ENERGY

Kinetics of Direct Oxidation of H_2S in Coal Gas to Elemental Sulfur

Final Report
for the Period October 1, 2000 to September 30, 2005

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November 2005

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
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DISCLAIMER

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SUMMARY

Removal of hydrogen sulfide (H_2S) 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 produce electric power and clean transportation fuels with coal and natural gas. These Vision 21 plants will require highly clean coal gas with H_2S 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 several research organizations in which the H_2S 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 H_2S

The direct oxidation of H_2S to elemental sulfur in the presence of SO_2 is ideally suited for coal gas from commercial gasifiers with a quench system to remove essentially all the trace contaminants except H_2S. 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 objectives of this research are to measure kinetics of direct oxidation of H_2S to elemental sulfur in the presence of a simulated coal gas mixture containing SO_2, H_2, and moisture, using 160-μm C-500-04 alumina catalyst particles and 400 square cells/inch^2, γ-Al_2O_3-wash-coated monolithic catalyst, and various reactors such as a micro packed-bed reactor, a micro bubble reactor, and a monolithic catalyst reactor, and to develop kinetic rate equations and model the direct oxidation process to assist in the design of large-scale plants. This heterogeneous catalytic reaction has gaseous reactants such as H_2S and SO_2. However, this heterogeneous catalytic reaction has heterogeneous products such as liquid elemental sulfur and steam.

To achieve the above-mentioned objectives using a micro packed-bed reactor, experiments on conversion of hydrogen sulfide into elemental sulfur were carried out over the space time range of 0.01 – 0.047 seconds at 125 - 155^{o}C to evaluate effects of reaction temperatures, moisture concentrations, and reaction pressures on conversion of hydrogen sulfide into elemental sulfur. Simulated coal gas mixtures consist of 61 – 89 v% hydrogen, 2,300 - 9,200-ppmv hydrogen sulfide, 1,600 - 4,900 ppmv sulfur dioxide, and 2.6 – 13.7 vol % moisture, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to the micro packed-bed reactor are 100 - 110 cm^3/min at room temperature and atmospheric pressure (SCCM). The temperature of the reactor is controlled in an oven at 125 - 155^{o}C. The pressure of the reactor is maintained at 28 - 127 psia.

To achieve the above-mentioned objectives using a micro bubble reactor, experiments on conversion of hydrogen sulfide into liquid elemental sulfur were carried out over the space time range of 0.06 – 0.87 seconds at 125 - 155°C to evaluate effects of reaction temperature, moisture concentration, and reaction pressure on conversion of hydrogen sulfide into liquid elemental sulfur. Simulated coal gas mixtures consist of 62 - 78 v% hydrogen, 3,000 – 7,500-ppmv hydrogen sulfide, 1,250 - 3,750 ppmv sulfur dioxide, and 0 – 15 vol % moisture, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to a micro bubble reactor are 50 - 100 cm^3/min at room temperature and atmospheric pressure. The temperature of the reactor is controlled in an oven at 125 - 155°C. The pressure of the reactor is maintained at 40 - 170 psia. The molar ratio of H_2S to SO_2 in the bubble reactor is maintained at 2 for all the reaction experiment runs, when volumetric feed rates of a simulated coal gas mixture to a micro bubble reactor are 50 SCCM.

To achieve the above-mentioned objectives using a monolithic catalyst reactor, experiments on conversion of hydrogen sulfide into elemental sulfur were carried out over the space time range of 110 – 557 seconds at 125 - 155°C to evaluate effects of reaction temperatures, moisture concentrations, and reaction pressures on conversion of hydrogen sulfide into elemental sulfur. Simulated coal gas mixtures consist of 50 – 70 v% hydrogen, 5,000 – 10,000-ppmv hydrogen sulfide, 2,500 – 5,000 ppmv sulfur dioxide, and 2.5 – 12 vol % moisture, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to the reactor are 50 SCCM. The temperature of the reactor is controlled in an oven at 125 - 155°C. The pressure of the reactor is maintained at 25 - 185 psia. The molar ratio of H_2S to SO_2 in the monolithic catalyst reactor is maintained at 2 for all the reaction experiment runs

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 (H_2) and carbon monoxide (CO) as the fuel components. Raw coal gas however, also contains a number of major and trace contaminants including hydrogen sulfide (H_2S), carbonyl sulfide (COS), ammonia (NH_3), hydrogen chloride (HCl), alkali, heavy metals, and particulate. Thus, this gas must be cleaned before further use. H_2S 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 H_2S 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 H_2S below 1 ppm and negligible amounts of other contaminants such as COS, HCl, NH_3, alkali, heavy metals, and particulate.

The conventional method of removing H_2S 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_2S-containing gas. This concentrated H_2S-containing gas is then combusted to produce a gas with a H_2S to sulfur dioxide (SO_2) 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:

$$2\ H_2S\ (g) + SO_2\ (g) \leftrightarrow 3S\ (\ell) + 2\ H_2O\ (g)$$

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_2S 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

$$ZnO + H_2S \leftrightarrow ZnS + H_2O \quad \text{(HGD)}$$

(ii) sorbent regeneration using air to produce SO_2

$$ZnS + 3/2\ O_2 \leftrightarrow SO_2 + ZnO \quad \text{(regeneration)}$$

(iii) catalytic reduction of SO_2 using a small portion of the coal gas, to elemental sulfur by the Direct Sulfur Recovery Process (DSRP):

$$SO_2 + 2H_2\ (\text{or } 2CO) \leftrightarrow S + 2H_2O\ (\text{or } 2CO_2) \quad \text{(DSRP)}$$

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_2 by DSRP. Furthermore, since trace contaminants e.g. NH_3 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, several research organizations are 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.

The direct oxidation process 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^{o}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 125 to 155^{o}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 and HGD/DSRP.

The objectives of this research are to measure kinetics of direct oxidation of H_2S to elemental sulfur in the presence of a simulated coal gas mixture containing SO_2, H_2, and moisture, using 160-µm C-500-04 alumina catalyst particles and 400 square cells/inch^2, γ-Al_2O_3-wash-coated monolithic catalyst, and various reactors such as a micro packed-bed reactor, a micro bubble reactor, and a monolithic catalyst reactor, and to develop kinetic rate equations and model the direct oxidation process to assist in the design of large-scale plants.

Experiments on conversion of hydrogen sulfide into elemental sulfur using a micro packed bed reactor were carried out over the space time range of 0.01 – 0.047 seconds at 125 - 155^{o}C and 28 - 127 psia to evaluate effects of reaction temperatures, moisture concentrations, and reaction pressures on conversion of hydrogen sulfide into elemental sulfur. Simulated coal gas mixtures consist of 61 – 89 v% hydrogen, 2,300 - 9,200-ppmv hydrogen sulfide, 1,600 - 4,900 ppmv sulfur dioxide, and 2.6 – 13.7 vol % moisture, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to the reactor are 100 - 110 SCCM.

Experiments on conversion of hydrogen sulfide to elemental sulfur using a micro bubble reactor were carried out over the space time range of 0.06 – 0.87 seconds at 125 - 155^{o}C and 40 - 170 psia to evaluate effects of reaction temperature, moisture concentration, and reaction pressure on conversion of hydrogen sulfide to elemental sulfur. Simulated coal gas mixtures consist of 62 - 78 v% hydrogen, 3,000 – 7,500-ppmv hydrogen sulfide, 1,250 - 3,750 ppmv sulfur dioxide, and 0 - 15 vol % moisture, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to the micro bubble reactor are 50 - 100 cm^3/min at room temperature and atmospheric pressure. The molar ratio of H_2S to SO_2 in the bubble reactor is maintained at 2 for all the reaction experiment runs, when the volumetric feed rate of a simulated coal gas mixture to a micro bubble reactor is 50 cm^3/min at room temperature and atmospheric pressure.

Experiments on conversion of hydrogen sulfide to elemental sulfur using a monolithic catalyst reactor were carried out over the space time range of 110 – 557 seconds at 125 - 155^{o}C and 25 - 185 psia to evaluate effects of reaction temperature, H_2S concentration, and reaction pressure on conversion of hydrogen sulfide to elemental sulfur. Simulated coal gas mixtures consist of 50 – 70 -v% hydrogen, 5,000 – 7,000-ppmv hydrogen sulfide, 2,500 – 5,000 ppmv sulfur dioxide, and 2.5 – 12 vol % moisture, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to the monolithic catalyst reactor are 50 SCCM. The molar ratio of H_2S to SO_2 in the monolithic catalyst reactor is maintained at 2 for all the reaction experiment runs.

EXPERIMENTAL SETUPS

A micro packed-bed reactor and a micro bubble reactor were fabricated with a ¼-inch Teflon tee. The C-500-04 alumina catalyst in the form of 160-μm spherical particles was examined in the micro packed-bed reactor as well as the micro bubble reactor. A simulated coal gas mixture containing H_2S and sulfur dioxide was reacted with the aid of the catalyst in the micro reactor at 125 - 155°C. Conversion of hydrogen sulfide into elemental sulfur was analyzed with a thermal conductivity detector (TCD) of a SRC gas chromatograph. The range of space (residence) time of the reaction gas mixture in the reactor was 0.01 – 0.35 s under the reaction conditions. Space times for the packed-bed/bubble reactor are obtained by dividing the volume of a catalyst bed with a volumetric flow rate at reaction conditions, where a minimum fluidization is assumed to occur in the micro bubble reactor.

A monolithic catalyst reactor was fabricated with a 2.2-cm inside diameter and 15-cm long 316-stainless steel HPLC column. A γ-alumina wash-coated monolithic catalyst is 2-cm in the diameter and 15-cm long. The monolithic catalyst has 200 square cells and 1040 cm^2 flat surface area. The cell density and the wall thickness of the cordierite monolithic catalyst are 400 square cells/$inch^2$ and 0.02 cm, respectively. A simulated coal gas mixture containing H_2S and SO_2 was reacted with the aid of the catalyst in the monolithic catalyst reactor at 125 - 155°C. Conversion of hydrogen sulfide to elemental sulfur was analyzed with the thermal conductivity detector (TCD) of the SRC gas chromatograph. The range of space (residence) time of the reaction gas mixture in the reactor was 69 - 513 seconds under the reaction conditions. Space times are obtained by dividing the bulk volume of the monolithic catalyst in the reactor with the volumetric flow rate of a feed gaseous mixture at reaction conditions.

A reactor assembly mainly consists of four mass flow meters for gases, one 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, as shown in Figures 1 and 2. The preheaters are made of 20-ft-long 1/16-inch Teflon tubing. The typical reaction conditions are shown in Tables 1 through 3. The properties of the catalyst are shown in Tables 4 and 5.

Table 1. Experimental conditions for the reaction of hydrogen sulfide with sulfur dioxide as an oxidant using the packed-bed reactor.

Volume of the catalyst-packed bed, cm^3:	0.012 – 0.14
Temperature, °C:	125 - 155
Reaction Pressure, psia	28 - 127
Space Time under the reaction conditions, s:	0.01 – 0.047
Mean Particle Size, μm	160
Amount of Catalyst, g	0.01 – 0.12
Gas Flow Rate, cc/min at room temperature and 1 atm (SCCM)	98 - 110
Hydrogen, vol %	61 - 89
Moisture, vol %:	2.6 – 13.7
Concentration of H_2S, ppmv	2,300 – 9,200
Concentration of SO_2, ppmv	1,600 – 4,900
Nitrogen, vol %	Remainder

Table 2. Experimental conditions for the reaction of hydrogen sulfide with sulfur dioxide as an oxidant using the bubble reactor.

Amounts of catalyst particles in the reactor, g	0.01 – 0.1
Temperature, °C:	125 - 155
Reaction Pressure, psia	40 - 170
Space Time under the reaction conditions, second:	0.06 – 0.35
Mean Particle Size, μm	160
Gas Flow Rate, SCCM	50 - 100
Hydrogen, vol %	62 - 78
Moisture, vol %:	0 -15
Concentration of H_2S, ppmv	2,500 – 7,500
Concentration of SO_2, ppmv	1,250 – 3,750
Nitrogen, vol %	Remainder

Table 3. Experimental conditions for the reaction of hydrogen sulfide with sulfur dioxide as an oxidant using the monolithic catalyst reactor.

Volume of the honeycomb catalyst bed, cm^3:	47
Temperature, °C:	125 -155
Reaction Pressure, psia	25 - 185
Space Time under the reaction conditions, s:	110 – 557
Gas Feed Rate, SCCM	50
Concentration of H_2S, ppmv	5,000 – 10,000
Concentration of SO_2, ppmv	2,500 – 5,000
Moisture, vol %:	2.5 - 12
Hydrogen, vol %	50 - 70
Nitrogen, vol %	Remainder

Table 4. Properties of the C-500-04 alumina catalyst

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

Table 5. Properties of the monolithic catalyst

Diameter, cm	2
Length, cm	15
Flat Surface Area, cm^2	1,040
Wash Coat	γ-Al_2O_3
Cell Shape	square
Cells/$inch^2$ (CPSI)	400
Wall Thickness, cm	0.02
Flat Area/Length/Cell, cm^2/cm-length/cell	0.345
Chemical Composition	Cordierite ($2MgO$-$2AL_2O_3$-$5SIO_2$)

Figure 1. Schematic Diagram on the packed-bed/monolithic catalyst reactor assembly

