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Lyndon R. Babcock, Jr.

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A METHOD FOR ESTIMATION OF EMISSION CONTROL COSTS

*By Lyndon R. Babcock, Jr.**

ABSTRACT

This article describes a generalized cost estimation method called "emcost" and relationships are presented for six individual particulate control methods. More useful, however, is a generalized composite relationship which consists of a single exponential equation using flue gas flow rate and recovery efficiency terms to approximate total hourly capital and operating costs for unspecified particulate pollution control equipment. Within the discretion of the user, the method is applicable to any efficiency, for any process, for which a flue gas flow rate is known or can be estimated. The described method is applied to five major sources of particulate matter: coal-burning power plants, cement plants, refuse incinerators and blast and open hearth furnaces. An expenditure amounting to one percent of product value would result in only 90% control for a coal-fired electric power plant where gas flow rate is very high. The same relative rate of expenditure could achieve 99% control in a large cement plant or over 99.9% control in the steel industry processes which have relatively small gas volumes. Although emcost can approximate the cost of any level of emission control, it does not forecast the necessity or desirability of such control.

INTRODUCTION

Emission control is an important and necessary part of air quality management within densely populated urban areas. An optimum emission control strategy would generate the greatest improvement in air quality at the lowest cost. At the same time, attempts should be made to achieve equity so that no segment of the economy pays an unnecessarily large share of this total environmental cost. This article addresses part of this problem by proposing and applying a rapid generalized method for approximation of the costs of industrial particulate emission control. When used in the absence of often-proprietary cost and operating information, estimates thus obtained can only be approximate. Yet such estimates can provide a useful framework for evaluating the relative cost effectiveness of individual control methods as well as for allocating the relative burden associated with various emission control policies. Emission control as discussed herein pertains only to end-of-process or stack-control equipment. Other useful techniques such as fuel switching are excluded from the discussion.

By some measures, particulates still rank as our most serious air pollution problem.[1] Particulate control technology is relatively well understood, has been practiced for many years, and considerable, albeit fragmentary and conflicting, cost information is available. For these reasons, particulate emissions from stationary sources were selected for study, but the approximate methods as proposed herein could also be applied to a variety of other pollutants and sources.

Cost Estimation Variables

The cost of doing business is composed of many elements such as labor, raw materials, utilities, etc. Emission control expenditures comprise an additional cost element for many companies. In order to assess impact on a given industry, emission control costs should be meaningfully related to the other cost elements and to total business cost.

Industry makes complete cost breakdowns, but such information is usually considered proprietary and is often closely guarded. In lieu of complete incremental cost information, this article suggests a more approximate method of cost comparison wherein product selling value (as derived from unit prices) is substituted for less accessible specific manufacturing costs. Hourly production rates and prices can usually be approximated, and meaningful emission control impacts can be assessed by estimating emission control expenditures on a comparable hourly basis.

Throughput rate is an important cost variable. Later in this article, control costs for certain processes are related to product value; it might seem advantageous to measure throughput in terms of product production rate. Unfortunately, such a system becomes impractical when several products or by-products of varying value are produced by a single process. Thus many control regulations relate allowable emissions to a "process rate." For instance, the following recipe might be used in a blast furnace to yield one ton of pig iron:[2]

1.7 ton iron ore;
0.9 ton coke;
0.4 ton limestone;
0.2 ton cinders, scale and scrap; and
4.2 ton air.

Process air is rarely included in the process weight; similarly, free water should be excluded. By this definition, blast furnace production rate of pig iron is 30 percent of process rate.

The cost estimation method described herein also requires a flue gas flow rate. Several federal publications[3] have approximated flue gas rates and emission factors as functions of process or product rates for many specific processes. Sometimes, as in fuel or refuse burning operations, no product is produced. In such cases, flue gas rate and inlet emissions can be related to fuel tonnage or to heat input rate.[4] Table 1 supplies the pertinent information for the processes studied in this article. Additional discussion of relationships between process rate, product rate, emission factor, and flue gas flow rate has been presented earlier.[5]

Hourly emission control costs must in themselves include several elements such as a fraction of the purchase price and installation cost, interest, taxes, insurance and other miscellaneous charges as well as operating costs such as utilities and labor.

The estimation equations presented are based upon data and methods published by the National Air Pollution Control Administration[6] (now Environmental Protection Agency) wherein the expected equipment life is 15 years and straight-line depreciation (6.7% per year) is used to yield a constant annual write-off. Other capital charges including interest are assumed equal to the depreciation charge yielding non-operating annual charges totaling 13.3% of initial capital cost. NAPCA-EPA estimates of operating charges were likewise employed in the derivations.

