

INVESTIGATIONS ON THE REMOVAL OF HYDROGEN
SULFIDE AT HIGH TEMPERATURE FROM COAL GAS

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505 King Avenue
Columbus, Ohio 43201WHY HOT-GAS CLEANUP?

At current consumption levels, proven U.S. natural gas reserves are estimated to last 8 years.^{(1)*} Gasification of oils with negligible sulfur content is not feasible since the U.S. oil supply, slowly dwindling, is sufficient for only 10 years.⁽¹⁾ Thus, if continued gas supply is desired, coal gasification may be the only immediately feasible alternative.

Lurgi and Kopper-Totzek (K-T) gasifiers are among the older commercially proven processes. The Lurgi process produces low- or medium-Btu gases contaminated with varying amounts of sulfur compounds such as hydrogen sulfide (H₂S) and carbonyl sulfide (COS). The Lurgi gas is at a higher pressure (350 psi) and lower temperature (750 to 1100 F depending on coal type) than K-T gas which is at 1 atmosphere and 2500 F. Both processes produce gas with a heating value (HHV) of 300 Btu/scf when using oxygen. The Lurgi process can also produce a 180 Btu/scf gas when air blown.

These medium- and low-Btu gases can be used in many ways. The high-pressure-low-temperature Lurgi gas, after removal of its H₂S, tar, and dust content is well suited for synthesis of methane to produce substitute natural gas (SNG). Also, because of its high pressure, the gas can be desulfurized by any of the established wet processes, although this requires cooling the gas to 200 F or -50 F, depending on the liquid scrubbing process chosen. In contrast, if the gas is desulfurized and cleaned until free of particulates at close to the gasifier exit temperature, the sensible heat of the gas can be utilized to efficiently generate electric power in a combined-cycle power plant or to avoid the large heat-exchange hardware requirements in a SNG production scheme.

The K-T gas, at atmospheric pressure and 2500 F, needs compression to 450 psig and cooling before the wet desulfurization and subsequent methanation steps if SNG is the desired product. The prior compression and cooling may be less attractive compared with the direct utilization of the K-T gas in a power plant boiler if a means can be found to desulfurize and clean the crude gas at near gasifier exit temperature. In the latter event, the sensible heat of the medium-Btu gas (45 Btu/scf or 15 percent of its heating value) could be usefully employed. The K-T gasifier can gasify any type of solid fuel (caking coals, chars, petroleum coke, tar, oils, and slurries) and has quick startup and shutdown capabilities. The K-T gasifier is expected to be a suitable source of fuel gas to many power plants in western United States now using natural gas; the retrofit difficulties are estimated to be minimal. If the electric utility industry and other industrial markets now using over 65 percent of the natural gas supply convert to low-Btu gas, about 5 trillion cu ft (35 percent) of natural gas would be freed for other uses.⁽¹⁾

Doubtless, the K-T gasifier--hot-gas-cleanup approach needs to compete with the emerging flue-gas desulfurization (FGD) processes which permit the use of sulfur containing coal. Currently, the FGD processes generate large volumes of secondary wastes, including sludges and liquid purge streams. A detailed evaluation of FGD versus the K-T gasifier--hot-gas-cleanup system may demonstrate the latter

* References are listed at the end.

approach to be favorable, since it does not produce significant secondary wastes; the choice could be largely site specific.

If hot-gas-cleanup systems can be developed to remove sulfur compounds in crude gases, to less than the 0.1-ppm level, they may also be applicable to the SNG production processes. Significant savings appear possible by eliminating the cooling step or minimizing the degree of cooling and heat exchange.

The above arguments suggest that the development of a hot desulfurization process has merit. Also, as evidenced in the development of FGD processes and their wide but slow acceptance, a factor that favors the development of new systems is that when a well-proven system exists, the best use will be made of it. The Energy Research and Development Administration (ERDA) has been investigating hot-gas H_2S -removal techniques since 1967.⁽²⁾ Others independently involved in the study are the University of Kentucky (since 1972), Air Products and Chemicals, Inc., and Conoco. Battelle's work began in 1974 as a result of funding under the Battelle Energy Program* initiated early in 1973. This paper describes the results of the Battelle investigations on the development of sorbents for removal of H_2S at high temperature from coal gases.

