

Long Life Moving-Bed Zinc Titanate Sorbent

Robert J. Copeland (copeland@tda.com; 303-940-2323)

Mike Cesario (czar@ecentral.com; 303-940-2336)

Daniel A. Feinberg (daf@tda.com; 303-940-2311)

Jack Sibold (siboldj@tda.com; 303-940-2319)

Brian Windecker (mech@tda.com; 303-940-2306)

TDA Research, Inc.

12345 West 52nd Avenue

Wheat Ridge, CO 80033

Jing Yang (yangjing@stout.entertain.com; 303-934-5086)

Independent Consultant

679 S. Reed Ct., #5-302

Lakewood, CO 80226

Introduction

Combined cycles (combinations of a gas turbine and a steam bottoming cycle) are an efficient power generation technology, while coal is the lowest-cost fuel. The combination of Coal Gasifiers and Combined Cycles therefore is predicted to be the lowest-cost source of baseload electric power in the next decade. In a GCC, the sulfur and particulates are removed from the gasifier gases before they enter the turbine combustor. While H_2S (and COS/CS_2) can be removed effectively by cooling hot gases down to near room temperature and scrubbing them with an aqueous amine solution, removing the H_2S without cooling the gases (i.e., hot gas cleanup) is more advantageous.

The leading hot gas sulfur absorbent uses a regenerable zinc oxide- (ZnO) based sorbent to remove the H_2S and other sulfur compounds from the hot coal gases. The zinc absorbs H_2S , forming zinc sulfide (ZnS); ZnS is then regenerated with oxygen (air), releasing the sulfur as a concentrated stream of SO_2 . The SO_2 can be converted into sulfuric acid, sulfur, or reacted with calcium carbonate to form calcium sulfate (gypsum). The sorbent may be operated in a fluidized bed reactor, transport reactor, or moving bed reactor.

TDA Research, Inc. (TDA) is developing sorbents suitable for moving-bed and other types of reactors. Under one contract, TDA is evaluating 3 to 5 mm sized sorbents for moving bed reactors ("A Long Life ZnO-TiO_2 Sorbent"); under a second contract ("A Novel Desulfurization Sorbent") we are evaluating 50 to 400 micron sized sorbents suitable for fluidized bed or transport reactors.

In this paper we discuss the application to the Moving-Bed reactor. A schematic of a moving bed system with the production of sulfuric acid from the SO_2 is shown in Figure 1. Two reactors are utilized with the sorbent moving between the absorber and regenerator. The particle size is large (i.e., 3 to 5 mm = 3000 to 5000 micron).

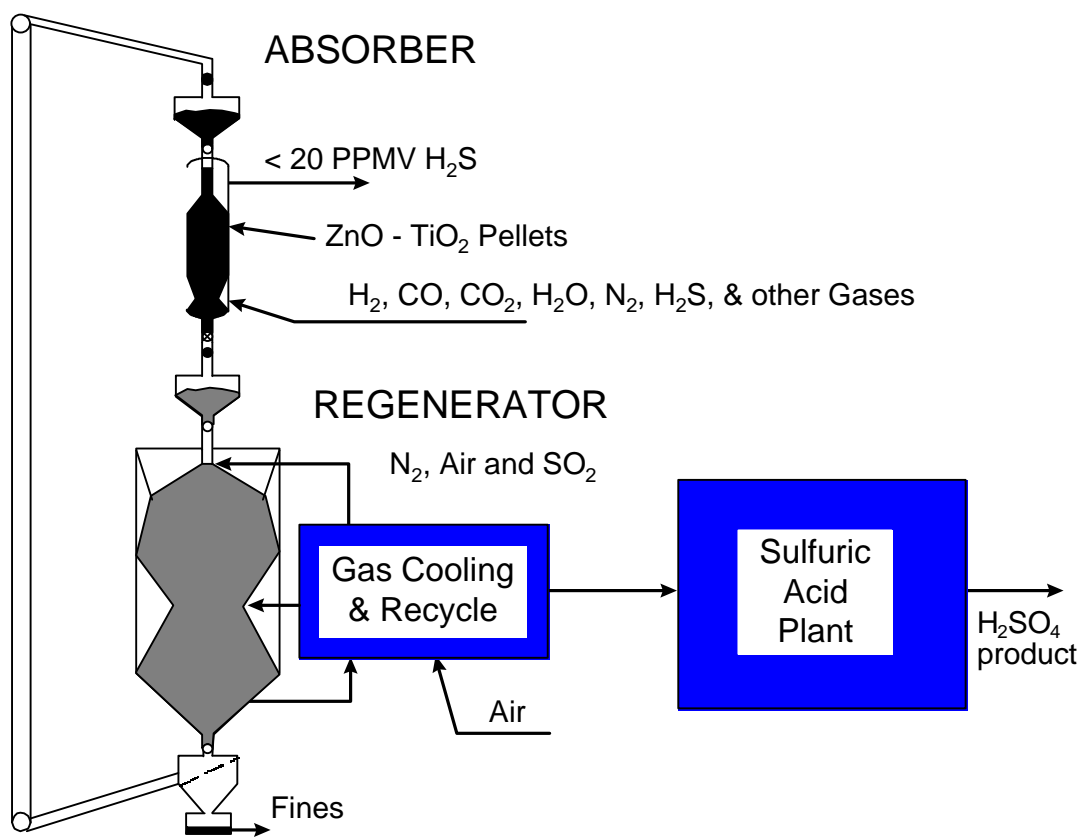


Figure 1. Moving Bed Reactor System.

ZnO has a high affinity for H₂S and produces a very clean gas stream. Unfortunately, the life of many ZnO-based sorbents is very limited, especially in fixed and moving bed reactors. The molar volume of the ZnS is 50% greater than that of ZnO. During regeneration some zinc sulfate can form, which can occupy more than 250% of the original ZnO volume of the original ZnO. Prior to returning to the absorber, the zinc sulfate is decomposed and returns the sorbent to its original oxide form. The zinc atoms thus move substantially during absorption (to ZnS), to regeneration (to ZnO and some ZnO*2ZnSO₄), and finally back to the oxide (ZnO). This repeated expansion and contraction of the sorbent as it is cycled causes many sorbents to spall (i.e., break into small pieces), which eventually destroys the sorbent (Jung et al. 1992, Mei et al. 1993). Because of the high sorbent loss rate, fresh sorbent must be continually added to the process which in turn increases the cost of sulfur removal; substantial cost reductions could be achieved by making a more durable sorbent.

