LIFE-CYCLE COST BENEFITS OF CONSTRUCTING AN FGD SYSTEM WITH SELECTED STAINLESS STEELS AND NICKEL-BASE ALLOYS

by

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ABSTRACT

Life-cycle cost analyses of the use of stainless steels and corrosion-resistant alloys were compared with those of nonmetallic lined-carbon steel in the construction of FGD scrubbers.

The life-cycle costs of the corrosion-resistant alloys are often substantially less than the costs for nonmetallic-lined steel. The benefits of using better materials of construction are improved reliability and reduced downtime; even a minor improvement in these areas can add substantially to the life-cycle cost savings.

Additional savings can be achieved by selecting materials for individual components in order to match the operating environment of the component with the characteristics of the materials.

Extensive field experience confirms the favorable conclusions of the cost analyses.

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SECTION 1

INTRODUCTION

Frequently, performance failures and the resulting shutdowns of utility flue gas desulphurization (FGD) systems are directly related to materials of construction.

The flue gas-handling components that promote the initial reactions between the flue gases and the absorbing slurry or quench water are most susceptible to material failures. The costs of these forced shutdowns are significant.

Service experience has shown that flue gas-handling equipment constructed of stainless steel or nickel-base alloys can significantly reduce the number of shutdowns and their associated costs (please see case histories). These demonstrations have resulted in increased interest in the use of stainless steels and nickel-base alloys in lieu of nonmetallic materials – either monolithic or lining materials – and several installations have successfully solved their operational problems by switching to corrosion-resistant alloys. The higher initial costs of these materials, however, have discouraged their widespread use.

Because system selection cannot be based on initial costs alone, a life-cycle cost analysis of available alternatives should be performed to arrive at an economically justifiable decision.

Life-cycle costing is an evaluation method that takes into account all of the relevant costs of a system over its lifetime. Life-cycle costing incorporates initial investment costs, future replacement costs, operation and maintenance costs, and salvage and resale values. The individual costs are adjusted to a consistent time basis and are combined into a single measure of cost-effectiveness that makes it easy to compare alternative systems.

This report presents a life-cycle cost comparison of selected stainless steels and nickel-base alloys with other materials of construction for major flue gas-handling equipment. Although the analysis presented is based on lime/ limestone FGD process, the conclusions are broadly applicable.

The life-cycle cost comparison considers only the cost components that are dependent on materials of construction.

Cost components such as operating labor, raw materials, and utilities are not included in the cost analysis because they are not affected by the material of construction. Cost data presented, therefore, should not be construed as total life-cycle costs. The life-cycle cost analysis does not account for the cost of downtime and shutdowns associated with materials failures; even a small improvement in this area could result in significant cost savings. The cost analysis is based on existing (1986) tax laws in the United States; any changes in these laws may affect the life-cycle analysis.

Owners of FGD systems, and engineers involved in selecting and specifying the materials of construction, should benefit from this analysis.

This report is not intended to provide detailed technical information on the behavior and performance of high-alloy materials in the FGD environment; these data are already available in several publications (see bibliography).

SECTION 2

COMPARISON OF MATERIALS OF CONSTRUCTION

Various high-alloy materials have been tried and found to be successful for use in FGD equipment. Based on a literature review and the FGD data base maintained by PEI, the following materials were selected for a life-cycle cost analysis:

Alloy 254SMO
Stainless steel AISI Type 316L
Stainless steel AISI Type 317LM
Ferralium 255
Alloy G
Hastelloy C-22
Alloy 625
Alloy 20Cb-3
Alloy 20Mo-6
Alloy 825
Alloy 904L
Alloy C-276

The life-cycle costs of these materials are compared with those for nonmetallic (Neoprene) lined-carbon steel. Cost comparisons are presented for two types of construction options: (1) solid alloy construction, and (2) high alloy-clad carbon steel construction.

The compositions of the corrosion-resistant alloys selected for this analysis are summarized in *Table 1*. The case histories outlining the experiences with alternative construction materials are included in the case history section.

TABLE 1
COMPOSITIONS OF REPRESENTATIVE HIGH-ALLOY MATERIALS

UNS[a] Number	Alloy*	Nominal composition, weight per cent								C, max. %
		Ni	Mo	Cr	Fe	Cu	W	Cb	N	
S31254	254SMO[b]	18	6.1	20		0.7	–	–	0.2	0.02
S31613	S.S. 316L	10	2	16	70	–	–	–	0.05	0.03
S31725	S.S. 317LM	15.5	4	18.5	62	–	–	–	0.06	0.02
S32550	Ferralium 255[c]	6	3	25.5		2	–	–	0.2	0.04
N06007	Alloy G	44	7	22	20	2	1	2	–	0.05
N06022	Hastelloy C-22[e]	Bal.	13	22	3	–	3	–	–	0.01
N06625	Alloy 625	61	9	22	3	–	–	4	–	0.10
N08020	20Cb-3[d]	34	2	20		3.5	–	0.5	–	0.07
N08026	20Mo-6[d]	34	6	23		3	–	–	0.10	0.03
N08825	Alloy 825	42	3	22	30	2	–	–	–	0.05
N08904	Alloy 904L	25	5	21	45	2	–	–	–	0.02
N10276	Alloy C-276	56	16	16	5	–	3.5	–	–	0.01

[a] Unified Numbering System, UNS.
[b] Trademark of Avesta AB.
[c] Trademark of Langley Alloys.
[d] Trademark of Carpenter Technology Corporation.
[e] Trademark of Cabot Corporation.
* May be produced by other suppliers under licensing arrangements.

SECTION 3

FGD COMPONENTS INVOLVED

To demonstrate the benefits of using corrosion-resistant alloys, a life-cycle cost analysis has been performed on several major components of an FGD system. The most critical applications have been in the flue gas-handling components because they are subjected to the most severe operating chemistry and environment. The FGD components included in this study are:

Scrubber/presaturator
Absorber
Ductwork

Figure 1 indicates the severity of environmental conditions within the various components of a typical FGD system. The environmental conditions are divided into three categories (chemical, abrasion/erosion, and temperature) and assigned a rating of 1 to 3. A rating of 3-3-3 represents the most severe environmental conditions.

It should be noted that the physical configuration of the components plays a major role in creating environmental conditions in FGD components. For example, a design that allows formation of dead pockets may suffer from material failures due to corrosion. The life-cycle cost analysis does not address the design aspect of the components and assumes that the compared systems use identical designs.

SCRUBBER/PRESATURATOR

The scrubber/presaturator is the first component in the FGD system in which flue gases come in contact with the wet slurry or quench water. The high velocities created by the venturi configuration and sudden quenching of hot gases create the most severe environmental conditions. Solving the material failure problems in this component alone can result in a significant reduction in system downtime.

The design of the scrubber/presaturator differs widely among the FGD systems. Many systems eliminate the separate scrubber/presaturator unit, and the presaturator becomes an integral part of the absorber. The life-cycle cost analysis of this report is based on a design in which a separate venturi scrubber is placed ahead of the absorber because a separate unit facilitates the analysis of life-cycle costs.

ABSORBER

The chemical reactions between the flue gases and the absorbing slurry take place in the absorber. Various absorber designs are used to promote adequate reaction times and intimate contact between the slurry and flue gases.