Cost estimation should also include consideration of the recovered materials. There may be significant disposal costs for a material of marginal value such as fly ash or for aqueous scrubber effluent. Conversely, the recovered material might have significant monetary value (e.g., cement dust). Such considerations, albeit important, are specific to each process and have not been included in the proposed generalized cost estimation method.

DERIVATION

An approximate generalized estimation model should be kept as simple as possible; a continuous function which yields zero cost at zero efficiency and infinite cost at 100% control efficiency was desired. The modified exponential form shown below satisfies these constraints:

$$\text{emcost} = a \times (Q)^{b} \left(\frac{R}{1-R}\right)^{c}$$

where emcost = annualized capital and operating cost ($/hr)
Q = flue gas flow rate (actual ft^3/min)
R = recovery efficiency (decimal)
a,b,c = empirically-derived constants

The form of the equation is shown in Figure 1. Low values of the efficiency exponent (c) yield long, relatively horizontal portions on the curve. The curve based on an exponent of 0.1-0.2 might be expected to represent the cost function for an electrostatic precipitator: even at low efficiencies, costs are considerable, but costs remain moderate at collection efficiencies above 95%. Conversely, larger efficiency exponents would be expected to characterize simpler control devices such as gravitational collectors where costs are much lower at low efficiencies, but high efficiencies are practically unattainable no matter how large and expensive the equipment.

Data published by NAPCA[7] and multiple regression techniques[8] were used to derive the constants in the proposed model. Equations were derived for individual control-device types and in addition, a generalized, composite equation was defined. The equations are listed in Table 2. The equations all follow the proposed model, although the filter version is independent of efficiency because only one efficiency value was given by NAPCA-EPA (99.9%, independent of cost). Thus for filters the efficiency exponent (c) = 0.0 and

$$\left(\frac{R}{1-R}\right)^{0.0} = 1.0$$

The high correlations (R^2) for the individual equations are not surprising. These are largely due to the small number of data points and to the smoothed nature of the NAPCA-EPA data. Less expected is the high R^2 value of 0.81 for the composite equation. In situations where the control device is not specified, one seems well-justified in using the composite equation for approximating particulate control costs.

The composite equation can be applied (with discretion) throughout the range of the initial data: 42 to 99.9% efficiency and for flowrates from zero to 1,000,000 ft^3/min. The equations for individual devices, of course, have narrower applications:

	efficiency range
Wet collector	75–99
Low voltage electrostatic precipitator	88–99
High voltage electrostatic precipitator	90–99.5
Filter	99.9
Dry centrifugal	50–95
Gravitational	42–72

These limits are shown in Figures 2, 3, and 4 which compare the equations at three different flow rates (50,000, 100,000, and 500,000 ft^3/min).

The contributions of the individual devices to the composite is clear. For most control efficiencies there appears to be a clear least-cost control device. Further, use of the non-specific composite equation usually results in a conservative (high) estimate of hourly control costs.

Wet collectors seem to be an exception. They are shown in Figures 2–4 to be more expensive than dry-centrifugal and precipitator alternatives, througout the 70 to 99% efficiency range. Yet the large number of wet collectors in use indicates there must be situations where wet collectors are the least-cost alternative; collection of gaseous pollutants along with the particulates is an important example.

Economies of scale for most devices are slight, and the relationships between equations are relatively independent of flowrate; most of the flow exponents (b) are close to unity. However, the flow exponent for the high voltage electrostatic precipitator is only

0.69; this device clearly becomes more attractive at the higher flow rates.

It is suggested that either the composite or the individual equations be used in lieu of actual design information for the approximation of costs associated with particulate emission control. However, prior to such use, the equations should be corrected for changing construction costs. A 35% increase would adjust the equations (based on mid-1960s costs) to December 1972 conditions.[9] The composite equation as adjusted was used exclusively for the calculated comparisons made in this article:

$$\text{emcost} = 21.0 \times 10^{-6}\, Q^{0.96} \left(\frac{R}{1 - R}\right)^{0.3}$$