Objective

The objective of this work was to develop and test long-life sorbents for hot gas cleanup. Specifically, we measured the sulfur loading at space velocities typically used for absorption of H₂S and regenerated the sorbent with diluted air for multiple cycles. Based on the experimental results, we prepared a conceptual design of the sorbent-fabrication system, and estimated the cost of sorbent production and of sulfur removal.

Technology

In order to make a sorbent pellet capable of holding large amounts of sorbent without being destroyed by the absorption-regeneration process, TDA has developed a new sorbent structure with the following characteristics: 1) it is very strong, 2) it allows the sorbent to expand and contract freely without disrupting the pellet structure, 3) it allows the H_2S to diffuse quickly into the interior of the pellet, and 4) it can contain very large amounts of sorbent without spalling.

TDA prepared sorbents and evaluated them for moving bed applications. Last year (Copeland et al. 1996) we reported on a spalling resistant sorbent. This year we have improved our sorbent formulation and modified the regeneration procedure. We have improved our attrition resistance to better than 98% while retaining high chemical activity and sulfur loadings.

We selected one sorbent formulation which was made by Norton to TDA's specifications. This sorbent is identified as TNT-MB for TDA and Norton - Moving-Bed. This sorbent is a zinc ferrite ($ZnFe_2O_4$) with improved resistance to spalling.

Pervious work in zinc ferrite has shown a tendency for the sorbent to spall (Jung et al 1992) (i.e., to break into small pieces when exposed to the regeneration gases). Krishnan et al. (1991) also reported that the zinc ferrite can make iron carbon and accumulated carbon during cycling. However, Krishnan et al (1991) also reported that "Carbon deposition rate exceeds the rate of removal by *steam*, and hence carbon is likely to accumulate on the sorbent". Since the Moving-Bed system regenerates the sorbent with oxygen, the limitation imposed by regenerating only with steam does not apply.

Fortunately, previous work by Cook et al. (1992) has shown successful application of a zinc ferrite sorbent in a moving bed (i.e., at the pilot plant facility in Schenectady, NY). Initially their tests were run with a low regeneration temperature (less than 1200°F, 649°C) and sulfate was formed which was carried into the absorber in the next cycle. Sulfate formation can also cause spalling of the zinc ferrite. However, when the regenerator exit temperature was greater than 1200°F (649°C), the sulfate was almost completely eliminated, and a small quantity of sulfide (about 2% sulfur as sulfide with very low levels of sulfate) remained in the sorbent when leaving the regenerator.

Although zinc ferrite was shown to be a successful sorbent in a moving bed, the interest in sorbents in 1992 was toward the higher temperature absorption. Gangwal and Gupta (1991) reported: "zinc ferrite sorbents were found to be limited to 550°C" (1022 °F) during absorption and the emphasis shift to research on zinc titanate and related type sorbents. However, the moving bed absorber at Tampa Electric is designed to operate at 900°F (482°C) and thus zinc ferrite can be used at the temperature anticipated without concern.

TDA assembled a team to evaluate, produce, and test sorbents for moving-bed and fluidized-bed reactors. The team members are TDA, Norton Chemical Process Products Corporation (Norton), and the Institute of Gas Technology (IGT). TDA defined the sorbents to be evaluated and conducted multiple cycle screening tests in our fixed bed reactors. Norton produced the sorbent

by techniques representative of commercial production.

IGT is testing our sorbents to the requirements of the DOE 25 cycle test protocol. In addition, DOE-FETC performed the 10 cycle tests without SO₂ required by the test protocol under a Cooperative Research and Development Agreement (CRADA) agreement with TDA.

Results

As of this writing, TDA has completed two of the three required tests of the DOE test protocol. The CRADA with FETC evaluated the performance of TNT-MB without added SO₂ in the inlet of the regeneration gas in accordance with the DOE test protocol. The CRADA included both a Low Temperature Scoping Test and 10 cycles at 900°F sulfidation temperature. Samples were taken of the regenerated material and TGA tests of the 10th regeneration are being evaluated at the Institute of Gas Technology (IGT) under subcontract to TDA. This paper presents the results of the 10 cycle tests at FETC, some data from the 3 ½ cycle scoping tests at IGT, and some data from tests on TNT-MB at TDA. The 25 cycles with 10% SO₂ in the regeneration gases at 5 atm are planned at IGT in August 1997.

Sulfiding

Two types of Sulfiding experiments were conducted under the CRADA with FETC: 1) Scoping and 2) 10 cycle without SO₂ in accordance with the DOE test protocol. The Scoping tests were conducted to resolve control issues for FETC's reactor and to evaluate the performance of TNT-MB in low temperature absorption; the low temperature tests were all conducted with 600 to 700°F inlet gas, 20 atm, 2000 h⁻¹ space velocity, and 1.2% H₂S. The 10 cycle tests were all conducted with 900°F inlet gas, 20 atm, 2000 h⁻¹ space velocity, and 1.2% H₂S. All regenerations at FETC were conducted without SO₂ in the inlet gas, 2000 h⁻¹ space velocity, and 7 atm pressure.

Figure 2 shows the first absorption with an inlet gas temperature of 600°F for 30 minutes to simulate the startup of the moving bed absorber from a cold condition. After 30 minutes heater power was increased to raise the bed temperature to 700°F. During the temperature increase the H₂S concentration increased. However, as the bed warmed to 700°F, the H₂S concentration stabilized and then began to decrease due to the better absorption at the higher temperature. Finally, the concentration broke through at 700°F condition, reaching a concentration of 180 ppm at 125 minutes.

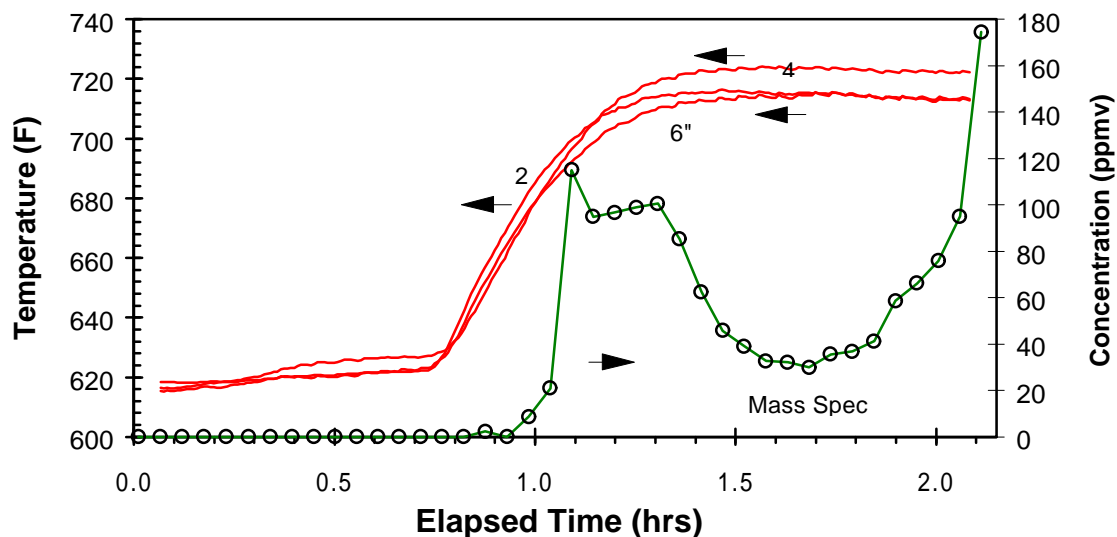


Figure 2. First absorption of TNT-MB at 600/700°F.

