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Project Summary

Computer Programs for Estimating the Cost of Particulate Control Equipment

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The report describes an interactive computer program, written to estimate the capital and operating expenses of electrostatic precipitators (ESPs) fabric filters, and venturi scrubbers used on coal-fired boilers. The program accepts as input the current interest rate, coal analysis, emission limit, and design and operating parameters of the control device. The installed cost of the collector and the annual fixed and variable operating and maintenance costs are estimated. Based on the interest rate specified, an annual payment of interest and principal is calculated for the amount of capital required. This annual capital cost is added to the annual operating and maintenance costs to yield a total annual cost of the collector. A comparison between reported and predicted costs indicates that the model is capable of ±25 percent accuracy.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Predicting the lowest cost of meeting a proposed particulate emissions standard requires a rigorous engineering analysis of the available control options. A complete engineering analysis of a project includes process design, estimation of equipment costs, and investment analysis. Although the methods used in process design and investment analysis are well developed, there are no convenient means for estimating the cost of pollution control equipment.

This report describes a set of empirical models developed to aid in estimating capital and operating costs of particulate control systems for coal-fired boilers. The models predict process costs based on the design and operating conditions of the control device and are capable of ±25 percent accuracy. The output from the models includes an itemization of the capital costs, the annual operating and maintenance costs, annual capital cost, and total annual cost. These models have been implemented into a computer program that is available on the Radio Shack® TRS-80 Models I and III computers. Complete details of the models and the computer program are included in the full report.

Cost Modeling

The simplest way to estimate the capital cost of equipment of known size is to scale it according to the size and cost of an existing unit of the same design. The equations used in the cost estimation models are similar to Williams' "six-tenths factor"[1] (where the size increase of the equipment is raised to a fractional power) and are based on estimated equipment costs. There is a separate equation for each major equipment item or group of items; e.g., one equation is used to estimate the cost of a coldside ESP, including the cost of the ESP and hoppers, hopper heaters, electrical hardware, control room, and ESP support steel. Other equations are used to estimate the cost of insulation, ducting and supports, ash handling system, ash pond, and induced draft fans. Sometimes, more than one size factor is used in the calculation with a separate exponent for each. For example, the ESP cost model predicts capital cost for an ESP based on its specific collection area and flow rate through the ESP. These equations were developed by Chapman et al.[2] The data from which the ESP and baghouse models are derived are contained in a report by Campbell et al.[3] The data for the scrubber cost model are from reports by Ponder et al.[4] and Kinkley and Neveril.[5]

The calculation of operating and maintenance costs is much more straightforward because these costs are directly proportional to system size and the amount of throughput of the control device. For example, the cost of maintenance for an ESP is estimated to be $0.769/m^2 of collector per year at full capacity. For an ESP operating at only 70 percent of capacity, the cost would be proportionately less. The cost of operating labor and materials and electricity required to run the control device is calculated similarly.

Accuracy of the Model Predictions

Since the models for capital cost are based on estimates of equipment costs, it is prudent to compare the predictions of the models with accurate and well-documented data on the cost of existing units. These stringent requirements for data quality eliminate guesses and estimates from models similar to our own. Table 1 lists available data.

Predictions of costs for the units listed in Table 1 are from several sources. Pertinent design and operating information was obtained from the reports cited in Table 1. Where information was not available, reasonable values were assumed. For parameters where it was necessary to assume a value, the same assumption was made for all similar control devices (e.g., all fabric filter bags have a life of 2 years). Engineering and contingency costs were each assumed to be equal to 20 percent of the total field cost of the project. All of this information was input to the computer program (described below) to obtain the results. For a comparison between these predicted costs and the actual costs to be made, it was necessary to subtract the retrofit costs from the reported costs. In the absence of an itemized retrofit cost, a value equal to 10 percent of the reported total field cost was subtracted, based on recommendations by Ensor et al.[8]

Results of an overall comparison between the actual and predicted costs are shown in Figure 1. The dashed lines in the figure represent 25 percent bounds on the x=y line. That is, the upper dashed line represents a predicted cost that is 25 percent greater than the corresponding reported cost, and the lower dashed line indicates a predicted cost that is 25 percent less than the reported cost. Some of the data points have error bars around them to denote a range of values for predicted costs because the reported costs for these data points include the costs of two or more control devices at one site. The upper value of the range represents the cost of a single large control device equivalent in size to the actual units, and the lower value represents the predicted cost of two or more