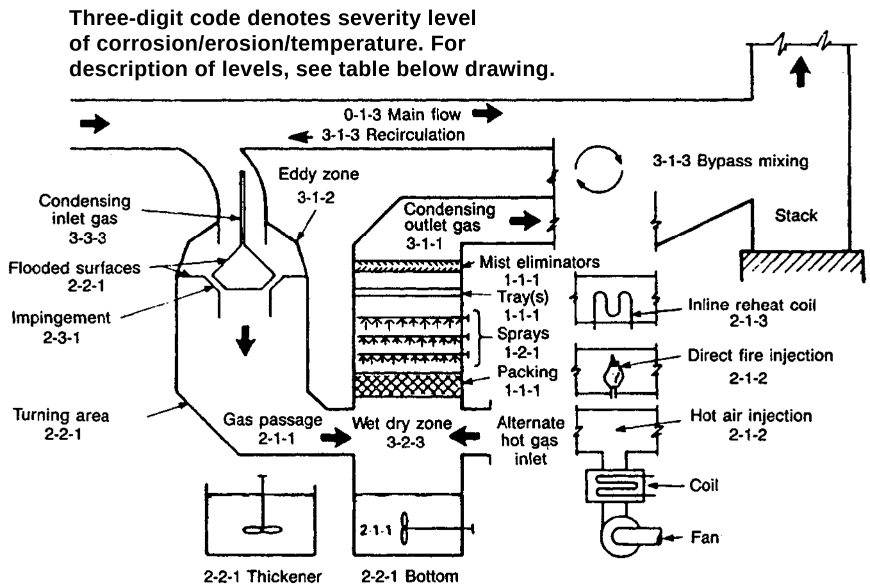
A turbulent-contact absorber design was selected for this analysis because this design is widely used in FGD systems in the United States. Levels of environmental severity vary among the different parts of the absorber. In general, the environmental levels are less severe than in other flue gas-handling components, such as the presaturator and outlet ductwork.

DUCTWORK

The outlet ductwork is another flue gas-handling component that can benefit from better materials of construction. Because the clean gases exiting the absorber are wet, they create condensation in the ductwork and promote corrosion.

The most severe environmental conditions, however, are created in the bypass mixing zone, where the hot uncleaned flue gases come in contact with the cool clean gases. In most FGD systems, the chemical environment is further aggravated by horizontal ductwork, which allows condensation on the duct floors.

GENERIC SCHEMATIC DIAGRAM INCORPORATING FEATURES OF SEVERAL WET FGD SYSTEMS



ENVIRONMENTAL SEVERITY LEVEL

LEVEL	CHEMICAL ENVIRONMENT	ABRASION/ EROSION	TEMPERATURE
1	pH 3-8 Saturated flue gas; process slurry, continuous flow or immersion	Slow-moving liquids & gases; tank walls	Ambient to 60°C; process slurry
2	pH 0.1-3 Up to 15% acid concentration; saturated wet gas; acid liquids; slurries	Spray impingement (6 m/s or more); strong agitation; spray zones; some tank bottoms & wall areas	66-93°C; reheated gas
3	Acid concentration greater than 15%; intermittent wet/dry zones	High energy venturi; turning vanes; struts; targets	93-166°C*; inlet gas; bypass gas; reheat gas injection (hot air, fuel fired, inline reheat coil)

* Temperatures in the range of 216-227°C have been recorded.

Figure 1: Schematic diagram of FGD environmental severity levels. (Reprinted with permission, from STP 837. Copyright, ASTM, 1916 Race Street, Philadelphia, PA 19103.)

SECTION 4

LIFE-CYCLE COSTS

METHODOLOGY

Life-cycle costs take into account all the relevant costs of a system over its lifetime. For a meaningful comparison of available options, life-cycle costs must be all-inclusive, i.e., they must include all the direct and indirect costs. The following cost components were analyzed for a life-cycle cost comparison of FGD system materials of construction:

Initial capital investment
Major maintenance
Routine maintenance
Insurance and miscellaneous annual charges
Investment tax credit
Depreciation tax credit

All of the above cost components are affected by the material of construction. The operating costs (i.e., the costs of raw materials, utilities, and operating and supervisory labor) are assumed to be independent of the materials of construction and thus are not included in the analysis.

The Electric Power Research Institute (EPRI) has published guidelines for performing cost analyses of utility projects in a report entitled *Technical Assessment Guide**. These guidelines provide a consistent set of economic factors, financial assumptions, and other cost estimating parameters necessary for utility projects. PEI followed the EPRI document for this life-cycle analysis.

The basis and assumptions for the analysis are summarized in *Table 2*.

*Technical Assessment Guide (TAG). Electric Power Research Institute, Palo Alto, CA, U.S.A. Publication P-2410-SR, May 1982.

TABLE 2

LIFE-CYCLE COSTING BASES AND ASSUMPTIONS

Capital cost	Initial turnkey cost of the component; includes equipment, installation, and indirects
Major maintenance	For nonmetallic lined-carbon steel (baseline) components only: Lining replacement every five years; No major maintenance for high-alloy systems
Routine maintenance	12 per cent/year of capital cost for nonmetallic lined-carbon steel systems; 7.2 per cent for other solid-alloy constructions, and for all alloy-clad systems
Annual insurance and miscellaneous	0.7 per cent of capital cost
Investment tax credit	First-year credit of eight per cent of capital cost
Depreciation tax credit	Based on a depreciation period of five years and credit straight-line depreciation method. Tax equals 50 per cent of depreciation.
Operating labor, raw materials, & utilities	Assumed to be independent of material of construction and not included in the life-cycle costs
Present-worth basis	Constant dollars
Discount rate	6.1 percent (constant dollar basis)
System life	35 years
Flue gas rate	1 MW – 1.42 m^3 per second of gas flow at 149°C
Type of lining for baseline system	Neoprene rubber

Each of the cost components is discounted to the 1986 base year by use of the present-worth method. The calculations are performed in constant dollars, and an EPRI-recommended discount rate of 6.1 per cent is used.

CAPITAL INVESTMENT

The capital investment of a system component represents the initial installed cost. It includes equipment and auxiliary costs, costs of installing the component, and other related costs (indirect costs).

The capital cost of nonmetallic (Neoprene) lined-carbon steel components was estimated by using PEI's integrated air pollution control system design and cost estimating model. The FGD module in the cost model is based on the latest version of TVA's Shawnee study. The model provided a detailed breakdown of equipment, installation, and indirect costs.

The costs of corrosion-resistant alloy components were estimated by adjusting the equipment costs for higher material costs. The estimated material cost factors for the 6.35 mm plate used in the analysis are shown in *Table 3*. These alloy cost factors are based on industry price data provided at the time this study was prepared.

TABLE 3

ESTIMATED MATERIAL COST FACTORS

Nonmetallic (Neoprene) lined-carbon steel	1.0
Stainless steel AISI Type 316L	1.0
Stainless Steel AISI Type 317LM	1.4
Alloy 904L	1.9
Ferralium 255	2.0
Alloy 254SMO	2.6
Alloy 825	3.0
Alloy 20Cb-3	3.0
Alloy G	3.8
Alloy 20Mo-6	3.8
Alloy 625	5.3
Alloy C-276	5.6
Hastelloy C-22	5.6

The capital cost of alloy-clad systems is based on an alloy cladding thickness of 1.6 mm on 6.35 mm-thick carbon steel. It was determined that the life-cycle costs are not highly sensitive to the cladding thickness.

MAJOR MAINTENANCE COSTS

Field experience indicates that nonmetallic linings for carbon steel components are gradually degraded in operation through chemical, abrasive, and thermal action. Linings are also subject to rapid or even catastrophic damage by significant excursions in scrubber operation. Linings require major maintenance during the design life of an FGD scrubber, and for this analysis costs were estimated for lining replacement every five years.

In the first stage of this analysis, it is assumed that entire components are fabricated from a single grade of corrosion-resistant alloy. It is further assumed that the selected grade does not corrode in service and that it requires no major maintenance.

This simple approach is unrealistic.

In the first place, lesser grades of alloy are not corrosion-resistant in all locations, and higher grades are too costly for use throughout an FGD scrubber. In actual constructions, combinations of corrosion-resistant alloys are used to attain adequate corrosion resistance most economically. Therefore, the life-cycle cost analysis of a single corrosion-resistant grade only provides information for use in combination with cost analyses of other grades for optimal system design.

The second stage of this analysis considers the cost benefits to be derived from the fabrication of components of alloy-clad carbon steel as an alternative to solid alloy fabrication.

ROUTINE MAINTENANCE COSTS

The routine maintenance costs of corrosion-resistant alloy components are expected to be low because of their better performance characteristics. Nonmetallic lined-carbon steel components are expected to require more maintenance because of localized lining problems and repairs. The routine maintenance costs of any system are generally estimated as a percentage of capital investment. The EPRI TAG document recommends a range of 6-10 per cent for the maintenance costs for an entire FGD system. The recommended percentage represents the weighted maintenance requirement for the entire FGD system.

