Date: September 7, 1995

To: MWI Project File

From: Tom Holloway

Subject: Approach Used to Estimate the Capital and Annual Costs for MWI Wet Scrubbers

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I. INTRODUCTION

The following information was used in estimating model wet scrubber costs for intermittent and continuous MWI's:

TABLE 1. MODEL MWI PARAMETERS

Incinerator size	Small	Medium	Large
Incinerator capacity, lb/hr	100	350	1,000
Exhaust gas flow rate, acfm dscfm	 1,503 316	 5,260 1,108	 15,030 3,165
Operating hours, hr/yr	3,744	3,922	4,696
Temperature, °F Incinerator exit Boiler exit	 1,800 450	 1,800 450	 1,800 450
Total PM, gr/dscf Baseline Control level 1 Control level 2 Control level 3	 0.10 0.08 0.03 0.015	 0.10 0.08 0.03 0.015	 0.10 0.08 0.03 0.015
HCl, ppmdv Scrubber inlet Scrubber outlet	 1,460 3.13	 1,460 3.13	 1,460 3.13

The operating hours were estimated as weighted averages of a mixture of intermittent and continuous units for three model MWI capacity ranges (<200, 201-500, and >500 lb/hr). The model HCl concentrations were determined based on controlled and uncontrolled HCl emissions data from MWI's.

The wet scrubber costs for batch MWI's will be addressed in a separate memo.

Wet scrubber vendors were asked in a survey to provide scrubber costs for the three model MWI's based on the three PM control levels. The wet scrubber cost data provided by the vendors are in 1995 dollars. Most of the cost data have been declared confidential. In order to preserve the confidentiality of the cost estimates, the cost data have been summarized together on graphs. These graphs are provided in the attached figures. The range of costs from the vendors is represented on each graph as a shaded area. None of the vendors or vendor costs are identified on the graph. Linear regression analyses were performed on the cost data to determine an "average" wet scrubber cost for each model incinerator size and PM control level. The regression line and corresponding equation are presented along with the shaded range. For those graphs that have only one data point above or below the regression line, the bounds of the shaded range were extrapolated linearly along the regression line. The wet scrubber costs from the survey are presented alongside comparable wet scrubber costs from the MWI background document (which are based on a PM control level of 0.03 gr/dscf). Because most of the vendors provided costs with and without a waste heat recovery boiler after the incinerator, the cost summaries also present wet scrubber costs with and without a boiler.

II. CAPITAL COSTS

Each of the scrubber vendors provided purchased equipment costs for new wet scrubbers and wet scrubber upgrades. The vendors also provided either installation costs or installation cost factors.

In its survey response, Andersen 2000 provided capital costs for wet scrubbers for each of the model MWI's.[1] The capital costs included costs for both new wet scrubbers and wet scrubber upgrades.[1] According to Andersen, the same equipment is required for an upgraded PM level of 0.03 or 0.015 gr/dscf.[1] Therefore, the cost to upgrade to 0.03 or 0.015 gr/dscf would be the same. The upgrade cost assumes no pump would be required for an upgrade. The installation cost was estimated by Andersen to be equal to 30 percent of the equipment capital cost (excluding land, building, support facilities, and foundations).[1] Therefore, the TCI for wet scrubbers was estimated to be equal to 1.3 times the equipment prices provided by Andersen. Because Andersen did not mention whether or not their costs were based on an MWI with a waste heat recovery boiler, the equipment costs and parameters were assumed to be based on an MWI with no boiler.

Because its wet scrubber technology is best suited for large size MWI's, Belco provided costs only for the large model size (1,000 lb/hr).[2] Belco provided capital costs for design/engineering and materials and for installation/erection.[2] The costs were provided for MWI's with and without waste heat recovery boilers.[2] In estimating its wet scrubber costs for MWI's with boilers, Belco assumed a boiler outlet temperature of 500°F.[2] Belco provided costs for both new wet scrubbers and wet scrubber upgrades.[2] Scrubber upgrade costs were estimated to be the same, with or without a boiler.[2]

Monsanto provided purchased equipment and installation costs for three model MWI's without waste heat recovery boilers and for one large size MWI with a boiler.[3] Monsanto provided costs for both new wet scrubbers and wet scrubber upgrades.[3] According to Monsanto, the costs to upgrade wet scrubbers from 0.08 to 0.015 gr/dscf and 0.03 to 0.015 gr/dscf would be the same.[3]

Emcotek developed a series of model MWI's and provided wet scrubber costs for those model sizes. The models include a medium size MWI (300 to 500 lb/hr), a large size MWI (500 to 750 lb/hr), and a commercial/large size MWI (1,000 to 1,500 lb/hr).[4] The midpoints for those model sizes were used in graphing the cost data. The midpoints for the model sizes are 400 lb/hr for the medium size MWI, 625 lb/hr for the large size MWI, and 1,250 lb/hr for the commercial/large size MWI. Operating hours of 3,922, 4,696, and 4,696 hr/yr were assigned to the 400, 625, and 1,250 lb/hr model MWI's, respectively. Factors of 15.03 and 3.165 were applied to the model MWI capacities to estimate the acfm and dscfm exhaust gas flow rates, respectively.

Emcotek provided costs for both new wet scrubbers and wet scrubber upgrades.[4] The new wet scrubber costs were provided for MWI's with or without waste heat recovery boilers.[4] The scrubber upgrade costs were provided only for MWI's with waste heat recovery boilers; however, Emcotek estimated that 10 percent could be added to the scrubber upgrade costs for installations without the boiler.[4]

An error was detected in the Emcotek cost data for new wet scrubbers.[4] A graph of the cost data for the 0.015 gr/dscf PM control level for MWI's with boilers revealed the capital cost for the 625 lb/hr model to be too low (it was identical to the cost for the 400 lb/hr model). According to the graph, the cost should be $10,000 higher. This higher cost was used in preparing the final cost graph for the 0.015 gr/dscf PM control level.

III. ANNUAL COSTS

In the survey, scrubber vendors were asked to provide information which could be used to calculate annual costs for new wet scrubbers and wet scrubber upgrades. The information requested included: (1) pressure drop through the system, (2) fan horsepower, (3) pump horsepower, and (4) maximum total dissolved solids and total suspended solids in recirculating water. The information on horsepower provided by vendors was chosen to estimate the annual electricity costs (pressure drop was not needed to estimate electricity costs since it is related to horsepower). The cost equations used to estimate the annual costs are presented in Table 2.

A. New Wet Scrubbers

Some wet scrubber vendors provided annual cost estimates for labor and maintenance materials. Andersen estimated the maintenance and labor costs to be approximately 5 percent of the equipment capital cost.[1] For the rest of the vendors, the labor costs were estimated using procedures from the OAQPS Control Cost Manual.[5] Operating and maintenance labor costs were estimated to be the product of the hourly wage rate and the operating hours.[5] For operating labor, the wage rate was assumed to be $12/hr, and the operating hours were assumed to be 0.4 hr/8-hr shift.[6] For maintenance labor, the wage rate was assumed to be 10 percent more than for operating labor, and the maintenance hours were assumed to be 0.3 hr/8-hr shift.[5,6] Supervisory labor costs were estimated as 15 percent of operating labor costs.[5]

The cost of maintenance materials was included in the 5 percent cost factor provided by Andersen, and Belco provided cost estimates for routine replacement parts for each model MWI.[1,2] For the other vendors, the maintenance materials were estimated as 2 percent of the TCI.[6] Because of the size and cost of wet scrubber systems, the OAQPS procedure of estimating the maintenance materials costs (i.e., setting maintenance materials costs equal to 100 percent of maintenance labor costs) was believed to underestimate the costs.[6]

Annual electricity costs were estimated as a product of the electricity unit cost and the horsepower requirements provided by the scrubber vendors in their survey responses. The electricity unit cost was estimated to be $0.06/kWh.[6] In their responses, Andersen, Belco, and Monsanto provided fan and pump horsepower requirements for wet scrubbers for each PM control level.[1-3] Andersen provided both brake and total horsepower estimates for the fan and pump.[1] Because brake horsepower is the actual horsepower used to perform the work, the annual electricity costs for the Andersen wet scrubber were estimated using the brake horsepower estimates. Although the horsepower estimates from Belco or Monsanto were not identified as either brake or total horsepower, they were reasonably close to the brake horsepower estimates from Andersen.[2,3] Therefore, the estimates were assumed to be brake horsepower estimates. Because Emcotek did not provide horsepower estimates in its survey response, the electricity cost equation from the MWI background document was used instead; the cost equation had been developed based on cost information from wet scrubber vendors.[6] The equations used to

TABLE 2. EQUATIONS TO ESTIMATE ANNUAL COSTS FOR WET SCRUBBER SYSTEMS

Parameters	Equations
1. Direct annual costs, $/yr	
a. Operating labor	(0.4 hr/8-hr shift) x (hr/yr) x ($12/hr)
b. Supervisory labor	0.15 x (operating labor cost)
c. Maintenance labor	(0.3 hr/8-hr shift) x (hr/yr) x (1.1) x ($12/hr)
d. Maintenance materials	(0.2) x (TCI)
e. Electricity	Without hp information from vendor: (0.001037 x dscfm + 0.2038) x (hr/yr) With hp information from vendor: (hp) x (0.746 kW/hp) x (hr/yr) x ($0.06/kWh)
f. Caustic	(ppmdv HCl) x (6.236 x 10^{-6}) x (dscfm) x (hr/yr) x ($400/ton caustic)
g. Sewage disposal	[Blowdown rate (gpm)] x (60 min/hr) x (hr/yr) x ($2/1,000 gal) Without wt % information from vendor: Blowdown rate (gpm) = 0.000747 x (dscfm) With wt % information from vendor: Blowdown rate (gpm) = [salt + PM (lb/hr)]/[(wt %) x (8.34 lb/gal) x (60 min/hr)] Salt (lb/hr) = [(lb HCl/hr)/(36.5 lb HCl/lbmole HCl)] x (1 lbmole NaCl/1 lbmole HCl) x (58.5 lb NaCl/lbmole NaCl) HCl (lb/hr) = (Δ ppmdv/10^6) x (36.5 lb HCl/lbmole HCl) x (dscfm) x (60 min/hr) x (lbmole HCl/385 scf) PM (lb/hr) = (Δ gr/dscf) x (lb/7,000 gr) x (dscfm) x (60 min/hr)
h. Makeup water	[Makeup water flow rate (gpm)] x (60 min/hr) x (hr/yr) x ($0.77/1,000 gal) Without wt % information from vendor: Makeup water flow rate (gpm) = 0.00512 x (dscfm) With wt % information from vendor: Makeup water flow rate (gpm) = [Blowdown rate (gpm) + evap. rate (gpm)] Blowdown rate (gpm)--equation presented above Evap. rate (gpm) = (acfm) x (lbmole/[(0.7302) x (460 + temp.)ft^3]) x (gal/8.34 lb) x [(0.9) x (29 lb/lbmole) x (abs. hum.) - (0.1) x (18 lb/lbmole)]
2. Indirect annual costs, $/yr	
a. Overhead	(0.6) x (labor + maintenance costs)
b. Property tax, insurance, and administrative	(0.04) x (TCI)
c. Capital recovery	(CRF) x (TCI) CRF = [i x $(1 + i)^n$]/[$(1 + i)^n$ - 1], where i = interest rate and n = equipment life
3. Total annual cost, $/yr	(Direct annual costs) + (Indirect annual costs)

estimate the electricity costs are presented in Table 2.

For each of the wet scrubber vendors, the annual cost for caustic was estimated based on a caustic cost equation from the MWI background document.[6] The caustic cost equation is presented in Table 2.

The sewage disposal costs were estimated as a product of the blowdown rate and the sewage disposal unit cost. The sewage disposal unit cost was estimated to be $2/1,000 gal.[6] In its survey response, Belco estimated water usage/discharge rates of less than 1 gpm for each PM control level.[2] To be conservative, the 1 gpm value was used to estimate costs. In its survey response, Andersen provided separate estimates for maximum total dissolved solids (6 weight percent) and maximum total suspended solids (0.5 weight percent) for the scrubber system.[1] Therefore, separate blowdown rates were estimated for total dissolved solids (i.e., salt) and total suspended solids (i.e, PM). The higher blowdown rate was used in determining the sewage disposal cost. Because Monsanto and Emcotek did not provide information on blowdown rate or on weight percent solids, the sewage disposal costs for those vendors were estimated based on a blowdown rate equation from the MWI background document; the blowdown rate equation had been developed based on information from wet scrubber vendors.[6] The equations used to estimate the sewage disposal costs are presented in Table 2.

The makeup water costs were estimated as a product of the makeup water unit cost and the makeup water usage. The makeup water unit cost was estimated to be $0.77/1,000 gal.[6] Makeup water includes water for scrubber blowdown plus water evaporated to cool the exhaust gas. In its survey response, Belco estimated water usage/discharge rates of less than 1 gpm for each PM control level.[2] To be conservative, the 1 gpm value was used to estimate costs. For Andersen, the makeup water usage was estimated by adding the evaporation rate to the scrubber blowdown rate discussed in the previous paragraph. The amount of water evaporated was estimated based on the temperature and absolute humidity of the gas exiting the incinerator (or boiler if the MWI has a waste heat recovery boiler). The absolute humidity was estimated using a psychrometric chart (Figure 20-11) in the 5th edition of Perry's Chemical Engineer's Handbook.[7] Vendors indicated that the saturated gas stream would be at about 175°F when the exhaust from the incinerator is at 1,800°F and 10 percent moisture; the absolute humidity of saturated gas at 175°F is 0.53 lb water/lb dry air. The saturated gas stream would be at about 140°F when the exhaust from the boiler exit is at 450°F; the absolute humidity of saturated gas at 140°F is 0.15 lb water/lb dry air. Because Monsanto and Emcotek did not provide information on blowdown rate or on weight percent solids, the makeup water costs for those vendors were estimated based on a makeup water rate equation from the MWI background document; the makeup water rate equation had been developed based on information from wet scrubber vendors.[6] The equations used to estimate the makeup water costs are presented in Table 2.