The second and third cycles were both conducted at 700°F for 125 minutes. Figure 3 presents the measured H_2S concentration and temperatures during the third absorption. The H_2S concentration leaving the bed was always very low (less than 1 ppm) throughout the entire 125 minute period. Tests at TDA under these conditions show breakthrough at over 3 hours (i.e., > 180 minutes).

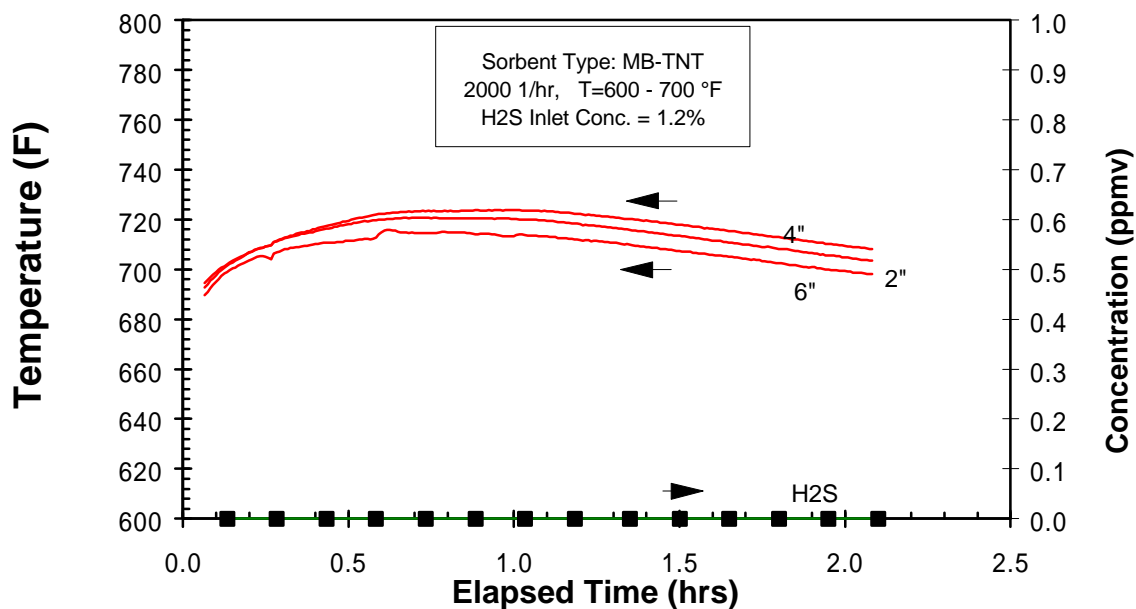


Figure 3. Absorption at 700°F.

Following the three scoping cycles, the reactor was loaded with fresh sorbent and 10 cycles were conducted with an inlet temperature of 900°F, 20 atm, 1.2% H_2S , and 2000 h^{-1} space velocity.

Figure 4 presents the measured H₂S outlet concentration for all 10 cycles. The first nine cycles were conducted for 125 minutes only and then regenerated. The 10th cycle was taken to breakthrough which required more than 7 hours.

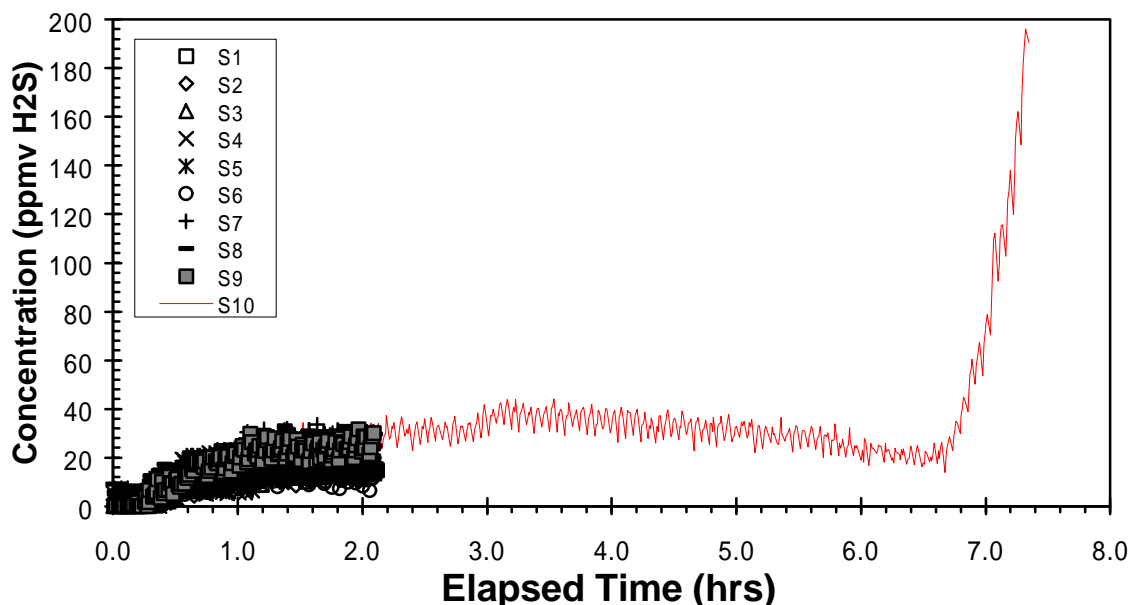


Figure 4. 10 sulfidations of TNT-MB at FETC.

Figure 5 presents the measured temperatures and H₂S outlet concentration on the 10th sulfidation. The inlet gas is at 900°F; however, due to water gas shift which is catalyzed by TNT-MB, the sorbent temperature in the bed rapidly rises. Based on measured gas compositions we measured a shift from CO to H₂ with a corresponding increase in CO₂. Within the accuracy of the measurements the total carbon in the inlet gas equaled the total carbon in the exit gas in the scoping tests at IGT; data of CO, CO₂, and H₂ from FETC has not been received as of this writing.