APPLICATION

Process conditions representative of five industrial processes are summarized in Table 1. These processes were selected for evaluation, since they are important to the nation's economy as well as being significant air pollution sources. The emcost composite equation could be applied in a similar manner to any other process for which the appropriate input variables could be estimated. The efficiencies required by regulation should consider both the cost impact to the industry as well as the air quality improvement to be derived. Note the wide disparities among the listed processes of both flue gas volumes and product values. In the extreme, a disposal cost rather than a product value is shown for the refuse incinerator. Solutions of the emcost composite equation using the data from Table 2 were used to define Figure 5. Note that control cost is shown not in $/hour but rather as a percentage of product value where

$$\begin{array}{c}\text{relative} \\ \text{control cost}\end{array} = \frac{\text{emcost (\$/hr)} \times 100}{\text{production (lb/hr)} \times \text{product price (\$/lb)}}$$

Figure 5 confirms the disparity of impact. Those processes with low product value (refuse incinerator) and/or high flue gas volumes (electric power plant) must devote a higher fraction of gross revenue to emission control in order to achieve a given recovery efficiency. Note that equivalent economic impact, say one percent of gross revenue, would entail a control efficiency of only 40% for the refuse incinerator, 90% for the power plant, but over 99%

for the cement plant, and over 99.9% for the blast furnace and for the open hearth furnace.

DISCUSSION

Individual situations can deviate considerably from emcost estimates. For example, cement and blast furnace processes have been identified earlier[10] as processes in which emission control costs could be largely offset by the value of recovered materials.

Also, the data used to derive the emcost composite equation seem intended for new installations. The "retrofitting" of existing processes introduces complications which almost always increase costs. The incorporation of large electrostatic precipitators into the small sites of aging urban electric power plants is a notable example.

The assumed 15-year amortization period is also directed at new installations. Industries are reluctant to invest sizable control expenditures in obsolescent processes having expected lifetimes shorter than those of the control equipment; open hearth furnaces are an example.[11]

Variability in throughput rate must also be considered. Emcost assumes a constant, average rate. Thus emcost should be applied to the maximum rather than the average throughput rate. Part-time operations increase the relative control cost, since no product value is generated during downtime (e.g., electric power plants with less than 100% load factor).

Simplicity, the major asset of the composite emcost equation, is also the method's most significant deficiency: the approximate equation avoids most of the complexities of cost and efficiency estimation for particulate control. Inlet concentration, particle size, shape, conductivity, cohesion, etc., as well as control mechanism, are not considered.

The validity of the emcost composite relationship itself will be difficult to verify without the cooperation of each specific industry in question. If the admittedly simplistic relationship is challenged, it at least serves the very useful purpose of drawing out more specific industrial control cost details.

A similar cost method has been used by NAPCA-EPA in a report presented by the Secretary of Health, Education and Welfare to Congress.[12] Using nationwide averages, NAPCA-EPA related control cost to value of shipments for several specific control-train configurations. For "maximum" control efficiency (97 to 99+%), relative control costs (as a percentage of value of shipments) were listed for the following industries:

Industry	Relative control cost for "maximum" recovery (percentage of value of shipments)
Steel	0.4
Grey iron foundaries	0.4
Cement	0.6
Asphalt batching	1.2
Pulp mills	1.7

The same reference also reported annualized recovery cost estimates for catalytic crackers, petroleum refineries, electric power plants, and for industrial and commercial fuel combustion.

The purposes of the NAPCA-EPA work and that reported here are similar. Using the same equipment-cost information, NAPCA-EPA studied specific combinations for specific processes of fixed size. The present work using emcost is more generalized and rapid, albeit more approximate. Without presuming specific combinations, emcost enables cost estimates to be made for any industry for which an emission factor and a flue gas flow rate are known or can be estimated. The emcost relationship is continuous rather than discrete and thus is useful in simulations of industries and cities for approximating control costs for any realistic efficiency without clearly defining the actual control mechanisms.

CONCLUSIONS

Both the NAPCA-EPA and emcost estimation methods indicate that, for several industries, extremely high levels of particulate emission control (above 99.9% in some cases) are feasible. Sometimes such control levels can be achieved by spending less than one percent of product value.

It should be noted, however, that relatively low percentages of gross revenue can have a dramatic effect on profits, particularly for low-margin businesses unable to raise prices. For example, a four-percent profit margin would be reduced 25% by a one percent (of gross revenue) control expenditure.

Relative control costs as related to efficiency can serve as useful guidelines toward postulation of equitable, effective control regulations. But while emcost can estimate the cost of emission control, it overlooks the extent of control actually required to achieve air quality goals. Modeling studies may indicate that an optimum air quality improvement strategy would require significant variation in the relative emission control costs (product value related) to be borne by each industry in a given region.

