Conf-920951--18

DOE/MC/23277-93/C0087

Integration and Testing of Hot Desulfurization and Entrained Flow Gasification for Power Generation Systems

Authors:

Leininger, T.F.
Robin, A.
Jung, D.Y.
Kassman, J.S.
Wolfenbarger, J.K.
Yang, P.P.

DOE/MC/23277--93/C0087

DE93 002614

Contractor:

Texaco, Inc.
Montebello Research Laboratory
P.O. Box 400
Montebello, CA 90640

Received by OSTI

NOV 06 1992

Contract Number:

DE-FC21-87MC23277

Conference Title:

Twelfth Annual Gasification and Gas Stream Cleanup Contractors Review Meeting

Conference Location:

Morgantown, West Virginia

Conference Dates:

September 15-17, 1992

Conference Sponsor:

U.S. Department of Energy, Morgantown Energy Technology Center

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615)576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

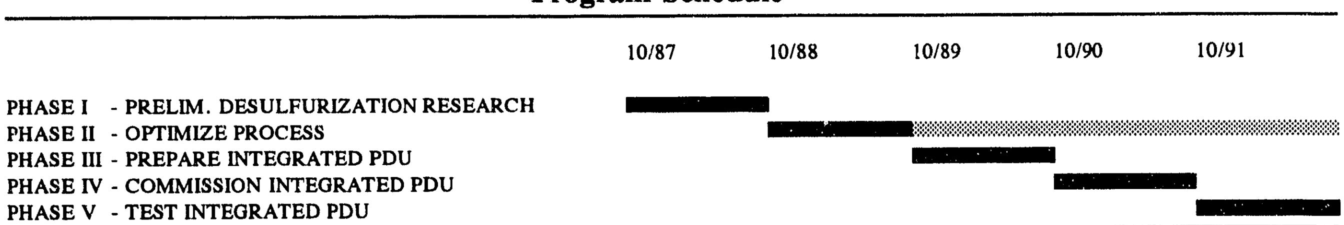
Integration and Testing of Hot Desulfurization and Entrained Flow Gasification for Power Generation Systems

CONTRACT INFORMATION

Cooperative Agreement	DE-FC21-87MC23277
Contractor	Texaco Inc. Montebello Research Laboratory P.O. Box 400 Montebello, CA 90640 (213) 699-0948
Contractor Project Manager	Allen Robin
Principal Investigators	Dick Y. Jung Jerrold S. Kassman Thomas F. Leininger J. Kenneth Wolfenbarger Paul P. Yang
METC Project Manager	Suresh C. Jain
Period of Performance	September 30, 1987 to September 30, 1992

Schedule and Milestones

Program Schedule



OBJECTIVES

The objective of this project is to develop hot gas cleanup processes for incorporation into the Texaco Coal Gasification Process (TCGP). Both in-situ and external hot gas desulfurization have been investigated from a technical and economical perspective.

BACKGROUND INFORMATION

The Texaco gasifier is a pressurized, entrained bed, slagging gasifier in which a coal-water slurry, or other hydrocarbon-containing liquid feed, is reacted with either oxygen or air. The product synthesis gas is cooled either by heat exchangers or by direct quench with water, depending on the end use. Currently, gas contaminants are removed by conventional methods that require the gas to be cooled to ambient temperature or below. As in the 120 MW TCGP-based Cool Water IGCC electric power plant, sulfur emissions are reduced to 10% of the New Source Performance Standards (NSPS). Economic studies indicate that, compared to a conventional pulverized coal plant with stack gas cleanup, a TCGP-based IGCC system is 15% more efficient and has comparable investment costs.

Studies also indicate that process thermal efficiency can be further increased if the hot synthesis gas is fed to a combustion turbine without cooling the gas to ambient temperature. However, gas contaminants such as sulfur still have to be removed. Desulfurization can be accomplished either in-situ, by including a sulfur sorbent with the coal-water slurry feed to the gasifier, or externally, by contacting the gas with a sorbent downstream of the gasifier vessel. In-situ desulfurization could provide the lowest investment cost and simplest design, while external desulfurization has the potential for very high sulfur removal and the production of a salable by-product. A significant amount of work has been done by other investigators in the areas of in-situ and external desulfurization using either a fluidized bed or a moving bed gasifier. However, prior to this study, little work had been done to study hot desulfurization in conjunction with an entrained bed gasifier such as that used in the TCGP.