Initially the temperature is highest at 2 inches from the inlet but after 4 hours, this temperature begins to decrease. As the sorbent is sulfided, the sulfur reduces the catalytic activity toward water gas shift with a corresponding decrease in the heat release. The 3 ½ cycle scoping tests at IGT showed a similar result during sulfidation.

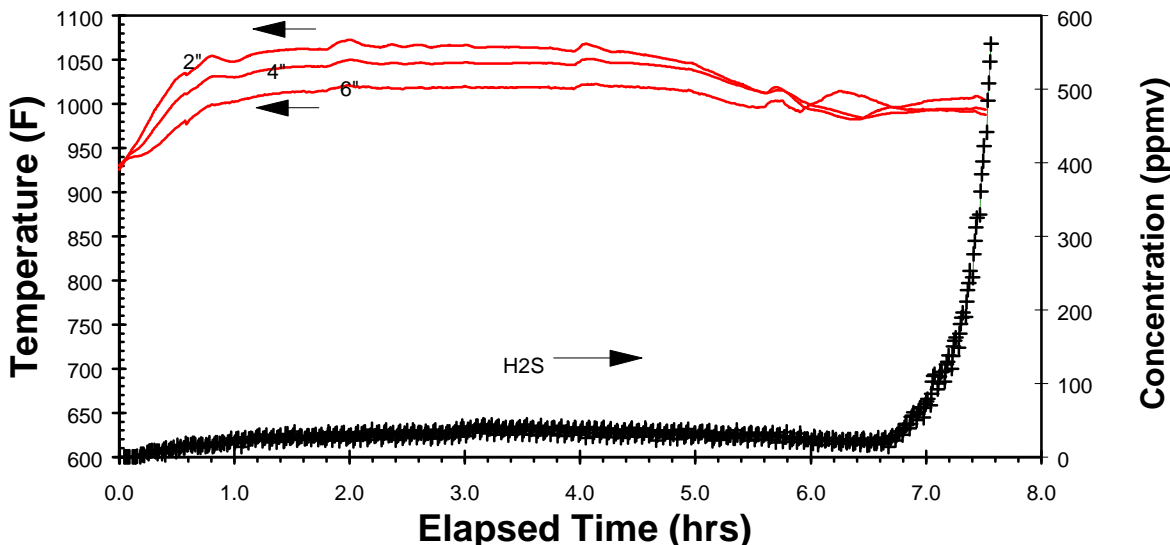


Figure 5. Temperatures and H₂S concentration during 10th sulfidation at FETC.

Regeneration

Cook et al. (1992) regenerated zinc ferrite successfully when the exit temperature exceed 1200°F. TDA studied the data from Cook et al. (1992) and conducted thermodynamic analysis of why this result was achieved. TDA found that above 1200°F, the iron sulfates are not thermodynamically stable, even in the presence of both oxygen (O₂) and SO₂ and at pressures up to 7 atm. We regenerate TNT-MB in a moving bed reactor using this proven approach to minimizing sulfate.

Figure 6 illustrates the preferred conditions to regenerate TNT-MB in a moving bed; the regenerator uses a simple co-flow reactor with only one inlet and one exit. Cook et al (1992) used a dual inlet regenerator in the tests of zinc ferrite. Our sorbent will initiate regeneration with 4% O₂ and with the sorbent and inlet gas at 700°F (TDA conducted some regenerations with 600°F initial sorbent and inlet gas temperature). We use the self heating of the oxidation of the sorbent to raises its temperature to over 1250°F, and allowing a small heat loss from the reactor. Without any heat loss the sorbent and gases would exit at 1295°F (702°C). The control of the reactor is relatively simple; inlet temperature is controlled by the cooling of the recycle gases and exit temperature is controlled to 1250°F ± 50°F by the air flow added to the reactor.

Theoretically 1.67 moles of oxygen are required to fully oxidized fully sulfided zinc ferrite. As shown in Figure 6, TDA calculated the maximum SO₂ concentration leaving the reactor as 13.6%.

In tests at TDA, we measured a ratio of 1.7 moles O₂ per mole of H₂S absorbed. The preliminary data from the 10th cycle at FETC indicate a ratio less than 1.5 based on the flow meter data; we do not believe this result and are current investigating the cause of this result.

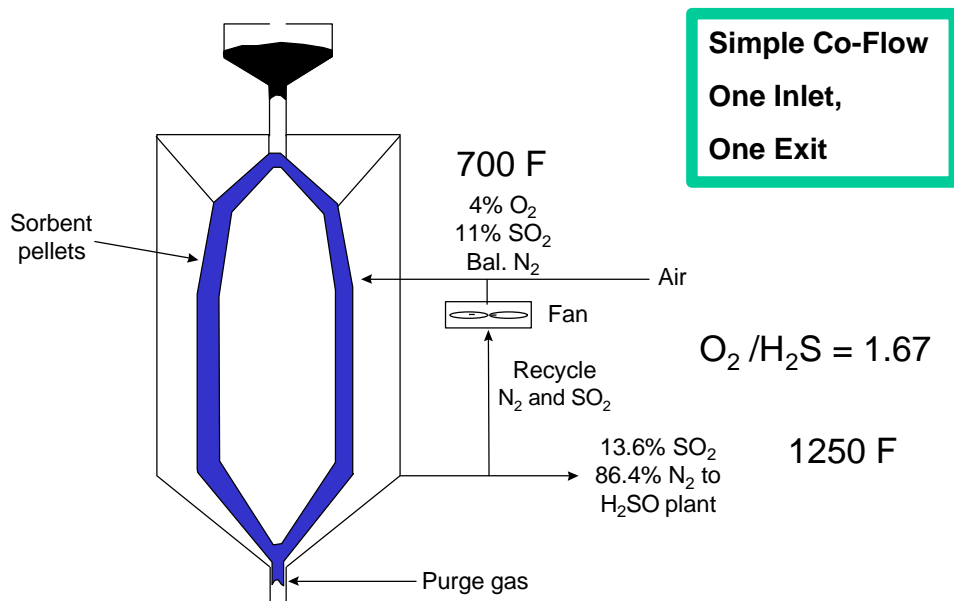


Figure 6. Moving bed regenerator with TNT-MB.

