

# ENERGY

## Kinetics of Direct Oxidation of H<sub>2</sub>S in Coal Gas to Elemental Sulfur

Annual Technical Progress Report for the Period  
October 1, 2000 to September 30, 2001

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February 2002

Work Performed Under Contract No  
DE-FG26-00NT40835

For  
U.S. Department of Energy  
National Energy Technology Laboratory  
Pittsburgh, PA 15236-0940

By  
Tuskegee University  
Tuskegee, Alabama 36088

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## SUMMARY

Removal of hydrogen sulfide ( $\text{H}_2\text{S}$ ) from coal gasifier gas and sulfur recovery are key steps in the development of Department of Energy's (DOE's) advanced Vision 21 plants that employ coal and natural gas and produce electric power and clean transportation fuels. These Vision 21 plants will require highly clean coal gas with  $\text{H}_2\text{S}$  below 1 ppm and negligible amounts of trace contaminants such as hydrogen chloride, ammonia, alkali, heavy metals, and particulate. The conventional method of sulfur removal and recovery employing amine, Claus, and tail-gas treatment is very expensive. A second generation approach developed under DOE's sponsorship employs hot-gas desulfurization (HGD) using regenerable metal oxide sorbents followed by Direct Sulfur Recovery Process (DSRP). However, this process sequence does not remove trace contaminants and is targeted primarily towards the development of advanced integrated gasification combined cycle (IGCC) plants that produce electricity (not both electricity and transportation fuels).

There is an immediate as well as long-term need for the development of cleanup processes that produce highly clean coal gas for next generation Vision 21 plants. To this end, a novel process is now under development at Research Triangle Institute (RTI) in which the  $\text{H}_2\text{S}$  in coal gas is directly oxidized to elemental sulfur over a selective catalyst. Such a process is ideally suited for coal gas from commercial gasifiers with a quench system to remove essentially all the trace contaminants except  $\text{H}_2\text{S}$ . This direct oxidation process has the potential to produce a super clean coal gas more economically than both conventional amine-based processes and HGD/DSRP. The objective of this research is to support the near- and long-term DOE efforts to commercialize this direct oxidation technology. Specifically, we aim to:

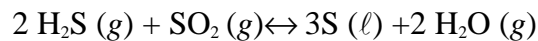
- Measure the kinetics of direct oxidation of  $\text{H}_2\text{S}$  to elemental sulfur over selective catalysts in the presence of major coal gas components.
- Develop kinetic rate equations and model the direct oxidation process to assist in the design of large-scale Vision 21 plants.

## INTRODUCTION

Coal is our most abundant energy resource. It is strategically important to our nation to increase coal use as an energy source in an environmentally acceptable manner. Coal gasification, a primary step in advanced coal utilization processes, produces a coal gas containing hydrogen ( $\text{H}_2$ ) and carbon monoxide ( $\text{CO}$ ) as the fuel components. Raw coal gas however, also contains a number of major and trace contaminants including hydrogen sulfide ( $\text{H}_2\text{S}$ ), carbonyl sulfide ( $\text{COS}$ ), ammonia ( $\text{NH}_3$ ), hydrogen chloride ( $\text{HCl}$ ), alkali, heavy metals, and particulate. Thus, this gas must be cleaned before further use.  $\text{H}_2\text{S}$  is a major coal gas contaminant that can range from 1000 to 10,000 ppm, depending on the sulfur content of the coal. Removal of  $\text{H}_2\text{S}$  from coal gas and sulfur recovery are key steps in the development of Department of Energy's (DOE's) advanced Vision 21 plants combining a power plant and a refinery based on coal and natural gas to co-produce electricity and clean transportation-grade liquid fuels. These Vision 21 plants will require highly clean coal gas with  $\text{H}_2\text{S}$  below 1 ppm

and negligible amounts of other contaminants such as COS, HCl, NH<sub>3</sub>, alkali, heavy metals, and particulate.

The conventional method of removing H<sub>2</sub>S and sulfur recovery involves a number of steps including amine scrubbing at low temperature followed by amine regeneration using steam to produce a concentrated H<sub>2</sub>S-containing gas. This concentrated H<sub>2</sub>S-containing gas is then combusted to produce a gas with a H<sub>2</sub>S to sulfur dioxide (SO<sub>2</sub>) ratio of 2 to 1 in a Claus furnace. This is followed by up to three (3) stages of Claus reaction at temperatures of around 250-280°C over an alumina catalyst to recover elemental sulfur:



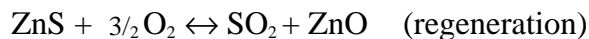
The Claus reaction is exothermic and equilibrium limited. To circumvent equilibrium limitations, the reaction is conducted in up to three (3) reaction stages with interstage cooling/sulfur condensation followed by interstage re-heating. However, even with three (3) stages, the reaction is not complete due to thermodynamic limitations at 250°C. The Claus tail gas contains sulfur that must be further treated in an expensive tail gas treatment plant (e.g., SCOT) before discharge. Thus, overall H<sub>2</sub>S removal and sulfur recovery using this conventional sequence is extremely cumbersome, equipment intensive, and expensive.

A second generation approach for sulfur removal/recovery developed under DOE's sponsorship involves three steps:

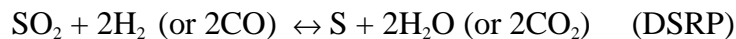
- (i) hot-gas desulfurization (HGD) using regenerable zinc oxide-based sorbents



- (ii) sorbent regeneration using air to produce SO<sub>2</sub>



- (iii) catalytic reduction of SO<sub>2</sub> using a small portion of the coal gas, to elemental sulfur by the Direct Sulfur Recovery Process (DSRP):