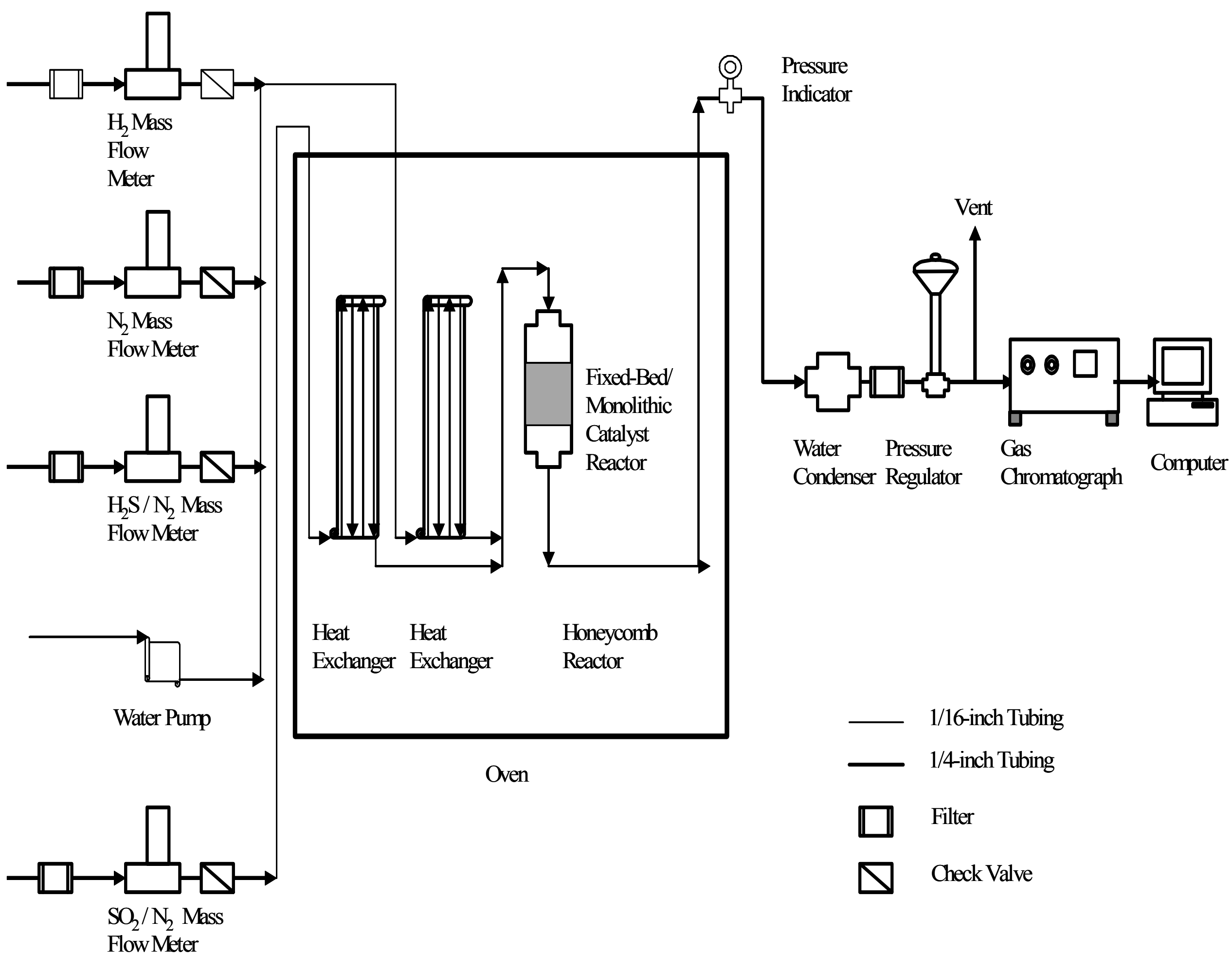
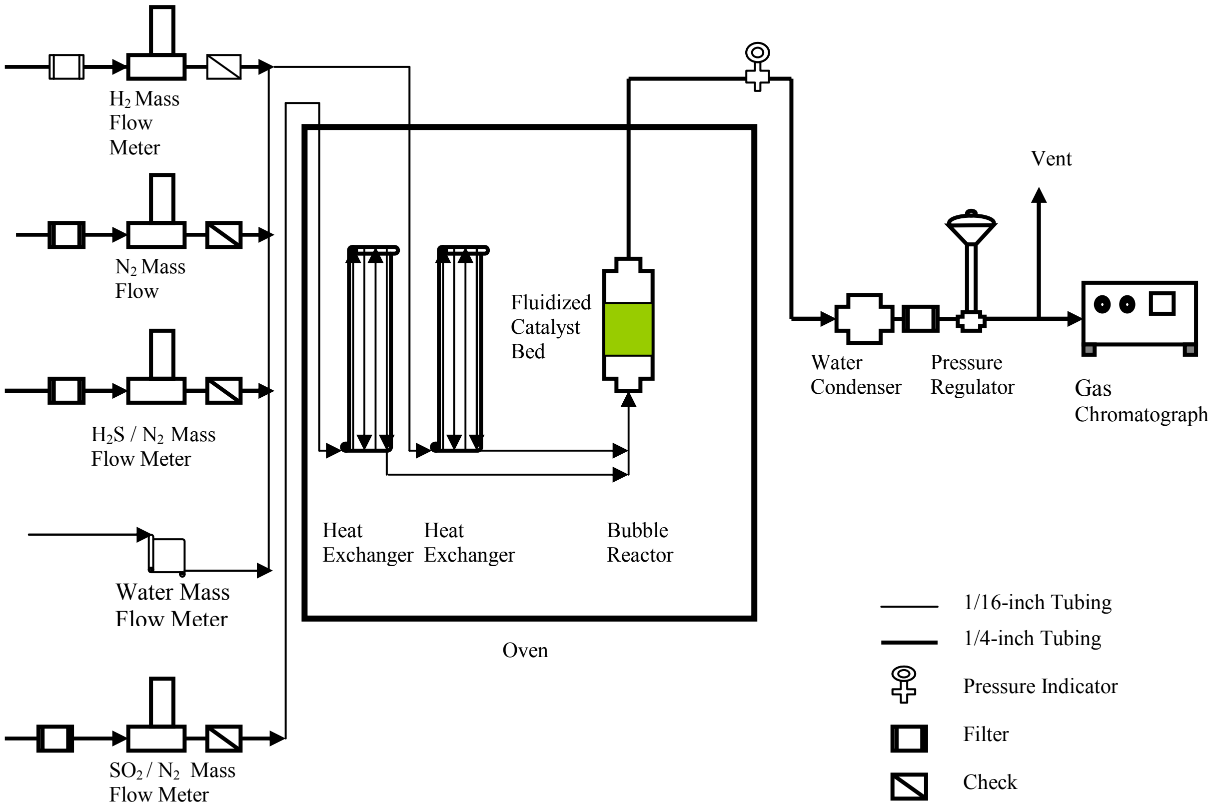


Figure 2. Schematic diagram on the bubble reactor assembly



The reaction gas mixtures are fed downward to the vertical packed-bed reactor and the vertical monolithic catalyst reactor, whereas the reaction gas mixtures are fed upward to the micro vertical bubble reactor, as shown in Figures 1 and 2.

The reactor was loaded with the C-500-04 alumina catalyst for the packed/bubble reactor and the γ-alumina-wash-coated monolithic catalyst for the monolithic catalyst reactor. The reactor, loaded with catalyst particles or the monolithic catalyst, 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_2S and another feed stream containing SO_2 were introduced into the reactor, by switching nitrogen with the simulated coal gas mixture.

Table 1-1. Conversion of hydrogen sulfide into elemental sulfur in the presence of 5,800 – 8,800 ppm H_2S, 1,900 – 3,000 ppm SO_2, 70-v% hydrogen, 4 – 15 v% moisture, and 0 – 0.12 g catalyst in a micro packed-bed reactor at 140°C and 60 – 113 psia.

Run #	Temperature, °C	Pressure, psia	Total Feed cc/min	Feed Composition, v% H_2	H_2S	SO_2	water	Space Time s	Catalyst, g	Conversion of H_2S, %
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

Table 2-1. Conversion of 4,400 -6,300 ppmv hydrogen sulfide with 3,300 - 4,800 ppmv sulfur dioxide in the presence of 61 - 89 v-% hydrogen, 5-v % moisture, and 0.1-g catalyst in a micro packed-bed reactor at 125 - 155 ^{o}C, 112 - 124 psia, and 0.040 - 0.046 s space time.

Run Number	Temperature, ^{o}C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
114	155	119.7	0.0103	99.7	0.042	70.211	0.499	0.378	5.015	23.897	0.399
115	155	119.7	0.0103	100	0.042	70.000	0.498	0.377	5.000	24.126	0.433
116	155	119.7	0.0102	100	0.042	70.000	0.498	0.377	5.000	24.126	0.502
117	155	119.7	0.0105	100	0.043	70.000	0.498	0.377	5.000	24.126	0.356
118	155	119.7	0.0105	100	0.043	70.000	0.498	0.377	5.000	24.126	0.535
113	155	119.7	0.0103	99.7	0.042	70.211	0.499	0.378	5.015	23.897	0.301
119	155	118.7	0.0104	99.7	0.042	70.211	0.499	0.378	5.015	23.897	0.303*
199	155	120.7	0.0101	100	0.042	70.000	0.498	0.377	5.000	24.126	0.262*
51	150	112.7	0.0105	95.5	0.043	73.298	0.521	0.394	5.236	20.550	0.341
58	150	114.7	0.0103	99.5	0.041	70.352	0.501	0.378	5.025	23.744	0.387
64	150	117.7	0.0104	99	0.043	70.707	0.503	0.380	5.051	23.359	0.458
65	150	118.7	0.0102	100.5	0.042	69.652	0.496	0.375	4.975	24.503	0.474
73	150	120.7	0.0103	100.7	0.043	69.513	0.495	0.374	4.965	24.653	0.492
103	150	123.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.461
121	150	122.7	0.0104	99	0.044	70.707	0.503	0.380	5.051	23.359	0.496
122	150	121.7	0.0104	100.5	0.043	69.652	0.496	0.375	4.975	24.503	0.490
200	150	122.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.243
46	150	113.7	0.0103	99	0.041	70.707	0.503	0.380	5.051	23.359	0.417*
56	150	114.7	0.0104	99.5	0.041	70.352	0.501	0.378	5.025	23.744	0.438*
112	150	119.7	0.0102	100	0.042	70.000	0.498	0.377	5.000	24.126	0.443*
120	150	118.7	0.0101	100	0.041	70.000	0.498	0.377	5.000	24.126	0.416*
226	150	115.7	0.0101	100	0.040	70.000	0.498	0.377	5.000	24.126	0.434*
45	145	113.7	0.0103	97.7	0.042	71.648	0.510	0.385	5.118	22.339	0.175
52	145	117.7	0.0102	95.5	0.044	73.298	0.521	0.394	5.236	20.550	0.334
57	145	114.7	0.0103	101	0.041	69.307	0.493	0.373	4.950	24.877	0.309
66	145	116.7	0.0103	99	0.042	70.707	0.503	0.380	5.051	23.359	0.459
74	145	119.7	0.0103	96	0.045	72.917	0.519	0.392	5.208	20.964	0.483
109	145	120.7	0.0103	100	0.043	70.000	0.498	0.377	5.000	24.126	0.402
110	145	119.7	0.0103	100	0.043	70.000	0.498	0.377	5.000	24.126	0.397
129	145	119.7	0.0104	100	0.043	70.000	0.498	0.377	5.000	24.126	0.493
50	145	115.7	0.0104	98	0.043	71.429	0.508	0.384	5.102	22.577	0.289*
201	145	121.7	0.0103	100	0.044	70.000	0.498	0.377	5.000	24.126	0.234*
227	145	121.7	0.0101	100	0.043	70.000	0.498	0.377	5.000	24.126	0.258*
49	140	115.7	0.0103	102.5	0.041	68.293	0.486	0.367	4.878	25.976	0.341
59	140	118.7	0.0102	100.7	0.042	69.513	0.495	0.374	4.965	24.653	0.361
67	140	116.7	0.0104	99.5	0.043	70.352	0.501	0.378	5.025	23.744	0.415
76	140	118.7	0.0104	99.5	0.044	70.352	0.501	0.378	5.025	23.744	0.437
101	140	117.7	0.0104	100	0.043	70.000	0.498	0.377	5.000	24.126	0.457
102	140	121.7	0.0105	100	0.045	70.000	0.498	0.377	5.000	24.126	0.448
123	140	121.7	0.0102	99.7	0.044	70.211	0.499	0.378	5.015	23.897	0.467
124	140	119.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.461

40	140	111.7	0.0104	100.5	0.041	69.652	0.496	0.375	4.975	24.503	0.312*

*: data selected for figures

Table 2-1. Continued – 1

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v%					Conversion
						H_2	H_2S	SO_2	moisture	N_2	
53	140	117.7	0.0104	101	0.043	69.307	0.493	0.373	4.950	24.877	0.318*
193	140	119.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.301*
198	140	121.7	0.0101	100	0.043	70.000	0.498	0.377	5.000	24.126	0.309*
222	140	118.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.286*
41	135	110.7	0.0103	101	0.040	69.307	0.493	0.373	4.950	24.877	0.406
54	135	116.7	0.0104	101.7	0.043	68.830	0.490	0.370	4.916	25.394	0.390
60	135	112.7	0.0104	91	0.046	76.923	0.547	0.414	5.495	16.621	0.413
61	135	118.7	0.0103	100.5	0.043	69.652	0.496	0.375	4.975	24.503	0.424
68	135	117.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.508
69	135	117.7	0.0103	79	0.055	88.608	0.630	0.477	6.329	3.956	0.442
70	135	119.7	0.0104	102	0.044	68.627	0.488	0.369	4.902	25.613	0.485
72	135	118.7	0.0103	99.5	0.044	70.352	0.501	0.378	5.025	23.744	0.421
75	135	116.7	0.0102	99	0.043	70.707	0.503	0.380	5.051	23.359	0.507
111	135	119.7	0.0102	100	0.044	70.000	0.498	0.377	5.000	24.126	0.373
128	135	120.7	0.0104	100	0.045	70.000	0.498	0.377	5.000	24.126	0.447
108	135	122.7	0.0104	100	0.046	70.000	0.498	0.377	5.000	24.126	0.353*
202	135	121.7	0.01	100	0.043	70.000	0.498	0.377	5.000	24.126	0.326*
43	130	110.7	0.0104	99	0.042	70.707	0.503	0.380	5.051	23.359	0.402
47	130	111.7	0.0104	113.9	0.037	61.463	0.437	0.331	4.390	33.379	0.218
55	130	119.7	0.0104	103.2	0.044	67.829	0.483	0.365	4.845	26.478	0.496
62	130	111.7	0.0103	92	0.045	76.087	0.541	0.409	5.435	17.528	0.459
63	130	111.7	0.01	100	0.040	70.000	0.498	0.377	5.000	24.126	0.447
71	130	118.7	0.0104	100	0.045	70.000	0.498	0.377	5.000	24.126	0.461
104	130	120.7	0.0103	100	0.045	70.000	0.498	0.377	5.000	24.126	0.487
105	130	118.7	0.0104	99.7	0.045	70.211	0.499	0.378	5.015	23.897	0.410
125	130	120.7	0.0104	99.5	0.046	70.352	0.501	0.378	5.025	23.744	0.481
126	130	120.7	0.0105	99.7	0.046	70.211	0.499	0.378	5.015	23.897	0.469
48	130	117.7	0.0101	98.7	0.044	70.922	0.505	0.381	5.066	23.126	0.343*
203	130	120.7	0.0101	100	0.044	70.000	0.498	0.377	5.000	24.126	0.333*
42	125	112.7	0.0102	101	0.042	69.307	0.493	0.373	4.950	24.877	0.364
44	125	110.7	0.0102	98	0.042	71.429	0.508	0.384	5.102	22.577	0.502
106	125	118.7	0.0103	99.7	0.045	70.211	0.499	0.378	5.015	23.897	0.340
127	125	120.7	0.0104	100.5	0.046	69.652	0.496	0.375	4.975	24.503	0.432
107	125	122.7	0.0102	99.7	0.046	70.211	0.499	0.378	5.015	23.897	0.285*
204	125	121.7	0.0103	100	0.046	70.000	0.498	0.377	5.000	24.126	0.265*

*: data selected for figures

Table 2-2. Conversion of 4,400 – 5,200 ppmv hydrogen sulfide with 3,400 – 3,900 ppmv sulfur dioxide in the presence of 63 - 73 v-% hydrogen, 2.6 – 14.2 v-% moisture, and 0.1-g catalyst in a micro packed-bed reactor at 140 °C, 112 - 123 psia, and 0.039 - 0.046 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v%					Conversion
						H_2	H_2S	SO_2	moisture	N_2	
78	140	121.7	0.0104	111.7	0.040	62.668	0.446	0.337	13.429	23.120	0.409
81	140	120.7	0.0103	106	0.041	66.038	0.470	0.355	14.151	18.986	0.506
132	140	120.7	0.0101	110	0.039	63.636	0.453	0.342	13.636	21.932	0.485
133	140	122.7	0.0102	110	0.040	63.636	0.453	0.342	13.636	21.932	0.436
194	140	121.7	0.0104	110	0.041	63.636	0.453	0.342	13.636	21.932	0.322*
77	140	115.7	0.0104	104	0.041	67.308	0.479	0.362	9.615	22.236	0.464
82	140	119.7	0.0101	104	0.041	67.308	0.479	0.362	9.615	22.236	0.506
131	140	120.7	0.0105	105	0.043	66.667	0.474	0.359	9.524	22.977	0.397
195	140	121.7	0.0103	105	0.042	66.667	0.474	0.359	9.524	22.977	0.317*
134	140	119.7	0.0104	102.5	0.043	68.293	0.486	0.367	7.317	23.537	0.443
196	140	122.2	0.0105	102.5	0.044	68.293	0.486	0.367	7.317	23.537	0.254*
49	140	115.7	0.0103	102.5	0.041	68.293	0.486	0.367	4.878	25.976	0.341
59	140	118.7	0.0102	100.7	0.042	69.513	0.495	0.374	4.965	24.653	0.361
67	140	116.7	0.0104	99.5	0.043	70.352	0.501	0.378	5.025	23.744	0.415
76	140	118.7	0.0104	99.5	0.044	70.352	0.501	0.378	5.025	23.744	0.437
101	140	117.7	0.0104	100	0.043	70.000	0.498	0.377	5.000	24.126	0.457
102	140	121.7	0.0105	100	0.045	70.000	0.498	0.377	5.000	24.126	0.448
123	140	121.7	0.0102	99.7	0.044	70.211	0.499	0.378	5.015	23.897	0.467
124	140	119.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.461
40	140	111.7	0.0104	100.5	0.041	69.652	0.496	0.375	4.975	24.503	0.312*
53	140	117.7	0.0104	101	0.043	69.307	0.493	0.373	4.950	24.877	0.318*
193	140	119.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.301*
198	140	121.7	0.0101	100	0.043	70.000	0.498	0.377	5.000	24.126	0.309*
222	140	118.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.286*
83	140	122.7	0.0103	96.5	0.046	72.539	0.516	0.390	2.591	23.964	0.467
130	140	120.7	0.0103	97.5	0.045	71.795	0.511	0.386	2.564	24.744	0.471
80	140	120.7	0.0104	97.2	0.046	72.016	0.512	0.387	2.572	24.512	0.339*
197	140	122.7	0.0103	97.5	0.046	71.795	0.511	0.386	2.564	24.744	0.325*

*: data selected for figures

Table 2-3. Conversion of 4,900 – 5,300 ppmv hydrogen sulfide with 3,700 – 4,900 ppmv sulfur dioxide in the presence of 68 - 74 v-% hydrogen, 2.6 – 13.7 moisture, and 0.1-g catalyst in a micro packed-bed reactor at 140 ^{o}C, 28 - 122 psia, and 0.010 - 0.045 s space time.