Figure 7 illustrates the temperature and gas concentrations in the sorbent as it moves down the reactor. Initially the sorbent is rapidly heated due to the oxidation of the sulfide, simultaneously reducing the oxygen concentration and increasing the SO₂ concentration. During this period some sulfate is formed by the reaction of oxygen, SO₂, and iron oxides. Since the amount of sulfate formed is a function of time, it is very desirable to minimize the time the sorbent is less than 1200°F. TDA prefers the high oxygen concentration (4%) with a low inlet temperature and a single inlet to minimize the time. This approach minimizes the quantity of sulfate formed and the tendency of the sorbent to spall.

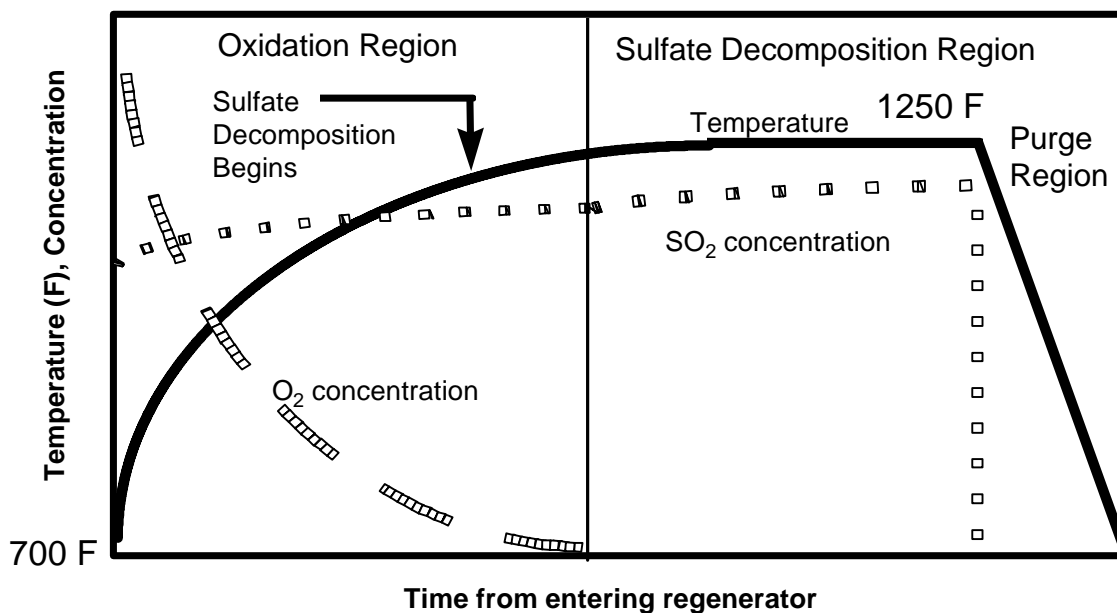


Figure 7. Temperature and concentrations during regeneration.

When the temperature reaches 1200°F sulfate decomposition begins even in the presence of oxygen and SO₂. Finally, a point is reached where essentially all of the oxygen is consumed and the temperature reaches 1250°F. TDA prefers that the sorbent remain in the bed at this high temperature for about one hour to fully decompose the sulfate and raise the SO₂ concentration to its maximum value. After the sorbent is regenerate it enters the nitrogen purge at the bottom of the reactor which cools the sorbent and purges SO₂ from the gas space before returning the sorbent to the sulfiding reactor.

TDA recognizes that the testing of the TNT-MB is done in a small scale fixed bed reactor and that the conditions of a real moving bed cannot be exactly duplicated. We therefore defined two regions of operation 1) Oxidation Region where the sorbent is self heating to 1250°F, and 2) Sulfate Decomposition where the sulfate is decomposing at 1250°F. All of the regenerations at TDA, FETC, and IGT use this two region regeneration approach.

The regeneration conditions at the inlet for the three testing sites are as follows:

- FETC: 7 atm, 700°F, no SO₂ - 3.3% O₂, balance N₂
- IGT: 5 atm, 750°F, 10% SO₂ - 4% O₂, balance N₂
- TDA: 2-3 atm, 700°F, 10% SO₂ - 4% O₂, balance N₂

The sulfate decomposition regions operate with the same pressures and SO₂ concentrations as the oxidation region at each of the three sites.

Figure 8 presents the measured temperatures and SO₂ and O₂ concentrations in this two region regeneration approach. Initially the temperature near the inlet (e.g., the 2 inch location) is low. As the oxidation of the sorbent near the inlet proceeds it warms the pellets in the fixed bed reactor at the downstream locations (i.e., 4 inch and 6 inch locations). The heating of the pellets by low oxygen containing gases effectively increases the temperature of some sulfided material before it is oxidized. This pellet preheating causes a rapid increase in the peak temperature and the inlet oxygen was reduced after about one hour to maintain a peak temperature of less than 1300°F. The reduce SO₂ concentration at one hour is due to the reduce inlet oxygen content. After about 1.5 hours, the oxygen breaks through and approaches its inlet value; since most of the sulfide has been oxidized away, the temperatures in the reactor decline. The oxygen supply is then terminated and the temperature of the reactor is ramped to 1250°F without any oxygen in the inlet gas. Since there is no SO₂ in the inlet gas, the sulfate decomposition begins at less than 1200°F as shown by the increase in SO₂ concentration at 1.75 hours.