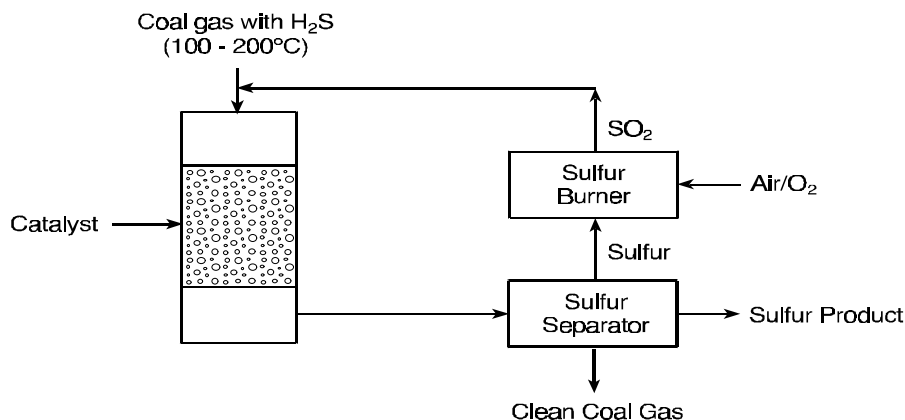


This approach integrates well with a coal gasifier in an integrated gasification (IGCC) system because the raw coal gas does not have to be cooled all the way down to near room temperature as is the case with the conventional amine/Claus/tail-gas treatment method. However, the overall process scheme requires solid sorbent handling/circulation, and three separate reactors. Also, there is a small energy penalty associated with the use of coal gas to reduce SO<sub>2</sub> by DSRP. Furthermore, since trace contaminants e.g. NH<sub>3</sub> and HCl are not removed by the zinc-based sorbents. This approach is primarily targeted towards the development of advanced IGCC plants that produce electricity only (but do not coproduce both electricity and clean transportation grade fuels).



There is an immediate as well as long-term need for the development of clean processes that produce highly clean coal gas for next generation Vision 21 plants producing both electricity and transportation-grade liquid fuels. To this end, our subcontractor, Research Triangle Institute (RTI) is developing a novel process in which the  $H_2S$  in coal gas is directly oxidized to elemental sulfur over a selective catalyst using sulfur dioxide ( $SO_2$ ) produced by burning a portion of the sulfur produced as shown in Figure 1.

Figure 1: RTI proposed direct oxidation process



The direct oxidation process shown in Figure 1 is ideally suited for coal gas from a commercial gasifier with a quench system. During quench, the trace contaminants (except sulfur) are essentially completely removed and  $H_2S$  (with some  $COS$ ) remains as the only contaminant. The gas contains all of the major coal gas components including  $H_2$ ,  $CO$ ,  $CO_2$  and  $H_2O$ . Its typical pressure and temperature conditions are 12 to 120 psia and 125 to 155°C. In our proposed direct oxidation process, the Claus reaction is carried out over a selective catalyst in the presence of the major gas components at around 150 to 160°C to yield liquid sulfur. The low-temperature phase change allows the  $H_2S$ - $SO_2$  reaction to proceed selectively over a catalyst and removes equilibrium limitation. Due to low reactant concentrations, the reaction proceeds nearly isothermally and has the potential to proceed to completion in a single reactor. Burning a required portion of the liquid sulfur in a sulfur burner produces the  $SO_2$  for the process. The process has the potential to produce a super clean coal gas much more economically than both conventional amine-based processes as well as HGD/DSRP.

To guide the catalyst development and optimization, there is a need to study the fundamental kinetics of the direct oxidation process in the presence of coal gas components at practical conditions of the coal gas. We propose to measure the kinetics of the reaction as a function of reactant and major coal gas component partial pressure over selected catalysts in a high-pressure differential micro reactor.

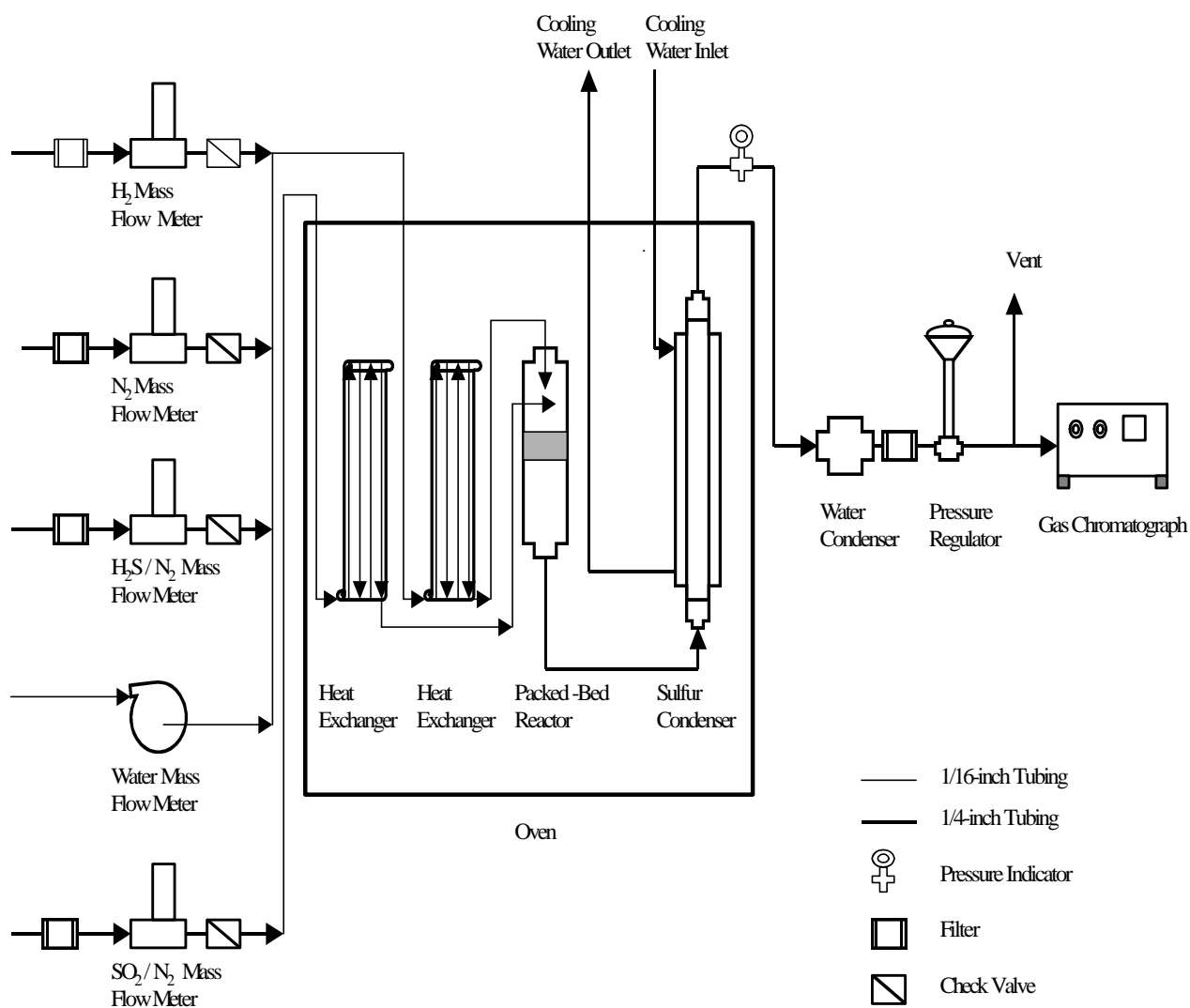
The objective of this research is to support the near and long term DOE efforts to develop and commercialize Vision 21 plants. Specifically, we aim to:

- Measure the kinetics of direct oxidation of  $H_2S$  using  $SO_2$  to elemental sulfur over selective catalysts in the presence of major coal gas components.
- Develop kinetic rate equations and model the direct oxidation process.