Overhead costs were estimated according to OAQPS procedures as 60 percent of labor and maintenance costs.[5]

Annual costs for administration, property taxes, and insurance were estimated according to OAQPS procedures as 4 percent of the TCI.[5]

Capital recovery costs were estimated as a product of a capital recovery factor and the TCI.[5] The capital recovery factor was estimated based on the expected equipment life and the interest rate. In their survey responses, both Andersen and Belco provided information on the equipment life for their wet scrubber systems.[1,2] The useful life of the Andersen wet scrubber system was given as 10 years.[1] Based on a 10-year equipment life and assuming a 10 percent interest rate, the capital recovery factor for the Andersen scrubber system would be 0.16275. The life expectancy for the Belco wet scrubber system was given as 20 years.[2] Based on a 20-year equipment life and assuming a 10 percent interest rate, the capital recovery factor for the Belco scrubber system would be 0.11746. For the other vendors, a 20-year equipment life (capital recovery factor = 0.11746) was assumed in estimating the capital recovery costs for the scrubber systems.[6]

B. Wet Scrubber Upgrades

Incremental annual costs were estimated for wet scrubber upgrades. Incremental costs refer to the incremental increase of total annual costs over current operation. The only incremental costs expected for wet scrubber upgrades are electricity costs and TCI-related costs.

There is expected to be little difference in labor requirements between current and upgraded scrubber systems. Therefore, for wet scrubber upgrades, labor and maintenance costs are assumed to remain unchanged (i.e., the incremental labor and maintenance costs would be zero).

Electricity requirements and costs are expected to increase when wet scrubber systems are upgraded to obtain better PM control. The methods for estimating electricity costs are presented in Section II.A.

Caustic costs will remain unchanged, since HCl concentrations will remain the same at each PM control level.

Based on the blowdown calculations for Andersen in Section II.A, the quantity of HCl removed by the wet scrubber is the deciding factor in determining the blowdown rate for the MWI wet scrubbers. Since HCl concentrations are expected to remain the same after the wet scrubber is upgraded, there is expected to be no change in blowdown rate and, therefore, no change in sewage disposal costs.

For all vendors, the evaporation rates are assumed to remain unchanged from one PM control level to another. Because blowdown rates are also expected to remain unchanged, there is expected to be no change in makeup water costs after a wet scrubber upgrade.

Because the incremental labor and maintenance costs are assumed to be zero, the overhead costs would also be zero.

In addition to electricity, the only other cost components in the wet scrubber upgrade annual costs are the TCI-related costs--i.e., administration, property taxes, and insurance, as well as capital recovery. The methods for estimating the TCI-related costs are presented in Section II.A.

III. REFERENCES

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2. Letter and attachment from Eagleson, S., Belco, to Toomer, M., EPA. July 7, 1995. Confidential cost information on wet scrubbers for MWI's.

3. Letter and attachment from Patterson, R., Monsanto Enviro-Chem, to Toomer, M., EPA. July 18, 1995. Confidential cost information on wet scrubbers for MWI's.

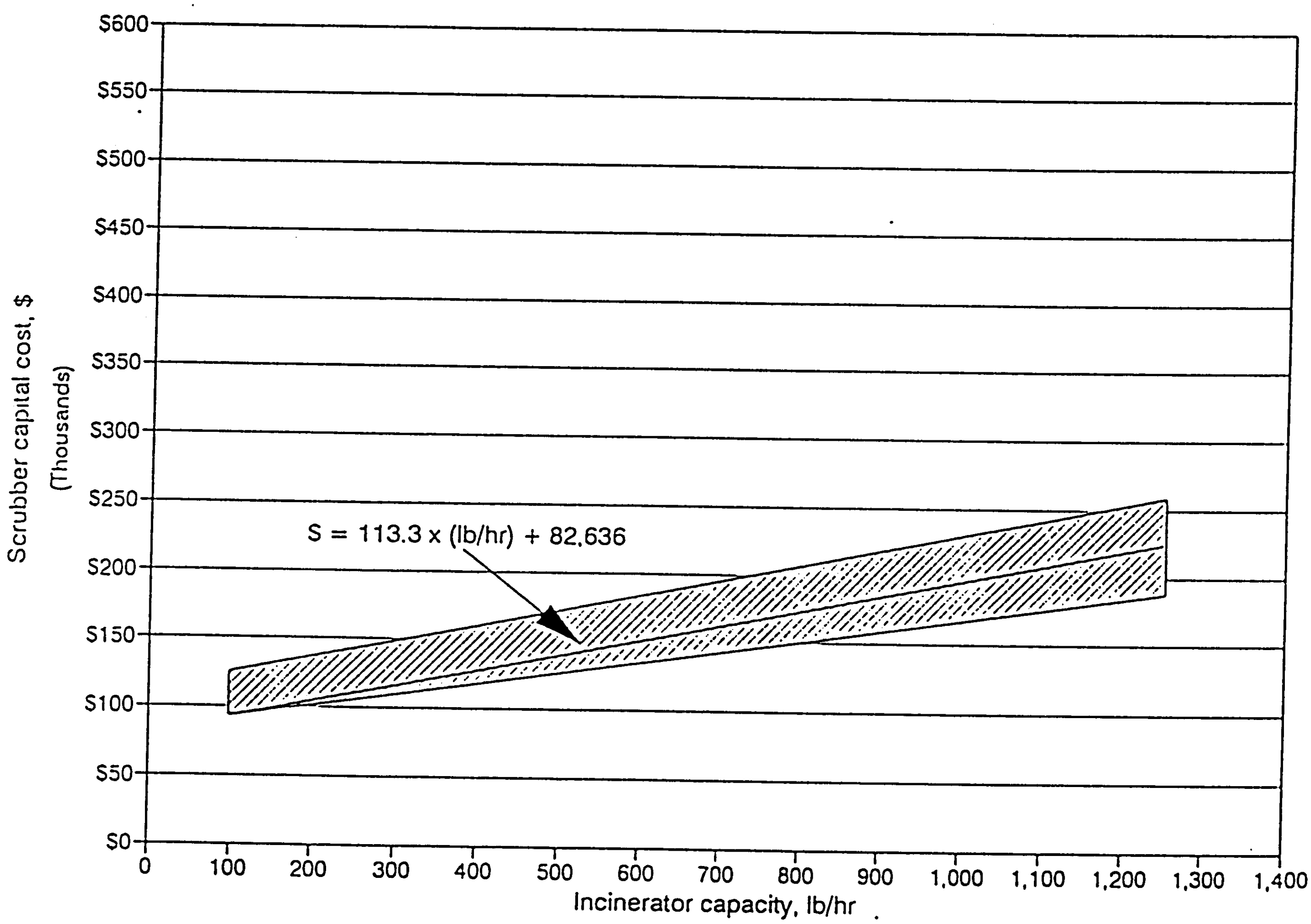
4. Letter and attachment from Hickerson, S., Emcotek Corp., to Copeland, R., EPA. July 26, 1995. Confidential cost information on wet scrubbers for MWI's.

5. OAQPS Control Cost Manual. 4th Edition. U. S. Environmental Protection Agency. Research Triangle Park, NC. Publication No. EPA-450/3-90-006. January 1990.

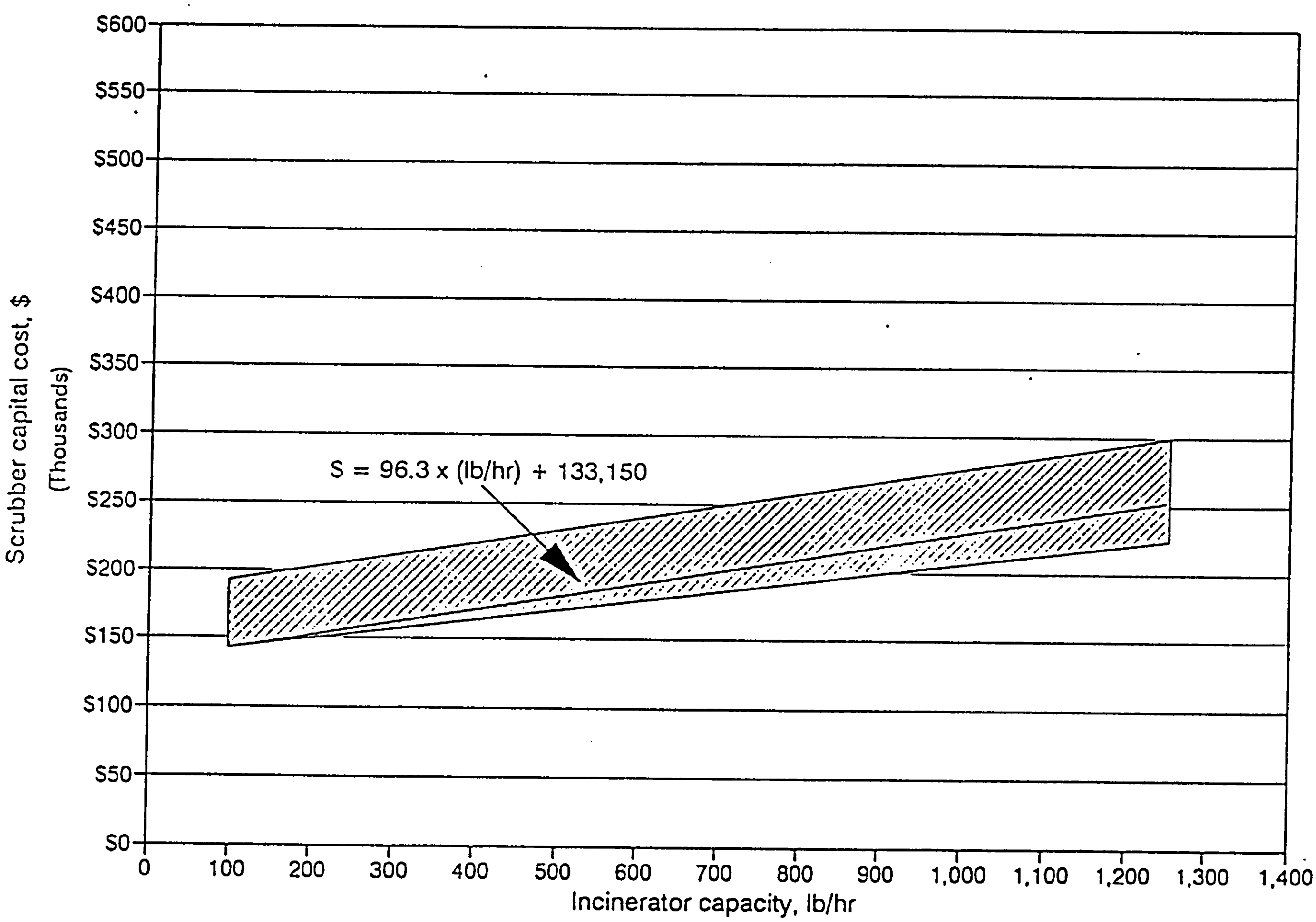
6. Medical Waste Incinerators--Background Information for Proposed Standards and Guidelines: Model Plant Description and Cost Report for New and Existing Facilities. U. S. Environmental Protection Agency. Research Triangle Park, NC. Publication No. EPA-453/R-94-044a. July 1994. p. 62.

