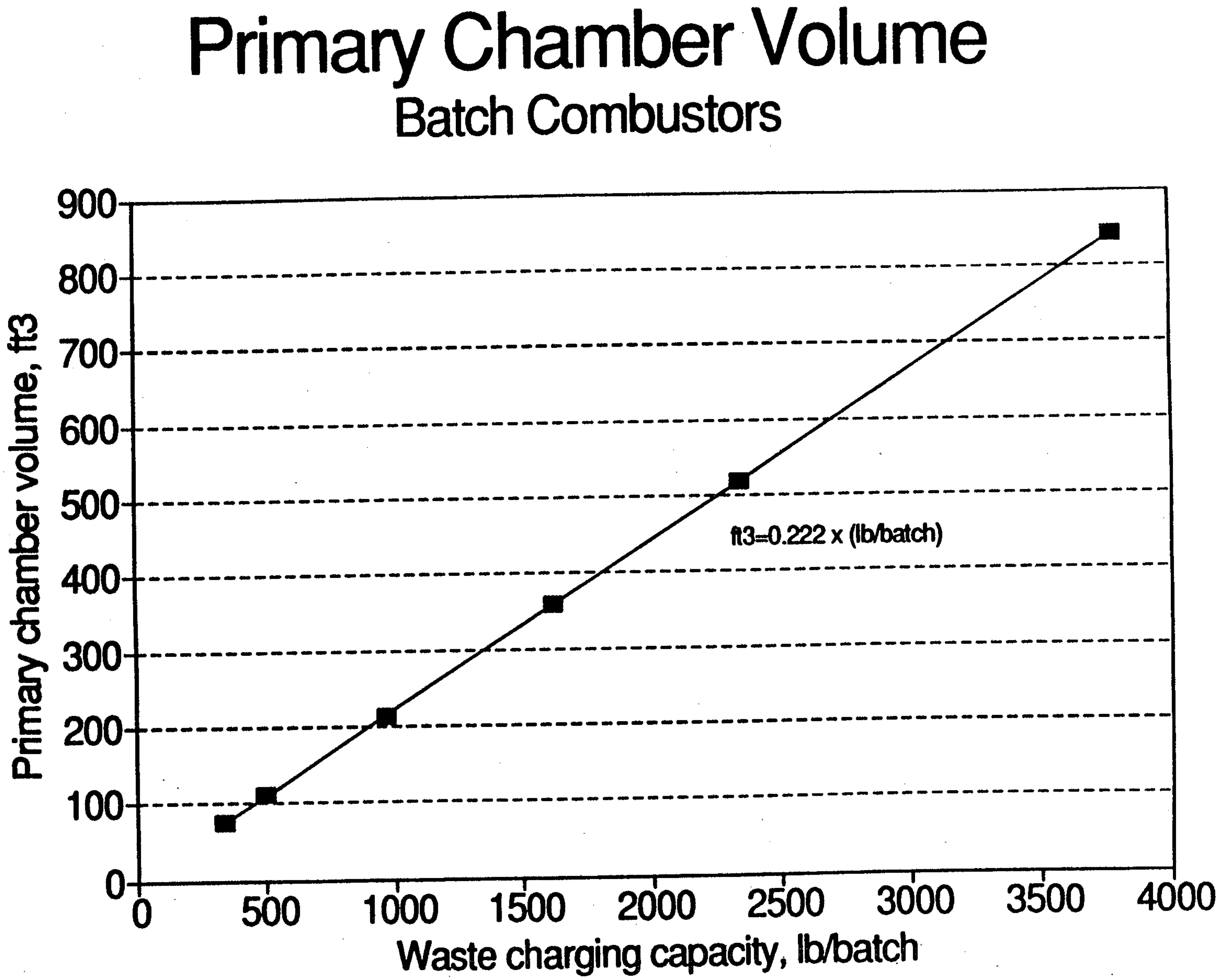

Figure 17. Primary chamber volume for batch combustors.

and $43/ft^3 for refractory and insulation, respectively. According to manufacturers, the average refractory life is about 8 years (although they indicated a range from 2 to 15+ years). The CRF based on this life and an interest rate of 10 percent is 0.18744.

3.3.10 Overhead

According to the OAQPS Control Cost Manual, overhead costs are about 60 percent of all labor and maintenance material costs.[69]

3.3.11 Property Tax, Insurance, and Administration

According to the OAQPS Control Cost Manual, annual costs for these items amount to about 4 percent of the total capital investment.[69]

3.3.12 Capital Recovery

According to MWI manufacturers, the combustor life expectancy is about 20 years. The CRF, 0.11746, was based on the life expectancy and an interest rate of 10 percent. This factor was multiplied by the TCI, minus the initial refractory cost, to estimate the capital recovery.

3.4 CONTROL TECHNOLOGY ANNUAL COSTS

This section presents annual costs for the same combustion and APCD control technologies for which capital costs were estimated in Section 3.2. Annual costs for FF-based control devices with activated carbon injection are presented in Section 3.5.

As indicated above, combustion controls are based on a larger secondary chamber with a gas residence time of 2 seconds and an operating temperature of 1800°F. Increasing the temperature increases the flow rate through the APCD because more water would need to be evaporated to cool the gas stream. The flow would also increase because additional combustion air is added with the additional natural gas. However, the impact on the flow rate is small (about 5 percent), and it was assumed that the same size APCD equipment could be used for an MWI with or without combustion controls.

3.4.1 Combustion Control Annual Costs

The additional capital cost for the larger secondary chamber results in additional maintenance, overhead, property tax, insurance, administration, and capital recovery costs. These costs were calculated by the same procedures described in Section 3.3. Refractory replacement costs are also higher, and they were calculated by the same procedure described in Section 3.3.9, except with twice the chamber volume.

Annual fuel costs were estimated for two additional auxiliary fuel requirements. First, additional fuel is required to maintain 1800°F rather than 1700°F in the secondary chamber. Second, additional fuel is needed to maintain the temperature at 1800°F for an average of 2 hours during cooldown in intermittent models and for 10 hours in batch models.

The resulting combustion control annual costs for each of the model combustors are presented in Table 15. A copy of the combustion control cost algorithm is presented in Appendix B.

3.4.2 Wet Control Device Annual Costs

Direct and indirect annual costs were estimated for wet control devices as applied to all of the model combustors. Direct annual operating costs were estimated for electricity for the fan and scrubber water pump (the items that consume nearly all of the electricity required by the system, according to two vendors), makeup scrubber water, operating and supervisory labor, maintenance labor and materials, caustic, and sewage disposal. Indirect annual costs were estimated for overhead, property tax, insurance, administrative charges, and capital recovery.

The equations used to estimate many of the annual costs are functions of the gas flow rate into the control system. In addition, each of the direct costs and the overhead cost are functions of the annual hours of operation. The annual costs for all control devices are based on the operating hours for each model combustor as described in Tables 6 through 8. The basis for each cost is described below. The operating parameters for the VS/PB control device were used as the starting point for VS and PB control device operating parameters and annual costs. The

TABLE 15. COMBUSTION CONTROL ANNUAL COSTS FOR NEW MWI'S

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm (a)	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr (b)	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. 2-second SC parameters							
(1) Sec. chamber volume, ft3 (c)	753	502	753	301	100	72	116
(2) Sec. chamber diameter, ft	7.8	6.8	7.8	5.8	4.0	3.6	4.2
(3) Sec. chamber length, ft	15.7	13.7	15.7	11.5	8.0	7.2	8.4
e. 1-second SC parameters							
(1) Sec. chamber volume, ft3 (c)	376	251	376	151	50.2	36	58
(2) Sec. chamber diameter, ft	6.2	5.4	6.2	4.6	3.2	2.8	3.3
(3) Sec. chamber length, ft	12.4	10.9	12.4	9.2	6.3	5.7	6.7
2. Total capital investment for combustion controls, $ (d)	64,283	47,084	64,283	33,320	19,556	17,620	20,610
3. Combustion control direct annual costs, $/yr							
a. Refractory replacement	1,876	1,438	1,876	1,028	502	405	551
b. Auxiliary fuel (e)	20,413	6,521	20,985	8,394	2,579	3,247	1,260
c. Maintenance materials	1,286	942	1,286	666	391	352	412
4. Combustion control indirect annual costs, $/yr							
a. Overhead	771	565	771	400	235	211	247
b. Property tax, insurance, and administrative	2,571	1,883	2,571	1,333	782	705	824
c. Capital recovery (f)	6,375	4,630	6,375	3,269	1,982	1,816	2,076
5. Total annual combustion control costs, $/yr	33,292	15,979	33,865	15,091	6,471	6,737	5,370

(a) The flow rate was assumed to be the same for both the 2-second and the 1-second combustors.
(b) The operating hours are based on the preheat, burning, burndown, and cooldown hours shown in Tables 6 through 8.
(c) The design temperature was assumed to be 1800 F for both the 2-second and 1-second SC's.
(d) The TCI is the difference between the capital costs for 2-second and 1-second SC's (see Table 21).
(e) Auxiliary fuel includes both the cost for additional fuel to raise the secondary chamber temperature form 1700F to 1800F and the cost of fuel to maintain 1800 F in the secondary chamber during cooldown until the combustion air blowers are turned off.
(f) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

formulas developed to calculate the annual costs for each wet control device are shown in Tables 16 to 18. Tables 19 through 21 present the APCD annual costs for each wet control device as applied to each model combustor. A copy of the algorithm showing the calculations and resulting equations for the VS/PB control device is presented in Appendix C.

3.4.2.1 Venturi Scrubber/Packed Bed. As indicated in Table 9, the typical pressure drop is 30 in. w.c. through the venturi throat and 4 in. w.c. through the PB. It was assumed that the pressure drop through the rest of the system is 4 in. w.c.

3.4.2.1.1 Fan electricity. The annual electricity cost for the fan is a function of the fan hp and the unit electricity cost. The fan hp values used in the algorithm were determined by the same method used to develop the capital costs (i.e., the hp requirements reported by the vendors were plotted versus the gas flow rate in dscfm, and the equation for the line through the averages was determined using linear regression).[28,29,31,45] Figure 18 presents the reported data and the line determined by linear regression. A unit cost of $0.06/kWh was provided by three vendors.[28,32,33]

3.4.2.1.2 Pump electricity. The annual electricity cost for the scrubber water pump was estimated by the same procedure as that described above for the fan electricity. Figure 19 presents the pump hp values reported by one vendor versus the gas flow rate.[28] Also shown is the equation developed by linear regression for the line through the data. The vendors use from one to three pumps to circulate liquid. The algorithm is based on only one pump because the highest horsepower ratings were reported by the vendor that uses only one pump.

3.4.2.1.3 Scrubber makeup water. The makeup water costs are a function of the makeup flow rates and the unit cost for water. The makeup water requirements were estimated by the same procedure as that described above for the electricity requirements. Figure 20 presents the reported makeup rates versus the gas flow rates in dscfm and the line determined by

TABLE 16. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR VS/PB CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	33.3*dscfm+118969
2. Direct annual costs, $/yr	
a. Electricity	(0.001037*dscfm+0.2038)*(hr/yr)
b. Scrubber water	(0.000237*dscfm)*(hr/yr)
c. Operating, supervisory, and maintenance labor	1.185*(hr/yr)
d. Maintenance materials	0.6660*dscfm+2379
e. Caustic	(0.00000125*ppm HCl)*(hr/yr)*(dscfm)
f. Sewer charge	(0.0000896*dscfm)*(hr/yr)
3. Indirect annual costs, $/yr	
a. Overhead	0.7110*(hr/yr)+0.3996*dscfm+1428
b. Property tax, insurance, and administrative	1.332*dscfm+4759
c. Capital recovery (a)	3.9114*dscfm+13974
4. Total annual cost, $/yr	([0.00000125*ppm HCl+0.001363]*dscfm +2.0998)*(hr/yr)+(6.3090*dscfm)+22540

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 17. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR VS CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	30.4*dscfm+100110
2. Direct annual costs, $/yr	
a. Electricity	(0.000880*dscfm+0.0917)*(hr/yr)
b. Scrubber water	0.000237*(dscfm)*(hr/yr)
c. Operating, supervisory, and maintenance labor	1.185*(hr/yr)
d. Maintenance materials	0.6080*dscfm+2002
e. Caustic	(0.00000125*ppm HCl)*(hr/yr)*(dscfm)
f. Sewer charge	0.000090*(dscfm)*(hr/yr)
3. Indirect annual costs, $/yr	
a. Overhead	0.7110*(hr/yr)+0.3648*dscfm+1201
b. Property tax, insurance, administrative	1.216*dscfm+4004
c. Capital recovery (a)	3.5708*dscfm+11759
4. Total annual cost, $/yr	([0.00000125*ppm HCl+0.001206]*(dscfm) +1.9877)*(hr/yr)+(5.7596*dscfm)+18967

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 18. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR PB CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	27.6*dscfm+109603
2. Direct annual costs, $/yr	
a. Electricity	(0.000276*dscfm+0.1427)*(hr/yr)
b. Scrubber water	(0.000237*dscfm)*(hr/yr)
c. Operating, supervisory, and maintenance labor	1.185*(hr/yr)
d. Maintenance materials	0.5520*dscfm+2192
e. Caustic	(0.00000125*ppm HCl)*(dscfm)*(hr/yr)
f. Sewer charge	(0.0000896*dscfm)*(hr/yr)
3. Indirect annual costs, $/yr	
a. Overhead	0.7110*(hr/yr)+0.3312*dscfm+1315
b. Property tax, insurance, and administrative	1.104*dscfm+4384
c. Capital recovery (a)	3.2419*dscfm+12874
4. Total annual cost, $/yr	([0.00000125*ppm HCl+0.000603]*dscfm +2.0387)*(hr/yr)+(5.2291*dscfm)+20765

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 19. VS/PB ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control system, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. HCl concentration, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	277,044	224,364	277,044	182,206	140,048	134,121	143,278
3. Direct annual costs, $/yr							
a. Electricity	39,867	12,990	22,394	9,493	3,221	2,433	2,998
b. Scrubber water	8,731	2,790	4,905	1,962	561	387	539
c. Operating, supervisory, and maintenance labor	9,215	4,415	5,176	5,176	4,437	4,266	3,697
d. Maintenance materials	5,541	4,487	5,541	3,644	2,801	2,682	2,866
e. Caustic	33,595	10,733	18,871	7,549	2,157	204	170
f. Sewer charge	3,309	1,057	1,859	744	212	147	204
4. Indirect annual costs, $/yr							
a. Overhead	8,853	5,342	6,430	5,292	4,343	4,169	3,938
b. Property tax, insurance, and administrative	11,082	8,975	11,082	7,288	5,602	5,365	5,731
c. Capital recovery (a)	32,542	26,354	32,542	21,402	16,450	15,754	16,829
5. Total annual cost, $/yr	152,734	77,142	108,800	62,550	39,783	35,407	36,972

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE 20. VS ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models		Intermittent models			Batch model	Pathological model
	1	2	3	4	5	6	7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control system, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. HCl concentration, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	244,419	196,326	244,419	157,840	119,353	113,942	122,302
3. Direct annual costs, $/yr							
a. Electricity	33,182	10,715	18,639	7,697	2,428	1,771	2,290
b. Scrubber water	8,731	2,790	4,905	1,962	561	387	539
c. Operating, supervisory, and maintenance labor	9,215	4,415	5,176	5,176	4,437	4,266	3,697
d. Maintenance materials	4,888	3,927	4,888	3,157	2,387	2,279	2,446
e. Caustic	33,595	10,733	18,871	7,549	2,157	204	170
f. Sewer charge	3,309	1,057	1,859	744	212	147	204
4. Indirect annual costs, $/yr							
a. Overhead	8,462	5,005	6,039	5,000	4,094	3,927	3,686
b. Property tax, insurance, and administrative	9,777	7,853	9,777	6,314	4,774	4,558	4,892
c. Capital recovery (a)	28,709	23,060	28,709	18,540	14,019	13,384	14,366
5. Total annual cost, $/yr	139,868	69,555	98,863	56,138	35,069	30,923	32,290

(c) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE 21. PB ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models		Intermittent models			Batch model	Pathological model
	1	2	3	4	5	6	7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control system, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. HCl concentration, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	240,620	196,957	240,620	162,015	127,074	122,161	129,751
3. Direct annual costs, $/yr							
a. Electricity	11,310	3,791	6,353	2,916	1,189	966	1,075
b. Scrubber water	8,731	2,790	4,905	1,962	561	387	539
c. Operating, supervisory, and maintenance labor	9,215	4,415	5,176	5,176	4,437	4,266	3,697
d. Maintenance materials	4,812	3,939	4,812	3,240	2,541	2,443	2,595
e. Caustic	33,595	10,733	18,871	7,549	2,157	204	170
f. Sewer charge	3,309	1,057	1,859	744	212	147	204
4. Indirect annual costs, $/yr							
a. Overhead	8,416	5,013	5,993	5,050	4,187	4,026	3,775
b. Property tax, insurance, and administrative	9,625	7,878	9,625	6,481	5,083	4,886	5,190
c. Capital recovery (a)	28,263	23,135	28,263	19,030	14,926	14,349	15,241
5. Total annual cost, $/yr	117,277	62,750	85,858	52,148	35,293	31,675	32,486

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

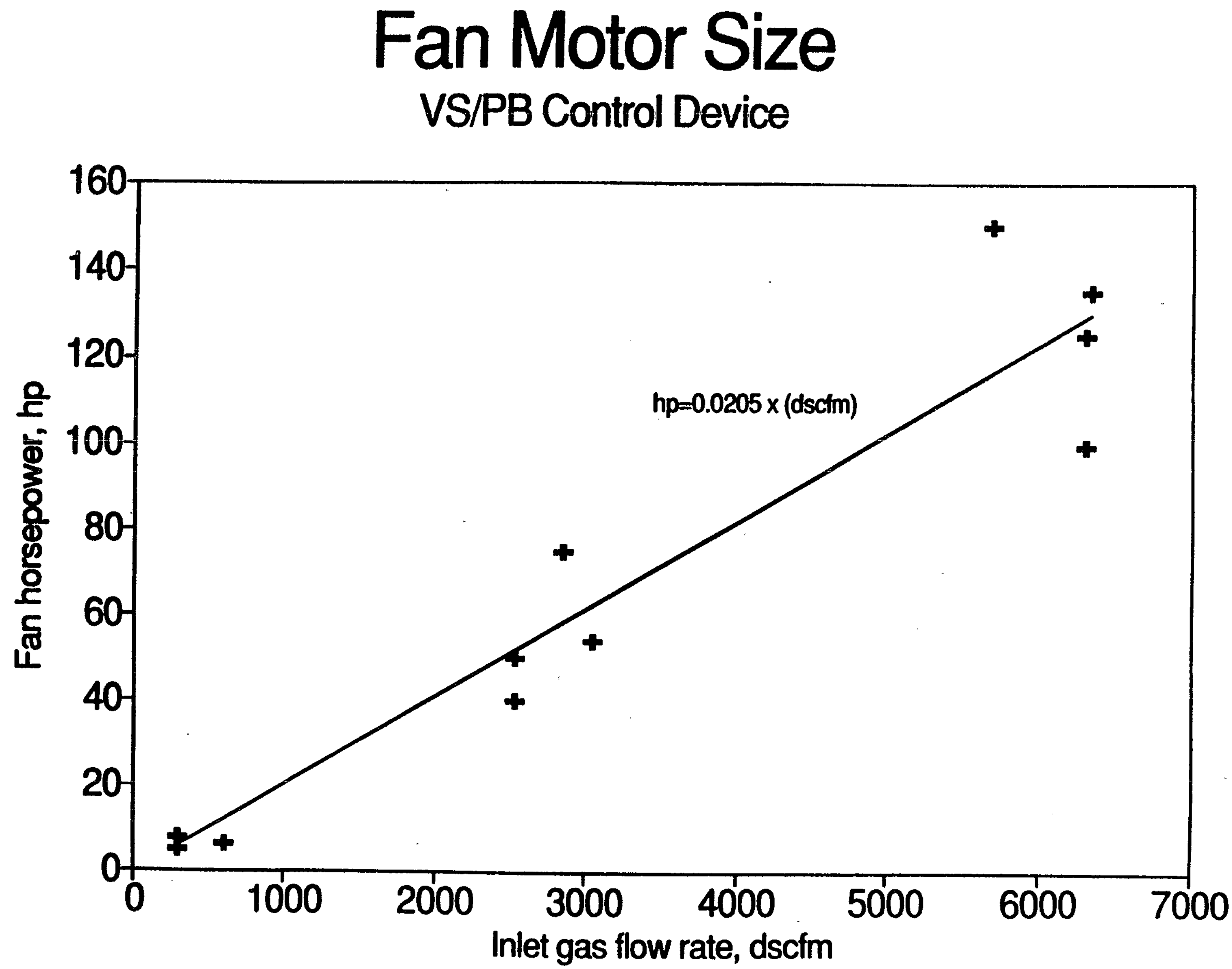

Figure 18. Fan motor size for VS/PB control device.

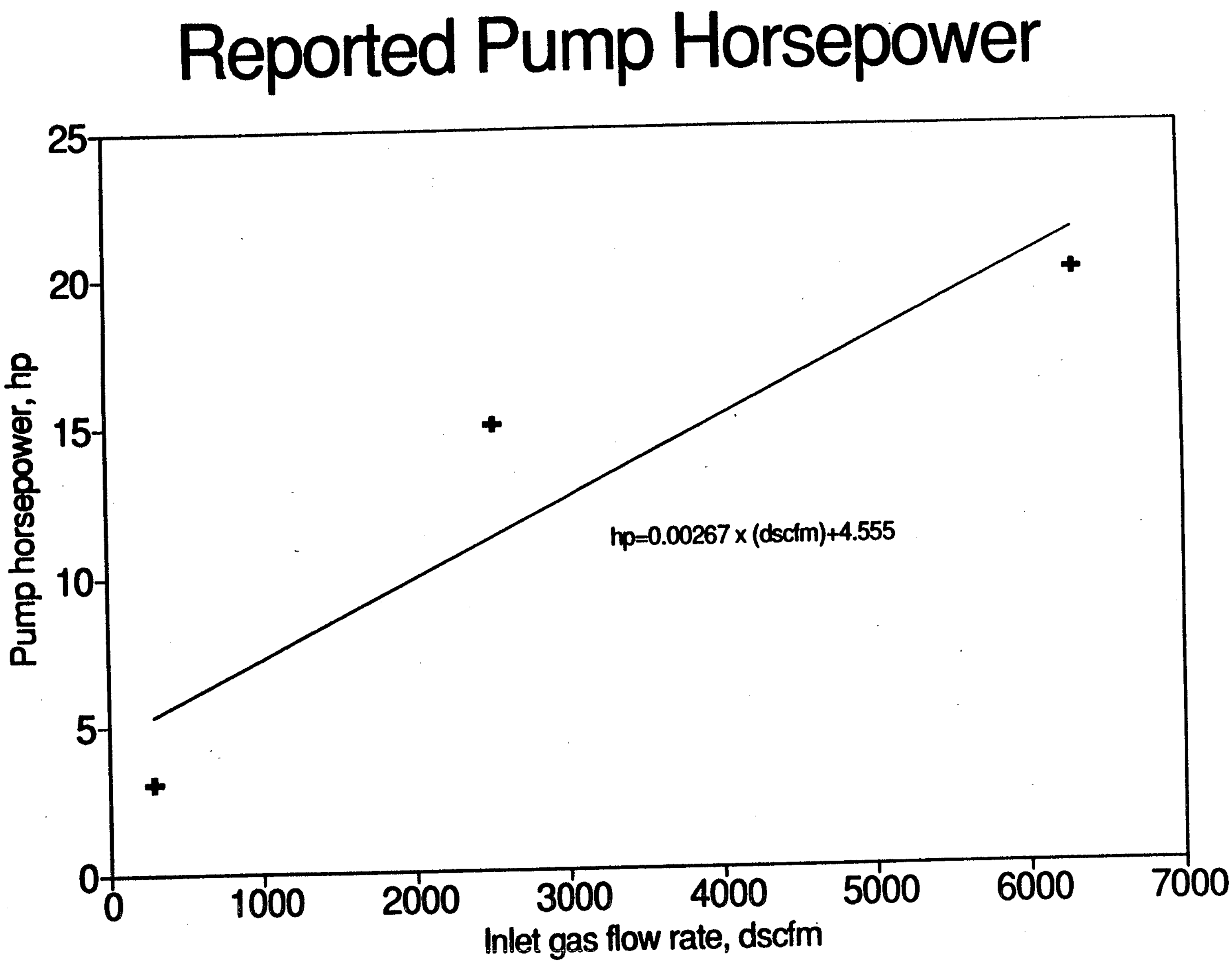

Figure 19. Pump horsepower for VS/PB control device.

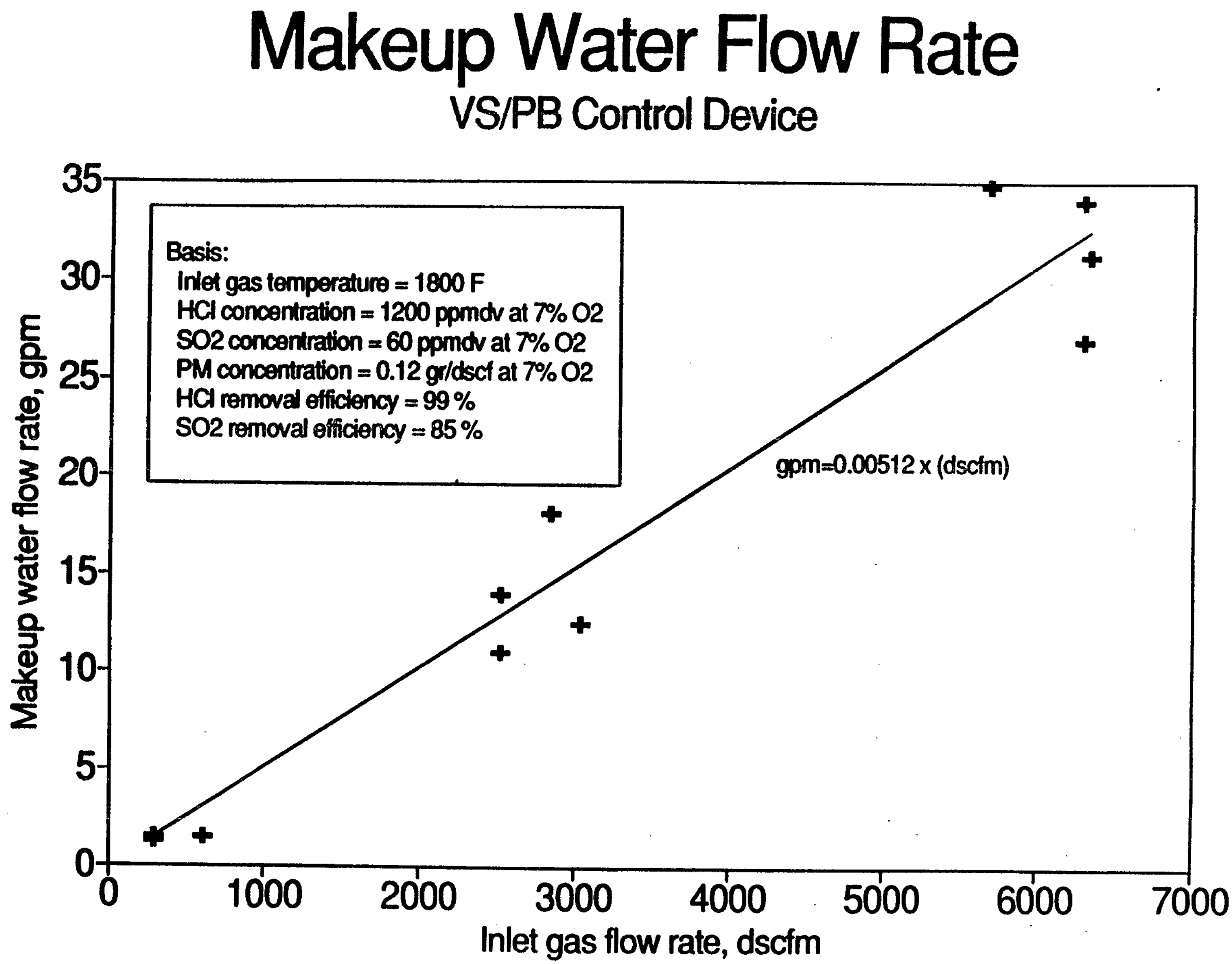

Figure 20. Makeup water flow rate for VS/PB control device.

least-squares linear regression through the averages of the reported values. The reported makeup rates were based on the amount of water needed to replenish losses due to evaporation in the quench and to replace blowdown losses. The evaporation rates are for cooling the exhaust gas (10 percent moisture and 1800°F) to saturation. Blowdown rates are presented in Section 3.4.2.1.9. Based on a 1989 estimate from the American Water Works Association, water was assumed to cost $0.77/1,000 gal.[61]

3.4.2.1.4 Operating labor. Vendors estimated that average operating labor rates are about 0.4 hr/8-hr shift. A labor wage rate of $12/hr was used to be consistent with the rate for incinerator operators.