PROJECT DESCRIPTION

To help achieve the goal of clean, low cost power generation from coal, Texaco submitted an unsolicited proposal in July 1986 to develop and demonstrate the integration of high temperature desulfurization with the TCGP. The main goals of the proposed program were:

- Develop and demonstrate in-situ desulfurization of synthesis gas in an entrained flow gasifier using both air and oxygen gasification.

- Develop and demonstrate a high efficiency integrated system on a process development unit (PDU) scale which would include coal preparation, gasification, sulfur removal, particle and trace element removal and a gas turbine.

In addition, secondary goals were proposed which would help further major research in which DOE/METC was already involved. These were:

- Test advanced instruments developed by METC for coal conversion processes.

- Screen alternative high temperature sulfur removal sorbents that could be used external to the gasifier. Development of these sorbents would provide a backup to the in-situ desulfurization approach.

A contract (Cooperative Agreement) with the DOE/METC was awarded on September 30, 1987 for conducting an extended (5 years) cost shared test program. The work was divided into five phases, with each phase originally corresponding to approximately one year. The phases are defined as shown on the schedule/milestone chart. The first two phases cover proof of concept and process selection for the integrated system, with the following three phases covering the design, construction and operation of the integrated PDU.

All of the Phase I work has been completed and summarized in our 1989 Contractors Review Meeting paper (Robin, *et al.* 1989). Completion of the Phase II work has taken longer than initially expected, partly because of difficulties experienced during the PDU tests and partly because the initial scope of work for Phase II has been modified as more has been learned. These modifications have involved a significant expansion of the process optimization studies and the inclusion of additional PDU testing.

RESULTS

The research efforts in this program can be grouped into two areas: 1) the PDU test program, which is supported by theoretical studies and bench scale tests, and 2) the process optimization (economics) studies. These two areas form an integrated research program, with the experimental data forming the basis for the optimization studies, and with the results of those studies guiding the ongoing PDU test program. (A sketch of the PDU configuration can be found in the 1989 review paper.) The progress to date in both of these areas is summarized below.

PDU Test Program

We previously reported the results of the initial theoretical studies and bench scale tests in which we investigated potential sorbents that could be used to remove sulfur either in the gasifier (in-situ sorbents), or downstream of the gasifier (external sorbents). We also have reported the results of both air and oxygen blown gasification PDU test runs using the most promising sorbents (Robin, *et. al.* 1990 and Robin, *et. al.* 1991).

Calcium, sodium and iron were evaluated in in-situ desulfurization tests. Iron, the most promising in-situ sorbent, was limited to a maximum of 50 to 60% sulfur removal. Calcium was evaluated as an external sorbent in both entrained and fixed bed reactors. Although as much as 80% desulfurization was achieved, steady state data were never obtained because of operating difficulties. Zinc based mixed metal oxides were also evaluated in external desulfurization tests. Data were obtained for several formulations at a variety of inlet temperatures, sulfur loadings and space velocities during single sulfidation (half-cycle) tests. Zinc titanate (ZnTi), the most promising sorbent, achieved sulfur removal levels greater than 99%.

Zinc Titanate Regenerable Fixed Bed. Sorbent durability is critical to the economics of hot gas desulfurization using mixed metal oxides. Our economics calculations for fixed bed desulfurizers indicated that a sorbent lifetime of several hundred cycles is needed in order for the sorbent replacement cost not to dominate the plant operating cost. Most of the previous data on zinc titanate durability have been obtained with bench scale equipment and simulated syngas for a limited number of cycles. Obtaining data with actual PDU syngas (containing trace metals, halides, etc.) under realistic operating conditions is necessary if accurate predictions of process performance and economics are to be made.

For this reason we designed and built a regenerable fixed bed which allows us to expose one cubic foot of zinc titanate to multiple cycles of sulfidation and regeneration. A process flow diagram was shown in our 1991 Contractors Review Meeting paper (Robin, *et. al.* 1991). The fixed bed, which is integrated with our gasification PDU, was tested for the first time in September 1991. Two cycles were completed using L-3140, a 1.5 Zn/Ti molar ratio sorbent from United Catalysts Inc. (UCI). Following this initial test, the bed was reloaded with fresh L-3140 pellets; and five cycles were completed during November and December 1991. Table 1 summarizes the averaged data for the initial test (cycles A-1 and A2) and the five-cycle test (cycles B-1 through B-5).