7. Perry, R. and C. Chilton (eds.). Chemical Engineer's Handbook. 5th edition. 1973. pp. 20-6.

CAPITAL COSTS FOR NEW WET SCRUBBERS-- 0.08 GR/DSCF OUTLET (W/ BOILER)



CAPITAL COSTS FOR NEW WET SCRUBBERS-- 0.03 GR/DSCF OUTLET (W/ BOILER)



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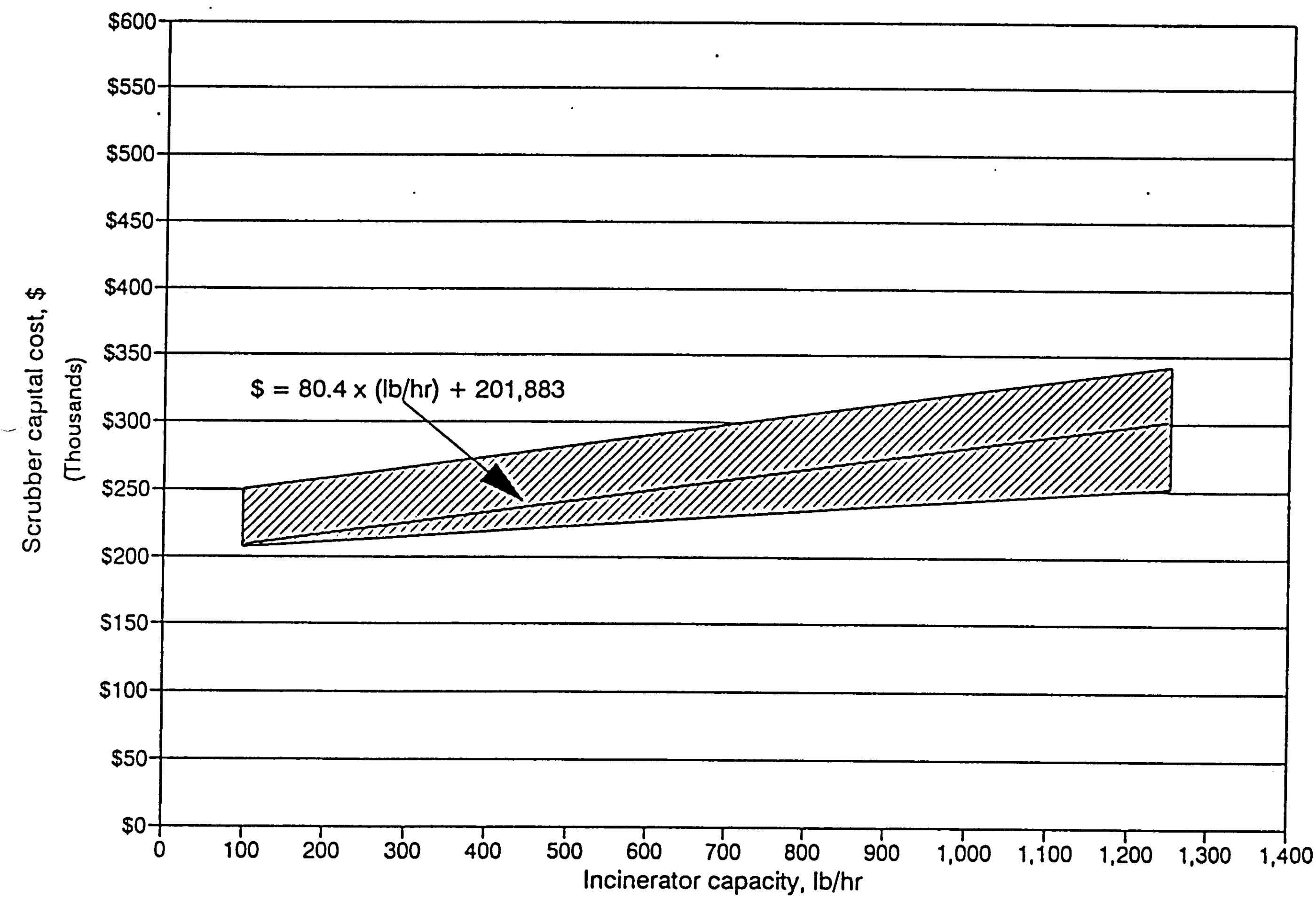
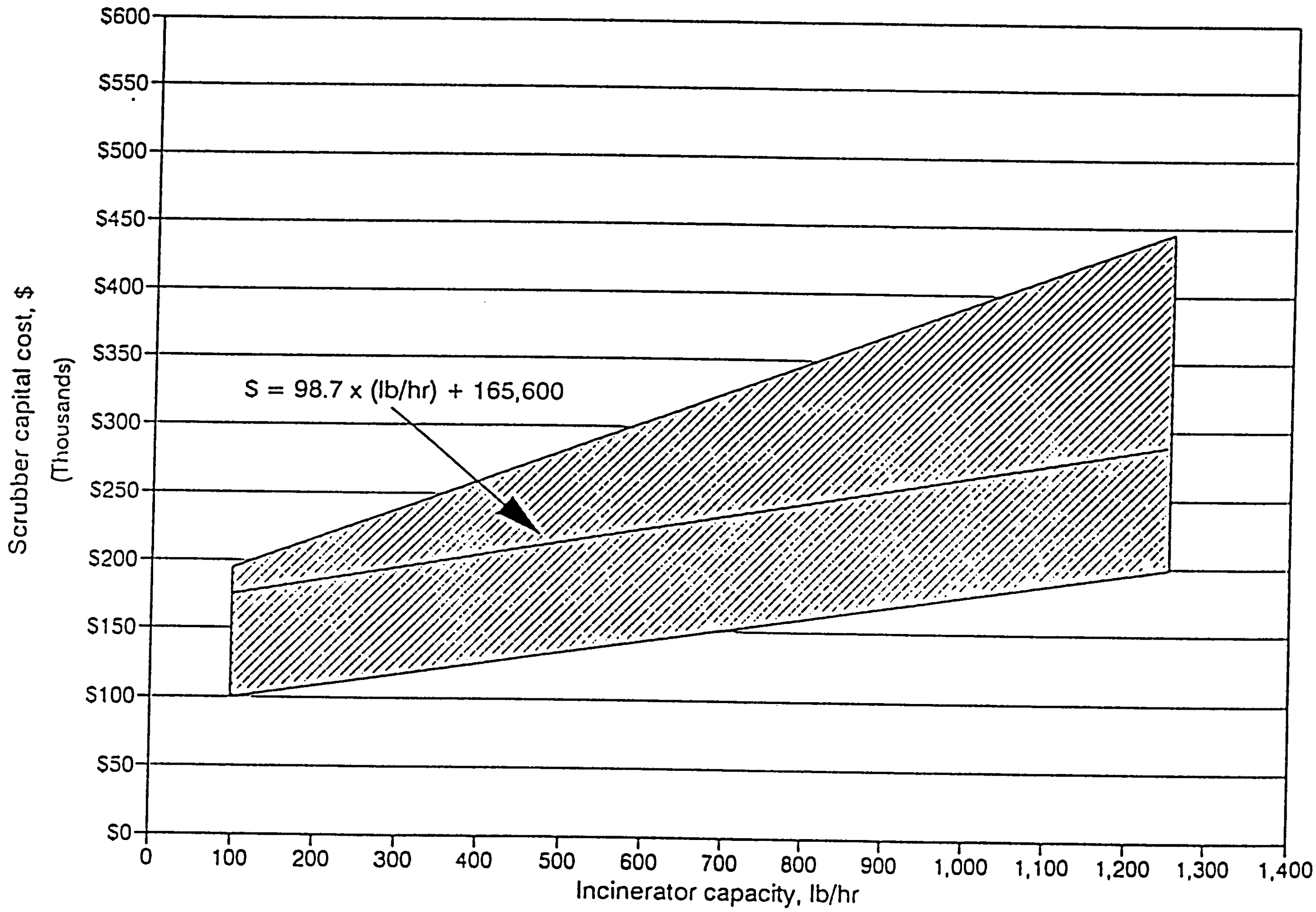


CAPITAL COSTS FOR NEW WET SCRUBBERS--
0.08 GR/DSCF OUTLET (W/O BOILER)



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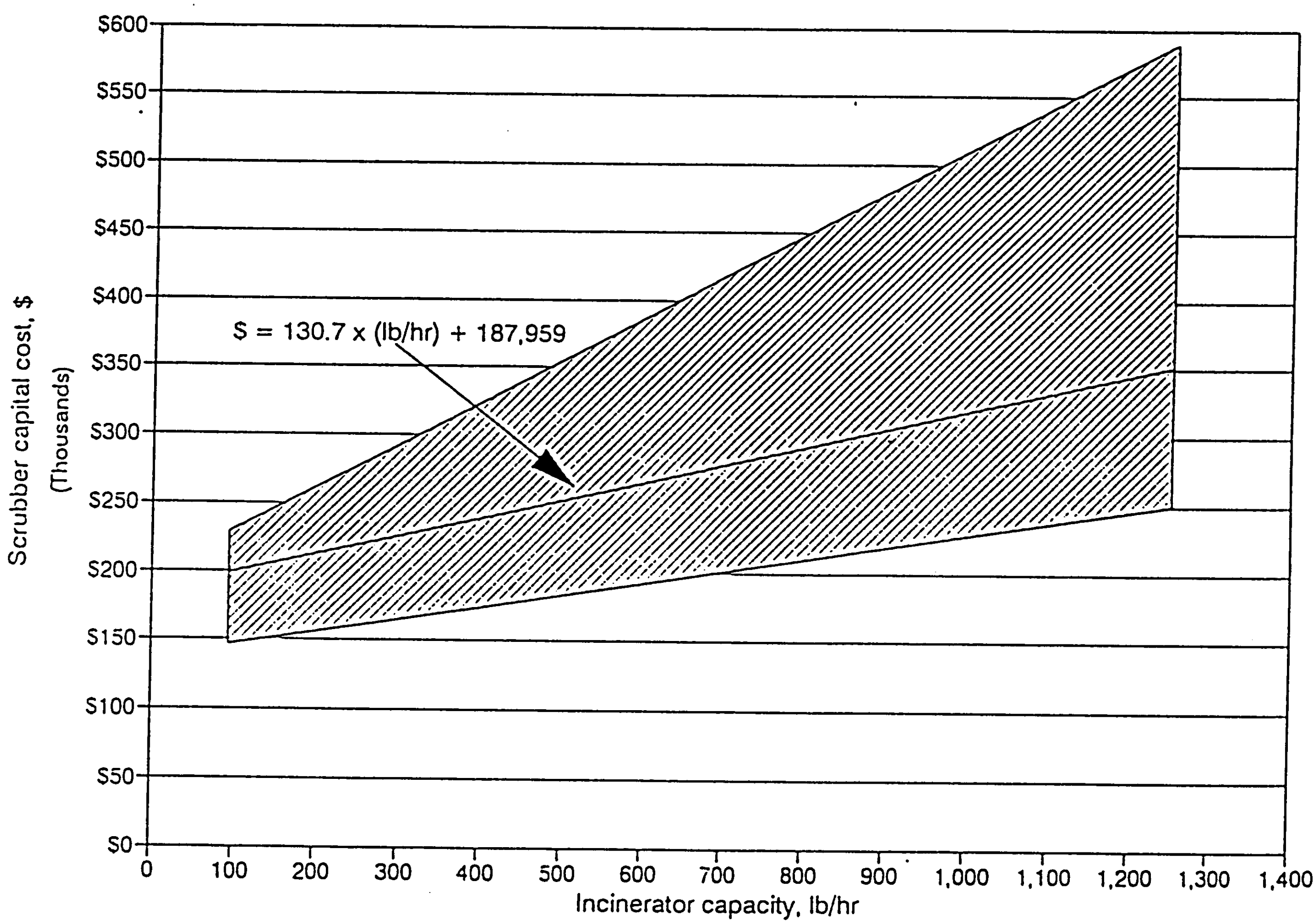

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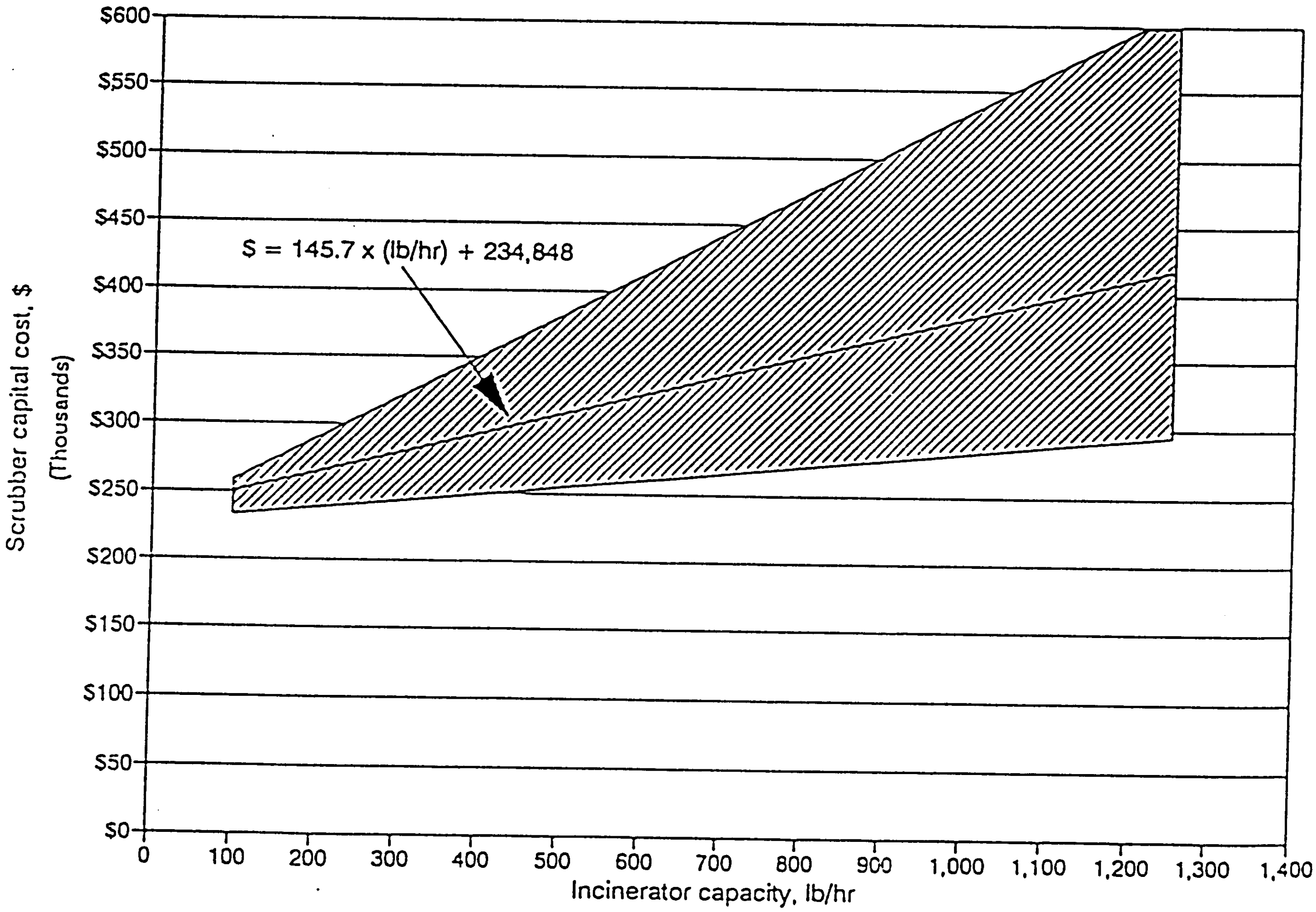