Table 1. *Sources of Cost Data on Actual Installations*

Plant	Type of collector	Size MW	Year of installation	Citation
Cherokee #3 (r)	TCA wet scrubber	160	1971	Ensor et al.[6]
Nucla (r)	Baghouse	38	1974	Ensor et al.[7]
Kramer (r)	Baghouse	115	1977	Ensor et al.[8]
Sunbury (r)	Baghouse	175	1973	Cass and Bradway[9]
Shawnee (r)	Baghouse	1,750	1978	Hudson et al.[10]
Harrington #2	Baghouse	350	1977	Turner[11]
George Neal #3	ESP coldside	500	1975	Ensor et al.[12]
Plant A	ESP hotside	576	1975	Sparks[13]
Navajo	ESP hotside	750	1977	Marchant and Gooch[14]

(r) = retrofit.

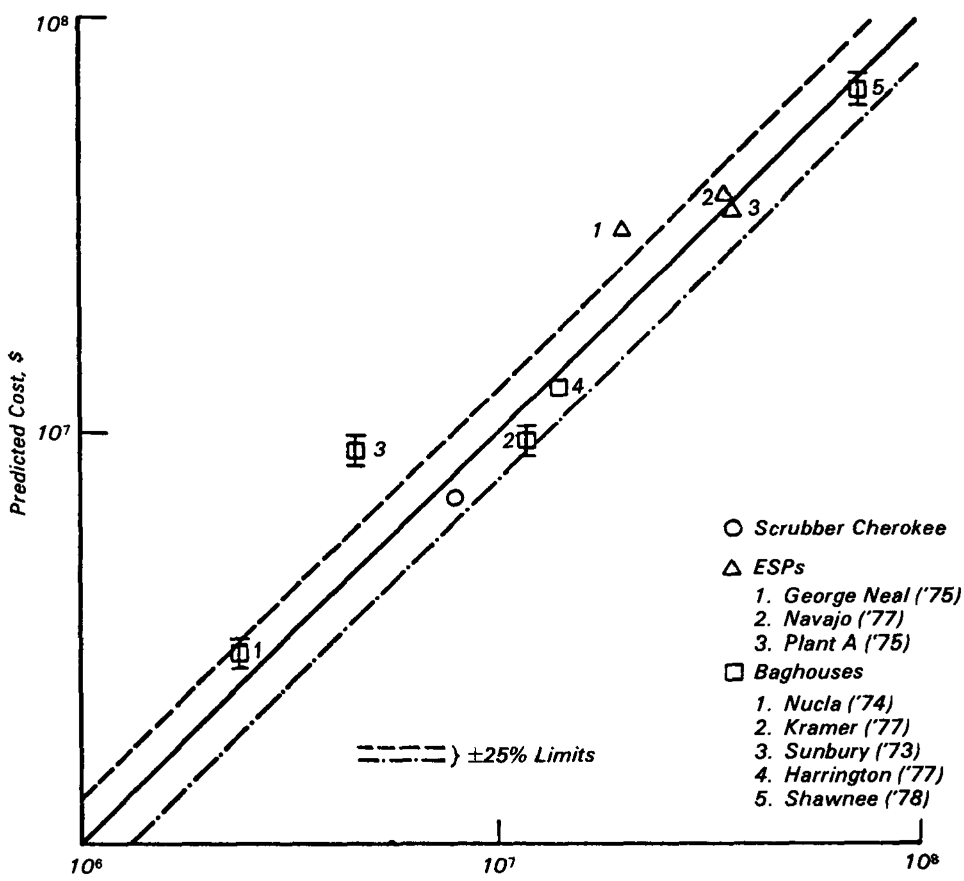

Figure 1. *Comparison between actual and predicted costs.*

independent projects. The best prediction should fall somewhere within this range, accounting for both the added cost of separate installations and the savings associated with a large-scale project.

No attempt was made to verify the accuracy of the predictions of operating and maintenance costs, but they are believed to be adequate. Since the annual capital cost represents the major portion of the total annual cost, even a large error in prediction of operating expenses would not affect the ±25 percent accuracy of the total annual cost.

Table 2. George Neal Costs Summary (1975 Dollars x 10^3)

	Reported	Predicted[a]	Predicted[b]
Collector and supports	11,200	12,100	12,300
Ducting and supports	2,100	3,360	3,760
Ash removal system	1,700	1,450	1,700
Insulation	1,200	1,390	1,420
Miscellaneous	3,200	7,580	7,490
Total field cost	19,400	25,900	26,700
Engineering	600	4,520	4,720
Contingency	c	c	c
Turn-key cost	20,000	30,400	31,400

[a]Cost computed for one 530-MW ESP.
[b]Cost computed as twice the cost of one 265-MW ESP.
[c]Contingency has been factored into equipment costs.