## EXPERIMENTAL SETUPS

A differential micro reactor was fabricated with a ¼-inch Teflon tee. The volume of a C-500-04 alumina catalyst packed in the reactor is 0.008 - 0.1 cm<sup>3</sup>. The C-500-04 alumina catalyst in the form of 160-µm spherical particles was examined. A simulated coal gas mixture containing H<sub>2</sub>S and sulfur dioxide was reacted with the aid of the catalyst in the differential micro reactor at 140°C. Conversion of hydrogen sulfide into elemental sulfur was analyzed with the gas chromatograph. The range of space (residence) time of the reaction gas mixture in the reactor was 0.01 – 0.5 s under the reaction conditions. Space times are obtained by dividing the volume of a catalyst bed with a volumetric flow rate at reaction conditions

Figure 2. Schematic Diagram of the packed-bed reactor assembly.



A differential reactor assembly mainly consists of four mass flow meters for gases, one differential reactor, two preheaters, one high pressure liquid pump for water, one four-way switch valve, one oven, five filters for gases, four check valves, and one water collection bottle (see Figure 1). The differential reactor is fabricated with one ¼-inch Teflon tee. The preheaters are made of 1/16-inch Teflon tubing. The reactor was loaded with C-500-04 alumina catalyst. The reactor, loaded with the catalyst particles, was placed inside the oven to be heated at a desired temperature. Nitrogen was introduced into the catalyst-loaded reactor during preheating the reactor. When the temperature of the reactor was raised at the desired temperature, one simulated coal gas mixture stream containing H<sub>2</sub>S and another feed stream containing SO<sub>2</sub> were introduced into the reactor, by switching nitrogen with the simulated coal gas mixture. The typical reaction conditions are shown in Table 1. The properties of the catalyst are shown in Table 2.

Table 1. Experimental conditions for the reaction of hydrogen sulfide with sulfur dioxide.

Volume of the catalyst-packed bed, cm <sup>3</sup> :	0.0083 - 0.1
Temperature, °C:	140
Reaction Pressure, psia	61 - 112
Space Time under the reaction conditions, s:	0.01 – 0.5
Mean Particle Size, μm	160
Amount of Catalyst, g	0.1 - 0.12
Gas Flow Rate, cc/min at room temperature and 1 atm (SCCM)	50 - 200
Hydrogen, vol %	70
Moisture, vol %:	5 – 15
Concentration of H <sub>2</sub> S, ppm	7,500
Concentration of SO <sub>2</sub> , ppm	2,500
Nitrogen, vol %	Remainder

Table 2. Properties of the C-500-04 alumina catalyst from the Research Triangle Institute (RTI).

BET Area, m <sup>2</sup> /g	227
Bulk Density, g/cm <sup>3</sup>	0.8346
Pore Volume, cm <sup>3</sup> /g	0.6211
Mean Particle Size, μm	160
Composition	Alumina

Table 3. Conversion of hydrogen sulfide with sulfur dioxide in the presence of 70 v-% hydrogen and 0.03 - 0.12-g catalyst at 140°C and 60 - 113 psia

Run #	Temperature, °C	Pressure, psia	Total Feed cc/min	Feed Composition, v%				Space Time s	Catalyst, g	Conversion of H <sub>2</sub> S, %
				H <sub>2</sub>	H <sub>2</sub> S	SO <sub>2</sub>	water			
1	140	61	188	70	0.7947	0.2670	0.0000	0.0000	0	0
2	140	61	198	70	0.7545	0.2535	5.0505	0.0000	0	13.36
3	140	62	200	70	0.7470	0.2510	5.0000	0.1307	0.12	30.79
4	140	62	209	70	0.7148	0.2402	9.5694	0.1250	0.12	21.03
5	140	62	222	70	0.6730	0.2261	13.514	0.1177	0.12	15.34
6	140	63	212	70	0.7047	0.2368	9.4340	0.0000	0	0.08
7	140	64	222	70	0.6730	0.2261	13.514	0.0000	0	0.11
8	140	62	85	70	0.8788	0.2953	5.8824	0.3069	0.1198	54.84
9	140	62	91	70	0.8209	0.2758	5.4945	0.2862	0.1196	40.31
10	140	63	95.5	70	0.7822	0.2628	10.471	0.2778	0.1199	48.90
11	140	62	102	70	0.7324	0.2461	14.706	0.2555	0.1197	51.78
12	140	62	82.5	70	0.6791	0.2282	9.0909	0.3167	0.12	34.79
13	140	61	101	70	0.7396	0.2485	4.9505	0.2537	0.1196	38.11
14	140	64	97.5	70	0.7662	0.2574	5.1282	0.2765	0.1199	40.77
15	140	63	102	70	0.7324	0.2461	4.9020	0.2593	0.1195	38.11
16	140	64	101	70	0.7396	0.2485	4.9505	0.2658	0.1194	39.23
17	140	64	106	70	0.7047	0.2368	9.4340	0.2541	0.1198	34.47
18	140	62	111	70	0.6730	0.2261	13.5135	0.2352	0.1199	35.03
19	140	60	55.7	70	0.6706	0.2253	4.4883	0.4532	1.1198	47.13
20	140	60	56	70	0.6670	0.2241	8.9	0.4511	0.1199	56.73
21	140	59	63.5	70	0.5882	0.1976	11.8	0.3905	0.1197	58.59
22	140	59	60.8	70	0.6143	0.2064	4.1	0.0845	0.0248	56.82
23	140	62	100.5	70	0.7433	0.2498	5.0	0.0648	0.0299	20.63
24	140	63	100.5	70	0.7433	0.2498	5.0	0.0440	0.02	22.02
25	140	63	100.5	70	0.7433	0.2498	5.0	0.0443	0.0201	15.80
26	140	64	98	70	0.7622	0.2561	5.1	0.0234	0.0102	18.32
27	140	61	105	70	0.7114	0.2390	9.5	0.0210	0.0103	16.28
28	140	61	109.5	70	0.6822	0.2292	13.7	0.0200	0.0102	18.28
29	140	63	99.7	70	0.7492	0.2518	5.0	0.0113	0.0051	13.89
30	140	62	98.5	70	0.7584	0.2548	5.1	0.0336	0.0152	14.89
31	140	84	97	70	0.7701	0.2588	5.2	0.0314	0.0103	25.29
32	140	111	96	70	0.7781	0.2615	5.2	0.0411	0.0101	44.67
33	140	111	102	70	0.7324	0.2461	9.8	0.0398	0.0104	34.39
34	140	113	106	70	0.7047	0.2368	14.2	0.0390	0.0104	35.46

