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Project Summary

Acid Rain Mitigation Study: Volumes I and II.

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The U.S. EPA has initiated a multi-phased study of the acid rain problem. As part of Phase I, Radian Corporation investigated SO_2 emissions and controls in the industrial sector. The primary objective of this work was to provide a consistent set of capital investment and operating costs for flue gas desulfurization (FGD) systems applied to both industrial and electric utility boilers. Retrofit factors and the cost of FGD systems applied to new boilers were addressed. Wet limestone scrubbing and lime spray drying FGD systems were evaluated.

In conducting the work to provide a consistent set of capital investment and operating costs for FGD systems retrofitted to existing boilers, the following issues were investigated:

- **Apparent discontinuities in both FGD system capital investment and operating costs as a function of boiler capacity in the region between industrial boilers and small utility boilers.**
- **FGD retrofit factors applied to existing boilers based on published reports.**
- **Differences between PEDCo Environmental, Inc. and TVA cost estimates for utility boiler FGD systems.**

These costing issues were examined on the bases of design scope, costing factors (for equipment installation, indirect investment, etc.), year of costs, inherent strengths and weaknesses, and published data of actual system costs. Recommendations are made for the cost bases to use in further acid rain studies.

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

There is a growing concern about the acidity of precipitation in the northeastern United States and Canada. Many scientists think that acidic precipitation kills aquatic and plant life, damages crop-growing soil, and accelerates erosion and damage to buildings. Although the mechanisms producing acid rain are not clearly understood, sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) are thought to be the precursors of the chemicals that cause acid rain. Large quantities of SO_2 and NO_x are produced by various combustion and non-combustion processes in both the utility and industrial sectors. Reducing these SO_2 and NO_x emissions to the atmosphere should reduce the potential for acid rain.

Because this concern is increasing, the U.S. EPA initiated a multi-phased study of the acid rain problem. As one part of Phase I, Radian Corporation investigated SO_2 emissions and controls in the industrial sector; Teknekron, Inc. made a similar study of the utility sector. The results of these studies would provide direction for additional phases. The objectives of the later phases are to investigate SO_2 sources in more detail than Phase I, to investigate

NO_x sources, and to model source/receptor relationships.

In support of the Phase I efforts, Radian Corporation was asked to provide a consistent set of capital investment and operating costs for flue gas desulfurization (FGD) systems applied to both industrial and electric utility boilers. Since existing SO_2 sources are the primary targets for reducing the impacts of acid rain, retrofit factors as well as the cost for FGD systems applied to new boilers were addressed This report summarizes the results of that cost work.

The cost estimates used as the basis for this study are:

- Utility boiler FGD systems by TVA and PEDCo Environmental, Inc.
- Industrial boiler FGD systems by Radian Corporation.

Wet limestone scrubbing and lime spray drying FGD systems were evaluated. The U S EPA has recognized that there appear to be discrepancies in these published cost estimates in two areas:

- Utility boiler limestone FGD system costs prepared by TVA and PEDCo Environmental, Inc.
- FGD system costs in the capacity transition from industrial boilers to small utility boilers.

To achieve the primary objective of the study (provide a consistent set of capital investment and operating costs for FGD systems retrofitted to existing boilers), the following issues were investigated:

- Apparent discontinuities in both FGD system capital investment and operating costs as a function of boiler capacity in the region between industrial boilers and small utility boilers.
- FGD retrofit factors applied to existing boilers based on published reports.
- The differences between PEDCo Environmental, Inc. and TVA cost estimates for utility boiler FGD systems.

The above costing issues are examined on the bases of design scope, costing factors (for equipment installation, indirect investment, etc.), year of costs, inherent strengths and weaknesses, and published data of actual system costs Recommendations are made for the cost bases to use in further acid rain studies.

Summary of Results

The results of the investigations of each issue are summarized below.

Utility and Industrial Boiler FGD System Costs

Significant discontinuities in both the FGD system capital investment and operating cost areas as a function of boiler capacity have been observed in the capacity transition from industrial to small utility boiler systems. This study attempts to determine the causes of these discontinuities and to provide a consistent set of costs (capital and operating) for both types of FGD systems applied to new boilers. Cost estimates by TVA (for utility boilers) and Radian Corporation (for industrial boilers) were used for this analysis since these estimates are current and well-documented. In order to properly compare the TVA and Radian estimates, the costs were adjusted to the same economic and technical bases, which include:

- Identical design scope.
- Same year of construction basis.
- Same indirect investment algorithm basis.
- Same unit cost basis for labor, raw materials, utilities, etc.