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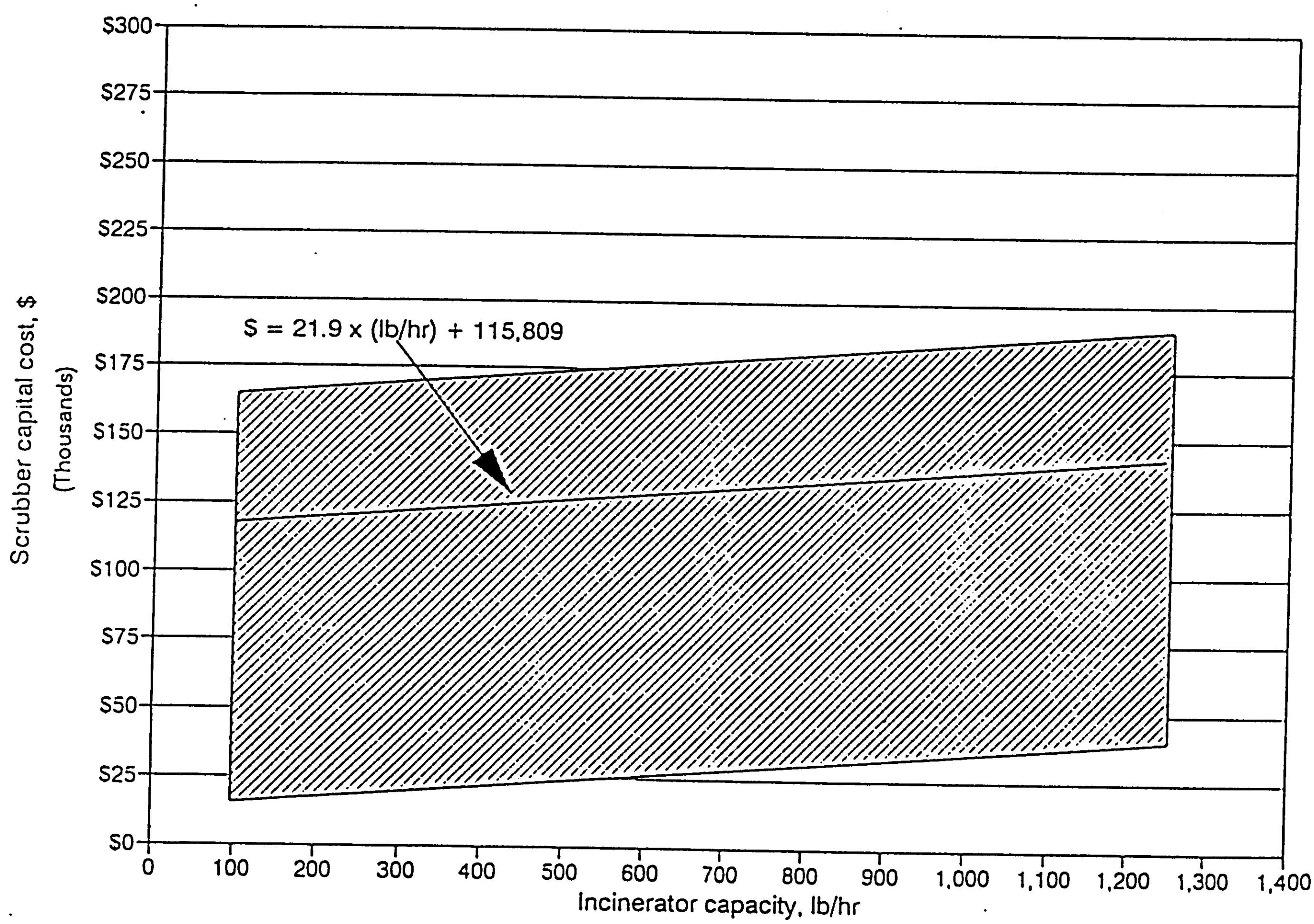

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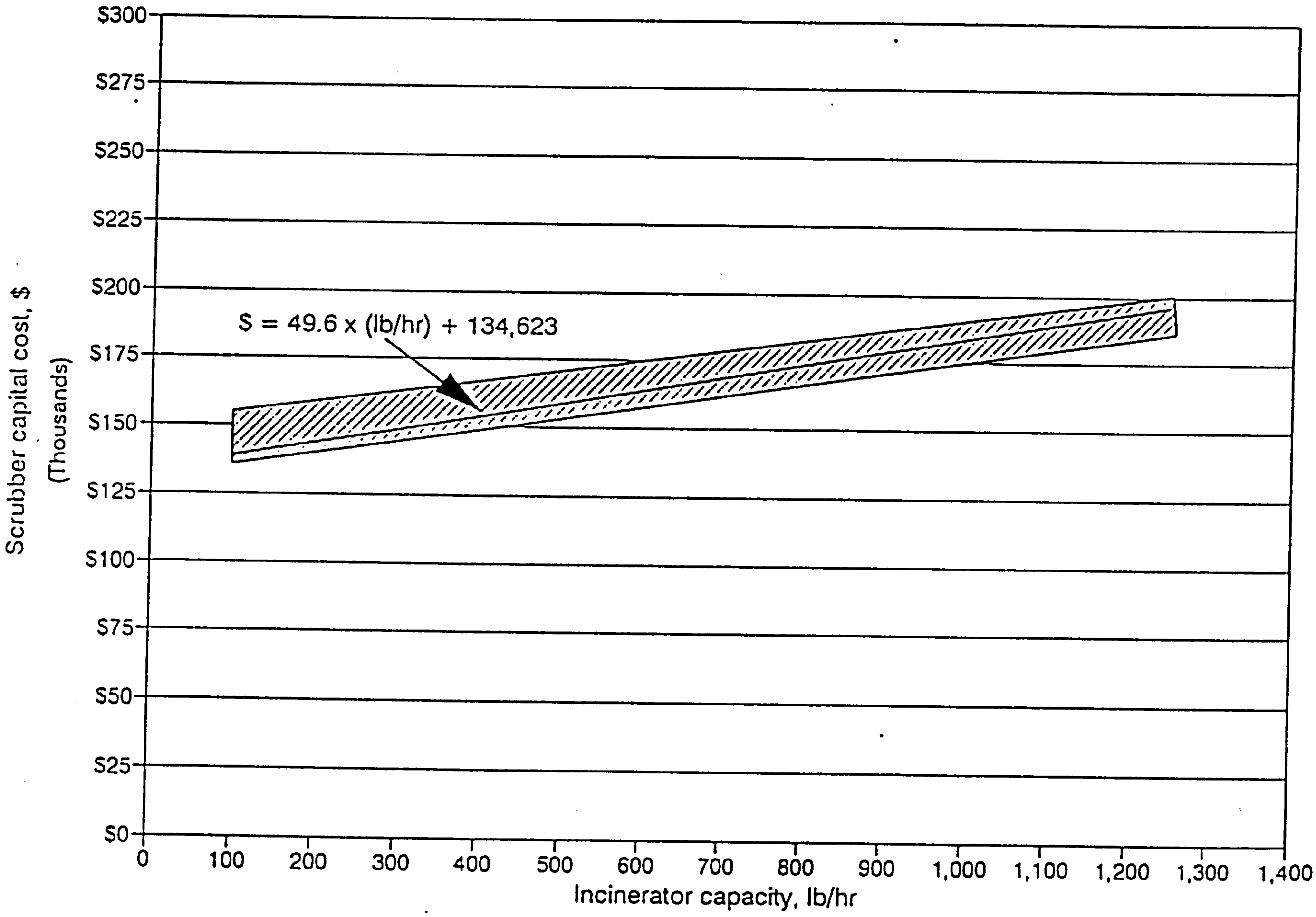
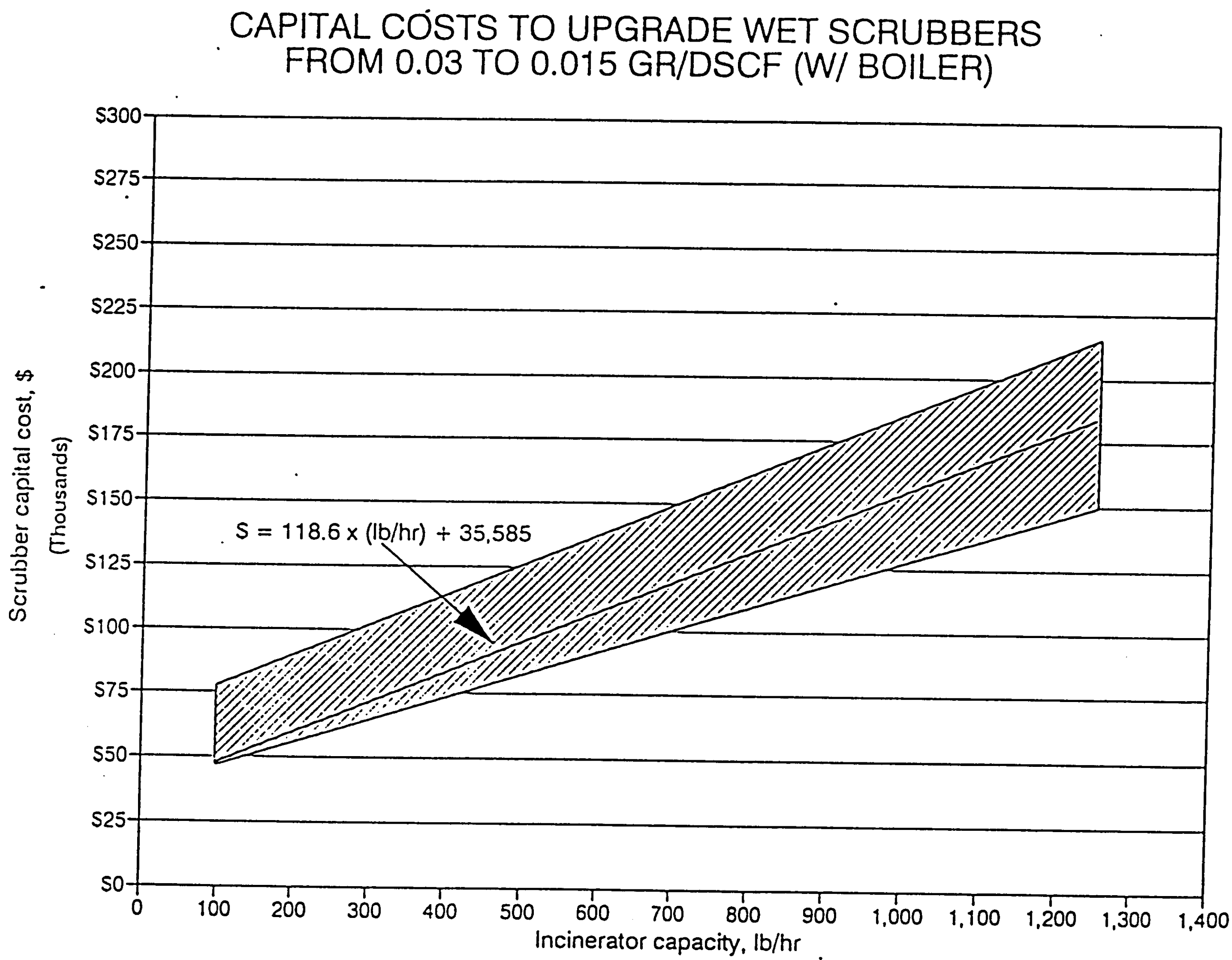
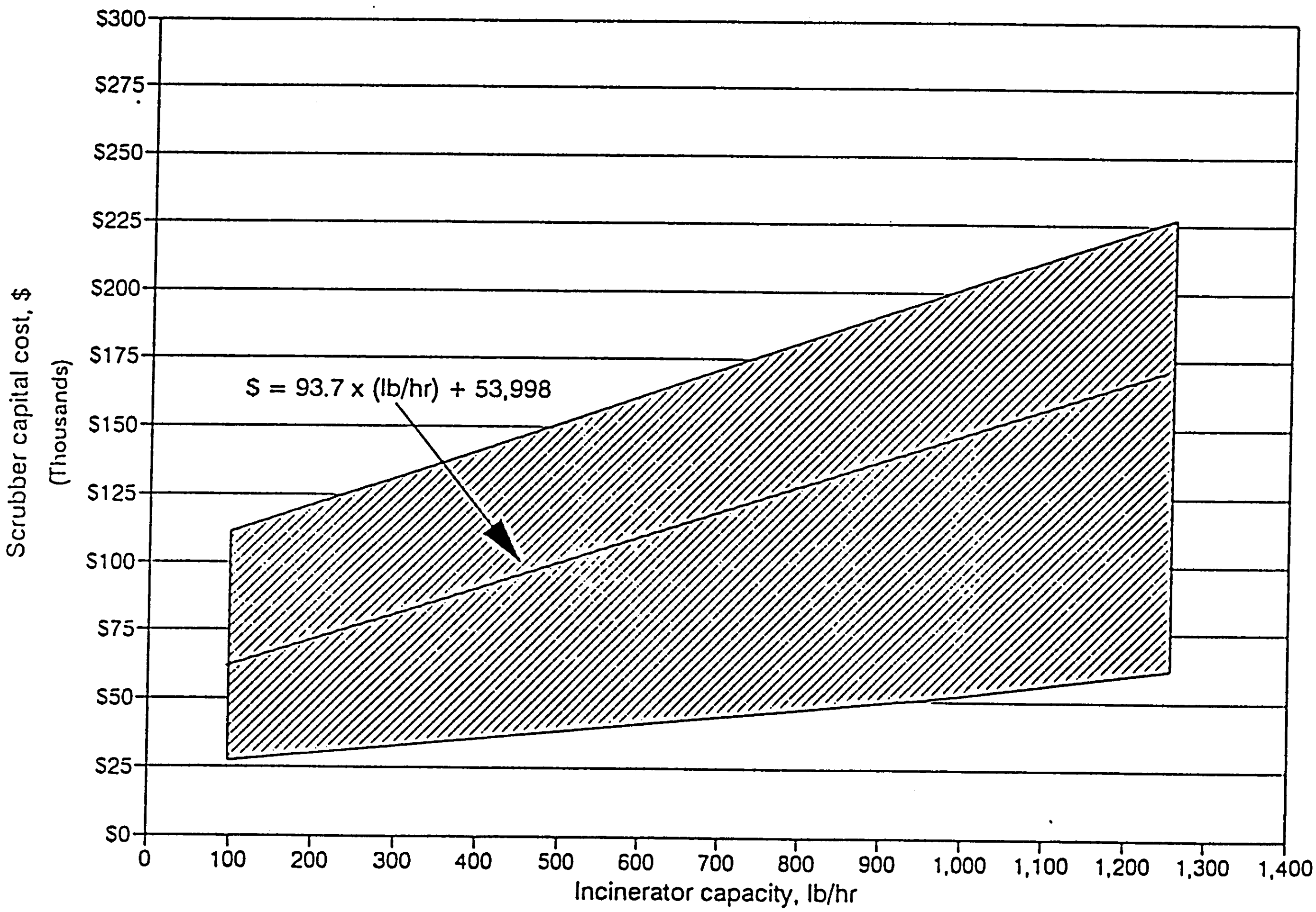