## CALCULATIONS

Gaseous samples from the outlet stream from the differential reactor are injected into a gas chromatograph to analyze gas chromatography (GC) area % of H<sub>2</sub>S out of the combined GC area of H<sub>2</sub>S and SO<sub>2</sub>. Experimental data of gas chromatography (GC) area % of H<sub>2</sub>S are applied to a calibration curve (see Equation 1 and Figure 3) to obtain mole % of H<sub>2</sub>S out of the combined mole of H<sub>2</sub>S and SO<sub>2</sub>. Conversions of H<sub>2</sub>S are obtained with mole % of H<sub>2</sub>S in a feed stream to

the reactor and mole % of H<sub>2</sub>S in an outlet stream from the reactor, using Equation 2. Equation 2 was developed with the stoichiometric reaction formula and a material balance with respect to H<sub>2</sub>S.

$$y = 0.9227A + 6.4468 \quad (1)$$

where A: GC area % of H<sub>2</sub>S out of the combined GC area of H<sub>2</sub>S and SO<sub>2</sub>.

y: mole % of H<sub>2</sub>S out of the combined mole of H<sub>2</sub>S and SO<sub>2</sub>.

$$x = \frac{(FM - IM)}{IM (0.015 FM - 1)} \quad (2)$$

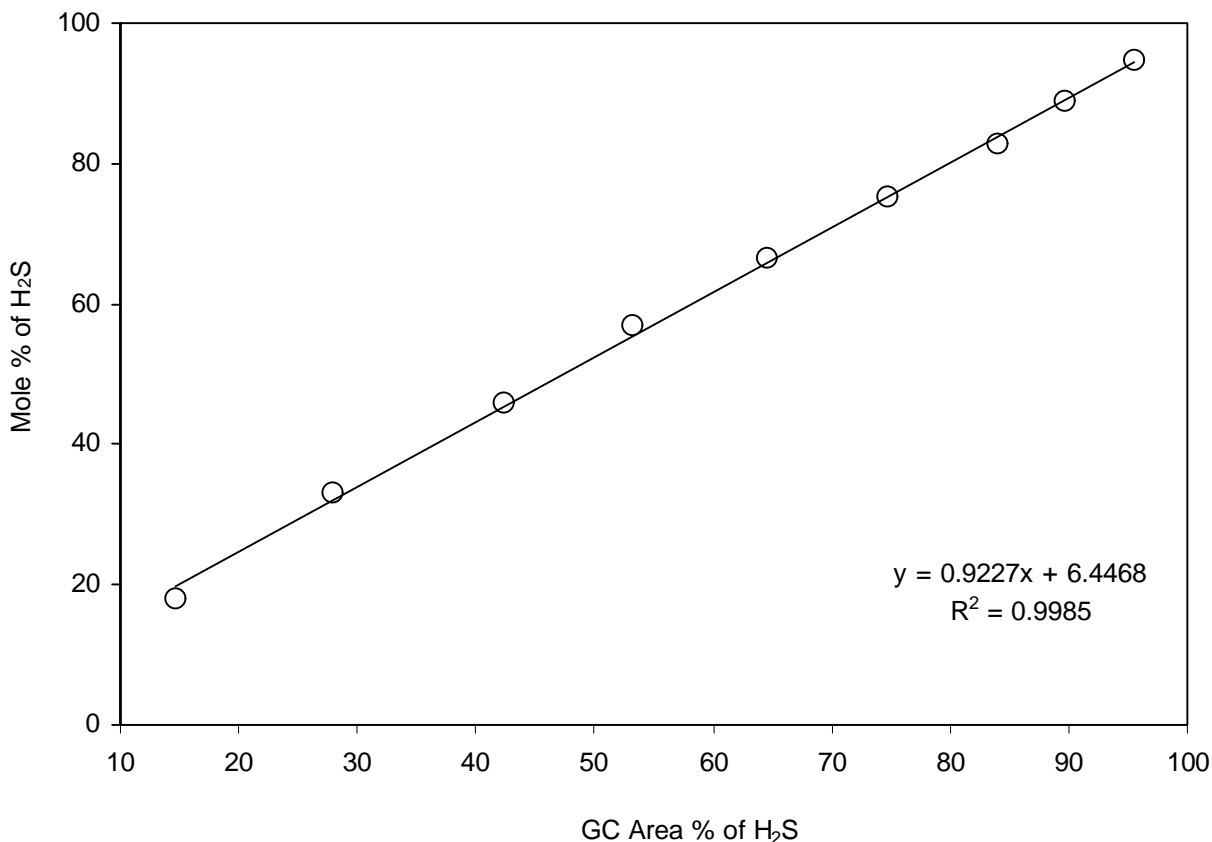
where x: conversion of H<sub>2</sub>S.

FM: mole % of H<sub>2</sub>S out of the combined mole of H<sub>2</sub>S and SO<sub>2</sub> in an outlet stream.

IM: mole % of H<sub>2</sub>S out of the combined mole of H<sub>2</sub>S and SO<sub>2</sub> in a feed stream.



Figure 3. Mole % of H<sub>2</sub>S in the combined mole of H<sub>2</sub>S and SO<sub>2</sub> against gas chromatography (GC) area % of H<sub>2</sub>S of the combined GC area of H<sub>2</sub>S and SO<sub>2</sub>.