The emcost method is proposed for use either alone or as a part of modeling studies. As more cost information becomes available, the suggested method should be applicable to additional pollutants and is proposed here as a generalized model which should undergo continual revision and improvement as more information becomes available. Emcost not only enables rapid cost estimation but also should be useful for comparing the relative cost effectiveness of devices operating at different efficiencies and throughput rates. As such, vendors might find it useful to compare their cost and performance with the emcost equations. Such emcost-enabled comparisons, when published, should be very helpful in shedding light on an area of air quality management which has often tended to be shrouded in mystery. Emission control can be expensive, but expense is a relative item.

TABLE 1
PROCESS SUMMARY: REPRESENTATIVE LARGE PLANTS[13]

	Production (lb/hr)	Process (lb/hr) rate	Flue gas volume (actual ft^3/min)	Inlet emissions		Product value ($/lb)
				(lb/lb process)	(lb/hr)	
Open hearth furnace (250 ton/heat)	50 000	56 000	40 000	0.006	336	0.06
Blast furnace (1000 ton/day)	83 400	266 000	100 000	0.031	8 246	0.03
Refuse incinerator (1000 ton/day)	83 400	83 400	200 000	0.01	834	0.002
Cement plant (10 000 barrel/day)	150 000	270 000	300 000	0.055	14 850	0.01
Coal-fueled electric power plant (1000 Megawatt)	— —	854 000	3 500 000	0.1	85 400	0.006*

* Per kilowatt-hour.

TABLE 2
COST EQUATIONS (1965 BASIS)

		R^2*	Number of data points
Wet collector	$\text{emcost} = 41.5 \times 10^{-6} Q^{0.91} \left(\frac{R}{1-R}\right)^{0.52}$	0.997	9
Low-voltage electrostatic precipitator	$\text{emcost} = 75.9 \times 10^{-6} Q^{0.90} \left(\frac{R}{1-R}\right)^{0.14}$	0.996	9
High-voltage electrostatic precipitator	$\text{emcost} = 520.5 \times 10^{-6} Q^{0.69} \left(\frac{R}{1-R}\right)^{0.18}$	0.982	9
Filter	$\text{emcost} = 119.5 \times 10^{-6} Q^{0.89}$	0.978	8
Dry centrifugal	$\text{emcost} = 18.7 \times 10^{-6} Q^{0.96} \left(\frac{R}{1-R}\right)^{0.12}$	0.999	9
Gravitational	$\text{emcost} = 3.2 \times 10^{-6} Q^{0.98} \left(\frac{R}{1-R}\right)^{1.31}$	0.987	9
Composite of above	$\text{emcost} = 15.5 \times 10^{-6} Q^{0.96} \left(\frac{R}{1-R}\right)^{0.30}$	0.814	53

* (explained variation)/(total variation)