Table 1. Zinc Titanate Regenerable Fixed Bed Averaged Test Data

Cycle Number [1]	A-1	A-2	B-1	B-2	B-3	B-4	B-5
Average Sulfidation Temperature, °F	1080	1040	1090	970	1015	1030	925
Maximum Sulfidation Temperature, °F	1180	1110	1170	1040	1050	1080	1008
Sulfidation Space Velocity[2], dry, NTP, hr^{-1}	2880	3010	3840	5520	5510	5900	5900
Sulfidation Pressure, psig	331	341	335	336	324	321	330
Total Sulfur Capture, g-moles	151	109	128	138	128	120	114
Sorbent Utilization, % (mole S/mole Zn)	73	53	67	72	66	62	64
Average Regeneration Temperature[3], °F	1010	1100	1140	1260	1280	1260	1270
Maximum Regeneration Temperature, °F	1390	1290	1270	1390	1400	1400	1320
Regeneration Space Velocity[3], dry, NTP, hr^{-1}	2730	3020	3580	3390	2980	3060	2910
Regeneration O_2 Partial Pressure, psia	3.45	4.55	2.75	1.75	1.44	1.19	0.59
Regeneration O_2 Concentration, mol%	1.57	1.37	1.07	1.08	0.98	1.04	0.45
Total Regeneration O_2 Fed, g-mole	406	474	392	216	246	204	84
Total SO_2 Produced During Regeneration[4], g-mole (calculated from energy balance)	103	155	140	126	135	110	50

[1] During cycles A-1 through B-4, a 19-element ceramic candle filter was used to dedust the syngas upstream of the fixed bed. During cycle B-5, a cyclone was used.

[2] The sulfidation space velocity was increased during test B in order to shorten cycle length so that more cycles could be obtained during the test.

[3] The average regeneration temperature was increased during test B in order to increase the regeneration kinetics and reduce the O_2 requirement. Also, the O_2 partial pressure was decreased in order to reduce the likelihood of sulfate formation.

[4] SO_2 produced during regeneration was measured using an on-line mass spectrometer and a UV process gas analyzer. However, the data obtained by these instruments do not appear to be as reliable as the calculated SO_2 production obtained from an energy balance around the bed. Cycle B-5 regeneration was incomplete. When the sorbent was analyzed after shutdown, 56 g-mole sulfur was found remaining in the bed.

The sorbent utilization decreased from cycle A-1 to cycle A-2. This can be explained by noting that cycle A-1 regeneration was incomplete. However, the residual sulfur was removed during the cycle A-2 regeneration. Overall, 99% of the sulfur fed to the reactor during cycles A-1 and A-2 was recovered as SO_2 during regeneration.

During cycles B-1 through B-5, there was less variation in sorbent utilization between cycles. Regeneration B-5 was incomplete, and 56 g-moles of sulfur were found remaining in the sorbent throughout the bed. If this residual sulfur is included, 98% of the sulfur fed to the reactor during cycles B-1 through B-5 is accounted for either as SO_2 produced during regeneration or as residual sulfur.

Following each test, the sorbent was removed in eight sections for sampling and inspection. Pellet cracking and spalling was apparent throughout both beds, with the exception of the sulfidation outlet, where little