Surface reaction rates of conversion of H<sub>2</sub>S into elemental sulfur in a differential reactor are obtained with amounts of the alumina catalyst loaded in the differential reactor, molar feed rates of H<sub>2</sub>S to the differential reactor and conversion of H<sub>2</sub>S, as shown in the following equation.

$$-r_A' = \frac{F_{A_0}x}{W} \quad (4)$$

where  $-r_A'$ : surface reaction rates

$F_{A_0}$ : molar flow rates of H<sub>2</sub>S in a feed stream to a reactor

x: conversion of H<sub>2</sub>S into elemental sulfur

## RESULTS AND DISCUSSION

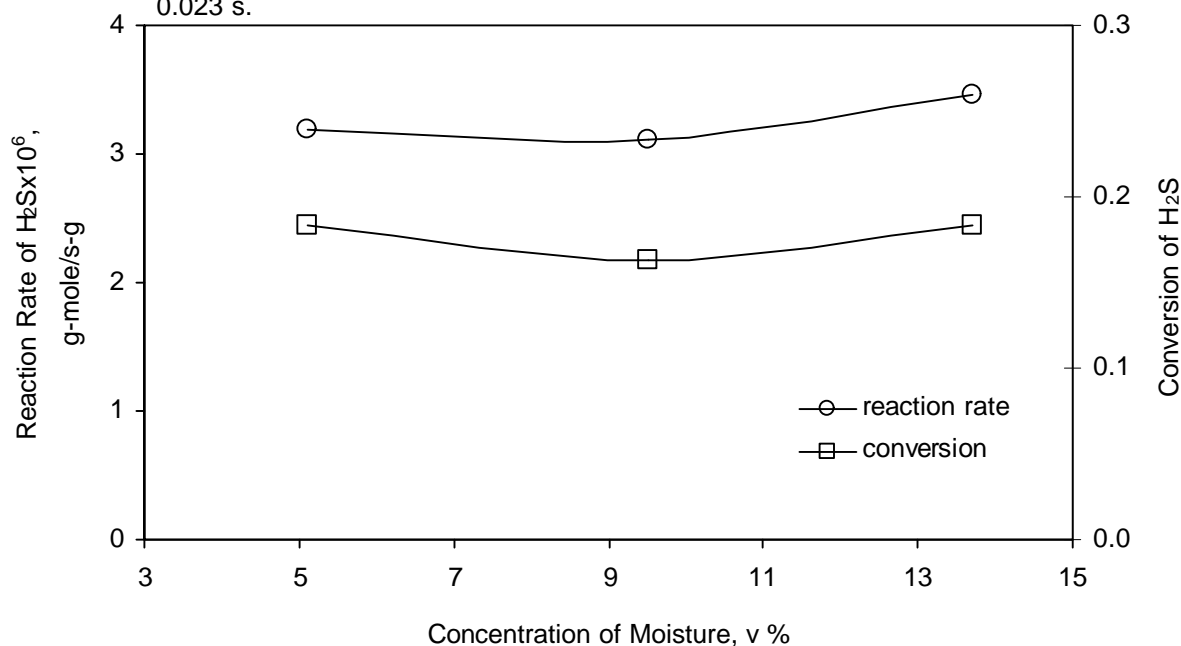
Experiments on conversion of hydrogen sulfide into element sulfur were carried out for the space time range of 0.01 – 0.5 seconds at 140°C (see Table 3) to evaluate effects of catalyst amounts, moisture concentrations, reaction pressures on conversion of hydrogen sulfide into elemental sulfur. A typical simulated coal gas mixture consists of 70-v% hydrogen, 7,500-ppm hydrogen sulfide, 2,500-ppm sulfur dioxide, and 5-vol % moisture, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to the reactor are 50 - 200 cm<sup>3</sup>/min at room temperature and atmospheric pressure (SCCM). The temperature of the reactor is controlled in an oven at 140°C. The pressure of the reactor is maintained at 60 - 115 psia.

### Effects of Moisture on Conversion of H<sub>2</sub>S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst were carried out for the space time range of 0.020 – 0.023 seconds (see Table 3) to evaluate effects of moisture concentrations on conversion of hydrogen sulfide into elemental sulfur at 140°C and 61 – 64 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 6,800 - 7,600-ppm H<sub>2</sub>S, 2,300- 2,600 ppm SO<sub>2</sub>, and 5 – 14 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 110 cm<sup>3</sup>/min at room temperature and atmospheric pressure (SCCM). Conversions of H<sub>2</sub>S into elemental sulfur are 0.16 – 0.18, whereas reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur are 3.1 – 3.5 x10<sup>-6</sup> g-mole/s-g-cat.

Concentrations of moisture appear not to affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5 – 14 v% in a simulated coal gas mixture at 61 – 64 psia. Concentrations of moisture appear to affect slightly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5 – 14 v% in a simulated coal gas mixture at 61 – 64 psia (see Figure 4).

Figure 4. Effects of moisture on reaction rates and conversion of H<sub>2</sub>S with 0.01-g catalyst and a 100-SCCM feed containing 7,500-ppmv H<sub>2</sub>S and 2,500-ppmv SO<sub>2</sub> at 140°C, the pressure range of 61 - 64 psia and the space time range of 0.02 - 0.023 s.



Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst were carried out for the space time range of 0.039 – 0.041 seconds (see Table 3) to evaluate effects of moisture concentrations on conversion of hydrogen sulfide into elemental sulfur at 140°C and 111 – 113 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 7,000 - 7,800-ppm H<sub>2</sub>S, 2,400- 2,600 ppm SO<sub>2</sub>, and 5.2 – 14.2 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 96 - 106 cm<sup>3</sup>/min at room temperature and atmospheric pressure (SCCM). Conversions of H<sub>2</sub>S into elemental sulfur are 0.34 – 0.45, whereas reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur are 5.7 – 7.4 x10<sup>-6</sup> g-mole/s-g-cat.

Concentrations of moisture appear to affect conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5.2 – 9.8 v% in a simulated coal gas mixture at 111 psia (see Figures 5 and 6). However, concentrations of moisture appear not to affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5 – 14 v% in a simulated coal gas mixture at 61 – 64 psia.

Concentrations of moisture also appear to affect reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5.2 – 9.8 v% in a simulated coal gas mixture at 111 psia (see Figures 5 and 6). However, concentrations of moisture appear to affect slightly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5 – 14 v% in a simulated coal gas mixture at 61 – 64 psia.

Figure 5. Effects of moisture on reaction rates and conversion of H<sub>2</sub>S with 0.01-g catalyst and a 100-SCCM feed containing 7,500-ppmv H<sub>2</sub>S and 2,500-ppmv SO<sub>2</sub> at 140°C, the pressure range of 111 - 113 psia and the space time range of 0.039 - 0.041 s.