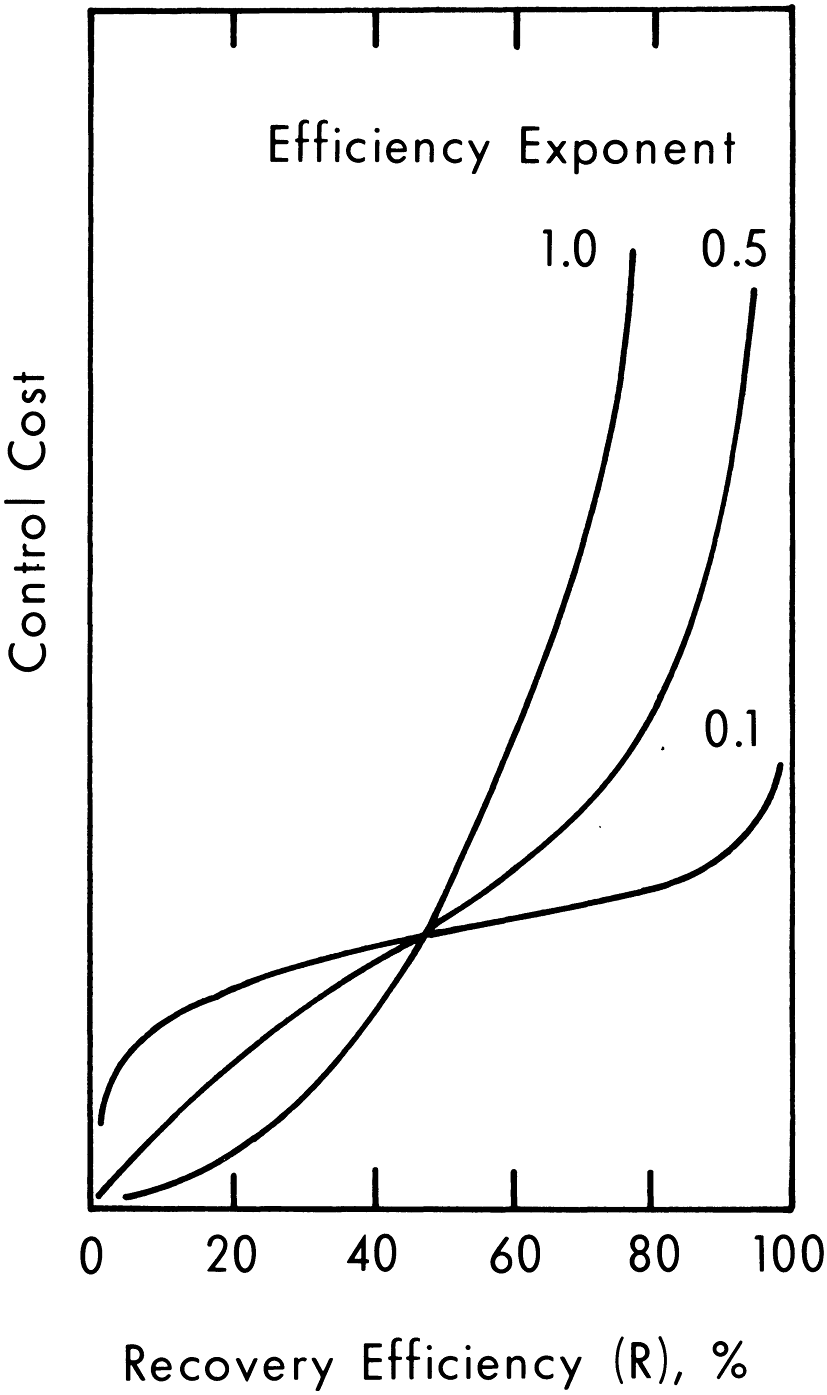

FIGURE 1
Control cost model.