EXPERIMENTAL FACILITY

The Battelle experimental facility is presented in Figure 1. It consists of a gas-mixing section, a preheater, and a fixed-bed tubular glass reactor. Both the reactor and preheater operate in the range 100 to 1800 F, and precise control of temperature of the gas and sorbent bed is possible. The preheater and reactor used are made of clear quartz tube, 50-mm ID. Quartz was chosen after stainless steel reactors (Types 304 and 446) were found to react severely with H_2S . No particular hazard was observed with the operation of the unit when the gases were properly scrubbed and vented.

EXPERIMENTAL PROCEDURES

Certified standard gas mixtures** were used to obtain simulated coal gas of the following composition in volume percent: H_2 , 17; CO, 26.0; CO_2 , 5.0; N_2 , 50.5; and H_2S , 1.5. The large amount of nitrogen suggests simulation of a low-Btu gas obtained by air-blown process. The gas does not resemble any actual producer gas exactly; the H_2S content is rather high and also free of the usual moisture, tar, and dust present in actual coal gases. The rationale for choice of this composition was that Battelle studies were designed to generate data for comparison with the results of ERDA studies.⁽²⁾ A gas chromatographic analysis confirmed that actual gas composition was close to the desired values. Matheson flow controllers were helpful

* Research described here was supported by The Battelle Energy Program (BEP). The Program has been established to carry out major R&D efforts aimed at developing practical solutions to some of the extremely serious energy shortage and utilization problems expected to exist in the United States during 1975-1995. Battelle Memorial Institute has allocated millions of its own funds to support this effort because of the importance of the energy problem to the nation. The primary emphasis of BEP is on the development of coal as a clean fuel source since coal holds the greatest promise for filling the gap between the U.S. energy requirements and the ability to meet these requirements in the time period of interest. Additional energy sources being investigated under the program include solar energy.

** Matheson Gas Products, Joliet, Illinois, was the vendor.

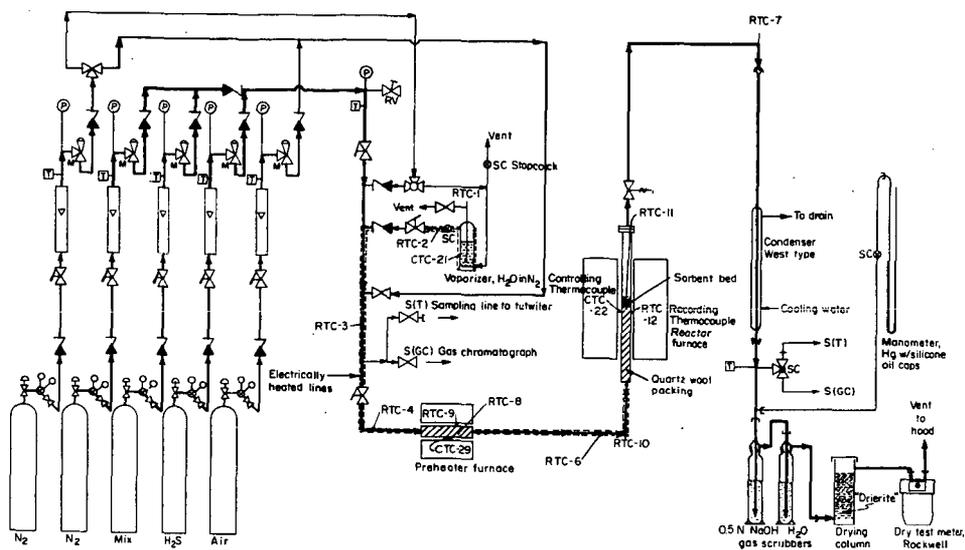


FIGURE 1. FLOW DIAGRAM OF THE HIGH-TEMPERATURE H_2S -REMOVAL ASSEMBLY

in maintaining flow accuracy and precision to within ± 3 percent on the total flow. H_2S was fed as a 25 percent gas mixture in nitrogen and the H_2S in test gas was 950 grains/100 scf with a precision of ± 10 grains.