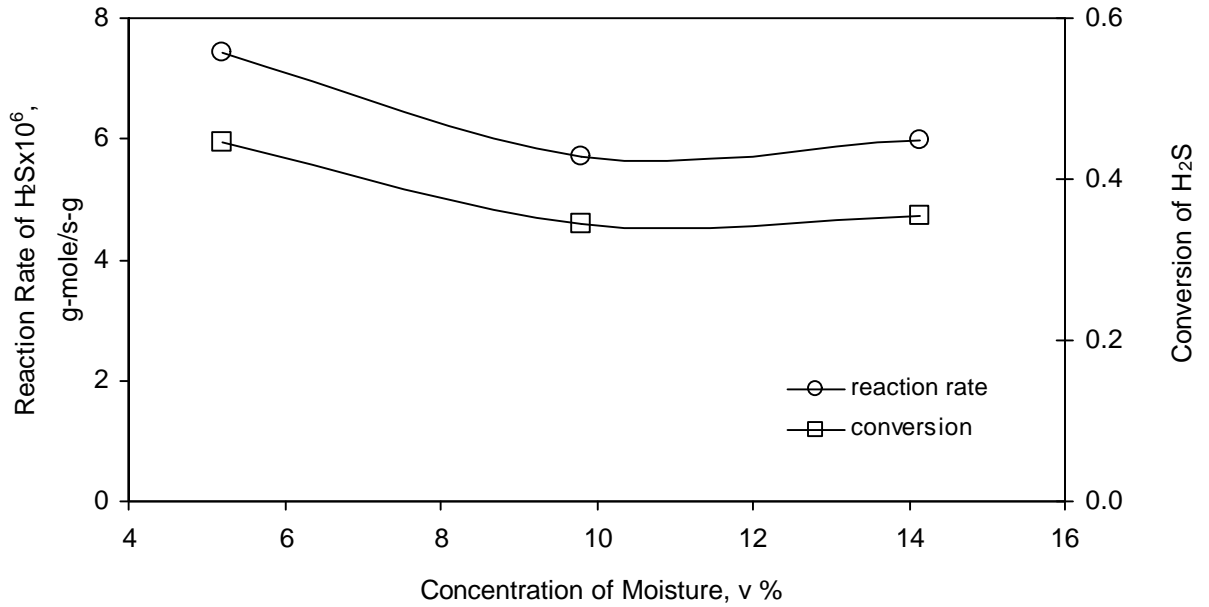
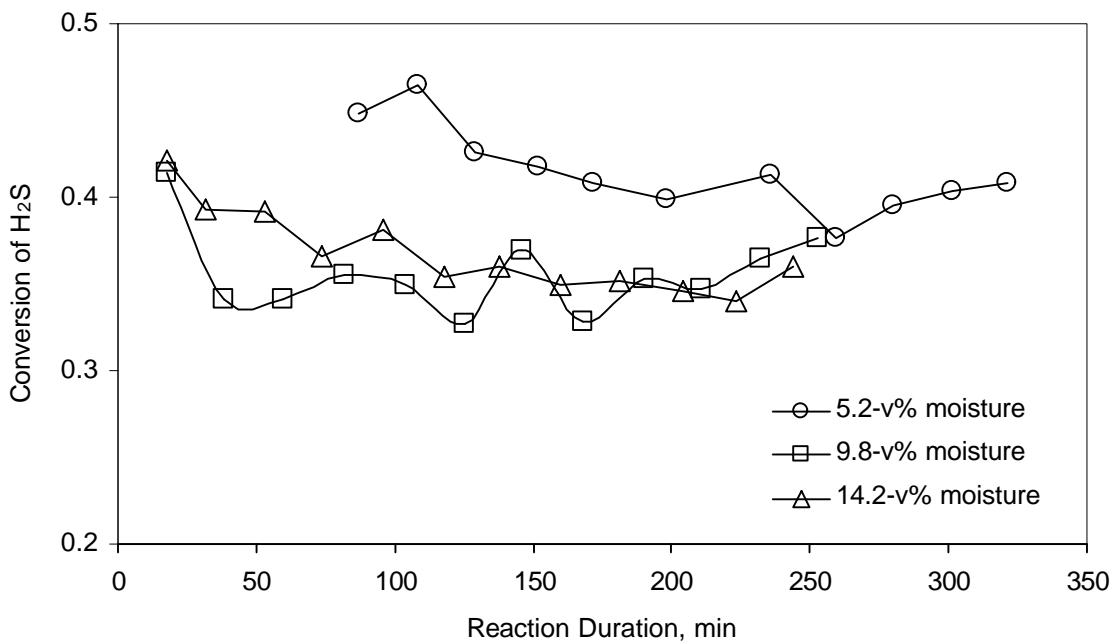


Figure 6. Effects of moisture on conversion of H<sub>2</sub>S into elemental sulfur with 0.01-g catalyst and a 100-SCCM feed stream containing 7,500-ppm H<sub>2</sub>S and 2,500-ppm SO<sub>2</sub> at 140°C and 111 - 113 psia.