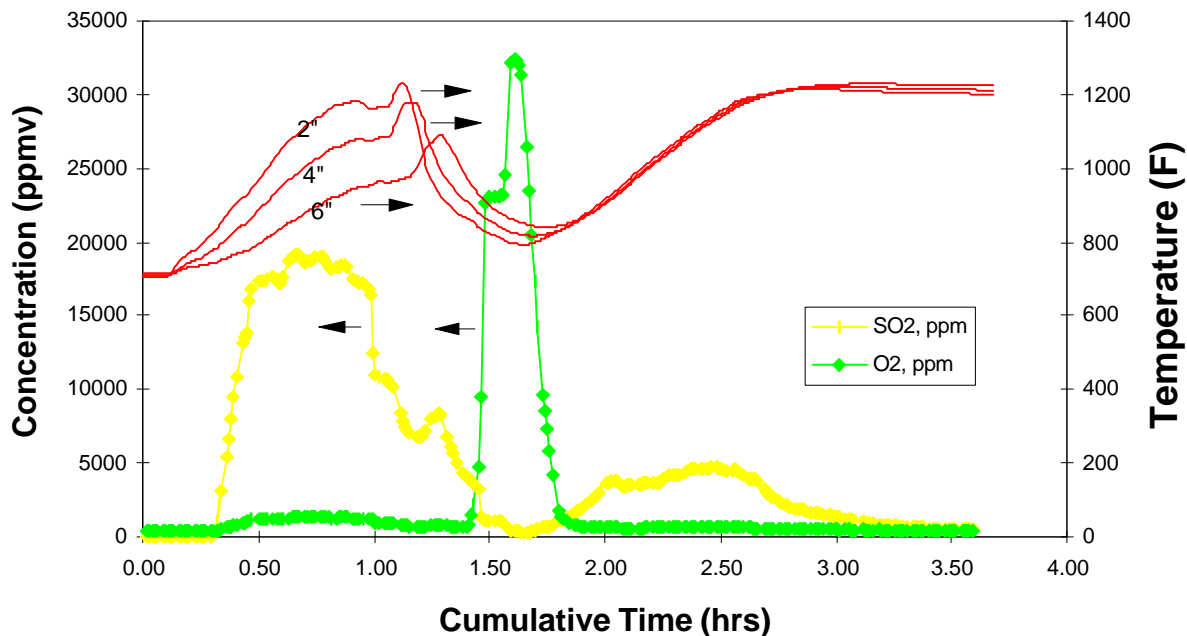


Figure 8. 5th Regeneration at FETC 7 atm, 700°F (372°C), No Inlet SO₂ 2000 h⁻¹.

Figure 9 presents the measured concentrations from the scoping tests at IGT. Due to a difference in reactor design, the IGT reactor loses more heat than the FETC reactor and 4% oxygen in the inlet was maintained throughout the oxidation region. During the oxidation region, the SO₂ in the inlet gas was raised several times to maintain an exit concentration of 10% SO₂. Toward the end of the oxidation region, the SO₂ in the exit actually fell below the inlet value with oxygen present; probably due to the formation of sulfate. After 60 minutes the oxygen supply was terminated and the reactor temperature increased while maintaining 10% SO₂ in the inlet. After a few minutes the exit SO₂ concentration rapidly increases due to the decomposition of sulfate. Although oxygen is released with SO₂ with sulfate decomposition, that oxygen is simply consumed by unreacted sulfide remaining in the sorbent. After 150 minutes the sulfate decomposition is complete and the reactor is purge with N₂.

Excluding the time which is required to heat the sorbent to 1250°F following the oxidation region, the regeneration requires a total time of about 120 minutes following a 125 minute absorption. The oxidation regeneration requires 60 minutes and sulfate decomposition 60 minutes. The regeneration thus can be conducted in about the same volume as the sulfidation since both are operated at the same space velocity.

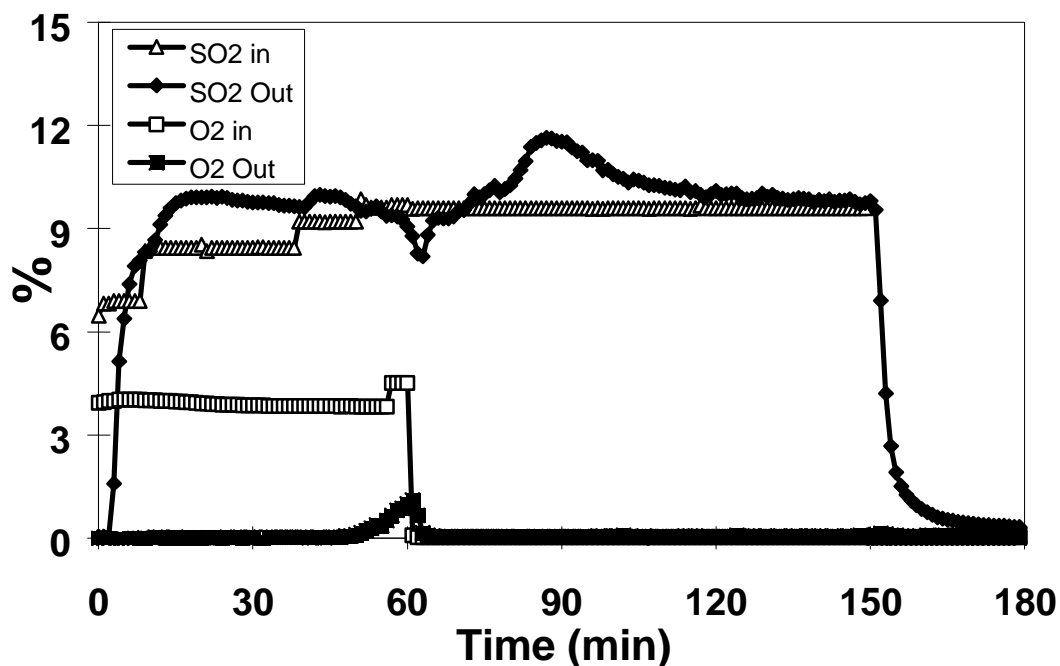


Figure 9. Regeneration at 5 atm, 10% SO₂ at IGT, 2000 h⁻¹.

However, the regenerator at Tampa Electric Company (TECo) has about twice the volume as the Sulfiding reactor. If the regeneration gases were introduced at the top inlet at TECo, the sorbent would be sitting at 1250°F for about 3 hours after the oxidative regeneration. To minimize the potential loss of surface area and activity of the sorbent from this long period at high temperature, we prefer that our TNT-MB be regenerate by introducing gas at the middle location with no gas or gas without oxygen introduced at the top location. This approach is illustrated in Figure 6.

Figure 10 presents the measured temperatures and concentrations for the 10th regeneration which follows the 7.25 hour 10th sulfidation. In this cycle the regeneration is completed in less than 5 hours (versus 7.25 hour absorption), which shows that the more completely sulfided the sorbent the smaller the required regeneration time in comparison to the sulfidation or absorption time. In the 10th regeneration the inlet oxygen was a constant 3.3% throughout; the SO₂ concentration thus does not decrease until the oxygen begins to breakthrough which also corresponds to a decrease in the maximum temperature seen in the sorbent bed.