CAPITAL COSTS TO UPGRADE WET SCRUBBERS
FROM 0.03 TO 0.015 GR/DSCF (W/ BOILER)
Scrubber capital cost, $
(Thousands)
$300
$275
$250
$225
$200
$175
$150
$125
$100
$75
$50
$25
$0
S = 118.6 x (lb/hr) + 35,585
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
1,400
Incinerator capacity, lb/hr

CAPITAL CÓSTS TO UPGRADE WET SCRUBBERS FROM 0.08 TO 0.03 GR/DSCF (W/O BOILER)



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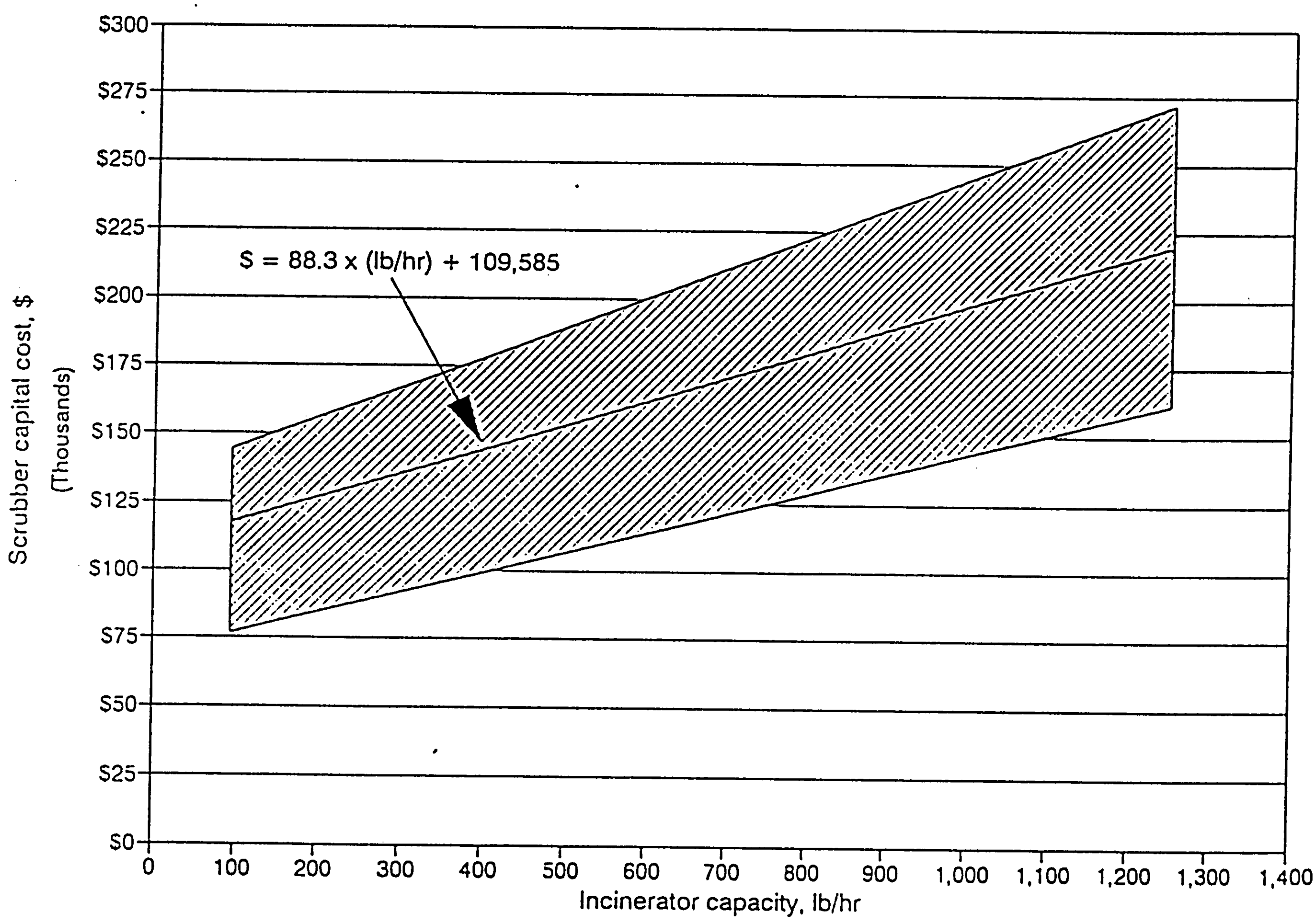
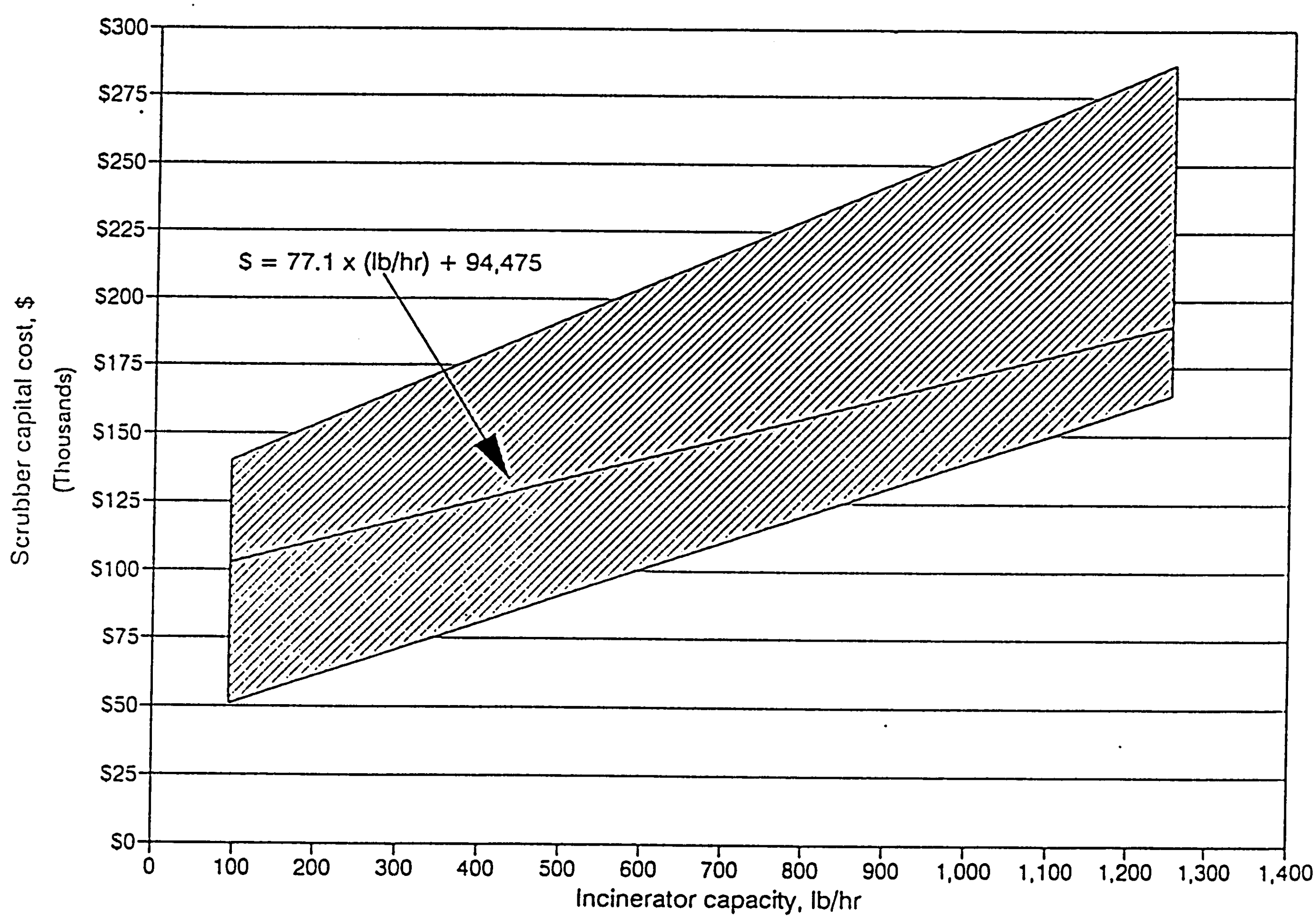
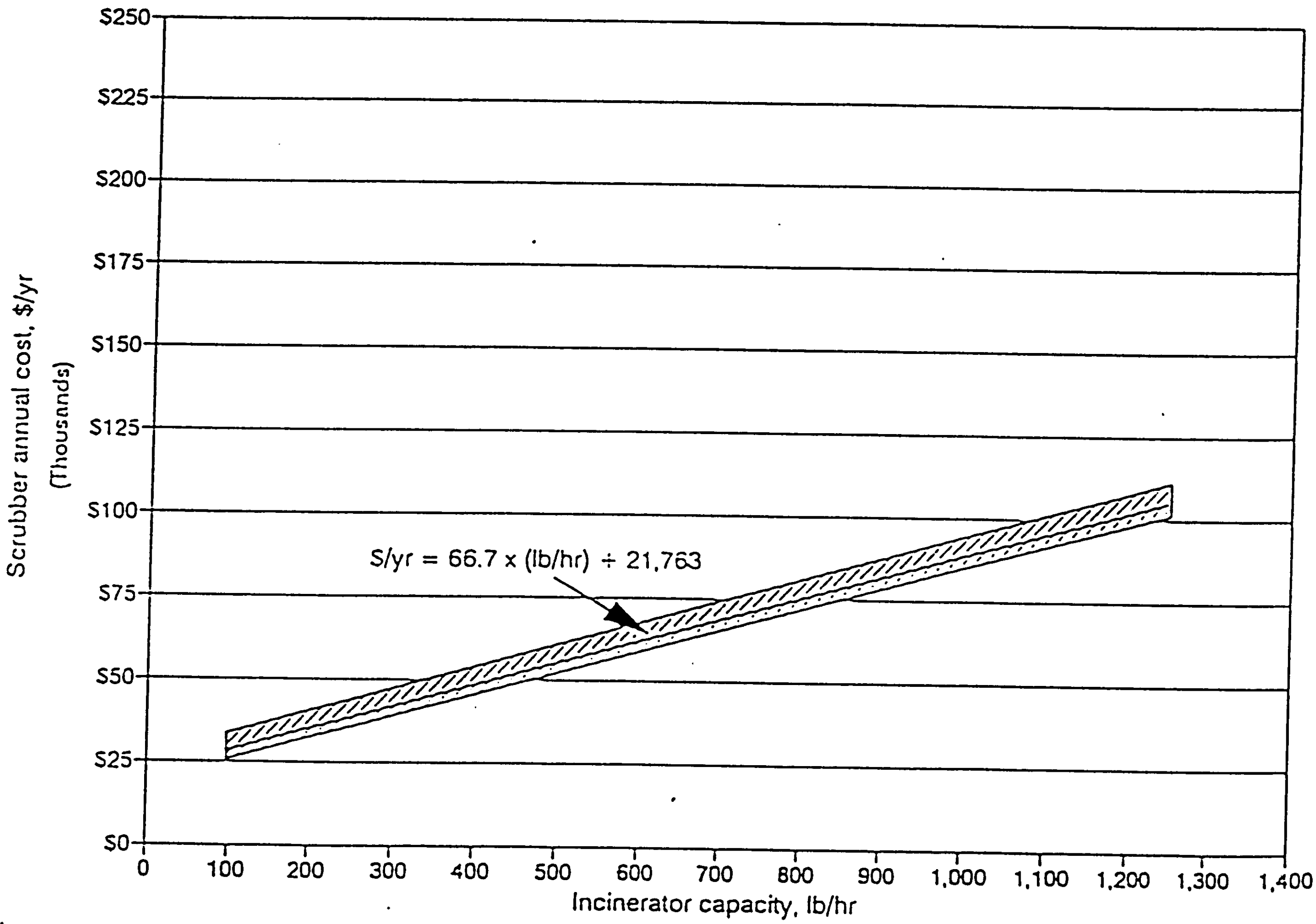