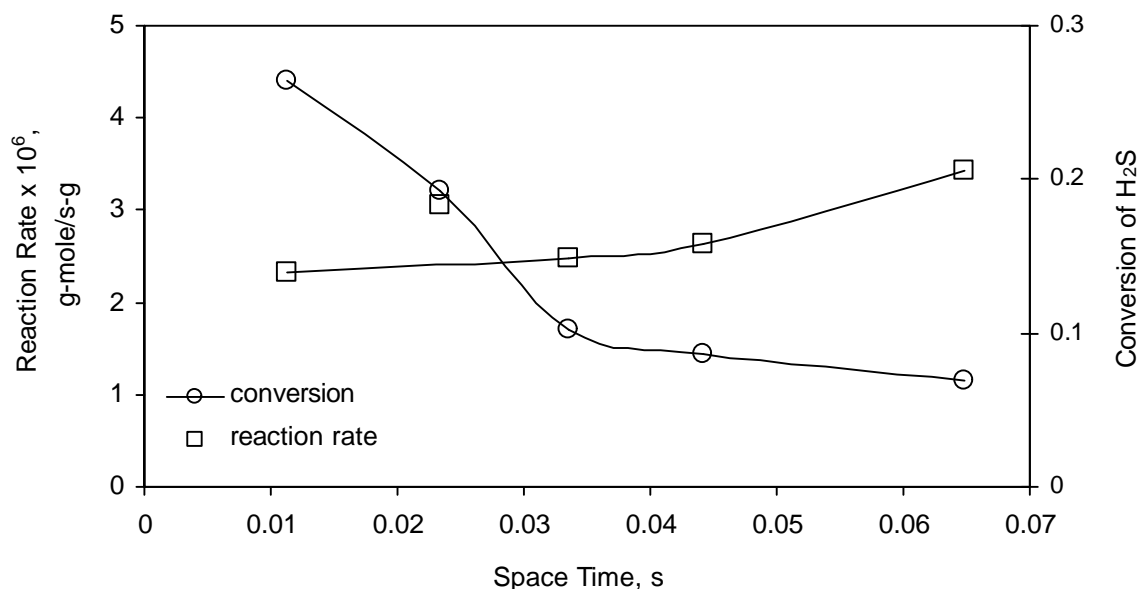


## Effects of Space Time on Conversion of H<sub>2</sub>S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst were carried out for the space time range of 0.011 – 0.064 seconds (see Table 3) to evaluate effects of space times on conversion of hydrogen sulfide into elemental sulfur at 140°C and 61 – 64 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 7,430 - 7,620-ppm H<sub>2</sub>S, 2,490-2,560 ppm SO<sub>2</sub>, and 5 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 101 cm<sup>3</sup>/min at room temperature and atmospheric pressure (SCCM). Conversions of H<sub>2</sub>S into elemental sulfur are 0.14 – 0.21, whereas reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur are 1.15 – 4.41 x10<sup>-6</sup> g-mole/s-g-cat.

Space times affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the space time range of 0.011 – 0.064 seconds. Space times appear to affect significantly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the space time range of 0.011 – 0.064 seconds (see Figure 7).

Figure 7. Effects of space time on surface reaction rates for the conversion H<sub>2</sub>S into elemental sulfur with a 100-SCCM feed containing 7,500-ppm H<sub>2</sub>S and 2,500-ppm SO<sub>2</sub> at 140°C and the pressure range of 61 - 64 psia.

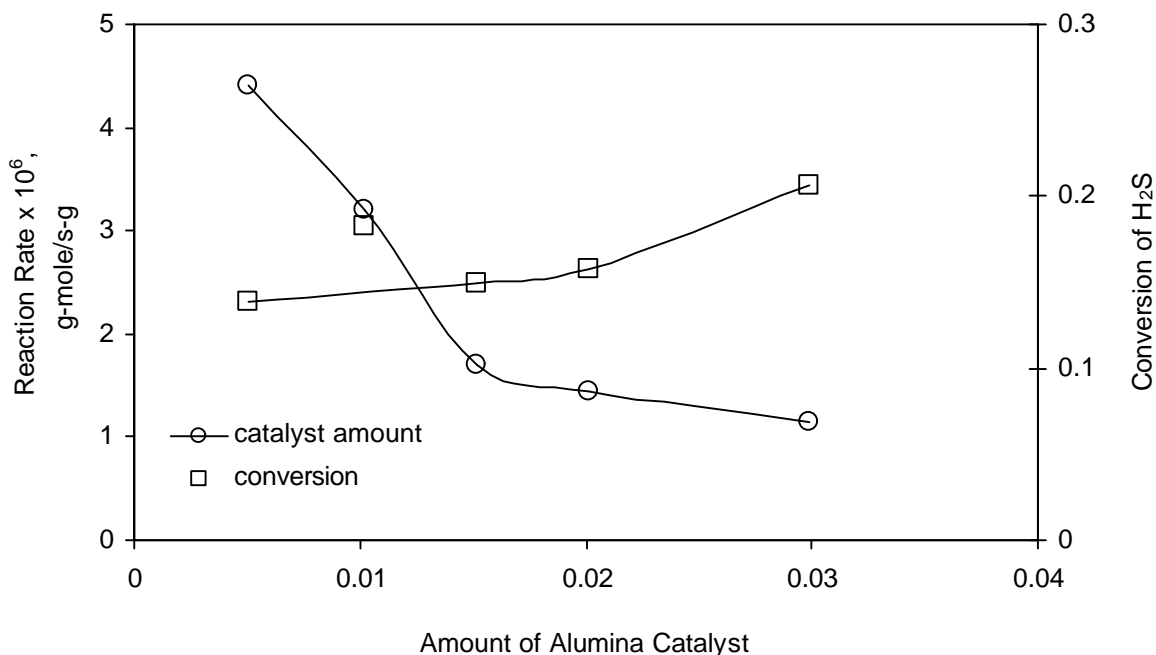


## Effects of Catalyst Amounts on Conversion of H<sub>2</sub>S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst were carried out for the space time range of 0.011 – 0.064 seconds (see Table 3) to evaluate effects of catalyst loadings on conversion of hydrogen sulfide into elemental sulfur at 140°C and 62 – 64 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 7,430 - 7,620-ppm H<sub>2</sub>S, 2,490- 2,560 ppm SO<sub>2</sub>, and 5 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 101 cm<sup>3</sup>/min at room temperature and atmospheric pressure (SCCM). Conversions of H<sub>2</sub>S into elemental sulfur are 0.14 – 0.21, whereas reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur are 1.15 – 4.41 x10<sup>-6</sup> g-mole/s-g-cat.

Catalyst loadings affect significantly conversion of H<sub>2</sub>S into elemental sulfur. Catalyst loadings appear to affect significantly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur (see Figure 8).

Figure 8. Effects of catalyst amounts on surface reaction rates and conversion of H<sub>2</sub>S with a 100-SCCM feed containing 7,500-ppm H<sub>2</sub>S, 2,500-ppm SO<sub>2</sub> and 5-v% moisture at 140°C and the pressure range of 61 - 64 psia.



#### Effects of Pressure on Conversion of H<sub>2</sub>S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst were carried out for the space time range of 0.023 – 0.041 seconds (see Table 3) to evaluate effects of reaction pressures on conversion of hydrogen sulfide into elemental sulfur at 140°C and 64 -113 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 7,620 – 7,780-ppm H<sub>2</sub>S, 2,560- 2,610 ppm SO<sub>2</sub>, and 5 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 96 – 98 cm<sup>3</sup>/min at room temperature and atmospheric pressure (SCCM). Conversions of H<sub>2</sub>S into elemental sulfur are 0.18 – 0.45, whereas reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur are 3.2 – 7.4 x10<sup>-6</sup> g-mole/s-g-cat.

Reaction pressures affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the pressure range of 64 -113 psia. Reaction pressures appear to affect significantly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the pressure range of 64 -113 psia (see Figures 9 and 10). Reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur were obtained with initial reaction data, since reaction rates decrease with increased reaction durations (see Figure 10).

