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Project Summary

Economic Evaluation of a Sodium/Limestone Double-Alkali FGD Process

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A conceptual design and economic evaluation of a sodium/limestone double-alkali flue gas desulfurization (FGD) process was prepared based on recent EPA-sponsored pilot-plant and prototype test work. The results of this evaluation were compared with the results from a recent forced-oxidation limestone process evaluation. For a 500-MW new power unit burning 3.5% sulfur coal and meeting the 1979 new source performance standards (NSPS), the estimated capital investments in 1982 costs are $95 million ($190/kW) for the sodium/limestone double-alkali process and $103 million ($206/kW) for the forced-oxidation limestone process. Estimated first-year annual revenue requirements in 1984 costs for these processes are $26 million and $29 million (9.3 and 10.6 mills/kWh), respectively. Although the sodium/limestone double-alkali process appears to be about 8% lower in capital investment, given the accuracy associated with studies of this type (±10%), it is uncertain whether the sodium/limestone double-alkali process has a lower capital investment. In terms of first-year and levelized annual revenue requirements, the sodium/limestone double-alkali process shows a 12% and 14% lower cost than the forced-oxidation limestone process and thus is marginally less expensive. However, some of the design assumptions used to generate the estimated costs for the sodium/limestone double-alkali process are based on short-term pilot-plant tests and are unconfirmed. Therefore, the economics are more uncertain for the double-alkali process than for the forced-oxidation limestone process.

This Project Summary was developed by EPA's Air and Energy Engineering 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

For the past 15 years, wet limestone- and lime-scrubbing processes have in almost all cases held a distinct cost advantage over other flue gas desulfurization (FGD) processes. However, limestone and lime processes have several inherent disadvantages; i.e., erosion, corrosion, and a high liquid recirculation rate. They were also plagued during the course of their early development by operating problems such as scaling and plugging. These various shortcomings have added impetus to the continuing development of alternative FGD processes.

One such alternative is the use of double-alkali (dual alkali) processes in which the absorption function is separated from the precipitation function. A highly reactive absorbent solution is used to absorb SO_2, which is precipitated as $CaSO_3 \cdot 1/2H_2O$ and $CaSO_4 \cdot 2H_2O$ outside the absorber. The waste produced is thus identical to that produced by limestone and lime processes but the difficulties of scrubbing with a calcium-based slurry are avoided.

During the course of the development of double-alkali processes in the U.S., a solution of sodium sulfite has been used as the absorbent and lime has been used as the precipitant. The use of lime, due to its high reactivity, has come to be regarded as a disadvantage because of its cost. One phase of a continuing EPA double-alkali development program has been devoted to the development of a double-alkali process using limestone instead of lime. That process was tested recently on a pilot scale at Gulf Power Company's Scholz Power Station. The results of that test program are subject to question because the pilot plant did not achieve a long-term, closed-loop operation.

This study is an economic evaluation of the sodium/limestone double-alkali process and an economic comparison of the sodium/limestone double-alkali process with a conventional forced-oxidation limestone-scrubbing process.

Design and Economic Premises

The major design premises for this study are listed in Table 1. The base case power plant is a new, 500-MW coal-fired power unit located in the north-central U.S. The fuel is a bituminous coal with a heating value of 11,700 Btu/lb* and containing 3.5% sulfur (dry basis), 15.14% ash, and 4.0% moisture. The boiler heat rate is 9,500 Btu/kWh.

The FGD unit includes all the equipment necessary to meet the 1979 new source performance standards (NSPS) for SO_2 removal. The overall design for the sodium/limestone double-alkali process is based on pilot-plant studies at the Scholz Power Station and bench-scale work at EPA's Air and Energy Engineering Research Laboratory (AEERL), Research Triangle Park (RTP), NC. The design of the forced-oxidation limestone process is based on industry data and previous evaluations by TVA.

The project is assumed to have begun in mid-1980 with a 3-year construction period ended in mid-1983. The midpoint for the capital investment costs was mid-1982. The annual revenue requirements are based on 1984 costs.

Capital investment consists of direct investment, indirect investment, and other capital charges. The direct investment is based on equipment costs and installation costs (e.g., piping, electrical, and instrumentation). Indirect investment (e.g., engineering design and supervision, and construction expense) is estimated based on the direct investment. Other capital costs (e.g., allowance for start-up and modification, and interest during construction) are estimated from the total direct and indirect investment. These preliminary capital investment estimates are considered to have a -15% to +30% range of accuracy and to be comparable within 10%.

*Readers more familiar with metric units may use the conversion factors at the back of this Summary.

Table 1. Major Design Premises

Item	*Premise*
Power plant	*North-central U.S., 500-MW coal-fired boiler, 9,500 Btu/kWh heat rate*
Operating schedule	*165,000 hr, 30-yr life, 5,500-hr first-year operation*
Fuel	*Eastern bituminous coal, 11,700 Btu/lb, 3.5% sulfur, 15.14% ash, 4.0% moisture*
Base year	*Capital investment: mid-1982* *Revenue requirements: 1984*
FGD waste disposal	*Sodium/limestone double-alkali fixation and landfill*
	Forced-oxidation limestone scrubbing: landfill
SO_2 removal efficiency	*89%*
Particulate removal efficiency	*99.8% (0.03 lb of particulates/10^6 Btu heat input)*
SO_2 absorber redundancy	*25% (4 operating trains, 1 spare)*

Two types of annual revenue requirements are projected—first year and levelized. Both are based on 5,500 hours of operation per year at full load (about a 63% capacity factor) and both use a levelized capital charge. However, levelized annual revenue requirements differ from first-year annual revenue requirements in that they take into consideration the time value of money over the life of the FGD unit and are calculated using a 10% discount factor, a 6% inflation factor, and a 30-year economic life.

Process Descriptions

The sodium/limestone double-alkali process (Figure 1) is similar in design and operation to utility and industrial sodium/lime double-alkali processes except for the additional reaction tanks and the limestone-grinding equipment. The forced-oxidation limestone process (Figure 2) is a generic design based on current technology, including the use of forced oxidation to produce gypsum. Both systems have five absorber trains—four operating and one spare—supplied with flue gas from a plenum downstream from the electrostatic precipitator (ESP) and the boiler induced-draft (ID) fan. In both cases, ducts provide for emergency bypass of 50% of the flue gas. Process design conditions for both systems are summarized in Table 2.

Each train of the sodium/limestone double-alkali system consists of a sieve tray absorber, a steam reheater, and a booster fan. The absorbent liquid is a sodium sulfite solution containing 1.7 mol percent sodium and 0.7 mol percent active alkali (SO_3^{2-} and HSO_3^-) when regenerated. Bleedstreams from the absorbers are combined and treated with ground limestone in two parallel trains of four reaction tanks operating in an overflow mode. The resulting slurry is pumped to a thickener-filter train where a 55% solids filter cake is produced. The filter cake is blended with dry fly ash and lime and trucked 1 mile to a landfill.

Each train of the forced-oxidation limestone process consists of a spray tower absorber, a steam reheater, and a booster fan. The absorbent liquid is an 8% solids slurry containing ground limestone. The scrubbing slurry drains from the absorber into a tank where air is sparged into it to oxidize the sulfite to sulfate before it overflows to a hold tank where the makeup limestone slurry is added. A bleedstream from the oxidation tank is pumped to a thickener-filter train where an 85% solids filter cake is produced. The filter cake is then trucked 1 mile to a landfill.

Results

The capital investments and annual revenue requirements of the sodium/limestone double-alkali process and the forced-oxidation limestone process are shown in Table 3. Fly ash disposal costs

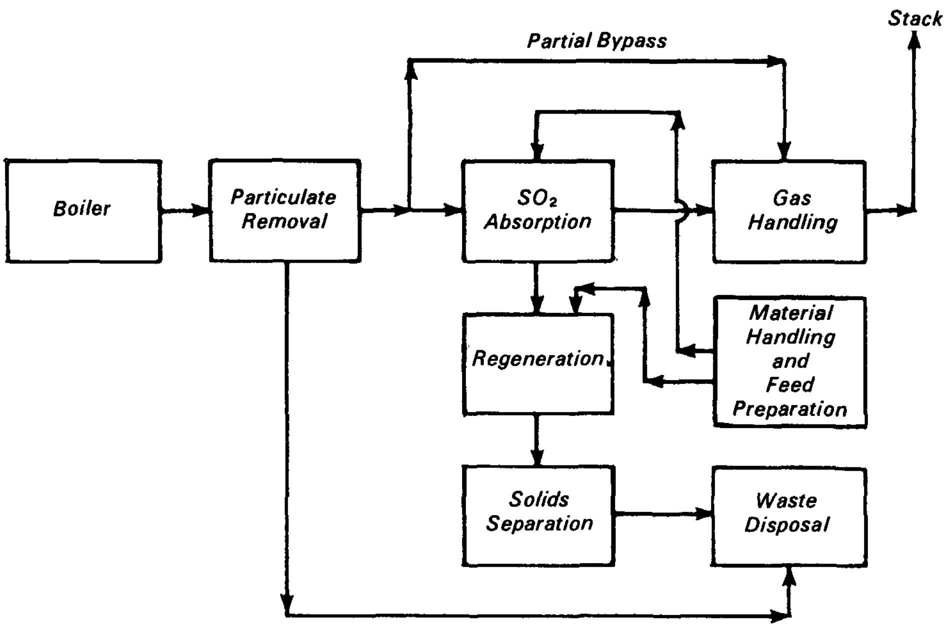

Figure 1. Sodium/limestone double-alkali process flow diagram.

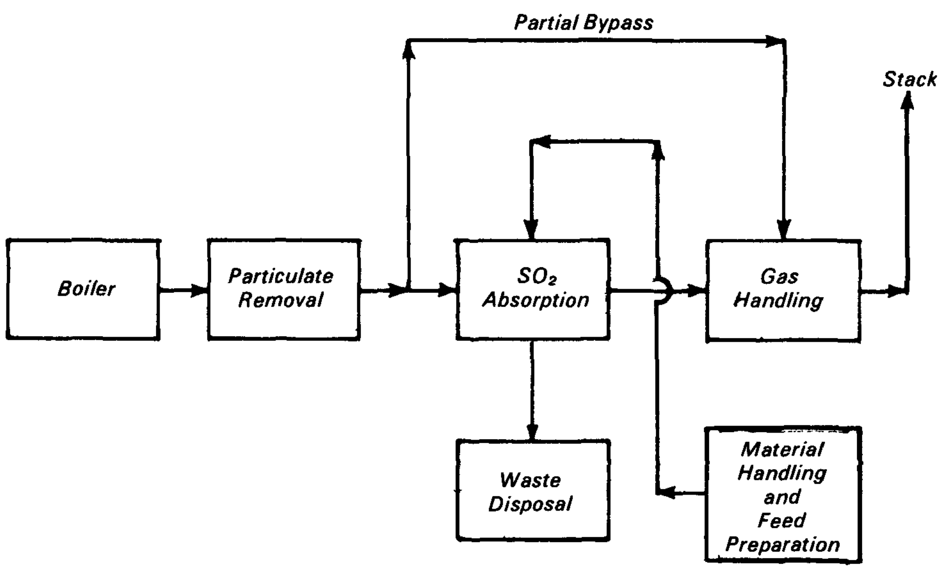

Figure 2. Forced-oxidation limestone process flow diagram.

are not included in the forced-oxidation limestone process costs. Since fly ash disposal is an integral part of the fixation portion of the sodium/limestone double-alkali process, a credit for fly ash disposal is applied to the costs of the sodium/limestone double-alkali process for comparability with the forced-oxidation limestone process costs. The capital investment and annual revenue requirements of the sodium/limestone double-alkali process are both lower than those of the forced-oxidation limestone process—by 8% and 12%, respectively. Since the comparative accuracy of these cost estimates is 10%, the capital investment of the double-alkali process can be regarded as marginally less expensive.

Capital Investment

The direct capital investments (the cost of material and labor to install the system) are compared by process area in Table 4. It is apparent that the key to the economic advantage of the sodium/limestone double-alkali process is the less expensive SO_2 absorption area that results from the reduced pumping requirements made possible by the low liquid-to-gas (L/G) ratio (the absorber sizes are similar because the size is determined largely by the flue gas volume). The SO_2 absorption area costs for the double-alkali process are 50% of those for the limestone process and constitute 24% of the total direct investment; while, for the limestone process, they constitute 36% of the total direct investment. Cost differences in other processing areas are a much lower portion of the total. Regeneration area costs (3%) and fixation area costs (2%) for the sodium/limestone double-alkali process are minor, as are oxidation area costs (5%) for the forced-oxidation limestone process. The solids separation area (dewatering) costs for the double-alkali process are 50% higher; but these, too, are a relatively small part of the total direct investment—12% for the sodium/limestone double-alkali process and 7% for the forced-oxidation limestone process.

Annual Revenue Requirements

A comparison of the major components of the first-year annual revenue requirements is shown in Table 5. Among the direct costs, the major costs for the sodium/limestone double-alkali process, in order of importance, are maintenance, raw materials, labor, steam, and electricity. For the forced-oxidation limestone process, they are maintenance, electricity, steam, labor, and raw materials. The major differences in direct costs between the processes are in maintenance, electricity, and raw material costs. Maintenance costs for the sodium/limestone double-alkali process are 37% lower than for the forced-oxidation limestone process as a result of the forced-oxidation limestone process having high maintenance costs associated with circulating large volumes of slurry. This also results in electricity costs for the sodium/limestone double-alkali process being about half those of the forced-oxidation limestone process. Raw material costs are over twice as high for the sodium/limestone double-alkali process, however, and are divided about equally between costs for limestone, soda ash, and lime for fixation.

Table 2. *Process Design Conditions*

	Sodium/limestone double-alkali process	Forced-oxidation limestone process
Absorber type	Sieve tray tower	Spray tower
Superficial gas velocity, ft/sec	9	10
L/G, gal./1000 aft^3		
Presaturator/underspray	2/1	4/0
Absorber	5	106
Stoichiometry, mol Ca/mol (SO_2 + 2HCl) absorbed	1.0	1.4
Soda ash feed rate, mol NA^+/mol SO_2 absorbed	0.07	--
Sulfite oxidation, %	10	95
Thickener feed solids, %	1.4	8
Thickener underflow solids, %	25	40
Filter cake solids, %	55	85

Table 3. *Comparison of Capital Investments and Annual Revenue Requirements*

	Sodium/limestone double-alkali process	Forced-oxidation limestone process
Capital investment (1982 $)		
$ Millions	95.2	103.1
$/kW	190.3	206.1
First-year revenue requirements (1984 $)		
$ Millions	25.5	29.1
Mills/kWh	9.3	10.6
Levelized annual revenue requirements (1984 $)		
$ Millions	35.7	41.5
Mills/kWh	13.0	15.1

Table 4. *Comparison of Direct Investment by Processing Area*

	Direct investment, 1982 $ thousands	
Processing area	Sodium/limestone double-alkali process	Forced-oxidation limestone process
Materials handling	2,426	2,528
Feed preparation	4,506	4,715
Gas handling	10,800	11,281
SO_2 absorption	11,348	20,288
Reheat	3,630	3,634
Regeneration	1,506	--
Oxidation	--	2,670
Solids separation	5,493	3,679
Fixation	906	--
Services, utilities, and misc.	2,437	2,928
Landfill construction	5,247	3,781
Landfill equipment	1,454	1,123
Landfill credit (fly ash disposal)	(2,312)	--
Total	47,441	56,627

Overall, the sodium/limestone double-alkali process direct costs are about 13% lower than those of the forced-oxidation limestone process because of lower maintenance and electricity costs, both a result of using a highly reactive scrubbing solution instead of a limestone slurry. With the lower overheads, which are based on direct costs, and lower capital charges, the annual revenue requirements of the sodium/limestone double-alkali process are 12% lower than those of the forced-oxidation limestone process.

Energy Consumption

A comparison of the total energy consumption for each process is shown in Table 6. Steam, diesel fuel, and electricity are shown in Btu equivalents.

The energy consumption in the sodium/limestone double-alkali process is only 71% of that for the forced-oxidation limestone process. Almost all of the difference is due to the significantly lower electrical consumption of the sodium/limestone double-alkali process.

Conclusions and Recommendations

The sodium/limestone double-alkali process is 8% lower in capital investment, 12% lower in first-year annual revenue requirements, and 14% lower in levelized annual revenue requirements than a comparable forced-oxidation limestone process. Although these economics may be only marginally attractive relative to limestone scrubbing (given the accuracy associated with this preliminary-grade economic evaluation), the sodium/limestone double-alkali process offers the potential for high SO_2 removal efficiencies at low absorber L/G ratios and for fewer maintenance problems with scaling, plugging, and erosion because calcium compounds are primarily confined to the regeneration area.

The sodium/limestone double-alkali process is less energy intensive than a forced-oxidation limestone process—primarily because of the lower electrical consumption of recirculating pumps in the scrubbing area.

More development work on the sodium/limestone double-alkali process needs to be undertaken to demonstrate that both the design assumptions used in this study are achievable and the problems associated with a previous pilot-plant work at Scholz can be overcome with only minor (and relatively inexpensive) modifications. Both of these areas of uncertainty could be minimized with additional pilot-plant

Table 5. Comparison of Annual Revenue Requirement Components

	Annual revenue requirements, 1984 $ thousands	
	Sodium/limestone double-alkali process	*Forced-oxidation limestone process*
Raw materials		
Limestone	*915*	*1,214*
Soda ash	*990*	--
Lime	*794*	--
Total labor	*1,357*	*1,269*
Utilities		
Steam	*1,321*	*1,356*
Electricity	*1,096*	*2,133*
Other	*234*	*192*
Maintenance	*2,715*	*4,285*
Landfill credit	*(312)*	--
Analysis	*105*	*105*
Direct costs	*9,215*	*10,554*
Overheads	*2,319*	*3,395*
Operating and maintenance costs	*11,534*	*13,949*
Levelized capital charges	*13,987*	*15,151*
Total first-year annual revenue requirements	*25,521*	*29,100*

Table 6. Comparison of Process Energy Consumption

	Energy input, 10^9 Btu equivalent			
Process	*Electricity*[a]	*Steam*[b]	*Diesel fuel*[c]	*% of plant capacity (gross)*
Sodium/limestone double alkali	*281.4*	*397.3*	*11.6*[d]	*2.6*
Limestone scrubbing	*547.7*	*407.7*	*14.9*	*3.7*

[a]*9,500 Btu/kWh.*
[b]*751.9 Btu/lb (based on recycle of condensate to power plant).*
[c]*144,000 Btu/gal.*
[d]*Includes credit for fly ash disposal.*

or prototype (3 to 30 MW equivalent) work which includes a long-term demonstration run. As a result of the unconfirmed design assumptions mentioned above, the estimated economics are considered potentially less accurate for the double-alkali process than for the forced-oxidation limestone process.

Metric Conversions

British units are used throughout this Summary for the reader's convenience. Readers more familiar with the metric system are asked to use the following conversion factors:

British	Multiplied by	Yields Metric
Btu	1.054	kJ
ft	0.3048	m
ft^3	28.32	liters
gal.	3.785	liters
lb	0.4536	kg
mi	1.609	km

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***Norman Kaplan** is the EPA Project Officer (see below).*
The complete report, entitled "Economic Evaluation of a Sodium/Limestone Double-Alkali FGD Process," (Order No. PB 85-169 886/AS; Cost: $11.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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