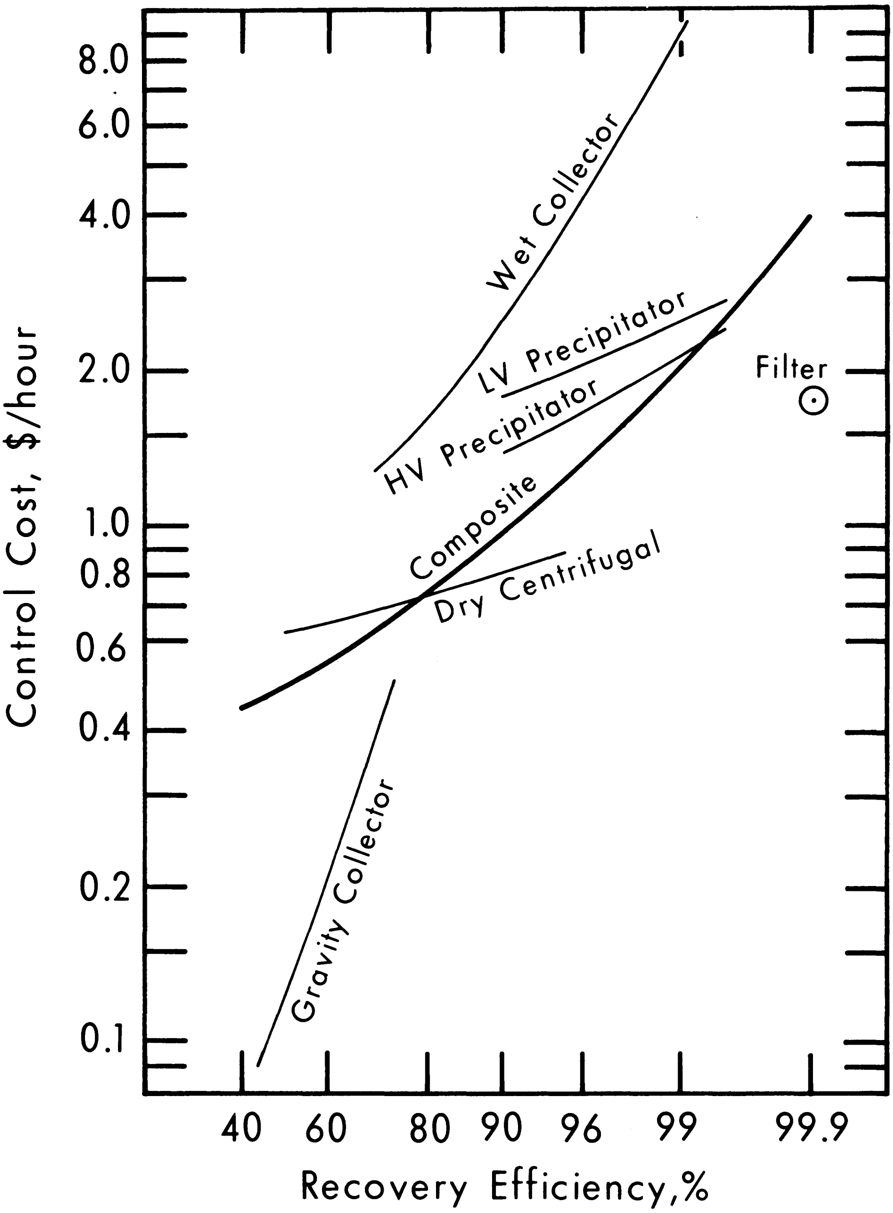

FIGURE 2
Control cost-efficiency relationships (50 000 ft^3/min).