In addition, major components of industrial boiler FGD systems are usually shop-fabricated whereas utility systems are field-erected. The capital and operating costs developed after accounting for the differences described above were compared to determine if the discontinuities were real or a result of inaccuracies in one or both sets of cost data.

Wet limestone scrubbing and lime spray drying FGD systems are the only processes evaluated in this study. For electric utility plants, wet lime and limestone systems dominate the operating units; wet lime/limestone scrubbing and lime spray drying processes are the prevalent systems being planned for future facilities. For industrial boilers, dual alkali and sodium (once-through) systems dominate operating and planned units, although spray drying systems are beginning to be applied. The dual alkali is more typical of the FGD system that will be applied to large industrial boilers Sodium (once-through) will most likely be applied to small boilers where the high TDS (total dissolved solids) liquid waste can be easily disposed of (such as on steam generators used in oil field injection where the liquid waste can be disposed of by well injection or in evaporation ponds)

To simplify the basis of this and other studies, only the wet lime/limestone FGD costs are recommended for use in developing cost impacts of FGD control for acid rain mitigation. The reasons for this recommendation are:

- The capital and operating costs for wet limestone and dual alkali FGD systems are comparable for industrial boiler FGD applications over the capacity range of 30 - 200 x 10^6 Btu/hr. boiler heat input.
- Due to the large amounts of data on existing utility boiler FGD systems, the cost estimates for limestone systems should be more accurate than for lime spray dryer systems. In addition, the cost estimates supplied by TVA for utility boiler spray dryer FGD systems were preliminary and had not been finalized prior to completing this report.

Only the costs for wet limestone FGD systems are presented and discussed in this summary. However, the analysis of spray drying in the report points out the major factors that affect the costs for these systems.

The capital and annual first year operating and maintenance (O&M)* costs for FGD systems applied to new industrial boilers are derived from the cost data developed by Radian Corporation. These costs are for limestone FGD systems, however, Radian found that dual alkali and limestone FGD costs were comparable (within 10 percent) for the capacity range evaluated. These cost data are part of the background information document which was developed to support new source performance standards for industrial boilers. Table 1 presents a complete breakdown of the capital investment costs (1980 dollars) for FGD systems applied to new industrial boilers ranging in capacity from 30 to 200 million Btu per hour. Table 2 shows the first year O&M costs for those same FGD systems These costs are recommended for use in the acid rain study.

TVA has performed a similar cost analysis for limestone FGD systems applied to new utility boilers Their costing work is part of an on-going

*Includes raw materials, labor, maintenance, utilities, solid waste disposal (if applicable), and overhead Does not include capital-related costs such as depreciation, income taxes, interest, and return-on equity

Table 1. Industrial Boiler Limestone FGD System Capital Investment

Boiler Heat Input Capacity, 10^6 Btu/hr	*Capital Investment*, 10^3 \$*			
	30	*75*	*150*	*200*
Direct Investment				
Raw Materials Handling	*59*	*99*	*147*	*171*
SO_2 Scrubbing	*149*	*244*	*368*	*401*
Fans	*20*	*40*	*69*	*76*
Solids Separation	*160*	*189*	*227*	*275*
Utilities & Service	*23*	*34*	*49*	*55*
Total Direct Investment (TDI)	*411*	*606*	*860*	*978*
Indirect Investment				
Engineering	*98*	*98*	*98*	*98*
Construction & Field Expense	*41*	*61*	*86*	*98*
Construction Fees	*41*	*61*	*86*	*98*
Start-up	*8*	*12*	*17*	*19*
Performance Test	*4*	*6*	*9*	*10*
Total Indirect Investment (TII)	*192*	*238*	*296*	*323*
Contingencies	*121*	*169*	*231*	*260*
Total Turnkey Investment (TTI)	*724*	*1,013*	*1,387*	*1,561*
Land	*0.6*	*0.8*	*1*	*1*
Working Capital	*52*	*72*	*106*	*126*
Total Cap. Investment (TCI)				
1978 \$	*777*	*1,086*	*1,494*	*1,688*
TCI x 1.21 = 1980 \$	*940*	*1,314*	*1,808*	*2,042*
TCI (1980 \$) 10^3\$/10^6 Btu/hr	*31.3*	*17.5*	*12.1*	*10.2*

**Bases given in Tables 2.1.2-4 and 2.1.2-5 of full report.*

Table 2. Industrial Boiler Limestone FGD System First Year Operating and Maintenance Costs