Discussion

Most of the points in Figure 1 lie within the ±25 percent error bounds with two notable exceptions: the Sunbury baghouse and the George Neal precipitator. For the Sunbury baghouse there is reason to question the accuracy of the reported costs. The Sunbury unit was the first fabric filter installed on a utility boiler. Conventional wisdom says that first-time installations have high costs relative to later projects of the same scope. Costs tend to decline as one progresses along the "learning curve" and acquires experience with the construction, installation, and start-up of control devices. In spite of this reasoning, the reported cost is lower than expected. One slight advantage that the Sunbury plant can claim is the use of a stripped ESP shell for the fabric filter housing. However, this salvage is not enough to account for the very low cost. It can only be speculated that this project went very smoothly, without costly errors, or that the reported costs are incomplete.

The George Neal ESP is the other point that lies outside of the ±25 percent error bounds. To understand this discrepancy, it is helpful to look at the more detailed breakdown of actual and reported costs in Table 2. The predicted and reported costs for each item agree fairly well except for the miscellaneous charges and the engineering costs. There is no ready explanation for the difference between the reported and predicted miscellaneous costs. This category is difficult to predict because it includes a variety of items such as earthwork, concrete foundations, painting, and all of the indirect charges. The model developed for the miscellaneous cost may need some fine tuning; however, insufficient information is available to make any changes.

The other source of discrepancy between the reported and predicted costs is the engineering cost. As mentioned earlier, the engineering cost is estimated as a fraction of the total field cost. In this case a value of 20 percent was assumed to be reasonable. Obviously this charge is too high, but note that it is difficult to predict the engineering charges without *a priori* knowledge of what obstacles may be faced during the course of the project. When in doubt it is wise to err to the conservative side in cost estimation.

Overall, the models do a fairly good job of predicting the cost of particulate control devices, usually within ±25 percent. It must be emphasized, however, that the accuracy of the model predictions is highly dependent on the quality of the design and operating information supplied by the user.

Computer Program

The COST program was written to facilitate use of these cost estimation techniques. It is written in the BASIC computer language and is designed with the user in mind. Program features include: interactive data entry with default values available, English and metric units, fast execution, hard copy printout, and storage of input and output parameters in files for easy retrieval. To ensure the ease of use and clarity of documentation, the program was distributed to a small group of users whose experience ranged from beginner to advanced programmer. Their helpful suggestions and comments have been incorporated into the final version of the program.

The current program has one important limitation: the COST program will *not* determine the design and operating criteria required to meet a given emissions limit. The user of the program is required to do the necessary modeling to determine the specific collection area and electrical characteristics for ESPs, air-to-cloth ratio and pressure drop for fabric filters, and liquid-to-gas ratio and pressure drop for venturi scrubbers. It is hoped that the ability to model these devices will be incorporated into a later version of the COST program.

Figure 2 is a simplified flowsheet of the COST program. The first step in the execution of the program is the input of the plant, coal, economic, and emissions data. Figure 3 shows a sample input worksheet that lists the parameters required by the program at this point. Similar worksheets aid the user in collecting input parameters for each control device. After the plant information has been entered, the program will do some preliminary calculations and then save all of the input data on a disk. The next step is selection of the desired control device. The user selects either the fabric filter, ESP, or venturi scrubber model. Finally the design and operating information must be entered. This information can be based on an operating plant, or it can be obtained from a computer model of the device. For example, the GCA fabric filter model,[15] the venturi scrubber performance model,[16] and the SoRI or RTI EPA models[16,17] can be used to obtain the necessary design and operating parameters for a given emission limit. It is up to the user to supply meaningful input to the program. Once the necessary information has been entered, the program calculates the capital costs, fixed annual operating cost, variable annual operating cost, cost of electricity, annual capital cost, and the total annual cost. The results are displayed on the computer's video screen and stored on a disk to be recalled when necessary. The program can also produce a hard copy of the results (see Figure 4) on a line printer.