H_2S in the inlet and outlet streams was measured by the Tutwiler method.⁽³⁾ The method consists of grab sampling 100 cc of the gas in a glass bulb connected to a burette containing standard iodine solution. The gas, collected over starch solution, is titrated with the iodine to a blue end point. Each milliliter of the iodine solution (prepared by diluting 13.5 ml of 0.1 N solution to 100 ml with distilled water) is equivalent to 100 grains of H_2S /100 scf of gas. The method can detect H_2S as low as 2 grains/100 scf of gas, or $3\frac{1}{2}$ ppm of H_2S .

The quartz preheater and reactor were packed with quartz wool to provide a heat-transfer surface. The test sorbent, 100-gram charge, was supported on a honeycomb structure made of quartz tube to provide even gas distribution. The sorbent bed was located ± 2 inches about the center of the reactor's length. The thermocouple tip was about 0.5 cm above the bed. The temperature profile through the bed indicated that the bed was nearly uniform in temperature, and the gas entered and exited the bed at nearly the reaction temperature. A 12-point recorder provided temperature read-out.

To insure a proper basis for comparison of results on sorbent performance, the experiments were performed at uniform operating conditions (1500 F reaction temperature, cold gas flow of 1 liter/min. at 70 F and 14.7 psia and 950 grains H_2S /100 scf). The cold-space velocity was 600 gas volumes per volume of bed per hour, equivalent to an operating GSV of 2000 V/V/hr varying slightly with bed volume. The acceptance run was terminated when the outlet-gas H_2S concentration approached 100 grains at an inlet-gas H_2S content of 950 grains. The regeneration run was ended when the sulfur dioxide in the regenerator gas dropped from 6 volume percent to 0.05 percent. Sulfur dioxide was also measured by the Tutwiler method. After one cycle of acceptance and regeneration, the sorbent was subjected to sieve analysis to determine attrition.

SORBENT PREPARATION

Sorbents were prepared utilizing CP or reagent-grade chemicals. These, as dry powder (-200 U.S. sieve), were weighed and mixed together with 1 gram each of starch, bentonite, and sodium silicate per 100 grams of the mixture. The resulting mix was made into a paste with distilled water. The paste was either pelletized or extruded. The pellets, after oven-drying at 250 F, were sintered at 1800 F (or 1600 F) for 2 hours. The sintered pellets were screened to -6 + 10 U.S. sieve mesh. The extrudates (1/8 inch in diameter and about 1/4 inch long) were also dried and sintered similarly and screened to remove all minus 10-mesh particles. The sorbent was free flowing and reasonably strong. The average density was about 0.9 cc/g.

EXPERIMENTAL RESULTS AND DISCUSSION

As a first step, five blank runs were performed with test gas. The reactor was not charged with sorbent. Results with Type 304 stainless steel and other reactor materials (Table 1) show that stainless steels are unsuitable as experimental reactors but that quartz resists H_2S attack satisfactorily. The steel reactor walls flaked off and thermocouple wells were damaged by corrosion.

TABLE 1. TEST RESULTS WITH BLANK REACTOR

Parameter	Stainless Steel		Quartz
	Type 304	Type 446	
Diameter (ID), inches	1.26	2.0	2.1
Length of Hot Zone, inches	16.0	16.0	16.0
Gas Flow Rate			
At 70F, 1 Atm, cm ³ /min	750	750	1000
H ₂ S absorbed, percent			
At 1000 F	15 ^(a)	8	0
At 1500 F	90	90	5
Test Duration, hours			
At 1000 F	15	8	3
At 1500 F	27	10	4

- (a) During the first 11 hours, the removal was 99.5 percent; a gradual drop to 15 percent occurred in the next 4 hours. At 1500 F, no significant reduction in removal was observed.

H₂S Acceptance Experiments

With the quartz reactor (using quartz thermocouple wells), 21 experiments were conducted to study the H₂S acceptance-regeneration characteristics of the 11 sorbents listed in Table 2. The USBM sorbent was provided by the Morgantown Energy Research Center (MERC).^{*} The fly ash used in the sorbent contained approximately 52 percent SiO₂, 25 percent Al₂O₃, 15 percent Fe₂O₃, with the remainder being CaO, MgO, K₂O, etc.⁽⁴⁾ This sorbent was studied in four experiments to establish baseline performance data at 1500 F, since the reported desulfacity^{**} results obtained with stainless steel reactors⁽²⁾ were suspected to be too high.