Run Number	Temperature, ^{o}C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v%					Conversion
						H_2	H_2S	SO_2	moisture	N_2	
49	140	115.7	0.0103	102.5	0.041	68.293	0.486	0.367	4.878	25.976	0.341
59	140	118.7	0.0102	100.7	0.042	69.513	0.495	0.374	4.965	24.653	0.361
67	140	116.7	0.0104	99.5	0.043	70.352	0.501	0.378	5.025	23.744	0.415
76	140	118.7	0.0104	99.5	0.044	70.352	0.501	0.378	5.025	23.744	0.437
101	140	117.7	0.0104	100	0.043	70.000	0.498	0.377	5.000	24.126	0.457
102	140	121.7	0.0105	100	0.045	70.000	0.498	0.377	5.000	24.126	0.448
123	140	121.7	0.0102	99.7	0.044	70.211	0.499	0.378	5.015	23.897	0.467
124	140	119.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.461
40	140	111.7	0.0104	100.5	0.041	69.652	0.496	0.375	4.975	24.503	0.312*
53	140	117.7	0.0104	101	0.043	69.307	0.493	0.373	4.950	24.877	0.318*
193	140	119.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.301*
198	140	121.7	0.0101	100	0.043	70.000	0.498	0.377	5.000	24.126	0.309*
222	140	118.7	0.0104	100	0.044	70.000	0.498	0.377	5.000	24.126	0.286*
97	140	87.7	0.0105	100.6	0.032	69.583	0.495	0.374	4.970	24.578	0.300
98	140	88.7	0.0102	100.6	0.032	69.583	0.495	0.374	4.970	24.578	0.286
135	140	91.7	0.0103	100	0.033	70.000	0.498	0.377	5.000	24.126	0.342
205	140	91.7	0.0101	100	0.033	70.000	0.498	0.377	5.000	24.126	0.208*
223	140	92.2	0.0101	100	0.033	70.000	0.498	0.377	5.000	24.126	0.232*
84	140	67.7	0.0102	102	0.024	68.627	0.488	0.369	4.902	25.613	0.238
85	140	65.7	0.0102	102	0.023	68.627	0.488	0.369	4.902	25.613	0.223
87	140	66.7	0.0102	94	0.026	74.468	0.530	0.401	5.319	19.282	0.106
88	140	67.7	0.0103	101	0.024	69.307	0.493	0.373	4.950	24.877	0.234
86	140	67.7	0.0102	99	0.025	70.707	0.503	0.380	5.051	23.359	0.183*
89	140	67.7	0.0102	99	0.025	70.707	0.503	0.380	5.051	23.359	0.207*
136	140	69.7	0.0103	100	0.025	70.000	0.498	0.377	5.000	24.126	0.182*
206	140	69.7	0.0105	100	0.026	70.000	0.498	0.377	5.000	24.126	0.180*
224	140	71.7	0.0104	100	0.026	70.000	0.498	0.377	5.000	24.126	0.192*
94	140	37.7	0.0103	99.7	0.014	70.211	0.499	0.378	5.015	23.897	0.150
95	140	36.7	0.0104	98	0.014	71.429	0.508	0.384	5.102	22.577	0.166
137	140	41.7	0.0103	100	0.015	70.000	0.498	0.377	5.000	24.126	0.151
207	140	41.7	0.0103	100	0.015	70.000	0.498	0.377	5.000	24.126	0.133*
225	140	39.7	0.0102	100	0.014	70.000	0.498	0.377	5.000	24.126	0.107*
90	140	28.7	0.0102	99	0.010	70.707	0.503	0.380	5.051	23.359	0.104*
91	140	27.7	0.0105	99	0.010	70.707	0.503	0.380	5.051	23.359	0.124*

*: data selected for figures

Table 2-4. Conversion of 3,200 – 3,600 ppmv hydrogen sulfide with 4,100 – 4,600 ppmv sulfur dioxide in the presence of 64 - 72 v-% hydrogen, 2.6 – 13.7 v-% moisture, and 0.1-g catalyst in a micro packed-bed reactor at 125 - 155 ^oC, 43 - 123 psia, and 0.016 - 0.046 s space time.

Run Number	Temperature, ^oC	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
168	155	120.7	0.0104	100	0.043	70.000	0.349	0.452	5.000	24.200	0.525*
165	150	119.7	0.0102	100	0.042	70.000	0.349	0.452	5.000	24.200	0.402*
164	140	121.7	0.0103	100	0.044	70.000	0.349	0.452	5.000	24.200	0.333*
166	130	120.7	0.0104	100	0.045	70.000	0.349	0.452	5.000	24.200	0.428*
167	125	120.7	0.0104	100	0.046	70.000	0.349	0.452	5.000	24.200	0.428*
178	140	92.7	0.0103	100	0.034	70.000	0.349	0.452	5.000	24.200	0.049
164	140	121.7	0.0103	100	0.044	70.000	0.349	0.452	5.000	24.200	0.333*
181	140	89.7	0.0102	100	0.032	70.000	0.349	0.452	5.000	24.200	0.215*
179	140	71.7	0.0102	100	0.026	70.000	0.349	0.452	5.000	24.200	0.193*
180	140	42.7	0.0103	100	0.016	70.000	0.349	0.452	5.000	24.200	0.136*
182	140	121.7	0.0103	110	0.040	63.636	0.317	0.411	13.636	22.000	0.415*
183	140	119.7	0.0101	105	0.041	66.667	0.332	0.430	9.524	23.047	0.351*
184	140	122.7	0.0104	102.5	0.044	68.293	0.340	0.441	7.317	23.609	0.425*
164	140	121.7	0.0103	100	0.044	70.000	0.349	0.452	5.000	24.200	0.333*
185	140	122.7	0.0101	97.5	0.045	71.795	0.358	0.463	2.564	24.820	0.347*

*: data selected for figures

Table 2-5. Conversion of 6,800 – 7,600 ppmv hydrogen sulfide with 2,300 – 2,600 ppmv sulfur dioxide in the presence of 64 - 72 v-% hydrogen, 2.6 – 13.7 v-% moisture, and 0.1-g catalyst in a micro packed-bed reactor at 125 - 155 ^oC, 38 - 125 psia, and 0.014 - 0.046 s space time.

Run Number	Temperature, ^oC	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
212	155	124.7	0.0105	100	0.045	70.000	0.747	0.251	5.000	24.002	0.047*
213	150	121.7	0.0104	100	0.044	70.000	0.747	0.251	5.000	24.002	0.142*
150	145	119.7	0.0103	100	0.043	70.000	0.747	0.251	5.000	24.002	0.324
214	145	122.7	0.0103	100	0.044	70.000	0.747	0.251	5.000	24.002	0.163*
142	140	121.7	0.0103	100	0.044	70.000	0.747	0.251	5.000	24.002	0.427
146	140	122.7	0.0104	100	0.045	70.000	0.747	0.251	5.000	24.002	0.378
149	140	120.7	0.0104	100	0.044	70.000	0.747	0.251	5.000	24.002	0.311
211	140	119.7	0.0102	100	0.043	70.000	0.747	0.251	5.000	24.002	0.142
141	140	119.7	0.0102	100	0.043	70.000	0.747	0.251	5.000	24.002	0.219*
218	140	122.7	0.0103	100	0.045	70.000	0.747	0.251	5.000	24.002	0.242*
151	135	119.7	0.0102	100	0.044	70.000	0.747	0.251	5.000	24.002	0.124
215	135	119.7	0.0105	100	0.045	70.000	0.747	0.251	5.000	24.002	0.230*
152	130	119.7	0.0105	100	0.045	70.000	0.747	0.251	5.000	24.002	0.336
216	130	119.7	0.0103	100	0.045	70.000	0.747	0.251	5.000	24.002	0.243*
153	125	121.7	0.0103	100	0.046	70.000	0.747	0.251	5.000	24.002	0.293*
217	125	121.7	0.0104	100	0.046	70.000	0.747	0.251	5.000	24.002	0.328*

Table 2-5. Continued – 1

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
142	140	121.7	0.0103	100	0.044	70.000	0.747	0.251	5.000	24.002	0.427
146	140	122.7	0.0104	100	0.045	70.000	0.747	0.251	5.000	24.002	0.378
149	140	120.7	0.0104	100	0.044	70.000	0.747	0.251	5.000	24.002	0.311
211	140	119.7	0.0102	100	0.043	70.000	0.747	0.251	5.000	24.002	0.142
141	140	119.7	0.0102	100	0.043	70.000	0.747	0.251	5.000	24.002	0.219*
218	140	122.7	0.0103	100	0.045	70.000	0.747	0.251	5.000	24.002	0.242*
100	140	88.7	0.0104	102	0.032	68.627	0.732	0.246	4.902	25.492	0.256
99	140	88.7	0.0104	100	0.033	70.000	0.747	0.251	5.000	24.002	0.232
140	140	91.7	0.0103	100	0.033	70.000	0.747	0.251	5.000	24.002	0.216
143	140	89.7	0.0105	100	0.033	70.000	0.747	0.251	5.000	24.002	0.315
210	140	90.7	0.0103	100	0.033	70.000	0.747	0.251	5.000	24.002	0.108*
139	140	72.7	0.0105	100	0.027	70.000	0.747	0.251	5.000	24.002	0.223
144	140	71.7	0.0105	100	0.027	70.000	0.747	0.251	5.000	24.002	0.190
209	140	70.7	0.0103	100	0.026	70.000	0.747	0.251	5.000	24.002	0.062*
93	140	38.7	0.0104	99.7	0.014	70.211	0.749	0.252	5.015	23.773	0.106*
96	140	37.7	0.0105	99	0.014	70.707	0.755	0.254	5.051	23.234	0.118*
138	140	41.7	0.0103	100	0.015	70.000	0.747	0.251	5.000	24.002	0.094*
145	140	41.7	0.0104	100	0.015	70.000	0.747	0.251	5.000	24.002	0.102*
208	140	42.7	0.0103	100	0.016	70.000	0.747	0.251	5.000	24.002	0.098*
187	140	120.7	0.0101	110	0.039	63.636	0.679	0.228	13.636	21.820	0.231*
190	140	120.7	0.0103	105	0.042	66.667	0.711	0.239	9.524	22.859	0.132
148	140	120.7	0.0104	105	0.042	66.667	0.711	0.239	9.524	22.859	0.202*
188	140	119.7	0.0102	105	0.041	66.667	0.711	0.239	9.524	22.859	0.187*
219	140	120.7	0.0102	105	0.041	66.667	0.711	0.239	9.524	22.859	0.189*
189	140	120.7	0.0101	102.5	0.042	68.293	0.729	0.245	7.317	23.417	0.140
191	140	120.7	0.0104	102.5	0.043	68.293	0.729	0.245	7.317	23.417	0.143
147	140	122.7	0.0101	102.5	0.043	68.293	0.729	0.245	7.317	23.417	0.267*
220	140	119.2	0.0103	102.5	0.042	68.293	0.729	0.245	7.317	23.417	0.268*
142	140	121.7	0.0103	100	0.044	70.000	0.747	0.251	5.000	24.002	0.427
146	140	122.7	0.0104	100	0.045	70.000	0.747	0.251	5.000	24.002	0.378
149	140	120.7	0.0104	100	0.044	70.000	0.747	0.251	5.000	24.002	0.311
211	140	119.7	0.0102	100	0.043	70.000	0.747	0.251	5.000	24.002	0.142
141	140	119.7	0.0102	100	0.043	70.000	0.747	0.251	5.000	24.002	0.219*
218	140	122.7	0.0103	100	0.045	70.000	0.747	0.251	5.000	24.002	0.242*
192	140	119.7	0.0102	97.5	0.044	71.795	0.766	0.257	2.564	24.617	0.200*
221	140	121.7	0.0103	97.5	0.045	71.795	0.766	0.257	2.564	24.617	0.253*

*: data selected for figures

Table 2-6. Conversion of 8,200 – 9,200 ppmv hydrogen sulfide with 1,600 – 1,800 ppmv sulfur dioxide in the presence of 64 - 72 v-% hydrogen, 2.6 – 13.7 v-% moisture, and 0.1-g catalyst in a micro packed-bed reactor at 130 - 155 °C, 43 - 127 psia, and 0.015 - 0.047 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	water	N_2	Conversion
174	140	121.7	0.0102	110	0.040	63.636	0.815	0.160	13.636	21.753	0.057*
175	140	121.7	0.0103	105	0.042	66.667	0.854	0.167	9.524	22.788	0.123*
176	140	120.7	0.0103	102.5	0.043	68.293	0.875	0.171	7.317	23.344	0.162*
154	140	126.7	0.0103	100	0.046	70.000	0.896	0.176	5.000	23.928	0.047
155	140	119.7	0.0102	100	0.043	70.000	0.896	0.176	5.000	23.928	0.086*
161	140	119.7	0.0103	100	0.044	70.000	0.896	0.176	5.000	23.928	0.258*
177	140	122.7	0.0105	97.5	0.047	71.795	0.919	0.180	2.564	24.541	0.136*
186	140	120.7	0.0101	97.5	0.044	71.795	0.919	0.180	2.564	24.541	0.132*
154	140	126.7	0.0103	100	0.046	70.000	0.896	0.176	5.000	23.928	0.047
155	140	119.7	0.0102	100	0.043	70.000	0.896	0.176	5.000	23.928	0.086*
161	140	119.7	0.0103	100	0.044	70.000	0.896	0.176	5.000	23.928	0.258*
171	140	91.7	0.0103	100	0.033	70.000	0.896	0.176	5.000	23.928	0.103*
172	140	70.7	0.0104	100	0.026	70.000	0.896	0.176	5.000	23.928	0.096*
173	140	42.7	0.0102	100	0.015	70.000	0.896	0.176	5.000	23.928	0.044*
169	155	121.7	0.0104	100	0.043	70.000	0.896	0.176	5.000	23.928	0.179*
162	150	120.7	0.0105	100	0.044	70.000	0.896	0.176	5.000	23.928	0.147*
163	145	120.7	0.0103	100	0.043	70.000	0.896	0.176	5.000	23.928	0.061
159	145	118.7	0.0102	100	0.042	70.000	0.896	0.176	5.000	23.928	0.209*
160	145	121.7	0.0102	100	0.043	70.000	0.896	0.176	5.000	23.928	0.132*
154	140	126.7	0.0103	100	0.046	70.000	0.896	0.176	5.000	23.928	0.047
155	140	119.7	0.0102	100	0.043	70.000	0.896	0.176	5.000	23.928	0.086
161	140	119.7	0.0103	100	0.044	70.000	0.896	0.176	5.000	23.928	0.258
156	130	121.7	0.0105	100	0.046	70.000	0.896	0.176	5.000	23.928	0.205*
157	130	121.7	0.0103	100	0.045	70.000	0.896	0.176	5.000	23.928	0.189*
158	135	119.7	0.0104	100	0.044	70.000	0.896	0.176	5.000	23.928	0.271*
170	135	121.7	0.0104	100	0.045	70.000	0.896	0.176	5.000	23.928	0.134*

*: data selected for figures

Table 3-1. Conversion of 2,500 – 7,500 ppmv hydrogen sulfide with 1,250 – 3,750 ppmv sulfur dioxide in the presence of 70 v-% hydrogen, 0 – 15 v-% moisture, and 0.02 – 0.08 g catalyst in a micro bubble reactor at 125 - 155 °C, 40 - 170 psia, and 0.06 – 0.35 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B1	140	121	0.02	100	0.084	70	0.498	0.25	10	19.252	0.092
B2	140	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.190
B3	140	120	0.02	100	0.084	70	0.498	0.25	10	19.252	0.097
B4	140	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.218
B5	140	122	0.06	100	0.258	70	0.498	0.25	10	19.252	0.272
B6	140	119	0.06	100	0.252	70	0.498	0.25	10	19.252	0.294