Table 2. UCI L-3140 Sorbent Analysis For Cycles A-1 Through A-2

Sorbent Bed Position[1]	Unused	Top							Bottom
Sample No.	0	1	2	3	4	5	6	7	8
wt% Sulfur	0.09	4.26	2.87	2.95	3.04	2.61	3.48	2.42	1.86
Phases[2]									
ZnS	0	2	2	2	2	2	2	1	0
$2ZnO \bullet 3TiO_2$	1	0	0	0	0	0	0	0	1
$2ZnO \bullet TiO_2$	3	2	2	2	2	2	2	2	3
ZnO	0	0	0	0	0	0	0	0	0
TiO_2	0	1	1	1	1	1	1	1	0
Zinc Sulfide / Zinc Titanate [3]	0	1	1	1	1	1	1	0.5	0
Crush Strength[4], lb	36.8	32.7	25.3	25.0	23.5	19.7	22.2	23.2	28.5
Pore Volume, cc/gm	0.38	0.31	0.32	0.32	0.36	0.36	0.35	0.37	0.37
Surface Area, m^2/gm	3.0	3.4	3.3	4.0	4.0	4.2	3.8	3.7	4.1
Zn/Ti molar ratio, DCP	1.43	1.37	1.40	1.39	1.31	1.44	1.34	1.29	1.30
Zn/Ti molar ratio, XRF	1.49	1.49	1.54	1.41	1.40	1.40	1.41	1.42	1.41
Zn/Ti molar ratio, ICP	1.35	1.41	1.40	1.41	1.44	1.39	1.37	1.37	1.48

(1) UNUSED = sample in "as received" condition; TOP = sulfidation inlet, regeneration outlet; BOTTOM = sulfidation outlet, regeneration inlet

(2) Digits represent relative presence of each phase

(3) Zinc Sulfide/Zinc Titanate = $ZnS/(2ZnO \bullet 3TiO_2 + 2ZnO \bullet TiO_2)$

(4) Average of six tests

(5) DCP = Direct Current Plasma Spectrometry; XRF = X-Ray Fluorescence Spectrometry; ICP = Inductively Coupled Plasma Spectrometry

sulfidation and regeneration occurred. The degradation was more severe in the bed exposed to five cycles, where 3 wt% of the sorbent passed through a 14-mesh screen (1.4 mm openings). Samples from each section were analyzed for residual sulfur, crystal phases, crush strength, pore volume, surface area and zinc and titanium content. Sulfate was also analyzed for; but none was found in any of the samples. The data for the two- and five-cycle tests are shown in Tables 2 and 3, respectively.

Table 2 shows that the crush strength of the sorbent decreased by as much as 46% in one section. From the DCP, XRF and ICP data, it is not clear whether or not the Zn/Ti molar ratio changed significantly during the two-cycle test. However, Table 3 shows that the sorbent exposed to five cycles suffered an average decrease of 7% in the Zn/Ti molar ratio, as detected by both XRF and DCP. Also, the crush strength decreased by as much as 40% in one section.

Table 3. UCI L-3140 Sorbent Analysis For Cycles B-1 Through B-5

Sorbent Bed Position[1]	Unused	Top							Bottom
Sample No.	0	1	2	3	4	5	6	7	8
wt% Sulfur	0.09	14.3	14.3	9.41	6.78	3.37	0.49	0.17	0.14
Phases[2]									
ZnS	0	4	4	2	2	2	0	0	0
$2ZnO \bullet 3TiO_2$	1	2	2	2	1	1	1	1	1
$2ZnO \bullet TiO_2$	3	1	1	2	3	3	3	3	3
ZnO	0	0	0	0	0	0	0	0	0
TiO_2	0	2	2	1	1	0	0	0	0
Zinc Sulfide / Zinc Titanate[3]	0	1.3	1.3	0.5	0.5	0.5	0	0	0
Crush Strength[4], lb	25.0	27.0	----	15.0	17.0	22.0	20.0	32.0	20.0
Pore Volume, cc/gm	0.40	0.32	0.31	0.32	0.33	0.34	0.36	0.37	0.38
Surface Area, m^2/gm	3.1	6.2	5.8	3.1	4.0	1.9	1.7	2.5	2.1
Zn/Ti molar ratio, DCP	1.51	1.39	1.38	1.41	1.36	1.39	1.37	1.39	1.36
Zn/Ti molar ratio, XRF	1.47	1.42	1.38	1.40	1.37	1.36	1.34	1.36	1.42

(1) UNUSED = sample in "as received" condition; TOP = sulfidation inlet, regeneration outlet; BOTTOM = sulfidation outlet, regeneration inlet
(2) Digits represent relative presence of each phase
(3) Zinc Sulfide/Zinc Titanate = $ZnS/(2ZnO \bullet 3TiO_2 + 2ZnO \bullet TiO_2)$
(4) Average of six tests
(5) DCP = Direct Current Plasma Spectroscopy; XRF = X-Ray Fluorescence Spectroscopy