3.4.2.1.5 Supervisory labor. According to the OAQPS Control Cost Manual procedures, the supervisory labor is estimated as 15 percent of the operating labor.[63]

3.4.2.1.6 Maintenance labor. Vendors estimated that maintenance labor requirements would be about 0.3 hr/8-hr shift. The wage rate was assumed to be 10 percent higher than the operating labor wage rate based on the OAQPS Control Cost Manual procedures.[64]

3.4.2.1.7 Maintenance materials. The annual maintenance materials costs were estimated by two vendors to be about 2 percent of the TCI.[28,29] The algorithm uses this approach rather than the OAQPS procedure, which is to equate the materials cost with the maintenance labor cost, because the OAQPS procedure estimates a very low cost considering the size and cost of the control systems.

3.4.2.1.8 Caustic. The sodium hydroxide (NaOH) costs are a function of the exhaust gas flow rate, the uncontrolled concentrations of acid gases, the NaOH-to-acid gases molar ratio, and the dry NaOH unit cost. Hydrogen chloride is the only acid gas evaluated in this analysis because EPA-sponsored emissions test of MWI's showed VS/PB devices did not reduce the low concentrations of SO_2. Uncontrolled HCl concentrations range from 120 ppm at 7 percent O_2 to 1,460 ppm at 7 percent O_2, depending on the type of waste burned and the combustor design. As indicated in Section 2.2, only enough NaOH is added to keep the pH at or just below 7.0. Therefore, the NaOH-to-HCl molar ratio is essentially 1:1. Caustic costs of $400/ton and $375/ton were provided by two vendors.[28,29] The higher unit cost was used in the algorithm.

3.4.2.1.9 <u>Sewage disposal</u>. The sewage disposal costs are a function of the blowdown rate and the unit cost for disposal. The blowdown rates used in the algorithm were developed by the same procedure used to estimate fan hp requirements. Figure 21 presents the reported data as well as the line determined by least-squares linear regression through the average of the reported values. Vendors estimated blowdown rates based on the acid gases concentrations that were provided in the EPA information requests (1,200 ppm HCl and 60 ppm SO_2 at 7 percent O_2) and on their guaranteed removal efficiencies. Differences in blowdown rates that may result from different uncontrolled acid gases concentrations or removal efficiencies were neglected in this analysis because they have only a small impact on the cost. One vendor estimated that sewage disposal costs are about $2/1,000 gal.[28]

3.4.2.1.10 <u>Overhead</u>. According to OAQPS procedures, overhead is estimated as 60 percent of the operating, supervisory, and maintenance labor and the maintenance materials.[69]

3.4.2.1.11 <u>Property tax, insurance, and administrative</u>. According to OAQPS procedures, these costs are estimated as 4 percent of the TCI.[69]

3.4.2.1.12 <u>Capital recovery</u>. According to the vendors, the equipment life expectancy is between 15 and 20 years. The CRF, 0.11746, was based on a 20-year life expectancy and an interest rate of 10 percent. This factor was multiplied by the TCI to estimate the capital recovery.

3.4.2.2 <u>Venturi Scrubber</u>. The fan hp requirements and electricity costs are 10 percent lower for this control device than for the VS/PB control device described above

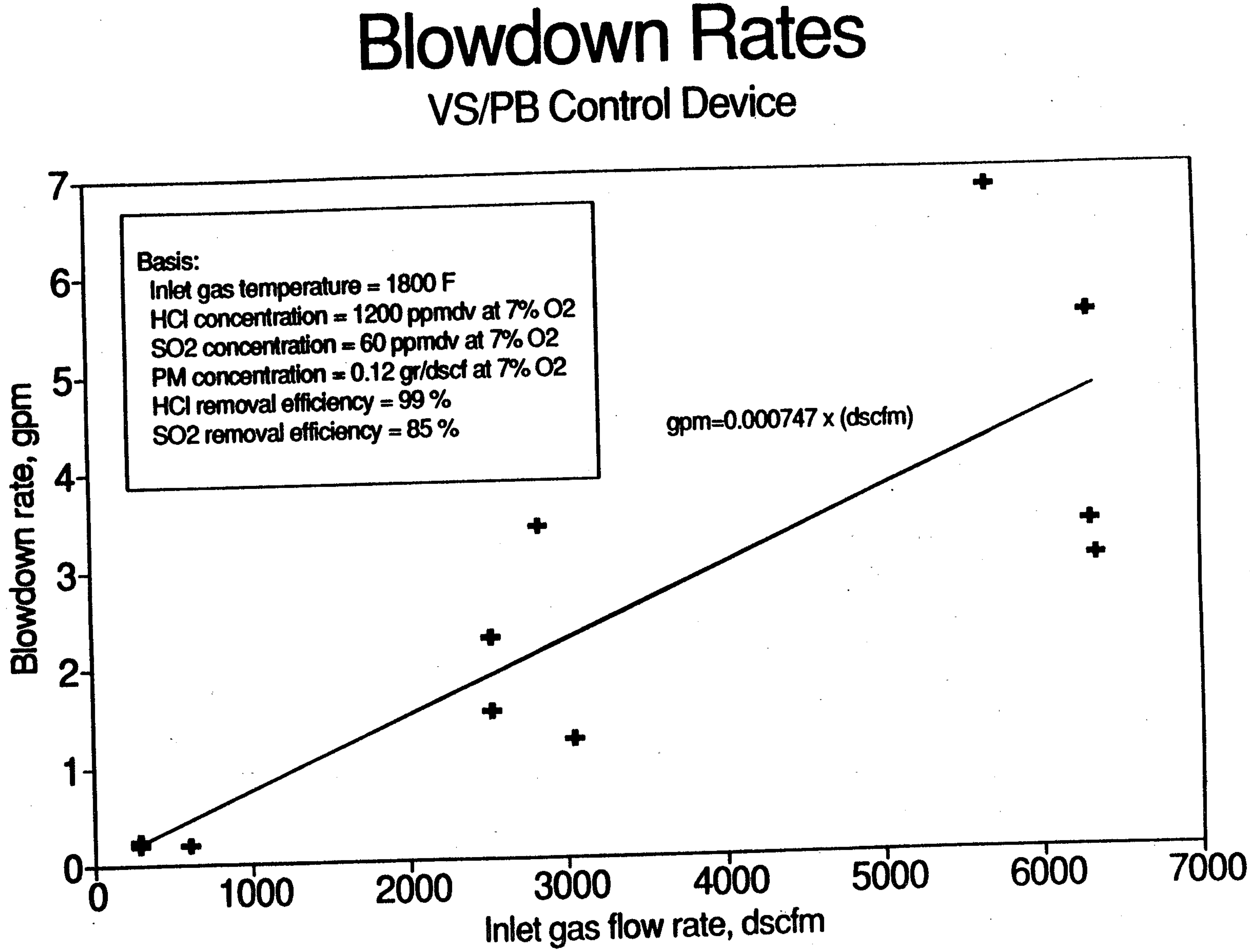

Figure 21. Blowdown rates for VS/PB control device.

(Section 3.4.2.1) because removal of the absorber reduces the system pressure drop by about 10 percent. The pump hp and electricity cost are 55 percent lower because three vendors indicated that about 55 percent of the total liquid flow is to the absorber in VS/PB control devices.[28,29,31] Maintenance materials and indirect costs are lower than those for the VS/PB control device because the capital costs are lower. Other annual costs are the same as those for the VS/PB control device. The annual cost equations are presented in Table 17, and the costs as applied to the model combustors are shown in Table 20.

3.4.2.3 Packed Bed. Removing the VS from the VS/PB control device reduces the system pressure drop and, thus, the fan hp and electricity cost by about 80 percent. The pump hp and electricity cost for this control device are 30 percent lower than those for the VS/PB device. This reduction is based on information from two vendors that 30 percent of the liquid flow in the VS/PB control device is to the venturi.[29,31] Maintenance materials and indirect costs are lower because the capital cost is lower than that for the VS/PB control device. Other annual cost components are the same as those for the VS/PB device. The annual cost equations are shown in Table 18, and the costs as applied to the model combustors are shown in Table 21.

3.4.3 Annual Costs for Control Devices with an FF

Direct and indirect annual costs were estimated for DI/FF, FF, FF/PB and SD/FF control devices for all of the model combustors. It was assumed that the DI/FF and FF control devices have an evaporative cooler to reduce the combustor exhaust gas to 300°F; the spray dryer also reduces the gas temperature to 300°F. It was also assumed that all four control devices have an FF with a G/C ratio of 3.5.

3.4.3.1 Dry Injection/Fabric Filter. Direct annual costs were estimated for electricity, makeup lime, evaporative cooler water, operating and supervisory labor, maintenance labor and materials, compressed air for the FF, dust disposal, bag replacement, and cage replacement. Indirect annual costs were estimated for overhead, property tax, insurance, administrative charges, and capital recovery. Information about many of the operating parameters was obtained from vendors; other parameters were estimated. The basis for each cost is described in the subsections below. The formulas developed to calculate the annual costs are shown in Table 22. Most of the equations are a function of the gas flow rate into the control device and many are also related to the annual hours of operation. Table 23 presents the annual costs for each model combustor. A copy of the algorithm showing the calculations and resulting equations for the DI/FF control device is presented in Appendix D.

3.4.3.1.1 Electricity. The annual fan electricity cost is a function of the fan hp, the unit electricity cost, and the annual hours of operation. The fan hp values used in the algorithm were determined by the same method used to develop the capital costs (i.e., the hp requirements reported by the vendors were plotted versus the gas flow rate, and the equation for the line through the data was determined using least-squares linear regression).[32,33,35] Figure 22 summarizes the data. A unit cost of $0.06/kWh was provided by three vendors.[28,32,33] Because two vendors indicated that other electrical components consume, on average, 22 percent as much electricity as the I.D. fan, the fan electricity demand was multiplied by a factor of 1.22 to estimate the total electricity demand.[46,49]

3.4.3.1.2 Makeup lime. Makeup lime rates were based on a lime-to-acid gases SR of 2.5:1 (see Section 2.2.2.5). For this analysis, HCl is the only acid gas evaluated because EPA-sponsored emissions tests of an MWI with a DI/FF control device showed no control of the low uncontrolled SO_2 emissions.[38] Dry lime costs of $100/ton and $90/ton were obtained from two vendors.[32,33] The higher unit cost was used in the algorithm.

3.4.3.1.3 Evaporative cooler water. The amount of water added in the evaporative cooler was estimated by subtracting the amount of moisture in the gas stream entering the control device from that in the gas entering the FF. The inlet gas stream flow rates that were provided to the vendors in information requests were assumed to be 10 percent moisture. According to the vendors

TABLE 22. EQUATIONS USED TO ESTIMATE ANNUAL COSTS FOR DI/FF CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	63.8*dscfm+407498
2. Direct annual costs, $/yr	
a. Electricity	(0.000355*dscfm+0.1573)*(hr/yr)
b. Makeup lime	(0.000000720*ppm HCl)*(dscfm)*(hr/yr)
c. Water	(0.000126*dscfm+0.0289)*(hr/yr)
d. Operating, supervisory, and maintenance labor	2.55*(hr/yr)
e. Maintenance materials	1.276*dscfm+8150
f. Compressor air	(0.000043*dscfm+0.00812)*(hr/yr)
g. Dust disposal	(0.00017*PM+0.000000343*HCl)*(dscfm)*(hr/yr)
h. Bag replacement	1.0418*dscfm+195
i. Cage replacement	0.12075*dscfm+22.6
3. Indirect annual costs, $/yr	
a. Overhead	(1.530*hr/yr)+0.7656*dscfm+4890
b. Property tax, insurance, and administrative	2.552*dscfm+16300
c. Capital recovery (a)	7.237*dscfm+47817
4. Total annual cost, $/yr	([0.000171*PM+0.00000106*HCl+0.000524] *dscfm+4.2743)*(hr/yr)+(12.993*dscfm)+77374

(a) CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 23. DI/FF ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models 1	Continuous models 2	Intermittent models 3	Intermittent models 4	Intermittent models 5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. Inlet PM, gr/dscf at 14% O2	0.08	0.08	0.08	0.08	0.08	0.022	0.012
e. Outlet PM, gr/dscf at 14% O2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
f. Inlet HCl, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	710,357	609,425	710,357	528,654	447,883	436,527	454,072
3. Direct annual costs, $/yr							
a. Electricity	14,325	4,772	8,047	3,631	1,430	1,148	1,299
b. Makeup lime	19,401	6,198	10,898	4,360	1,246	118	98
c. Water	4,866	1,590	2,733	1,169	406	310	377
d. Operating, supervisory, and maintenance labor	19,829	9,501	11,138	11,138	9,547	9,180	7,956
e. Maintenance materials	14,207	12,189	14,207	10,573	8,958	8,731	9,081
f. Compressor air	1,665	542	935	395	133	100	124
g. Dust disposal	9,711	3,103	5,455	2,182	624	61	50
h. Bag replacement	5,140	3,492	5,140	2,173	854	669	955
i. Cage replacement	596	405	596	252	99	78	111
4. Indirect annual costs, $/yr							
a. Overhead	20,422	13,014	15,207	13,027	11,103	10,746	10,222
b. Property tax, insurance, and administrative	28,414	24,377	28,414	21,146	17,915	17,461	18,163
c. Capital recovery (a)	82,169	70,720	82,169	61,559	52,397	51,109	53,099
5. Total annual cost, $/yr	220,745	149,903	184,940	131,606	104,713	99,710	101,536

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

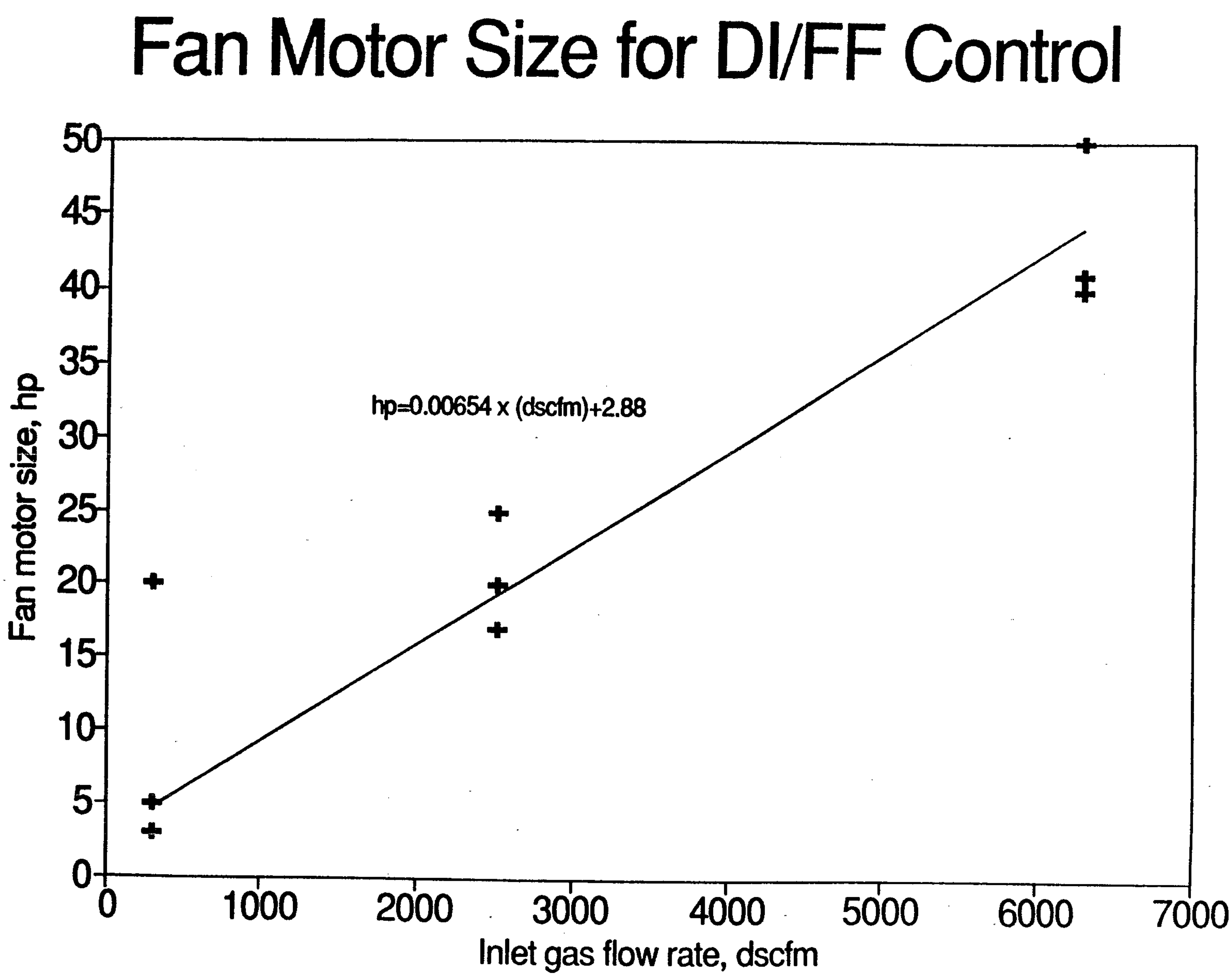

Figure 22. Fan motor size for DI/FF control device.

that use evaporative coolers, the average moisture content of the gas entering the FF was 38 percent, and the average temperature was 300°F.[33-35] The gas flow rates reported by all of the vendors were used to estimate the average gas flow rate in the FF by the same procedure described above to estimate the fan hp. Figure 23 summarizes the reported gas flow rates and presents the least-squares linear regression line through the averages. Based on a January 1989 estimate from the American Water Works Association, water was assumed to cost $0.77/1,000 gallons.[61]

3.4.3.1.4 Operating labor. Vendors estimated that operating labor requirements would be about 1 hr/8-hr shift. A labor wage rate of $12/hr was used based on information from one vendor and to be consistent with the incinerator operator wage rate.[33]

3.4.3.1.5 Supervisory labor. According to the OAQPS Control Cost Manual procedures, this cost is 15 percent of the operating labor cost.[63]

3.4.3.1.6 Maintenance labor. Vendors estimated that maintenance labor requirements would be about 0.5 hr/8-hr shift. The wage rate was estimated to be 10 percent higher than the operator's wage based on the OAQPS Control Cost Manual procedures.[64]

3.4.3.1.7 Maintenance materials. According to one DI/FF vendor (as well as two VS/PB vendors) this cost is about 2 percent of the total capital investment. The algorithm uses this approach rather than the OAQPS Control Cost Manual procedure, which is to equate the materials cost with the maintenance labor cost, because the OAQPS procedure estimates a very low cost considering the size and cost of the control systems.

3.4.3.1.8 Compressed air. The amount and cost of compressed air were both estimated based on OAQPS procedures. These procedures specify 2 ft^3 of compressed air per 1,000 ft^3 of filtered air and a cost of $0.16/1,000 ft^3 of compressed air.[70] The August 1986 costs were adjusted to October 1989 costs using the Chemical Engineering (CE) plant cost indexes.[67,71]

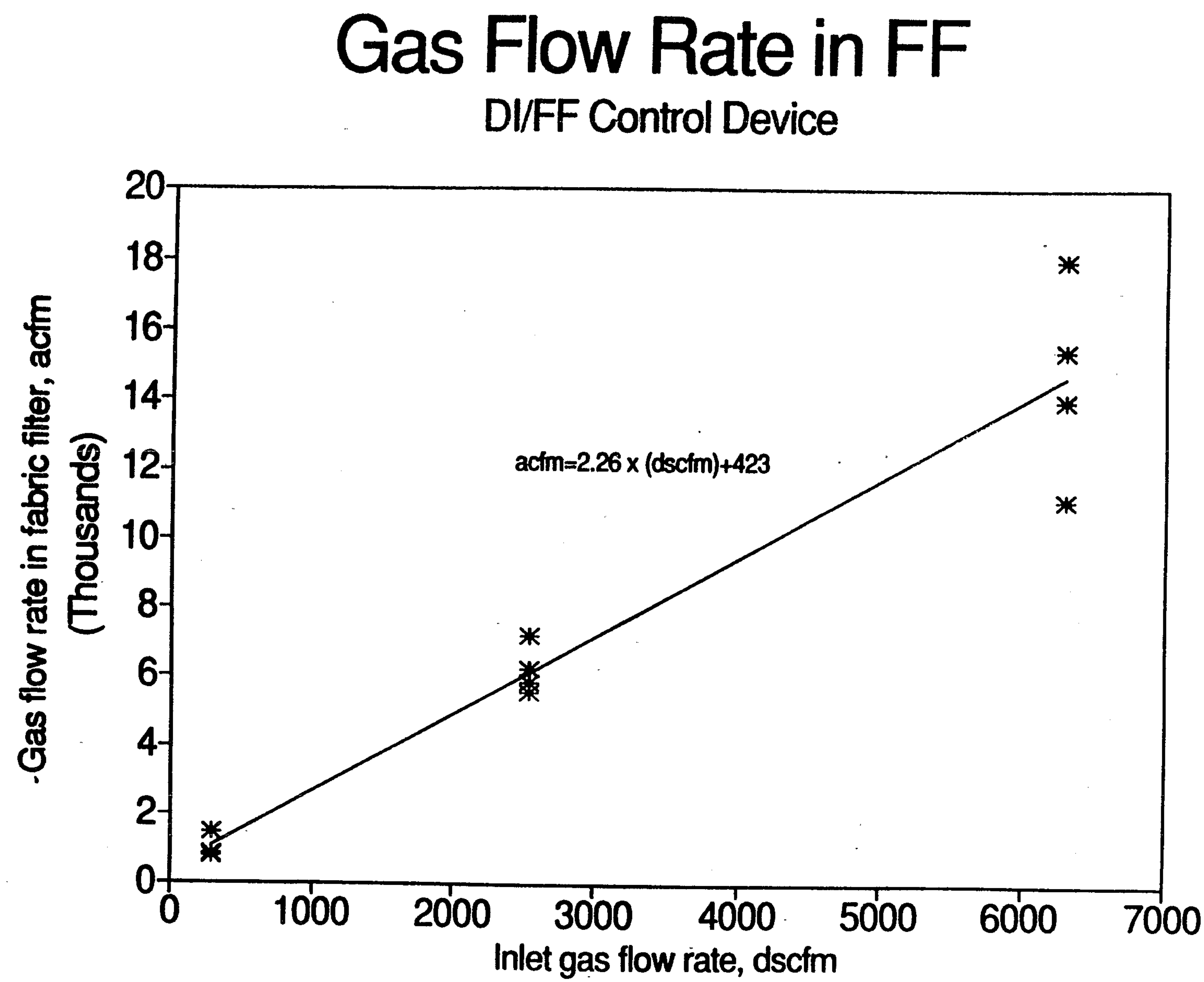

Figure 23. Gas flow rate in DI/FF control device.

3.4.3.1.9 Dust disposal. The cost of dust disposal is a function of the amount of material captured and the unit cost for disposal. The quantity of material captured by the FF's for each of the model combustor gas streams was estimated based on estimated inlet and outlet PM loadings, uncontrolled HCl concentrations and removal efficiency, and the amount of unreacted lime. Based on test data, the uncontrolled PM loadings range from 0.024 to 0.16 grain (gr)/dscf at 7 percent O_2, depending on the combustor design; control device outlet levels are 0.01 gr/dscf for all model combustors. Test data also showed the inlet HCl concentrations range from 120 ppm to 1,460 ppm at 7 percent O_2, depending on the type of waste burned and the combustor design.[72] The HCl removal efficiency is assumed to be 95 percent for all model combustors. Based on this removal efficiency and an SR of 2.5:1, about 62 percent of the makeup lime is unreacted.

The dust disposal cost was estimated assuming disposal at a municipal waste landfill because this is the method used by most facilities with DI/FF control devices. Typically, these facilities mix the fly ash/lime with incinerator bottom ash, either in a dumpster or by feeding the captured material back into the incinerator.[73-76] This mixture tests as nonhazardous waste under the Resource Conservation and Recovery Act's Toxicity Characteristic Leaching Procedure (TCLP) test. The unit disposal cost was assumed to be $40/ton, as noted above for bottom ash disposal costs.

A few facilities, primarily those from one commercial disposal firm, dispose of the fly ash/lime in a hazardous waste landfill because lead causes the material to test as hazardous waste under the TCLP test.[37,77]

3.4.3.1.10 Bag replacement. An equation to estimate the bag replacement costs was based on the CRF; the initial bag cost, including taxes and freight; and the bag replacement labor. The CRF is 0.5762, assuming an annual interest rate of 10 percent and a 2-year bag life, the average life reported by the vendors. The initial bag costs were based on estimates of the total fabric area, the taxes and freight adjustment factor, and the unit cost for the bag material. To estimate the total fabric area, the equation for the average flow rate in the FF (as determined in Section 3.4.3.1.3) was divided by the average G/C ratio (3.5:1). Taxes and freight were assumed to be equal to 8 percent of the bag cost. According to the vendors, the average cost for material that can achieve an emission level of 0.015 gr/dscf at 7 percent O_2 is about $\$2.5/ft^2$.[32,34,35,46,49,50,55]

Labor requirements were based on the number of bags, the time to replace each bag, and the wage rate. The number of bags was estimated by dividing the total FF area by the average bag area--18 ft^2 according to the vendors--and the G/C ratio. According to OAQPS procedures, the time to replace each bag is about 0.15 hr.[63] The labor wage rate was assumed to be the same as the operator wage rate ($12/hr).

3.4.3.1.11 Cage replacement. An equation to estimate the cage replacement costs was developed from the number of cages, the individual cage cost, the replacement labor requirements, and the CRF. The number of cages is equivalent to the number of bags estimated above. Individual cage costs in August 1986 dollars were estimated based on OAQPS procedures, except that the cost for 100 count lots was used for all systems.[63] This was done to simplify the analysis and because it has only a very small impact on the cost. The individual cage costs were adjusted to October 1989 costs using the CE plant cost indexes.[67,71] Because it was assumed that the time to replace the cages is equivalent to the time to replace the bags, the replacement labor costs are equivalent. The CRF is 0.3156, assuming an interest rate of 10 percent and a replacement frequency of 4 years. It was assumed that the cages would be replaced every 4 years because one vendor estimated that cages would need to be replaced (due to corrosion) every other time the bags are replaced.[75]

3.4.3.1.12 Overhead. According to the OAQPS Control Cost Manual, overhead is estimated as 60 percent of the operating, supervisory, and maintenance labor and the maintenance materials.[69]

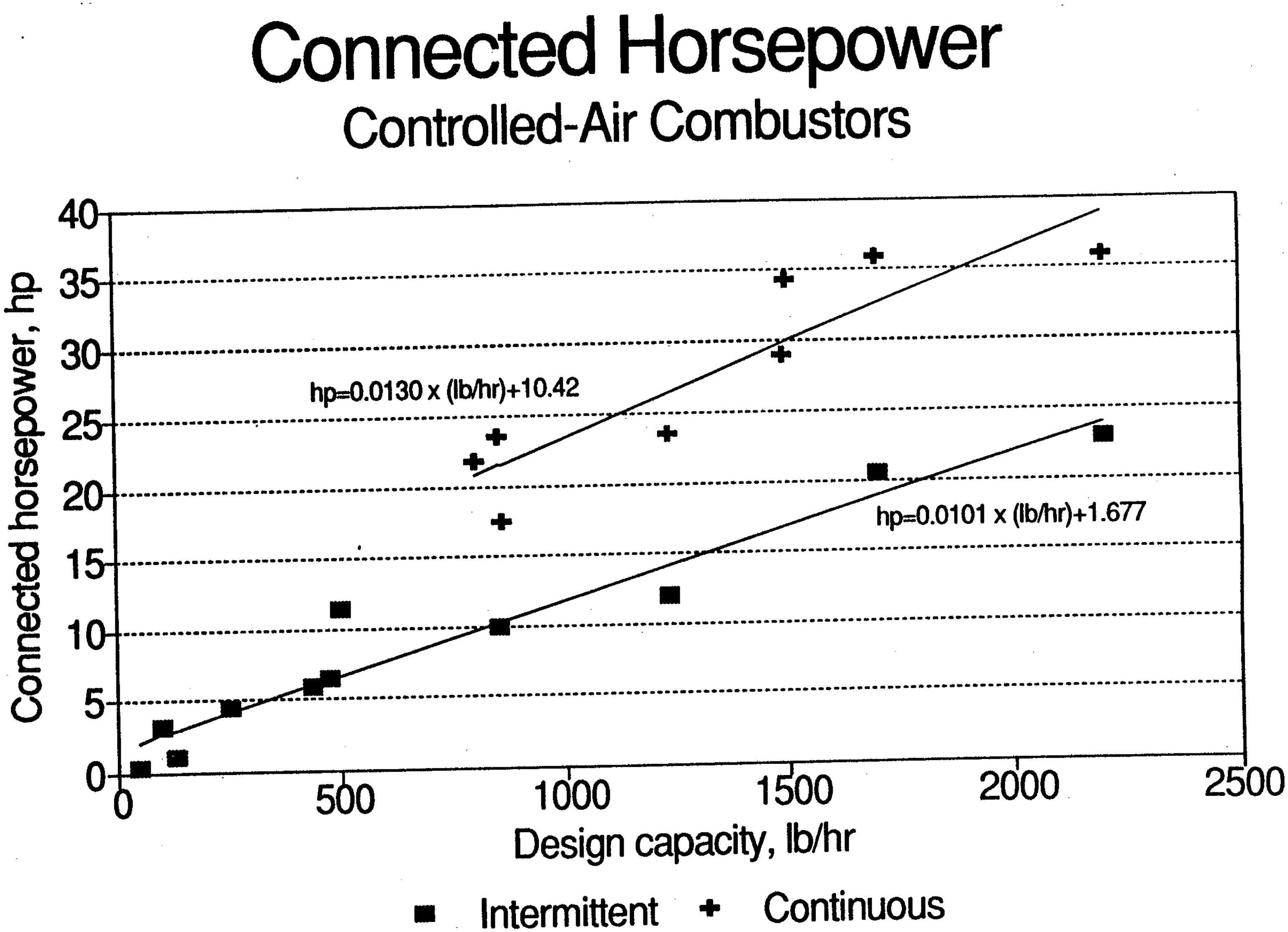

Figure 13. Connected horsepower requirements for intermittent and continuous combustors.