Table 3-1. Continued-1

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B7	140	121	0.06	100	0.258	70	0.498	0.25	10	19.252	0.272
B8	140	121	0.08	100	0.342	70	0.498	0.25	10	19.252	0.358
B9	140	123	0.08	100	0.348	70	0.498	0.25	10	19.252	0.283
B10	140	118	0.08	100	0.336	70	0.498	0.25	10	19.252	0.362
B11	140	120	0.04	100	0.168	70	0.647	0.175	10	19.178	0.146
B12	140	122	0.04	100	0.174	70	0.647	0.175	10	19.178	0.157
B13	140	124	0.04	100	0.174	70	0.349	0.325	10	19.326	0.161
B14	140	121	0.04	100	0.168	70	0.349	0.325	10	19.326	0.254
B15	140	121	0.04	100	0.168	70	0.349	0.325	10	19.326	0.266
B16	150	122	0.04	100	0.168	70	0.498	0.25	10	19.252	0.123
B17	150	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.180
B18	150	120	0.04	100	0.168	70	0.498	0.25	10	19.252	0.203
B19	130	122	0.04	100	0.174	70	0.498	0.25	10	19.252	0.136
B20	130	119	0.04	100	0.174	70	0.498	0.25	10	19.252	0.250
B21	130	122	0.04	100	0.174	70	0.498	0.25	10	19.252	0.139
B22	125	120	0.04	100	0.174	70	0.498	0.25	10	19.252	0.172
B23	125	120	0.04	100	0.174	70	0.498	0.25	10	19.252	0.166
B24	155	121	0.04	100	0.162	70	0.498	0.25	10	19.252	0.153
B25	155	120	0.04	100	0.162	70	0.498	0.25	10	19.252	0.179
B26	155	121	0.04	100	0.162	70	0.498	0.25	10	19.252	0.143
B27	145	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.110
B28	145	120	0.04	100	0.168	70	0.498	0.25	10	19.252	0.334
B29	145	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.096
B30	145	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.096
B31	140	91	0.04	100	0.126	70	0.498	0.25	10	19.252	0.142
B32	140	90	0.04	100	0.126	70	0.498	0.25	10	19.252	0.149
B33	140	61	0.04	100	0.084	70	0.498	0.25	10	19.252	0.127
B34	140	62	0.04	100	0.09	70	0.498	0.25	10	19.252	0.094
B35	140	62	0.04	100	0.09	70	0.498	0.25	10	19.252	0.132
B36	140	41	0.04	100	0.06	70	0.498	0.25	10	19.252	0.102
B37	140	42	0.04	100	0.06	70	0.498	0.25	10	19.252	0.197
B38	140	150	0.04	100	0.21	70	0.498	0.25	10	19.252	0.274
B39	140	149	0.04	100	0.21	70	0.498	0.25	10	19.252	0.164
B40	140	150	0.04	100	0.21	70	0.498	0.25	10	19.252	0.157
B41	140	149	0.04	100	0.21	70	0.498	0.25	10	19.252	0.161
B42	140	166	0.04	100	0.234	70	0.498	0.25	10	19.252	0.228
B43	140	171	0.04	100	0.24	70	0.498	0.25	10	19.252	0.344
B44	140	121	0.04	100	0.168	70	0.498	0.25	0	29.252	0.087
B45	140	121	0.04	100	0.168	70	0.498	0.25	0	29.252	0.071
B46	140	121	0.04	100	0.168	70	0.498	0.25	0	29.252	0.074
B47	140	122	0.04	100	0.174	70	0.498	0.25	5	24.252	0.126
B48	140	118	0.04	100	0.168	70	0.498	0.25	5	24.252	0.177
B49	140	119	0.04	100	0.168	70	0.498	0.25	5	24.252	0.184
B50	140	118	0.04	100	0.168	70	0.498	0.25	15	14.252	0.163
B51	140	122	0.04	100	0.174	70	0.498	0.25	15	14.252	0.154

Table 3-1. Continued-2

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B52	140	147	0.04	100	0.210	70	0.498	0.25	10	19.252	0.340
B53	140	146	0.04	100	0.204	70	0.498	0.25	10	19.252	0.331
B54	140	151	0.04	100	0.216	70	0.498	0.25	10	19.252	0.235
B55	140	150	0.04	100	0.210	70	0.498	0.25	10	19.252	0.256
B56	140	170	0.04	100	0.240	70	0.498	0.25	10	19.252	0.323
B57	140	171	0.04	100	0.240	70	0.498	0.25	10	19.252	0.283
B58	140	171	0.04	100	0.240	70	0.498	0.25	10	19.252	0.308
B59	140	42	0.04	100	0.060	70	0.498	0.25	10	19.252	0.117
B60	140	42	0.04	100	0.060	70	0.498	0.25	10	19.252	0.159
B61	140	42	0.04	100	0.060	70	0.498	0.25	10	19.252	0.147
B62	140	121	0.04	100	0.168	70	0.249	0.375	10	19.376	0.157
B63	140	122	0.04	100	0.174	70	0.249	0.375	10	19.376	0.158
B64	140	122	0.04	100	0.174	70	0.747	0.125	10	19.128	0.051
B65	140	120	0.04	100	0.168	70	0.249	0.375	10	19.376	0.069

Table 3-2. Effects of moisture concentration on conversion of H_2S to elemental sulfur with 0.04-g alumina catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 0 – 15 v% moisture, 70-v% H_2 at 140°C, 118 – 122 psia and 0.16 – 0.18 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B44	140	121	0.04	100	0.168	70	0.498	0.25	0	29.252	0.0874
B45	140	121	0.04	100	0.168	70	0.498	0.25	0	29.252	0.0706
B46	140	121	0.04	100	0.168	70	0.498	0.25	0	29.252	0.0737
B48	140	118	0.04	100	0.168	70	0.498	0.25	5	24.252	0.1772
B49	140	119	0.04	100	0.168	70	0.498	0.25	5	24.252	0.1838
B2	140	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.1903
B4	140	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.2183
B50	140	118	0.04	100	0.168	70	0.498	0.25	15	14.252	0.1634
B51	140	122	0.04	100	0.174	70	0.498	0.25	15	14.252	0.1538

Table 3-3. Effects of reaction temperature on conversion of H_2S to elemental sulfur with 0.04-g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 125 – 155°C, 119 – 122 psia and 0.16 – 0.18 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B2	140	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.1903
B4	140	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.2183
B17	150	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.1795
B18	150	120	0.04	100	0.168	70	0.498	0.25	10	19.252	0.2025
B19	130	122	0.04	100	0.174	70	0.498	0.25	10	19.252	0.1361
B21	130	122	0.04	100	0.174	70	0.498	0.25	10	19.252	0.1386
B22	125	120	0.04	100	0.174	70	0.498	0.25	10	19.252	0.1722
B23	125	120	0.04	100	0.174	70	0.498	0.25	10	19.252	0.1663
B24	155	121	0.04	100	0.162	70	0.498	0.25	10	19.252	0.1529
B26	155	121	0.04	100	0.162	70	0.498	0.25	10	19.252	0.1425
B27	145	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.1101
B29	145	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.0960
B30	145	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.0955

Table 3-4. Effects of reaction pressure on conversion of H_2S with 0.04-g alumina catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 140°C, 40 – 170 psia, and 0.06 – 0.24 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B2	140	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.1903
B4	140	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.2183
B31	140	91	0.04	100	0.126	70	0.498	0.25	10	19.252	0.1419
B32	140	90	0.04	100	0.126	70	0.498	0.25	10	19.252	0.1489
B33	140	61	0.04	100	0.084	70	0.498	0.25	10	19.252	0.1267
B34	140	62	0.04	100	0.090	70	0.498	0.25	10	19.252	0.0937
B35	140	62	0.04	100	0.090	70	0.498	0.25	10	19.252	0.1316
B36	140	41	0.04	100	0.060	70	0.498	0.25	10	19.252	0.1024
B43	140	171	0.04	100	0.240	70	0.498	0.25	10	19.252	0.3435
B54	140	151	0.04	100	0.216	70	0.498	0.25	10	19.252	0.2354
B55	140	150	0.04	100	0.210	70	0.498	0.25	10	19.252	0.2562
B56	140	170	0.04	100	0.240	70	0.498	0.25	10	19.252	0.3234
B57	140	171	0.04	100	0.240	70	0.498	0.25	10	19.252	0.2825

Table 3-4. Continued-1

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B38	140	150	0.04	100	0.210	70	0.498	0.25	10	19.252	0.2744
B58	140	171	0.04	100	0.240	70	0.498	0.25	10	19.252	0.3084
B59	140	42	0.04	100	0.060	70	0.498	0.25	10	19.252	0.1170
B60	140	42	0.04	100	0.060	70	0.498	0.25	10	19.252	0.1593
B61	140	42	0.04	100	0.060	70	0.498	0.25	10	19.252	0.1470

Table 3-5. A reaction model developed with experimental data of conversion of 3,500 -6,500 ppmv hydrogen sulfide with 1,750 – 3,250 ppmv sulfur dioxide in the presence of 70 v-% hydrogen, 10-v % moisture, and 0.04-g catalyst in a micro bubble reactor at 140 °C, 40 – 170 psia, and 0.06 – 0.24 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B2	140	121	0.04	100	0.174	70	0.498	0.25	10	19.252	0.1903
B4	140	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.2183
B11	140	120	0.04	100	0.168	70	0.647	0.175	10	19.178	0.1462
B12	140	122	0.04	100	0.174	70	0.647	0.175	10	19.178	0.1574
B14	140	121	0.04	100	0.174	70	0.349	0.325	10	19.326	0.2544
B15	140	121	0.04	100	0.174	70	0.349	0.325	10	19.326	0.2660
B31	140	91	0.04	100	0.126	70	0.498	0.25	10	19.252	0.1419
B32	140	90	0.04	100	0.126	70	0.498	0.25	10	19.252	0.1489
B33	140	61	0.04	100	0.084	70	0.498	0.25	10	19.252	0.1267
B34	140	62	0.04	100	0.090	70	0.498	0.25	10	19.252	0.0937
B35	140	62	0.04	100	0.090	70	0.498	0.25	10	19.252	0.1316
B36	140	41	0.04	100	0.060	70	0.498	0.25	10	19.252	0.1024
B38	140	150	0.04	100	0.210	70	0.498	0.25	10	19.252	0.2744
B54	140	151	0.04	100	0.216	70	0.498	0.25	10	19.252	0.2354
B55	140	150	0.04	100	0.210	70	0.498	0.25	10	19.252	0.2562
B56	140	170	0.04	100	0.240	70	0.498	0.25	10	19.252	0.3234
B58	140	171	0.04	100	0.240	70	0.498	0.25	10	19.252	0.3084
B59	140	42	0.04	100	0.060	70	0.498	0.25	10	19.252	0.1170

Table 3-6. Experimental surface reaction rates and predicted surface reaction rates of H_2S for conversion of 3,500 - 6,500 ppmv hydrogen sulfide with 1,750 – 3,250 ppmv sulfur dioxide in the presence of 70 v-% hydrogen, 10-v % moisture, and 0.04-g catalyst in a micro bubble reactor at 140 °C, 40 – 170 psia, and 0.06 – 0.24 s space time.

Run	Pressure, psia			Conversion	Molar Flow Rate	Left-Side Value of Rearranged Reaction Model	Surface Reaction Rate, g-mole/s-g-cat	
Number	Total	H_2S	SO_2	of H_2S	H_2S, g-mole/s	$psia^{1.5}$ (g-cat-s/g-mole)$^{0.5}$	Experimental	Predicted
B2	121	0.4879	0.2452	0.1903	3.3931E-07	190	1.6143E-06	1.9722E-06
B4	119	0.4633	0.2328	0.2183	3.3931E-07	164	1.8518E-06	1.8427E-06
B11	120	0.6629	0.1532	0.1462	4.4084E-07	204	1.6113E-06	1.3390E-06
B12	122	0.6651	0.1514	0.1574	4.4084E-07	196	1.7347E-06	1.3237E-06
B14	121	0.3149	0.3395	0.2544	2.3779E-07	149	1.5124E-06	2.3233E-06
B15	121	0.3100	0.3371	0.2660	2.3779E-07	143	1.5813E-06	2.2907E-06
B31	91	0.3889	0.1953	0.1419	3.3931E-07	157	1.2037E-06	1.4556E-06
B32	90	0.3815	0.1916	0.1489	3.3931E-07	149	1.2631E-06	1.4177E-06
B33	61	0.2653	0.1333	0.1267	3.3931E-07	93	1.0748E-06	8.4151E-07
B34	62	0.2798	0.1405	0.0937	3.3931E-07	118	7.9484E-07	9.1097E-07
B35	62	0.2681	0.1347	0.1316	3.3931E-07	93	1.1163E-06	8.5504E-07
B36	41	0.1833	0.0920	0.1024	3.3931E-07	60	8.6865E-07	4.7024E-07
B38	150	0.5420	0.2725	0.2744	3.3931E-07	185	2.3277E-06	2.2609E-06
B54	151	0.5750	0.2890	0.2354	3.3931E-07	219	1.9969E-06	2.4366E-06
B55	150	0.5556	0.2793	0.2562	3.3931E-07	199	2.1733E-06	2.3333E-06
B56	170	0.5728	0.2881	0.3234	3.3931E-07	186	2.7434E-06	2.4267E-06
B58	171	0.5890	0.2962	0.3084	3.3931E-07	198	2.6161E-06	2.5131E-06
B59	42	0.1847	0.0928	0.1170	3.3931E-07	56	9.9250E-07	4.7629E-07

Table 3-7. Effects of reaction duration on conversion of H_2S with 0.04-g alumina catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 for 25 – 274 min at 130°C and 120 psia.

Time, min	Conversion of H_2S
25	0.52
85	0.27
114	0.21
144	0.17
187	0.14
216	0.13
245	0.15
274	0.12

Table 3-8. Effects of catalyst loading on conversion of H_2S to elemental sulfur with 0.02 – 0.08 g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 118 - 123 psia and 140°C.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion
B2	140	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.1903
B4	140	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.2183
B1	140	121	0.02	100	0.084	70	0.498	0.25	10	19.252	0.0924
B2	140	121	0.04	100	0.168	70	0.498	0.25	10	19.252	0.1903
B3	140	120	0.02	100	0.084	70	0.498	0.25	10	19.252	0.097
B4	140	119	0.04	100	0.168	70	0.498	0.25	10	19.252	0.2183
B5	140	122	0.06	100	0.258	70	0.498	0.25	10	19.252	0.2724
B6	140	119	0.06	100	0.252	70	0.498	0.25	10	19.252	0.2935
B7	140	121	0.06	100	0.258	70	0.498	0.25	10	19.252	0.2715
B8	140	121	0.08	100	0.342	70	0.498	0.25	10	19.252	0.3581
B9	140	123	0.08	100	0.348	70	0.498	0.25	10	19.252	0.2831
B10	140	118	0.08	100	0.336	70	0.498	0.25	10	19.252	0.3623

Table 4-1. Conversion of 3,000 – 7,000 ppmv hydrogen sulfide with 1,500 – 3,500 ppmv sulfur dioxide in the presence of 62 - 78 v-% hydrogen, 10 v-% moisture, and 0.01 – 0.10 g catalyst in a micro bubble reactor at 125 - 155 °C, 40 - 170 psia, and 0.059 – 0.87 second space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion %
B5-1	140	120.2	0.0205	50	0.174	70	0.498	0.25	10	19.252	52.38
B5-2	140	120.7	0.0206	50	0.176	70	0.498	0.25	10	19.252	31.87
B5-3	140	117.7	0.0206	50	0.171	70	0.498	0.25	10	19.252	24.04
B5-4	140	121.03	0.0206	50	0.176	70	0.498	0.25	10	19.252	23.41
B5-5	140	119.7	0.0204	50	0.172	70	0.498	0.25	10	19.252	23.98
B5-6	140	122	0.0404	50	0.348	70	0.498	0.25	10	19.252	34.75
B5-7	140	121.3	0.0406	50	0.348	70	0.498	0.25	10	19.252	17.90
B5-8	140	118.9	0.0403	50	0.338	70	0.498	0.25	10	19.252	31.48
B5-9	140	117.87	0.0401	50	0.334	70	0.498	0.25	10	19.252	32.88
B5-10	140	119.5	0.0601	50	0.507	70	0.498	0.25	10	19.252	38.38
B5-11	140	118	0.0604	50	0.503	70	0.498	0.25	10	19.252	36.55
B5-12	140	119.2	0.0801	50	0.674	70	0.498	0.25	10	19.252	46.27
B5-13	140	122	0.0806	50	0.694	70	0.498	0.25	10	19.252	45.30
B5-14	140	114.45	0.0104	50	0.084	70	0.498	0.25	10	19.252	41.87
B5-15	140	120.08	0.0108	50	0.092	70	0.498	0.25	10	19.252	56.15
B5-16	140	119.03	0.0207	50	0.174	70	0.498	0.25	10	19.252	21.45
B5-17	140	168.99	0.0207	50	0.247	70	0.498	0.25	10	19.252	64.59