The flue gas-handling components are the most critical components in the FGD system, and the maintenance percentage for these components is expected to be higher than the recommended average. Because the flue gas-handling components are generally subjected to a more severe operating environment than the other components of an FGD system, it is estimated that the maintenance costs for these components are 20 per cent higher than the recommended range, i.e., 7.2-12 per cent.

PEI contacted various industry and utility specialists to obtain the data for maintenance requirements for nonmetallic lined-carbon steel components and corrosion-resistant alloy components. The maintenance costs of alloy systems were reported to be significantly lower. The case histories studied by PEI also support this conclusion.

Therefore, routine maintenance costs of 12 per cent for nonmetallic lined-carbon steel and 7.2 per cent for corrosion-resistant alloys were selected. These percentages represent the upper and lower limit of the EPRI-recommended range.

INSURANCE AND MISCELLANEOUS CHARGES

Annual costs (such as insurance, royalty, etc.) are estimated as a percentage of the capital investment. These charges are estimated to be 0.7 per cent of the capital costs of the component.

INVESTMENT TAX CREDIT

Investment tax credit enables utilities to claim an immediate reduction in income taxes equal to the percentage of the installed cost of the new system. This credit is realized in the year the plant item goes into service.

DEPRECIATION TAX CREDITS

Powerplants in operation before January 1, 1979, are allowed a five-year tax depreciation for new, identifiable, pollution-control facilities completed or acquired after December 31, 1982. The deduction of this depreciation amount from their income reduces the utilities' tax liability.

For this analysis, a straight-line depreciation method and a tax rate of 50 per cent are used.

COMPARISONS OF LIFE-CYCLE COSTS

Life-cycle costs for each material option were estimated for three FGD components. Cost relationships were formulated by estimating costs for three sizes (100, 150, and 200 MW*) for each option.

The life-cycle costs were calculated by estimating the annual cash flows for each cost component and then discounting them to a common base year. The individual discounted cost components were then combined to obtain the total life-cycle cost of the system. The analysis was performed in constant dollars by using an EPRI-recommended discount rate of 6.1 per cent.

Figures 2 through *7* present the life-cycle cost comparison for the analyzed options. The costs of venturi scrubbers constructed of an alloy and of carbon steel with alloy cladding are shown in *Figures 2* and *3*, respectively.

* 1 MW = 1.42 m^3 per second at 149°C

The life-cycle costs of venturi scrubbers constructed of Alloys C-276, C-22, and 625 are higher than those constructed of nonmetallic lined-carbon steel. The life-cycle costs of those constructed of the remaining alloys are lower than those constructed of nonmetallic lined-carbon steel. The life-cycle costs of all venturis constructed of carbon steel clad with alloy are significantly lower than those for nonmetallic lined-carbon steel venturis.

Trends of life-cycle costs for absorbers (shown in *Figures 4* and *5*) are similar to those for venturis. The life-cycle costs of absorbers constructed of Alloys C-276, C-22, and 625 are higher than those constructed of nonmetallic lined-carbon steel. The costs for absorbers constructed of the other alloys together with those of the clad alloy are lower than those constructed of nonmetallic lined-carbon steel.

Figures 6 and *7* show a cost comparison for outlet ductwork. Of the solid alloy construction options, Alloys 904L and 254SMO, Ferralium 255, and stainless steels 317LM and 316L are cheaper than the nonmetallic lined-carbon steel option; costs of the other alloy construction options are higher than the nonmetallic lined-carbon steel option. The life-cycle costs of alloy-clad ductwork compare favorably with the life-cycle costs of nonmetallic lined-carbon steel ductwork; most of the alloy-clad options are cheaper.

In actual application, material selection is optimized by using a combination of corrosion-resistant alloys and selecting the grade for each section in accordance with the demands of the operating environment.

For example, a particular scrubber system might use a venturi constructed of solid C-276; an absorber constructed of 317LM; and ductwork constructed of 904L with *wallpaper* lining of C-276 on 10 per cent of its surface in the region determined to be susceptible to condensate attack.

Life-cycle costs can be calculated for specific material selection scenarios based on the cost curves in *Figures 2* through *7*. Unit costs for individual components can be obtained for selected material and construction options and then combined to obtain the total cost of the combined system.

As an illustration of the impact of the different construction options for individual components, cost curves were plotted in *Figure 8* for the following construction scenarios:

Solid alloy venturi

Alloy-clad carbon steel absorber

Alloy-clad carbon steel ductwork

For each construction material, unit costs from *Figures 2*, *5*, and *7* were added to obtain the data points for the curves in *Figure 8*. The cost relationships in *Figure 8* show that the life-cycle costs of the indicated construction scenarios are lower than the nonmetallic lined-carbon steel material option for all the stainless steels and nickel-base alloys included in the analysis.

Even in the extreme case of a solid C-276 venturi and an absorber and ductwork clad with C-276, the use of corrosion-resistant alloy is less costly on a life-cycle basis than the use of nonmetallic lined-carbon steel. The curves in *Figure 8* are based on the assumption that the same construction material is used for all three components; however, additional savings can result from using different materials within and among the components.

Figure 9 shows the life-cycle cost comparison for the combined scenarios for a 200-MW system. The bars in the graph represent the construction material as a percentage of the nonmetallic lined-carbon system.

This life-cycle analysis understates the cost savings associated with corrosion-resistant alloys. These alloys also are resistant to catastrophic failures associated with operational excursions (e.g., blockage of a pipeline resulting in overheating or incomplete neutralization). The analysis presented in this report does not account for the cost of downtime or shutdowns associated with failure of materials. Even a small improvement in this area can result in large cost savings.

The design values (e.g., yield strength, tensile stress) of some of the corrosion-resistant alloys are substantially greater than those of carbon steel. Furthermore, no corrosion allowance is required in determining the thickness of the corrosion-resistant grades.

Reducing the thickness of corrosion-resistant grades relative to the plate thickness required for carbon steel could substantially lower the initial cost of the use of corrosion-resistant alloys, as could the use of well-established designs for thin-wall structures externally reinforced with lower-grade alloys.