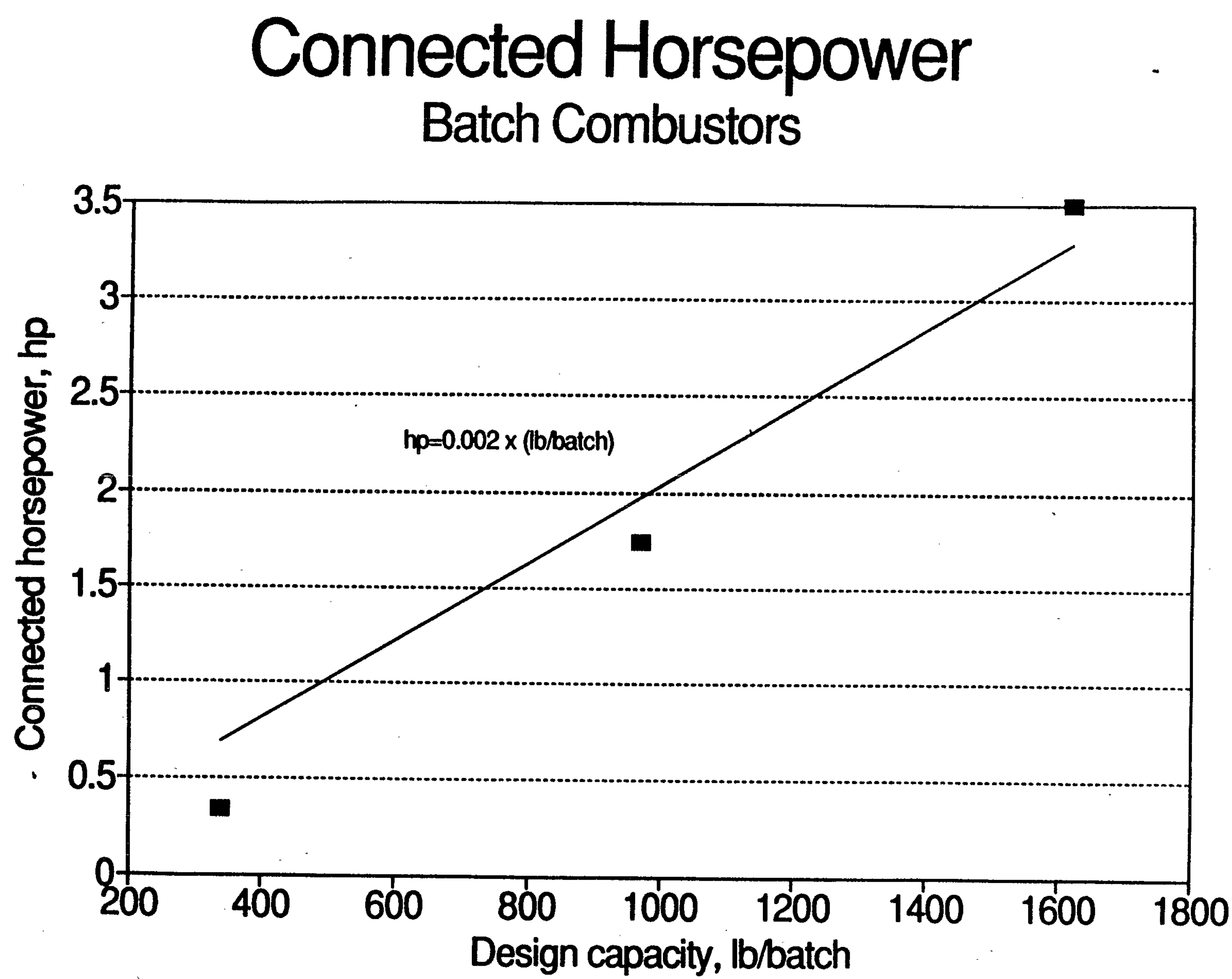

Figure 14. Connected horsepower requirements for batch combustors.

Electricity costs were estimated by assuming all of the motors were running continuously during all operating hours (including 2 hr of cooldown for intermittent units and 10 hr of cooldown for batch units). This assumption overestimates the cost because the feed and ash rams do not operate continuously. Electricity costs were assumed to be $0.06 per kilowatt-hour (Kwh).[28,32,33]

3.3.2 Auxiliary Fuel

Auxiliary fuel costs are based on the type of fuel, the burner capacities, and the burner utilization rates. Natural gas was specified as the auxiliary fuel for all of the models because it is used in nearly all existing MWI's.[7,12,13,22] Natural gas costs were assumed to be $0.35/therm, which is $3.5/1,000,000 Btu.[25]

Burner capacities for all combustor designs were obtained from one manufacturer each. The equation for the best-fit line through each data set as determined by least-squares linear regression was used to estimate burner capacities for the model combustors.

During the preheat phase, the secondary chamber burner is on continuously in all combustors. Because of its lower setpoint temperature, the primary chamber preheat for intermittent, continuous, and pathological combustors may be completed before the secondary chamber preheat. If so, the primary chamber burner will cycle on and off to maintain the setpoint temperature until the first charge is introduced. The primary chamber is not preheated in batch combustors.

After the first few charges during the burning phase, the primary chamber burner is typically off in intermittent and continuous combustors, as long as waste is charged regularly (although it can be significantly below the design rate). For batch combustors, the primary chamber burner fires for a preset time period (about 60 seconds) to ignite the waste; it then turns off. In pathological incinerators, the primary chamber burner cycles on and off as necessary. During the burning phase, the secondary chamber burners in all combustors cycle on and off or between high-fire and low-fire as necessary to maintain the setpoint temperature.

During burndown, burners in the primary chamber of intermittent, continuous, and pathological combustors may also cycle on and off or between high-fire and low-fire as needed to maintain setpoint temperatures. In batch combustors, the primary chamber burner remains off. The secondary chamber burner cycles in all combustors.

Fuel consumption rates during preheat were estimated by assuming the secondary chamber burners for all combustor types are on 100 percent of the time; the primary chamber burner was also assumed to be on 100 percent of the time, except in batch units, where it is off. During the burning phase (or the "low-air" phase for batch units), the secondary chamber burner was assumed to be on 50 percent of the time in all combustor types; the primary chamber burner was assumed to be on 50 percent of the time in pathological units, and it was assumed to be off in the others. During burndown (or the high-air" phase for batch models), the primary chamber burner was assumed to be on 75 percent of the time in all except batch units, where it is off. The secondary chamber burner was assumed to be on 90 percent of the time during burndown in all combustors.

3.3.3 Water

Three manufacturers indicated the water injection rates for cooling the primary chamber in intermittent and continuous combustors. The highest of the three flow rates was used in the analysis. Even so, the annual water cost is minor. Water costs were estimated to be $0.77/1,000 gallons.[61]

3.3.4 Operating Labor

Based on observation of operators at several facilities, it was estimated that, for all combustor types except batch units, operators spend about 50 percent of their time tending to the incinerator during the burning phase. For the batch model, it was assumed that operators spend about 1 hour to start the unit, add the waste, and monitor the process. For both intermittent and batch combustors, an additional 0.25 to 1 hour was allocated for ash removal, depending on the combustor size. Operator wage rates were assumed to be $12/hr--the same as the rate for MWC operators.[62]

3.3.5 Supervisory Labor

According to the OAQPS Control Cost Manual, the cost for supervisory labor is about 15 percent of the operating labor cost.[63]

3.3.6 Maintenance Labor

According to the OAQPS Control Cost Manual, maintenance labor requirements for air pollution control incinerators are about 0.5 hr/8-hr shift, and the wage rate is 10 percent higher than the operator wage rate.[64] The maintenance labor requirements were assumed to be the same for MWI's.

3.3.7 Maintenance Materials

Annual maintenance materials costs are assumed to be equal to 2 percent of the TCI.

3.3.8 Ash Disposal

Based on information from EPA-sponsored emissions tests, the weight of the ash that is removed from the combustor is 9 percent of the waste charged.[15,17] The costs to dispose of ash in a municipal waste landfill were estimated to be $40/ton in October 1989 dollars. This cost is based on an estimated cost in June 1991 of $43/ton and an assumed inflation rate of 5 percent per year.[65]

3.3.9 Refractory Replacement

Equations to estimate the annual costs for replacing the primary and secondary chamber refractory were developed from the installed refractory cost and the capital recovery factor (CRF). The installed refractory costs are a function of the volume and configuration of the chambers, the thickness of the refractory, and the unit cost to purchase and install 1 cubic foot (ft^3) material. Each of these parameters is discussed below.

Typically, the walls of the primary and secondary chambers are lined with either high-strength, castable refractory or high-heat-duty firebrick. Most manufacturers also add an insulating mineral wool block and/or ceramic fiber mat on top of the refractory; one manufacturer, however, circulates air between the primary chamber refractory, which is attached to an inner shell, and the outer shell. The refractory thickness in both chambers ranges from 3 to 6 in., depending on the manufacturer and the capacity of the combustor. Insulation thickness ranges from 1.5 to 3.0 in. For this analysis, it was assumed that the refractory and insulation thicknesses in both chambers are 4.5 and 2.0 in., respectively, for all models.

Primary and secondary chamber volumes are based on information from manufacturers, other model combustor parameters, and assumptions. The model primary chamber volumes are based on information from manufacturers of batch, intermittent, and continuous combustors. This information is shown, along with the equations that were determined by linear regression, in Figures 15 through 17. It was assumed that primary chamber volumes for pathological model combustors are similar to those for intermittent combustors because dual-purpose units are more common than hot-hearth designs. Secondary chamber volumes for all model combustors are based on the gas stream flow rate and the 1-second residence time.

The interior dimensions of the primary and secondary chambers are based on information from one manufacturer, observations of existing units, and assumptions. Typically, both chambers are enclosed in cylindrical shells. According to one manufacturer, the internal length-to-diameter (L/D) ratio is about 1.5 for horizontal primary chambers.[66] Based on observations of vertical primary chambers, the height is about 1.5 times the diameter. It was assumed that the L/D ratio is 2:1 for all secondary chambers. Although designs are unique to each manufacturer, the refractory volumes for both chambers in all of the model combustors were estimated based on the chamber volumes and this dimensional information.

Unit costs for refractory and insulation (material plus installation costs) were obtained from the OAQPS Control Cost Manual and updated from December 1977 to October 1989 costs using the CE plant cost indexes.[67,68] The resulting costs are $\$127/ft^3$

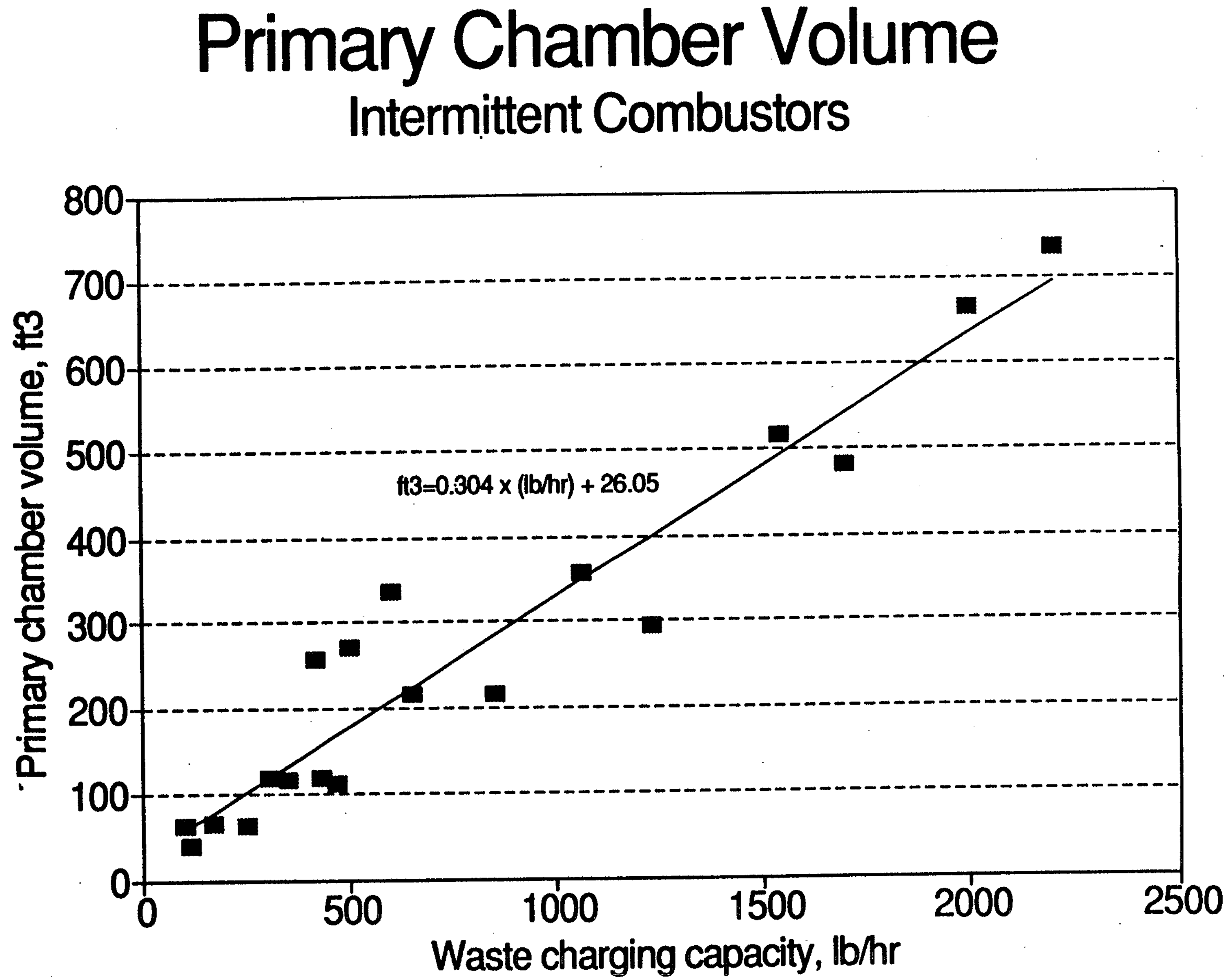

Figure 15. Primary chamber volume for intermittent combustors.

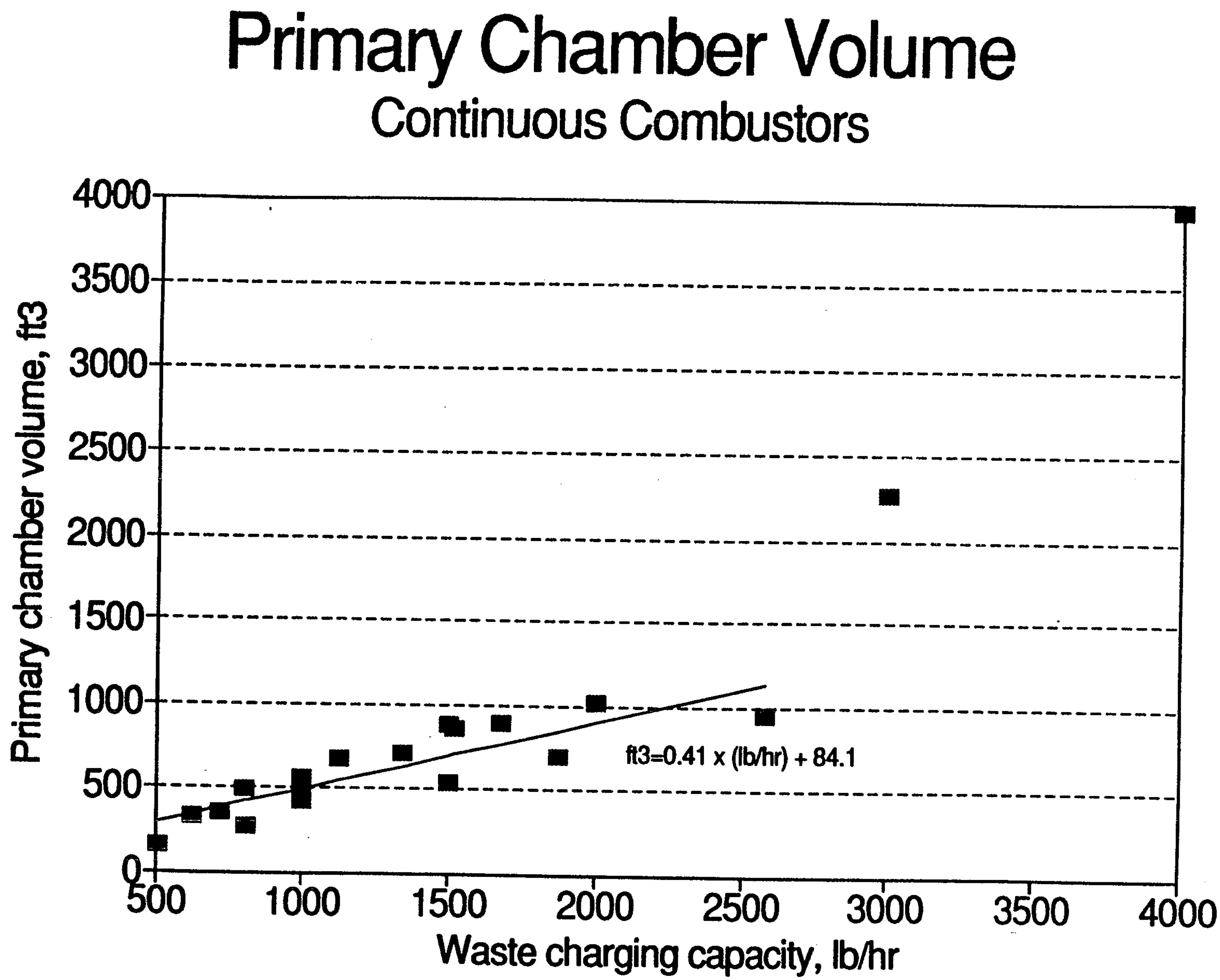

Figure 16. Primary chamber volume for continuous combustors.

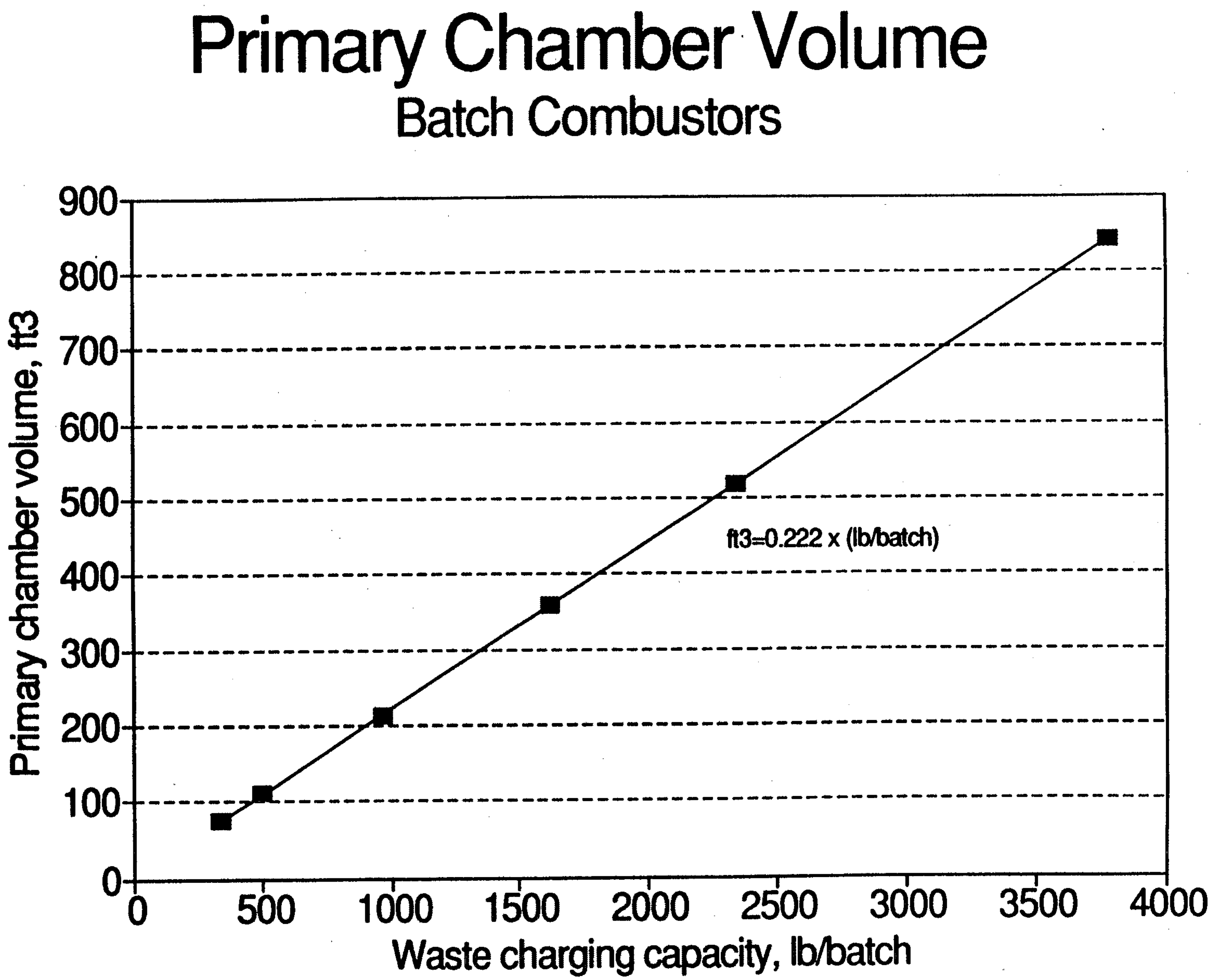

Figure 17. Primary chamber volume for batch combustors.

and $43/ft^3 for refractory and insulation, respectively. According to manufacturers, the average refractory life is about 8 years (although they indicated a range from 2 to 15+ years). The CRF based on this life and an interest rate of 10 percent is 0.18744.

3.3.10 Overhead

According to the OAQPS Control Cost Manual, overhead costs are about 60 percent of all labor and maintenance material costs.[69]

3.3.11 Property Tax, Insurance, and Administration

According to the OAQPS Control Cost Manual, annual costs for these items amount to about 4 percent of the total capital investment.[69]

3.3.12 Capital Recovery

According to MWI manufacturers, the combustor life expectancy is about 20 years. The CRF, 0.11746, was based on the life expectancy and an interest rate of 10 percent. This factor was multiplied by the TCI, minus the initial refractory cost, to estimate the capital recovery.

3.4 CONTROL TECHNOLOGY ANNUAL COSTS

This section presents annual costs for the same combustion and APCD control technologies for which capital costs were estimated in Section 3.2. Annual costs for FF-based control devices with activated carbon injection are presented in Section 3.5.

As indicated above, combustion controls are based on a larger secondary chamber with a gas residence time of 2 seconds and an operating temperature of 1800°F. Increasing the temperature increases the flow rate through the APCD because more water would need to be evaporated to cool the gas stream. The flow would also increase because additional combustion air is added with the additional natural gas. However, the impact on the flow rate is small (about 5 percent), and it was assumed that the same size APCD equipment could be used for an MWI with or without combustion controls.

3.4.1 Combustion Control Annual Costs

The additional capital cost for the larger secondary chamber results in additional maintenance, overhead, property tax, insurance, administration, and capital recovery costs. These costs were calculated by the same procedures described in Section 3.3. Refractory replacement costs are also higher, and they were calculated by the same procedure described in Section 3.3.9, except with twice the chamber volume.

Annual fuel costs were estimated for two additional auxiliary fuel requirements. First, additional fuel is required to maintain 1800°F rather than 1700°F in the secondary chamber. Second, additional fuel is needed to maintain the temperature at 1800°F for an average of 2 hours during cooldown in intermittent models and for 10 hours in batch models.

The resulting combustion control annual costs for each of the model combustors are presented in Table 15. A copy of the combustion control cost algorithm is presented in Appendix B.

3.4.2 Wet Control Device Annual Costs

Direct and indirect annual costs were estimated for wet control devices as applied to all of the model combustors. Direct annual operating costs were estimated for electricity for the fan and scrubber water pump (the items that consume nearly all of the electricity required by the system, according to two vendors), makeup scrubber water, operating and supervisory labor, maintenance labor and materials, caustic, and sewage disposal. Indirect annual costs were estimated for overhead, property tax, insurance, administrative charges, and capital recovery.

The equations used to estimate many of the annual costs are functions of the gas flow rate into the control system. In addition, each of the direct costs and the overhead cost are functions of the annual hours of operation. The annual costs for all control devices are based on the operating hours for each model combustor as described in Tables 6 through 8. The basis for each cost is described below. The operating parameters for the VS/PB control device were used as the starting point for VS and PB control device operating parameters and annual costs. The

TABLE 15. COMBUSTION CONTROL ANNUAL COSTS FOR NEW MWI'S

Parameters\model combustors	Continuous models		Intermittent models			Batch model	Pathological model
	1	2	3	4	5	6	7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm (a)	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr (b)	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. 2-second SC parameters							
(1) Sec. chamber volume, ft3 (c)	753	502	753	301	100	72	116
(2) Sec. chamber diameter, ft	7.8	6.8	7.8	5.8	4.0	3.6	4.2
(3) Sec. chamber length, ft	15.7	13.7	15.7	11.5	8.0	7.2	8.4
e. 1-second SC parameters							
(1) Sec. chamber volume, ft3 (c)	376	251	376	151	50.2	36	58
(2) Sec. chamber diameter, ft	6.2	5.4	6.2	4.6	3.2	2.8	3.3
(3) Sec. chamber length, ft	12.4	10.9	12.4	9.2	6.3	5.7	6.7
2. Total capital investment for combustion controls, $ (d)	64,283	47,084	64,283	33,320	19,556	17,620	20,610
3. Combustion control direct annual costs, $/yr							
a. Refractory replacement	1,876	1,438	1,876	1,028	502	405	551
b. Auxiliary fuel (e)	20,413	6,521	20,985	8,394	2,579	3,247	1,260
c. Maintenance materials	1,286	942	1,286	666	391	352	412
4. Combustion control indirect annual costs, $/yr							
a. Overhead	771	565	771	400	235	211	247
b. Property tax, insurance, and administrative	2,571	1,883	2,571	1,333	782	705	824
c. Capital recovery (f)	6,375	4,630	6,375	3,269	1,982	1,816	2,076
5. Total annual combustion control costs, $/yr	33,292	15,979	33,865	15,091	6,471	6,737	5,370

(a) The flow rate was assumed to be the same for both the 2-second and the 1-second combustors.
(b) The operating hours are based on the preheat, burning, burndown, and cooldown hours shown in Tables 6 through 8.
(c) The design temperature was assumed to be 1800 F for both the 2-second and 1-second SC's.
(d) The TCI is the difference between the capital costs for 2-second and 1-second SC's (see Table 21).
(e) Auxiliary fuel includes both the cost for additional fuel to raise the secondary chamber temperature form 1700F to 1800F and the cost of fuel to maintain 1800 F in the secondary chamber during cooldown until the combustion air blowers are turned off.
(f) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

formulas developed to calculate the annual costs for each wet control device are shown in Tables 16 to 18. Tables 19 through 21 present the APCD annual costs for each wet control device as applied to each model combustor. A copy of the algorithm showing the calculations and resulting equations for the VS/PB control device is presented in Appendix C.

3.4.2.1 Venturi Scrubber/Packed Bed. As indicated in Table 9, the typical pressure drop is 30 in. w.c. through the venturi throat and 4 in. w.c. through the PB. It was assumed that the pressure drop through the rest of the system is 4 in. w.c.

3.4.2.1.1 Fan electricity. The annual electricity cost for the fan is a function of the fan hp and the unit electricity cost. The fan hp values used in the algorithm were determined by the same method used to develop the capital costs (i.e., the hp requirements reported by the vendors were plotted versus the gas flow rate in dscfm, and the equation for the line through the averages was determined using linear regression).[28,29,31,45] Figure 18 presents the reported data and the line determined by linear regression. A unit cost of $0.06/kWh was provided by three vendors.[28,32,33]

3.4.2.1.2 Pump electricity. The annual electricity cost for the scrubber water pump was estimated by the same procedure as that described above for the fan electricity. Figure 19 presents the pump hp values reported by one vendor versus the gas flow rate.[28] Also shown is the equation developed by linear regression for the line through the data. The vendors use from one to three pumps to circulate liquid. The algorithm is based on only one pump because the highest horsepower ratings were reported by the vendor that uses only one pump.