Boiler Heat Input Capacity, 10^6 Btu/hr	*Annual O&M Cost,[a] 10^3 \$/yr (1978\$)*			
	30	*75*	*150*	*200*
Direct Costs				
Raw Material				
Limestone	*10*	*24*	*49*	*65*
Conversion Costs				
Operating Labor	*105*	*105*	*105*	*105*
Supervision	*21*	*21*	*21*	*21*
Utilities				
Process Water	*0.2*	*0.7*	*1*	*2*
Power	*7*	*18*	*36*	*42*
Maintenance Labor & Materials	*33*	*48*	*68*	*78*
Solid Waste Disposal	*28*	*71*	*143*	*190*
TOTAL DIRECT COSTS	*204*	*288*	*423*	*503*
Indirect Costs				
Payroll Overhead	*38*	*38*	*38*	*38*
Plant Overhead	*40*	*44*	*48*	*50*
G&A	*31*	*43*	*60*	*68*
TOTAL INDIRECT COSTS	*109*	*125*	*146*	*156*
Total First Year O&M, *1978\$*	*313*	*413*	*569*	*659*
1981 \$ (1978\$ x 1.285)	*402*	*531*	*731*	*847*
\$/10^6 Btu (1978\$)	*1.99*	*1.05*	*0.72*	*0.63*
\$/10^6 Btu (1981\$)	*2.56*	*1.35*	*0.93*	*0.81*

[a] Bases given in Tables 2.1.2-4, 2.1.2-5, and 2.1.3-3 of full report.

program to develop detailed and accurate costs for utility-sized FGD systems. Table 3 presents the capital investment costs; Table 4 shows the first year annual O&M costs. These costs are also recommended for use in the acid rain study.

The industrial and utility boiler FGD system capital investments, shown in Tables 1 and 3, respectively, should exhibit some discontinuity in the capacity transition from large industrial boilers to small utility boilers due to:

1. Design scope

Utility Boiler

Includes spare absorber modules, stack gas reheat, and on-site sludge disposal pond

Industrial Boiler

Does not include spare absorbers, stack gas reheat, or an on-site pond

2. Method of installation

Utility Boiler

Field-erection

Industrial Boiler

Shop-fabrication of major components

3. Indirect investment plus other capital requirements

Utility Boiler

~1.0 times direct investment

Industrial Boiler

~0.75 times direct investment

The analyses performed in this report illustrate that the three items listed above account for most of the discontinuity in the capital investment costs.

As with the capital investment costs, the industrial and utility boiler annual O&M costs presented in Tables 2 and 4, respectively, are also likely to exhibit some discontinuity due to:

Table 3. *Utility Boiler Limestone FGD System Capital Investment (1980$)*

	Capital Investment,[a] 10^3 $			
Utility Boiler Capacity MWe	*100*	*250*	*500*	*1,000*
Boiler Heat Input[b] *(10^6 Btu/hr)*	*1,000*	*2,500*	*5,000*	*10,000*
Direct Investment				
Raw Materials Handling	*1,738*	*1,875*	*3,844*	*4,541*
SO_2 Scrubbing	*9,399*	*16,070*	*26,764*	*53,272*
Waste Disposal	*5,013*	*8,859*	*14,058*	*22,743*
Total Direct Investment (TDI)	*16,149*	*26,805*	*44,666*	*80,556*
Indirect Investment (II)				
Engr. Design & Supv. plus Architectural & Engr. (A&E)	*1,453*	*2,412*	*4,020*	*7,250*
Construction Expenses	*2,584*	*4,289*	*7,147*	*12,889*
Contractor Fees	*807*	*1,340*	*2,233*	*4,028*
Contingency	*4,199*	*6,969*	*11,613*	*20,945*
Fixed Investment (TDI + II)	*25,192*	*41,816*	*69,679*	*125,667*
Other Capital Requirements				
Start-up & Modifications	*1,938*	*3,217*	*5,360*	*9,667*
Interest During Construction	*3,779*	*6,272*	*10,452*	*18,850*
Land	*634*	*1,247*	*2,107*	*3,573*
Working Capital	*820*	*1,388*	*2,349*	*4,270*
Total Capital Investment *(TCI)*[c]	*32,363*	*53,932*	*89,947*	*162,027*
$/$kW_e$	*323.6*	*215.7*	*179.9*	*162.0*
$10^3$$/10^6 Btu/hr[b]	*32.4*	*21.6*	*18.0*	*16.2*

[a]Bases given in Tables 2.1.2-1 and 2.1.2-2 of full report.
[b]Assumes 10,000 Btu/kWh.
[c]TCI = TDI + II + Other Capital Requirements.