A comparison of data reported by USBM (now ERDA) with those obtained in BCL studies (Table 3) for three sorbents, including fly ash--iron oxide sorbent, indicates that the influence of H₂S uptake by the reactor at 1500 F is a significant factor in the reported desulfacity results. Contrary to a reported increase in desulfacity at higher temperature, the BCL data establish that a significantly higher H₂S removal occurs at 1000 F than at 1500 F. Thermodynamic considerations support these data in that the predicted equilibrium conversion is high (approaching 100 percent) at temperatures of 1000 F and higher. This is modified by the fact that the reaction is exothermic, hence lower temperatures permit actual realization of the predicted high conversion.⁽⁵⁾

The data in Table 3 also indicate a significantly low exit H₂S concentration for all sorbents containing component X (used in BCL sorbents) at all temperatures. Also, BCL experiments show that pure iron oxide at 1000 F permits a very low exit-H₂S concentration. In certain applications of coal gas, the low H₂S level may be an advantage. A graphical comparison of the low exit H₂S concentration of various sorbents is presented in Figure 2.

Regeneration Results

A comparative plot of the regeneration curves of various sorbents is presented in Figure 3. All of these experiments were performed at uniform conditions of 1 liter/minute of air inflow at 70 F, 1 atm, and 1000 F sorbent bed temperature. The data do not provide conclusive evidence on comparative regeneration characteristics of the sorbents. This indicates that the need for further experimentation is more pronounced in the area of regeneration than in the area of H₂S acceptance. The major ambiguity is in reference to Curves 5 and 6 for the regeneration of sorbent BCL 29 E. These two curves, which should have been closely similar because of replication of the same experiment, are obviously very different. However, while the sorbent in Curve 5 was regenerated immediately after the end of the acceptance run (with no overnight cooling of the sulfided sorbent), the sorbent in Curve 6 was cooled overnight between the acceptance and regeneration runs. Neither of these occurrences was deliberate.

Although the reasons for the superior regeneration characteristics of Curve 5 are not clear, this curve represents a desirable regeneration trend. The 3 percent SO₂ in exit gas for over 5 hours followed by a sudden concentration drop should help in further processing of the SO₂-bearing gas to either sulfuric acid or sulfur. The sulfur balance, based on 23.7 grams of H₂S absorbed by the sulfided

* Courtesy of Ernest Oldaker, MERC, ERDA, Morgantown, West Virginia.

** Desulfacity is defined as grams of H₂S removed from the gas by 100 grams of sorbent charge, or weight percent H₂S-removal capacity either at breakthrough or when exit gas H₂S concentration reaches 100 grains/100 scf.

TABLE 2. LIST OF SORBENTS STUDIED

Sor bent Designation	Size	
	Pellet -6+10 U.S. Sieve	Extrudate, 1/8" Diam., 1/4" Long
USBM #0074*		3/16" diam. x 1/2" long
BCL #8WB**	X	
BCL #20	X	
BCL #20E		X
BCL #21	X	
BCL #23	X	
BCL #25E		X
BCL #26E		X
BCL #27E		X
BCL #28E		X
BCL #29E		X

* U.S. Bureau of Mines Sorbent Batch No. 0074 contains 75 percent fly ash and balance iron oxide.

** BCL (Battelle Columbus Laboratories) Sorbents. The composition of these Sorbents are withheld for proprietary reasons.

TABLE 3. COMPARISON OF DATA ON DESULFURIZATION* (Weight Percent) AND CONCENTRATION OF H₂S IN REACTOR EXIT GAS

Sorbent	USBM Reported Data in Stainless Steel Reactor (2), weight percent	BCL Data From Quartz Reactor, weight percent	H ₂ S in Exit Gas, (BCL Data) grains/100 scf
USBM #0074			
At 1000 F	8.7	No data	No data
At 1500 F	41.1	19.0	22.5
BCL SWB			
At 1000 F	22	26.3	4.4
At 1500 F	Bed plugged	19.2	21.6
BCL 29E Extrudates**			
At 1000 F	Not studied	22.2	10.2
At 1500 F	Not studied	17.2	12.0
BCL 20			
Pellets, 1500F**	Not studied	21.9	8.3
Extrudates, 1500F	Not studied	21.0	10.0
BCL 21			
(Pure Component X), 1500 F	Not studied	21.0	8.0

Note: All the BCL experiments were conducted under nearly identical conditions: 1000 scf cm/min of gas flow at 70 F, atmosphere pressure, inlet H₂S of 950 grain/scf, 100 grams of sorbent charge, and excellent temperature control.