3.4.2.1.3 Scrubber makeup water. The makeup water costs are a function of the makeup flow rates and the unit cost for water. The makeup water requirements were estimated by the same procedure as that described above for the electricity requirements. Figure 20 presents the reported makeup rates versus the gas flow rates in dscfm and the line determined by

TABLE 16. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR VS/PB CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	33.3*dscfm+118969
2. Direct annual costs, $/yr	
a. Electricity	(0.001037*dscfm+0.2038)*(hr/yr)
b. Scrubber water	(0.000237*dscfm)*(hr/yr)
c. Operating, supervisory, and maintenance labor	1.185*(hr/yr)
d. Maintenance materials	0.6660*dscfm+2379
e. Caustic	(0.00000125*ppm HCl)*(hr/yr)*(dscfm)
f. Sewer charge	(0.0000896*dscfm)*(hr/yr)
3. Indirect annual costs, $/yr	
a. Overhead	0.7110*(hr/yr)+0.3996*dscfm+1428
b. Property tax, insurance, and administrative	1.332*dscfm+4759
c. Capital recovery (a)	3.9114*dscfm+13974
4. Total annual cost, $/yr	([0.00000125*ppm HCl+0.001363]*dscfm +2.0998)*(hr/yr)+(6.3090*dscfm)+22540

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 17. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR VS CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	30.4*dscfm+100110
2. Direct annual costs, $/yr	
a. Electricity	(0.000880*dscfm+0.0917)*(hr/yr)
b. Scrubber water	0.000237*(dscfm)*(hr/yr)
c. Operating, supervisory, and maintenance labor	1.185*(hr/yr)
d. Maintenance materials	0.6080*dscfm+2002
e. Caustic	(0.00000125*ppm HCl)*(hr/yr)*(dscfm)
f. Sewer charge	0.000090*(dscfm)*(hr/yr)
3. Indirect annual costs, $/yr	
a. Overhead	0.7110*(hr/yr)+0.3648*dscfm+1201
b. Property tax, insurance, administrative	1.216*dscfm+4004
c. Capital recovery (a)	3.5708*dscfm+11759
4. Total annual cost, $/yr	([0.00000125*ppm HCl+0.001206]*(dscfm) +1.9877)*(hr/yr)+(5.7596*dscfm)+18967

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 18. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR PB CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	27.6*dscfm+109603
2. Direct annual costs, $/yr	
a. Electricity	(0.000276*dscfm+0.1427)*(hr/yr)
b. Scrubber water	(0.000237*dscfm)*(hr/yr)
c. Operating, supervisory, and maintenance labor	1.185*(hr/yr)
d. Maintenance materials	0.5520*dscfm+2192
e. Caustic	(0.00000125*ppm HCl)*(dscfm)*(hr/yr)
f. Sewer charge	(0.0000896*dscfm)*(hr/yr)
3. Indirect annual costs, $/yr	
a. Overhead	0.7110*(hr/yr)+0.3312*dscfm+1315
b. Property tax, insurance, and administrative	1.104*dscfm+4384
c. Capital recovery (a)	3.2419*dscfm+12874
4. Total annual cost, $/yr	([0.00000125*ppm HCl+0.000603]*dscfm +2.0387)*(hr/yr)+(5.2291*dscfm)+20765

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 19. VS/PB ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control system, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. HCl concentration, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	277,044	224,364	277,044	182,206	140,048	134,121	143,278
3. Direct annual costs, $/yr							
a. Electricity	39,867	12,990	22,394	9,493	3,221	2,433	2,998
b. Scrubber water	8,731	2,790	4,905	1,962	561	387	539
c. Operating, supervisory, and maintenance labor	9,215	4,415	5,176	5,176	4,437	4,266	3,697
d. Maintenance materials	5,541	4,487	5,541	3,644	2,801	2,682	2,866
e. Caustic	33,595	10,733	18,871	7,549	2,157	204	170
f. Sewer charge	3,309	1,057	1,859	744	212	147	204
4. Indirect annual costs, $/yr							
a. Overhead	8,853	5,342	6,430	5,292	4,343	4,169	3,938
b. Property tax, insurance, and administrative	11,082	8,975	11,082	7,288	5,602	5,365	5,731
c. Capital recovery (a)	32,542	26,354	32,542	21,402	16,450	15,754	16,829
5. Total annual cost, $/yr	152,734	77,142	108,800	62,550	39,783	35,407	36,972

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE 20. VS ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models		Intermittent models			Batch model	Pathological model
	1	2	3	4	5	6	7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control system, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. HCl concentration, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	244,419	196,326	244,419	157,840	119,353	113,942	122,302
3. Direct annual costs, $/yr							
a. Electricity	33,182	10,715	18,639	7,697	2,428	1,771	2,290
b. Scrubber water	8,731	2,790	4,905	1,962	561	387	539
c. Operating, supervisory, and maintenance labor	9,215	4,415	5,176	5,176	4,437	4,266	3,697
d. Maintenance materials	4,888	3,927	4,888	3,157	2,387	2,279	2,446
e. Caustic	33,595	10,733	18,871	7,549	2,157	204	170
f. Sewer charge	3,309	1,057	1,859	744	212	147	204
4. Indirect annual costs, $/yr							
a. Overhead	8,462	5,005	6,039	5,000	4,094	3,927	3,686
b. Property tax, insurance, and administrative	9,777	7,853	9,777	6,314	4,774	4,558	4,892
c. Capital recovery (a)	28,709	23,060	28,709	18,540	14,019	13,384	14,366
5. Total annual cost, $/yr	139,868	69,555	98,863	56,138	35,069	30,923	32,290

(c) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE 21. PB ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models		Intermittent models			Batch model	Pathological model
	1	2	3	4	5	6	7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control system, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. HCl concentration, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	240,620	196,957	240,620	162,015	127,074	122,161	129,751
3. Direct annual costs, $/yr							
a. Electricity	11,310	3,791	6,353	2,916	1,189	966	1,075
b. Scrubber water	8,731	2,790	4,905	1,962	561	387	539
c. Operating, supervisory, and maintenance labor	9,215	4,415	5,176	5,176	4,437	4,266	3,697
d. Maintenance materials	4,812	3,939	4,812	3,240	2,541	2,443	2,595
e. Caustic	33,595	10,733	18,871	7,549	2,157	204	170
f. Sewer charge	3,309	1,057	1,859	744	212	147	204
4. Indirect annual costs, $/yr							
a. Overhead	8,416	5,013	5,993	5,050	4,187	4,026	3,775
b. Property tax, insurance, and administrative	9,625	7,878	9,625	6,481	5,083	4,886	5,190
c. Capital recovery (a)	28,263	23,135	28,263	19,030	14,926	14,349	15,241
5. Total annual cost, $/yr	117,277	62,750	85,858	52,148	35,293	31,675	32,486

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

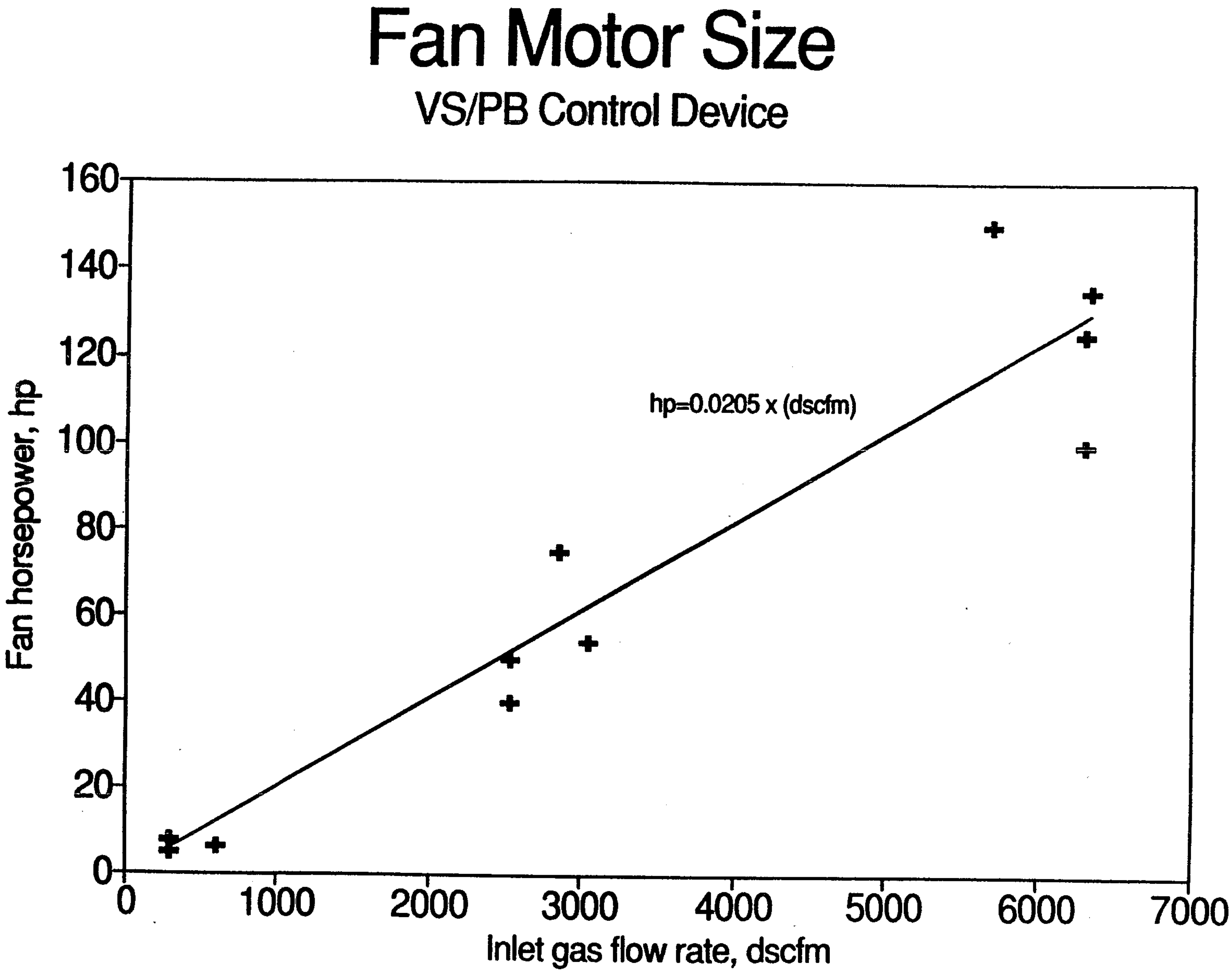

Figure 18. Fan motor size for VS/PB control device.

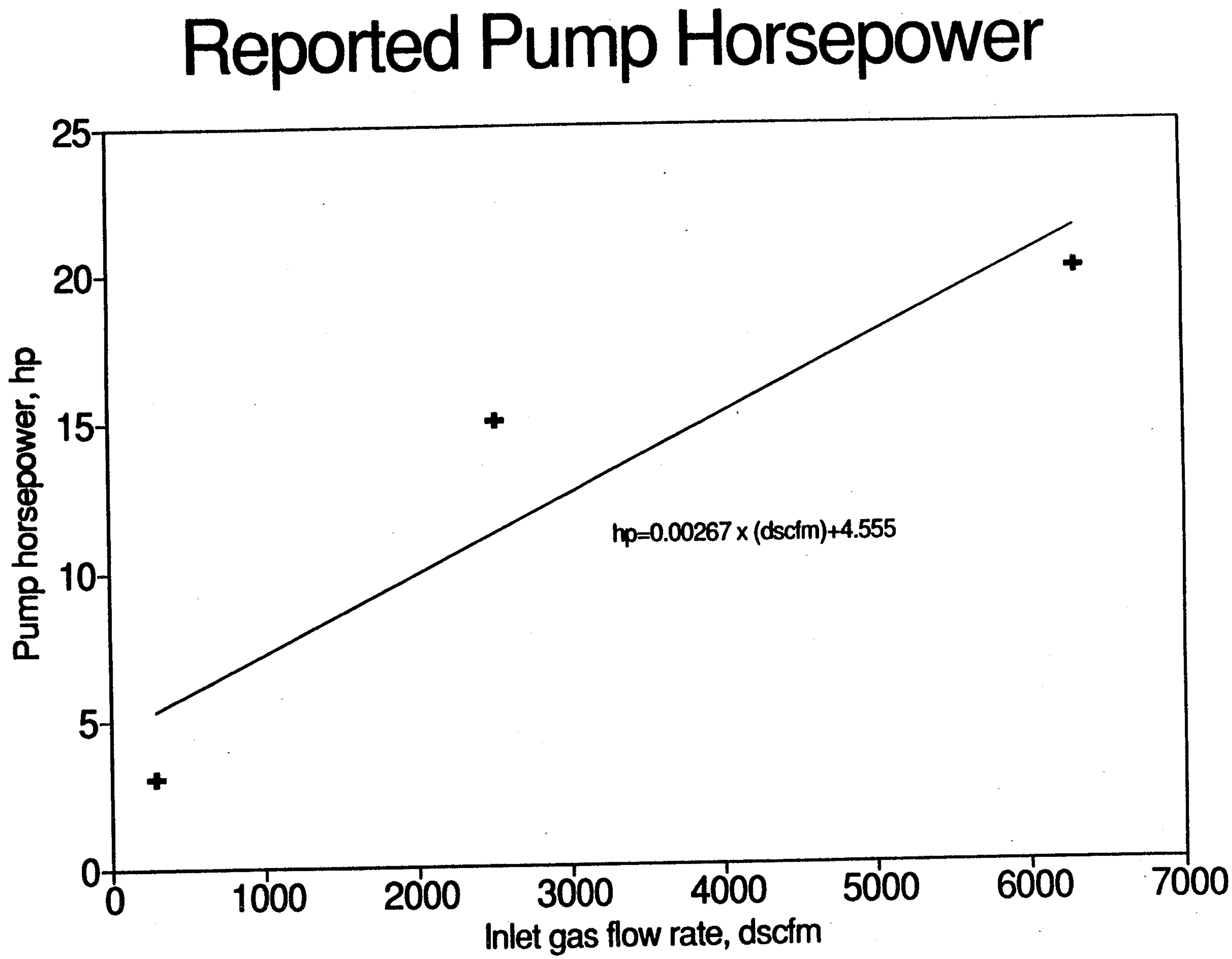

Figure 19. Pump horsepower for VS/PB control device.

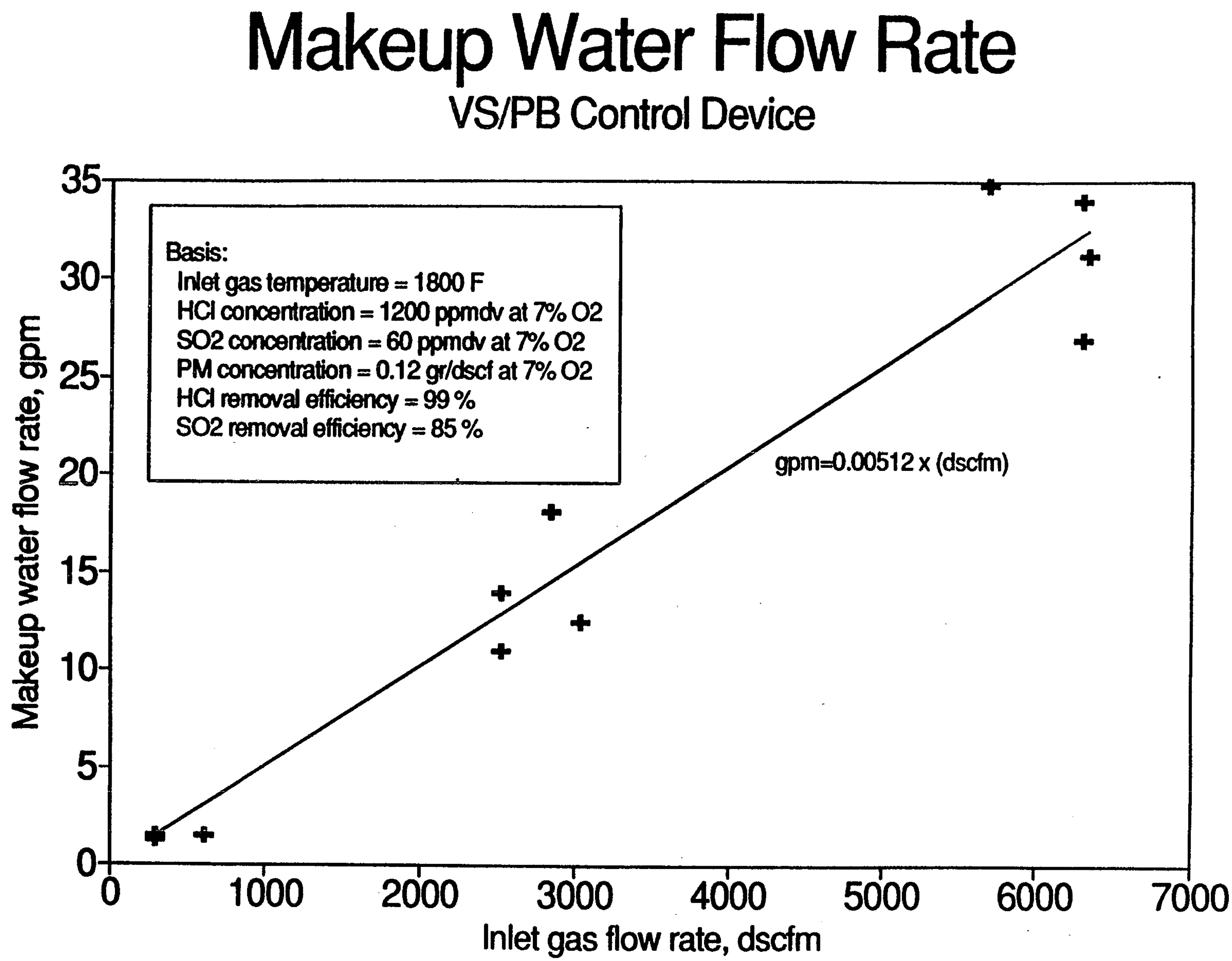

Figure 20. Makeup water flow rate for VS/PB control device.

least-squares linear regression through the averages of the reported values. The reported makeup rates were based on the amount of water needed to replenish losses due to evaporation in the quench and to replace blowdown losses. The evaporation rates are for cooling the exhaust gas (10 percent moisture and 1800°F) to saturation. Blowdown rates are presented in Section 3.4.2.1.9. Based on a 1989 estimate from the American Water Works Association, water was assumed to cost \$0.77/1,000 gal.[61]

3.4.2.1.4 Operating labor. Vendors estimated that average operating labor rates are about 0.4 hr/8-hr shift. A labor wage rate of \$12/hr was used to be consistent with the rate for incinerator operators.

3.4.2.1.5 Supervisory labor. According to the OAQPS Control Cost Manual procedures, the supervisory labor is estimated as 15 percent of the operating labor.[63]

3.4.2.1.6 Maintenance labor. Vendors estimated that maintenance labor requirements would be about 0.3 hr/8-hr shift. The wage rate was assumed to be 10 percent higher than the operating labor wage rate based on the OAQPS Control Cost Manual procedures.[64]

3.4.2.1.7 Maintenance materials. The annual maintenance materials costs were estimated by two vendors to be about 2 percent of the TCI.[28,29] The algorithm uses this approach rather than the OAQPS procedure, which is to equate the materials cost with the maintenance labor cost, because the OAQPS procedure estimates a very low cost considering the size and cost of the control systems.

3.4.2.1.8 Caustic. The sodium hydroxide (NaOH) costs are a function of the exhaust gas flow rate, the uncontrolled concentrations of acid gases, the NaOH-to-acid gases molar ratio, and the dry NaOH unit cost. Hydrogen chloride is the only acid gas evaluated in this analysis because EPA-sponsored emissions test of MWI's showed VS/PB devices did not reduce the low concentrations of SO_2. Uncontrolled HCl concentrations range from 120 ppm at 7 percent O_2 to 1,460 ppm at 7 percent O_2, depending on the type of waste burned and the combustor design. As indicated in Section 2.2, only enough NaOH is added to keep the pH at or just below 7.0. Therefore, the NaOH-to-HCl molar ratio is essentially 1:1. Caustic costs of $400/ton and $375/ton were provided by two vendors.[28,29] The higher unit cost was used in the algorithm.

3.4.2.1.9 <u>Sewage disposal</u>. The sewage disposal costs are a function of the blowdown rate and the unit cost for disposal. The blowdown rates used in the algorithm were developed by the same procedure used to estimate fan hp requirements. Figure 21 presents the reported data as well as the line determined by least-squares linear regression through the average of the reported values. Vendors estimated blowdown rates based on the acid gases concentrations that were provided in the EPA information requests (1,200 ppm HCl and 60 ppm SO_2 at 7 percent O_2) and on their guaranteed removal efficiencies. Differences in blowdown rates that may result from different uncontrolled acid gases concentrations or removal efficiencies were neglected in this analysis because they have only a small impact on the cost. One vendor estimated that sewage disposal costs are about $2/1,000 gal.[28]

3.4.2.1.10 <u>Overhead</u>. According to OAQPS procedures, overhead is estimated as 60 percent of the operating, supervisory, and maintenance labor and the maintenance materials.[69]

3.4.2.1.11 <u>Property tax, insurance, and administrative</u>. According to OAQPS procedures, these costs are estimated as 4 percent of the TCI.[69]

3.4.2.1.12 <u>Capital recovery</u>. According to the vendors, the equipment life expectancy is between 15 and 20 years. The CRF, 0.11746, was based on a 20-year life expectancy and an interest rate of 10 percent. This factor was multiplied by the TCI to estimate the capital recovery.

3.4.2.2 <u>Venturi Scrubber</u>. The fan hp requirements and electricity costs are 10 percent lower for this control device than for the VS/PB control device described above

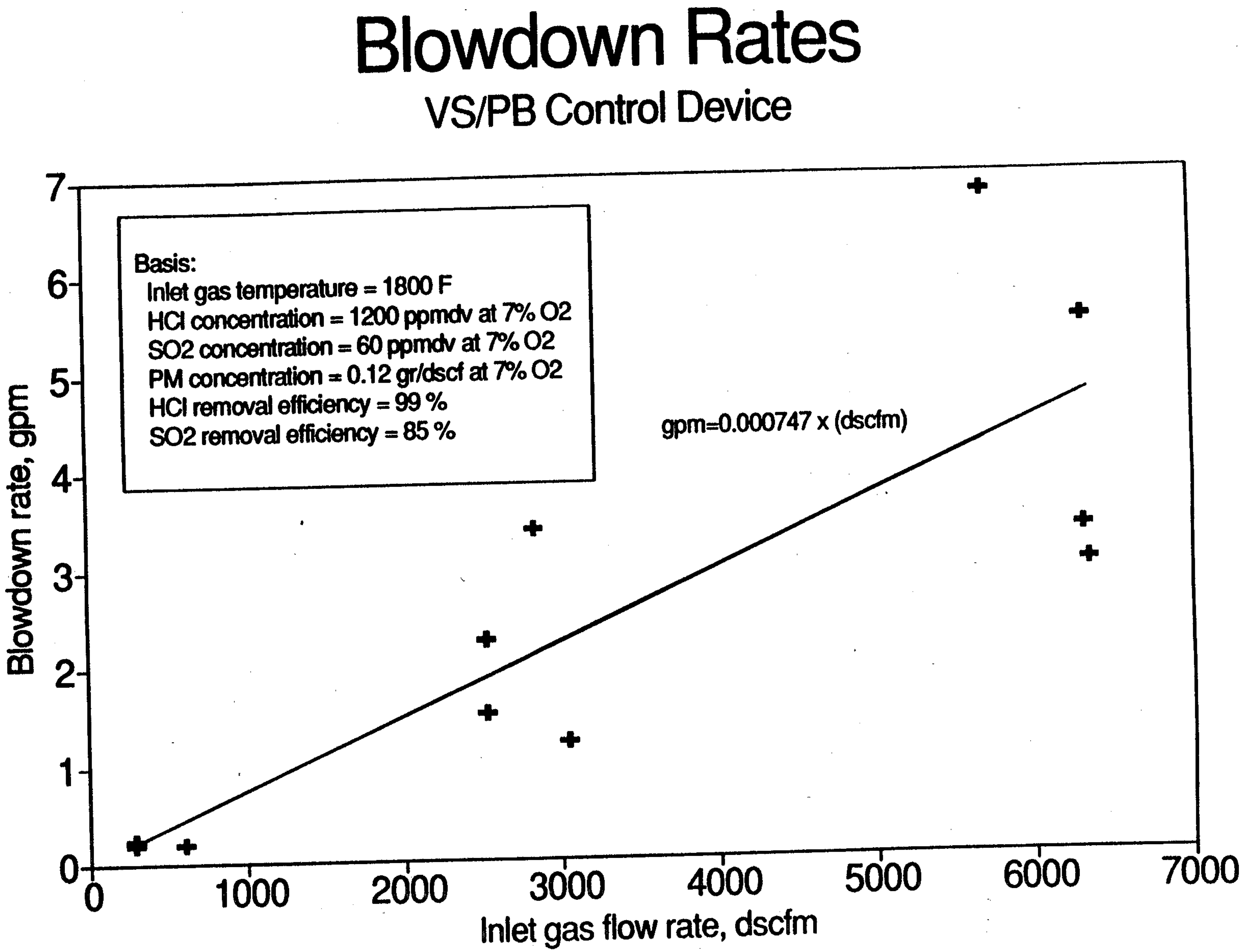

Figure 21. Blowdown rates for VS/PB control device.

(Section 3.4.2.1) because removal of the absorber reduces the system pressure drop by about 10 percent. The pump hp and electricity cost are 55 percent lower because three vendors indicated that about 55 percent of the total liquid flow is to the absorber in VS/PB control devices.[28,29,31] Maintenance materials and indirect costs are lower than those for the VS/PB control device because the capital costs are lower. Other annual costs are the same as those for the VS/PB control device. The annual cost equations are presented in Table 17, and the costs as applied to the model combustors are shown in Table 20.

3.4.2.3 Packed Bed. Removing the VS from the VS/PB control device reduces the system pressure drop and, thus, the fan hp and electricity cost by about 80 percent. The pump hp and electricity cost for this control device are 30 percent lower than those for the VS/PB device. This reduction is based on information from two vendors that 30 percent of the liquid flow in the VS/PB control device is to the venturi.[29,31] Maintenance materials and indirect costs are lower because the capital cost is lower than that for the VS/PB control device. Other annual cost components are the same as those for the VS/PB device. The annual cost equations are shown in Table 18, and the costs as applied to the model combustors are shown in Table 21.

3.4.3 Annual Costs for Control Devices with an FF

Direct and indirect annual costs were estimated for DI/FF, FF, FF/PB and SD/FF control devices for all of the model combustors. It was assumed that the DI/FF and FF control devices have an evaporative cooler to reduce the combustor exhaust gas to 300°F; the spray dryer also reduces the gas temperature to 300°F. It was also assumed that all four control devices have an FF with a G/C ratio of 3.5.

3.4.3.1 Dry Injection/Fabric Filter. Direct annual costs were estimated for electricity, makeup lime, evaporative cooler water, operating and supervisory labor, maintenance labor and materials, compressed air for the FF, dust disposal, bag replacement, and cage replacement. Indirect annual costs were estimated for overhead, property tax, insurance, administrative charges, and capital recovery. Information about many of the operating parameters was obtained from vendors; other parameters were estimated. The basis for each cost is described in the subsections below. The formulas developed to calculate the annual costs are shown in Table 22. Most of the equations are a function of the gas flow rate into the control device and many are also related to the annual hours of operation. Table 23 presents the annual costs for each model combustor. A copy of the algorithm showing the calculations and resulting equations for the DI/FF control device is presented in Appendix D.

3.4.3.1.1 Electricity. The annual fan electricity cost is a function of the fan hp, the unit electricity cost, and the annual hours of operation. The fan hp values used in the algorithm were determined by the same method used to develop the capital costs (i.e., the hp requirements reported by the vendors were plotted versus the gas flow rate, and the equation for the line through the data was determined using least-squares linear regression).[32,33,35] Figure 22 summarizes the data. A unit cost of $0.06/kWh was provided by three vendors.[28,32,33] Because two vendors indicated that other electrical components consume, on average, 22 percent as much electricity as the I.D. fan, the fan electricity demand was multiplied by a factor of 1.22 to estimate the total electricity demand.[46,49]

3.4.3.1.2 Makeup lime. Makeup lime rates were based on a lime-to-acid gases SR of 2.5:1 (see Section 2.2.2.5). For this analysis, HCl is the only acid gas evaluated because EPA-sponsored emissions tests of an MWI with a DI/FF control device showed no control of the low uncontrolled SO_2 emissions.[38] Dry lime costs of $100/ton and $90/ton were obtained from two vendors.[32,33] The higher unit cost was used in the algorithm.