Table 4. *Utility Boiler Limestone FGD System First Year Operating and Maintenance Costs (1981$)*

	Annual O&M Cost[a], 10^3 $/yr			
Boiler Capacity MWe	*100*	*250*	*500*	*1,000*
Boiler Heat Input[b] *(10^6 Btu/hr)*	*1,000*	*2,500*	*5,000*	*10,000*
Direct Costs				
Raw Material				
Limestone	*174*	*436*	*872*	*1,744*
Conversion Costs				
Operating Labor & Supervision	*172*	*260*	*356*	*486*
Utilities				
Process Water	*3*	*9*	*18*	*38*
Electricity	*264*	*604*	*1,201*	*2,343*
Steam	*166*	*414*	*829*	*1,657*
Maintenance Labor & Materials	*1,109*	*1,785*	*2,970*	*5,428*
Analyses	*52*	*52*	*78*	*104*
TOTAL DIRECT COSTS	*1,940*	*3,560*	*6,324*	*11,800*
Indirect Costs				
Overheads				
Plant & Administrative	*800*	*1,258*	*2,042*	*3,611*
Total First year O&M Costs[c]	*2,740*	*4,818*	*8,366*	*15,411*
Mills/kWh	*5.79*	*4.07*	*3.53*	*3.26*
$/$10^6$ Btu[d]	*0.58*	*0.41*	*0.35*	*0.33*

[a] Bases given in Tables 2.1.2-1, 2.1.2-2, and 2.1.3-1 of full report.
[b] Assumes 10,000 Btu/kWh.
[c] Direct plus indirect costs.
[d] Based on boiler heat input.

1. Design scope

Utility Boiler

Stack gas reheat steam used; sludge disposed of in pond on-site

Industrial Boiler

No stack gas reheat steam used; sludge disposed of by outside contractor at $15/ton