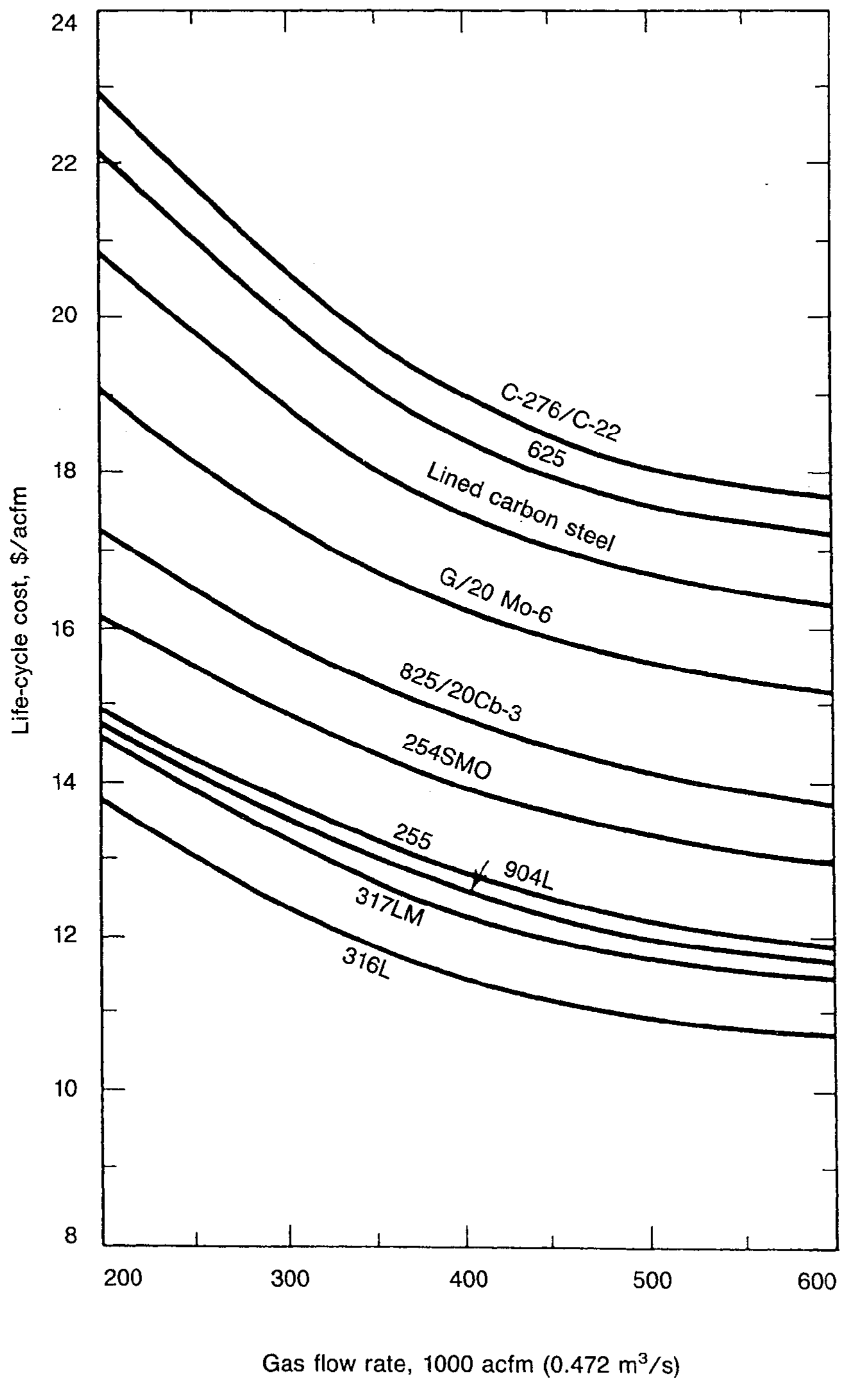


Figure 2: Life-cycle cost comparison, solid alloy venturi.

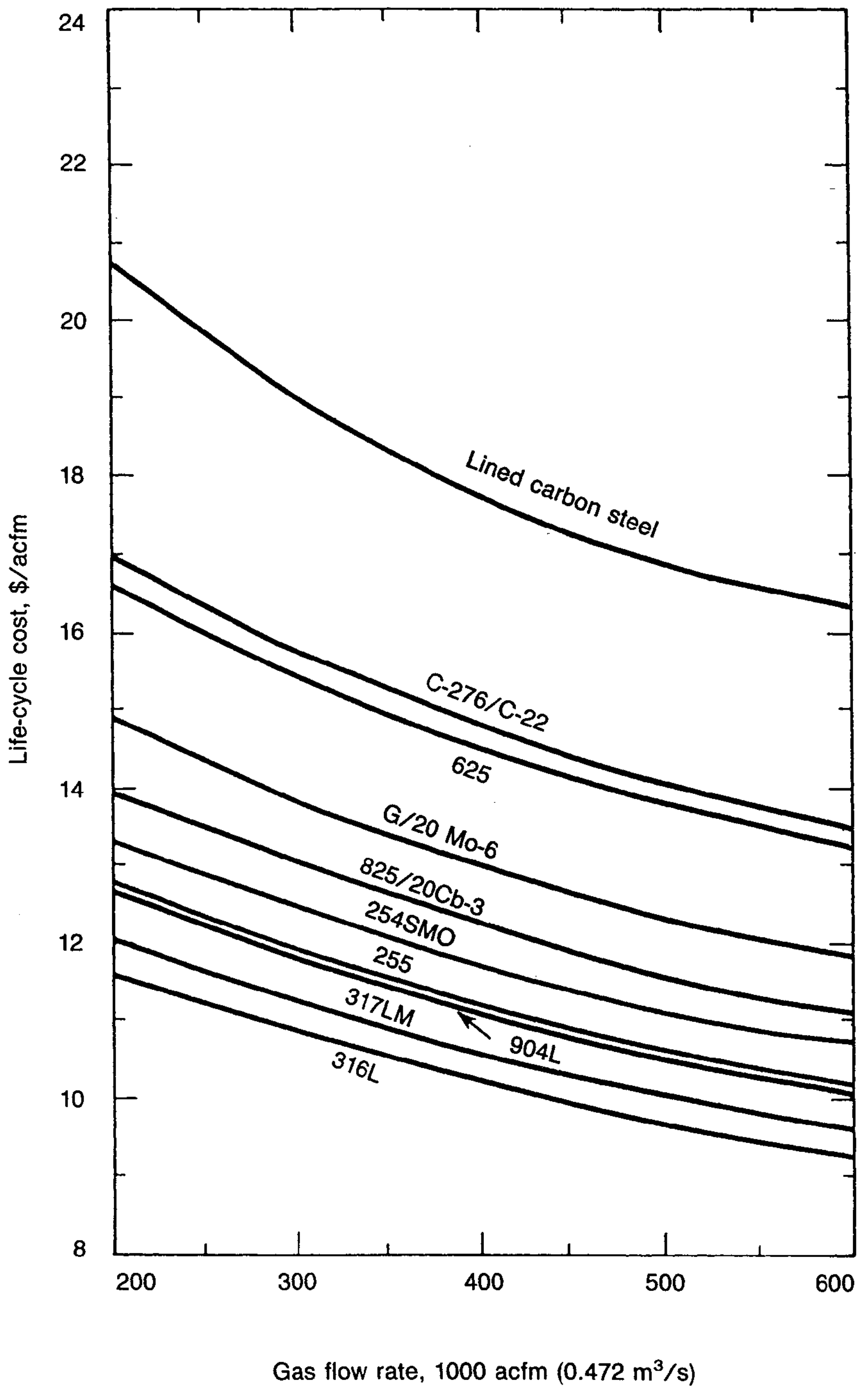


Figure 3: Life-cycle cost comparison, alloy-clad carbon steel venturi.