3.4.3.1.3 Evaporative cooler water. The amount of water added in the evaporative cooler was estimated by subtracting the amount of moisture in the gas stream entering the control device from that in the gas entering the FF. The inlet gas stream flow rates that were provided to the vendors in information requests were assumed to be 10 percent moisture. According to the vendors

TABLE 22. EQUATIONS USED TO ESTIMATE ANNUAL COSTS FOR DI/FF CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	63.8*dscfm+407498
2. Direct annual costs, $/yr	
a. Electricity	(0.000355*dscfm+0.1573)*(hr/yr)
b. Makeup lime	(0.000000720*ppm HCl)*(dscfm)*(hr/yr)
c. Water	(0.000126*dscfm+0.0289)*(hr/yr)
d. Operating, supervisory, and maintenance labor	2.55*(hr/yr)
e. Maintenance materials	1.276*dscfm+8150
f. Compressor air	(0.000043*dscfm+0.00812)*(hr/yr)
g. Dust disposal	(0.00017*PM+0.000000343*HCl)*(dscfm)*(hr/yr)
h. Bag replacement	1.0418*dscfm+195
i. Cage replacement	0.12075*dscfm+22.6
3. Indirect annual costs, $/yr	
a. Overhead	(1.530*hr/yr)+0.7656*dscfm+4890
b. Property tax, insurance, and administrative	2.552*dscfm+16300
c. Capital recovery (a)	7.237*dscfm+47817
4. Total annual cost, $/yr	([0.000171*PM+0.00000106*HCl+0.000524]*dscfm+4.2743)*(hr/yr)+(12.993*dscfm)+77374

(a) CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 23. DI/FF ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models 1	Continuous models 2	Intermittent models 3	Intermittent models 4	Intermittent models 5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. Inlet PM, gr/dscf at 14% O2	0.08	0.08	0.08	0.08	0.08	0.022	0.012
e. Outlet PM, gr/dscf at 14% O2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
f. Inlet HCl, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total APCD capital investment, $	710,357	609,425	710,357	528,654	447,883	436,527	454,072
3. Direct annual costs, $/yr							
a. Electricity	14,325	4,772	8,047	3,631	1,430	1,148	1,299
b. Makeup lime	19,401	6,198	10,898	4,360	1,246	118	98
c. Water	4,866	1,590	2,733	1,169	406	310	377
d. Operating, supervisory, and maintenance labor	19,829	9,501	11,138	11,138	9,547	9,180	7,956
e. Maintenance materials	14,207	12,189	14,207	10,573	8,958	8,731	9,081
f. Compressor air	1,665	542	935	395	133	100	124
g. Dust disposal	9,711	3,103	5,455	2,182	624	61	50
h. Bag replacement	5,140	3,492	5,140	2,173	854	669	955
i. Cage replacement	596	405	596	252	99	78	111
4. Indirect annual costs, $/yr							
a. Overhead	20,422	13,014	15,207	13,027	11,103	10,746	10,222
b. Property tax, insurance, and administrative	28,414	24,377	28,414	21,146	17,915	17,461	18,163
c. Capital recovery (a)	82,169	70,720	82,169	61,559	52,397	51,109	53,099
5. Total annual cost, $/yr	220,745	149,903	184,940	131,606	104,713	99,710	101,536

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

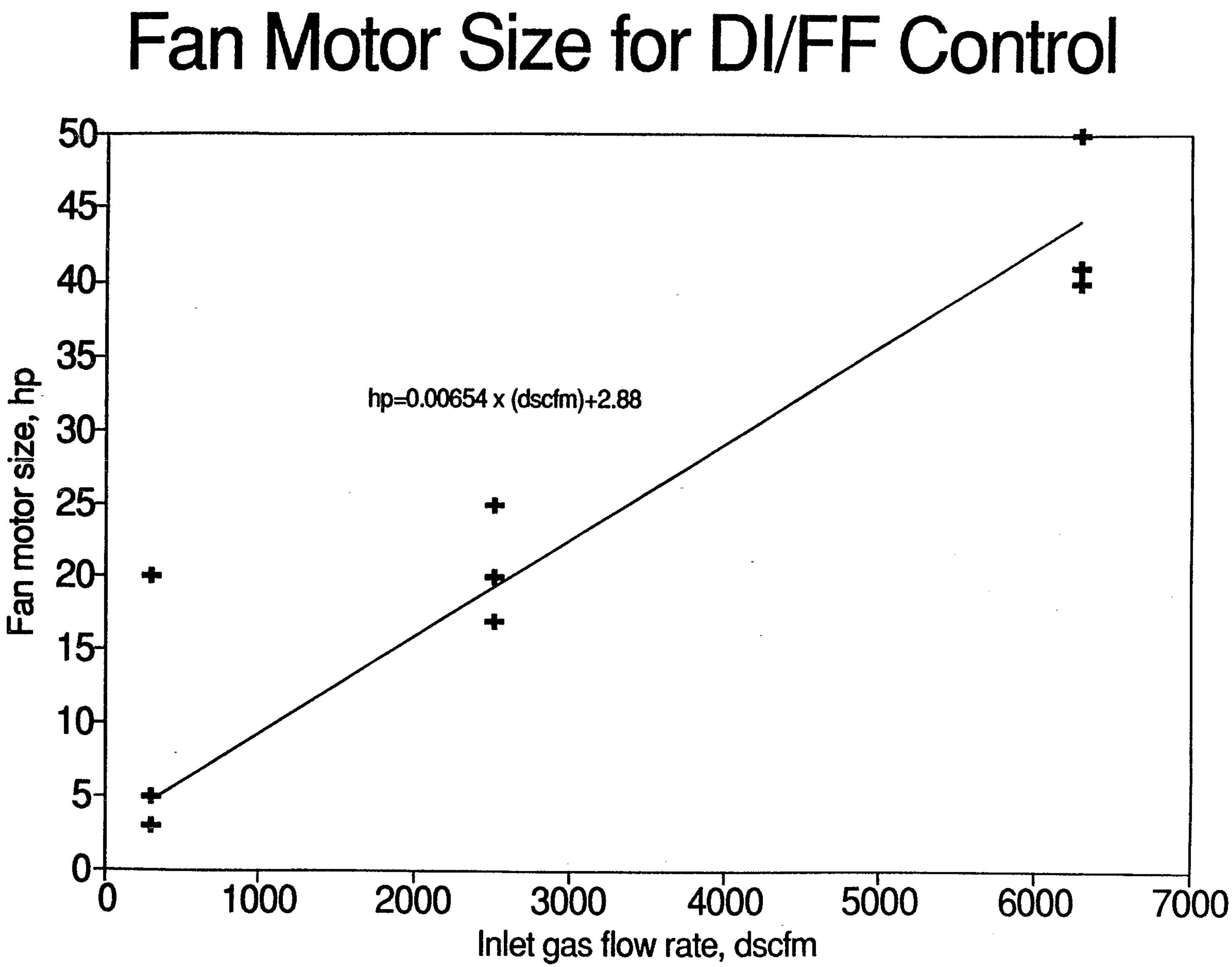

Figure 22. Fan motor size for DI/FF control device.

that use evaporative coolers, the average moisture content of the gas entering the FF was 38 percent, and the average temperature was 300°F.[33-35] The gas flow rates reported by all of the vendors were used to estimate the average gas flow rate in the FF by the same procedure described above to estimate the fan hp. Figure 23 summarizes the reported gas flow rates and presents the least-squares linear regression line through the averages. Based on a January 1989 estimate from the American Water Works Association, water was assumed to cost $0.77/1,000 gallons.[61]

3.4.3.1.4 Operating labor. Vendors estimated that operating labor requirements would be about 1 hr/8-hr shift. A labor wage rate of $12/hr was used based on information from one vendor and to be consistent with the incinerator operator wage rate.[33]

3.4.3.1.5 Supervisory labor. According to the OAQPS Control Cost Manual procedures, this cost is 15 percent of the operating labor cost.[63]

3.4.3.1.6 Maintenance labor. Vendors estimated that maintenance labor requirements would be about 0.5 hr/8-hr shift. The wage rate was estimated to be 10 percent higher than the operator's wage based on the OAQPS Control Cost Manual procedures.[64]

3.4.3.1.7 Maintenance materials. According to one DI/FF vendor (as well as two VS/PB vendors) this cost is about 2 percent of the total capital investment. The algorithm uses this approach rather than the OAQPS Control Cost Manual procedure, which is to equate the materials cost with the maintenance labor cost, because the OAQPS procedure estimates a very low cost considering the size and cost of the control systems.

3.4.3.1.8 Compressed air. The amount and cost of compressed air were both estimated based on OAQPS procedures. These procedures specify 2 ft^3 of compressed air per 1,000 ft^3 of filtered air and a cost of $0.16/1,000 ft^3 of compressed air.[70] The August 1986 costs were adjusted to October 1989 costs using the Chemical Engineering (CE) plant cost indexes.[67,71]

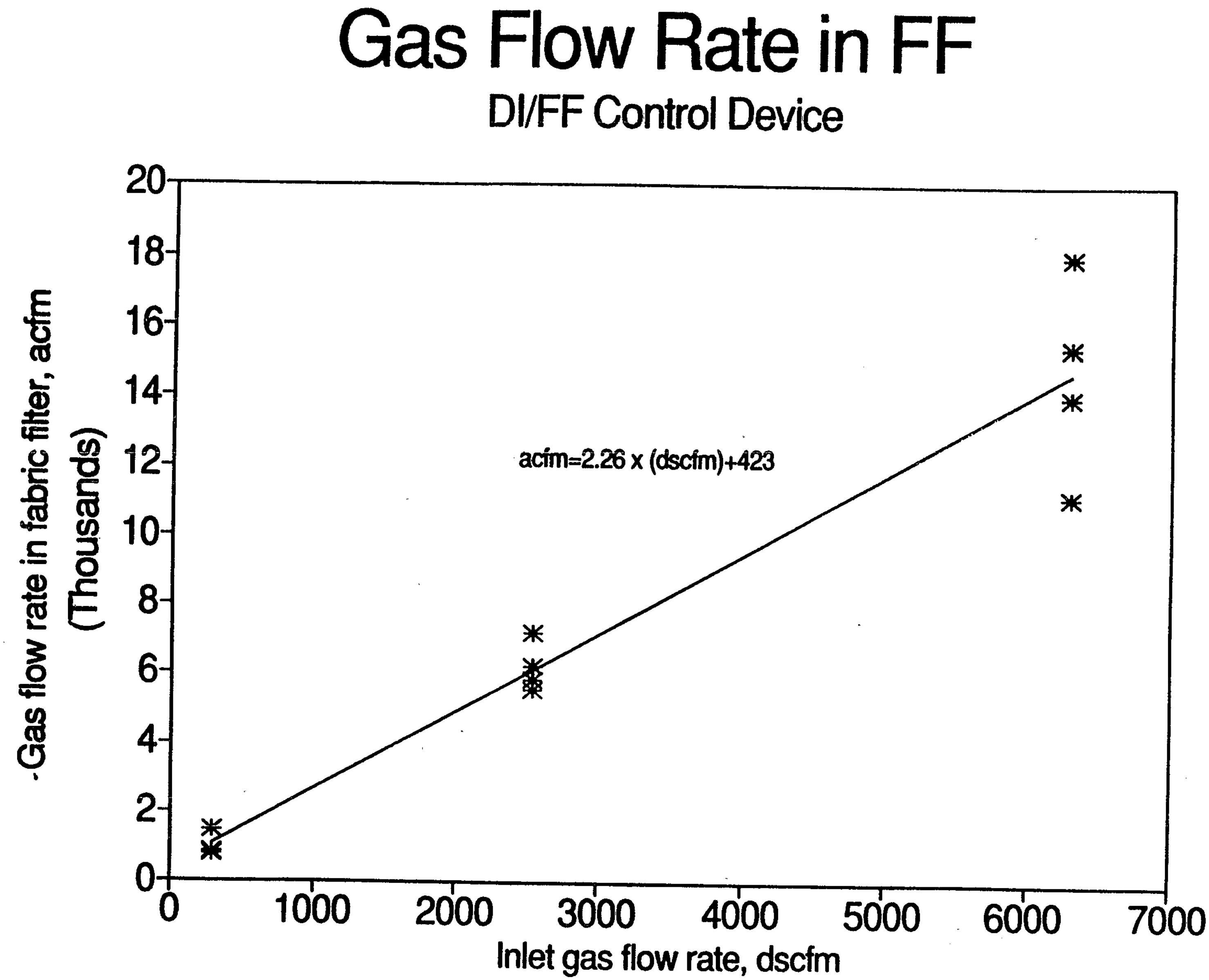

Figure 23. Gas flow rate in DI/FF control device.

3.4.3.1.9 Dust disposal. The cost of dust disposal is a function of the amount of material captured and the unit cost for disposal. The quantity of material captured by the FF's for each of the model combustor gas streams was estimated based on estimated inlet and outlet PM loadings, uncontrolled HCl concentrations and removal efficiency, and the amount of unreacted lime. Based on test data, the uncontrolled PM loadings range from 0.024 to 0.16 grain (gr)/dscf at 7 percent O_2, depending on the combustor design; control device outlet levels are 0.01 gr/dscf for all model combustors. Test data also showed the inlet HCl concentrations range from 120 ppm to 1,460 ppm at 7 percent O_2, depending on the type of waste burned and the combustor design.[72] The HCl removal efficiency is assumed to be 95 percent for all model combustors. Based on this removal efficiency and an SR of 2.5:1, about 62 percent of the makeup lime is unreacted.

The dust disposal cost was estimated assuming disposal at a municipal waste landfill because this is the method used by most facilities with DI/FF control devices. Typically, these facilities mix the fly ash/lime with incinerator bottom ash, either in a dumpster or by feeding the captured material back into the incinerator.[73-76] This mixture tests as nonhazardous waste under the Resource Conservation and Recovery Act's Toxicity Characteristic Leaching Procedure (TCLP) test. The unit disposal cost was assumed to be $40/ton, as noted above for bottom ash disposal costs.

A few facilities, primarily those from one commercial disposal firm, dispose of the fly ash/lime in a hazardous waste landfill because lead causes the material to test as hazardous waste under the TCLP test.[37,77]

3.4.3.1.10 Bag replacement. An equation to estimate the bag replacement costs was based on the CRF; the initial bag cost, including taxes and freight; and the bag replacement labor. The CRF is 0.5762, assuming an annual interest rate of 10 percent and a 2-year bag life, the average life reported by the vendors. The initial bag costs were based on estimates of the total fabric area, the taxes and freight adjustment factor, and the unit cost for the bag material. To estimate the total fabric area, the equation for the average flow rate in the FF (as determined in Section 3.4.3.1.3) was divided by the average G/C ratio (3.5:1). Taxes and freight were assumed to be equal to 8 percent of the bag cost. According to the vendors, the average cost for material that can achieve an emission level of 0.015 gr/dscf at 7 percent O_2 is about $\$2.5/ft^2$.[32,34,35,46,49,50,55]

Labor requirements were based on the number of bags, the time to replace each bag, and the wage rate. The number of bags was estimated by dividing the total FF area by the average bag area--18 ft^2 according to the vendors--and the G/C ratio. According to OAQPS procedures, the time to replace each bag is about 0.15 hr.[63] The labor wage rate was assumed to be the same as the operator wage rate ($12/hr).

3.4.3.1.11 Cage replacement. An equation to estimate the cage replacement costs was developed from the number of cages, the individual cage cost, the replacement labor requirements, and the CRF. The number of cages is equivalent to the number of bags estimated above. Individual cage costs in August 1986 dollars were estimated based on OAQPS procedures, except that the cost for 100 count lots was used for all systems.[63] This was done to simplify the analysis and because it has only a very small impact on the cost. The individual cage costs were adjusted to October 1989 costs using the CE plant cost indexes.[67,71] Because it was assumed that the time to replace the cages is equivalent to the time to replace the bags, the replacement labor costs are equivalent. The CRF is 0.3156, assuming an interest rate of 10 percent and a replacement frequency of 4 years. It was assumed that the cages would be replaced every 4 years because one vendor estimated that cages would need to be replaced (due to corrosion) every other time the bags are replaced.[75]

3.4.3.1.12 Overhead. According to the OAQPS Control Cost Manual, overhead is estimated as 60 percent of the operating, supervisory, and maintenance labor and the maintenance materials.[69]

3.4.3.1.13 Property tax, insurance, and administrative. These costs were estimated as 4 percent of the TCI based on the OAQPS Control Cost procedures.[69]

3.4.3.1.14 Capital recovery. According to four vendors, the equipment life expectancy is 15 to 20+ years.[32-34,46] The CRF, 0.11746, was based on a 20-yr life expectancy and an interest rate of 10 percent. This factor was multiplied by the TCI, minus the initial bag and cage costs, to estimate the capital recovery.

3.4.3.2 Fabric Filter. The costs for the DI/FF control device were used as the starting point for estimating the FF costs. Eliminating the dry injection equipment eliminates makeup lime costs. It also reduces dust disposal costs significantly because lime and reaction products are the major components of the FF dust in DI/FF control devices. No data are available to indicate how much of the non-I.D. fan electricity requirements are consumed by the dry injection feed equipment and controls. Therefore, it was assumed that the non-I.D. fan electricity requirements for the FF device would be 50 percent lower than these for the DI/FF device. Maintenance materials and all indirect costs are also lower because the TCI for this control device is lower. All other annual cost components are the same as for DI/FF control devices that are designed for the same gas flow rates. The equations for estimating the costs are shown in Table 24, and the costs are shown in Table 25.

3.4.3.3 Fabric Filter/Packed Bed. Annual costs for this control device were estimated by combining costs for various wet control devices with those for the FF device. The resulting equations that were used to estimate the annual costs are shown in Table 26, and the annual costs as applied to each model combustor are shown in Table 27. Assuming the pressure drop through the control device is about 19 in. w.c. (5 in. for FF, 5 in. through the heat exchanger both times, 4 in. for PB), the fan hp and electricity costs are about 50 percent of those for the VS/PB control device. The water recirculation and pump electricity costs are assumed to be the same as for the PB

TABLE 24. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR FF CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	47.0*dscfm+306720
2. Direct annual costs, $/yr	
a. Electricity	(0.000323*dscfm+0.1431)*(hr/yr)
b. Makeup lime	
c. Water	(0.000126*dscfm+0.0289)*(hr/yr)
d. Operating, supervisory, and maintenance labor	2.55*(hr/yr)
e. Maintenance materials	0.940*dscfm+6134
f. Compressor air	(0.000043*dscfm+0.00812)*(hr/yr)
g. Dust disposal	0.000171*(PM)*(dscfm)*(hr/yr)
h. Bag replacement	1.0418*dscfm+195
i. Cage replacement	0.12075*dscfm+22.6
3. Indirect annual costs, $/yr	
a. Overhead	(1.530*hr/yr)+0.5640*dscfm+3681
b. Property tax, insurance, and administrative	1.880*dscfm+12269
c. Capital recovery (a)	5.263*dscfm+35979
4. Total annual cost, $/yr	([0.000171*PM+0.000492]*dscfm+4.2601)*(hr/yr)+(9.810*dscfm) +58281

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 25. FF ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. Inlet PM, gr/dscf at 14% O2	0.08	0.08	0.08	0.08	0.08	0.022	0.012
e. Outlet PM, gr/dscf at 14% O2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
2. Total APCD capital investment, $	529,829	455,475	529,829	395,973	336,471	328,105	341,030
3. Direct annual costs, $/yr							
a. Electricity	13,033	4,342	7,321	3,304	1,301	1,044	1,182
b. Makeup lime							
c. Water	4,866	1,590	2,733	1,169	406	310	377
d. Operating, supervisory, and maintenance labor	19,829	9,501	11,138	11,138	9,547	9,180	7,956
e. Maintenance materials	10,597	9,110	10,597	7,919	6,729	6,562	6,821
f. Compressor air	1,665	542	935	395	133	100	124
g. Dust disposal	475	152	267	107	30	4.8	2.7
h. Bag replacement	5,140	3,492	5,140	2,173	854	669	955
i. Cage replacement	596	405	596	252	99	78	111
4. Indirect annual costs, $/yr							
a. Overhead	18,255	11,166	13,041	11,435	9,766	9,445	8,866
b. Property tax, insurance, and administrative	21,193	18,219	21,193	15,839	13,459	13,124	13,641
c. Capital recovery (a)	60,964	52,637	60,964	45,974	39,311	38,374	39,821
5. Total annual cost, $/yr	156,612	111,156	133,925	99,706	81,637	78,891	79,857

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE 26. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR FF/PB CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	76.7*dscfm+381928
2. Direct annual costs, $/yr	
a. Electricity	(0.000526*dscfm+0.1141)*(hr/yr)
b. Scrubber water	(0.0000781*dscfm)*(hr/yr)
c. Operating, supervisory, and maintenance labor	2.550*(hr/yr)
d. Maintenance materials	1.5340*dscfm+7639
e. Caustic	(0.00000125*ppm HCl)*dscfm*hr/yr
f. Sewer charge	(0.0000896*dscfm)*(hr/yr)
g. Compressed air	0.000031*(dscfm)*(hr/yr)
h. Dust disposal	0.000171*(dscfm)*(hr/yr)
i. Bag replacement	0.7372*(dscfm)
j. Cage replacement	0.0855*(dscfm)
3. Indirect annual costs, $/yr	
a. Overhead	1.5300*(hr/yr)+0.9204*dscfm+4583
b. Property tax, insurance, and administrative	3.068*dscfm+15277
c. Capital recovery (a)	8.8271*dscfm+44861
4. Total annual cost, $/yr	{([0.000171*PM+0.00000125*ppm HCl +0.000724)*dscfm+4.1941}*(hr/yr)+(15.1722*dscfm)+72360

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE 27. FF/PB ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models		Intermittent models			Batch model	Pathological model
	1	2	3	4	5	6	7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. Inlet PM, gr/dscf at 14% O2	0.08	0.08	0.08	0.08	0.08	0.022	0.012
e. Outlet PM, gr/dscf at 14% O2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
f. HCl concentration, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total capital investment, $	746,023	624,684	746,023	527,581	430,479	416,827	437,919
3. Direct annual costs, $/yr							
a. Electricity	20,293	6,625	11,399	4,859	1,673	1,272	1,554
b. Scrubber water	2,881	921	1,619	647	185	128	178
c. Operating, supervisory, and maintenance labor	19,829	9,501	11,138	11,138	9,547	9,180	7,956
d. Maintenance materials	14,920	12,494	14,920	10,552	8,610	8,337	8,758
e. Caustic	33,595	10,733	18,871	7,549	2,157	204	170
f. Sewer charge	3,309	1,057	1,859	744	212	147	204
g. Compressed air	1,133	362	637	255	73	50	70
h. Dust disposal	475	152	267	107	30	4.8	2.7
i. Bag replacement	3,500	2,333	3,500	1,400	467	335	538
j. Cage replacement	406	270	406	162	54	39	62
4. Indirect annual costs, $/yr							
a. Overhead	20,850	13,197	15,635	13,014	10,894	10,510	10,029
b. Property tax, insurance, and administrative	29,841	24,987	29,841	21,103	17,219	16,673	17,517
c. Capital recovery (a)	86,763	72,799	86,763	61,624	50,449	48,878	51,305
5. Total annual cost, $/yr	237,795	155,431	196,855	133,155	101,571	95,757	98,344

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

control device. The makeup water requirements are assumed to be the same as those for a VS/PB control device that uses a heat exchanger (e.g., a WHRB) to cool the gases from the MWI. One vendor indicated that the makeup water rate for such a system is 67 percent lower than that for a control device with an evaporative quench.[28] This difference in flow rate translates into an equivalent reduction in annual costs. Operating and maintenance labor requirements are estimated to be 1 hr/8-hr shift and 0.5 hr/8-hr shift, respectively. Caustic requirements and sewer charges are the same as those for the VS/PB control device. Compressed air, bag replacement, and cage replacement costs are slightly lower than those for the other FF-based control devices because a heat exchanger rather than evaporative cooling is used to reduce the gas temperature to 300°F; consequently, the gas flow rate is also lower and the size of the FF is smaller. Dust disposal costs are the same as for the FF control device.

3.4.3.4 Spray Dryer/Fabric Filter. The equations for estimating the annual costs are shown in Table 28, and the costs are shown in Table 29. Electricity, spray dryer water, makeup lime, labor, dust disposal and cage replacement, and compressed air costs are assumed to be the same as those for the DI/FF control device. Maintenance materials costs are higher because the SD/FF system is more complex than the DI/FF equipment. Consequently, overhead costs are also slightly higher for the SD/FF control device. Property tax, insurance, administrative and capital recovery costs are higher for the SD/FF control device because they are based on the total capital investment, which is higher for the SD/FF.

3.5 ACTIVATED CARBON INJECTION COSTS

This section presents capital and annual costs for the activated carbon injection system.

3.5.1 Total Capital Investment for Activated Carbon Injection Equipment

As discussed in Section 2.2, data from EPA-sponsored emissions tests indicate that injecting activated carbon before

TABLE 28. EQUATIONS USED TO ESTIMATE ANNUAL COSTS FOR SD/FF CONTROL DEVICES

Parameters	Equations
1. Total APCD capital investment, $	179.7 x dscfm+701268
2. Direct annual costs, $/yr	
a. Electricity	(0.000355 x dscfm+0.1573) x (hr/yr)
b. Makeup lime	(0.000000720 x ppm HCl) x (dscfm) x (hr/yr)
c. Water	(0.000126 x dscfm+0.0289) x (hr/yr)
d. Operating, supervisory, and maintenance labor	2.23 x (hr/yr)
e. Maintenance materials	3.594 x dscfm+14025
f. Compressor air	(0.000043 x dscfm+0.00812) x (hr/yr)
g. Dust disposal	(0.00017 x PM+0.000000343 x HCl) x (dscfm) x (hr/yr)
h. Bag replacement	1.0418 x dscfm+195
i. Cage replacement	0.12075 x dscfm+22.6
3. Indirect annual costs, $/yr	
a. Overhead	(1.530 x hr/yr)+2.1564 x dscfm+8415
b. Property tax, insurance, and administrative	7.188 x dscfm+28051
c. Capital recovery (a)	20.850 x dscfm+82323
4. Total annual cost, $/yr	([0.000171 x PM+0.00000106 x HCl+0.000524] x dscfm+4.2743) x (hr/yr)+(34.951 x dscfm)+133032

(a) CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years

TABLE 29. SD/FF ANNUAL COSTS FOR EACH MODEL COMBUSTOR

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr or batch	1,500	1,000	1,500	600	200	500	200
b. Flow rate into control device, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. Inlet PM, gr/dscf at 14% O2	0.08	0.08	0.08	0.08	0.08	0.022	0.012
e. Outlet PM, gr/dscf at 14% O2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
f. Inlet HCl, ppmdv at 14% O2	730	730	730	730	730	100	60
2. Total capital investment, $	1,554,115	1,269,893	1,554,115	1,042,443	814,994	783,014	832,421
3. Direct annual APCD costs, $/yr							
a. Electricity	14,325	4,772	8,047	3,631	1,430	1,148	1,299
b. Makeup lime	19,401	6,198	10,898	4,360	1,246	118	98
c. Water	4,866	1,590	2,733	1,169	406	310	377
d. Operating, supervisory, and maintenance labor	19,829	9,501	11,138	11,138	9,547	9,180	7,956
e. Maintenance materials	31,082	25,398	31,082	20,849	16,300	15,660	16,648
f. Compressor air	1,665	542	935	395	133	100	124
g. Dust disposal	9,712	3,103	5,455	2,182	624	61	50
h. Bag replacement	5,140	3,492	5,140	2,173	854	669	955
i. Cage replacement	596	405	596	252	99	78	111
4. Indirect annual APCD costs, $/yr							
a. Overhead	30,547	20,939	25,332	19,192	15,508	14,904	14,763
b. Property tax, insurance, and administrative	62,165	50,796	62,165	41,698	32,600	31,321	33,297
c. Capital recovery (a)	181,277	148,299	181,277	121,909	95,518	91,808	97,540
5. Total annual cost, $/yr	380,603	275,035	344,799	228,949	174,265	165,356	173,218

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.

the fabric filter in DI/FF and SD/FF systems improves the removal efficiency of both CDD/CDF and Hg. The TCI for activated carbon injection was estimated for MWI's with DI/FF or an FF/PB by scaling the cost for equipment used to inject activated carbon into one DI/FF system. The facility using this equipment has a 680 lb/hr intermittent MWI and the equipment cost was estimated to be $4,500.[78] The "six-tenths" costing rule was used to scale the cost. Exhaust gas flow rates were used to scale the cost. Exhaust gas flow rates were used as the capacity parameter in the procedure. The resulting equation is shown in Table 30.

The equipment required for the activated carbon injection process consists of a storage bin and a feeder mechanism to inject the carbon into the ductwork of a DI/FF or FF/PB control system. No capital costs are necessary for MWI's with an SD/FF control system since the activated carbon can be mixed with the lime slurry.

3.5.2 Annual Costs for Activated Carbon Injection

Direct and indirect annual costs were estimated for activated carbon injection for DI/FF and FF/PB control devices and for SD/FF control devices for all of the model combustors. Direct annual costs were estimated for operating and supervisory labor, maintenance, activated carbon, and dust disposal. Indirect annual costs were estimated for overhead, property tax, insurance, administrative charges, and capital recovery. The basis for each cost is described in the subsections below.

The formulas developed to calculate the annual costs are shown in Table 30. Most of the equations are a function of the gas flow rate into the control device, and many are also related to the annual hours of operation. Table 31 presents the annual costs for activated carbon injection for DI/FF and FF/PB control devices for each model combustor. Table 32 presents the annual costs for activated carbon injection for SD/FF control devices for each model combustor.