We had planned to continue testing the same batch of L-3140 for a total of 20 cycles. However, given the level of decrepitation after only five cycles, we decided to test other ZnTi formulations in order to find a more durable sorbent. Consequently, we designed the last test run of this program to simultaneously compare the durability of four different ZnTi formulations. Alternating layers of the four formulations were placed in the fixed bed so that they could be exposed to the same set of operating conditions over multiple cycles. The four sorbents included L-3140 (Zn/Ti=1.5) and L-3787M (Zn/Ti=2) from UCI, and TRZ-14 (Zn/Ti=0.8) and TRZ-21 (Zn/Ti=1.1) from Research Triangle Institute (RTI). Since the L-3140 had cracked during the previous tests, it was used as a control sample against which the other sorbents could be compared. The two RTI formulations and the UCI L-3787M were spherical pellets with nominal diameters of five millimeters. The UCI L-3140 extrudates were nominally five millimeters in diameter and 15 millimeters long. These sorbents were exposed to a total of six cycles during July and August 1992.

The sorbents were inspected following the first cycle. Both the L-3787M and TRZ-14 showed no visible signs of decrepitation. Approximately 10% of the TRZ-21 sorbent pellets showed some signs of spalling. As before, a significant quantity of the L-3140 pellets had cracked.

Following the inspection, the sorbents were replaced in the fixed bed and subjected to an additional four-and-a-half cycles. After the sixth sulfidation, the fixed bed reactor was cooled down and the sorbents were inspected in the sulfided state. All four formulations had cracked and spalled.

The UCI L-3787M suffered the least amount of degradation. Approximately 40 percent of the L-3787M pellets were broken, 50 percent had cracks which penetrated an unknown distance below the surface, and only 10 percent showed no visual signs of cracking. The whole, uncracked pellets appeared to have retained their crush strength, as they could not be crushed between two fingers. None of the cracked material passed through a 14-mesh screen.

Multiple, deep cracks were observed in all of the L-3140 extrudates, and roughly 50 percent of the pellets were broken. However, the level of degradation was less than the degradation that was observed in the December 1991 five-cycle test.

Cracking and spalling in the RTI formulations was most severe, with over 14% of the TRZ-21 passing through a 14-mesh screen. It appeared that similar levels of degradation had occurred in the TRZ-14. Both RTI sorbents had lost significant crush strength, as it was relatively easy to crush them between two fingers. Unlike the UCI L-3787M sorbent, which typically broke into two or threc large pieces, the RTI sorbents lost many small, thin, fragments from the surface of the shperical pellets. These fragments had the appearance of small pieces of an egg shell which had been peeled from the surface. The characteristic size of these flakes was less than 0.5 mm. Some pellets, which still retained the initial, generally spherical shape, were missing from 10 to 20 of these small flakes.

Following the inspection of these sulfided pellets, the sorbents were replaced in the reactor so that they could be regenerated. The final regeneration and the data analysis from this experiment were not available when this paper was prepared. The results will be reported to METC as soon as they are available.

Ceramic Candle Filter Testing. A ceramic cross flow filter was operated for a total of 345 hours during several PDU test runs. Any viable IGCC power plant using hot gas cleanup will need this filter, or some other high temperature particulate removal device, to limit emissions and to protect the combustion turbine from erosive particles. Several different internal configurations have been tried in the filter, and a considerable amount of operating experience has been gained. The ability of the filter to function essentially as an absolute filter has been demonstrated.

In August 1991, a nineteen-element candle array was substituted for the eight cross flow elements inside the Westinghouse filter vessel. Between September 1991 and August 1992, approximately 180 hours were logged on the candle filter. Inlet dust loadings were generally 1000 to 2000 wppm, as measured during runs in September, November and December 1991. The outlet gas samples appeared dust free, although the impactor collection plates appeared to contain debris from the process piping. The performance and operating characteristics of the candle filter did not appear to differ significantly from that of the cross flow filter.

Process Optimization Studies

The Phase II process optimization studies were intended to provide guidance for the design of the integrated PDU by revealing those hot gas cleanup configurations having the greatest potential for commercialization as part of a Texaco-based grass roots IGCC plant. The results of the first nine study cases were reported in our 1990 Contractors Review Meeting paper (Robin, *et. al.* 1990). These studies, which were first attempts at integrating hot gas cleanup with Texaco's gasification process, showed that IGCC power plants based on the Texaco gasifier using hot gas cleanup are more efficient than similar plants using conventional cold gas cleanup. Improvements in overall plant heat rates of up to 400 Btu/kWh were calculated. However, all of the plants were more expensive to build and operate than the cold gas cleanup base case.