Table 4-1. Continued-1

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion %
B5-18	140	169.7	0.0205	50	0.246	70	0.498	0.25	10	19.252	53.72
B5-19	140	169.2	0.0209	50	0.250	70	0.498	0.25	10	19.252	56.04
B5-20	140	145.5	0.0205	50	0.211	70	0.498	0.25	10	19.252	34.30
B5-21	140	144.87	0.0208	50	0.213	70	0.498	0.25	10	19.252	26.46
B5-22	140	144.45	0.0205	50	0.209	70	0.498	0.25	10	19.252	42.86
B5-23	140	143.12	0.0205	50	0.207	70	0.498	0.25	10	19.252	54.61
B5-24	140	144.41	0.0205	50	0.209	70	0.498	0.25	10	19.252	21.74
B5-25	140	145.7	0.0203	50	0.209	70	0.498	0.25	10	19.252	43.53
B5-26	140	95.84	0.0205	50	0.139	70	0.498	0.25	10	19.252	24.26
B5-27	140	95.7	0.0205	50	0.138	70	0.498	0.25	10	19.252	20.22
B5-28	140	96.7	0.02	50	0.137	70	0.498	0.25	10	19.252	24.57
B5-29	140	67.7	0.0202	50	0.097	70	0.498	0.25	10	19.252	20.78
B5-30	140	67.7	0.0201	50	0.096	70	0.498	0.25	10	19.252	28.36
B5-31	140	67.7	0.0208	50	0.099	70	0.498	0.25	10	19.252	17.50
B5-32	140	67.7	0.0207	50	0.099	70	0.498	0.25	10	19.252	18.09
B5-33	140	41.2	0.0205	50	0.060	70	0.498	0.25	10	19.252	9.10
B5-34	140	42	0.0205	50	0.061	70	0.498	0.25	10	19.252	14.47
B5-35	140	40.2	0.0207	50	0.059	70	0.498	0.25	10	19.252	12.46
B5-36	140	119.7	0.0205	50	0.173	70	0.5	0.25	10	19.25	27.58
B5-37	140	120.7	0.0207	50	0.176	70	0.5	0.25	10	19.25	28.90
B5-38	155	116.95	0.0202	50	0.161	70	0.5	0.25	10	19.25	21.42
B5-39	155	121.87	0.0205	50	0.170	70	0.5	0.25	10	19.25	23.45
B5-40	155	119.7	0.0108	50	0.088	70	0.5	0.25	10	19.25	43.60
B5-41	155	118.7	0.0102	50	0.082	70	0.5	0.25	10	19.25	24.58
B5-42	155	120.7	0.0206	50	0.169	70	0.5	0.25	10	19.25	23.44
B5-43	125	119.7	0.0201	50	0.176	70	0.5	0.25	10	19.25	19.90
B5-44	125	119.7	0.0206	50	0.181	70	0.5	0.25	10	19.25	35.31
B5-45	125	120.7	0.0205	50	0.181	70	0.5	0.25	10	19.25	15.78
B5-46	125	120.7	0.0204	50	0.180	70	0.5	0.25	10	19.25	17.94
B5-47	125	120.7	0.0207	50	0.183	70	0.5	0.25	10	19.25	16.65
B5-48	130	119.7	0.0205	50	0.178	70	0.5	0.25	10	19.25	23.65
B5-49	130	118.7	0.0206	50	0.177	70	0.5	0.25	10	19.25	33.92
B5-50	130	119.7	0.0203	50	0.176	70	0.5	0.25	10	19.25	28.14
B5-51	130	118.7	0.0202	50	0.173	70	0.5	0.25	10	19.25	18.12
B5-52	130	117.7	0.0207	50	0.176	70	0.5	0.25	10	19.25	18.76
B5-53	150	118.7	0.0205	50	0.168	70	0.5	0.25	10	19.25	19.50
B5-54	150	119.7	0.0204	50	0.168	70	0.5	0.25	10	19.25	21.29
B5-55	150	118.7	0.0204	50	0.167	70	0.5	0.25	10	19.25	23.69
B5-56	150	118.7	0.0202	50	0.165	70	0.5	0.25	10	19.25	22.37
B5-57	145	120.7	0.0205	50	0.173	70	0.5	0.25	10	19.25	31.83
B5-58	145	119.7	0.0207	50	0.173	70	0.5	0.25	10	19.25	30.46
B5-59	145	118.7	0.0207	50	0.171	70	0.5	0.25	10	19.25	32.12
B5-60	135	118.7	0.0202	50	0.171	70	0.5	0.25	10	19.25	31.10
B5-61	135	118.7	0.0206	50	0.175	70	0.5	0.25	10	19.25	27.23

Table 4-1. Continued-2

Run Number	Temperature, ºC	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v%					Conversion %
						H_2	H_2S	SO_2	moisture	N_2	
B5-62	135	119.7	0.0206	50	0.176	70	0.5	0.25	10	19.25	23.54
B5-63	135	119.7	0.0208	50	0.178	70	0.5	0.25	10	19.25	24.89
B5-64	135	118.4	0.0205	50	0.173	70	0.5	0.25	10	19.25	10.19
B5-65	135	116.7	0.0208	50	0.173	70	0.5	0.25	10	19.25	13.81
B5-66	135	119.7	0.0207	50	0.177	70	0.5	0.25	10	19.25	13.96
B5-67	140	121.7	0.0204	50	0.175	70	0.5	0.25	10	19.25	31.94
B5-68	140	119.7	0.0207	50	0.175	70	0.5	0.25	10	19.25	4.98
B5-69	140	122.7	0.0204	50	0.177	70	0.5	0.25	10	19.25	20.45
B5-70	140	114.7	0.0209	50	0.169	70	0.5	0.25	10	19.25	24.49
B5-71	140	118.7	0.0202	50	0.169	70	0.5	0.25	10	19.25	24.74
B5-72	140	119.7	0.1001	50	0.846	70	0.5	0.25	10	19.25	47.34
B5-73	140	118.7	0.1004	50	0.841	70	0.5	0.25	10	19.25	54.50
B5-74	140	122.7	0.1004	50	0.870	70	0.5	0.25	10	19.25	44.49
B5-75	140	119.7	0.1004	50	0.848	70	0.5	0.25	10	19.25	45.12
B5-76	140	121.7	0.0801	50	0.688	70	0.5	0.25	10	19.25	41.45
B5-77	140	121.7	0.0802	50	0.689	70	0.5	0.25	10	19.25	38.91
B5-78	140	120.7	0.0801	50	0.682	70	0.5	0.25	10	19.25	32.42
B5-79	140	121.7	0.0804	50	0.691	70	0.5	0.25	10	19.25	33.62
B5-80	140	122.7	0.0802	50	0.695	70	0.5	0.25	10	19.25	35.18
B5-81	140	122.7	0.0604	50	0.523	70	0.5	0.25	10	19.25	22.25
B5-82	140	120.7	0.0601	50	0.512	70	0.5	0.25	10	19.25	21.52
B5-83	140	121.7	0.0607	50	0.521	70	0.5	0.25	10	19.25	32.77
B5-84	140	122.7	0.0601	50	0.521	70	0.5	0.25	10	19.25	38.02
B5-85	140	117.7	0.0604	50	0.502	70	0.5	0.25	10	19.25	22.01
B5-86	140	119.7	0.0604	50	0.510	70	0.5	0.25	10	19.25	33.36
B5-87	140	121.7	0.0404	50	0.347	70	0.5	0.25	10	19.25	19.33
B5-88	140	120.7	0.0401	50	0.342	70	0.5	0.25	10	19.25	23.72
B5-89	140	119.7	0.0407	50	0.344	70	0.5	0.25	10	19.25	21.55
B5-90	140	121.7	0.0402	50	0.345	70	0.5	0.25	10	19.25	26.93
B5-91	140	119.7	0.04	50	0.338	70	0.5	0.25	10	19.25	16.75
B5-92	140	119.7	0.0404	50	0.341	70	0.5	0.25	10	19.25	27.82
B5-93	140	122.7	0.0207	50	0.179	62	0.7	0.35	10	26.95	26.33
B5-94	140	122.7	0.0206	50	0.178	62	0.7	0.35	10	26.95	30.54
B5-95	140	122.7	0.0204	50	0.177	62	0.7	0.35	10	26.95	30.7
B5-96	140	121.7	0.0206	50	0.177	62	0.7	0.35	10	26.95	29.74
B5-97	140	121.7	0.0203	50	0.174	78	0.3	0.15	10	11.55	14.86
B5-98	140	117.7	0.0204	50	0.169	78	0.3	0.15	10	11.55	13.24
B5-99	140	121.7	0.0202	50	0.174	78	0.3	0.15	10	11.55	16.65
B5-100	140	118.7	0.0201	50	0.168	78	0.3	0.15	10	11.55	11.31
B5-101	140	120.7	0.0204	50	0.174	78	0.3	0.15	10	11.55	13.78

Table 4-2. Effects of reaction temperature on conversion of H_2S to elemental sulfur with 0.01 – 0.02-g catalyst in a micro bubble reactor and a 50-SCCM feed stream containing 5,000-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 125 – 155°C, 117 – 122 psia and 0.082 – 0.183 second space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion %
B5-43	125	119.7	0.0201	50	0.176	70	0.5	0.25	10	19.25	19.90
B5-44	125	119.7	0.0206	50	0.181	70	0.5	0.25	10	19.25	35.31
B5-45	125	120.7	0.0205	50	0.181	70	0.5	0.25	10	19.25	15.78
B5-46	125	120.7	0.0204	50	0.180	70	0.5	0.25	10	19.25	17.94
B5-47	125	120.7	0.0207	50	0.183	70	0.5	0.25	10	19.25	16.65
B5-48	130	119.7	0.0205	50	0.178	70	0.5	0.25	10	19.25	23.65
B5-49	130	118.7	0.0206	50	0.177	70	0.5	0.25	10	19.25	33.92
B5-50	130	119.7	0.0203	50	0.176	70	0.5	0.25	10	19.25	28.14
B5-51	130	118.7	0.0202	50	0.173	70	0.5	0.25	10	19.25	18.12
B5-52	130	117.7	0.0207	50	0.176	70	0.5	0.25	10	19.25	18.76
B5-60	135	118.7	0.0202	50	0.171	70	0.5	0.25	10	19.25	31.10
B5-61	135	118.7	0.0206	50	0.175	70	0.5	0.25	10	19.25	27.23
B5-62	135	119.7	0.0206	50	0.176	70	0.5	0.25	10	19.25	23.54
B5-63	135	119.7	0.0208	50	0.178	70	0.5	0.25	10	19.25	24.89
B5-64	135	118.4	0.0205	50	0.173	70	0.5	0.25	10	19.25	10.19
B5-65	135	116.7	0.0208	50	0.173	70	0.5	0.25	10	19.25	13.81
B5-66	135	119.7	0.0207	50	0.177	70	0.5	0.25	10	19.25	13.96
B5-3	140	117.7	0.0206	50	0.171	70	0.498	0.25	10	19.25	24.04
B5-4	140	121.03	0.0206	50	0.176	70	0.498	0.25	10	19.25	23.41
B5-5	140	119.7	0.0204	50	0.172	70	0.498	0.25	10	19.25	23.98
B5-16	140	119.03	0.0207	50	0.174	70	0.498	0.25	10	19.25	21.45
B5-67	140	121.7	0.0204	50	0.175	70	0.5	0.25	10	19.25	31.94
B5-71	140	118.7	0.0202	50	0.169	70	0.5	0.25	10	19.25	24.74
B5-57	145	120.7	0.0205	50	0.173	70	0.5	0.25	10	19.25	31.83
B5-58	145	119.7	0.0207	50	0.173	70	0.5	0.25	10	19.25	30.46
B5-59	145	118.7	0.0207	50	0.171	70	0.5	0.25	10	19.25	32.12
B5-53	150	118.7	0.0205	50	0.168	70	0.5	0.25	10	19.25	19.50
B5-54	150	119.7	0.0204	50	0.168	70	0.5	0.25	10	19.25	21.29
B5-55	150	118.7	0.0204	50	0.167	70	0.5	0.25	10	19.25	23.69
B5-56	150	118.7	0.0202	50	0.165	70	0.5	0.25	10	19.25	22.37
B5-38	155	116.95	0.0202	50	0.161	70	0.5	0.25	10	19.25	21.42
B5-39	155	121.87	0.0205	50	0.170	70	0.5	0.25	10	19.25	23.45
B5-40	155	119.7	0.0108	50	0.088	70	0.5	0.25	10	19.25	43.60
B5-41	155	118.7	0.0102	50	0.082	70	0.5	0.25	10	19.25	24.58
B5-42	155	120.7	0.0206	50	0.169	70	0.5	0.25	10	19.25	23.44

Table 4-3. Effects of reaction pressure on conversion of H_2S with 0.02-g alumina catalyst in a micro bubble reactor and a 50-SCCM feed stream containing 5,000-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 140°C, 40 – 170 psia, and 0.059 – 0.25 second space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion %
B5-33	140	41.2	0.0205	50	0.060	70	0.498	0.25	10	19.252	9.10
B5-34	140	42	0.0205	50	0.061	70	0.498	0.25	10	19.252	14.47
B5-35	140	40.2	0.0207	50	0.059	70	0.498	0.25	10	19.252	12.46
B5-29	140	67.7	0.0202	50	0.097	70	0.498	0.25	10	19.252	20.78
B5-30	140	67.7	0.0201	50	0.096	70	0.498	0.25	10	19.252	28.36
B5-31	140	67.7	0.0208	50	0.099	70	0.498	0.25	10	19.252	17.50
B5-26	140	95.84	0.0205	50	0.139	70	0.498	0.25	10	19.252	24.26
B5-27	140	95.7	0.0205	50	0.138	70	0.498	0.25	10	19.252	20.22
B5-28	140	96.7	0.02	50	0.137	70	0.498	0.25	10	19.252	24.57
B5-3	140	117.7	0.0206	50	0.171	70	0.498	0.25	10	19.252	24.04
B5-4	140	121.03	0.0206	50	0.176	70	0.498	0.25	10	19.252	23.41
B5-5	140	119.7	0.0204	50	0.172	70	0.498	0.25	10	19.252	23.98
B5-16	140	119.03	0.0207	50	0.174	70	0.498	0.25	10	19.252	21.45
B5-67	140	121.7	0.0204	50	0.175	70	0.5	0.25	10	19.25	31.94
B5-68	140	119.7	0.0207	50	0.175	70	0.5	0.25	10	19.25	4.98
B5-69	140	122.7	0.0204	50	0.177	70	0.5	0.25	10	19.25	20.45
B5-70	140	114.7	0.0209	50	0.169	70	0.5	0.25	10	19.25	24.49
B5-71	140	118.7	0.0202	50	0.169	70	0.5	0.25	10	19.25	24.74
B5-20	140	145.5	0.0205	50	0.211	70	0.498	0.25	10	19.252	34.30
B5-21	140	144.87	0.0208	50	0.213	70	0.498	0.25	10	19.252	26.46
B5-22	140	144.45	0.0205	50	0.209	70	0.498	0.25	10	19.252	42.86
B5-23	140	143.12	0.0205	50	0.207	70	0.498	0.25	10	19.252	54.61
B5-24	140	144.41	0.0205	50	0.209	70	0.498	0.25	10	19.252	21.74
B5-25	140	145.7	0.0203	50	0.209	70	0.498	0.25	10	19.252	43.53
B5-17	140	168.99	0.0207	50	0.247	70	0.498	0.25	10	19.252	64.59
B5-18	140	169.7	0.0205	50	0.246	70	0.498	0.25	10	19.252	53.72
B5-19	140	169.2	0.0209	50	0.250	70	0.498	0.25	10	19.252	56.04

Table 4-4. A reaction model developed with experimental data of conversion of 5,000 – 7,000 ppmv hydrogen sulfide with 2,500 – 3,500 ppmv sulfur dioxide in the presence of 62 - 70 v-% hydrogen, 10-v % moisture, and 0.02-g catalyst in a micro bubble reactor at 140 °C, 40 – 123 psia, and 0.059 - 0.178 second space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion %
B5-33	140	41.2	0.0205	50	0.060	70	0.498	0.25	10	19.252	9.10
B5-34	140	42	0.0205	50	0.061	70	0.498	0.25	10	19.252	14.47
B5-35	140	40.2	0.0207	50	0.059	70	0.498	0.25	10	19.252	12.46

Table 4-4. Continued-1

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion %
B5-31	140	67.7	0.0208	50	0.099	70	0.498	0.25	10	19.252	17.50
B5-32	140	67.7	0.0207	50	0.099	70	0.498	0.25	10	19.252	18.09
B5-26	140	95.84	0.0205	50	0.139	70	0.498	0.25	10	19.252	24.26
B5-28	140	96.7	0.02	50	0.137	70	0.498	0.25	10	19.252	24.57
B5-3	140	117.7	0.0206	50	0.171	70	0.498	0.25	10	19.252	24.04
B5-67	140	121.7	0.0204	50	0.175	70	0.5	0.25	10	19.25	31.94
B5-71	140	118.7	0.0202	50	0.169	70	0.5	0.25	10	19.25	24.74
B5-94	140	122.7	0.0206	50	0.178	62	0.7	0.35	10	26.95	30.54
B5-95	140	122.7	0.0204	50	0.177	62	0.7	0.35	10	26.95	30.7
B5-96	140	121.7	0.0206	50	0.177	62	0.7	0.35	10	26.95	29.74

Table 4-5. A comparison of experimental surface reaction rates with predicted surface reaction rates of H_2S for conversion of 5,000 - 7,000 ppmv hydrogen sulfide with 2,500 - 3,500 ppmv sulfur dioxide in the presence of 62 - 70 v-% hydrogen, 10-v % moisture, and 0.02-g catalyst in a micro bubble reactor at 140 °C, 40 – 123 psia, and 0.059 - 0.178 second space time.