Most of the time required to get results from the COST program is spent filling in

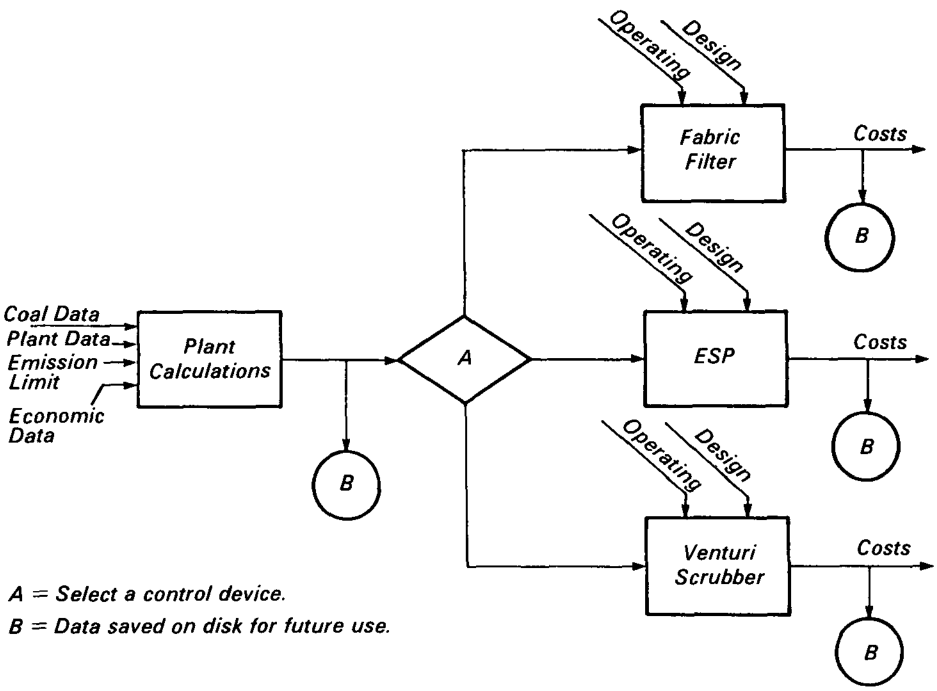

Figure 2. *COST program flow sheet.*

PLANT INPUT WORKSHEET

Plant: Test

Date: 6/12/81

Remarks: Demonstration of the COST program

PLANT DATA

Boiler size	500 MW net		
Capacity factor	70 %		
Chemical Engineering Plant Cost Index	270		
Emission limit	43 ng/J	or	____ lb.MBtu
Plant altitude	300 m	or	____ ft
Interest rate	15 %/yr		
Cost of electricity	30 mill/kWh		
Contingency as percent of field cost	20 %		
Engineering as percent of field cost	20 %		
Stem cycle efficiency	38 %		
Coal heating value	23,240 kJ/kg	or	____ Btu/lb
Fraction excess air	0.25		
Percent carbon in coal	60 %		
Percent hydrogen in coal	5.4 %		
Percent oxygen in coal	11.2 %		
Percent sulfur in coal	0.6 %		
Percent nitrogen in coal	1.6 %		
Percent ash in coal	7.6 %		
Percent water in coal	13.6 %		

Figure 3. *Plant input worksheet.*

the worksheets. The program itself can be run in less than 5 minutes.

System Requirements

The COST program is written for a Radio Shack® Level II, Model I or Model III TRS-80 microcomputer with 48 kilobytes of RAM and at least one 5¼-inch floppy disk drive. The program requires Radio Shack's TRSDOS Disk Operating System (DOS) or any other DOS that is capable of running Microsoft Disk Basic and is file-compatible with TRSDOS. The COST program is also designed to provide a listing of results on a line printer. Complete documentation for the program is contained in the full report.

Summary

The empirical models that have been developed provide a convenient and reliable means for estimating capital and operating costs for particulate control systems. The results from these models can be used in an investment analysis to compute levellized cost or some other measure of merit. The computer program that was written to implement these models provides a quick and easy way to compare alternative designs and check estimates.

At present, the models cannot consider any site-specific factors that would affect costs, nor can they consider the effect of new technologies on capital and operating costs. It is possible to expand the models to provide this flexibility. The utility of the computer program can be enhanced by incorporating control device performance models to allow a user to predict the collector performance more easily before going on to the cost estimation procedure.