* Grams H₂S removed by 100-g sorbent charge; see full definition on Page 6.

** Both these sorbents contain Component X.

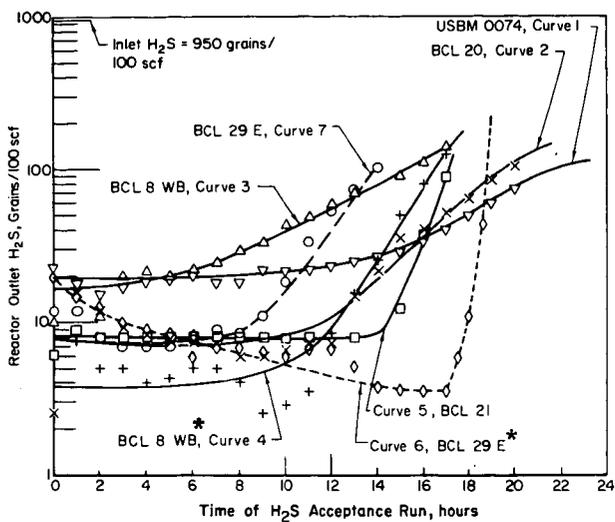
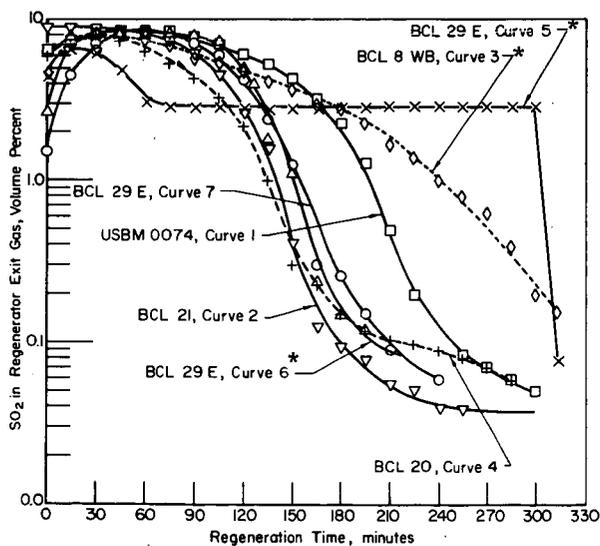
FIGURE 2. H_2S - ACCEPTANCE CURVES

FIGURE 3. SORBENT REGENERATION CURVES

* For these runs, H_2S acceptance temperature was 1000 F, while for the remaining, it was 1500 F. All regeneration runs were done at 1000 F. Gas and air flow rates and all other conditions were the same for all runs shown here. Also, Regeneration Curves 5 and 6 are discussed on Page 6.

sorbent, indicates that 80 percent of the sulfur absorbed is accountable in the regenerator exit gas as SO_2 . Also about 0.25 gram of sulfur was formed during regeneration, thus accounting for another 1 percent of the sulfur.

Sulfur balance calculations for Curve 1 (USBM 0074) show that 85 percent of the sulfur absorbed was accountable as SO_2 in the regenerator exit gas. The formation of sulfur in the case of the sorbent represented by Curve 5 needs further evaluation to determine whether direct sulfur formation is possible during regeneration.

Studies on Sorbent Attrition

In an actual commercial processing scheme, sorbent attrition is an important property contributing to the rate of sorbent makeup required. If attrition occurs during H_2S removal, the coal gas will carry additional particulate load which may interfere with the utilization of the gas. Ideally, an attrition loss of zero is desirable. However, catalyst attrition-loss rates of 0.3 wt %/hr (0.09 lb/bbl feed) in fluidized-bed cracking are known to be tolerable. In high-temperature coal gas desulfurization, an attrition loss of, say, 1.0 lb/million scf of gas treated* may be perhaps tolerable. It appears preferable that such loss occur during regeneration.