Run Number	Pressure, psia Total	H_2S	SO_2	Conversion of H_2S	Molar Flow Rate H_2S, g-mole/s	Left-Side Value of Rearranged Reaction Model $psia^{1.5}$ (g-cat-s/g-mole)$^{0.5}$	Surface Reaction Rate, g-mole/s-g-cat Experimental	Predicted
B5-33	41.2	0.1865	0.0937	9.10	1.6966E-07	66	7.535E-07	9.355E-07
B5-34	42	0.1789	0.0899	14.47	1.6966E-07	49	1.198E-06	8.911E-07
B5-35	40.2	0.1752	0.0880	12.46	1.6966E-07	52	1.022E-06	8.695E-07
B5-31	67.7	0.2781	0.1397	17.50	1.6966E-07	87	1.427E-06	1.481E-06
B5-32	67.7	0.2762	0.1388	18.09	1.6966E-07	85	1.483E-06	1.469E-06
B5-26	95.84	0.3615	0.1817	24.26	1.6966E-07	109	2.007E-06	1.982E-06
B5-28	96.7	0.3632	0.1826	24.57	1.6966E-07	108	2.085E-06	1.992E-06
B5-3	117.7	0.4452	0.2238	24.04	1.6966E-07	150	1.980E-06	2.484E-06
B5-67	121.7	0.4141	0.2071	31.94	1.7034E-07	116	2.656E-06	2.290E-06
B5-71	118.7	0.4467	0.2233	24.74	1.7034E-07	146	2.078E-06	2.483E-06
B5-94	122.7	0.5966	0.2983	30.54	2.3847E-07	173	3.535E-06	3.360E-06
B5-95	122.7	0.5952	0.2976	30.7	2.3847E-07	171	3.589E-06	3.352E-06
B5-96	121.7	0.5985	0.2993	29.74	2.3847E-07	176	3.443E-06	3.372E-06

Table 4-6. Effects of catalyst loading and space time on both conversion of H_2S to elemental sulfur and reaction rate of H_2S with 0.02 – 0.1 g catalyst in a micro bubble reactor and a 50-SCCM feed stream containing 5,000-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 115 - 123 psia, 140°C, and 0.169 – 0.870 s space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Reaction Rate of H_2S, g-mole/s-g-cat	Space Time, s	Feed Composition, v%					Conversion %
						H_2	H_2S	SO_2	moisture	N_2	
B5-3	140	117.7	0.0206	1.9801E-06	0.171	70	0.498	0.25	10	19.252	24.04
B5-4	140	121.03	0.0206	1.9282E-06	0.176	70	0.498	0.25	10	19.252	23.41
B5-5	140	119.7	0.0204	1.9946E-06	0.172	70	0.498	0.25	10	19.252	23.98
B5-16	140	119.03	0.0207	1.7579E-06	0.174	70	0.498	0.25	10	19.252	21.45
B5-69	140	122.7	0.0204	1.7073E-06	0.177	70	0.5	0.25	10	19.25	20.45
B5-70	140	114.7	0.0209	1.9963E-06	0.169	70	0.5	0.25	10	19.25	24.49
B5-71	140	118.7	0.0202	2.0862E-06	0.169	70	0.5	0.25	10	19.25	24.74
B5-88	140	120.7	0.0401	1.0076E-06	0.342	70	0.5	0.25	10	19.25	23.72
B5-90	140	121.7	0.0402	1.1411E-06	0.345	70	0.5	0.25	10	19.25	26.93
B5-92	140	119.7	0.0404	1.1728E-06	0.341	70	0.5	0.25	10	19.25	27.82
B5-81	140	122.7	0.0604	6.2737E-07	0.523	70	0.5	0.25	10	19.25	22.25
B5-83	140	121.7	0.0607	9.1968E-07	0.521	70	0.5	0.25	10	19.25	32.77
B5-84	140	122.7	0.0601	1.0775E-06	0.521	70	0.5	0.25	10	19.25	38.02
B5-85	140	117.7	0.0604	6.2083E-07	0.502	70	0.5	0.25	10	19.25	22.01
B5-86	140	119.7	0.0604	9.4075E-07	0.510	70	0.5	0.25	10	19.25	33.36
B5-77	140	121.7	0.0802	8.2645E-07	0.689	70	0.5	0.25	10	19.25	38.91
B5-78	140	120.7	0.0801	6.8951E-07	0.682	70	0.5	0.25	10	19.25	32.42
B5-79	140	121.7	0.0804	7.1231E-07	0.691	70	0.5	0.25	10	19.25	33.62
B5-80	140	122.7	0.0802	7.4729E-07	0.695	70	0.5	0.25	10	19.25	35.18
B5-72	140	119.7	0.1001	8.0551E-07	0.846	70	0.5	0.25	10	19.25	47.34
B5-74	140	122.7	0.1004	7.5478E-07	0.870	70	0.5	0.25	10	19.25	44.49
B5-75	140	119.7	0.1004	7.6557E-07	0.848	70	0.5	0.25	10	19.25	45.12

Table 4-7. Effects of concentrations of H_2S on conversion of H_2S with 0.02-g alumina catalyst in a micro bubble reactor and a 50-SCCM feed stream containing 3,000 – 7,000-ppmv H_2S and 1,500 - 3,500-ppmv SO_2, 10-v% moisture, and 62 - 78-v% H_2 at 140°C, 115 – 123 psia, and 0.168 – 0.178 second space time.

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v%					Conversion %
						H_2	H_2S	SO_2	moisture	N_2	
B5-3	140	117.7	0.0206	50	0.171	70	0.498	0.25	10	19.252	24.04
B5-4	140	121.03	0.0206	50	0.176	70	0.498	0.25	10	19.252	23.41
B5-5	140	119.7	0.0204	50	0.172	70	0.498	0.25	10	19.252	23.98
B5-16	140	119.03	0.0207	50	0.174	70	0.498	0.25	10	19.252	21.45
B5-36	140	119.7	0.0205	50	0.173	70	0.5	0.25	10	19.25	27.58
B5-37	140	120.7	0.0207	50	0.176	70	0.5	0.25	10	19.25	28.90

Table 4-7. Continued-1

Run Number	Temperature, °C	Pressure psia	Catalyst Amount, g	Total Feed scc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	moisture	N_2	Conversion %
B5-69	140	122.7	0.0204	50	0.177	70	0.5	0.25	10	19.25	20.45
B5-70	140	114.7	0.0209	50	0.169	70	0.5	0.25	10	19.25	24.49
B5-71	140	118.7	0.0202	50	0.169	70	0.5	0.25	10	19.25	24.74
B5-94	140	122.7	0.0206	50	0.178	62	0.7	0.35	10	26.95	30.54
B5-95	140	122.7	0.0204	50	0.177	62	0.7	0.35	10	26.95	30.7
B5-96	140	121.7	0.0206	50	0.177	62	0.7	0.35	10	26.95	29.74
B5-97	140	121.7	0.0203	50	0.174	78	0.3	0.15	10	11.55	14.86
B5-98	140	117.7	0.0204	50	0.169	78	0.3	0.15	10	11.55	13.24
B5-99	140	121.7	0.0202	50	0.174	78	0.3	0.15	10	11.55	16.65
B5-100	140	118.7	0.0201	50	0.168	78	0.3	0.15	10	11.55	11.31
B5-101	140	120.7	0.0204	50	0.174	78	0.3	0.15	10	11.55	13.78

Table 5-1. Conversion of 3,000 - 10,000 ppm hydrogen sulfide with 1,500 - 5,000 ppm sulfur dioxide in the presence of 50 - 78 v-% hydrogen and 2-cm diameter, 15-cm long, 400-cells/in^2, γ-alumina wash-coated monolithic catalyst at 125 -155 °C, 40 - 201 psia, and 110 – 557 s space time.

Run Number	Temperature °C	Pressure psia	Total Feed cc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	water	N_2	H_2S Conversion, %
M-1	140	121	50	335	70	0.50	0.25	10	19.25	59.27
M-2	140	120	50	332	70	0.50	0.25	10	19.25	56.74
M-3	140	123	50	341	70	0.50	0.25	10	19.25	54.8
M-4	140	123	50	341	70	0.50	0.25	10	19.25	49.89
M-5	140	122	50	338	70	0.50	0.25	10	19.25	54.76
M-6	155	116	50	310	70	0.50	0.25	10	19.25	46.52
M-7	155	122	50	326	70	0.50	0.25	10	19.25	44.2
M-8	155	120	50	321	70	0.50	0.25	10	19.25	44.97
M-9	125	119	50	342	70	0.50	0.25	10	19.25	60.1
M-10	125	120	50	345	70	0.50	0.25	10	19.25	60.99
M-11	125	120	50	345	70	0.50	0.25	10	19.25	60.78
M-12	133	122	50	344	70	0.50	0.25	10	19.25	57.31
M-13	133	122	50	344	70	0.50	0.25	10	19.25	54.04
M-14	133	122	50	344	70	0.50	0.25	10	19.25	48.76
M-15	133	122	50	344	70	0.50	0.25	10	19.25	51.96
M-16	133	122	50	344	70	0.50	0.25	10	19.25	53.38
M-17	148	120	50	326	70	0.50	0.25	10	19.25	41.47
M-18	148	122	50	331	70	0.50	0.25	10	19.25	40.96
M-19	148	122	50	331	70	0.50	0.25	10	19.25	41.98
M-20	140	79	50	218	70	0.50	0.25	10	19.25	50.44
M-21	140	78	50	216	70	0.50	0.25	10	19.25	48.59
M-22	140	79	50	218	70	0.50	0.25	10	19.25	47.79

Table 5-1. Continued-1

Run Number	Temperature °C	Pressure psia	Total Feed cc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	water	N_2	H_2S Conversion, %
M-23	140	40	50	110	70	0.50	0.25	10	19.25	40.82
M-24	140	41	50	113	70	0.50	0.25	10	19.25	41.88
M-25	140	42	50	116	70	0.50	0.25	10	19.25	42
M-26	140	163	50	452	70	0.50	0.25	10	19.25	31.66
M-27	140	163	50	452	70	0.50	0.25	10	19.25	33.02
M-28	140	162	50	449	70	0.50	0.25	10	19.25	33.57
M-29	140	199	50	552	70	0.50	0.25	10	19.25	31.73
M-30	140	199	50	552	70	0.50	0.25	10	19.25	22.49
M-31	140	199	50	552	70	0.50	0.25	10	19.25	19.44
M-32	140	201	50	557	70	0.50	0.25	10	19.25	22.77
M-33	140	122	50	338	70	0.50	0.25	10	19.25	51.2
M-34	140	123	50	341	70	0.50	0.25	10	19.25	49.73
M-35	140	123	50	341	70	0.50	0.25	10	19.25	46.94
M-36	140	122	50	338	70	0.50	0.25	10	19.25	46.83
M-37	140	123	50	341	70	0.50	0.25	10	19.25	46.89
M-38	140	119	55	300	64	0.45	0.23	18.18	17.50	41.42
M-39	140	120	55	302	64	0.45	0.23	18.18	17.50	40.09
M-40	140	120	55	302	64	0.45	0.23	18.18	17.50	42.93
M-41	140	123	47.5	359	74	0.52	0.26	5.26	20.26	52.97
M-42	140	121	47.5	353	74	0.52	0.26	5.26	20.26	51.02
M-43	140	122	47.5	356	74	0.52	0.26	5.26	20.26	52.21
M-44	140	124	57	301	61	0.44	0.22	21.05	16.89	32.22
M-45	140	122	57	296	61	0.44	0.22	21.05	16.89	35.33
M-46	140	123	57	299	61	0.44	0.22	21.05	16.89	36.24
M-47	140	123	57	299	61	0.44	0.22	21.05	16.89	33.46
M-48	140	123	57	299	61	0.44	0.22	21.05	16.89	31.28
M-49	140	121	50	335	70	0.50	0.25	10	19.25	44.34
M-50	140	122	50	338	70	0.50	0.25	10	19.25	39.55
M-51	140	122	50	338	70	0.50	0.25	10	19.25	40.1
M-52	140	123	50	341	70	0.50	0.25	10	19.25	40.29
M-53	140	120	50	332	62	0.70	0.35	10	26.95	89.97
M-54	140	119	50	330	62	0.70	0.35	10	26.95	72.82
M-55	140	122	50	338	62	0.70	0.35	10	26.95	63.49
M-56	140	124	50	343	62	0.70	0.35	10	26.95	60.53
M-57	140	119	50	330	62	0.70	0.35	10	26.95	57.92
M-58	140	119	50	330	62	0.70	0.35	10	26.95	59.37
M-59	140	122	50	338	62	0.70	0.35	10	26.95	57.83
M-60	140	124	50	343	62	0.70	0.35	10	26.95	56.2
M-61	140	123	50	341	62	0.70	0.35	10	26.95	56.63
M-62	140	120	50	332	50	1.00	0.50	10	38.50	76.97
M-63	140	122	50	338	50	1.00	0.50	10	38.50	76.82
M-64	140	119	50	330	50	1.00	0.50	10	38.50	78.19
M-65	140	120	50	332	78	0.30	0.15	10	11.55	45.09
M-66	140	124	50	343	78	0.30	0.15	10	11.55	42.71
M-67	140	124	50	343	78	0.30	0.15	10	11.55	42.52
M-68	140	121	50	335	78	0.30	0.15	10	11.55	44.14

Table 5-2. Effect of moisture on conversion of H_2S to elemental sulfur with 2-cm diameter, 15-cm long, 400-cells/in^2, γ-alumina wash-coated monolithic catalyst and a 50-SCCM feed stream containing 4,400 - 5,200 ppm H_2S and 2,200 - 2,600 ppm SO_2, and 61 - 74 v-% hydrogen at 140°C, 119 - 124 psia, and 296 - 359 s space time.