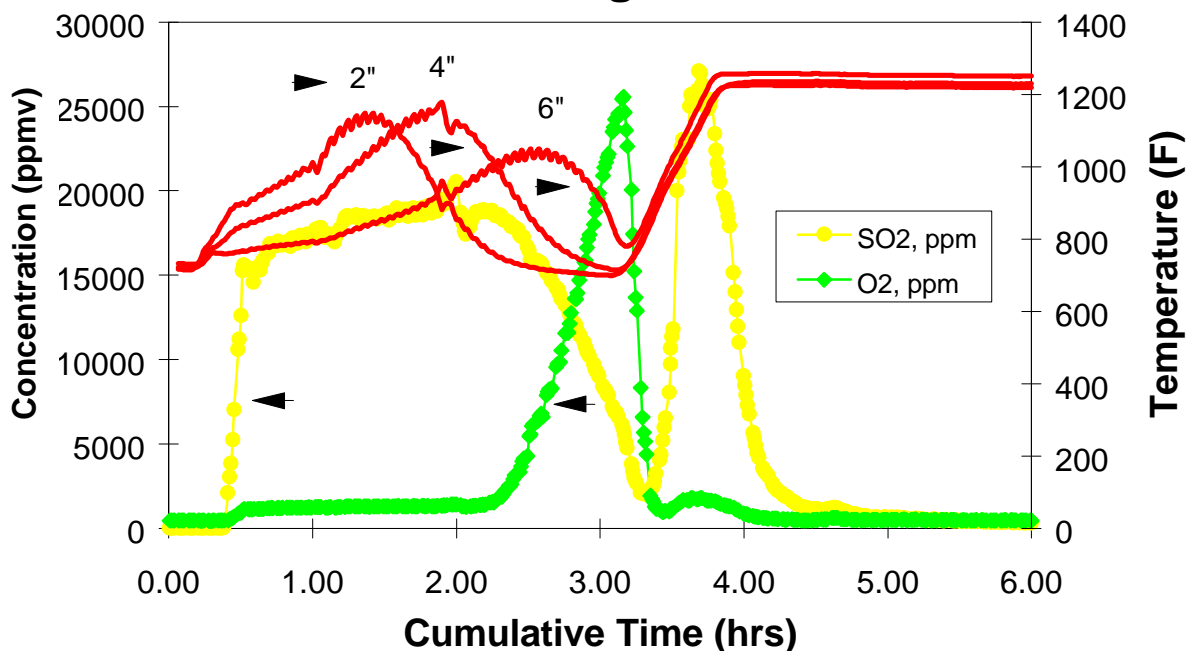


Figure 10. 10th Regeneration at FETC.

In the 10th regeneration the temperature of the 2 inch location from the inlet first increases and reaches a maximum at about 1.5 hours and then decreases and approaches 700°F even with oxygen flowing over it. Obviously the sorbent at that location has been regenerated and no more oxidation will occur. A similar effect occurs at the 4 inch location, but it does not cool all the way back down during the oxidation region.

After 3.2 hours the oxygen flow is terminated and the reactor ramped to 1250°F. In comparison to the 5th regeneration (see Figure 8) a much larger quantity of sulfate is decomposed in the sulfate decomposition region in the 10th regeneration as shown by the high concentration of SO₂ which is released.

Properties

Following the 10th sulfidation and the 10th regeneration at FETC, samples were taken from the bottom (inlet) and the top (exit) of the sorbent bed. In addition, TDA conducted a 4 ½ cycle test with 10% SO₂ in the inlet during regeneration but at a pressure of 2 to 3 atm (a limitation of our apparatus which supplies SO₂ from a liquid tank and the vapor pressure at room temperature limits the maximum pressure which can be achieved). The sulfidation conditions during TDA's tests were the same as the FETC tests. Table 1 presents the measured properties of TNT-MB from these tests.

Table 1. Measured Properties of TNT-MB.

Property	Fresh	4 th Regen.	5 th Abs.	10 th Abs.	10 th Regen.
Sulfur (wt%)	0.44	2.0	16.8	14.4	2.8
Sulfate Sulfur (wt%)	0.42	0.30	NA	0.07	0.27
ASTM Attrition (wt.%)	1.8	1.3	1.1	NA	0.87 inlet (0.64 exit
Carbon (wt%)	NA	< 0.05 *	0.05	< 0.5 *	NA

The fresh TNT-MB has a small quantity of sulfur present which is sulfate remaining at the end of the natural gas firing of the sorbent. After the 4th regeneration at TDA and the 10th regeneration at FETC, very small levels of sulfate sulfur remain in the sorbent (0.30% and 0.27% respectively), indicating that the sulfate decomposition region is achieving the desired effect. Higher levels of sulfur as sulfide remain in the sorbent following regeneration (2.0% and 2.8%) which is similar to the levels measured by Cook et al. (1992) in their regeneration in a real moving bed (1.2% total sulfur, 0.2% sulfate sulfur).

High levels of sulfide sulfur were measured following the 5th absorption or sulfidation at TDA and the 10th sulfidation at FETC (16.8% and 14.4%). Very low levels of sulfate sulfur (i.e., 0.07%) were also seen at the end of a sulfidation. The high level of sulfide sulfur is consistent with the measured > 7 hour breakthrough measured in the 10th sulfidation; with 1.2% H₂S and 2000 h⁻¹ space velocity, the calculated sulfur loading was 15.4 lb (sulfur) per ft³ of bed. In comparison the minimum sulfur loading per unit volume according to the DOE protocol is 7 lb/ft³ at the inlet of the bed. TNT-MB thus has more than twice the minimum sulfur loading after 10 cycles.

The ASTM attrition loss was measured for the fresh material (1.8% wt. loss after 30 minutes). After 4 regenerations with SO₂ in the inlet of the regeneration gas the attrition improved (1.3% loss) and after 10 regenerations without added SO₂ the attrition loss was only 0.87% wt at the inlet and 0.64% from the exit locations. In comparison the allowable loss is 5% after 25 cycles; clearly, the data indicates that we have the potential to surpass this requirement but we need to complete the 25 cycle tests with SO₂ before a definitive conclusion can be reached.

Zinc ferrite is known to form small quantities of carbon (Krishnan et al. 1991) and potentially can make iron carbide. We measured the total carbon content of the TNT-MB following the 5th sulfidation and the 10th sulfidation. The limit of detection of the samples at TDA was 0.05% wt carbon but at FETC the detection limit was 0.5% wt carbon. The 5th absorption contained only 0.05% wt carbon, indicating that indeed a small quantity of carbon is formed but it does not accumulate with cycling since the oxidation region of the regeneration simply burns the carbon out before the next sulfidation. The carbon content following the 10th sulfidation was less than the detection limit of the equipment used by FETC's contractor.

Application

TNT-MB is a NON-SPALLING Zinc Ferrite Sorbent which is being tested for application to a moving bed reactor system at TECo. The testing to date shows that the sorbent can easily meet the requirements for sulfur loading, ASTM attrition loss, and operating conditions required at TECo. In addition the sorbent is able to operate at relatively low temperatures @600°F: > 30

minutes to breakthrough; @ 700°F: > 3 hours to breakthrough, and @ 900°F: > 7 hours to breakthrough. TNT-MB offers the potential to reduce the costs of future moving bed hot gas cleanup systems. Since our regenerator requires only a single inlet, the complexity of the regeneration gas flow is reduced which reduces capital costs. In addition, our regenerator could be half the size of the current TECo regenerator, which further reduces capital costs. The sorbent has a dynamic sulfur capacity of more than twice the requirements for TECo which could substantially reduce the circulation rate of the sorbent, improving the mechanical attrition loss by more than a factor of two with a corresponding reduction in sorbent replacement costs.