Figure 9. Effects of reaction pressure on reaction rates and conversion of H<sub>2</sub>S with 0.01-g catalyst and a 100-SCCM feed stream containing 7,500-ppm H<sub>2</sub>S, 2,500-ppm SO<sub>2</sub> and 5-v% moisture at 140°C.

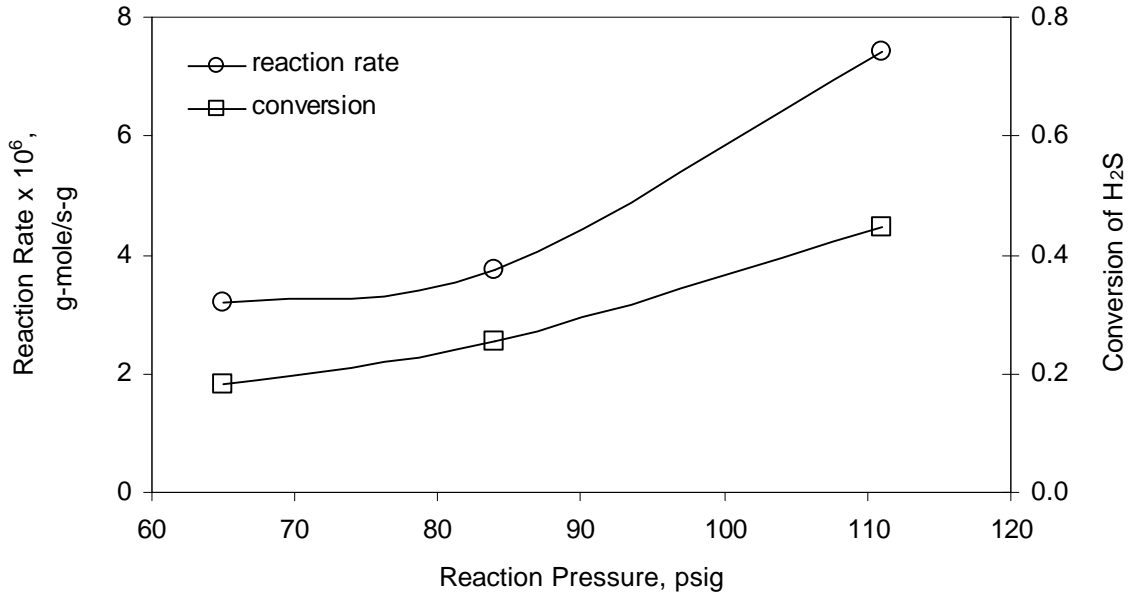
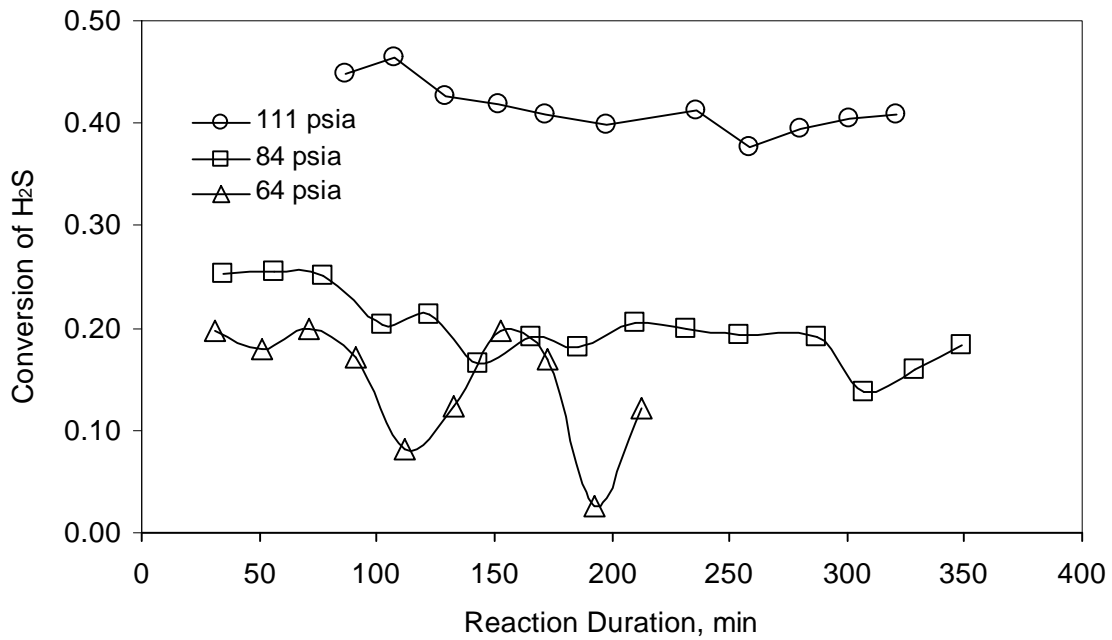


Figure 10. Effects of pressure on conversion of H<sub>2</sub>S into elemental sulfur with 0.01-g catalyst and a 100-SCCM feed stream containing 7,500-ppm H<sub>2</sub>S, 2,500-ppm SO<sub>2</sub> and 5-v% moisture at 140°C.



## CONCLUSIONS

The following conclusions were drawn based on the limited experimental data generated from the differential reactor system, and their interpretations,

Concentrations of moisture appear to affect conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5.2 – 9.8 v% in a simulated coal gas mixture at 111 psia (see Figures 5 and 6). However, concentrations of moisture appear not to affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5 – 14 v% in a simulated coal gas mixture at 61 – 64 psia.

Concentrations of moisture also appear to affect reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5.2 – 9.8 v% in a simulated coal gas mixture at 111 psia (see Figures 5 and 6). However, concentrations of moisture appear to affect slightly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the moisture range of 5 – 14 v% in a simulated coal gas mixture at 61 – 64 psia.

Space times affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the space time range of 0.011 – 0.064 seconds. Space times appear to affect significantly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the space time range of 0.011 – 0.064 seconds.

Catalyst loadings affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the space time range of 0.011 – 0.064 seconds. Catalyst loadings appear to affect significantly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the space time range of 0.011 – 0.064 seconds.

Reaction pressures affect significantly conversion of H<sub>2</sub>S into elemental sulfur in the pressure range of 64 -113 psia. Reaction pressures appear to affect significantly reaction rates for the conversion of H<sub>2</sub>S into elemental sulfur in the pressure range of 64 -113 psia.

## REFERENCES

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## PUBLICATIONS AND PRESENTATIONS

No paper was published and presented from this research.