References

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OUTPUT FROM PARTICULATE CONTROL COST MODEL VERSION 1.1          PAGE 1 OF 3

PLANT : KRAMER
DATE : 09/23/81
REMARKS : COMPARISON WITH ACTUAL COSTS

                              PLANT DATA
================================================================================
     BOILER SIZE                                        115 MW NET
     CAPACITY FACTOR                                   69.0 %
     CHEM. ENG. PLANT COST INDEX                      202.0
     EMISSION LIMIT                                     0.0 LB/MBTU
     PLANT ALTITUDE                                     973 FT
     INTEREST RATE                                    20.00 %/YR
     COST OF ELECTRICITY                              30.00 MILL/KWH
     CONTINGENCY AS PERCENT OF FIELD COST              20.0 %
     ENGINEERING AS PERCENT OF FIELD COST              20.0 %
     STEAM CYCLE EFFICIENCY                            38.0 %
     GAS FLOW RATE                                      558 KACFM
     BOILER EMISSIONS                                   0.0 LB/MBTU
     COAL HEATING VALUE                              10,911 BTU/LB
     FRACTION EXCESS AIR                               0.25
     PERCENT CARBON IN COAL                           67.50 %
     PERCENT HYDROGEN IN COAL                          5.30 %
     PERCENT OXYGEN IN COAL                           10.60 %
     PERCENT SULFUR IN COAL                            0.30 %
     PERCENT NITROGEN IN COAL                          1.51 %
     PERCENT ASH IN COAL                               4.20 %
     PERCENT WATER IN COAL                            11.00 %

OUTPUT FROM PARTICULATE CONTROL COST MODEL VERSION 1.1          PAGE 2 OF 3
PLANT : KRAMER
DATE : 09/23/81

BAGHOUSE NAME : BAG1
REMARKS : ONE LARGE BAGHOUSE
                              BAGHOUSE DATA
================================================================================
     GAS TEMPERATURE                                    365 F
     EXPECTED BAGHOUSE LIFE                              20 YRS
     AIR TO CLOTH RATIO                               1.690 FT/MIN
     MAXIMUM PRESSURE DROP                             6.00 IN H2O
     AVERAGE PRESSURE DROP                             4.50 IN H2O
     NUMBER OF MODULES                                   46
     REVERSE AIR FAN SIZE (KW/10E5 M2 BAG AREA)         165
     BAG LIFE                                           2.0 YEARS
     BAG LIFE EXPONENT                                0.600
     BAG REPLACEMENT COST                          $   0.65 /FT2
     LABOR RATE                                    $  14.00 /HR
     MATERIAL OVERHEAD FRACTION                       0.100
     FAN LOAD FACTOR                                  0.820
     FAN EFFICIENCY                                    80.0 %
     HOPPER HEATER DUTY FACTOR                        0.300
     ACCESORIES DUTY FACTOR                           0.800
     ASH REMOVAL SYSTEM DUTY FACTOR                   0.600
     SCHEDULED BAG REPLACEMENT TIME                       2 MIN/M2
     UNSCHEDULED BAG REPLACEMENT TIME                     7 MIN/M2
     FRACTION OF UNSCHEDULED BAG REPLACEMENTS         0.050
     NON BAG MAINTENANCE TIME (HR/YR/1000 CMS)          560

OUTPUT FROM PARTICULATE CONTROL COST MODEL VERSION 1.1          PAGE 3 OF 3
PLANT : KRAMER
DATE : 09/23/81

BAGHOUSE NAME : BAG1
REMARKS : ONE LARGE BAGHOUSE
                              RESULTS
================================================================================

        COLLECTOR & SUPPORTS                     $ 2.92E+06
        DUCTING & SUPPORTS                       $ 3.13E+05
        ASH REMOVAL SYSTEM                       $ 5.39E+05
        INSULATION                               $ 9.69E+05
        ASH POND                                 $ 2.43E+05
        ID FAN                                   $ 5.74E+04
        MISCELLANEOUS                            $ 1.77E+06
        TOTAL FIELD COST.................................$ 6.81E+06
        ENGINEERING                              $ 1.36E+06
        CONTINGENCY                              $ 1.36E+06
        TURN-KEY COST....................................$ 9.54E+06

        FIXED OPERATING COSTS                    $ 7.52E+04
        VARIABLE OPERATING COSTS                 $ 1.46E+05
        COST OF ELECTRICITY                      $ 1.27E+05
        ANNUAL CAPITAL COST..............................$ 1.96E+06
        TOTAL ANNUAL COST................................$ 2.31E+06
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igure 4. *An example of the hard copy printout.*

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The complete report, entitled "Computer Programs for Estimating the Cost of Particulate Control Equipment," (Order No. PB 84-183 573; Cost: $16.00, subject to change) will be available only from:

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