CAPITAL COSTS TO UPGRADE WET SCRUBBERS FROM 0.03 TO 0.015 GR/DSCF (W/O BOILER)



ANNUAL COSTS FOR NEW WET SCRUBBERS-- 0.08 GR/DSCF OUTLET (W/ BOILER)



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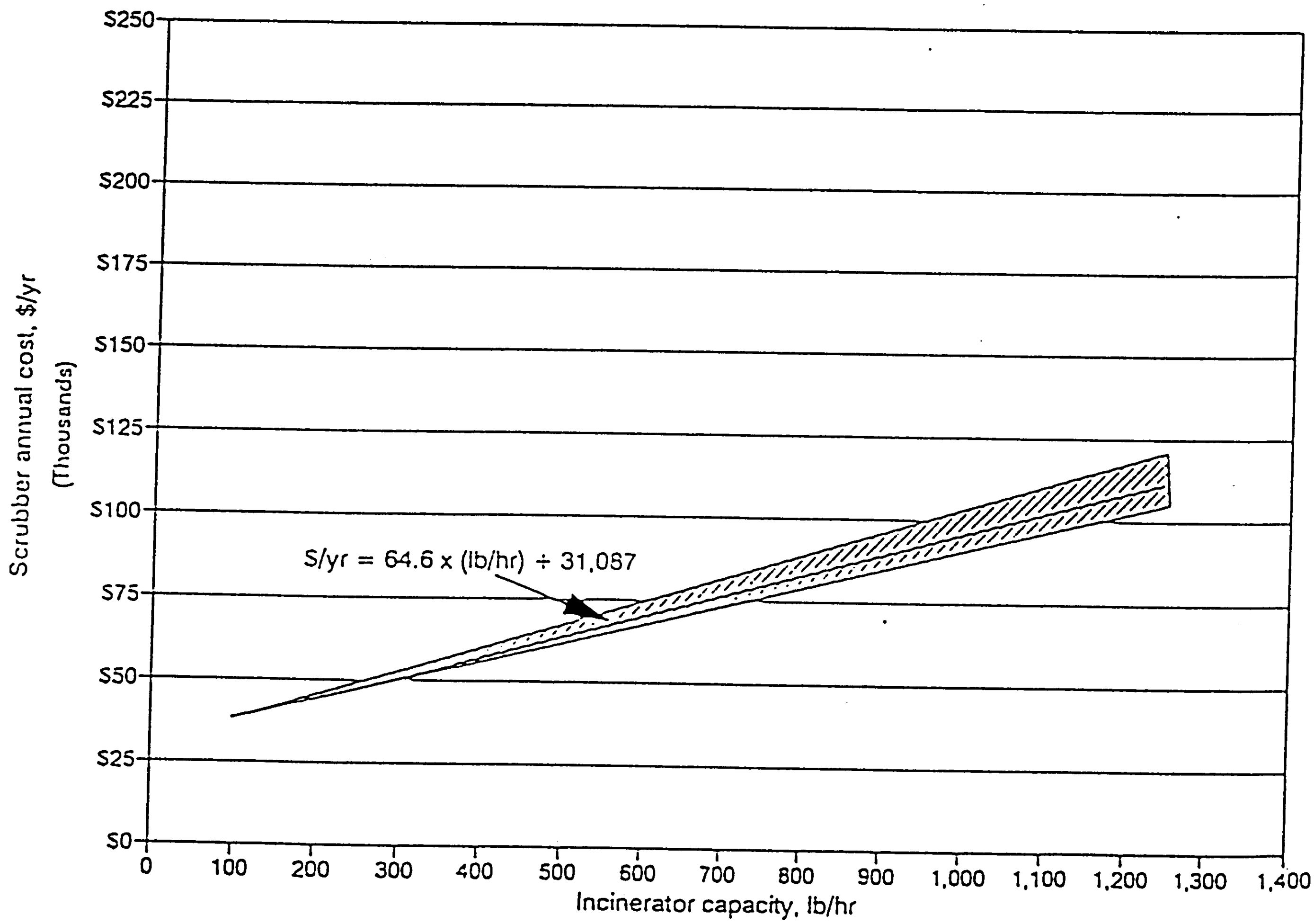

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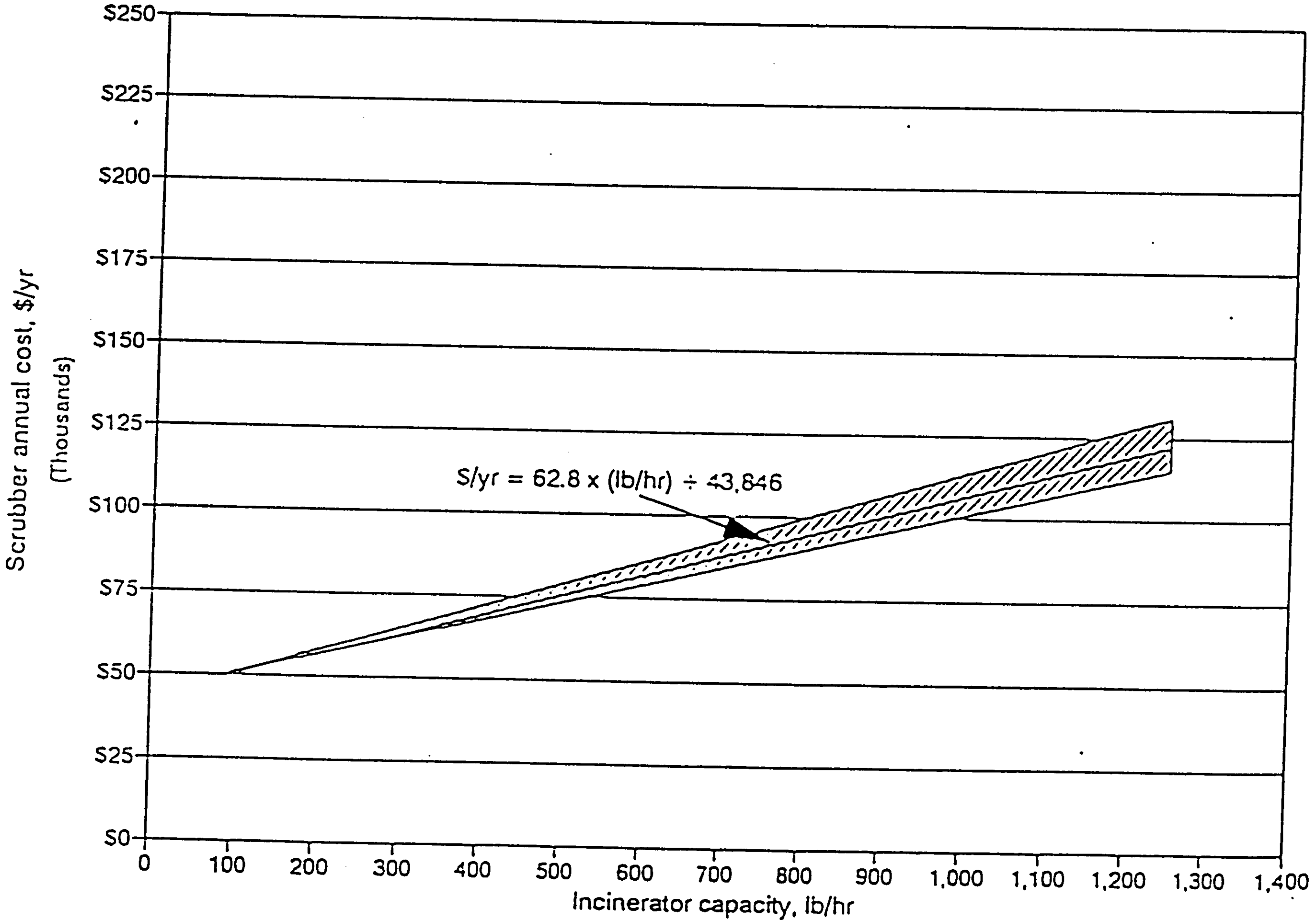
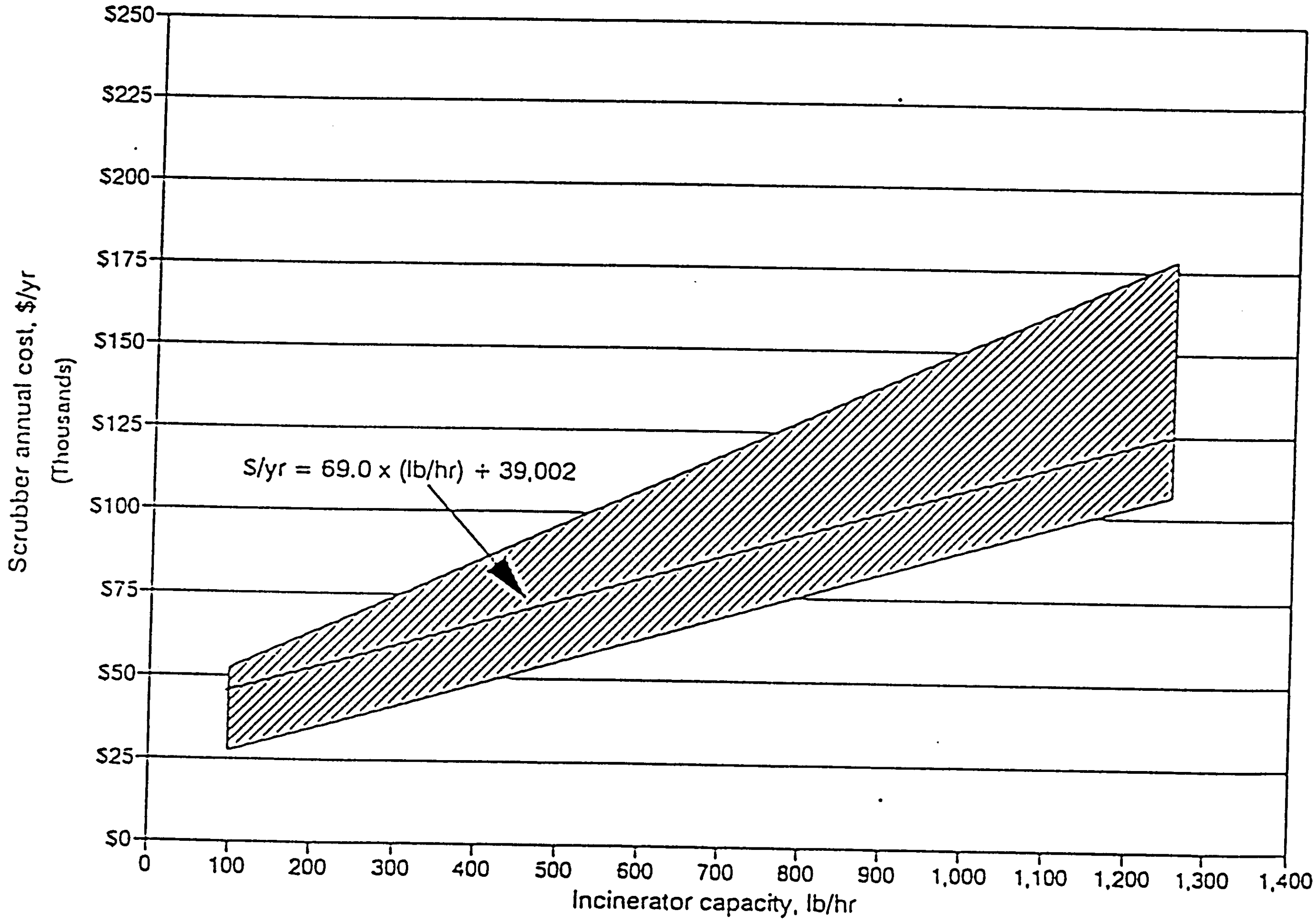


ANNUAL COSTS FOR NEW WET SCRUBBERS-- 0.08 GR/DSCF OUTLET (W/O BOILER)