3.5.2.1 Operating Labor. Operating labor requirements to load the activated carbon into the storage bin and to perform other daily system checks are expected to be small. For this

TABLE 30. EQUATIONS TO ESTIMATE CAPITAL AND ANNUAL COSTS FOR ACTIVATED CARBON INJECTION

A. Total capital investment, \$[a]	$= 4{,}500\ (Q/1{,}976)^{0.6}$
B. Direct annual costs, \$/yr	
1. Operating labor[b]	= (0.25 hr/8 hr shift) x (\$12/hr) x (H)
2. Supervisory labor	= 0.15 x (operating labor)
3. Maintenance[c]	= 0.04 x TCI
4. Activated carbon	
a. For DI/FF and FF/PB devices[d]	$= (1.27 \times 10^{-3})$ x (\$0.75/lb) x (Q) x (H)
b. For SD/FF devices[e]	$= (7.05 \times 10^{-4})$ x (\$0.75/lb) x (Q) x (H)
5. Dust disposal	
a. For DI/FF and FF/PB devices	$= (1.27 \times 10^{-3})$ x (Q) x (H) x (\$40/ton) x (1 ton/2,000 lb)
b. For SD/FF devices	$= (7.05 \times 10^{-4})$ x (Q) x (H) x (\$40/ton) x (1 ton/2,000 lb)
C. Indirect annual costs, \$/yr	
1. Overhead	= (0.6) x (all labor maintenance materials costs)
2. Property taxes, insurance, and administration	= (0.04) x (TCI)
3. Capital recovery[f]	= (0.11746) x (TCI)

[a]The variable Q is the exhaust gas flow rate in dscfm.
[b]The variable H is the operating hours in hr/yr.
[c]Maintenance cost includes maintenance labor and maintenance materials cost.
[d]The factor is based on injecting carbon at a rate to achieve a carbon concentration of 338 mg/dscm.
[e]The factor is based on injecting carbon at a rate to achieve a carbon concentration of 188 mg/dscm.
[f]The capital recovery factor is 0.11746, based on equipment life of 20 years and an interest rate of 10 percent.

TABLE 31. CAPITAL AND ANNUAL COSTS FOR ACTIVATED CARBON INJECTION FOR DI/FF AND FF/PB CONTROL DEVICES

	Continuous models		Intermittent models			Batch model	Pathological model
Parameters\model combustors	1	2	3	4	5	6	7
1. Model plant parameters							
a. Capacity, lb/hr or batch	1,500	1,000	1,500	600	200	500	200
b. Exhaust gas flow rate, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
2. Total capital investment, $	7,234	5,672	7,234	4,175	2,159	1,771	2,352
3. Direct annual costs, $/yr							
a. Operating labor	2,916	1,397	1,638	1,638	1,404	1,350	1,170
b. Supervisory labor	437	210	246	246	211	203	176
c. Maintenance	289	227	289	167	86	71	94
d. Activated carbon (a)	35,044	11,196	19,685	7,875	2,250	1,555	2,162
e. Dust disposal (b)	935	299	525	210	60	41	58
4. Indirect annual costs, $/yr							
a. Overhead	2,186	1,100	1,304	1,230	1,021	974	864
b. Property taxes, insurance, and administrative	289	227	289	167	86	71	94
c. Capital recovery	850	666	850	490	254	208	276
5. Total annual cost, $/yr	42,946	15,321	24,826	12,023	5,372	4,473	4,894

(a) The cost is estimated using the carbon injection concentration of 338 mg/dscm from the emissions test at Facility A and a unit cost of $0.75/lb of activated carbon.

(b) Dust disposal cost is estimated at $40/ton of solid waste generated.

TABLE 32. CAPITAL AND ANNUAL COSTS FOR ACTIVATED CARBON INJECTION FOR SD/FF CONTROL DEVICES

	Continuous models		Intermittent models			Batch model	Pathological model
Parameters\model combustors	1	2	3	4	5	6	7
1. Model plant parameters							
a. Capacity, lb/hr or batch	1,500	1,000	1,500	600	200	500	200
b. Exhaust gas flow rate, dscfm	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
2. Total capital investment, $	0	0	0	0	0	0	0
3. Direct annual costs, $/yr							
a. Operating labor	2,916	1,397	1,638	1,638	1,404	1,350	1,170
b. Supervisory labor	437	210	246	246	211	203	176
c. Maintenance	0	0	0	0	0	0	0
d. Activated carbon (a)	19,492	6,227	10,949	4,380	1,251	865	1,203
e. Dust disposal (b)	520	166	292	117	33	23	32
4. Indirect annual costs, $/yr							
a. Overhead	2,012	964	1,130	1,130	969	932	807
b. Property taxes, insurance, and administrative	0	0	0	0	0	0	0
c. Capital recovery	0	0	0	0	0	0	0
5. Total annual cost, $/yr	25,377	8,964	14,255	7,511	3,868	3,372	3,388

(a) The cost is estimated using the carbon injection concentration of 338 mg/dscm from the emissions test at Facility A and a unit cost of $0.75/lb of activated carbon.

(b) Dust disposal cost is estimated at $40/ton of solid waste generated.

analysis, they were estimated to be 0.25 hr/8-hr shift. The labor wage rate was estimated to be $12/hr to be consistent with incinerator operator wage rates.

3.5.2.2 Supervisory Labor. According the OAQPS Control Cost Manual procedures, this cost is 15 percent of the operating labor cost.[63]

3.5.2.3 Maintenance. The cost of maintenance labor and materials was assumed to be 4 percent of the TCI. Since no capital investment is necessary for carbon injection systems for SD/FF control devices, there is no maintenance cost for MWI's using those systems.

3.5.2.4 Activated Carbon. The activated carbon requirements for MWI's with DI/FF and FF/PB control devices were estimated using the carbon injection concentration of 338 mg/dscm from the emissions test at Facility A and a unit cost of $0.75/lb of activated carbon. The activated carbon requirements for MWI's with SD/FF control devices were estimated using the carbon injection concentration of 188 mg/dscm from the emissions test at Facility M and the same unit cost of activated carbon. The activated carbon unit cost was the average of the costs for four different carbons.[79]

3.5.2.5 Dust Disposal. The cost of dust disposal is a function of the concentration of activated carbon injected and the unit cost for disposal. Since the addition of activated carbon does not change the outlet PM emissions, all of the carbon injected is assumed to be captured by the FF. The unit disposal cost was assumed to be $40/ton, as noted for bottom ash and FF dust disposal costs.

3.5.2.6 Overhead. According the OAQPS Control Cost Manual, overhead is estimated as 60 percent of the operating and supervisory labor and maintenance costs.[69]

3.5.2.7 Property Tax, Insurance, and Administrative. These costs were estimated as 4 percent of the TCI based on the OAQPS Control cost procedures.[69] Since there is no capital investment necessary for activated carbon injection systems for SD/FF control devices, there are no property tax, insurance, and administrative costs for MWI's using those systems.

3.5.2.8 Capital Recovery. The CRF, 0.11746, was based on a 20-year life expectancy for the activated carbon injection system (assumed to be the same as that reported by DI/FF vendors) and an interest rate of 10 percent. This factor was multiplied by the TCI to estimate the capital recovery. Since there is no capital investment necessary for activated carbon injection systems for SD/FF control devices, there is no capital recovery cost for MWI's using those systems.

3.6 SUMMARY OF COMBUSTOR AND CONTROL TECHNOLOGY COSTS

A summary of the model combustor and control technology capital costs are shown in Table 33. A summary of the total annual costs for each model combustor and each model control technology are presented in Table 34.

4.0 MODEL COMBUSTORS AND CONTROL TECHNOLOGIES FOR EXISTING FACILITIES

This section describes the model combustors and control technologies that represent existing MWI's. The model combustors are described in Section 4.1; the control technologies are described in Section 4.2.

4.1 MODEL COMBUSTORS

A total of seven model combustors were developed to represent the population of existing MWI's. These model combustors are the same as the seven model combustors that also represent new MWI's in Section 2 (see Tables 6 through 8), except that the secondary chambers are smaller for most of the models. Most newer units (installed since 1985) have secondary chambers with residence times of 1 second. Older units typically have secondary chambers with gas residence times of about 1/4 second.

Sales data collected in 1990 from combustor manufacturers show most large continuous MWI's have been installed since 1985 and, thus, are more likely to have secondary chambers with gas residence times of 1-second. Consequently, the 1,500 lb/hr continuous model representing existing MWI's was developed with a 1-second residence time (i.e., the model is identical to that

TABLE 33. SUMMARY OF COMBUSTOR AND CONTROL TECHNOLOGY CAPITAL COSTS

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model combustor parameters							
Capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
Gas flow rate, dscfm	4,747	3,165	4,747	1,899	633	455	730
2. Combustor capital cost, $	650,000	521,000	238,000	157,000	95,000	72,000	96,000
3. Combustion control capital costs, $	64,300	47,100	64,300	33,300	19,600	17,600	20,600
4. APCD capital costs, $ (a):							
VS	244,000	196,000	244,000	158,000	119,000	114,000	122,000
PB	241,000	197,000	241,000	162,000	127,000	122,000	130,000
VS/PB	277,000	224,000	277,000	182,000	140,000	134,000	143,000
FF	530,000	455,000	530,000	396,000	336,000	328,000	341,000
DI/FF	710,000	609,000	710,000	529,000	448,000	437,000	454,000
FF/PB	746,000	625,000	746,000	528,000	430,000	417,000	438,000
SD/FF	1,554,000	1,270,000	1,554,000	1,043,000	815,000	783,000	832,000
DI/FF with carbon	718,000	615,000	718,000	533,000	450,000	438,000	456,000
FF/PB with carbon	753,000	630,000	753,000	532,000	433,000	419,000	440,000
SD/FF with carbon	1,554,000	1,270,000	1,554,000	1,043,000	815,000	783,000	832,000

(a) The combustion control costs are not included as part of the APCD costs.

TABLE 34. SUMMARY OF COMBUSTOR AND CONTROL TECHNOLOGY TOTAL ANNUAL COSTS

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
Combustor design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
1. Combustor annual costs, $/yr	294,000	169,000	119,000	83,000	52,600	33,600	57,300
2. Combustion control annual costs, $/yr	33,300	16,000	33,900	15,100	6,470	6,740	5,370
3. APCD annual costs, $/yr (a)							
VS	140,000	70,000	99,000	56,000	35,000	31,000	32,000
PB	117,000	63,000	86,000	52,000	35,000	32,000	32,000
VS/PB	153,000	77,100	109,000	62,600	39,800	35,400	37,000
FF	157,000	111,000	134,000	99,700	81,600	78,900	79,900
DI/FF	221,000	150,000	185,000	132,000	105,000	99,700	101,500
FF/PB	238,000	155,000	197,000	133,000	102,000	95,800	98,300
SD/FF	381,000	275,000	345,000	229,000	174,000	165,000	173,000
DI/FF with carbon	264,000	165,000	210,000	144,000	110,000	104,000	106,000
FF/PB with carbon	281,000	170,000	222,000	145,000	107,000	100,000	103,000
SD/FF with carbon	406,000	284,000	359,000	237,000	178,000	168,000	176,000

(a) The APCD annual costs do not include the combustion control annual costs.

representing new MWI's). The other six model combustors were developed with 1/4-second residence times because the majority of existing MWI's represented by these models were installed before 1985 and, thus, are more likely to have secondary chambers with 1/4-second residence times.

The retort is a combustor design that comprises a significant percentage of the existing MWI population, but it is not used for new MWI's. In one State, 30 percent of the existing MWI's are retorts.[80] A separate model combustor was not developed to represent retorts because their sizes and operation are similar to those for pathological or intermittent combustors. Retorts were originally designed to burn primarily pathological waste; however, some facilities have also used them to burn general/red bag waste. In two States, retort sizes were determined to range from 50 to 250 lb/hr.[80,81] Other State surveys did not distinguish retorts from either pathological or intermittent MWI's.

4.2 MODEL CONTROL TECHNOLOGIES

4.2.1 Combustion Controls

Combustion controls consist of retrofitting the combustor with a larger secondary chamber and operating it above a specified minimum temperature. Two levels of combustion control were evaluated. One level of combustion control is identical to that specified in Section 2.2.1 for new MWI's; i.e., secondary chambers that achieve a gas residence time of 2 seconds and operate at a temperature of 1800°F (2-sec combustion control technology). The second level of combustion control is based on secondary chambers that achieve a gas residence time of 1 second and operate at a temperature of 1700°F (1-sec combustion control technology). For both control levels, the temperature requirements apply to the cooldown phase, as well as the burning and burndown phases, as long as the primary combustion air blower is operating and the primary chamber exhaust gas temperature is above 300°F. As noted in Section 2.1.4.5 and in Tables 6 and 7, the applicable cooldown time is an average of 2 hr for intermittent combustors and 10 hr for batch combustors.

4.2.2 APCD Control Technologies

The APCD control technologies are the same as those described in Section 2.2.2. The parameters characterize design and operation of control devices that are installed after a combustor has been retrofitted with a 2-sec secondary chamber. Slightly smaller control devices could be installed on combustors with smaller secondary chambers because the gas flow rate would be lower. The difference in the flow rate is small (only a few percent), and it is much less than the scatter in the flow rates that were used to establish the exhaust gas flow rates for new units. Therefore, the parameters presented in Section 2.2.2 would also adequately characterize control devices installed on combustors with smaller (1/4-sec to 1-sec) secondary chambers.

5.0 COSTS FOR EXISTING FACILITIES

This section presents the capital and annual control costs for model combustors that represent existing MWI's. The control costs include costs to retrofit existing MWI's with combustion controls and add-on controls.

5.1 COMBUSTOR CAPITAL AND ANNUAL COSTS

Total annual costs for existing 1-sec and 1/4-sec combustors are needed to conduct impact analyses. Capital and annual costs for both combustors are estimated in this section.

Capital costs for existing combustors were assumed to be the same as the capital costs for new combustors (i.e., the actual capital investment of an existing combustor in 1989 dollars was assumed to be the same as the capital investment of a new combustor in 1989). Therefore, the costs for existing 1-sec combustors are the same as those for the new 1-sec combustors that are presented in Table 11. Since 1/4-sec combustors are no longer produced, the costs for these units were estimated by subtracting the difference between estimated 1-sec and 1/4-sec secondary chamber costs from the 1-sec combustor costs. The 1-sec secondary chamber costs were assumed to be equal to the incremental cost difference between 1-sec and 2-sec secondary chambers shown in Figure 5. The 1/4-sec secondary chambers were estimated to be equal to 1/4 of the 1-sec secondary chamber costs. Capital costs for the 1/4-sec combustors are shown in Table 35.

Annual costs for existing combustors were calculated by the same procedures described in Section 3.3 and in Appendix A. For existing 1-sec combustors, the annual costs are the same as those for new units in Table 14. Annual costs for existing 1/4-sec combustors are shown in Table 35. The only differences between the costs for 1/4-sec and 1-sec combustors are the secondary chamber refractory replacement costs and all costs that are estimated to be equal to a percentage of the TCI (i.e., maintenance materials, overhead, property taxes, insurance, administration, and capital recovery). Fuel costs are assumed to be the same for both combustors, even though heat losses may be slightly higher for the larger 1-sec secondary chambers.

5.2 CONTROL TECHNOLOGY CAPITAL COSTS

Total capital investments were developed for combustion control and APCD control technology retrofits. Combustion control costs are presented in Section 5.2.1, and APCD retrofit costs are described in Section 5.2.2.

The TCI consists of purchased equipment and installation costs. However, downtime costs associated with combustion control retrofits were also developed and treated as capital costs. It was assumed that downtime costs for APCD retrofits are negligible because most of the existing MWI's are outdoors with adequate space to install the control equipment without shutting down the incinerator; connecting the ductwork can be performed during a scheduled downtime for maintenance.

5.2.1 Combustion Control Total Capital Investment

A secondary chamber retrofit can be accomplished in several ways: (1) replace the existing secondary chamber with one large enough to achieve the necessary residence time, (2) add a tertiary chamber to achieve the additional residence time that is needed, or (3) expand the existing chamber by removing one end and making the chamber longer. The replacement option was evaluated in this analysis; according to two manufacturers, it is the most common way to retrofit combustors that currently have

TABLE 35. CAPITAL AND ANNUAL COSTS FOR EXISTING COMBUSTORS

Cost parameters\model combustors	Continuous models		Intermittent models			Batch model	Pathological model
	1	2	3	4	5	6	7
1. Capital costs							
a. TCI for 1-sec combustor		520,871	237,659	156,822	95,266	71,669	96,345
b. TCI for 1-sec secondary chamber		47,084	64,283	33,320	19,556	17,620	20,610
c. TCI for 1/4-sec secondary chamber		11,771	16,071	8,330	4,889	4,405	5,153
d. TCI for 1/4-sec combustor		485,558	189,446	131,833	80,599	58,454	80,887
2. Combustor annual costs, $/yr							
a. Electricity		3,906	2,820	1,297	516	164	516
b. Auxiliary fuel		17,980	20,524	10,128	4,901	7,564	9,284
c. Water		135	108	54	0	0	0
d. Operating labor		17,496	17,784	16,848	12,168	2,880	12,168
e. Supervisory labor		2,624	2,668	2,527	1,825	432	1,825
f. Maintenance labor		3,074	3,089	3,089	2,574	2,970	2,574
g. Maintenance materials		9,711	3,789	2,637	1,612	1,169	1,618
h. Ash disposal		5,249	6,318	2,527	618	144	618
i. Refractory replacement		4,845	5,101	2,924	1,610	1,749	1,645
j. Overhead		20,167	16,976	15,360	11,084	4,629	11,096
k. Property tax, insurance, and administration		19,422	7,578	5,273	3,224	2,338	3,235
l. Capital recovery (a)		56,465	21,653	15,142	9,278	6,661	9,308
3. Total annual cost, $/yr	NA (b)	161,074	108,407	77,806	49,410	30,700	53,888

(a) The CRF is 0.11746, based on an interest rate of 10 percent and an equipment life of 20 years.
(b) Model 1 is not developed with a 1/4-second residence time secondary chamber.

small secondary chambers (i.e., those modeled with 1/4-second residence times).[82,83]

5.2.1.1 Two-Second Secondary Chamber Retrofit. Purchased equipment costs for the 2-sec secondary chamber control technology were estimated as double the difference between the costs presented in Section 3 for new MWI's that have secondary chambers with 1- and 2-second residence times (see Figure 5). These costs account for larger burners and blowers in the 2-second units, but they may underestimate the overall cost slightly because the material requirements for a 2-second unit should be less than double the material needed for a 1-second unit.

The installation cost factor was estimated to be 0.96 times the PEC, or twice as much as for new installations. This higher factor accounts for demolition and removal costs and additional field work to modify the system controls for the new burner and blower. Thus, the TCI for 2-sec secondary chamber retrofits is 1.96 times the PEC. Table 36 presents the TCI for each of the model combustors.

TABLE 36. TOTAL CAPITAL INVESTMENT FOR 2-SECOND SECONDARY CHAMBER COMBUSTION CONTROL RETROFITS

Model combustor	Exhaust gas flow rate, dscfm	Volume, ft^3	Retrofit costs for 2-second SC		
			Purchased equipment cost, $	Installation cost, $	Total capital investment, $[a]
1	4,747	753	86,870	83,395	170,000
2	3,165	502	63,627	61,082	125,000
3	4,747	753	86,870	83,395	170,000
4	1,899	301	45,027	43,226	83,300
5	633	100	26,427	25,370	51,800
6	455	72	23,811	22,859	46,700
7	730	116	27,852	26,738	54,600

[a]Total capital invstment does not include downtime cost.

Downtime costs are presented in Table 37. According to two manufacturers, the downtime to retrofit a 2-sec secondary chamber

TABLE 37. DOWNTIME COSTS ASSOCIATED WITH COMBUSTION CONTROL DEVICES

Model combustor	Waste charging rate lb/hr	Waste charging rate lb/batch	Waste charging hours hr/d	Waste charging hours d/w	Time to retrofit, days (a)	Downtime days (b)	Downtime costs, $ (c)
1	1,500		24	6.5	13	12	87,000
2	1,000		8.5	6.5	11	6	10,251
3	1,500		7.5	6	13	8	18,090
4	600		7.5	6	9	4	3,618
5	200		5.5	6	8	3	663
6		500	N/A	3	7	3	302
7	200		5.5	6	8	3	663

(a) Downtime is based on estimates from manufacturers that retrofit work takes from 1 to 4 weeks, depending on the size of the combustor.

(b) Downtime days are less than the number of days to retrofit by the number of days that the incinerator is normally down for maintenance or because it is not needed. For noncommercial, non-batch models, it is assumed that the incinerator is normally down one day per week and that the amount of waste generated in three days can be saved and burned in addition to the normal waste load in the days after the retrofit is completed. For batch units, it is also assumed that the incinerator is normally down one day per week but waste can not be saved for burning at a later date because the incinerator is normally charged at its design rate. For commercial models, it was assumed that the incinerator is normally down one day every other week and that waste can not be saved for burning at a later date.

(c) Downtime costs for non-batch models are based on the following equation:

Downtime cost, $=($0.3/lb)*(design lb/hr * 0.67)*(hr/d)*(downtime days)

For batch models, the following equation was used:

Downtime cost, $=($0.3/lb)*(design lb/batch * 0.67)*(downtime days) would be between 1 and 4 weeks, depending on site-specific conditions and the size of the combustor.[82,83] For this analysis, it was assumed that the downtime would be 1 week for the smallest MWI's and 4 weeks for a large MWI (i.e., larger than 5,000 lb/hr). Downtime for other sizes was estimated based on the assumption that there is a linear relationship between these two points on a plot of down time versus exhaust gas flow rate. It was assumed that all facilities except commercial disposal firms and those with batch combustors can save waste for up to 3 days and burn it after the retrofit work is completed. These facilities also shut the incinerator down at least 1 day per week for preventive maintenance or because they do not generate enough waste on the weekends to justify operating the incinerator. For the remaining downtime, it was assumed that these facilities would have to contract with a commercial disposal firm to dispose of their waste. Average disposal costs at commercial facilities were estimated to be $0.30/lb.[84-88]

For continuous units at commercial facilities, the downtime costs were estimated as the amount of lost revenues. The total number of downtime days was adjusted by the assumption that commercial incinerators are down for preventive maintenance 1 day every 2 weeks.

5.2.1.2 <u>One-Second Secondary Chamber Retrofit</u>. The secondary chamber volume that is needed to achieve 1-sec residence time in one application is the same as that needed to achieve 2-sec residence time in another application with half the gas flow rate. For this analysis, it was assumed that the same secondary chamber would be used in both applications and that the retrofit costs would also be the same. The average disposal and downtime costs may actually be slightly higher for 1-sec retrofits because larger existing units would be replaced, but this difference has been assumed to be small. For example, for 2-sec retrofits, a 400 ft^3 secondary chamber would replace mostly 50 to 200 ft^3 original units, whereas for 1-sec retrofits, it would replace units from 100 to 400 ft^3.

The TCI costs presented in Table 36 for 2-sec retrofits were used to estimate the TCI costs for 1-sec retrofits. A linear regression analysis was performed to determine the equation of the line through a plot of 2-sec TCI values versus the secondary chamber volumes. The TCI values for 1-sec retrofits were then estimated by plugging the secondary chamber volumes needed to achieve 1-second residence times into this equation. The resulting TCI values are presented in Table 38. There was no TCI cost for 1-sec retrofit for model No. 1 because the baseline for this model already includes a secondary chamber with a 1-second residence time and an operating temperature of 1700°F.

TABLE 38. TOTAL CAPITAL INVESTMENT FOR 1-SECOND SECONDARY CHAMBER COMBUSTION CONTROL RETROFITS

Model combustor	Exhaust gas flow rate, dscfm	Volume, ft^3	Total capital investment, $[a]
1	4,747	376	0
2	3,165	251	79,100
3	4,747	376	102,000
4	1,899	151	60,900
5	633	50	42,700
6	455	36	40,100
7	730	58	44,100

[a]There is no retrofit total capital investment for model 1 because the baseline for that model already includes a secondary chamber that has a gas residence time of 1 second and operates at a temperature of 1700°F.

Downtime costs were assumed to be the same as for the 2-sec secondary chamber retrofit. This assumption may overestimate the cost because it should be easier and less time consuming to remove a 1/4-sec chamber and set a 1-sec unit in place than to remove a 1-sec chamber and replace it with a 2-sec unit. However, the time to disconnect and reconnect the fuel lines, air ducts, interlocks, thermocouples, electricity, etc., would be about the same regardless of the secondary chamber size.

5.2.2 APCD Total Capital Investment

On a nationwide basis, average APCD retrofit costs were estimated to be the same as for new facilities. This estimate is based on limited information about the population of existing MWI's. This information shows that most MWI's are accessible and have room for an APCD system. Retrofit costs for these facilities would be the same as the costs to purchase and install APCD's at new facilities.[83]

5.3 CONTROL TECHNOLOGY ANNUAL COSTS

Annual costs were estimated for combustion controls and add-on controls; the estimating procedures are described in the following sections.

5.3.1 Combustion Control Annual Costs

Annual costs for 1-sec and 2-sec secondary chamber retrofits are shown in Tables 39 and 40, respectively. These costs were estimated by the same procedures described in Section 3.4.1, with three exceptions. First, the downtime cost is an intitial cost that is annualized over the 20-yr life of the retrofit combustor. Second, there is no 1-sec secondary chamber retrofit cost for model No. 1 because this model already has a secondary chamber that operates at 1700°F and has a gas residence time of 1 sec. Third, the auxiliary fuel costs are lower for the 1-sec secondary chamber retrofit because the secondary chamber operating temperature does not have to be increased from 1700° to 1800°F.

5.3.2 APCD Annual Costs

On a nationwide basis, the average annual costs for APCD retrofits are the same as the annual costs for new units because it was assumed that the TCI is the same for retrofit and new units. The costs for these models are presented in Table 34.

6.0 DISTRIBUTION OF MWI POPULATION

In order to conduct nationwide cost, environmental, and energy impacts analyses, it is necessary to distribute the projected population of new MWI's and the existing MWI population among the final model combustors. For the economic impact

TABLE 39. TOTAL ANNUAL 1-SECOND SECONDARY CHAMBER COMBUSTION CONTROL RETROFIT COSTS

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm (a)	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. 1-second SC parameters							
(1) Volume, ft3 (b)	376	251	376	151	50	36	58
(2) Diameter, ft	6.2	5.4	6.2	4.6	3.2	2.8	3.3
(3) Length, ft	12.4	10.9	12.4	9.2	6.3	5.7	6.7
e. 1/4- and 1-second SC parameters (c)							
(1) Volume, ft3 (b)	376	60	90	36	12	9	14
(2) Diameter, ft	6.2	3.4	3.9	2.8	2.0	1.8	2.1
(3) Length, ft	12.4	6.7	7.7	5.7	3.9	3.5	4.1
2. Total capital investment for SC retrofit, $ (d)	0	79,123	101,882	60,911	42,698	40,137	44,093
3. Downtime cost, $	0	10,251	18,090	3,618	663	302	663
4. Direct annual costs, $/yr							
a. Refractory replacement	0	1,523	1,985	1,091	536	433	587
b. Auxiliary fuel (e)	0	0	11,463	4,586	1,529	2,817	0
c. Maintenance materials	0	1,582	2,038	1,218	854	803	882
5. Indirect annual costs, $/yr							
a. Overhead (f)	0	949	1,223	731	512	482	529
b. Property tax, insurance, and administrative	0	3,165	4,075	2,436	1,708	1,605	1,764
c. Capital recovery (g)	0	8,340	10,723	6,471	4,679	4,443	4,811
d. Annualized downtime cost (h)	0	1,204	2,125	425	78	35	78
6. Total annual 1-sec SC combustion control retrofit cost, $/yr	0	16,763	33,632	16,958	9,896	10,619	8,651

(a) The flow rate is assumed to be the same for existing and retrofitted combustors.
(b) The design temperature is assumed to be 1700 F for the existing 1/4-second SC, existing 1-second SC, and the retrofitted 1-second SC.
(c) Gas residence time in the SC is 1/4 second for all models except model No. 1, which has a 1-second gas residence time.
(d) The TCI is the cost to remove the existing SC and retrofit a new 1-second SC. No retrofit is necessary for model No. 1, which already has a 1-second SC.
(e) Auxiliary fuel includes the cost of fuel to maintain 1700 F in the secondary chamber during cooldown until the combustion air blowers are turned off.
(f) The overhead cost is based on 60 percent of the maintenance materials cost; the operating and maintenance labor costs are assumed to be the same for both existing and retrofitted combustors.
(g) The CRF is 0.11746, based on an interest rate of 10 percent and 20-year equipment life.
(h) Downtime cost is a one-time cost that was annualized over the 20-yr life of the retrofit equipment (i.e., it was annualized using the CRF).