Run	Temperature	Pressure	Total Feed	Space	Feed Composition, v%					H_2S
Number	°C	psia	cc/min	Time, s	H_2	H_2S	SO_2	water	N_2	Conversion, %
M-35	140	123	50	341	70	0.50	0.25	10	19.25	46.94
M-36	140	122	50	338	70	0.50	0.25	10	19.25	46.83
M-37	140	123	50	341	70	0.50	0.25	10	19.25	46.89
M-38	140	119	55	300	63.64	0.45	0.23	18.18	17.50	41.42
M-39	140	120	55	302	63.64	0.45	0.23	18.18	17.50	40.09
M-40	140	120	55	302	63.64	0.45	0.23	18.18	17.50	42.93
M-41	140	123	47.5	359	73.68	0.52	0.26	5.26	20.26	52.97
M-42	140	121	47.5	353	73.68	0.52	0.26	5.26	20.26	51.02
M-43	140	122	47.5	356	73.68	0.52	0.26	5.26	20.26	52.21
M-44	140	124	57	301	61.40	0.44	0.22	21.05	16.89	32.22
M-45	140	122	57	296	61.40	0.44	0.22	21.05	16.89	35.33
M-46	140	123	57	299	61.40	0.44	0.22	21.05	16.89	36.24
M-47	140	123	57	299	61.40	0.44	0.22	21.05	16.89	33.46

Table 5-3. Effect of H_2S concentration on conversion of H_2S to elemental sulfur with 2-cm diameter, 15-cm long, 400-cells/in^2, γ-alumina wash-coated monolithic catalyst and a 50-SCCM feed stream containing 3,000 - 10,000 ppm H_2S and 1,500 - 5,000 ppm SO_2, and 50 - 78 v-% hydrogen at 140°C, 119 - 124 psia, and 330 - 343 s space time.

Run	Temperature	Pressure	Total Feed	Space	Feed Composition, v%					H_2S
Number	°C	psig	cc/min	Time, s	H_2	H_2S	SO_2	water	N_2	Conversion, %
M-1	140	121	50	335	70	0.50	0.25	10	19.25	59.27
M-2	140	120	50	332	70	0.50	0.25	10	19.25	56.74
M-3	140	123	50	341	70	0.50	0.25	10	19.25	54.8
M-4	140	123	50	341	70	0.50	0.25	10	19.25	49.89
M-5	140	122	50	338	70	0.50	0.25	10	19.25	54.76
M-33	140	122	50	338	70	0.50	0.25	10	19.25	51.2
M-34	140	123	50	341	70	0.50	0.25	10	19.25	49.73
M-35	140	123	50	341	70	0.50	0.25	10	19.25	46.94
M-36	140	122	50	338	70	0.50	0.25	10	19.25	46.83
M-37	140	123	50	341	70	0.50	0.25	10	19.25	46.89
M-59	140	122	50	338	62	0.70	0.35	10	26.95	57.83
M-60	140	124	50	343	62	0.70	0.35	10	26.95	56.2
M-61	140	123	50	341	62	0.70	0.35	10	26.95	56.63
M-62	140	120	50	332	50	1.00	0.50	10	38.50	76.97
M-63	140	122	50	338	50	1.00	0.50	10	38.50	76.82
M-64	140	119	50	330	50	1.00	0.50	10	38.50	78.19
M-65	140	120	50	332	78	0.30	0.15	10	11.55	45.09
M-66	140	124	50	343	78	0.30	0.15	10	11.55	42.71
M-67	140	124	50	343	78	0.30	0.15	10	11.55	42.52
M-68	140	121	50	335	78	0.30	0.15	10	11.55	44.14

Table 5-4. Effect of reaction temperature on conversion of H_2S to elemental sulfur with 2-cm diameter, 15-cm long, 400-cells/in^2, γ-alumina wash-coated monolithic catalyst and a 50-SCCM feed stream containing 5,000 ppm H_2S and 2,500 ppm SO_2, and 70 v-% H_2 at 125 - 155°C,116 - 123 psia, and 310 - 345 s space time.

Run Number	Temperature °C	Pressure psia	Total Feed cc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	water	N_2	H_2S Conversion, %
M-1	140	121	50	335	70	0.50	0.25	10	19.25	59.27
M-2	140	120	50	332	70	0.50	0.25	10	19.25	56.74
M-3	140	123	50	341	70	0.50	0.25	10	19.25	54.8
M-4	140	123	50	341	70	0.50	0.25	10	19.25	49.89
M-5	140	122	50	338	70	0.50	0.25	10	19.25	54.76
M-6	155	116	50	310	70	0.50	0.25	10	19.25	46.52
M-7	155	122	50	326	70	0.50	0.25	10	19.25	44.2
M-8	155	120	50	321	70	0.50	0.25	10	19.25	44.97
M-9	125	119	50	342	70	0.50	0.25	10	19.25	60.1
M-10	125	120	50	345	70	0.50	0.25	10	19.25	60.99
M-11	125	120	50	345	70	0.50	0.25	10	19.25	60.78
M-12	133	122	50	344	70	0.50	0.25	10	19.25	57.31
M-13	133	122	50	344	70	0.50	0.25	10	19.25	54.04
M-14	133	122	50	344	70	0.50	0.25	10	19.25	48.76
M-15	133	122	50	344	70	0.50	0.25	10	19.25	51.96
M-16	133	122	50	344	70	0.50	0.25	10	19.25	53.38
M-17	148	120	50	326	70	0.50	0.25	10	19.25	41.47
M-18	148	122	50	331	70	0.50	0.25	10	19.25	40.96
M-19	148	122	50	331	70	0.50	0.25	10	19.25	41.98

Table 5-5. Effect of reaction pressure and space time on conversion of H_2S to elemental sulfur with 2-cm diameter, 15-cm long, 400-cells/in^2, γ-alumina wash-coated monolithic catalyst and a 50-SCCM feed stream containing 5,000 ppm H_2S and 2,500 ppm SO_2, 10-v% moisture, and 70 v-% hydrogen at 125 - 155°C, 40 - 201 psia, and 110 - 557 s space time.

Run Number	Temperature °C	Pressure psia	Total Feed cc/min	Space Time, s	Feed Composition, v% H_2	H_2S	SO_2	water	N_2	H_2S Conversion, %
M-20	140	79	50	218	70	0.50	0.25	10	19.25	50.44
M-21	140	78	50	216	70	0.50	0.25	10	19.25	48.59
M-22	140	79	50	218	70	0.50	0.25	10	19.25	47.79
M-23	140	40	50	110	70	0.50	0.25	10	19.25	40.82
M-24	140	41	50	113	70	0.50	0.25	10	19.25	41.88
M-25	140	42	50	116	70	0.50	0.25	10	19.25	42
M-26	140	163	50	452	70	0.50	0.25	10	19.25	31.66
M-27	140	163	50	452	70	0.50	0.25	10	19.25	33.02
M-28	140	162	50	449	70	0.50	0.25	10	19.25	33.57
M-30	140	199	50	552	70	0.50	0.25	10	19.25	22.49
M-31	140	199	50	552	70	0.50	0.25	10	19.25	19.44
M-32	140	201	50	557	70	0.50	0.25	10	19.25	22.77
M-35	140	123	50	341	70	0.50	0.25	10	19.25	46.94
M-36	140	122	50	338	70	0.50	0.25	10	19.25	46.83
M-37	140	123	50	341	70	0.50	0.25	10	19.25	46.89

Table 5-6. Effects of reaction duration on conversion of H_2S with 2-cm diameter, 15-cm long, 400-cells/in^2, γ-alumina wash-coated monolithic catalyst and a 50-SCCM feed stream containing 5,000-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 for 6 – 33 hrs at 140°C and 120 psia.

Reaction Duration, hr	Conversion of H_2S, %
5.9	89.97
10.4	72.82
14.4	63.49
17.4	60.53
20.4	57.92
22.9	59.37
25.4	57.83
29.1	56.2
33.1	56.63

CALCULATIONS

Gaseous samples having a 4-cm^3 volume, obtained from the outlet stream of a reactor, are injected into a gas chromatograph to analyze gas chromatography (GC) areas of gaseous samples. Conversions of H_2S are obtained by dividing the GC area of H_2S from a reaction run with that from its blank run.

$$x = \frac{(A_B - A_R)}{A_B} \tag{1}$$

where x: conversion of H_2S.

A_B: GC area of H_2S of the 4-cc gaseous sample for a blank run.

A_R: GC area of H_2S of the 4-cc gaseous sample for a reaction run.

$$2H_2S\ (g) + SO_2\ (g) \leftrightarrow 3S\ (\ell) + 2H_2S\ (g) \tag{2}$$

Surface reaction rates of conversion of H_2S into elemental sulfur in a micro packed-bed/bubble reactor are obtained with amounts of the alumina catalyst loaded in the micro reactor, molar feed rates of H_2S to the micro reactor and conversion of H_2S, as shown in the following equation.

$$-r_A' = \frac{F_{Ao}x}{W} \tag{3}$$

where $-r_A'$: surface reaction rates

F_{Ao}: molar flow rates of H_2S in a feed stream to a micro reactor

x: conversion of H_2S into elemental sulfur

Reaction rates of conversion of H_2S into elemental sulfur in a monolithic catalyst reactor are obtained with the bulk volume of the monolithic catalyst loaded in the monolithic catalyst reactor, molar feed rates of H_2S to the monolithic catalyst reactor and conversion of H_2S, as shown in the following equation.

$$-r_A' = \frac{F_{Ao}x}{V} \tag{4}$$

where $-r_A'$: reaction rates

F_{Ao}: molar flow rates of H_2S in a feed stream to a reactor

x: conversion of H_2S into elemental sulfur

V: bulk volume of the monolithic catalyst in a reactor

Space time of gaseous reaction mixtures in a micro reactor or a monolithic catalyst reactor is calculated by dividing bulk volume of catalyst particles or a monolithic catalyst with volumetric flow rate of gaseous reaction mixtures fed under reaction conditions, as shown in the following equation.

$$\tau = \frac{V}{v_o} \tag{5}$$

where τ: space time

V: bulk volume of catalyst particles or a monolithic catalyst

vo: volumetric flow rate of gaseous reaction mixture fed under reaction conditions

RESULTS AND DISCUSSION

Experiments on conversion of hydrogen sulfide into element sulfur were carried out at various experimental conditions (see Tables 1 through 3) to evaluate effects of catalyst amounts, , space times, moisture concentrations, reaction pressures, reaction temperatures, and concentrations of H_2S and SO_2, partial pressures of H_2S and SO_2, and reaction durations on conversion and reaction rates of hydrogen sulfide into elemental sulfur.

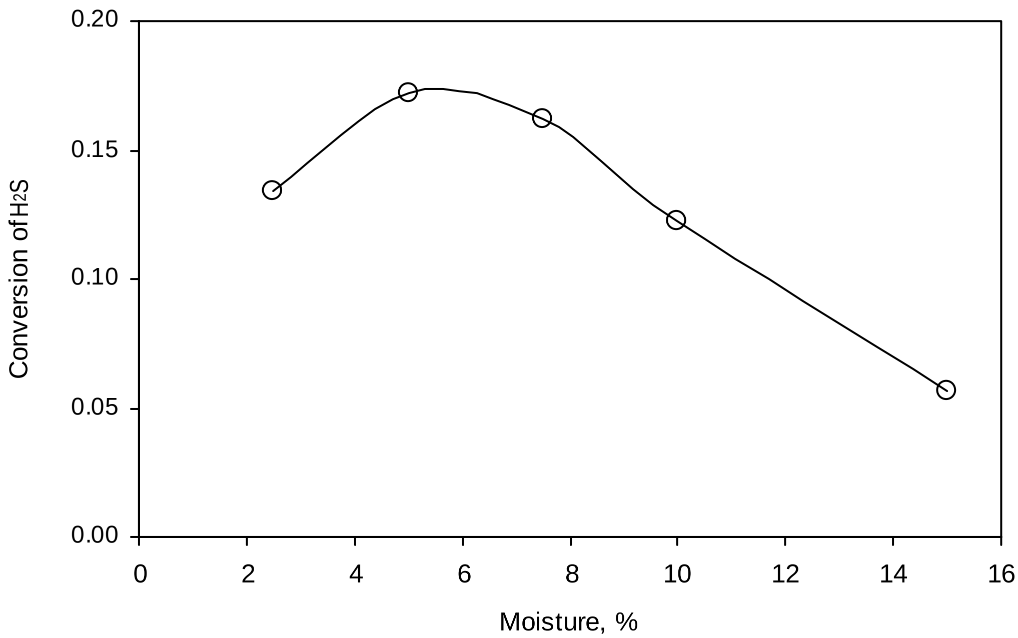
Effects of Moisture on Conversion of H_2S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.040 – 0.047

seconds (see Table 2-8) to evaluate effects of moisture concentrations on conversion of hydrogen sulfide into elemental sulfur at 140°C and 120 – 123 psia. Gas mixtures fed to the reactor contain 64 – 72 v% hydrogen, 8,200 - 9,200-ppmv H_2S, 1,600- 1,800 ppmv SO_2, 2.5 – 13.6 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 110 cm3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.06 – 0.17.

Concentrations of moisture in the presence of 8,200 – 9200 ppmv H_2S, 1,600 - 1,800 ppmv SO_2, 64 – 72 v-% hydrogen, and nitrogen as remainder appear to affect significantly conversion of H_2S into elemental sulfur in the moisture range of 2.5 – 15 v% in a simulated coal gas mixture at 140°C and 120 – 123 psia. Conversion of H_2S decreases with increased concentration of moisture over the moisture range of 5 – 15 v%, as shown in Figure 2-1.

Figure 2-1. Effects of moisture on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 98 - 110 SCCM feed stream containing 8,200 - 9,200 ppm H_2S, 1,600 - 1,800 ppm SO_2, and 64 - 72 H_2 at 120 - 123 psia and 140°C.

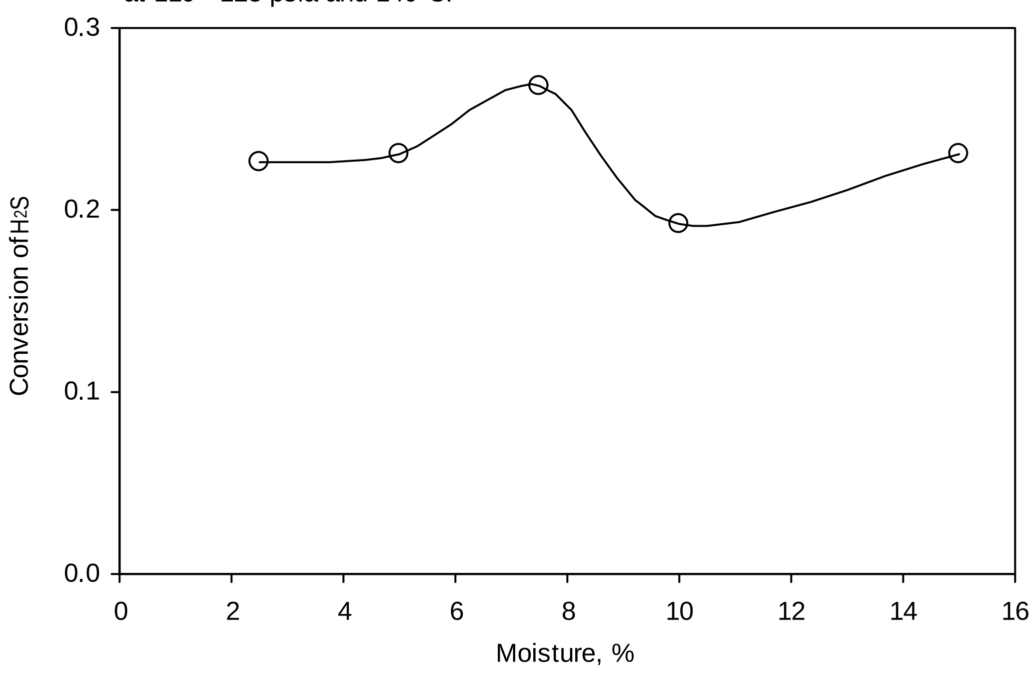


Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.040 – 0.047 seconds (see Table 2-5) to evaluate effects of moisture concentrations on conversion of hydrogen sulfide into elemental sulfur at 140°C and 119 – 123 psia. Gas mixtures fed to the reactor contain 64 – 77 v% hydrogen, 6,800 - 7,700 ppmv H_2S, 2,300 – 2,600 ppmv SO_2, 2.6 – 13.6 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 110 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.19 – 0.27.

Concentrations of moisture in the presence of 6,800 - 7,700 ppmv H_2S and 2,300 – 2,600 ppmv SO_2 appear to affect slightly conversion of H_2S into elemental sulfur in the moisture range of 2.6 – 13.6 v% in a simulated coal gas mixture at 119 – 123 psia (see Figure 2-2). However, conversion of H_2S is highest at 7.3-v % moisture.