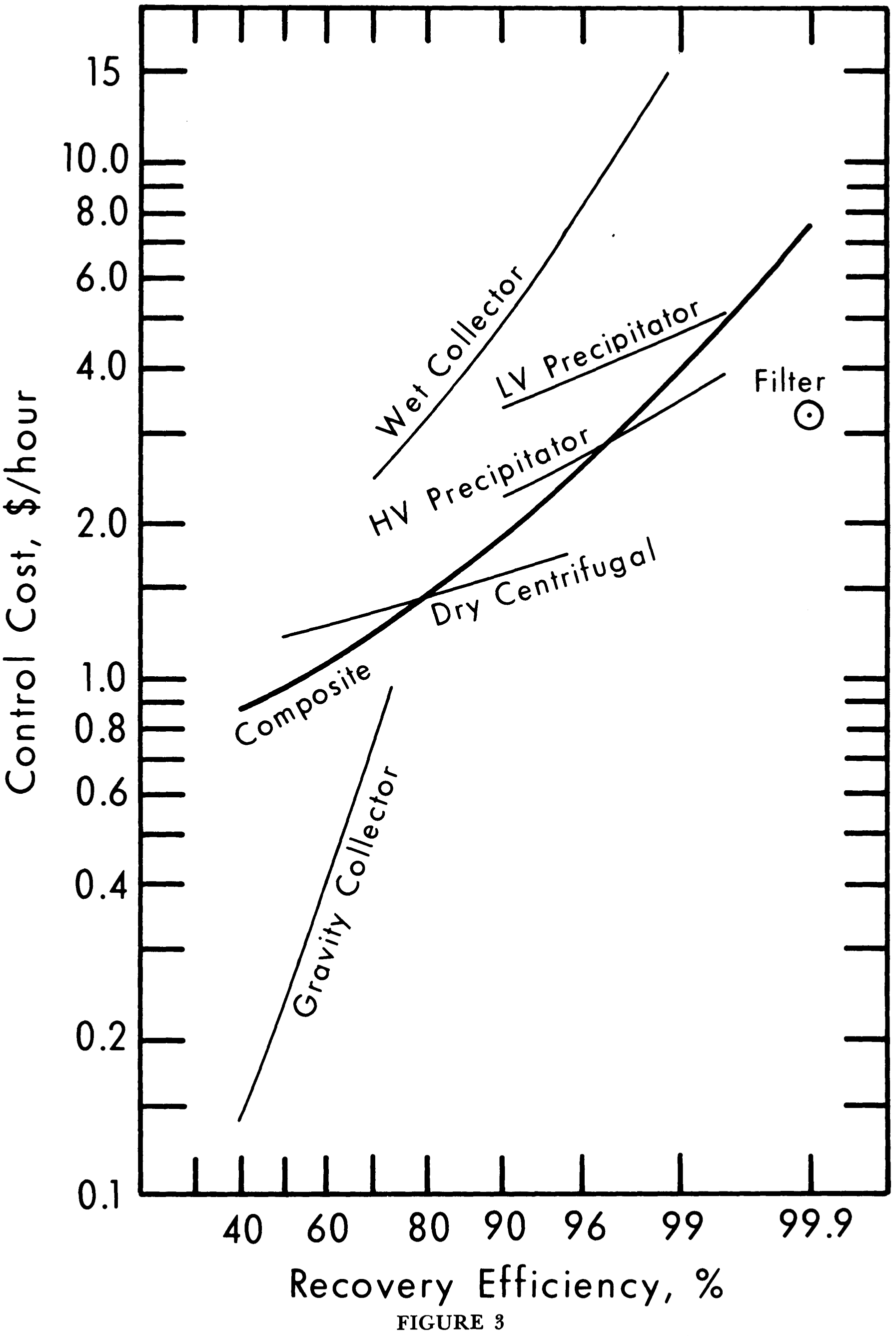

FIGURE 3
Control cost-efficiency relationships (100 000 ft^3/min).

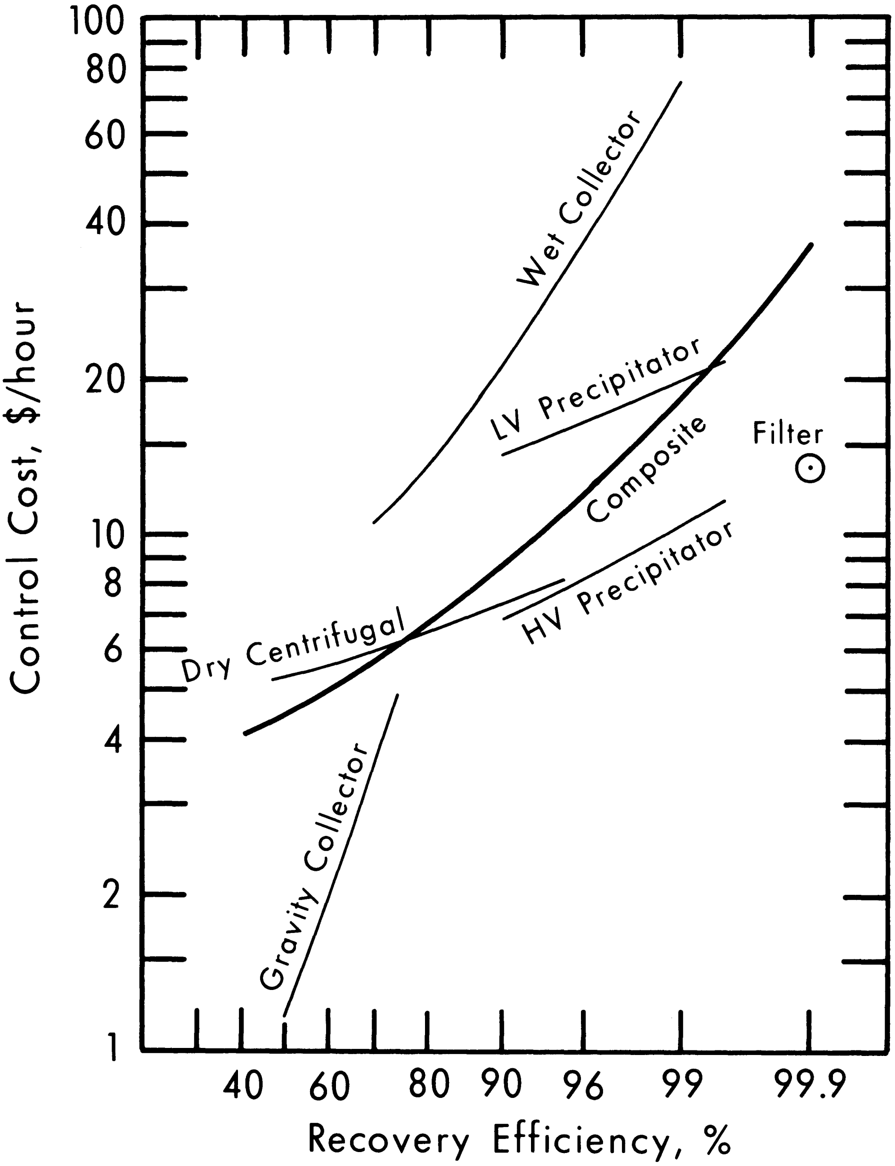

FIGURE 4
Control cost-efficiency relationships (500 000 ft^3/min).