We originally envisioned that the results of the nine studies would provide clear guidance in selecting an economically viable process configuration to be demonstrated in an integrated PDU at Montebello. However, because none of the first nine configurations studied resulted in a plant which was less expensive than the cold gas cleanup base case, we proposed a second group of studies aimed at improving the overall economics while maintaining, as much as possible, the calculated efficiency gains.

These studies again looked at various combinations of in-situ desulfurization, external desulfurization using either once-through, non-regenerable sorbents (such as dolomite or iron oxide) or regenerable zinc titanate sorbents, and air- versus oxygen-blown operation of the gasifier. However, the expensive radiant syngas coolers were replaced with direct contact heat exchangers, and the regenerable sorbent fixed bed designs were replaced with either moving bed or fluidized bed designs. These reactor design changes allowed the sorbent to be regenerated with pure, rather than diluted, air. The more concentrated SO_2 regeneration off-gas streams resulting from these changes meant that smaller, less costly sulfur recovery units could be used. Design improvements to the reactors using once-through, non-regenerable sorbents were also made in an attempt to improve the sulfur removal efficiency of these units.

The key results of this second group of economics cases are summarized in Table 4. Brief process descriptions for each case are given in the footnotes to the table; and costs are expressed in terms of mid-91 dollars. Case 1 is the cold gas cleanup base case against which all the hot gas cleanup cases are compared in terms of efficiency and cost.

All of the oxygen-blown hot gas cleanup cases are more efficient than the cold gas cleanup base case. The air-blown hot gas cleanup cases are the least efficient and most expensive of all the cases shown in the table. The lower efficiencies of the air-blown cases can be attributed to the lower efficiency of the Texaco gasifier blown with air instead of oxygen. This decreased gasification efficiency was measured during several air-blown gasification PDU runs (Robin, *et. al.* 1990 and Robin, *et. al.* 1991). In addition, the increased volume of the air-blown syngas results in larger equipment, more processing trains and increased in-plant power use.

The most efficient and least expensive cases use zinc titanate for bulk sulfur removal. And, even though zinc titanate is expensive, little is gained by using a less expensive once-through, non-regenerable sorbent, in combination with zinc titanate used as a polishing step. All of the cases using a non-regenerable sorbent (12, 13 and 14) had high operating costs, which translated into higher costs of electricity. Also,

Table 4. Process Optimization Studies - Summary of Key Results

Case	1	10M	10F	11M	11F	12	13	14	15	16
Heat Rate, Btu/kWh	8930	8785	8664	8854	8720	8773	8847	8745	9366	9227
Plant Facilities Investment, $/kW	1601	1527	1505	1559	1545	1504	1633	1445	1659	1678
Total Capital Requirement, $/kW	1758	1689	1658	1727	1703	1660	1796	1595	1829	1852
Dispatch Cost, mills/kWh	17.1	16.1	15.9	17.7	17.3	18.2	20.2	18.1	17.1	17.0
Levelized Cost Of Electricity, mills/kWh	51.2	48.7	48.0	50.9	50.2	51.1	54.9	49.0	52.1	52.4

Case Definitions

Case 1 is the cold gas cleanup (MDEA-based acid gas removal) case previously reported. Although this case was completed in 1989, the cost numbers shown here have been updated to mid-91 dollars for comparison with the new cases. However, it should be noted that since this case was completed, improvements have been made to Texaco's commercially available gasification technology that have resulted in significant reductions in heat rate and plant cost.

The cases labelled 10 recover sulfur as sulfuric acid using the conventional "contact process", while the cases labelled 11 recover sulfur in the elemental form using RTI's direct sulfur recovery process. An M after the case number means that moving beds of zinc titanate were used to remove sulfur species from the syngas. An F after the case number means that fluidized beds of zinc titanate were used to remove sulfur species from the syngas.