In the experiments reported here, the sorbents (fresh and after one cycle of acceptance-regeneration) were subjected to sieve analysis. The results are summarized in Table 4. Pure Fe_2O_3 and pure Component X disintegrate as well as agglomerate, as the data show. However, when the two are mixed, there is neither disintegration nor agglomeration. The USBM sorbent showed considerable particle disintegration and flake formation on the extrudates. In the case of sorbent BCL 29 E, the fines formed in Experiment 36 were very high, while in Experiment 37, a replicate, no fines were formed at all. This could probably be due to the overnight cooling of the absorbed sorbent before regeneration in Experiment 37, whereas in Experiment 36, there was no time lag between the acceptance and regeneration runs. Once again these data indicate the need for further studies of the regeneration mode. The strength of sorbent BCL 20 appears better in comparison with that of most other sorbents.

H_2S -Acceptance Thermodynamics

The performance of the mixture of Fe_2O_3 -Component X is enhanced over the performance of individual components, particularly in regard to physical strength. While this is an accidental discovery, the actual reasons are speculative and Component X may be a stabilizing agent. The partial pressure of H_2S in the exit gas stream is lower for the mixture than for both pure Fe_2O_3 and fly ash- Fe_2O_3 sorbent formulations.

The reaction mechanism of H_2S with Component X is not understood. Also free-energy data for component X are not available to compute equilibrium conversions. Experimental data at 1500 F show that the equilibrium conversion of H_2S with Component X is higher than with Fe_2O_3 ; however, the effect of steam on H_2S conversion with Component X cannot be predicted, and actual experiments are needed to obtain the data.

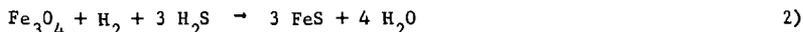
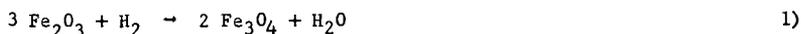
For Fe_2O_3 , considerable thermodynamic data are available. According to ICI, fresh iron oxide (Fe_2O_3) is converted to Fe_3O_4 in the presence of hydrogen above 350 F. (6) Thus, in the range of 650 to 1500 F, Fe_3O_4 is the sorbent.

* At 10 wt % desulfuricity, for an inlet gas containing 280 grains/100 scf H_2S (0.45 vol %) this is equivalent to an attrition loss of 0.025 wt % per cycle.

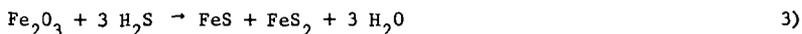
TABLE 4. SIZE ANALYSIS OF SELECTED SORBENTS TESTED

Average Particle Size	Grams of Sorbent in Size Mentioned													
	18, 23		20, 24		27, 28		29, 30		31		36		37	
	USBM	BCL	USBM	BCL	USBM	BCL	USBM	BCL	USBM	BCL	USBM	BCL	USBM	BCL
	0074	0074E	20	20E	21	21	26E	26E	29E(1)	29E(1)	36	36	37	37
<u>Fresh Sorbent</u>														
Pellet, 2680 μ	100	100	100	--	100	--	100	--	100	--	--	--	--	--
Extrudate, 1/8" x 1/4" long	--	--	--	100 ⁽⁵⁾	--	--	100	--	100	--	100	100	100	100
<u>Sorbent After Test Run</u>														
Total weight, all fractions	98.0	98.0	100.6	108.7	107.2	108.9	101.9	107.4	107.9	109.0	107.4	107.4	107.9	109.0
>2680 μ (agglomeration)	48.5	6.7	0	2.5	0	26.1	0	0	0	0	0	0	0	0
2680 μ	38.1	78.3	98.6	102.8	106.9	44.5	100.4	31.0	107.9	107.9	31.0	31.0	107.9	107.9
1420 μ	6.8	3.0	0.3	2.8	0.3	6.8	0.2	18.8	0.9	0.9	18.8	18.8	0.9	0.9
570 μ	2.3	8.8	0.7	0.5	0	11.7	0.2	25.2	0.1	0.1	25.2	25.2	0.1	0.1
200 μ	1.8	0.8	0.7	0.1	0	19.4	1.0	22.6	0.1	0.1	22.6	22.6	0.1	0.1
75 μ	0.5	0.3	0.3	0	0	0.4	0.1	7.7	0	0	7.7	7.7	0	0
40 μ	0	1.0	0.0	0	0	0	0	2.1	0	0	2.1	2.1	0	0
Fines formed (≤ 570)	4.6	10.9	1.7	0.6	0	31.5	1.3	57.6	0.2	0.2	57.6	57.6	0.2	0.2
Fused particles (>2680)	48.5	6.7	0	2.5	0	26.1	0	0	0	0	0	0	0	0
Finger crushing strength ⁽³⁾	P	S	E	G	G	P	G	G	G	G	P	G	G	G
Free flowing tendency	S	S	G	G	E	P	E	E	E	E	P	E	E	E
Flaking tendency ⁽⁴⁾	None	None	High	None	None	None	None	None	None	None	None	None	None	None