TABLE 40. TOTAL ANNUAL 2-SECOND SECONDARY CHAMBER COMBUSTION CONTROL RETROFIT COSTS

Parameters\model combustors	Continuous models 1	2	Intermittent models 3	4	5	Batch model 6	Pathological model 7
1. Model parameters							
a. Design capacity, lb/hr	1,500	1,000	1,500	600	200		200
lb/batch						500	
b. Flow rate into control device, dscfm (a)	4,747	3,165	4,747	1,899	633	455	730
c. Operating hours, hr/yr	7,776	3,726	4,368	4,368	3,744	3,600	3,120
d. 2-second SC parameters							
(1) Volume, ft3 (b)	753	502	753	301	100	72	116
(2) Diameter, ft	7.8	6.8	7.8	5.8	4.0	3.6	4.2
(3) Length, ft	15.7	13.7	15.7	11.5	8.0	7.2	8.4
e. 1/4- and 1-second SC parameters (c)							
(1) Volume, ft3 (b)	376	60	90	36	12	9	14
(2) Diameter, ft	6.2	3.4	3.9	2.8	2.0	1.8	2.1
(3) Length, ft	12.4	6.7	7.7	5.7	3.9	3.5	4.1
2. Total capital investment for SC retrofit, $ (d)	170,282	124,720	170,282	88,259	51,798	46,672	54,592
3. Downtime cost, $	87,000	10,251	18,090	3,618	663	302	663
4. Direct annual costs, $/yr							
a. Refractory replacement	1,876	2,960	3,861	2,120	1,038	839	1,138
b. Auxiliary fuel (e)	20,413	6,521	22,121	8,849	2,731	3,776	1,260
c. Maintenance materials	3,406	2,494	3,406	1,765	1,036	933	1,092
5. Indirect annual costs, $/yr							
a. Overhead (f)	2,043	1,497	2,043	1,059	622	560	655
b. Property tax, insurance, and administrative	6,811	4,989	6,811	3,530	2,072	1,867	2,184
c. Capital recovery (g)	18,825	12,795	17,582	9,039	5,434	4,957	5,699
d. Annualized downtime cost (h)	10,219	1,204	2,125	425	78	35	78
6. Total annual 2-sec SC combustion control retrofit cost, $/yr	63,594	32,460	57,949	26,787	13,010	12,967	12,105

(a) The flow rate is assumed to be the same for existing and retrofitted combustors.
(b) The design temperature is assumed to be 1700 F for the existing 1/4-second SC and 1800 F for the retrofitted 2-second SC and the existing 1-second SC.
(c) Gas residence time in the SC is 1/4 second for all models except model No. 1, which has a 1-second gas residence time.
(d) The TCI is the cost to remove the existing SC and retrofit a new 2-second SC.
(e) Auxiliary fuel includes both the cost for additional fuel to raise the secondary chamber temperature from 1700 F to 1800 F and the cost of fuel to maintain 1800 F in the secondary chamber during cooldown until the combustion air blowers are turned off.
(f) The overhead cost is based on 60 percent of the maintenance materials cost; the operating and maintenance labor costs are assumed to be the same for both existing and retrofitted combustors.
(g) The CRF is 0.11746, based on an interest rate of 10 percent and 20-year equipment life.
(h) Downtime cost is a one-time cost that was annualized over the 20-yr life of the retrofit equipment (i.e., it was annualized using the CRF).

analysis, the population also must be distributed among the MWI industry segments. The distribution of new units projected to be installed in the 5 years after proposal of the NSPS is presented in Table 41; the distribution of existing MWI's is presented in Tables 42 and 43.[89,90] Table 42 presents the distribution of 4,850 existing MWI's at facilities in five major industries (hospitals, commercial incineration, laboratories, nursing homes, and veterinaries). Table 43 presents the size distribution of 150 existing MWI's in other/unidentified industries; this distribution is assumed to be the same as that for 4,850 MWI's. While not all new or existing MWI's exactly match the final model combustors, the distributions presented in Tables 41 through 43 have been derived by assigning the various sizes and types of MWI's to the most representative model combustor.

7.0 CONTINUOUS EMISSION MONITOR COSTS

Continual compliance with emission limits can be demonstrated by using continuous emission monitors. Alternatively, the periodic use of portable CO monitors would allow operators to assess the condition of the incinerator and determine whether repairs are necessary. The use of process monitors and periodic preventive maintenance inspections can also help ensure that the incinerator is operating at its design efficiency. This section presents estimated costs for each of these monitoring and inspection activities.

7.1 CONTINUOUS EMISSION MONITORS

A computer program that was distributed by EPA's Emission Measurement Technical Information Center (EMTIC) was used to estimate capital costs and certain annual costs for several CEM systems.[91] Other annual costs (property taxes, insurance, administration, and capital recovery costs) were estimated using standard OAQPS cost factors.[69] Table 44 shows the resulting TCI and total annual costs at new facilities for opacity monitors; a combination of CO and O_2 monitors; a combination of CO, O_2, and opacity monitors; and a combination of CO, O_2, opacity, and HCl monitors. The documentation for the program also indicates that the cost of the HCl monitor is variable and could be as high as

TABLE 41. DISTRIBUTION OF NEW UNITS

Combustor design	Industry	Model combustor design capacity[a]	Total identified in industry[b]	Total identified by design capacity[c]	Fraction of type in industry[d]	Projected No. of new units by design[e]	Projected No. of new units in industry[f]
Continuous	Hospital	1,000 1,500	62 0	66 39	0.93939 0.00000	60 77	56 0
	Commercial	1,000 1,500	0 39	66 39	0.00000 1.00000	60 77	0 77
	Lab	1,000 1,500	4 0	66 39	0.06061 0.00000	60 77	4 0
Intermittent	Hospital	200 600 1,500	513 212 50	606 235 56	0.84653 0.90213 0.89286	280 95 20	237 86 18
	Lab	200 600 1,500	46 21 6	606 235 56	0.07591 0.08936 0.10714	280 95 20	21 8 2
	Nursing	200 600 1,500	37 2 0	606 235 56	0.06106 0.00851 0.00000	280 95 20	17 1 0
	Vet	200 600 1,500	10 0 0	606 235 56	0.01650 0.00000 0.00000	280 95 20	5 0 0
Batch	Hospital	500	115	115	1.00000	165	165
Pathological	Hospital	200	158	308	0.51299	5	3
	Lab	200	50	308	0.16234	5	1
	Nursing	200	14	308	0.04545	5	0
	Vet	200	86	308	0.27922	5	1
			1,425				702

[a]The design capacities are in lb/hr for all combustors except the batch model, which is in lb/batch.

[b]The total identified in industry is the known population of MWI's in a particular industry that is represented by each model combustor (see Tables 2 through 5).

[c]The total identified by design capacity is the total known population of MWI's represented by each of the seven model combustors (See Tables 2 through 5).

[d]The fraction of type in industry is the ratio of total identified in industry to total identified by design capacity.

[e]The projected number of new units by design capacity is the total number of new MWI's represented by each model combustor that are projected to be installed in the 5 years after proposal of the NSPS (e.g., 280 MWI's in the 200 lb/hr intermittent category are projected to be installed.)[89]

[f]The projected number of new units in industry is equal to the projected number of new units by design capacity times the fraction of type in industry (e.g., 280 x 0.84653 = 237 of the 200 lb/hr intermittent combustors are projected in the hospital industry).

TABLE 42. DISTRIBUTION OF EXISTING UNITS IN FIVE MAJOR INDUSTRIES

Combustor type	Industry	Model combustor design capacity[a]	Total identified by design capacity[b]	Total identified in industry[c]	Fraction of type in industry[d]	Estimated No. of existing units in industry[e]	Projected No. of existing units by design capacity[f]
Continuous	Hospital	1,000	62	1,110	0.05586	3,150	176
		1,500	0	1,110	0.00000	3,150	0
	Commercial	1,000	0	39	0.00000	150	0
		1,500	39	39	1.00000	150	150
	Lab	1,000	4	127	0.03150	500	16
		1,500	0	127	0.00000	500	0
Intermittent	Hospital	200	513	1,110	0.46216	3,150	1,456
		600	212	1,110	0.19099	3,150	602
		1,500	50	1,110	0.04505	3,150	142
	Lab	200	46	127	0.36220	500	181
		600	21	127	0.16535	500	83
		1,500	6	127	0.04724	500	24
	Nursing	200	37	53	0.69811	500	349
		600	2	53	0.03774	500	19
		1,500	0	53	0.00000	500	0
	Vet	200	10	96	0.10417	550	57
		600	0	96	0.00000	550	0
		1,500	0	96	0.00000	550	0
Batch	Hospital	500	115	1,110	0.10360	3,150	326
Pathological	Hospital	200	158	1,110	0.14234	3,150	448
	Lab	200	50	127	0.39370	500	197
	Nursing	200	14	53	0.26415	500	132
	Vet	200	86	96	0.89583	550	493
			1,425				4,850[g]

[a]The design capacities are in lb/hr for all combustors except the batch model, which is in lb/batch.

[b]The total identified by design capacity is known population of MWI's in the particular industry that is represented by each model combustor (See Tables 2 through 5).

[c]The total identified in industry is the sum of all known MWI's in a particular industry (e.g., 513 + 212 + 50 + 62 + 115 + 158 = 1,110 known MWI's in the hospital industry).

[d]The fraction of type in industry is the ratio of total identified by design capacity to the total identified in industry.

[e]The estimated number of existing units in industry is the total estimated number of MWI's in a particular industry (e.g., there are an estimated 3,150 MWI's at hospitals).[90]

[f]The estimated number of existing units by design capacity is the estimated number of MWI's represented by each model combustor in each industry (e.g., 3,150 x 0.46216 = 1,456 MWI's in the 200 lb/hr intermittent category at hospitals).

[g]The sum of the projected units does not equal 4,850 due to rounding.

TABLE 43. DISTRIBUTION OF EXISTING MWI'S IN MISCELLANEOUS/UNIDENTIFIED INDUSTRIES

Model	Number of existing MWI's
1	5
2	6
3	5
4	22
5	63
6	10
7	39
Total	150

TABLE 44. CONTINUOUS EMISSION MONITOR COSTS FOR NEW MWI'S[a]

	CEM system costs			
Parameters	Opacity	CO and O_2	CO, O_2, and opacity	CO, O_2, opacity, and HCl
Total capital investment, $				
Planning	700	3,000	3,700	3,900
Select type of equipment	3,800	10,500	13,200	13,500
Provide support facilities	1,500	9,200	10,700	11,700
Purchased equipment cost[b]	22,000	68,000	90,000	111,500
Install and check CEM's[c]	700	12,700	13,500	15,000
Performance spec. tests (certification)	1,400	15,200	16,000	16,800
Prepare QA/QC plan	7,200	12,900	17,000	18,100
Total capital investment	37,300	131,500	164,100	190,500
Annual costs, $/yr				
Operation and maintenance	7,000	10,300	17,500	19,300
Annual RATA[d]	0	10,300	10,300	11,400
Supplemental RATA	0	9,800	9,800	10,200
Quarterly CGA's[e]	0	3,900	3,900	4,200
Recordkeeping and reporting	5,900	12,400	18,300	19,100
Annual review and update	3,600	17,400	20,800	22,600
Property taxes, insurance, and	1,500	5,300	6,600	7,600
administrative	4,400	15,400	19,300	22,400
Capital recovery[f]				
Total annual cost, $/yr	22,400	84,800	106,400	116,800

[a]All costs are based on EMTIC's CEM program, except for property taxes, insurance, administrative, and capital recovery costs, which are all based on procedures from the OAQPS Control Cost Manual.
[b]Includes vendor costs to install equipment and train plant technicians.
[c]Installation costs incurred by facility personnel.
[d]Relative accuracy test audit
[e]Cylinder gas audits
[f]The CRF is 0.11746, based on an assumed equipment life of 20 years and an interest rate of 10 percent.

$150,000. The TCI for retrofits is site-specific because of higher planning and support facility costs. According to the program, typical retrofit costs are 10 percent higher than costs for new facilities. However, retrofit annual costs would be only about 2 percent higher than costs for new installations because only the capital recovery costs are higher.

Purchased equipment, installation, and certification costs were obtained from several CEM vendors and compared with the results from the EMTIC program.[92] This comparison is presented in Table 45 for a system of CO, O_2, and opacity monitors. The vendor equipment costs vary over a wide range primarily because of differences in the design, sophistication, and quality of materials, especially for data acquisition systems (DAS's). The average vendor installation costs are higher than those from the EMTIC program primarily because one vendor reported a much higher cost than all the other vendors. The items included in the installation costs also differ. The vendors included only costs for contractor/vendor activities, while the program also included the facility installation costs (e.g., the time for getting regulatory approval, supervision of contractor/vendor installation, start-up, calibration, and problem resolution). Despite the variation, the overall average purchased equipment, installation, and certification costs from the vendors differ from the cost generated with the program by only about 10 percent.

7.2 PORTABLE CO MONITORS

Portable CO monitors would allow incinerator operators to check the CO emissions on a periodic basis, and the cost would be significantly less than the cost of a CO CEM. According to two vendors, portable CO monitors cost about $1,100. Both monitors are powered by rechargeable batteries, and the recharger is included in the cost of the monitor. One vendor indicated that a 30-sec warm-up period is required before reliable readings are produced. Both monitors measure CO concentrations in the range of 0 to 2,000 ppm. The accuracy is ±2 percent of the reading for one monitor and ±5 percent for the other monitor. For continuous

TABLE 45. COMPARISON OF VENDOR AND EMTIC CEM CAPITAL COSTS

Parameters	Vendor costs		EMTIC program costs
	Range	Average	
Purchased equipment costs, $			
CO monitor	6,500 to 20,600	14,000	10,000
O_2 monitor	3,600 to 16,100	7,800	5,000
Opacity monitor	14,300 to 28,700	23,000	20,000
Data acquisition system	6,000 to 42,100	22,000	N/A[a]
Total[b]	66,600 to 136,500	92,000	90,000
Installation costs, $			
Contractor/vendor costs	7,400 to 60,900	24,800	--[c]
Facility personnel costs	--[d]	--[d]	13,500
Certification costs, $	10,850 to 31,200	16,500	16,000
Total costs, $	84,850 to 228,600	133,300	119,500

[a]The computer program does not give a separate cost for data acquisition equipment.
[b]The total includes costs for sample probes, lines, conditioning system, enclosures, etc. in addition to the monitors and the data acquisition system.
[c]The contractor/vendor costs are included in the purchased equipment costs.
[d]The facility costs were not addressed in the vendor costs.

operation, the maximum operating temperature rating of the probes for both monitors is 1200°F. However, one vendor indicated that the standard probe can be replaced with an Inconel probe that can handle temperature up to 2000°F. The other vendor indicated that the standard probe has a short term temperature rating of 1800°F, but replacing the probe with ceramic tubing would allow operation at that temperature for a longer time or allow operation at higher temperatures. One vendor indicated that the electrochemical sensor and battery pack may need to be replaced every 1 to 2 years at a cost of $200. Both vendors also produce other portable monitors that can measure concentrations of several pollutants and are designed for continuous operation at 1800° to 2200°F. These monitors cost 2 to 6 times more than the CO monitors.[93-95]

7.3 PROCESS MONITORS

Process parameters such as primary and secondary chamber temperature, differential pressure across a FF, liquid flow rates in a VS/PB device, and pressure drop across the venturi throat in a VS/PB device can all be monitored continuously. By detecting deviations from design specifications, these monitors could show when corrective maintenance is needed to restore the incinerator to good operating condition. Weighing the waste before charging helps the operator introduce uniform charges at the design rate, which minimizes overloading.

The cost to continuously monitor temperatures, pressures, and flow rates will depend on the type of control device used. Furthermore, numerous systems can be designed to monitor these parameters. For this analysis, costs were developed for two systems. One system consists of a strip chart recorder and signal wire to monitor the primary and secondary chamber temperatures. The cost for this equipment is about $1,200.[96] The purchased equipment cost for a more comprehensive monitoring system was estimated to be about $8,100. Included in this cost is about $3,000 for a 14-channel data acquisition system that plugs into the parallel printer port of a PC.[97] The system measures signals from thermocouples directly, and it accepts 4- to 20-milliamp signals from pressure transducers and flow meters. A 386 computer (with monitor) that would be more than adequate to record and process the data could be purchased for about $3,000. Software programs to record, process, and generate reports generally cost about $500 to $1,000. Even if a program is not currently available to generate output in an EPA-required format, vendors would quickly modify existing programs to make it available. The cost of a 9-pin dot matrix printer is about $300. Other equipment, including a pressure transducer, flow meters, and signal wire can be purchased for less than $800.

For this analysis, it was assumed that most facilities would choose to use a floor scale to weigh the waste--either by weighing a cart that contains bags of waste or by manually placing on the scale the number of bags that the hopper can hold.

According to two scale distributors, the PEC for a 4' x 4' scale with a digital display and one ramp would be about $3,000.[98,99]

7.4 MAINTENANCE SERVICE

Routine maintenance/service inspections on a periodic basis can help keep the system operating efficiently. Information about the cost to perform routine preventive maintenance service was obtained from one incinerator dealer, one maintenance contractor, and two incinerator manufacturers. Typical functions that these contractors perform during a visit include cleaning and adjusting burners; lubricating hinges and door latches; inspecting/checking the controls, thermocouples, valves, door gaskets, refractory lining, stack, and waste charging ram; and firing the unit with typical waste to confirm that it is operating properly. The cost for a visit depends on the size of the incinerator and the distance travelled. A typical visit requires one full day and costs between $500 and $800, plus travel, expenses, and parts.[100]

8.0 PERFORMANCE TESTING COSTS

This section presents estimated costs to conduct performance testing. An EPA study estimates that the cost to conduct an opacity test and to test for the pollutants PM, Cd, Pb, Hg, CDD/CDF, HCl, and CO would be about $47,000.[101]

Typically, Method 5 is used to measure PM alone, and the sampling and analytical cost for three runs is estimated to be $8,000. The additional cost to conduct three Method 29 runs for three trace metals, including Hg, is approximately $8,000. Other strategies also can be used to measure PM and metals, and, in each case, the cost would be about $16,000.

The estimated cost for conducting three Method 23 runs for CDD/CDF is $21,000. This cost includes analysis of reagent blanks and one audit sample, and it assumes that the test is conducted in conjunction with PM performance testing.

Hydrogen chloride emissions should be measured using EPA Method 26. The estimated cost to conduct three runs in conjunction with PM performance testing is approximately $5,000.

Performance testing for CO should be conducted using EPA Method 10 or 10B. The sampling and analysis cost for three Method 10B runs in conjunction with PM performance testing is approximately $4,000. The cost for instrumental CO testing (Method 10 also would be about $4,000.

Method 9 is used to determine the opacity of emissions. The estimated cost to conduct three Method 9 runs in conjunction with PM performance testing is $1,000.

9.0 REFERENCES

1. Incinerator Sizing Guide and Waste Classification. Cleaver Brooks product literature. May 1989.

2. Letter and attachments from R. Massey, Consumat Systems, Inc., to J. Farmer, EPA/ESD. February 20, 1990. Response to Section 114 information request to MWI manufacturers.

3. Letter and attachments from G. Swann, Joy Energy Systems, Inc., to J. Farmer, EPA/ESD. February 23, 1990. Response to Section 114 information request to MWI manufacturers.

4. Letter and attachments from K. Wright, John Zink, to J. Farmer, EPA/ESD. March 2, 1990. Response to Section 114 information request to MWI manufacturers.

5. Letter and attachments from J. Basic, Sr., John Basic, Inc., to J. Farmer, EPA/ESD. February 26, 1990. Response to Section 114 information request to MWI manufacturers.

6. Letter and attachments from D. Brown, Consertherm Systems, Inc., to J. Farmer, EPA/ESD. March 23, 1990. Response to Section 114 information request.

7. Memorandum from D. Randall, MRI, to Project Files. April 30, 1992. Summary of data provided by hospitals and commercial facilities in response to Section 114 information request.

8. Memorandum from D. Randall and T. Holloway, MRI, to Project files. April 30, 1992. Summary of process data from EPA and non-EPA emissions tests.

9. Letter and attachments from T. Kendron, Simonds Manufacturing Corp., to J. Farmer, EPA/ESD. April 9, 1990. Response to Section 114 information request to MWI manufacturers.

10. Telecon. M. Cassidy, MRI, with J. McCarthy, Air Pollution Control District of Jefferson County. November 13, 1989.

11. National Incinerator, Inc. Product literature. Corsicana, Texas. Undated.

12. Air Pollution Source Management System, Current Application Data List, Hospital Incinerator List. Compiled by New York State Department of Environmental Conservation, Albany, New York. October 17, 1985.

13. Listing of Incinerators in the State of New Jersey. Compiled by New Jersey Department of Environmental Protection, Trenton, New Jersey. Received in 1989.

14. Survey of Medical Waste Incinerators in the State of Washington. August 18, 1989.

15. Radian Corporation. Medical Waste Incineration Emission Test Report, Volumes I, II, and III - Lenior Memorial Hospital, Kinston, North Carolina. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. May 1990.

16. Energy and Environmental Research Corporation. Michigan Hospital Incinerator Emissions Test Program. Volume II. Site Summary Report Borgess Medical Center Incinerator. Prepared for Public Service Commission, State of Michigan, Department of Commerce, and U. S. Environmental Protection Agency. Irvine, CA. August 13, 1991.

17. Energy and Environmental Research Corporation. Michigan Hospital Incinerator Emissions Test Program. Volume III. Site Summary Report University of Michigan, Prepared for State of Michigan, Department of Commerce and U. S. Environmental Protection Agency. Irvine, CA. August 13, 1991.

18. Radian Corporation. Medical Waste Incineration Emission Test Report, Volumes I, II, and III. Cape Fear Memorial Hospital, Wilmington, North Carolina. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. November 1990.

19. Radian Corporation. Medical Waste Incineration Emission Test Report, Volumes I, II, and III - AMI Central Carolina Hospital, Sanford, North Carolina. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. December 1990.

20. Letter from G. Maxwell, Waste Management of North America, Inc., to J. Eddinger, EPA/ISB. May 9, 1991. Comments on draft regulatory support documents.

21. Radian Corporation. Medical Waste Incineration Emission Test Report, Volumes I, II, and III - Jordan Hospital, Plymouth, Massachusetts. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, N.C. February 1991.

22. Telecon. D. Randall, MRI, with W. Wiley, Consumat Systems, Inc. February 23, 1990.

23. Letter and attachments from K. Shodeen, CIL Incineration Systems, Inc., to W. Maxwell, EPA/ISB. February 13, 1990. Response to Section 114 information request to MWI manufacturers.

24. U. S. Environmental Protection Agency. Operation and Maintenance of Hospital Medical Waste Incinerators. Research Triangle Park, NC. EPA-450/3-89-002. March 1989. p. 4-13.

25. Letter and attachments from M. Gaskin, Morse Boulger, Inc., to J. Farmer, EPA/ESD. February 28, 1990. Response to Section 114 information request to MWI manufacturers.

26. Telecon. D. Randall, MRI, with M. Voight, Simonds Manufacturing Corp. February 2, 1990. Design and operation data for batch and pathological MWI's.

27. Memorandum from D. Randall, MRI, to Project files. December 31, 1992. Calculation of stack gas flow rates for model combustors.

28. Letter and attachments from D. Sanders, Andersen 2000, Inc., to W. Maxwell, EPA/ISB. January 29, 1990. Response to request for control equipment design and cost information.

29. Letter and attachments from A. Dozier, Advanced Concepts, Inc., to W. Maxwell, EPA/ISB. January 21, 1990. Response to request for control equipment design and cost information.

30. Telecon. M. Turner, MRI, with D. Sanders, Andersen 2000. March 16, 1990. Design and operating parameters for APCD.

31. Letter and attachments from S. Sheppard, The Ceilcote Co., to W. Maxwell, EPA/ISB. January 31, 1990. Response to request for control equipment design and cost information.

32. Letter and attachments from E. Mull, Interel, to W. Maxwell, EPA/ISB. January 30, 1990. Response to request for control equipment design and cost information.

33. Letter and attachments from P. Finnis, Procedair, to W. Maxwell, EPA/ISB. February 1, 1990. Response to request for control equipment design and cost information.

34. Letter and attachments from J. Childress, United McGill Corp., to W. Maxwell, EPA/ISB. February 9, 1990. Response to request for control equipment design and cost information.

35. Letter and attachments from W. Wiley, Consumat Systems, Inc., to W. Maxwell, EPA/ISB. March 19, 1990. Response to request for control equipment and cost information.

36. Fax transmission from W. Wiley, Consumat Systems, Inc., to M. Turner, MRI. June 6, 1991. MWI's with Consumat's DI/FF equipment.

37. Telecon. D. Randall, MRI, with a Commercial Medical Waste Incineration Company. July 20, 1990. Design and operation of MWI's and APCD's.

38. Radian Corporation Medical Waste Incineration Emission Test Report, Volumes I, II, and III - Borgess Medical Center, Kalamazoo, Michigan. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, N.C. December 1991.

39. Incineration permit for Jordan Hospital, Plymouth, Massachusetts. April 19, 1989.

40. Telecon. T. Holloway, MRI, with R. Gleiser, Joy Environmental Equipment Company. March 17, 1992. Design and cost information for SD/FF control device.

41. Radian Corporation. Medical Waste Incineration Emission Test Report, Volumes I and II - Morristown Memorial Hospital, Morristown, New Jersey. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, N.C. December 1991.

42. Letter and attachments from R. Gleiser, Joy Environmental Equipment Company, to W. Maxwell, EPA:ISB. May 3, 1990. Response to request for control equipment design and cost information.

43. Telecon. T. Holloway, MRI, with J. Childress, United McGill Corp. April 7, 1992. Design information for SD/FF control device.

44. Letter and attachments from G. Blizard, Jr., ThermAll, Inc., to W. Maxwell, EPA:ISB. December 28, 1990. Response to request for design and cost information about rotary kiln combustors.

45. Letter and attachments from R. Hosler, Sly Manufacturing Company, to W. Maxwell, EPA:ISB. March 6, 1990. Response to request for information about APCD's used with MWI's.

46. Telecon. D. Randall, MRI, with W. Wiley, Consumat Systems, Inc. May 21, 1990. Design and cost information about APCD's used with MWI's.

47. Telecon. D. Randall, MRI, with S. Shuler, Joy Energy Systems, Inc. September 13, 1990. MWI costs.

48. Letter from J. Childress, United McGill, to W. Maxwell, EPA:ISB. August 7, 1990. Design and cost information about APCD.

49. Telecon. D. Randall, MRI, with E. Kniss, Procedair Industries. July 27, 1990. Design and cost information about APCD's.

50. Telecon. D. Randall, MRI, with J. Childress, United McGill Corp. May 24, 1990. Design and cost information about APCD's.

51. Letter from E. Mull, Interel Corp., to D. Randall, MRI. September 24, 1990. APCD component costs.

52. Telecon. D. Randall, MRI, with S. Sheppard, Ceilcote. June 17 and July 23, 1990. Design and cost information about APCD.

53. Letter and attachments from S. Sheppard, Ceilcote, to W. Maxwell, EPA:ISB. June 25, 1990. Design and cost information about APCD.

54. Letter and attachments from L. Henson, Andersen 2000, Inc., to W. Maxwell, EPA:ISB. June 5, 1990. APCD component costs.

55. Telecon. D. Randall, MRI, with E. Mull, Interel Corp. September 17, 1990. Design and cost information about APCD's.

56. Telecon. D. Randall, MRI, with W. Wiley, Consumat Systems, Inc. November 19, 1990. Design and cost information for APCD's.

57. Letter and attachments from G. Maxwell, Waste Management of North America, Inc., to W. Maxwell, EPA:ISB. January 22, 1991. Costs for MWI's and APCD's.

58. Telecon. D. Randall, MRI, with G. Blizard, ThermAll, Inc. February 11, 1991. MWI and APCD costs.

59. Memorandum from D. Randall, MRI, to project files. February 1, 1991. Procedures for estimating MWI and APCD capital costs.

60. Neveril, R.B. Capital and Operating Costs of Selected Air Pollution Control Systems. GARD, Inc. Prepared for U. S. EPA Office of Air and Waste Management. December 1978. EPA 450/5-80-002. pp. 4-28 and 4-73.

61. Telecon. M. Caldwell, MRI, with G. Kraft, American Water Works Association. March 13, 1989. Information regarding nationwide residential and commercial water rates for January 1989.

62. Municipal Waste Combustors-Background Information for Proposed Standards: Cost Procedures. Prepared for U. S. EPA Office of Air Quality Planning and Standards. August 14, 1989. EPA 450/89-27a. p. 3.2-13.

63. OAQPS Control Cost Manual (Fourth Edition). EPA 450/3-90-006. January 1990. p. 2-25.

64. Reference 64, p. 2-26.

65. Memorandum from S. Shoraka, MRI, to K. Durkee, EPA/ISB. November 14, 1991. Costs for alternative methods of medical waste treatment.

66. Incinerator specifications literature from Cleaver Brooks. March 1987.

67. Economic Indicators. Chemical Engineering. Plant Cost Equipment Index for October 1989. January 1990. p. 216.

68. Reference 61, pp. 4-25 and B-2.

69. Reference 64, p. 2-29.

70. Reference 64, p. 5-49.

71. Equipment Index for August 1986. October 27, 1986. p. 7.

72. Memorandum from S. Shoraka and C. Hester, MRI, to project files. August 4, 1992. Emission rates for MWI's.

73. Telecon. D. Randall, MRI, with C. Cutting, Sparrow Hospital. July 23, 1990. Ash disposal procedures.

74. Telecon. D. Randall, MRI, with R. Poll, Valley City Disposal. July 20, 1990. Ash disposal procedures.

75. Telecon. D. Randall, MRI, with G. Druen, Evanston Hospital. July 20, 1990. Ash disposal procedures.

76. Telecon. D. Randall, MRI, with G. Lowe, Fairfax Hospital. July 24, 1990. Ash disposal procedures.

77. Telecon. D. Randall, MRI, with P. Stearns, Borgess Medical Center. July 20, 1990. Ash disposal procedures.

78. Telecon. T. Holloway, MRI, with L. Romesberg, Radian Corporation. October 17-18, 1991. Cost of the activated carbon injection equipment used during emission test at Facility A.

79. Letter from B. Brown, Joy Environmental Equipment Company, to T. Brna, EPA:CRB. May 10, 1991. Cost of activated carbon.

80. Telecon. D. Randall, MRI, with A. Jackson, Minnesota Pollution Control Agency. January 4, 1991. Discussion of retort incinerators.

81. Telecon. D. Kapella, MRI, with T. Gordy, Washington State Department of Ecology. January 22, 1991. Discussion of retort incinerators.