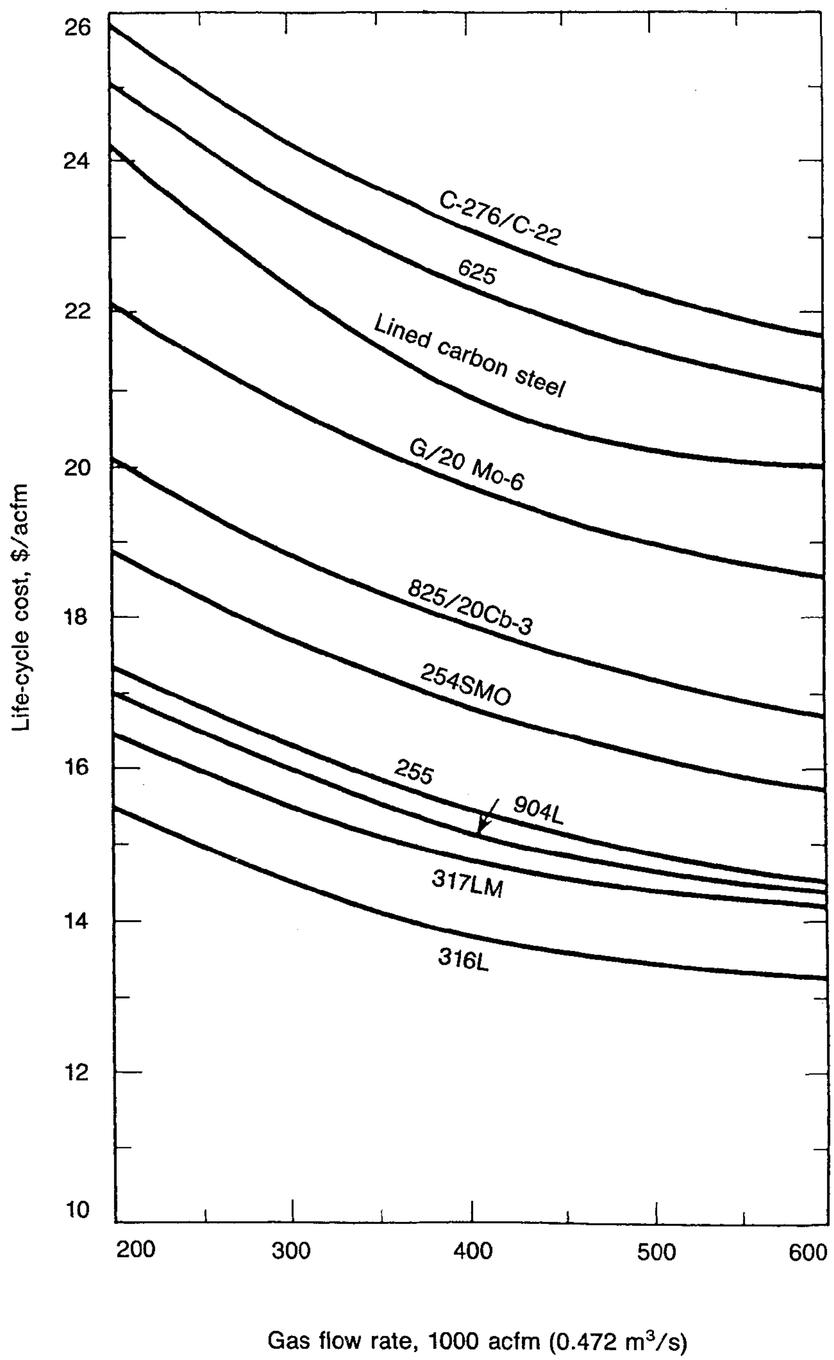


Figure 4: Life-cycle cost comparison, solid alloy absorber.

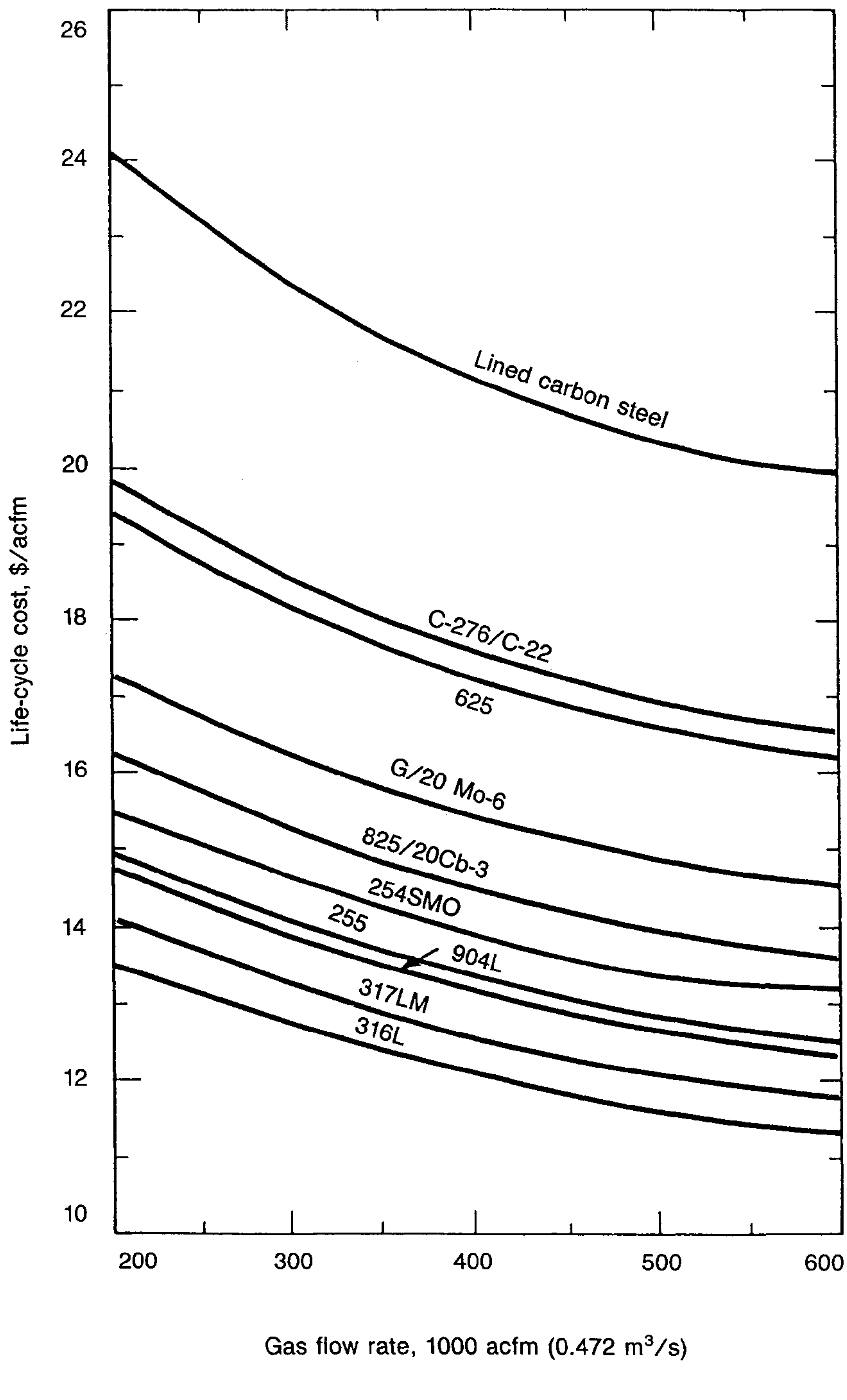


Figure 5: Life-cycle cost comparison, alloy-clad carbon steel absorber.

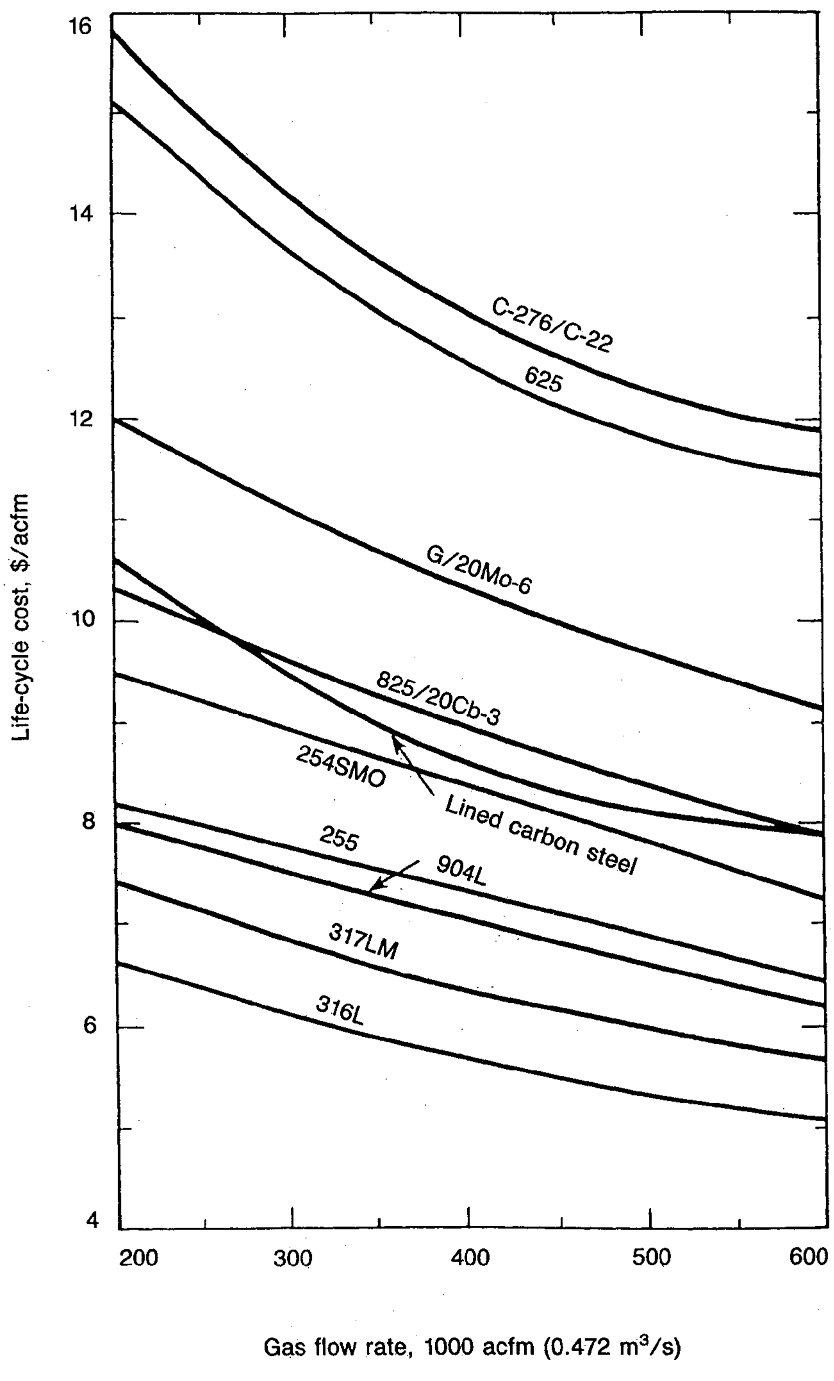


Figure 6: Life-cycle cost comparison, solid alloy ductwork.