(1) Run 36 and 37 are same except for the difference in regeneration quality described before.
 (2) A test run includes one cycle of one acceptance run and one regeneration run.
 (3) P = poor, S = satisfactory, G = good, E = excellent.
 (4) Flaking is observable only on extrudates. The extrudates were covered with thin flakes.
 (5) 3/16-inch diameter and 1/4-inch long extrudates.



According to this reaction, each mole of Fe_2O_3 reacts with 2 moles of H_2S ; the theoretical desulfacity is 40 percent by weight. However, USBM reports that the following reaction takes place:



on this basis the desulfacity of Fe_2O_3 would be 60 percent by weight. The amount of water evolved by either reaction is the same. Actual experimental data on the fly ash + Fe_2O_3 sorbent (64 grams H_2S removed per 100 grams Fe_2O_3) support the USBM reaction mechanism (2) which can be utilized for computing the equilibrium conversions.

For Reaction 3), the standard free-energy change (ΔF° at 25 C and 1 atmosphere) is -26,270 cal/g-mole. Thus, the equilibrium constant

$$K = \exp\left(\frac{-\Delta F^\circ}{RT}\right) = 1.85 \times 10^{19} \text{ at } 25 \text{ C.}$$

K at 1000 F (537 C) can be computed using the equation

$$\frac{d \ln K}{dT} = \frac{\Delta H^\circ}{RT^2},$$

where ΔH , the heat of reaction can be shown to be substantially constant over the temperature range under study. Thus,

$$K_{1000 \text{ F}} = 8.6 \times 10^9.$$

The high K value indicates that conversions are very high and approach 100 percent. These reactions are heterogeneous and the change in number of moles of gas is zero. Therefore, there should be no effect of pressure on conversion.

The above calculations for Fe_2O_3 also hold for other dry oxides. Thus, BaO , CaO , CoO , Cu_2O , Na_2O , NiO , and ZnO all show high equilibrium conversions. Two oxides (MgO and ZrO_2) show positive standard free-energy changes, indicating thermodynamic infeasibility. Regeneration (reaction with oxygen) of the sulfides of all these sorbents is thermodynamically feasible.

Effect of Steam on Conversion

Coal gases usually contain steam, at least 10 percent by volume. Since steam is a product of the reaction of oxides with H_2S , the presence of steam in feed gas can reduce H_2S conversion. For the iron oxide sorbent, calculations show that at 1000 F ($K = 8.6 \times 10^9$), for a gas containing 5000 ppm H_2S and 10 percent steam, the equilibrium H_2S content in exit gas is 4.6 ppm based on the USBM reaction mechanism. If the ICI reaction is used, the equilibrium H_2S in exit gas is >300 ppm. These calculations cannot be made for Component X since thermodynamic data are not available. Further, the behavior of a mixture of materials reactive with H_2S as a sorbent in presence of steam is more complex than thermodynamics can predict.

A CONCEPTUAL PROCESSING SCHEME

It is important not only to have a good sorbent but also a processing scheme in which it can be used. Many processing schemes can be visualized to desulfurize hot coal gases. One such scheme is presented in Figure 4. The sorbent (pellets or extrudates) moves at a slow rate in a moving bed and discharges into a fluidized-bed regenerator. Air acts as the fluidizing medium and supplies the oxygen for the sulfide oxidation. The scheme has the advantages of a continuous process but reduces attrition problems during H₂S removal. Thus, no dust particles are introduced into the hot gas stream. This scheme is intended mainly for atmospheric pressure gases like K-T gas. The design of the H₂S-acceptance zone can be critical to the successful performance of the process.