82. Telecon. D. Randall, MRI, with S. Shuler, Joy Energy Systems, Inc. February 13, 1991. Secondary chamber retrofit on MWI's.

83. Telecon. D. Kapella, MRI, with W. Wiley, Consumat Systems, Inc. February 11, 1991. Secondary chamber retrofits on MWI's.

84. Telecon. S. Shoraka, MRI, with P. Guller, Biomedical Services, Inc. January 23, 1991. Costs for alternatives to onsite incineration of medical waste.

85. Telecon. S. Shoraka, MRI, with L. Roberts, Bio-Environmental Services, Inc. January 18, 1991. Costs for alternatives to onsite incineration of medical waste.

86. Telecon. S. Shoraka, MRI, with D. Setley, Medical Disposal Services, Inc. February 4, 1991. Costs for alternatives to onsite incineration of medical waste.

87. Telecon. S Shoraka, MRI, with B. Borton, Med-Waste, Inc. February 4, 1991. Costs for alternatives to onsite incineration of medical waste.

88. Telecon. S. Shoraka, MRI, with P. Wall, Medical Area Service Corp. February 4, 1991. Costs for alternatives to onsite incineration of medical waste.

89. Memorandum from S. Shoraka, MRI, to project files. December 10, 1990. Projections for new MWI population.

90. U. S. Environmental Protection Agency. Medical Waste Incinerators - Background Information for Proposed Standards and Guidelines: Industry Profile Report for New and Existing Facilities. EPA-453/R-94-042a. July 1994. pp. 73-75.

91. U. S. Environmental Protection Agency. CEM computer program cost model. Emission Measurement Technical Information Center. Research Triangle Park, NC. Prepared by Entropy Environmentalists, Inc. March 21, 1991.

92. Memorandum from D. Randall, MRI, to project files. April 30, 1992. Summary of CEM costs from vendors.

93. Fax transmission from L. Gallaro, COSA Instrument Corporation, to T. Holloway, MRI. December 13, 1991. Design specifications and costs for portable emissions monitors.

94. Fax transmission from C. Trent, Energy Efficiency Systems, Inc., to T. Holloway, MRI. December 13, 1991. Design specifications and costs for portable emissions monitors.

95. Telecon. T. Holloway, MRI, with C. Trent, Energy Efficiency Systems, Inc. December 13, 1991 and April 22, 1992. Specifications and costs for portable CO monitors.

96. The OMEGA Temperature Handbook. Volume 27. OMEGA Engineering, Inc. Stamford, Connecticut. p. N-65.

97. The OMEGA Instrumentation and Reference Yearbook. Volume 27, Supplement. OMEGA Engineering, Inc. Stamford, Connecticut. p. F-45.

98. Letter from S. Gaines, J.A. King & Company, Inc. , to D. Randall, MRI. December 10, 1991. Price quotation for floor scale.

99. Letter from S. Johnson, W.B.. Porter & Company, to D. Randall, MRI. April 22, 1992. Price quotation for floor scales.

100. Memorandum from T. Holloway, MRI, to R. Copland, EPA:SDB. August 31, 1992. Industry comments on Maintenance/ Inspection and Monitoring Programs for MWI's.

101. U. S. Environmental Protection Agency. Medical Waste Incinerator Study: Emission Measurement and Continuous Monitoring. October 8, 1992.

Appendix A

Cost Algorithm for Intermittent Combustor Annual Costs

	Factors	Model Combustors 3	4	5
A. Model parameters				
1. Design waste charging capacity, lb/hr		1,500	600	200
2. Operating hours, hr/yr				
a. preheat phase		156	156	156
b. burning phase		2,340	2,340	1,716
c. burndown phase		1,248	1,248	1,248
3. Operating days, d/yr		312	312	312
4. Volumetric flow rate out of SC, dscfm		4,747	1,899	633
B. Total capital investment (TCI)				
1. Combustor cost, $=1.48*5817*lb/h^0.4537		$237,659	$156,822	$95,266
C. Annual costs				
1. Electricity				
a. hp=0.0101*lb/hr+1.677				
b. unit cost, $/kwh	0.06			
c. $/yr=(0.746)(hp)($/kwh)(hr/yr)		$2,820	$1,297	$516
2. Natural gas				
a. PC burner capacity, Btu/hr (129.1)(lb/hr)+170,273		363,923	247,733	196,093
b. SC burner capacity, Btu/hr (1290)(lb/hr)+297,036		2,232,036	1,071,036	555,036
c. preheat phase				
(1) PC burner utilization rate, %	100			
(2) SC burner utilization rate, %	100			
d. burning phase				
(1) PC burner utilization rate, %	0			
(2) SC burner utilization rate, %	50			
e. burndown phase				
(1) PC burner utilization rate, %	75			
(2) SC burner utilization rate, %	90			
f. unit cost, $/1000 ft3	3.5			
g. heating value, Btu/ft3	1000			
h. therefore, $/1,000,000 Btu	3.5			
i. $/yr=(burner capacities)(utilization rates)(hr/yr)($/1000 ft3)(ft3/Btu)		$20,524	$10,128	$4,901
3. Water				
a. unit cost, $/1000 gallons	0.77			
b. consumption, gpm		1	0.5	0
c. $/yr=(gpm)(60 min/hr)(burning phase hr/yr)($/1000 gal)		$108	$54	$0
4. Operating labor				
a. burning phase labor, percent	50			
b. Ash removal, hr/day		1	0.75	0.5
c. wage rate, $/hr	12			
d. $/yr=((percent/100)(hr/yr)+(ash hr/d)(d/yr))($/hr)		$17,784	$16,848	$12,168
5. Supervisory labor				
a. $/yr=(0.15)(operating labor)		$2,668	$2,527	$1,825

6.	Maintenance labor				
	a. labor, hr/8hr (for all operating hours)	0.5			
	b. wage rate, $/hr=(1.1)($12/hr)	13.2			
	c. $/yr=(hr/8hr)($/hr)(hr/yr)		$3,089	$3,089	$2,574
7.	Maintenance materials				
	a. $/yr=0.02*TCI		$4,753	$3,136	$1,905
8.	Ash disposal				
	a. ash, % of waste charge	9			
	b. disposal charge, $/ton	40			
	c. $/yr=(lb/hr)(burning phase hr/yr) (ton/2000 lb)(ash %)($/ton)		$6,318	$2,527	$618
9.	PC refractory replacement				
	a. Assume PC is enclosed in a cylindrical shell				
	(1) Horizontal cylinder for units with capacity greater than 500 lb/hr				
	(2) Vertical cylinder for units with capacity less than 500 lb/hr				
	b. PC volume, ft^3 V=(0.304)(lb/hr)+26.05		482.05	208.45	86.85
	c. L/D ratio	1.5			
	d. Internal diameter, ft D=((4*V)/(3.1416*1.5))^(1/3)		7.42	5.61	4.19
	e. Internal length, ft		11.14	8.42	6.29
	f. Refractory thickness, in.	4.5			
	g. Refractory volume, ft^3 (includes sides and ends of cylinder)		134.78	77.98	44.20
	h. Unit refractory cost, $/ft^3	127			
	i. Total refractory cost, $		$17,117	$9,904	$5,614
	j. Insulation thickness, in.	2			
	k. Insulation volume, ft^3 (outside of refractory on all walls)		64.56	38.19	22.29
	l. Unit insulation cost, $/ft^3	43			
	m. Total insulation cost, $		$2,776	$1,642	$958
	n. Refractory and insulation replacement frequency, yr	8			
	o. Capital recovery factor (CRF)	0.18744			
	p. Replacement cost, $/yr =CRF*(refractory cost+insulation cost)		$3,729	$2,164	$1,232
10.	SC refractory replacement				
	a. Assume SC for all combustor types is enclosed in a cylindrical shell				
	b. Assumed L/D ratio	2			
	c. SC volume, ft^3 =(dscfm/0.9)*(2260/528)*(1 sec)*(min/60 sec) The design temperature of 1800 F was used instead of the typical operating temperature of 1700 F in this equation		376.27	150.52	50.17
	d. Internal diameter, ft =((V)*(2)/3.1416))^(1/3)		6.21	4.58	3.17
	e. Internal length, ft =(V*4)/(3.1416*d^2)		12.42	9.15	6.35
	f. Refractory thickness, in.	4.5			
	g. Refractory volume, ft3		119.09	65.72	32.45
	h. Unit refractory cost, $/ft3	127			
	i. Total refractory cost, $		$15,124	$8,346	$4,122
	j. Insulation thickness, in.	2			
	k. Insulation volume, ft3		57.71	32.74	16.88
	l. Unit insulation cost, $/ft3	43			
	m. Total insulation cost, $		$2,481	$1,408	$726
	n. Refractory and insulation replacement frequency, yr	8			

o. Capital recovery factor (CRF)	0.18744			
p. Replacement cost, \$/yr = CRF*(refractory cost+insulation cost)		\$3,300	\$1,828	\$909
11. Overhead				
a. \$/yr=(0.6)(all labor and maintenance materials)		\$16,976	\$15,360	\$11,084
12. Property tax, insurance, and administration				
a. \$/yr=(0.04)(TCI)		\$9,506	\$6,273	\$3,811
13. Capital recovery				
a. Equipment life, yr	20			
b. Interest rate, percent	10			
c. capital recovery factor	0.11746			
d. \$/yr=(CRF)(TCI-refractory replacement cost)		\$27,528	\$18,206	\$11,083
D. Total annual cost		\$119,103	\$83,437	\$52,626
1. \$/yr=sum of annual costs above				

Appendix B

Cost Algorithm for 2-second Secondary Chamber Combustion Control for all APCD Control Technologies

A. Total Capital Investment

1. 2-sec SC cost = 10.87*dscfm+12,674

B. Annual Combustor Control Costs

1. Additional Refractory Replacement Costs For 2-Second Secondary Chambers

a. Assume SC for all combustor types are enclosed in cylindrical shell
b. Assumed L/D ratio = 2:1
c. 2-second SC refractory replacement
   (1) 2-sec SC volume, ft3 = dscfm/0.9*2260R/528R*2sec*1min/60sec
   (2) 2-sec SC diameter, ft = (SC volume*2/3.1416)^0.3333
   (3) 2-sec SC length, ft = SC volume*4/(3.1416*(SC dia.)^2)
   (4) 2-sec SC refractory replacement cost, 2SRR =
   (3.1416/4*(((0.75ft+SC dia.)^2-SC dia.^2)*SC length)
   + 2*(3.1416/4*(SC dia)^2*(4.5 in.*1 ft/12 in.)))*$127/1ft3
   (5) 2-sec SC insulation replacement cost, 2SIR =
   (3.1416/4*(((0.75ft+0.333ft+SC dia.)^2-(SC dia.+0.75)^2)*SC length)
   + 2*(3.1416/4)*(SC dia+4.5/12)^2*2/12)*$43/1ft3

d. 1-second SC refractory replacement
   (1) 1-sec SC volume, ft3 = dscfm/0.9*2260R/528R*1sec*1min/60sec
   (2) 1-sec SC diameter, ft = (SC volume*2/3.1416)^0.3333
   (3) 1-sec SC length, ft = SC volume*4/(3.1416*(SC dia.)^2)
   (4) 1-sec SC refractory replacement cost, 1SRR =
   (3.1416/4*(((0.75ft+SC dia.)^2-SC dia.^2)*SC length)
   + 2*(3.1416/4*(SC dia)^2*(4.5 in.*1 ft/12 in.)))*$127/1ft3
   (5) 1-sec SC insulation replacement cost, 1SIR =
   (3.1416/4*(((0.75ft+0.333ft+SC dia.)^2-(SC dia.+0.75)^2)*SC length)
   + 2*(3.1416/4)*(SC dia+4.5/12)^2*2/12)*$43/1ft3

e. Additional cost for 2-sec refractory replacement, AC2SC = (2SRR+2SIR)-(1SRR+1SIR)

f. Additional annual cost for 2-sec refractory replacement, AAC2SC = AC2SC*0.11746

2. Natural gas

a. Fuel to raise operating temperature from 1700F to 1800F (all models), $/yr
   = (0.32BTU/lb/F)*(28.5lb/lbmole)*(100F)*(lbmole/385ft3))*
   (ft3/1000 BTU)*($3.5/1000 ft3)*(dscfm/0.9)*
   (60min/h)*(total operating hr/d)*(d/yr)
   = (0.000553*dscfm)*hr/yr

b. Fuel used during cooldown (intermittent and batch models), $/yr
= (0.32BTU/lb/F)*(28.5lb/lbmole)*(1800F-(1800-300F)/2)*(lbmole/385ft3))*
(ft3/1000 BTU)*($3.5/1000 ft3)*(dscfm/0.9)*
(60min/h)*(cooldown operating hr/d)*(d/yr)
= (0.00415*dscfm)*hr/yr

3. Maintenance materials

   a. $/yr=(0.02)*(TCI for Combustion Control)

4. Overhead

   a. $/yr=(0.6)*(Additional maintenance materials)

5. Property tax, insurance, and administration

   a. $/yr=(0.04)*(TCI for Combustion Control)

6. Capital recovery

   a. CRF = 0.11746
   b. $/yr=(CRF)*(TCI for Combustion Control - Additional refractory capital cost, AC2SC)

Appendix C

Cost Algorithm for VS/PB Control Device

A. Total capital investment

1. APCD cost, \$=A*dscfm+B

where A=	33.3
B=	118,969

B. Direct annual costs

1. Fan electricity

a. Form Figure 18, average fan hp=C*dscfm

where C=	0.0205

b. Avg. unit electricity cost, \$/kwh	0.06
c. \$/yr=(0.746)*(hp)*(unit cost)*(hr/yr)	
=(0.746)*(C*dscfm)*(\$/kwh)*(hr/yr)	
=(E*dscfm)*(hr/yr)	
where E=	0.000918

2. Pump electricity

a. From Figure 19, hp=(G*dscfm+H)	
where G=	0.00267
H=	4.554
b. \$/yr=0.746*(G*dscfm+H)*(\$/kwh)*(hr/yr)	
=(I*dscfm+J)*(hr/yr)	
where I=	0.000120
J=	0.2038

3. Makeup scrubber water

a. From Figure 20, gpm=K*dscfm

where K=	0.00512

b. Unit water cost, \$/1,000 gal	0.77
c. \$/yr=(K*dscfm)*(\$/1,000 gal)*(hr/yr)*(60 min/hr)	
=(M*dscfm)*(hr/yr)	
where M=	0.000237

4. Operating labor

a. Operating labor required, hr/shift	0.4
b. Labor wage rate, \$/hr	12
c. \$/yr=(hr/shift)*(1 shift/8hr)*(\$/hr)*(hr/yr)	
=P*(hr/yr)	
where P=	0.6

5. Supervisory labor

a. Supervisory labor=0.15*(operating labor)
b. $/yr=0.15*(P)*(hr/yr)
=Q*(hr/yr)
where Q= 0.09

6. Maintenance labor

a. Maintenance labor required, hr/shift 0.3
b. Wage rate=1.1*(operating labor wage rate)
c. $/yr=(hr/shift)*(1 shift/8 hr)*(operator $/hr)*(1.1)*(hr/yr)
=R*(hr/yr)
where R= 0.495

7. Maintenance materials

a. Materials cost=0.02*TCI
b. $/yr=0.02*(A*dscfm+B)
=RR*dscfm+SS
where RR= 0.666
SS= 2379

8. Caustic (NaOH)

a. Assume stoichiometric amount of NaOH is added for reaction with acid gases

b. HCl in exhaust gas, lb/hr=(ppm HCl/1,000,000)*(lbmole/385 dscf)
(dscfm)(36.5 lb HCl/lbmole HCl)*(60 min/hr)
=S*dscfm*(ppm HCl)
where S= 5.688E-06
c. NaOH to neutralize HCl,
lb/hr=S*dscfm*(ppm HCl)*(40/36.5)*(1 lbmole NaOH/1 lbmole HCl)
=T*dscfm*(ppm HCl)
where T= 6.234E-06

d. Dry NaOH cost, $/ton 400
e. Caustic cost, $/yr=(NaOH to neutralize HCl, lb/hr)*($/ton)
(ton/2,000 lb)(hr/yr)
=(W*ppm HCl)*(dscfm)*(hr/yr)
where W= 1.247E-06

9. Sewer charge

a. From Figure 21, blowdown, gal/min=X*dscfm
where, X= 0.000747
b. unit cost, $/1,000 gal 2.00
c. $/yr=(X*dscfm)*($/1,000 gal)*(60 min/hr)*(hr/yr)
=(Z*dscfm)*(hr/yr)
where Z= 8.964E-05

C. Indirect Annual Costs

1. Overhead

a.	$/yr=(60 percent)*[(all labor, in hr/yr)+(maintenance materials)]		
	=0.6*[(P+Q+R)*(hr/yr)+(RR*dscfm+SS)]		
	=(BB*h/yr)+PP*dscfm+QQ		
	where	BB=	0.711
		PP=	0.3996
		QQ=	1428

2. Property tax, insurance, administration

a.	$/yr=(4 percent)*(Total Capital Investment)		
	=(0.04)*(A*dscfm+B)		
	=CC*dscfm+DD		
	where	CC=	1.332
		DD=	4,759

3. Capital recovery

a.	Equipment life, years		20
b.	Interest rate, percent		10
c.	Capital recovery factor		0.11746
d.	$/yr=CRF*(TCI)		
	=0.11746*((A*dscfm+B)		
	=EE*dscfm+FF		
	where	EE=	3.9114
		FF=	13,974

D. Total annual costs

1.	a.	Sum of all annual costs		
	b.	$/yr={((W*ppm HCl)+(E+I+M+Z))*dscfm+(J+P+Q+R+BB)}*(hr/yr)		
		+(CC+EE+PP+RR)*dscfm+(DD+FF+QQ+SS)		
		=(((W*ppm HCl)+AB)*dscfm+AC)*(hr/yr)+(AD*dscfm)+AE		
		where	AB=	0.00136
			AC=	2.0998
			AD=	6.3090
			AE=	22,540
			W=	1.247E-06

Appendix D

Cost Algorithm for DI/FF Control Device

A. Total Capital Investment

1. APCD cost from Figure 6, $=PP*dscfm+QQ

where PP=	63.8
QQ=	407,498

B. Direct Annual Operating Costs

1. Fan electricity

a. Average fan hp from Figure 18=A*dscfm+B

where A=	0.0065
B=	2.88

b. Avg. unit electricity cost, $/kwh 0.06

c. $/yr=(0.746)*(hp)*(unit cost)*(hr/yr)
=(0.746)*(A*dscfm+B)*($/kwh)*(hr/yr)
=(C*dscfm+D)*(hr/yr)

where C=	0.00029094
D=	0.129

2. Other electricity

a. Avg. is 22 percent of fan electricity, according to two vendors

b. $/yr=0.22*(C*dscfm+D)*(hr/yr)
=(E*dscfm+F)*(hr/yr)

where E=	6.401E-05
F=	0.0284

3. Makeup lime

a. No recycle, but the system includes a retention chamber

b. Avg. lime makeup, lb/hr = (2.5 lbmole lime/2 lbmole HCl)*(ppm HCl/10E6)*
(lbmole HCl/385 dscf HCl)*(dscfm)(60 min/hr)(MW lime)
=(1.44*10E-5)*(ppm HCl)*(dscfm)
=(G)*(ppm HCl)*(dscfm)

where G=	1.44E-05

c. Lime cost, $/ton 100

d. $/yr=(G*ppm HCL*dscfm)*($100/ton)*(1 ton/2000 lb)*(hr/yr)
=(I*ppm HCl)*(dscfm)*(hr/yr)

where I=	7.200E-07

4. Evaporative cooler water

a.	Moisture in gas before cooler, percent	10
b.	Moisture in gas after cooler, percent	38
c.	Temperature of gas before cooler, F	1800
d.	Temperature of gas after cooler, F	300
e.	Gas flow rate out of cooler from Figure 19, acfm=(K*(dscfm:in)+L)	
	where K=	2.26
	L=	423

f.	Unit water cost, $/1,000 gal	0.77
g.	Water added in cooler, ft3/min at 300 F=(acfm:out)*(% H20)-(acfm:in)*(%H20) =(K*(dscfm:in)+L)*(0.38) -(dscfm:in/0.9)*(0.1)*(760/528) =M*dscfm+N	
	where M=	0.6989
	N=	160.7
h.	$/yr=(M*dscfm+N)*($/1,000gal)*(60 min/hr)*(lbmole/ft3 at 300 F) *(18 lb/lbmole)*(1 lb/8.33 gal)*(hr/yr) =(P*dscfm+Q)*(hr/yr)	
	where P=	0.0001257213
	Q=	0.0289

5. Operating labor

a.	Operating labor required, hr/shift	1
b.	Labor wage rate, $/hr	12
c.	$/yr=(hr/shift)*(1 shift/8hr)*($/hr)*(hr/yr) =R*(hr/yr)	
	where R=	1.5

6. Supervisory labor

a.	Supervisory labor=0.15*(operating labor)	
b.	$/yr=0.15*(R)*(hr/yr) =S*(hr/yr)	
	where S=	0.225

7. Maintenance labor

a.	Maintenance labor required, hr/shift	0.5
b.	Wage rate=1.1*(operating labor wage rate)	
c.	$/yr=(h/shift)*(1 shift/8 hr)*(operator $/hr)*(1.1)*(hr/yr) =T*(hr/yr)	
	where T=	0.825

8. Maintenance materials

a.	Materials cost=0.02*TCI	
b.	$/yr=0.02*(PP*dscfm+QQ) =BA*dscfm+CA	
	where BA=	1.276
	CA=	8150

9. Compressed air

a.	Air required, ft3/1,000 ft3 filtered	2
b.	Air cost, $/1,000 ft3	0.16
c.	Air filtered=air flow in fabric filter =(K*dscfm:in+L)	
d.	$/yr=(K*dscfm+L)*(ft3 air/1,000 ft3 filtered)*($/1,000 ft3)*(60 min/h)*(h/yr) =(U*dscfm+V)*(hr/yr)	
	where U=	4.3392E-05
	V=	0.00812

10. Dust disposal

a. Inlet-outlet PM in gr/dscf at 14% O2 = PM
b. Inlet HCl concentration in ppmdv at 14% O2 = HCl
c. HCl removal efficiency, percent — 95
d. Molecular weight of CaCl2 — 111
e. Molecular weight of CaOH2 — 74
f. Assume dscfm:inlet=dscfm:outlet

g. PM capture, lb/hr=(PM)*(dscfm)*(60 min/hr)*(1 lb/7,000 gr)
   =W*dscfm*PM
   where W= — 0.00857
h. HCl reaction products captured, lb CaCL2/hr
   =(HCl/1,000,000)*(HCl removal efficiency)*(dscfm)*(lbmole CaCl2/2 lbmole HCl)
   (MW CaCl2)(lbmole/385 scf)*(60 min/hr)
   =X*dscfm*HCl
   where X= — 8.217E-06

i. Unreacted lime captured,lb/hr=(makeup lime)-(reacted lime)
   =((G*dscfm*ppm HCl-(X*dscfm*ppm HCl))*(MW CaOH2/MW CaCl2)
   =1.44*10E-5*dscfm*(ppm HCl)-(8.217E-6)*(dscfm)*(ppm HCl)*(74/111)
   =8.922*10E-6*(ppm HCl)*dscfm
   =(Z*HCl)*dscfm
   where Z= — 8.922E-06

j. Unit disposal cost at municipal landfill, $/ton=DC — 40
k. $/yr={(W*dscfm*PM)+((X+Z)*dscfm*HCl)}
   (1 ton/2000 lb)(DC)*(hr/yr)
   =(BB*PM+BC*HCl)*(dscfm)*(hr/yr)
   where BB= — 1.71429E-04
   BC= — 3.42779E-07

11. Bag replacement

a. Avg. bag cost (for outlet conc. of 0.015 gr/dscf), $/ft2 — 2.5
b. Avg. gas flow in ff, acfm = (K*(dscfm:in)+L)
c. Avg bag life, years — 2
d. Interest rate, percent — 10
e. Capital recovery factor — 0.5762
f. Avg. bag area, ft2 — 18
g. Avg. G/C ratio, ft/min — 3.5
h. Bag replacement labor wage rate, $/hr — 12
i. Bag replacement time, hr/bag — 0.15
j. Taxes and freight, percent added to bag cost — 8
k. Total bag cost = (acfm, ff)*(bag cost)*(taxes and freight factor)/(G/C ratio)
   = (K*dscfm+L)*($/bag)*(1.08)/(G/C ratio)
   = DD*dscfm+EE
   where DD= — 1.743
   EE= — 326
l. Total replacement labor cost = (acfm, ff)*(wage rate)*(bag replacement time)/
   (bag area)/(G/C ratio)
   = (K*dscfm+L)*($/hr)*(hr/bag)/(ft2)/(G/C ratio)
   = FF*dscfm+GG
   where, FF= — 0.0646
   GG= — 12.09

m. \$/yr=(Total bag cost + Total labor cost)*(CRF)
=((DD*dscfm+EE)+(FF*dscfm+GG))*(0.5762)
=HH*dscfm+II

where HH=	1.042
II=	195

12. Cage replacement

a. Assume mild steel cages (actual units are galvanized)

b. According to the Cost Manual, for <100 cages, one cage cost in Aug 1986 = (4.941+0.163)*(bag area, ft2))
This equation is also used for >100 cages in this algorithm because it
1. simplifies the algorithm
2. is only slightly different than the appropriate equation. Consequently, the difference in the total cost is negligible.
3. it results in a slightly higher cost than that estimated by the appropriate equation. Therefore, it may better represent the cost of galvanized cages.

c. Avg. cage life, yrs (assumes replacement every other time the bags are replaced)	4
d. Interest rate, percent	10
e. Capital recovery factor	0.31547
f. CE plant index ratio (Oct 89/Aug 86) = 357.5/317.4	1.12634

g. Number of bags = (acfm in ff)/(G/C ratio)/(single bag area)
= (K*dscfm+L)/(G/C ratio)/(ft2)
=JJ*dscfm+KK

where JJ=	0.03587
KK=	6.7143

h. Assume cage replacement labor is the same as bag replacement labor
=FF*dscfm+GG

where FF=	0.0646
GG=	12.09

i. \$/yr={total cage costs + total labor cost}*(CRF)
\$/yr={[(one cage cost)*(number of bags)*(CE plant cost index)]+(FF*dscfm+GG)}*(CRF)
={[4.941+0.163*(bag area, ft2)]*{JJ*dscfm+KK}*(357.5/317.4)+(FF*dscfm+GG)}*(0.31547)
=LL*dscfm+MM

where LL=	0.12075
MM=	22.6006

C. Indirect Annual Costs

1. Overhead

a. \$/yr=(60 percent)*[(all labor)*(hr/yr)+maintenance materials]
=0.6*[(R+S+T)*(hr/yr)+(BA*dscfm+CA)]
=(NN*hr/yr)+DA*dscfm+EA

where NN=	1.5300
DA=	0.7656
EA=	4,890

2. Property tax, insurance, administration

a. \$/yr=(4 percent)*(Total Capital Investment)
=(0.04)*(PP*dscfm+QQ)
=RR*dscfm+SS

where RR=	2.552
SS=	16,300

3. Capital recovery

a. Equipment life, years	20
b. Interest rate, percent	10
c. Capital recovery factor	0.11746
d. Bag replacement cost = (HH*dscfm+II)/0.5762	
= TT*dscfm+UU	
where TT=	1.8080
UU=	338
e. Cage replacement cost = (LL*dscfm+MM)/0.31517	
= VV*dscfm+WW	
where VV=	0.38276
WW=	71.6
f. $/yr=CRF*(TCI-Bag replacement cost-Cage replacement cost)	
=0.11746*((PP*dscfm+QQ)-(TT*dscfm+UU)-(VV*dscfm+WW))	
=XX*dscfm+YY	
where XX=	7.2366
YY=	47,817

D. Total Annual Cost

1. Sum of all annual costs	
2. $/yr={(I*HCl+BB*PM+BC*HCl+C+E+P+U)*dscfm	
+(D+F+Q+R+S+T+V+NN)}*hr/yr+(HH+LL+RR+XX+BA+DA)*dscfm	
+(II+MM+SS+YY+CA+EA)	
=((BB*PM+AF*HCl+AB)*dscfm+AC)*(hr/yr)+(AD*dscfm)+AE	
where AB=	0.00052
AC=	4.274
AD=	12.993
AE=	77,374
AF=	1.063E-06

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

1. REPORT NO. EPA-453/R-94-045a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Medical Waste Incinerators - Background Information for Proposed Standards and Guidelines: Model Plant Description and Cost Report for New and Existing Facilities		5. REPORT DATE July 1994 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Emission Standards Division (Mail Drop 13) Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-D1-0115
12. SPONSORING AGENCY NAME AND ADDRESS Director Office of Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/200/04
15. SUPPLEMENTARY NOTES Published in conjunction with proposed air emission standards and guidelines for medical waste incinerators		

16. ABSTRACT

This report presents the design and operating parameters and costs for model plants that represent the medical waste incinerator (MWI) source category. Costs are presented for both MWI's and air pollution control equipment. The model plants are then used in subsequent environmental and economic analyses. This is one in a series of reports used as background information in developing air emission standards and guidelines for new and existing MWI's.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Pollution Control Standards of Performance Emission Guidelines Medical Waste Incinerators	Air Pollution Control Solid Waste Medical Waste Incineration	
18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(Report)* Unclassified	21. NO. OF PAGES 146
	20. SECURITY CLASS *(Page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE