APPENDIX E Engineering Evaluation of Hot-Gas Desulfurization with Sulfur Recovery, Topical Report, May 1998

May 1998

Engineering Evaluation of Hot-Gas Desulfurization with Sulfur Recovery

Topical Report

Work performed under
Contract No. DE-AC21-94MC31258

for
U.S. Department of Energy
Federal Energy Technology Center
3610 Collins Ferry Road
Morgantown, WV 26505

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ABSTRACT

Engineering evaluations and economic comparisons of two hot-gas desulfurization (HGD) processes with elemental sulfur recovery, being developed by Research Triangle Institute, are presented. In the first process, known as the Direct Sulfur Recovery Process (DSRP), the SO_2 tail gas from air regeneration of zinc-based HGD sorbent is catalytically reduced to elemental sulfur with high selectivity using a small slipstream of coal gas. DSRP is a highly efficient first-generation process, promising sulfur recoveries as high as 99% in a single reaction stage. In the second process, known as the Advanced Hot Gas Process (AHGP), the zinc-based HGD sorbent is modified with iron so that the iron portion of the sorbent can be regenerated using SO_2. This is followed by air regeneration to fully regenerate the sorbent and provide the required SO_2 for iron regeneration. This second-generation process uses less coal gas than DSRP. Commercial embodiments of both processes were developed. Process simulations with mass and energy balances were conducted using ASPEN Plus. Results show that AHGP is a more complex process to operate and may require more labor cost than the DSRP. Also capital costs for the AHGP are higher than those for the DSRP.

However, annual operating costs for the AHGP appear to be considerably less than those for the DSRP with a potential break-even point between the two processes after just 2 years of operation for an integrated gasification combined cycle (IGCC) power plant using 3 to 5 wt% sulfur coal. Thus, despite its complexity, the potential savings with the AHGP encourage further development and scaleup of this advanced process.

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EXECUTIVE SUMMARY

INTRODUCTION

Hot-gas desulfurization (HGD) of coal gas in integrated gasification combined cycle (IGCC) power systems has received a great deal of attention over the past two decades due to the potential for high thermal efficiency (up to 47%) and low environmental impact of these advanced power systems. In an advanced IGCC system, coal is gasified at elevated pressures, typically 20 to 30 atm, to produce a low-volume fuel gas which is desulfurized prior to burning in a combustion turbine to produce electricity. Higher efficiency and lower cost are achieved by efficient air and steam integration, and modular designs of the gasification, hot-gas cleanup, and turbine subsystems (Figure E-1). Hot gas cleanup primarily involves removal of particulates and sulfur—mostly hydrogen sulfide (H_2S) and some carbonyl sulfide (COS). H_2S and COS can be efficiently removed to less than 20 ppmv at 350 to 650 °C using zinc-based metal oxide sorbents that can be regenerated for multicycle operation.

Air regeneration of these sorbents results in a dilute sulfur dioxide (SO_2)-containing tail gas that needs to be disposed. Options include conversion of the SO_2 to calcium sulfate using lime (or limestone) for landfilling or conversion to saleable products such as sulfuric acid or elemental sulfur. Elemental sulfur, an essential industrial commodity, is an attractive option because it is the lowest volume product and can be readily stored, disposed, transported, and/or sold.

Research Triangle Institute (RTI), with U.S. Department of Energy (DOE) sponsorship, is pursuing the development of two processes for elemental sulfur production in conjunction with

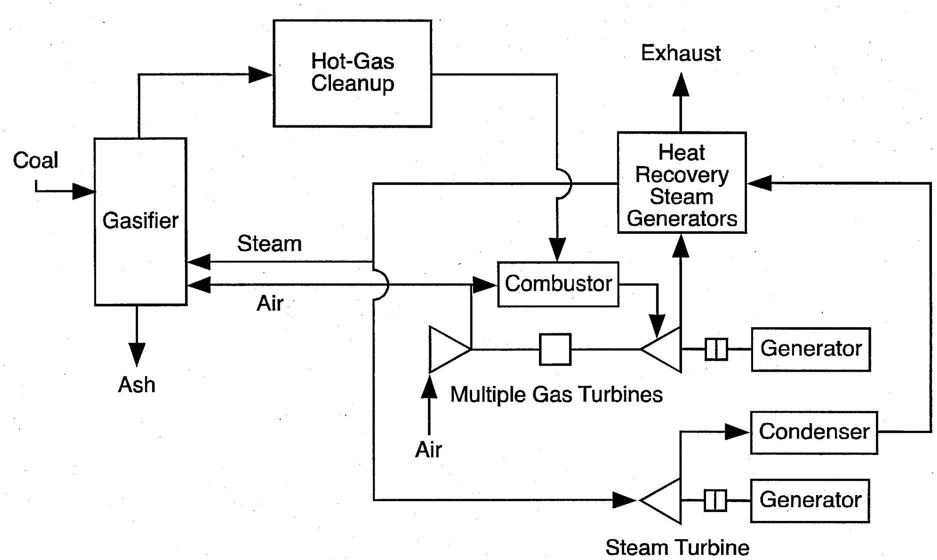

Figure E-1. Advanced IGCC system.

hot-gas desulfurization. The first process, called the Direct Sulfur Recovery Process (DSRP), involves the selective catalytic reduction of the SO_2 tail gas to sulfur using a small slipstream of the coal gas. DSRP is a highly efficient process that can recover up to 99% of SO_2 as elemental sulfur in a single catalytic reactor. However, for every mole of sulfur produced two moles of hydrogen (H_2) and/or carbon monoxide (CO) are consumed in DSRP and this represents an energy penalty for the IGCC plant. DSRP is currently in an advanced state of development.

A second-generation process being pursued by RTI involves the use of a modified zinc-based sorbent (containing zinc and iron). This sorbent can be regenerated using SO_2 and O_2 to directly produce sulfur. This process, called the Advanced Hot-Gas Process (AHGP), is expected to use much less coal gas than DSRP. DSRP is currently at the pilot-plant scale development stage, whereas AHGP has been demonstrated at small bench-scale. Both DSRP and AHGP are scheduled for slipstream testing at DOE's Power Systems Development Facility (PSDF), Wilsonville, Alabama, in 1999.

OBJECTIVE

The objective of this report is to develop process simulations with mass and heat balances for the DSRP and AHGP and to provide a **preliminary** economic comparison of the two processes in conjunction with an IGCC power plant employing HGD. The process simulation and economic evaluation were carried out by RTI's subcontractor, North Carolina State University (NCSU). NCSU's report of this work in its entirety is attached as an appendix. Background, brief process description, and important results and conclusions are provided below as a stand-alone executive summary.

BACKGROUND

Sorbent Development

Research on HGD methods for coal gas in IGCC systems has concentrated on the use of regenerable metal oxide sorbents (Gangwal, 1991, 1996; Gangwal et al., 1993, 1995; Harrison, 1995; Jalan, 1985; Thambimuthu, 1993). This research and development effort has been spearheaded by DOE's Federal Energy Technology Center (FETC) and its predecessor agencies since 1975.

The HGD process using a regenerable metal oxide (MO) sorbent is typically carried out in a two-reactor system consisting of a desulfurizer and an air regenerator

$$MO + H_2S \rightarrow MS + H_2O \qquad \text{(desulfurizer)}$$
$$MS + (3/2)\,O_2 \rightarrow MO + SO_2 \qquad \text{(regenerator).}$$

The main requirement of the metal oxide sorbent is that it should selectively react with H_2S and COS in a reducing fuel gas at desired conditions (2 to 3 Mpa, 350 to 750 °C). The thermodynamics of the reaction should be favorable enough to achieve the desired level of H_2S and COS removal (as much as 99% or more). The metal oxide should be stable in the reducing gas environment, i.e., reduction of MO to M should be slow or thermodynamically unfavorable since it leads to loss of valuable fuel gas and could also lead to volatile metal evaporation and decrepitation of sorbent structure.

The principle requirement during air regeneration is that the sorbent should predominantly revert back to its oxide rather than to sulfate ($MO + SO_2 + 1/2\ O_2 \rightarrow MSO_4$). Air regeneration is highly exothermic and requires tight temperature control using large quantities of diluent (N_2) or other means to prevent sorbent sintering and sulfate formation.

The bulk of research on regenerable sorbents has been on zinc-based sorbents because sorbents based on zinc oxide appear to have the fewest technical problems among all sorbents. Zinc oxide (ZnO) has highly attractive thermodynamics for H_2S adsorption and can reduce the H_2S to parts-per-million levels over a very wide temperature range. Iron oxide appears to be the most popular sorbent for use at around 400 °C.

A combined ZnO-iron oxide (Fe_2O_3) sorbent, namely, zinc ferrite ($ZnFe_2O_4$) was developed by Grindley and Steinfeld (1981) to combine the advantages of ZnO and Fe_2O_3. A temperature range of 550 to 750 °C received the major research emphasis in the United States during the 1980s and early 1990s. Because of zinc oxide's potential for reduction ($ZnO + H_2 \rightarrow Zn + H_2O$) at >600 °C followed by evaporation, a zinc oxide-titanium oxide sorbent, namely zinc titanate sorbent, was developed and tested at high temperature and high pressure (HTHP) (Gangwal et al., 1988). Zinc titanate is currently one of the leading sorbents.

During recent years, research emphasis has shifted toward lower temperatures (350 to 550 °C) based on a study in the Netherlands (NOVEM, 1991). According to this study, the thermal efficiency of an 800-MWe IGCC plant increased from 42.75% using cold-gas cleanup to 45.14% using HGD at 350 °C and to 45.46% using HGD at 600 °C. The small efficiency increase from 350 to 600 °C suggested that temperature severity of HGD could be significantly reduced without much loss of efficiency.

Reactor and Systems

A two-reactor configuration is necessary for HGD due to its cyclic nature. Early developments emphasized fixed beds. The highly exothermic regeneration led to a move away from fixed beds toward moving beds (Ayala et al., 1995; Cook et al., 1992) and fluidized beds (Gupta and Gangwal, 1992). Two DOE Clean Coal Technology IGCC demonstration plants, namely TECO and Sierra-Pacific, employing General Electric's (GE's) moving-bed HGD reactor system and M.W. Kellogg's transport reactor HGD system, respectively, are scheduled to begin operation this year. Fluidized-bed HGD systems are receiving a lot of emphasis due to several potential advantages over fixed- and moving-bed reactors, including excellent gas-solid contact, fast kinetics, pneumatic transport, ability to handle particles in gas, and ability to control the highly exothermic regeneration process. However, an attrition-resistant sorbent that can withstand stresses induced by fluidization, transport, chemical transformation, and rapid temperature swings must be developed.

Development of an iron-oxide sorbent-based fluidized-bed HGD reactor system has been carried out in Japan over the past several years (Sugitani, 1989). The process is now up to 200 tons of coal per day. The sorbent is prepared by crushing raw Australian iron oxide which is inexpensive, but attrition is a big problem with this sorbent. Durable zinc titanate and other zinc-based sorbent development is ongoing for application at the Sierra-Pacific plant for Kellogg's transport reactor (Gupta et al., 1996, 1997; Jothimurugesan et al., 1997; Khare et al., 1996).

A schematic of Kellogg's transport reactor system at Sierra-Pacific is shown in Figure E-2. This technology represents a significant development in HGD because it allows regeneration with neat air. Neat air regeneration produces a more concentrated SO_2 tail-gas stream containing around 14 vol% SO_2.

The initial sorbent tested at Sierra-Pacific was Phillips Z-Sorb III. Its attrition resistance was not acceptable. Phillips is continuing efforts to improve their sorbent. Recently RTI and Intercat have provided a much more attrition-resistant zinc titanate sorbent, EX-SO3, to Sierra-Pacific for testing after qualifying it through a series of bench- and process development unit (PDU)-scale tests (Gupta et al., 1997). This sorbent has been circulated in the system and has demonstrated satisfactory attrition resistance. Chemical reactivity tests with the sorbent are to be conducted shortly after the Sierra coal gasifier is fully commissioned and begins smooth operation.

Direct Sulfur Recovery Process

The patented DSRP being developed by RTI is a highly attractive option for recovery of sulfur from regeneration tail gas. Using a slipstream of coal gas as a reducing agent, it efficiently converts the SO_2 to elemental sulfur, an essential industrial commodity that is easily stored and transported. In the DSRP (Dorchak et al., 1991), the SO_2 tail gas is reacted with a slipstream of coal gas over a fixed bed of a selective catalyst to directly produce elemental sulfur at the HTHP conditions of the tail gas and coal gas. Overall reactions involved are shown below:

$$2\ H_2 + SO_2 \rightarrow (1/n)\ S_n + 2\ H_2O$$

$$2\ CO + SO_2 \rightarrow (1/n)\ S_n + 2\ CO_2$$

$$CO + H_2O \rightarrow H_2 + CO_2$$

$$H_2 + (1/n)\ S_n \rightarrow H_2S$$

$$2\ H_2S + SO_2 \rightarrow (3/n)\ S_n + 2\ H_2O\ .$$

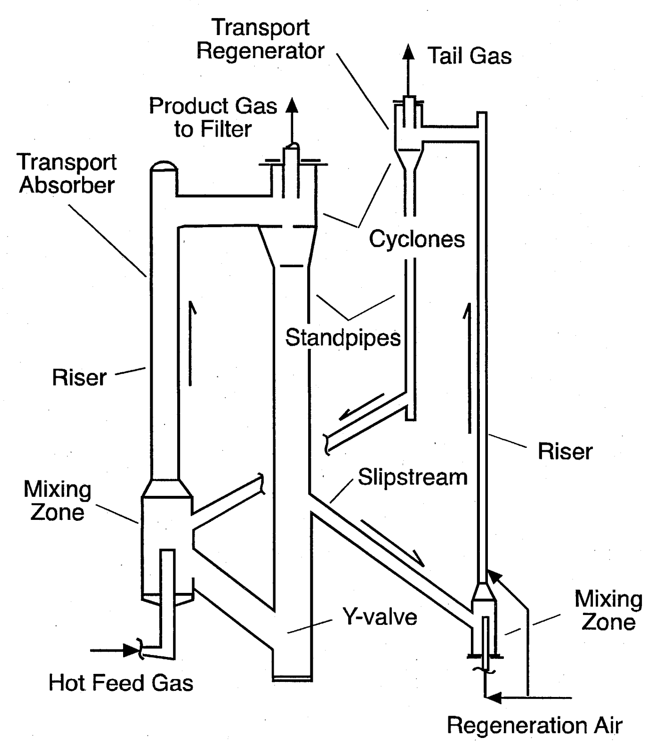

Figure E-2. Schematic of Sierra hot-gas desulfurization system.

RTI constructed and commissioned a mobile laboratory for DSRP demonstration with actual coal gas from the DOE-Morgantown coal gasifier. Slipstream testing using a 1-L fixed-bed of DSRP catalyst with actual coal gas (Portzer and Gangwal, 1995; Portzer et al., 1996) demonstrated that, with careful control of the stoichiometric ratio of the gas input, sulfur recovery of 96% to 98% can be consistently achieved in a single DSRP stage. The single-stage process, as it is proposed to be integrated with a metal oxide sorbent regenerator, is shown in Figure E-3. With the tail-gas recycle stream shown in the figure, there are no sulfur emissions from the DSRP. RTI also demonstrated the ruggedness of the DSRP catalyst by exposing it to coal gas for over 250 hours in a canister test.

The results show that, after a significant exposure time to actual coal gas, the DSRP catalyst continues to function in a highly efficient manner to convert SO_2 in a simulated regeneration tail gas to elemental sulfur. This demonstration of a rugged, single-stage catalytic process resulted in additional online experience and the assembling of more process engineering data. The development of the DSRP continues to look favorable as a feasible commercial process for the production of elemental sulfur from hot-gas desulfurizer regeneration tail gas.

Canisters of fixed-bed DSRP catalyst have been prepared for another exposure test with actual coal gas, this time at FETC's PSDF at Wilsonville, Alabama. Exposure is expected to take place sometime during FY 2000.

Additional development and testing of a fluidized-bed process is planned, capable of producing elemental sulfur from 14 vol% SO_2 at HTHP. These tests intend to demonstrate the use of DSRP in conjunction with the Kellogg transport regenerator producing 14 vol% SO_2. Due to the exothermic nature of the DSRP reactions, a fluidized-bed reactor is a preferred configuration at these high SO_2 concentrations. Two candidate attrition-resistant fluidizable DSRP catalysts have been prepared in cooperation with a catalyst manufacturer. A series of tests was conducted using these catalysts with up to 14 vol% SO_2 tail gas, at pressures from 1.0 to 2.0 Mpa, temperatures

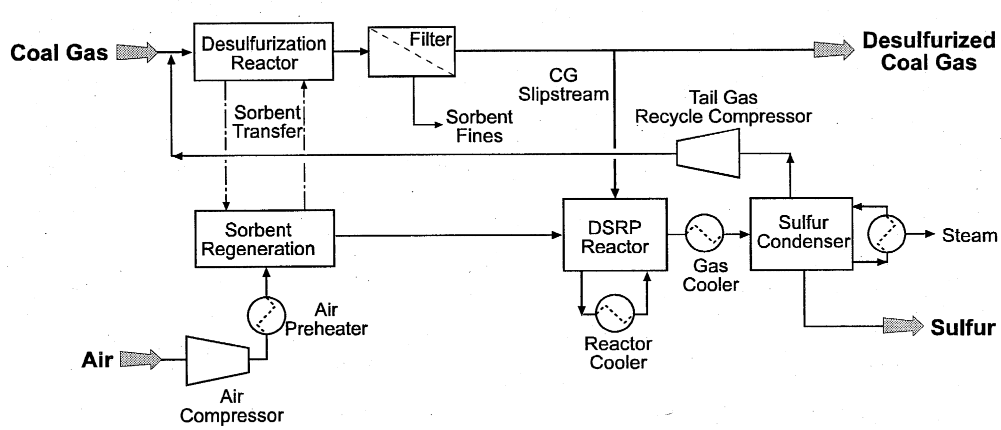

Figure E-3. Hot-gas desulfurization with DSRP.

from 500 to 600 °C, and space velocities from 3,000 to 6,000 stdcm^3/cm^3. Sulfur recoveries up to 98.5% were achieved during steady-state operation, and no attrition of the catalyst occurred in the fluidized-bed tests.

Planning is underway to conduct a long-duration field test using a skid-mounted six-fold larger (based on reactor volume) (6X) DSRP unit with a slipstream of actual coal gas at PSDF. The mobile laboratory will be refitted at RTI as a control room for the 6X unit and will be moved along with the skid-mounted 6X unit to Wilsonville, Alabama, for the testing to be conducted in FY 2000. This larger unit will utilize a fluidized-bed reactor and will be designed for production of up to 22 times more sulfur than the 7.5-cm I.D. bench-scale unit used in the previous slipstream tests.

Advanced Hot-Gas Process

In the DSRP, for every mole of SO_2, 2 mol of reducing components are used, leading to a small but noticeable consumption of coal gas. Novel regeneration processes that could lead to elemental sulfur without use of coal gas or with limited use of coal gas are being developed (Gangwal et al., 1996; Harrison et al. 1996). KEMA's hot-gas cleanup process (Meijer et al., 1996) uses a proprietary fluidized-bed sorbent which can remove H_2S to below 20 ppmv and can be regenerated using SO_2, O_2 mixtures to directly produce elemental sulfur. Along similar lines, a second-generation process, known as the Advanced Hot-Gas Process (AHGP), is being developed by RTI to regenerate the desulfurization sorbent directly to elemental sulfur with minimal consumption of coal gas. In this process (Figure E-4), a zinc-iron sorbent is used and the regeneration is carried out in two stages with SO_2 and O_2, respectively. The iron sulfide is regenerated by SO_2 in one stage to elemental sulfur. In the other stage, zinc sulfide and any remaining iron sulfide are regenerated by O_2 to provide the required SO_2. The sorbent is then returned to the desulfurizer.

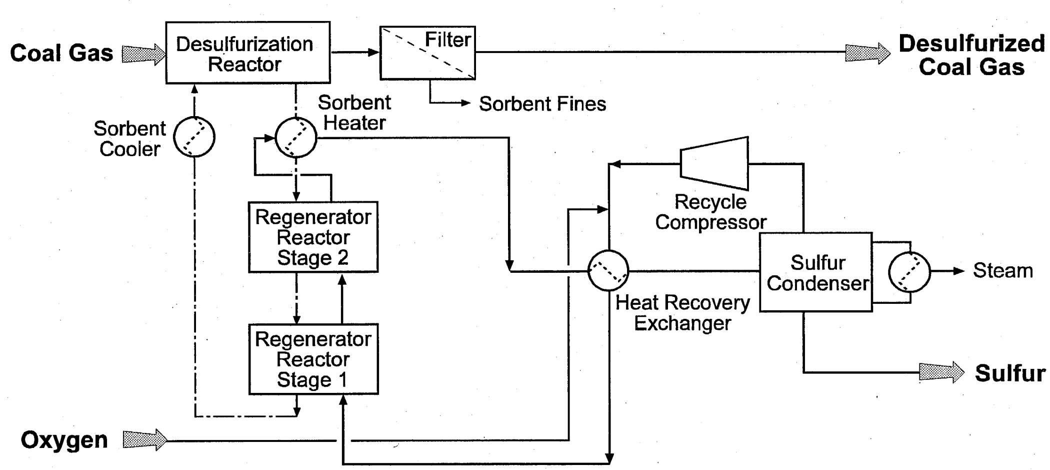

Figure E-4. Advanced hot-gas process.

The key chemical reactions of interest are as follows:

1. Sulfidation

$$Fe_2O_3 + 2H_2S + H_2 \rightarrow 2FeS + 3H_2O$$
$$ZnO + H_2S \rightarrow ZnS + H_2O$$

2. SO_2 regeneration

$$4FeS + 3SO_2 \rightarrow 2Fe_2O_3 + 7/2\ S_2$$

3. O_2 regeneration

$$2FeS + 7/2\ O_2 \rightarrow Fe_2O_3 + 2SO_2$$
$$ZnS + 3/2\ O_2 \rightarrow ZnO + SO_2.$$

The feasibility of SO_2 regeneration of combined zinc-iron sorbents was demonstrated using a thermogravimetric analyzer and high-pressure microreactor. Zinc sulfide shows essentially no SO_2 regeneration at temperatures of interest (500 to 600 °C), but zinc is needed to act as a polishing agent in the desulfurizer. A number of sorbents were prepared and tested at the bench scale over multiple cycles. Based on these tests, a highly attrition-resistant sorbent (R-5-58) was prepared and the process was demonstrated over 50 cycles in a 5.0-cm I.D. bench-scale reactor.

The results showed that R-5-58 removed H_2S down to 50 to 100 ppm levels with stable desulfurization activity over the duration. The surface area and pore volume of the sorbent did not change appreciably and the attrition index before and after the test was 3.6% and 1.2%, respectively. Sulfur balances were adequate and the SO_2 regeneration step accounted for up to 70% of the total regeneration of the sorbent. This compares to a theoretical limit of approximately 80%, assuming complete regeneration by SO_2 of the iron component.

The sorbent is being optimized further to increase its desulfurization efficiency. The goal is to develop a sorbent that can remove H_2S below 20 ppmv. Plans call for demonstrating the process at PSDF with a slipstream of actual coal gas in FY 1999 in conjunction with the DSRP field test at PDSF.

APPROACH

An engineering and economic evaluation of the DSRP (Figure E-3) and AHGP (Figure E-4) for large-scale IGCC plants was conducted using ASPEN PLUS® computer process simulation software by NCSU. The NCSU report is attached in its entirety as an appendix. Here we present a summary of the approach, key results, and conclusions.

Base case simulations of both processes assumed 0.85 mol% H_2S in the coal-gas feed. Such an H_2S concentration in the coal gas would be produced by an oxygen-blown Texaco gasification using roughly a 3.6 wt% sulfur-containing coal. Both base cases generate 260 MWe from the clean coal gas. Simulations that deviate from the base cases use suffixes to denote the changes. Table E-1 displays the significance of the suffixes. In all cases a coal-gas feed pressure and temperature of 275 psia and 482 °C, respectively, was used. However, H_2S concentration was varied from 0.25 to 2.5 mol% and power produced was varied from 110 to 540 MWe. Table E-2 shows the composition and flow rate of the raw coal gas feed to the base case HGD processes. The requirement of a higher amount of coal gas to produce the same 260 MW power by DSRP versus the AHGP is noteworthy. The DSRP was assumed to use the standard Sierra-Pacific dual transport reactor configuration shown in Figure E-2 for HGD. The DSRP reactor used for the 14% SO2 tail gas was a fast fluidized bed with an alumina-based catalyst. The AHGP reactor configuration on the other hand used a transport sulfider and a bubbling multistage fluidized-bed regenerator as shown in Figure E-5. The large bubbling reactor was required to provide a greater residence time for the slow SO_2 regeneration stage.

Table E-1. Simulation Cases Considered

Simulations	H_2S feed concentration (mol%)	MW produced
DSRP, AHGP (base cases)	0.85	260
DSRP-b, AHGP-b	2.50	260
DSRP-c, AHGP-c	0.25	260
DSRP-100, AHGP-100	0.85	110
DSRP-500, AHGP-500	0.85	540

Table E-2. Raw Gas Feed to Base Case Simulations

Component	DSRP (lb/h)	AHGP (lb/h)
H_2S	6,300	6,100
H_2O	70,500	69,000
H_2	11,800	11,500
CO	218,200	213,400
CO_2	117,400	114,800
N_2	36,300	35,500
Total	460,500	450,300

RESULTS

The preliminary process and economic evaluations conducted using ASPEN Plus are summarized. Figure E-6 compares key elements using a simple method in which each parameter for the DSRP-based process is arbitrarily assigned the value of 1.0. A range of values is produced for AHGP to cover the various cases being considered. The big advantage of the AHGP is clearly the reduced parasitic consumption of coal gas. The other operating cost elements are also lower for AHGP, because that process has a considerably lower compression power requirement. A desulfurization process based on the DSRP requires a large flow of compressed air to provide the oxygen necessary to regenerate the sulfided sorbent, and thus has a large compressor horsepower duty. By comparison, the AHGP uses oxygen only for a smaller, polishing regeneration and, by using pure oxygen, the compression duty is lowered further. The AHGP also has the SO_2 loop recycle compressor, but its duty is quite small compared to the DSRP air compressor.

[It should be noted that in the NCSU economic analysis (Appendix) the AHGP recycle compressor duty may be understated, as the calculation was based on a rough estimate for pressure drop, not a calculated value based on a piping design. By comparison, the duty for the DSRP air compressor is primarily a function of the head pressure of the system, which is well defined.]

The value of "capital cost of all equipment" for the AHGP is higher than for the DSRP-based process, as Figure E-5 shows. The higher equipment cost is primarily due to the higher cost of the AHGP reactor vessel(s). Although there are three separate reactor steps required with the DSRP-based process, the single AHGP multistage reactor vessel(s) is larger. The larger size is primarily due to the longer residence time required for the SO_2 regeneration. [It should be noted that the NCSU cost estimates (Appendix) do not include piping costs, so that the total plant capital costs will be higher than the installed equipment costs. However, since piping costs are often estimated as a direct function of the equipment cost numbers, the ratio of the installed equipment costs for the two processes shown in the figure will approximate the ratio of the total plant costs.]

Another advantage of the DSRP is that it is the easier, more understood, process to operate. This is because balancing the SO_2 production and consumption in the AHGP may be difficult.

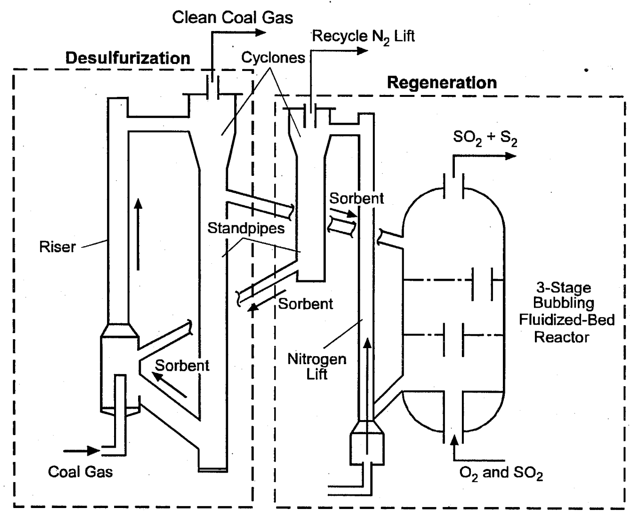

Figure E-5. Schematic of AHGP desulfurization and regeneration reactors.

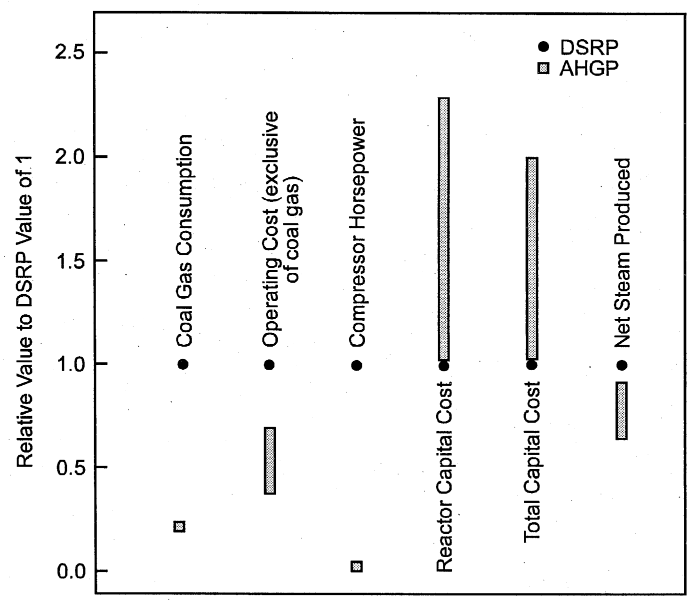

Figure E-6. Comparison of key elements of DSRP and AHGP.

Although the AHGP has a higher initial cost, indicated by its larger capital requirements, it has a significantly lower annual operating cost than DSRP. As shown in Figure E-7, the operating cost advantage of the AHGP increases as the sulfur to be recovered increases. The negative annual costs of AHGP at higher sulfur feed result from the sulfur credit with less consumption of coal gas. The operating cost difference is large enough to offset the installation cost of AHGP. As shown in Figure E-8, AHGP has a lower cumulative HGD investment after only 2 years of operation. Both Figures E-7 and E-8 are presented to illustrate only cost comparison of the two processes. Emphasis should not be placed on the accuracy of the absolute cost numbers presented in these figures.

CONCLUSIONS

ASPEN simulations of DSRP and AHGP revealed the complexity of both HGD processes. The AHGP appears to be the more difficult process to operate and may require more employees than

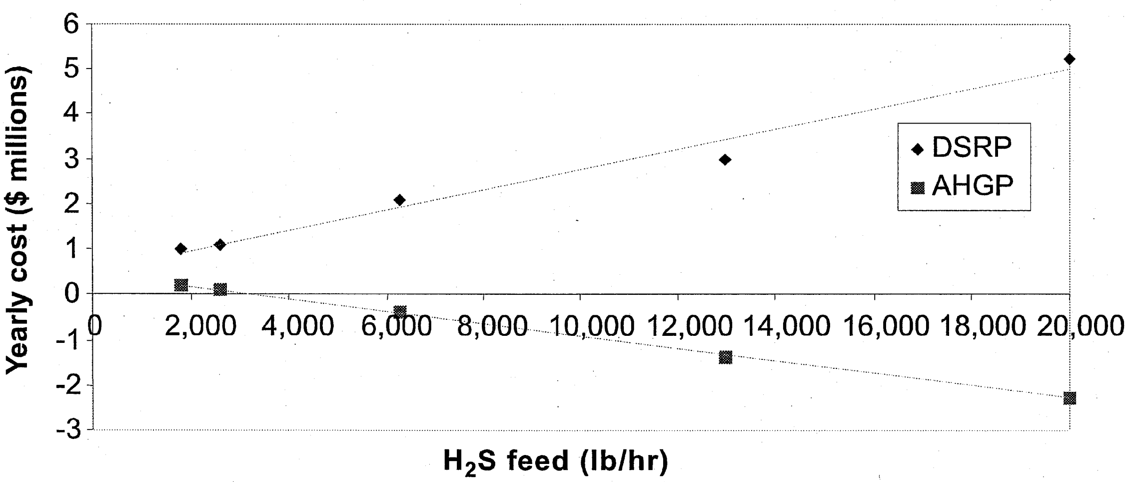

Figure E-7. Annual costs as a function of sulfur feed.

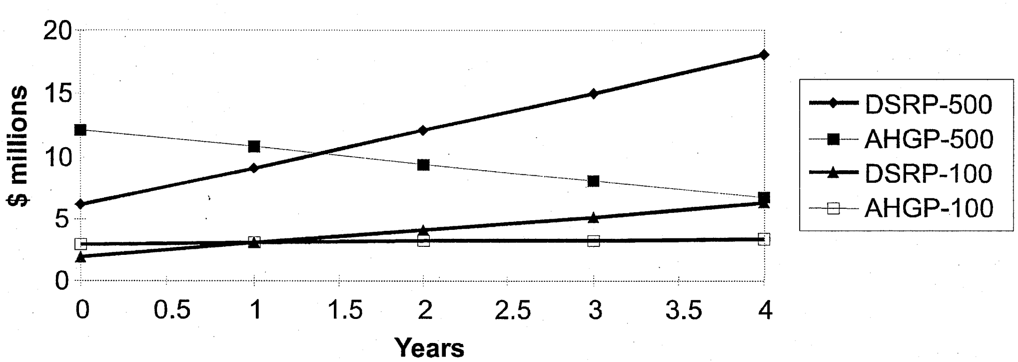

Figure E-8. Cumulative HGD investment.

the DSRP. Capital costs for the AHGP are higher than those for the DSRP—development of DSRP is also much closer to commercialization than AHGP. However, annual operating costs for the AHGP appear to be considerably less than those of the DSRP. Preliminary economic comparison shows that the total cost of implementing AHGP will be less than that of implementing DSRP after as little as 2 years of operation. Thus, despite its greater complexity, the potential savings with the AHGP encourage further development and scaleup of this advanced process.

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Appendix

Process Modeling of Hot-Gas Desulfurization

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EXECUTIVE SUMMARY

This report summarizes the process simulation work and economic evaluations that were done under contract to Research Triangle Institute to aid in the design of hot gas desulfurization (HGD) processes. Two processes were evaluated for the removal of sulfur (as H_2S) from coal gas at high temperatures, that produce elemental sulfur as a byproduct. Complete mass and energy balances were accomplished for the Direct Sulfur Recovery Process (DSRP) -based process, for various feed conditions. The Advanced Hot Gas Desulfurization Process (AHGP) was also simulated for various feed conditions. ASPEN PLUS 9.3-1 was used for simulating the processes. The mass and energy balances were used in determining the equipment requirements. Equipment requirements were used for the estimation of capital costs and yearly operating costs.

The technical feasibility of the two processes was briefly evaluated. Operating the DSRP is less complicated than operating the AHGP. The AHGP contains a SO_2 loop that is balanced by reactions that consume and generate SO_2. The reaction that consumes SO_2 is equilibrium limited, and its equilibrium fractional conversion varies substantially over the range of possible reactor temperatures.

The economic evaluation shows that the AHGP has higher capital costs than the DSRP. However, the savings the AHGP provides with lower operating costs makes it the more attractive process. The economics in this report use two key assumptions: that there is a market credit for recovered elemental sulfur, and that the coal gas consumed by the HGD has an operating cost equal to the cost of the electricity that could have been generated from it. Using these and other assumptions, the analysis shows that, after only two years the AHGP should make up for its higher capital cost. After four years, AHGP could save millions over the DSRP (savings depend on plant size and the coal's sulfur concentration).

I. INTRODUCTION

1. Background

Integrated gasification combined cycle (IGCC) power plants gasify coal and then combust the coal gas to generate power. All new power plants are required to meet federal SO_X emission limitations, currently limited to 1.2 lbs per million BTU (Jaffee). Hot-gas desulfurization (HGD) removes sulfur from coal gas before combustion. HGD has the potential of reducing the cost of electricity (COE) in IGCC plants, compared to conventional liquid absorption desulfurization.

IGCC plants gasify coal using steam and either air or oxygen. The coal gas is then combusted and passes through a gas turbine, generating power. The hot exhaust gas from the turbine is then used to generate steam, which is used for additional power generation. Coal gas is produced at high temperatures and high pressures (HTHP), typically 450 to 800°C and 145 to 580 psia (Gangwal). HGD reduces the coal gas sulfur content before combustion while maintaining the coal gas at HTHP conditions. Currently, IGCC plants remove sulfur with liquid phase scrubbing. The scrubbing process cools the coal gas stream below 150°C. The temperature drop reduces thermal efficiency and limits the potential electricity cost reduction that is theoretically possible with IGCC power plants. IGCC power plants using liquid phase scrubbing have COE's equivalent to those of pulverized coal-based power plants (Gangwal). HGD would give IGCC power plants a competitive advantage. Implementing HGD will increase thermal efficiency, reduce the COE, and ensure SO_2 emissions are acceptable.

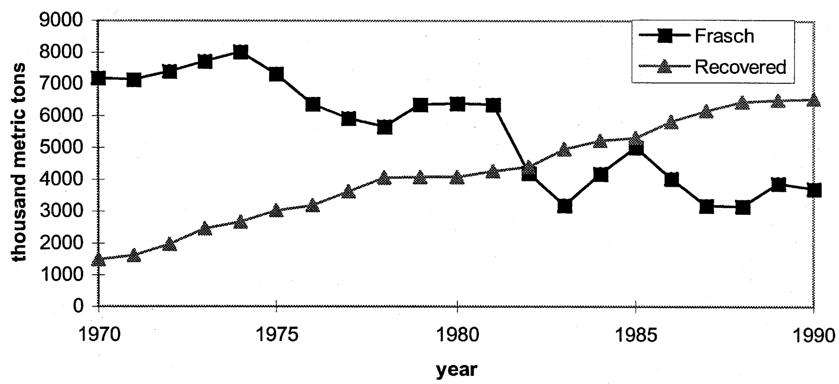
Another benefit of HGD is that the sulfur removed from the coal gas would be recovered as elemental sulfur, a valuable byproduct and easily stored material. This report describes work subcontracted to North Carolina State University (NCSU) from Research Triangle Institute (RTI). Two HGD processes that produce elemental sulfur were simulated using ASPEN PLUS 9.3-1. This work contributes to RTI efforts towards developing HGD technology. RTI research and development work includes sorbents development, characterization and a pilot-scale desulfurization testing.

Coal gas HGD and sulfur recovery could also be implemented in non-power producing applications. Although not the focus of this report, coal gas is used in methanation and Fischer-Tropsh synthesis. Methanation and Fisher-Tropsh catalysts require H_2S concentrations below 1 ppm (Cusumano) because H_2S and SO_2 poison catalysts with the formation of elemental sulfur.

2. Sulfur Production

The main purpose of the two desulfurization processes investigated is to remove sulfur from the coal gas prior to combustion, thereby reducing stack emissions. An advantage of these two processes is that elemental sulfur, which has commercial value, will be generated. Such "recovered sulfur" has been steadily replacing Frasch sulfur as a sulfur source (Figure 1). Frasch sulfur is obtained by drilling into sulfur deposits and injecting hot water, pushing molten sulfur to the surface.

Figure 1: U.S. Sulfur Production



-Data from U.S. Geological Survey

Sulfur is used in both industrial and agricultural applications. In the U.S., the majority of sulfur is used for agricultural purposes (U.S. Geological).

Recovered sulfur can be sold for $50 to $150/ton (Caruanan). Since sulfur purification was not modeled, a $50/ton credit was assigned to the recovered sulfur for the economic evaluation.