Case 12 uses in-situ desulfurization (FineOx mixed with the coal slurry feed) to capture 50% of the sulfur in the slag leaving the gasifier. Fluidized beds of zinc titanate are used to remove the remaining sulfur external to the gasifier. Sulfur removed by the zinc titanate is recovered as sulfuric acid. This case is very similar to case 10F, except that in-situ desulfurization is used in the gasifier.

Case 13 uses an entrained bed of dolomite, injected into the syngas as a dry powder, to capture 90-95% of the sulfur as CaS. The remaining sulfur is removed in fluidized beds of zinc titanate. The spent dolomite, along with the SO_2 from the regeneration of the zinc titanate, is oxidized to $CaSO_4$ for disposal.

In Case 14, fine particles of iron oxide are passed once through a fluidized bed desulfurizer and a fluidized bed regenerator before being mixed with the feed coal slurry as an in-situ desulfurization additive. Total sulfur removal is about 96%. The sulfur captured by the iron oxide inside the gasifier (50%) is disposed of along with the slag, while the sulfur captured in the fluidized bed desulfurizer (46%) is recovered as sulfuric acid. All of the above cases recover 98% of the sulfur. However, at this time, we do not believe that the addition of a zinc titanate desulfurizer to raise the Case 14 sulfur recovery to 98% can be justified.

Case 15 uses four air-blown gasifier and hot gas cleanup trains compared to the previous seven cases where two oxygen-blown gasifier and hot gas cleanup trains are used. The hot syngas is desulfurized in a GE moving bed zinc titanate desulfurizer system; and sulfur is recovered as sulfuric acid. Selective Catalytic Reduction (SCR) is used downstream of the turbines to control NO_x emissions.

Case 16 uses the exact same process configuration as Case 15, except that the gasifier is operated at 300 psig rather than at 480 psig. The purpose of doing cases at two different pressures is to investigate the effect of operating pressure on the economics of IGCC power plants based on air-blown entrained bed gasifiers.

use of a once-through, non-regenerable sorbent solves an air pollution problem by creating a solid waste disposal problem, with its attendant long-term liability.

The two cases which surpassed the cold gas cleanup base case (in terms of efficiency and all the key cost numbers) used zinc titanate for bulk desulfurization and sulfuric acid plants for sulfur recovery. Recovering sulfur in the elemental form resulted in plants with operating costs only slightly higher than the base case. With respect to the zinc titanate reactor design, the plants using fluidized beds were more efficient than the ones using moving beds. This difference can be attributed largely to the power consumption of the moving bed regenerator's recycle compressor. However, it should be noted that the moving bed design is much closer to commercial demonstration than the fluidized bed design.

FUTURE WORK

The analytical work from the last PDU test comparing the durabilities of four zinc titanate formulations in real Texaco syngas will be completed. The best hot gas cleanup process economics case (10F) and the cold gas cleanup base case (1) are being updated to include some recent process improvements. Also, cost numbers for these two cases will be recalculated in terms of 1992 dollars. The accomplishments of this research program, which is scheduled to terminate September 30, 1992, will be summarized in a Final Report. An integrated PDU will not be built.

REFERENCES

Robin, A.M., *et. al.* 1989 Integration and Testing of Hot Desulfurization and Entrained Flow Gasification for Power Generation Systems. In *Proceedings of the Ninth Annual Gasification and Gas Cleanup Systems Contractors Review Meeting*, ed. R.A. Johnson and T.P.Dorchak, p.25-36. DOE/METC-89/6107. NTIS/DE89011706.

Robin, A.M., *et. al.* 1990 Integration and Testing of Hot Desulfurization and Entrained Flow Gasification for Power Generation Systems. In *Proceedings of the Tenth Annual Gasification and Gas Cleanup Systems Contractors Review Meeting*, ed. V.P. Kothari and J.L Beeson, p.15-24. DOE/METC-90/6115. NTIS/DE90009689.

Robin, A.M., *et. al.* 1991 Integration and Testing of Hot Desulfurization and Entrained Flow Gasification for Power Generation Systems. In *Proceedings of the Eleventh Annual Gasification and Gas Cleanup Systems Contractors Review Meeting*, ed. V.K. Venkataraman, L.K. Rath, J.W. Martin and R.C. Bedick, p.56-65. DOE/METC-91/6123. NTIS/DE92001101.

DATE
FILMED
2/9/93