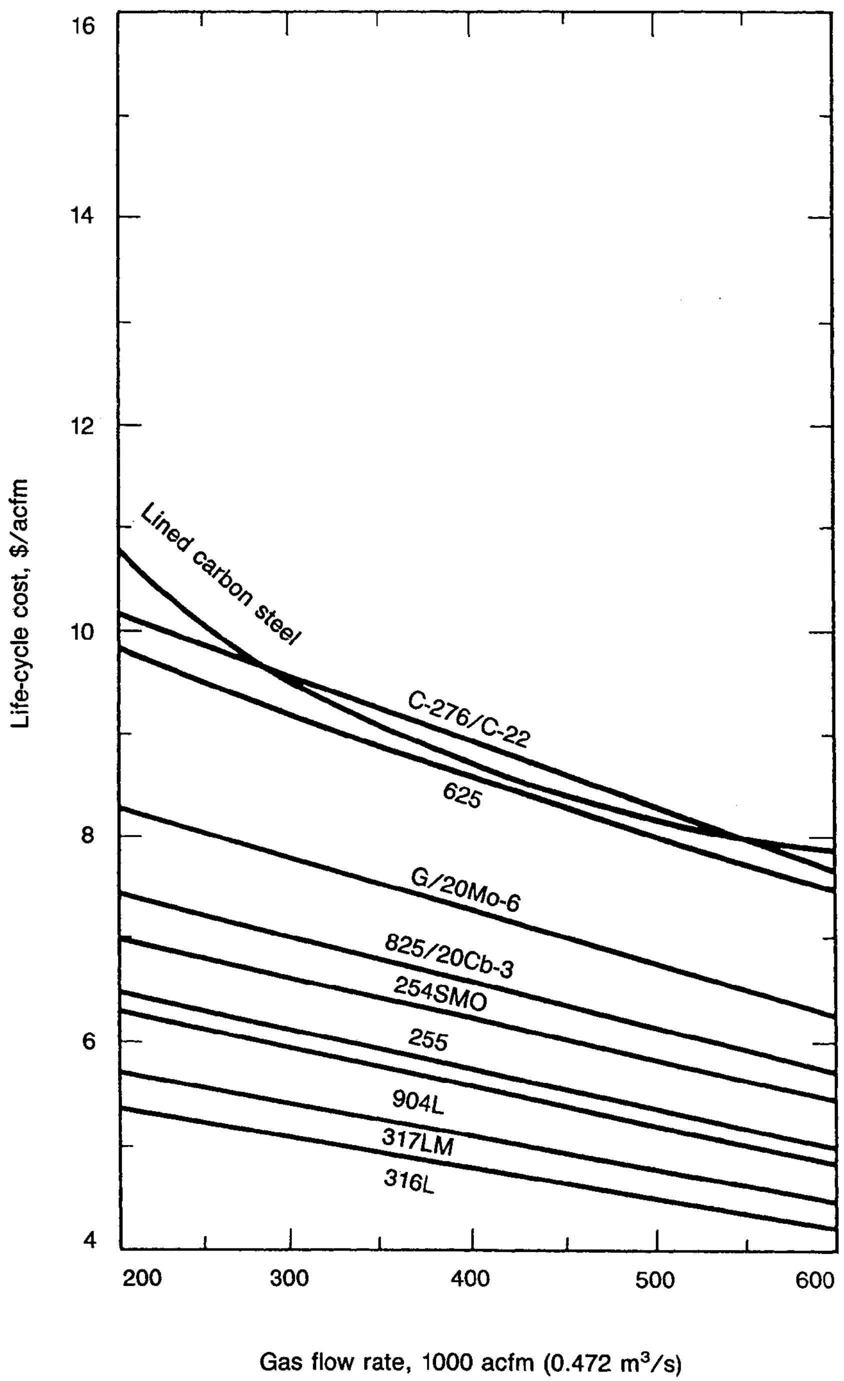


Figure 7: Life-cycle cost comparison, alloy-clad carbon steel ductwork.

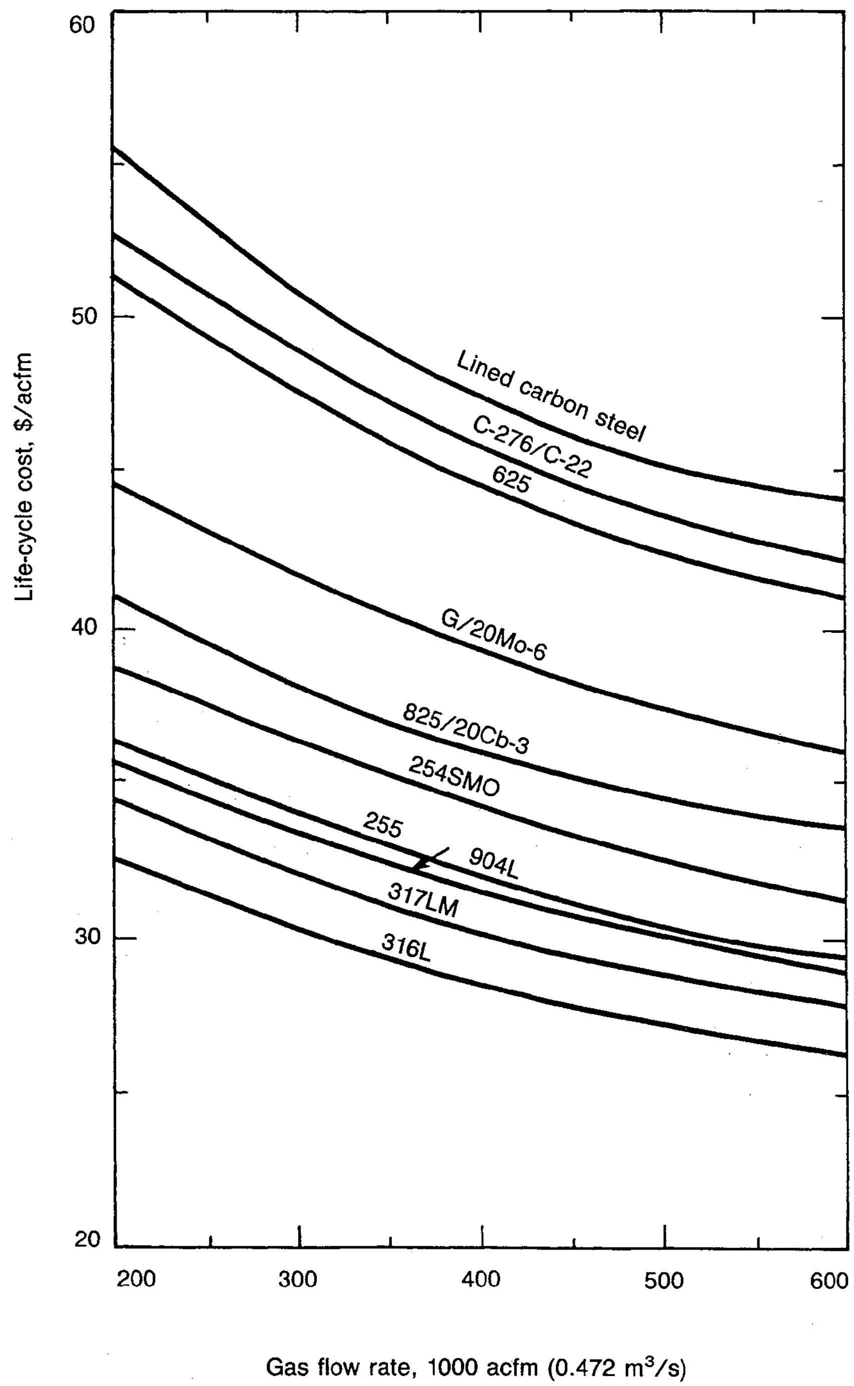


Figure 8: Life-cycle cost comparison of a combined system comprised of an alloy venturi, alloy-clad absorber, and alloy-clad ductwork.