2. **Unit costs for raw materials, labor, utilities, etc.**

Utility Boiler

See Table 2.1.3-1 in full report

Industrial Boiler

See Table 2.1.3-3 in full report

3 Capacity utilization factor

Utility Boiler

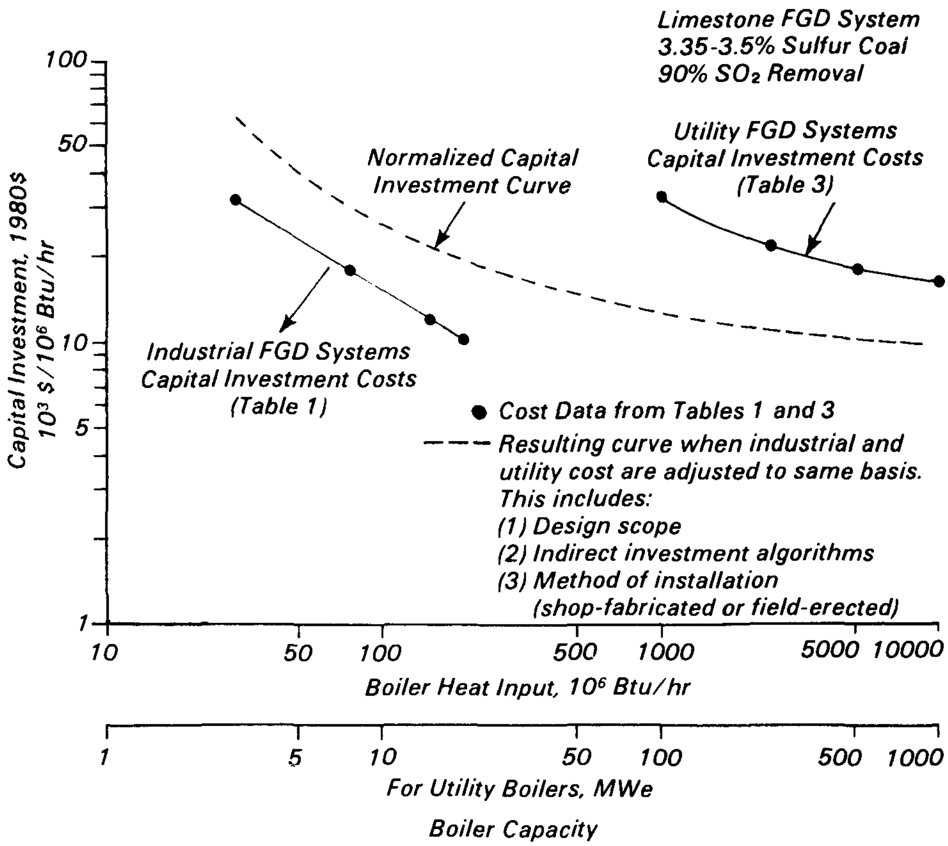
0.54

Industrial Boiler

0.60

In addition to these factors, O&M costs that are estimated based on capital investment (such as maintenance and sometimes overhead) will be significantly different for the two systems because of factors which cause discontinuities in the capital investment (see previous discussion on capital investment). The analyses performed illustrate that the items identified above account for most of the cost discontinuity

The discontinuities are shown graphically by plotting the data presented in Tables 1 through 4. Figure 1 is a plot of the capital investment costs and Figure 2 is a plot of the first year O&M costs. Also shown on these graphs is a plot of the normalized cost values which result from elimination of the differences in design scope, installation and indirect investment algorithms, capacity utilization factors, and unit costs mentioned above The final normalized curves eliminate most of the discontinuities in both sets of data. The rationale for developing the normalized curve is



NOTE: Utility boiler FGD unit investment estimates are provided for boiler capacities of 100-500 MWe and are expressed as dollars per 10^6 Btu/hr of capacity assuming a plant heat rate of 10,000 Btu/kWh. Industrial boiler FGD system estimates are also expressed as dollars per 10^6 Btu/hr of boiler capacity. The utility and industrial boiler investment and capacity scales are interchangeable if the same 10,000 Btu/kWh conversion factor is assumed. This is a close approximation of the heat rate for most utility plants.

Figure 1. *Capital investment for industrial and utility boiler wet limestone FGD systems.*

discussed in detail in Section 2 of the full report

However, due to the environmental regulations and economy of scale, the design scope is likely to be considerably different for industrial and utility boiler FGD systems as discussed previously. Many components of industrial boiler FGD units are likely to be shop-fabricated; whereas, utility systems are field-erected. In addition, unit costs for raw materials, utilities, and solid waste disposal are likely to be considerably different due to volume or quantity considerations. Different capacity utilization factors may also be expected The factors affecting capital investment and, therefore, certain O&M costs (such as maintenance and overhead), are also important. Therefore, discontinuities in the capital investment and O&M curves similar to those shown in Figures 1 and 2 should be expected.

In summary, the annual O&M and capital investment cost estimates for wet limestone FGD systems presented in this study* should be considered as valid consistent data Therefore, it is recommended that the cost data shown in Tables 1 through 4 be used in later acid rain studies as the basis for assessing cost impacts for FGD controls.** Of course, adjustment to the bases (such as design scope, start-up date, and site-specific unit costs for raw materials, utilities, etc.) may be required by a particular reader. The data in this report is documented so that these adjustments can be made, if desired.

*For FGD systems applied to new industrial and utility boilers

**Retrofit factors will have to be used to adjust these costs to reflect the costs of applying FGD systems to existing boilers

FGD System Retrofit Factor Evaluation

A retrofit factor is defined as the ratio of the capital investment or operating cost for installing a process in an existing plant to the capital investment or operating cost for the same process in a new installation. This factor is often applied to new installation costs to estimate the costs of putting the same basic equipment into an existing facility.

Retrofit factors were only evaluated for utility boilers because there was no published information on retrofit factors for industrial boilers. Therefore, there is no retrofit factor recommendation for industrial boiler FGD systems.

Capital Investment

Retrofit factor studies performed by TVA, PEDCo Environmental, Inc., M.W. Kellogg, and Radian Corporation were examined. Retrofit factors ranging from 0 9 to 3.0 were found in these studies. Space availability was identified as the principal factor affecting the capital investment associated with retrofitting FGD systems.