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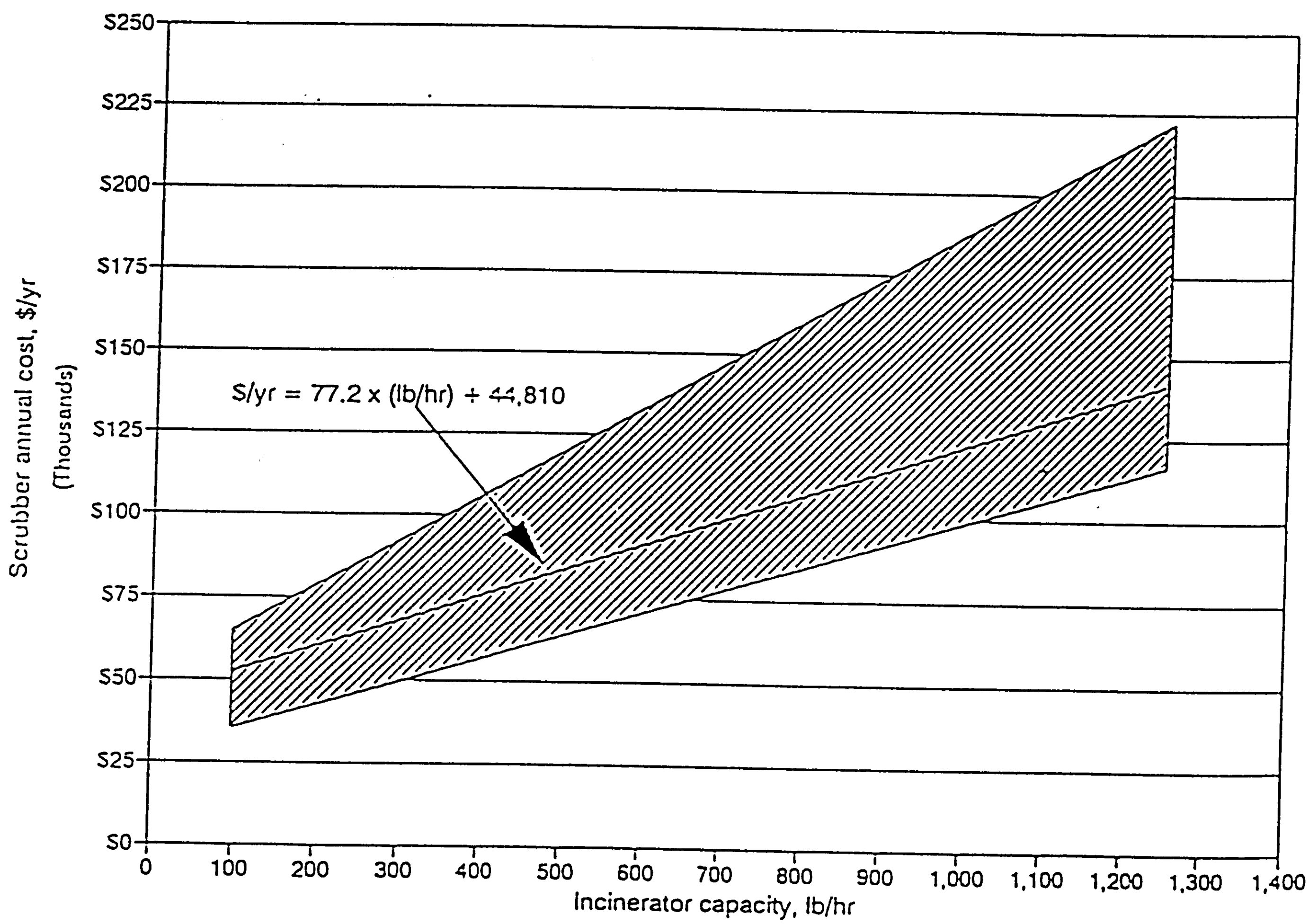

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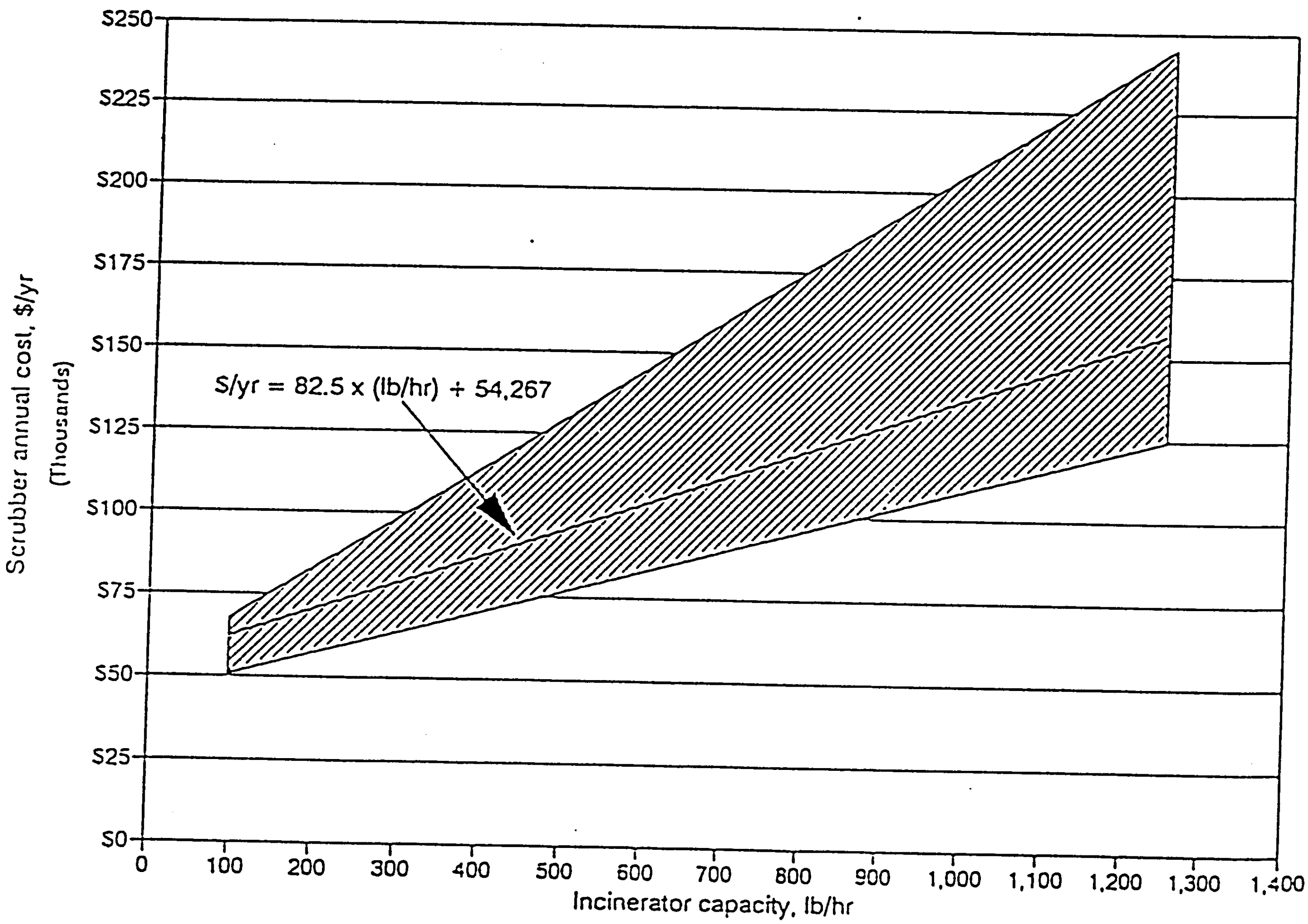
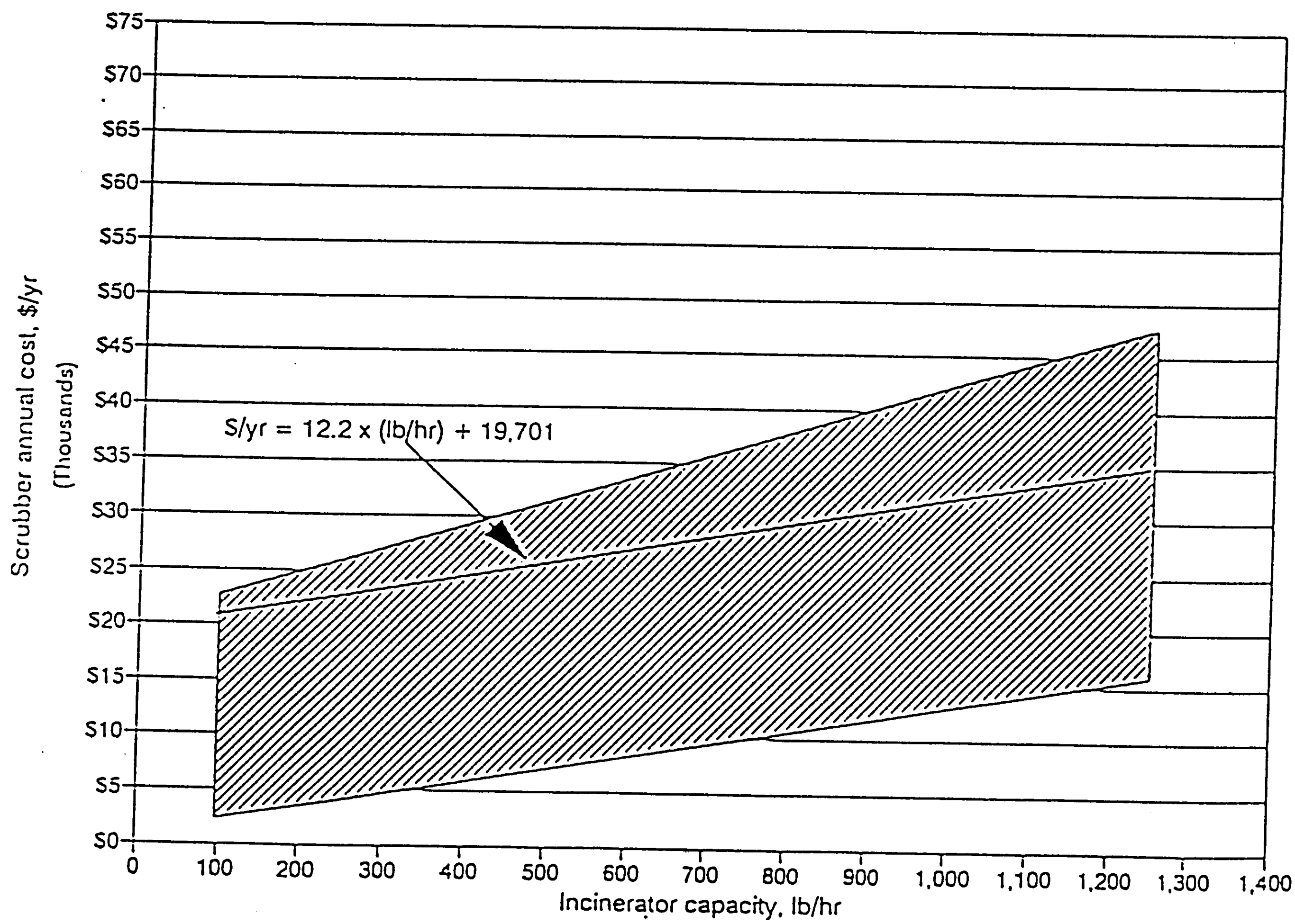


ANNUAL COSTS TO UPGRADE WET SCRUBBERS FROM 0.08 TO 0.03 GR/DSCF (W/ BOILER)