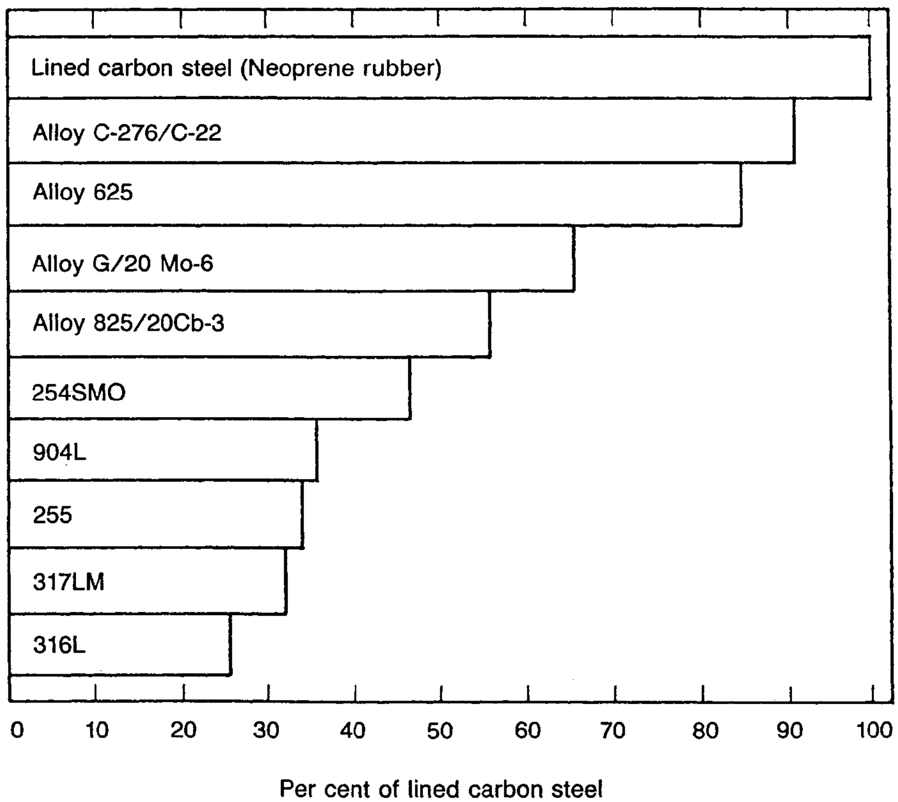


Figure 9: Life-cycle cost percentage comparison for a combined system comprised of an alloy venturi, alloy-clad absorber, and alloy-clad ductwork.

SECTION 5

CONCLUSIONS

The analysis performed in this report has led to the following conclusions:

1. Life-cycle cost studies based on conservative assumptions and the EPRI Technical Assessment Guide indicate that the use of corrosion-resistant alloys can result in significantly lower total costs than the use of nonmetallic lined carbon steel in the construction of FGD systems.

2. Optimization of material selection for each FGD component (restricting the use of the higher-alloy grades to the critical sections of each component as necessary and the use of lighter-gauge corrosion-resistant alloys) can lower costs even further.

3. Field experience confirms the conclusions of cost studies indicating that appropriate combinations of corrosion-resistant alloys represent the lowest total cost approach to FGD scrubber construction.

SECTION 6

CASE HISTORIES

Selected case histories detailing the performance of stainless steels and nickel-base alloys are presented in this section.

CITY UTILITIES - SOUTHWEST 1

Southwest 1 of City Utilities is a 190-MW pulverized coal-fired boiler located in Springfield, Missouri.

The emission control system for this unit consists of a cold-side electrostatic precipitator (ESP) followed by two limestone tower absorbers. The coal fired in this unit contains 2.5-4.5 per cent sulphur and up to 0.3 per cent chlorides. The system operates in a closed water-loop mode.

The original construction of the presaturator was carbon-steel lined with an inorganic grout-like material, which began to fail soon after its application, even before the absorbers were placed in service.

Severe cracking appeared to be shrinkage-induced, but the installation contractor reported that it was induced by vibration. Several repairs were made on two separate occasions in an attempt to save the lining, but to no avail.

By late summer 1977, only months after the initial start-up in April, corrosion had formed holes in the outer wall of the presaturator quench duct. During an outage beginning in September, 1977, the system supplier removed the inorganic material and relined the entire presaturator quench duct with alloy 904L, which was considerably more serviceable than the inorganic lining material.

The alloy 904L lining required no maintenance until October, 1979, when several sections had to be patched. Some degree of deterioration was evident over most of the alloy 904L lining, however, which indicated that a more corrosion-resistant material was needed.

Initial repairs were made by patching alloy 904L with alloy G; however, after continued deterioration of the 904L alloy, a decision was made to reline the presaturator with an inorganic grout-like material over an organic membrane lining. This material combination remained in place until the spring of 1985.

At that time, the utility finally decided that inorganic and/or organic linings were not the answer to their presaturator corrosion problems. Continued failure of the grout-like material due to cracking and/or erosion and the subsequent failure of the organic membrane lining again resulted in rapid corrosion of the presaturator quench duct.

During the spring and fall outages in 1985, the utility removed the inorganic/organic lining material and relined the entire presaturator quench duct with 1.6 mm alloy C-276. After almost a year of service, the utility has reported that no appreciable corrosion is evident and that the *wallpaper* alloy lining appears to be holding up very well. Corrosion has been noted at various welds, but the utility does not attribute this to the material itself.

All presaturator stainless steel tubing and nozzles that are now failing will soon be replaced with like components fabricated from alloy C276; these were not available when this equipment was initially ordered in 1985.

TAMPA ELECTRIC - BIG BEND 4

Big Bend 4 of Tampa Electric Company is a 458-MW pulverized coal-fired unit located near Ruskin, Florida.

The limestone FGD system consisting of four spray/packed towers is designed to remove 90 per cent of the sulphur dioxide from flue gas produced by burning a coal with 3.5 per cent sulphur content and a 0.20 per cent maximum chloride content. A cold-side ESP provides primary particulate removal.

The FGD system operates in a closed water-loop mode and produces gypsum as a salable by-product. The chloride content of the slurry in the quench area of the absorber vessel was expected to range between 28 000 mg/m and 75 000 mg/m. The FGD system for Unit 4 began commercial operation in February 1985.

Because of the high sulphur and chloride contents of the coal coupled with operation of the FGD system in a closed water-loop mode, Tampa Electric elected to construct their spray/packed absorbers of high-alloy metals. The inlet quencher, which forms the base of the absorber vessel, is constructed of 9.53 mm alloy 625.

The remainder of the vessel, from the down-comer bowl to the absorber outlet, is constructed of 6.35 mm alloy 904L. After one year of operation, routine inspections of the quencher's vessel walls constructed of alloy 625 have shown only minor discoloration of metal surfaces located beneath scale deposits. According to the utility, no appreciable amount of corrosion could be measured; however, the dry/wet interface located immediately at the entrance of the quencher is suffering pitty corrosion.

Because the operating conditions have been more severe than expected, the utility plans to conduct tests with alloy C-276 in this area of the quencher. Reportedly, the alloy 904L material has shown no evidence of any attack resulting from the operating environment.