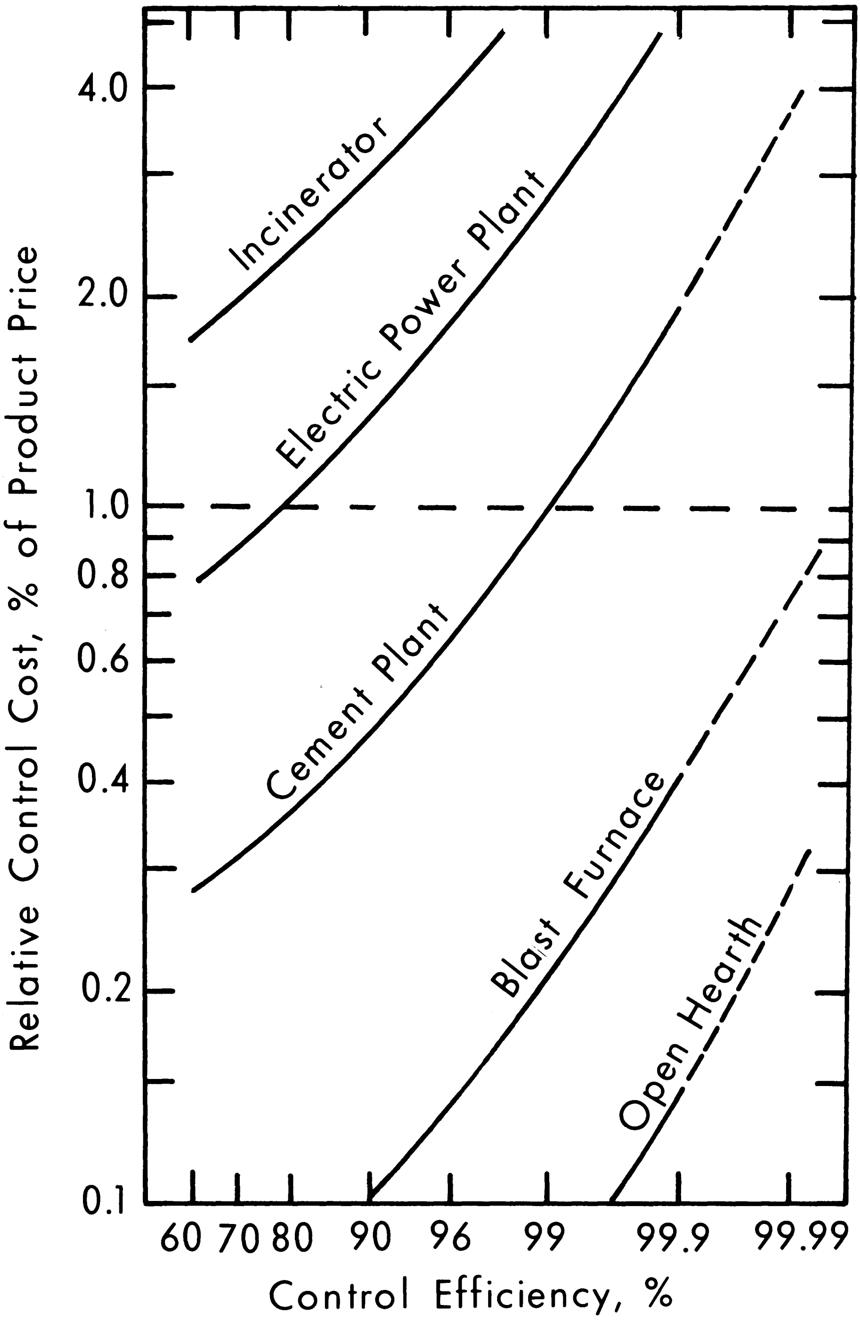

FIGURE 5
Relative costs of particulate emission control.

FOOTNOTES

* Associate Professor, School of Public Health and College of Engineering, University of Illinois. This article is part of work undertaken at the request of the Illinois Pollution Control Board. L. R. Babcock, INDUSTRIAL PARTICULATE EMISSIONS (Chicago: Illinois Pollution Control Board, January, 1971). Financial support was provided by the Illinois Institute for Environmental Quality, the National Science-Foundation (Grant GK 27772), and the University of Illinois.

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[11] *Id.*

[12] Secretary of Health, Education and Welfare, THE COST OF CLEAN AIR (Washington, D.C.: U.S. Government Printing Office, 1969) (Doc. No. 91-40).

[13] R. L. Duprey, *supra* n.3; T. E. Kreichelt, *et al., supra* n.3; J. J. Schueneman, *et al., supra* n.2; W. S. Smith, and C. W. Gruber, *supra* n.4.