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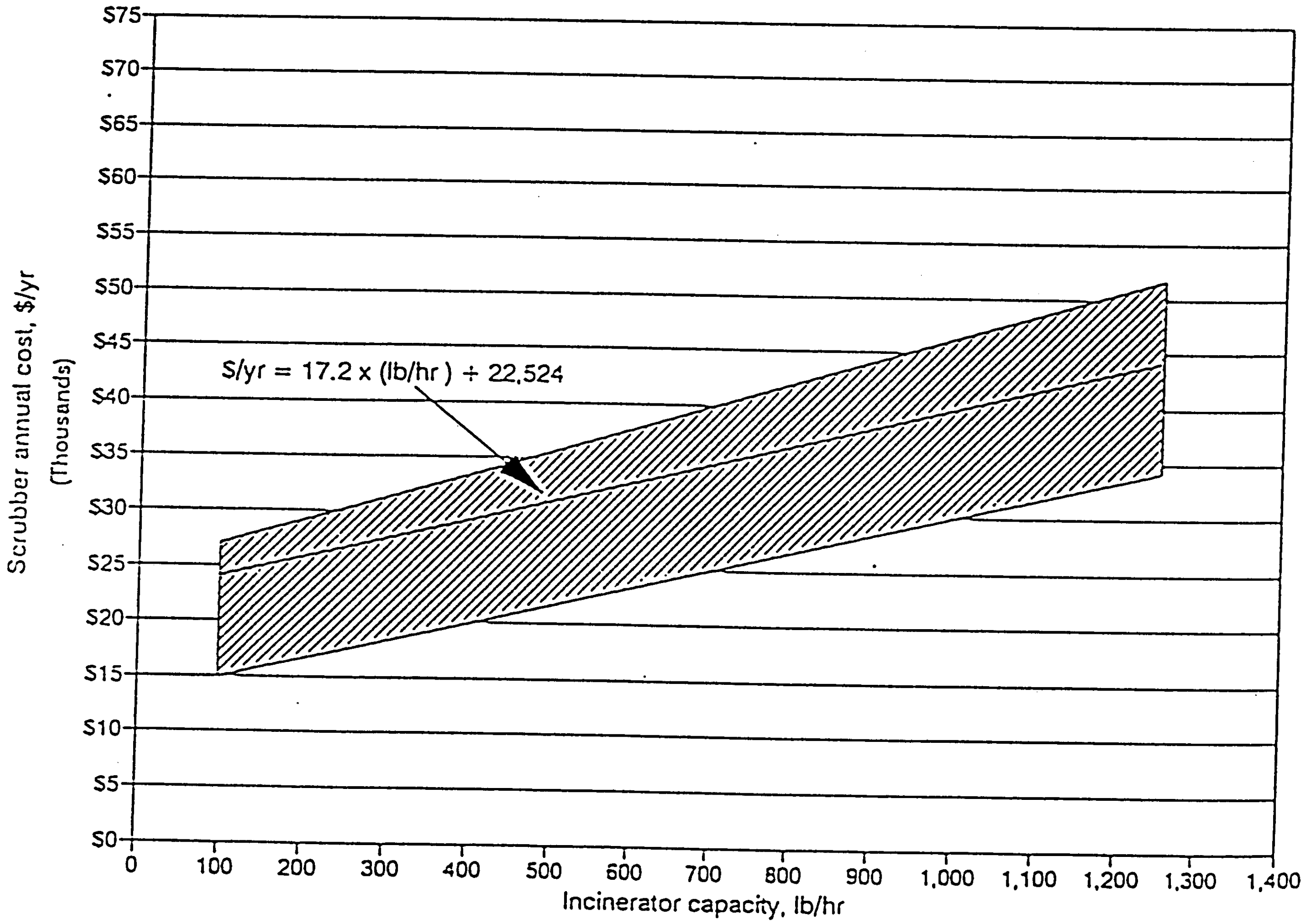

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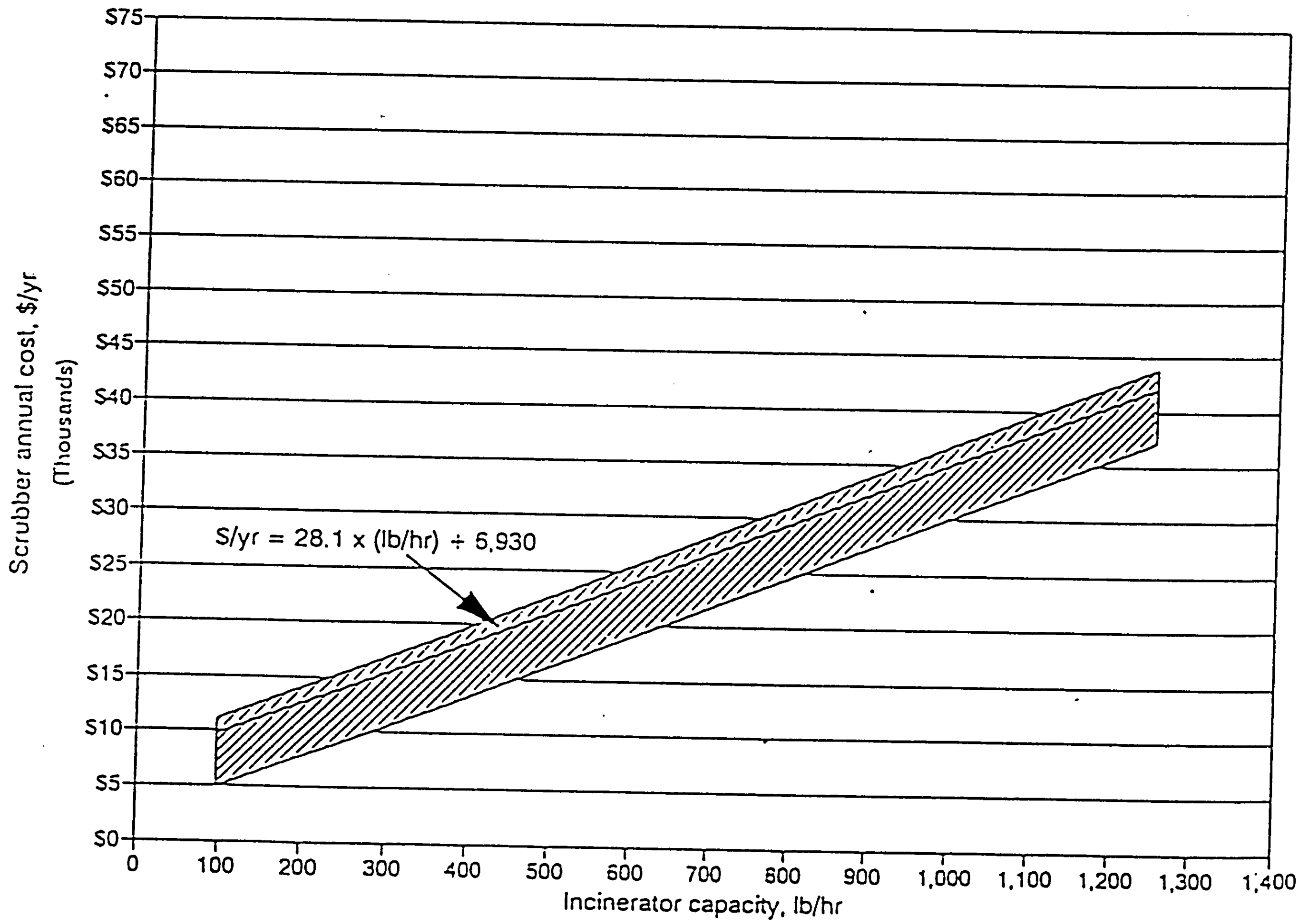

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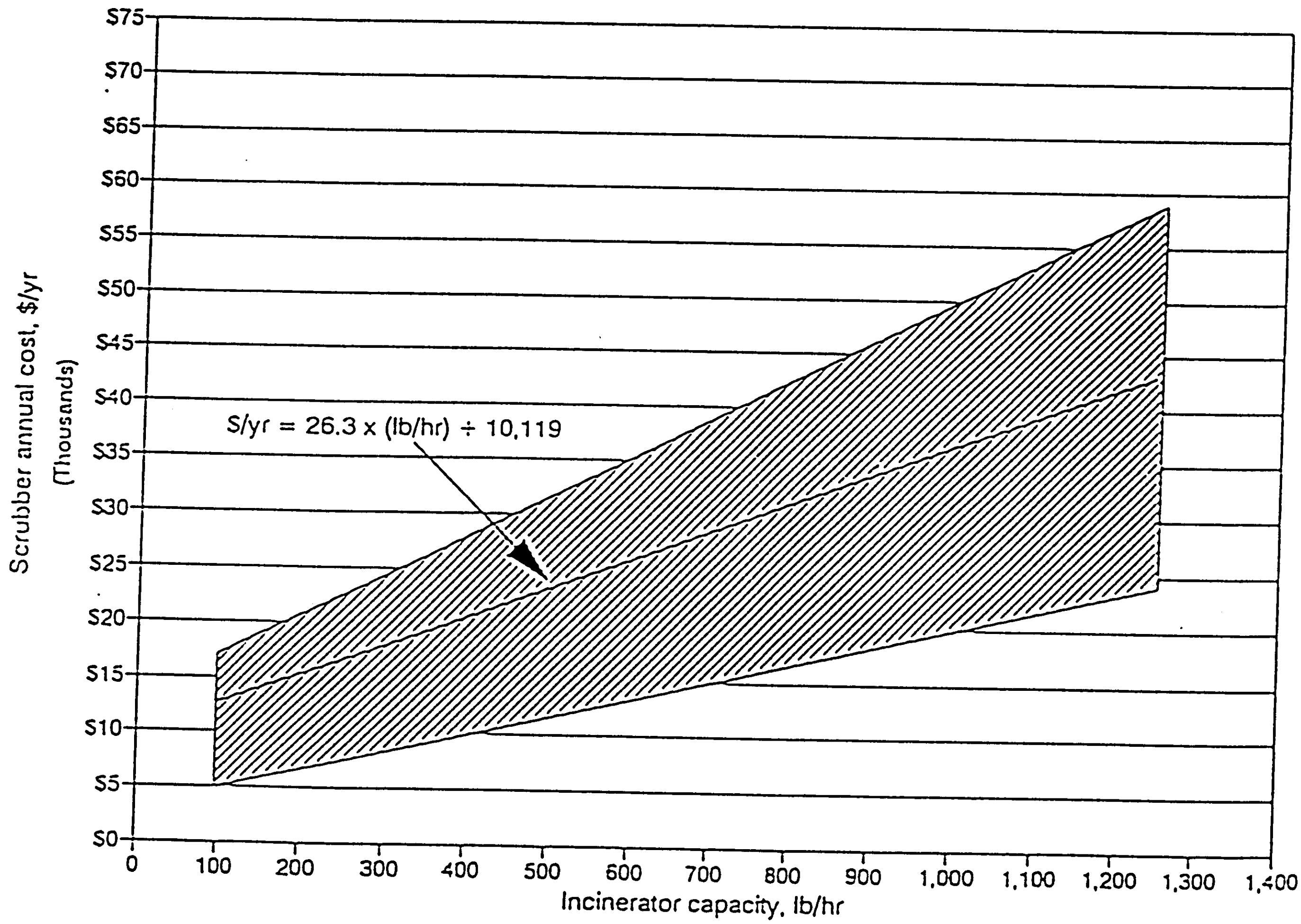

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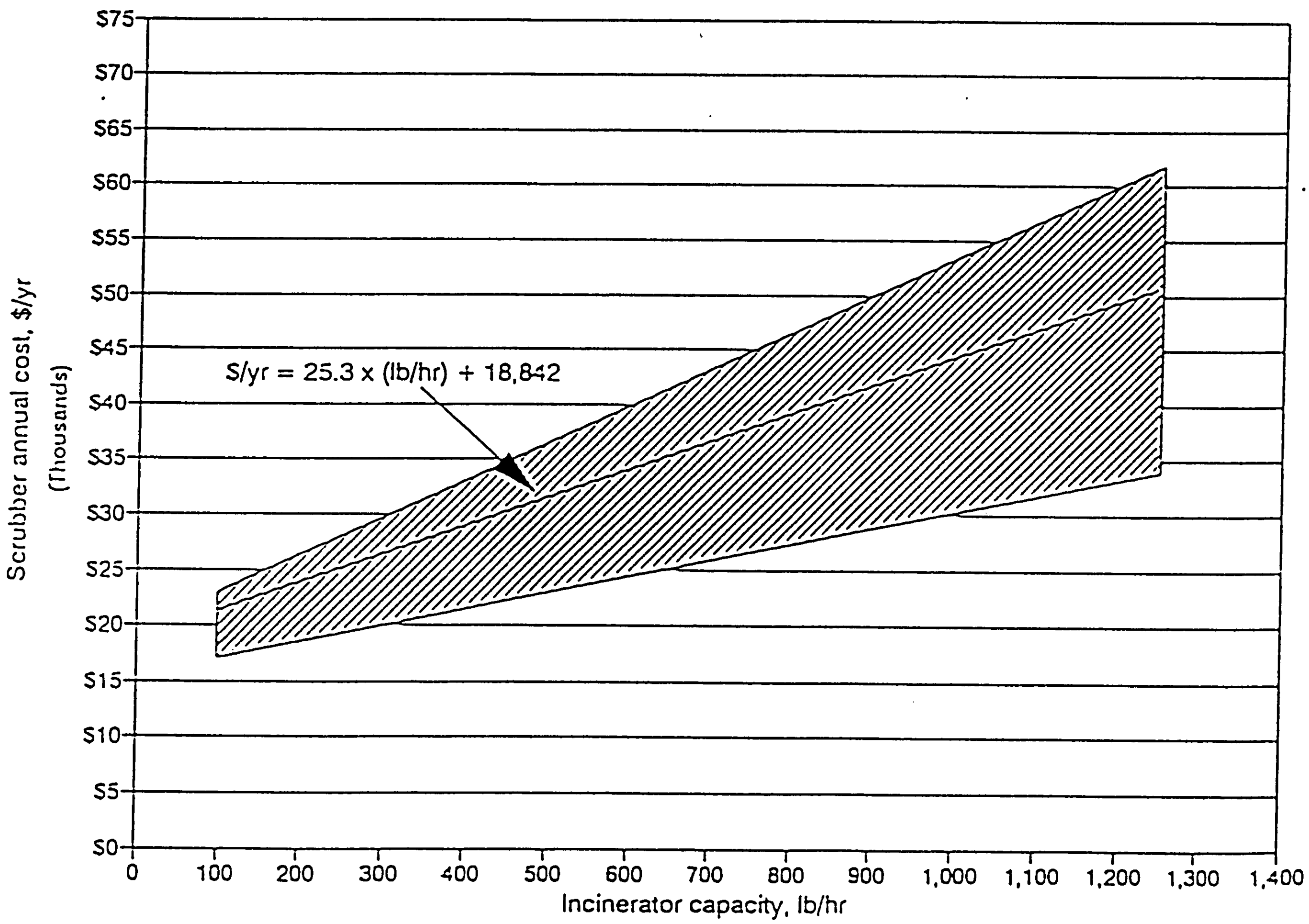

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