SOUTH MISSISSIPPI ELECTRIC POWER ASSOCIATION – R. D. MORROW, SR., 1 AND 2

The R. D. Morrow, Sr. generating station consists of duplicate units, each with a name-plate capacity of 203 MW.

The emission control system for both units consists of a hot-side ESP followed by a single limestone spray/packed tower absorber. Both units burn coal with an average sulphur content of 1.2 per cent and up to 0.12 per cent chloride. The fluoride concentration averages around 0.01 per cent. Forty per cent of the flue gas is bypassed untreated for reheating purposes.

The R. D. Morrow plant was one of the first limestone FGD systems to be operated continuously in a real closed-loop mode. During initial start-up and characterization of the FGD system, absorber slurry chloride contents built up to or exceeded a level of 15 000 ppm. Initial operation of the FGD system for Unit 1 began in August, 1978, whereas initial operation of the FGD system for Unit 2 began in June, 1979.

The two FGD systems were originally constructed primarily of carbon steel. Where necessary for corrosion protection, an organic lining was used. This lining failed approximately three months into operation. Attempts to solve the problems by relining with other organic and inorganic liners produced similar results.

The most severe problems were in the mixing zone outlet duct area, where the bypass and scrubbed gases interface, and in the inlet duct of the absorber. In July, 1979, a review of all materials of construction included an inspection of the alloy G material used in the fabrication of the mixing tube support system located in the mixing zone. Initial inspections indicated the material would have a service life of approximately 20 years.

Based on this information, a decision was made to reline the absorber inlet duct and all ductwork from the absorber outlet to the stack with 3.18 mm alloy G material. Alloy C-276 weld wire was used for installation. The utility believed this had solved their corrosion problems; however, the subsequent six-month inspection revealed severe pitting of the alloy G material on the inlet duct floor at the wet/dry interface and throughout the entire outlet duct. The most severe attack occurred in the mixing zone. None of the alloy C-276 weldments showed any attack, however.

Based on the performance of the weldments, the utility decided to reline severely damaged areas with 1.6 mm alloy C-276. This included all of the absorber inlet duct floor, including the wet/dry zone, and part of the outlet duct in the mixing zone. Subsequent successful periodic inspections of the wallpaper alloy C-276 led to the relining of additional portions of the outlet duct. By the end of 1980, approximately half of the original 1 022 m^2 of alloy G material had been replaced with alloy C-276.

Four years later (November, 1984), the utility used ultrasonic measuring techniques to conduct a comprehensive inspection of the alloy C-276 inlet floor and the outlet duct, including the mixing zone, and no evidence of any localized attack in the base metal or weldments was found after 1-4 years of service. To date, the utility reports that alloy C-276 has solved their corrosion problems, and strongly recommends the use of this material of construction in wet/dry interface applications.

BASIN ELECTRIC POWER – LARAMIE RIVER 1 AND 2

Basin Electric Power Co-op's Laramie River 1 and 2 units are duplicate 570-MW pulverized coal-fired boilers located in Wheatland, Wyoming.

The emission control system for each unit consists of a cold-side ESP followed by five limestone spray/packed absorbers.

The subbituminous coal burned by both units has an average sulphur content of 0.54 per cent and an average chloride content of 0.04 per cent. No reheat is used and each FGD system operates in a closed water-loop mode. The FGD system for Unit 1 commenced operation in July, 1980, whereas the FGD system for Unit 2 began operation in July, 1981.

A high-molybdenum, 317L stainless steel was used in the original construction of the absorber outlet duct. The dimensions of the horizontal outlet ducts are approximately 4.6 m wide, 9.4 m high, and 30.5 m long. After 5-6 years of service, both ducts show no evidence of any kind of corrosion. The utility reports that the ducts appear to be brand-new and that no sign of discoloration is even present.

CENTRAL ILLINOIS LIGHT – DUCK CREEK 1

Duck Creek 1 of Central Illinois Light Company is a 416-MW pulverized coal-fired unit located near Canton, Illinois.

The unit burns 3.6 per cent sulphur bituminous coal and has a limestone process FGD system for SO_2 control. The FGD system has been operational since July 1976 and operates in a closed water-loop mode.

Prior to the final design of the FGD system, the utility conducted several tests at its nearby E. D. Edwards generating station in Peoria. Based on the results obtained from this test program, alloy G was selected as the original construction material for several FGD components, including the outlet duct leading to the stack.

After three years of service, however, inspection of the outlet duct revealed some signs of pitting. As a test precaution, the utility installed a small test panel of alloy C-276 in the outlet duct near the stack breeching area.

Subsequent inspections of the ductwork showed that the pitting in the alloy G had become severe and was increasing at an accelerated rate. Because installation of 1.6 mm alloy C-276 at the South Mississippi R. D. Morrow Station was successful, and the alloy C-276 test panels showed no signs of attack, the utility decided in the spring of 1983 to reline the entire outlet duct and the breeching area with 1.6 mm alloy C-276.

To date, after approximately three years of service, the utility reports that, except for a few weldments, the alloy looks brand-new. No evidence of any localized attack or even signs of discoloration are detectable in any of the base metal.

ALABAMA ELECTRIC – TOMBIGBEE 2 AND 3

Alabama Electric Cooperative's Tombigbee Station Units 2 and 3 are duplicate 255-MW pulverized coal-fired boilers located in Leroy, Alabama.

The emission control system for each unit consists of a hot-side ESP followed by two limestone spray-tower absorbers. The bituminous coal burned by both units has a maximum sulphur content of 2.0 per cent and a chloride content ranging 0.05-0.06 per cent.

The FGD system operates in a closed water-loop mode, and gas reheat is provided by bypassing 30 per cent of the boiler flue gas. Initial operation of the FGD system for Unit 2 was in September, 1978, whereas the initial operation of the FGD system for Unit 3 was in June, 1979.

Organic lined carbon steel was used extensively in the original construction of both FGD installations. Natural rubber and glass flake-filled polyester resin linings are used in the absorber vessels and recycle tanks, and a fluoroelastomer lining is used in the outlet ductwork. The quench duct at the inlet of the absorber is constructed of alloy 825. Both systems have now been in service for approximately seven years.

Recently, the utility reported that no major corrosion problems had been experienced with the quenchers constructed of alloy 825. To date, the only signs of abrasion have been those due to direct impingement of the nozzle spray on the quencher walls. The utility did not consider this a major problem; however, they are currently experiencing outlet ductwork corrosion.

The highest point of attack is in the bypass reheat mixing zone. The utility has experienced and still is experiencing absorber mist carryover, which has deposited as much as 0.9 m of scale in the outlet ductwork.

Periodic removal of this scale has inadvertently deteriorated the lining, which allows the base carbon steel to corrode. The utility has made the necessary changes to the system to reduce the formation of scale buildup.

To reduce the high maintenance costs associated with the necessary periodic replacement of the organic lining, the utility is planning to reline the entire outlet ductwork, from the absorber outlet to the stack, with 1.6 mm Hastelloy C-22. The relining was to be performed during the annual plant outage scheduled for fall of 1986.

LOUISVILLE GAS AND ELECTRIC – MILL CREEK 3 AND 4

Louisville Gas and Electric's Mill Creek Units 3 and 4 are duplicate 427-MW pulverized coal-fired boilers located in Louisville, Kentucky.

The original FGD system for each unit included four lime mobile-bed absorbers designed to remove sulphur dioxide from the flue gas produced by burning a 3.8 per cent sulphur coal. These two FGD systems, which have been operating since 1978 and 1982, respectively, are now undergoing major design changes to improve their reliability and to reduce their excessive operating maintenance costs.

The fact that corrosion is one of the major inherent problems associated with these second-generation FGD facilities has prompted the utility to make extensive modifications in the materials of construction.

For example, inorganic linings in the absorber vessels have failed; so current designs call for lining the absorber inlet quench area with alloy C-276 and the absorber vessel walls with a high-molybdenum 317L stainless steel (4.25 % minimum).

The selection of these replacement materials was based on utility performance evaluations of their suitability as demonstrated in other operating FGD systems. Additional absorber design changes include conversion to an open spray tower design and the use of limestone as the scrubbing reagent.

SECTION 7

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