For a preliminary evaluation, a retrofit factor of 1 2 is recommended for "average" retrofits for boilers less than 10 years old and with capacities greater than 200 MW. A retrofit factor range of 1.1 to 1.4 is also recommended. The lower end of the range is applicable when installation of the FGD system is relatively uninvolved and when available space for FGD equipment is adequate. Retrofit factors in the upper range nearer 1.4 would be used when retrofitting is complex

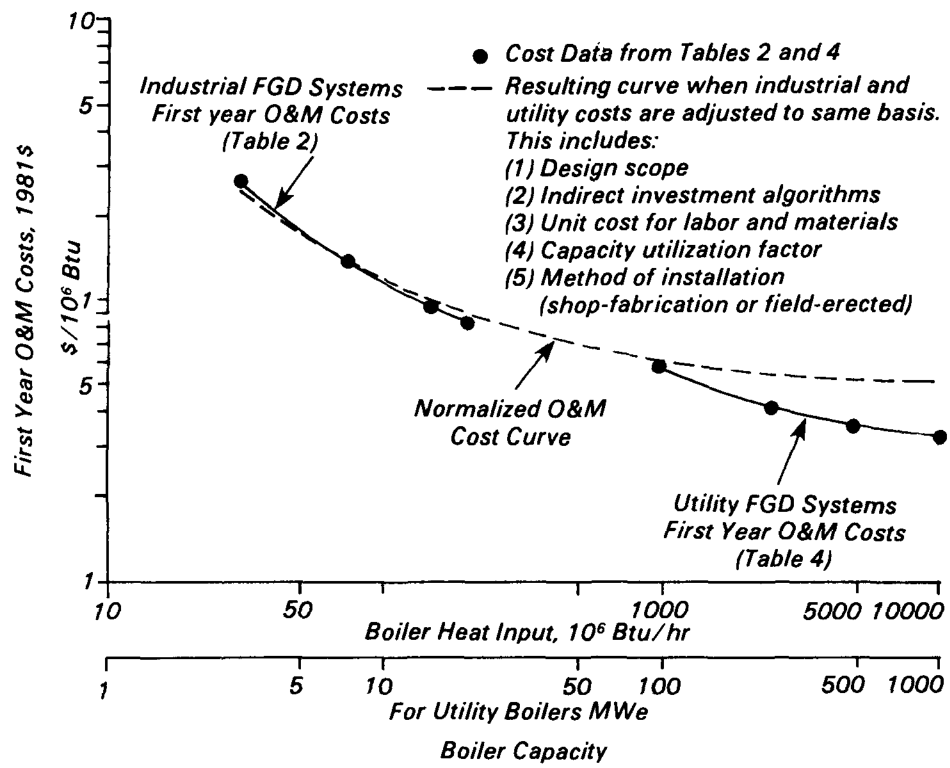
The retrofit factor 1.2 is recommended for use in a preliminary evaluation of FGD system retrofit costs for utility boilers. The reader should note that:

(1) Retrofit of FGD systems to some boilers will be infeasible.
(2) Retrofit factors greater than 1.4 are possible.

Only a site-specific evaluation of the factors associated with retrofit can accurately quantify the costs.

Annualized Costs

No retrofit factor for annualized costs is recommended. Increased annualized costs for retrofits compared to new



NOTE: Utility boiler FGD unit annual O&M estimates are provided for boiler capacities of 100-500 MWe and are expressed as $\$/10^6$ Btu assuming a plant heat rate of 10,000 Btu/kWh. Industrial boiler FGD system estimates are provided for boiler heat input capacities of 30-200 x 10^6 Btu/hr and are expressed as $\$/10^6$ Btu. The utility and industrial boiler capacity scales are interchangeable if the same 10,000 Btu/kWh conversion factor is assumed. This is a close approximation of the heat rate for most utility plants.

Figure 2. ***First year O&M costs for industrial and utility wet limestone FGD systems.***

systems are primarily associated with the higher capital investment. Therefore an annualized cost retrofit factor would be a strong function of the capital investment retrofit factor, the load factor of the boiler, and the remaining useful life of the boiler.

TVA and PEDCo Environmental, Inc. FGD System Cost Comparison

Both TVA and PEDCo have developed cost estimating procedures for utility boiler FGD systems. In the past, estimates from the two organizations have shown significant differences. Cost estimates by TVA and PEDCo were evaluated to determine whether the differences are real or a function of such factors as design scope, indirect investment algorithms, unit cost for raw materials, utilities, and other economic parameters.

The results of the study show that capital investment and O&M costs for a lime wet scrubbing system prepared by both organizations are very similar when all bases (economical and technical) are made identical.

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The complete report consists of two volumes, entitled "Acid Rain Mitigation Study:"
"Volume I. FGD Cost Estimates (Technical Report)," (Order No. PB 83-101 329; Cost: $16.00, subject to change)
"Volume II. FGD Cost Estimates (Appendices)," (Order No. PB 83-117 366; Cost: $20.50, subject to change)
The above reports will be available only from:
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