CONCLUSIONS

A good desulfurizing sorbent should regenerate well, have a long life (activity) and high desulfacity. The SO₂ concentration in regenerator exit gas should be high with a sharp breakthrough. Also, the equilibrium H₂S concentration in exit gas during acceptance should be low, even in the presence of steam in feed gas. The attrition resistance should be high.

The fly ash--Fe₂O₃ sorbent did not show as good a resistance to attrition as BCL 20 sorbent. The BCL 20 sorbent showed lower exit equilibrium H₂S concentration and performed better at 1000 F than at 1500 F. The superior performance at lower temperature is in accordance with the thermodynamic rule that for exothermic reactions, the attained equilibrium conversion is higher at lower temperature. The addition of Component X improved the sorbent composition.

In conclusion, in this study, an effort has been made to define properties of a good sorbent, develop such a sorbent and conceptualize a processing scheme for its use. The commercial feasibility of the process can be demonstrated by using the sorbent in such a scheme over a number of acceptance-regeneration cycles. The following recommendations are made toward achieving that end.

RECOMMENDATIONS

The use of high-temperature H₂S removal technology should be investigated for the following cases.

- Low-Btu gasification and gas utilization in electric power plants
- Packaged coal-gasification plants (medium- and low-Btu gases)
- Synthetic natural-gas production.

High-temperature H₂S removal is a novel technology with good potential to compete with other desulfurizing processes. An overall process engineering and economic study of the novel technology vis-a-vis other processes (like Rectisol) is needed. Also needed is an experimental program to develop solid sorbents that can remove H₂S to less than 1-ppm levels. Both the Process engineering/economics study and the experimental program to screen sorbents should proceed concurrently. Intense efforts are needed to explore the full potential of this emerging technology and measure its impact on the national energy needs.

ACKNOWLEDGEMENTS

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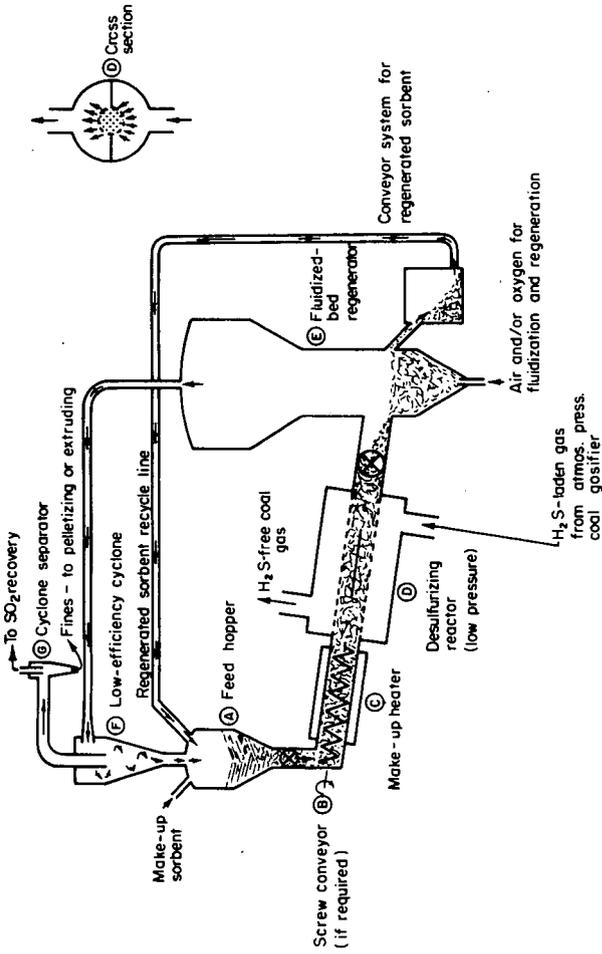


FIGURE 4. CONCEPTUAL PROCESS SCHEME FOR HIGH-TEMPERATURE, SOLID-GAS REACTION IN A MOVING BED WITH REGENERATION IN A FLUIDIZED BED

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