Future Activities

TDA produced several different sorbent formulations with different zinc oxide contents, and different strengths and pore volumes. One sorbent formulation was selected for multiple-cycle tests. The sorbent is resistant to spalling and retained its reactivity, porosity, and crush strength with cycling. That sorbent identified as TNT-MB is being tested to the requirements of the DOE 25 cycle test protocol. IGT will complete the 25 cycle with SO₂ required by the DOE protocol in August 1997.

Following the completion of the 25 cycle tests, the sorbent will be qualified for application to moving-bed reactors. TDA will offer our sorbent to the Tampa Electric Company in their next request for quote for sorbent. Norton will be the manufacturer of the TNT-MB.

Contract Information

Research sponsored by the U.S. Department of Energy's Small Business Innovation Research (SBIR) program:

Contract Number: DE-FG03-94ER84881; **Contractor:** TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033; (303) 422-7819; FAX (303) 422-7763. TDA Research, Inc. Contractor Project Manager: Michael E. Karpuk. Principal Investigator: Dr. Robert J. Copeland; E-mail copeland@tda.com.

In addition, DOE-FETC performed testing under a CRADA with TDA:

CRADA Number: 97-F003, "Evaluation of TDA's Zinc-Based Hot Gas Cleanup Sorbent for Moving Bed Reactors"; **Participants:** TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033. Contact: Dr. Robert J. Copeland; E-mail copeland@tda.com; (303) 422-7819; FAX (303) 422-7763; Federal Energy Technology Center, U.S. Department of Energy, P.O. Box 880, Morgantown, WV 26507. Contact: David A. Berry; E-mail dberry@metc.doe.gov; (304) 285-4430; FAX (304) 285-4469.

Acknowledgments

TDA gratefully acknowledges the technical guidance of Ronald Staubly, our initial FETC Project Manager, and Tom Feeley of FETC, our current Project Manager, the work of our two subcontractors: Norton Chemical Process Products Corporation, who fabricated sorbents for our

tests, and the Institute of Gas Technology, who conducted the high pressure Scoping tests, and the technical data on moving bed reactors from Dr. Raul Ayala of General Electric. Period of Performance: August 1994 - June 1998.

References

- Ayala, R.E., T. Chuck, E. Gal, and R.P. Gupta (1994). Development of Sorbents for High Temperature Desulfurization in Moving-Bed Systems," in Proceedings of the Coal-Fired Power Systems 94 -- Advances in IGCC and PFBC Review Meeting, Bonk, sponsored by U.S., Department of Energy, Morgantown Energy Technology Center: Morgantown, WV, Report No. DOE/METC-94/1008, (CONF-9406131). Springfield, VA: National Technical Information Service.
- Cook, C.S., E. Gal, A.H. Furman, and R. Ayala (1992). "Integrated Operation of a Pressurized Fixed Bed Gasifier and Hot Gas Desulfurization System," *Proceedings of the Twelfth Annual Gasification and Gas Stream Cleanup Systems Contractors Review Meeting*, sponsored by the U.S. Department of Energy, Morgantown Energy Technology Center: Morgantown WV, Report No. DOE/METC-92/6128 (DE93000228).
- Copeland, R.J., M. Cesario, M. Dubovik, D. Feinberg, and B. Windecker (1995). "A Long Life ZnO-TiO₂ Sorbent," in *Proceedings of the Advanced Coal-Fired Power Systems 95 Review Meeting*, sponsored by U.S., Department of Energy, Morgantown Energy Technology Center: Morgantown, WV, Report No. DOE/METC-95/1018, (NTIS/DE95009733). Springfield, VA: National Technical Information Service.
- Copeland, R.J., M. Cesario, M. Dubovik, D. Feinberg, D.B. MacQueen, J. Sibold, J. Yang and B. Windecker (1996). "Long Life ZnO-TiO₂ and Novel Sorbents," in *Proceedings of the Advanced Coal-Fired Power Systems 96 Review Meeting*, sponsored by U.S., Department of Energy, Morgantown Energy Technology Center: Morgantown, WV, Report No. DOE/METC-96/1037, (NTIS/DE96011356). Springfield, VA: National Technical Information Service.
- Gangwal, S.K. and R.P. Gupta (1994). "Fluidized-Bed Sorbents," in *Proceedings of the Coal-Fired Power Systems 94 -- Advances in IGCC and PFBC Review Meeting*, editor H.M. McDaniel, R.K. Staibly, and V.K. Venkataraman, sponsored by U.S., Department of Energy, Morgantown Energy Technology Center: Morgantown, WV, Report No. DOE/METC-94/1008 (CONF-9406131). Springfield, VA: National Technical Information Service.
- Gangwal, S.K. and R.P. Gupta (1991). "Enhanced Durability of desulfurization Sorbents for Fluidized-Bed Applications," *Proceedings of the Eleventh Annual Gasification and Gas Stream Cleanup Systems Contractors Review Meeting*, report No. DOE/METC-91/6123 (DE92001102), Morgantown WV: Morgantown Energy Technology Center.
- Jung, D.Y., J.S. Kassman, T.F. Leininger, J.K. Wolfenbarger, and P.P. Yang (1992). "Integration and Testing of Hot Desulfurization and Entrained Flow Gasification for Power Generation Systems," presented at the *Twelfth Annual Gasification and Gas Stream Cleanup Systems Contractors Review Meeting*, Morgantown, WV: Morgantown Energy Technology Center, U.S. Department of Energy, September 15-17. Springfield, VA: National Technical Information Service.
- Krishnan, G.N., V.K. Wong, and B.J. Wood (1991). *A Preliminary Study of Carbon Deposition on Zinc Ferrite Sorbents*, DOE/MC/25006-3057, contract AC21-88MC25006; Research Triangle Park, NC: Research Triangle Institute and Menlo Park California: SRI International.

Mei, J.S., L. Gasper-Galvin, C.E. Everitt, and S. Katta (1993). "Fixed-Bed Testing of a Molybdenum-Promoted Zinc Titanate Sorbent for Hot Gas Desulfurization," in *Proceedings of the Coal-Fired Power Systems 93 -- Advances in IGCC and PFBC Review Meeting*, editor D.L. Bonk, sponsored by U.S., Department of Energy, Morgantown Energy Technology Center: Morgantown, WV, Report No. DOE/METC-93/6131 (CONF-9306148). Springfield, VA: National Technical Information Service.