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.040 – 0.045 seconds (see Table 2-4) to evaluate effects of moisture concentrations on conversion of hydrogen sulfide into elemental sulfur at 140°C and 120 – 123 psia. Gas mixtures fed to the reactor contain 64 – 72 v% hydrogen, 3,200 - 3,600-ppmv H_2S, 4,100 - 4,600 ppmv SO_2, 2.5 – 13.6 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 110 cm3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.33 – 0.43. Concentrations of moisture in the presence of 3,200 - 3,600 ppmv H_2S and 4,100 - 4,600 ppmv SO_2 appear to affect slightly conversion of H_2S into elemental sulfur in the moisture range of 2.5 – 13.6 v% in a simulated coal gas mixture at 120 – 123 psia (see Figure 2-3). Conversion of H_2S slightly increases with moisture concentration. However, conversion of H_2S is highest at 7.3-v % moisture.

Figure 2-2. Effects of moisture on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 98 - 110 SCCM feed stream containing 6,800 - 7,700 ppm H_2S, 2,300 - 2,600 ppm SO_2, 64 - 77 v% H_2 at 119 - 123 psia and 140°C.



Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.041 – 0.046 seconds (see Table 2-2) to evaluate effects of moisture concentrations on conversion of hydrogen sulfide into elemental sulfur at 140°C and 112 – 123 psia. Gas mixtures fed to the reactor contain 64 – 72 v% hydrogen, 4,500 - 5,100 ppmv H_2S, 3,400 – 3,900 ppmv SO_2, and 2.6 – 13.6

v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 110 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.25 – 0.34. Concentrations of moisture in the presence of 4,500 - 5,100 ppmv H_2S and 3,400 – 3,900 ppmv SO_2 appear to affect slightly conversion of H_2S into elemental sulfur in the moisture range of 2.6 – 13.6 v% in a simulated coal gas mixture at 112 – 123 psia (see Figure 2-4). Conversion of H_2S is not affected significantly by moisture concentration. However, conversion of H_2S is lowest at 7.3-v % moisture.

Figure 2-3. Effects of moisture on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 98 - 110 SCCM feed stream containing 3,200 - 3,600 ppm H_2S, 4,100 - 4,600 ppm SO_2 , 64 - 72 v% H_2 at 120 - 123 psia and 140°C.

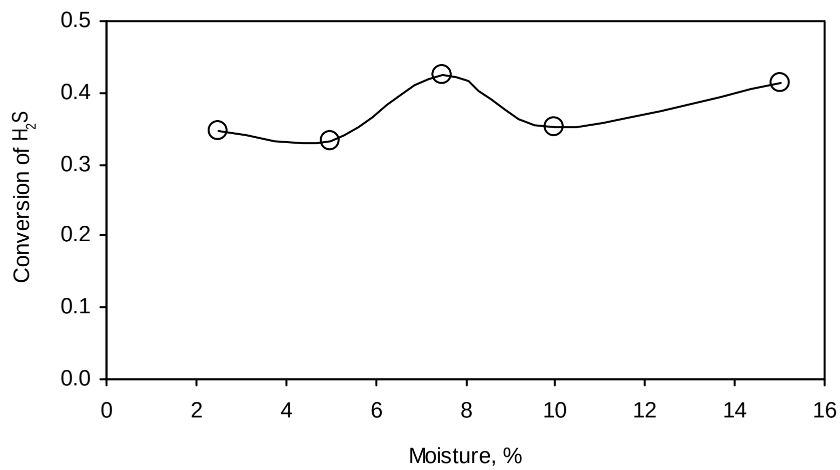


Figure 2-4. Effects of moisture on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 98 - 110 SCCM feed stream containing 4,500 - 5,100 ppm H_2S and 3,400 - 3,900 ppm SO_2, 64 - 72 v% H_2 at 120 - 123 psia and 140°C.

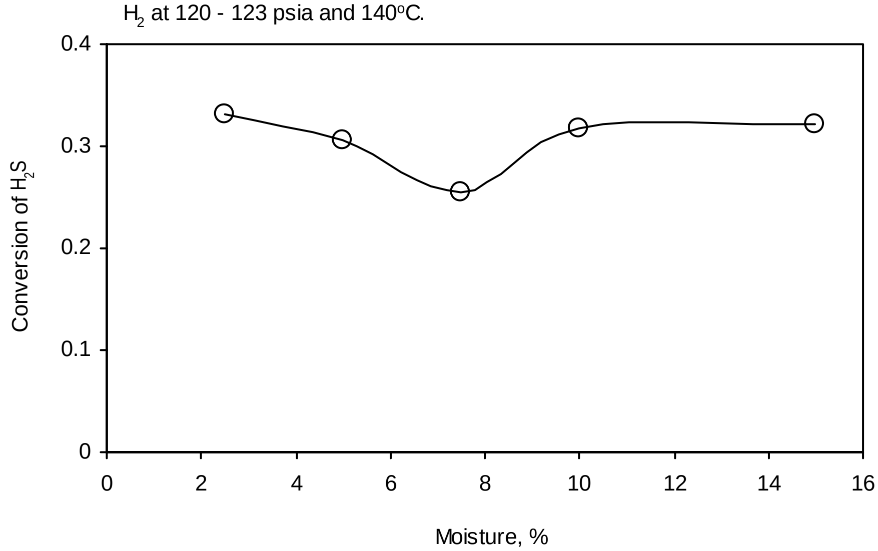
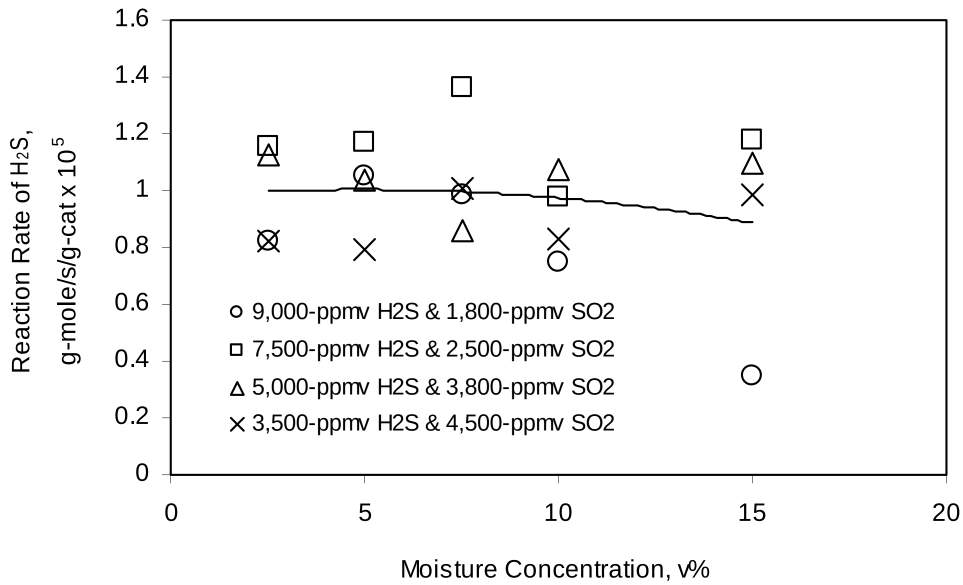
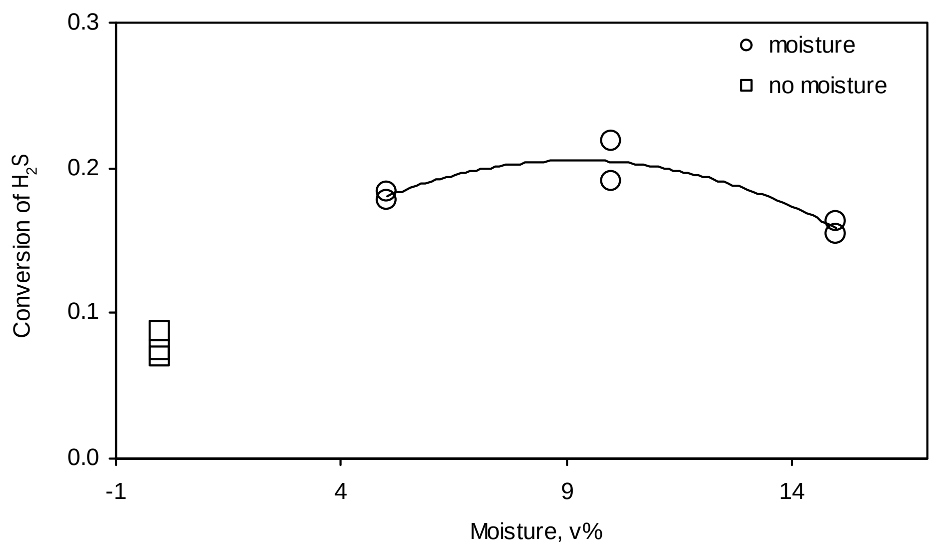


Figure 2-5. Effects of moisture on reaction rate of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 70-v% H_2 at 140°C.



Reaction rates of H_2S in Figure 2-5 were calculated with experimental data of various feed concentrations of H_2S and SO_2 shown in Figures 2-1 through 2-4. These reaction rates of H_2S were plotted against various moisture concentrations. Concentrations of H_2S and SO_2 affect significantly reaction rates of H_2S. Reaction rates of H_2S slightly decrease with increased concentrations of moisture.

Figure 3-1. Effects of moisture on conversion of H_2S with 0.04-g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, and 70-v% H_2 at 140°C, 118 - 122 psia, and 0.168- 0.174 s space time.

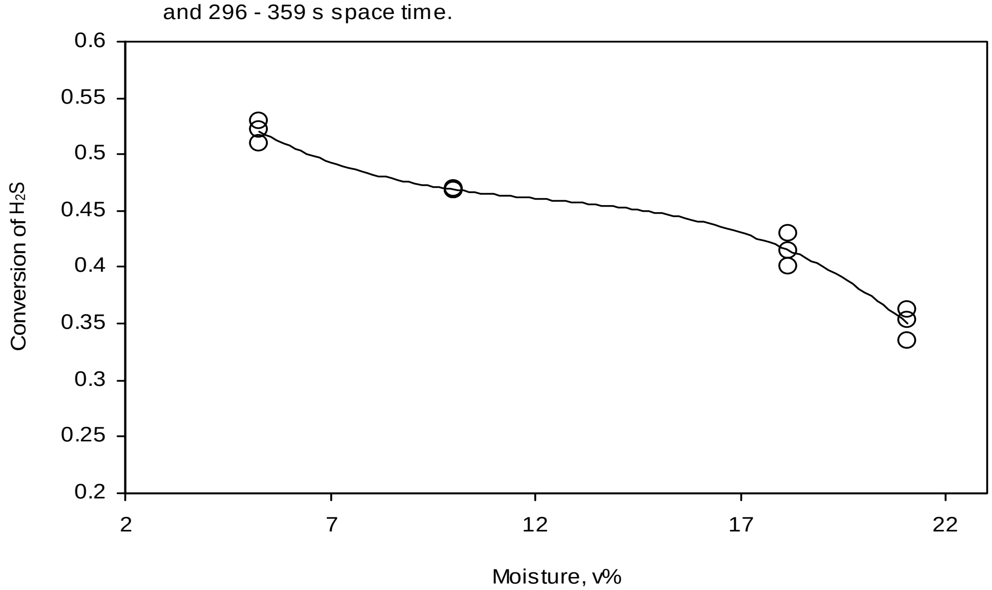


Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.04-g catalyst in a micro bubble reactor were carried out over the space time range of 0.168 – 0.174 s to evaluate effects of moisture concentration on conversion of hydrogen sulfide to elemental sulfur at 140^{o}C and 118 – 122 psia. A gas mixture consisting of 70 v% hydrogen, 4,980-ppmv H_2S, 2,500 ppmv SO_2, 0 – 15 v% moisture, and nitrogen as remainder is fed to a micro bubble reactor. Volumetric feed rates of the gas mixture to the micro bubble reactor are 100 SCCM. Conversion of H_2S to elemental sulfur is 0.07 – 0.22.

Concentration of moisture in the presence of 4,980 ppmv H_2S and 2,500 ppmv SO_2 affects conversion of H_2S to elemental sulfur in the moisture range of 0 - 15 v% in a simulated coal gas mixture at 118 – 122 psia (see Figure 3-1). However, conversions of H_2S to elemental sulfur in the presence of moisture are higher than those in the absence of moisture. Conversion of H_2S to elemental sulfur in the presence of moisture appears to be not affected significantly by amount of moisture. Conversion of H_2S to elemental sulfur is highest at 10-v % moisture.

Concentration of moisture in a 50-SCCM feed stream containing a stoichiometric feed ratio of H_2S and SO_2, 4,400 – 5,000 ppmv H_2S and 2,200 – 2,500 ppmv SO_2, affects conversion of H_2S to elemental sulfur in the moisture range of 5 - 21 v% in a simulated coal gas mixture at 119 – 123 psia (see Figure 5-1). Conversions of H_2S to elemental sulfur in a monolithic catalyst reactor decreases with increased concentration of moisture.

Figure 5-1. Effects of moisture on conversion of H_2S in a monolith catalyst reactor with a 50-SCCM feed stream containing 4400 - 5200 ppm H_2S, 2200 - 2600 ppm SO_2, 61 - 74 v% H_2, and 10-v% moisture at 119 - 124 psia, 140^{o}C, and 296 - 359 s space time.



Concentrations of moisture in the micro packed-bed reactor and the micro bubble reactor affect slightly conversion of H_2S. Conversion of H_2S in the monolithic catalyst reactor decrease with increased concentrations of moisture.

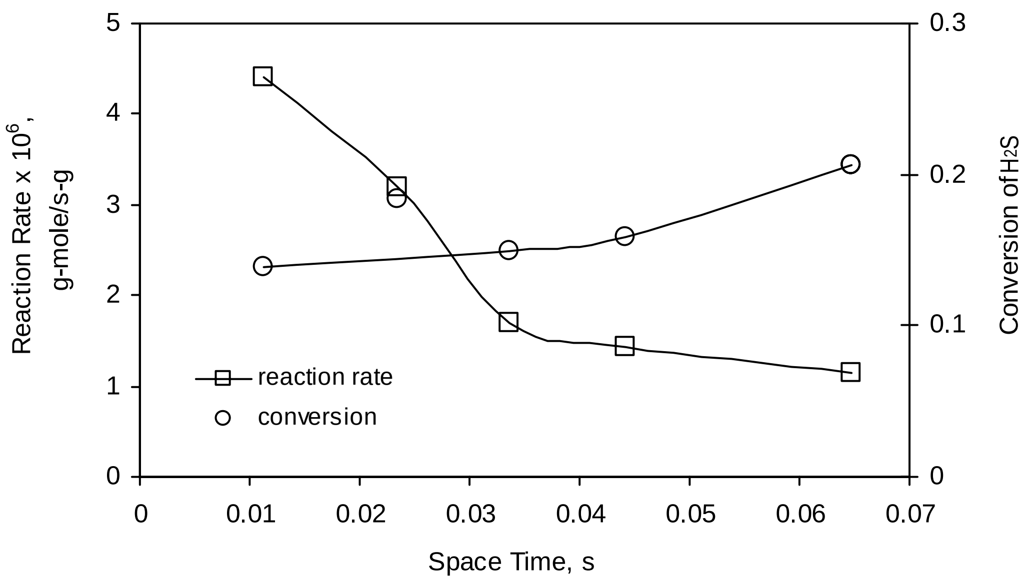
Effects of Space Time on Conversion of H_2S into Elemental Sulfur

Space times for a micro packed-bed reactor and a micro bubble reactor are dependent on feed rates of gas mixtures, catalyst loadings, reaction pressures, and reaction temperatures. Space times increase with increased total reaction pressures and catalyst loadings, and decreased feed rates of gas mixture with the other reaction conditions fixed.

Experiments on conversion of hydrogen sulfide into element sulfur with 0.005 – 0.03 g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.011 – 0.064 seconds (see Table 1-1) 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_2S, 2,490- 2,560 ppm SO_2, 5 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 101 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.14 – 0.21, whereas reaction rates for the conversion of H_2S into elemental sulfur are 1.15 – 4.41 $x10^{-6}$ g-mole/s-g-cat.

Space times affect conversion of H_2S into elemental sulfur and reaction rates for the conversion of H_2S into elemental sulfur in the space time range of 0.011 – 0.064 seconds. Conversion of H_2S into elemental sulfur increases with space times, whereas reaction rates for the conversion of H_2S into elemental sulfur decrease sharply with increased space time over the space time range of 0.011 – 0.032 s and moderately with increased space time over the space time range of 0.032 - 0.064 seconds (see Figure 1-1).

Figure 1-1. Effects of space time on surface reaction rates for the conversion H_2S in a micro packed-bed reactor with 0.005 - 0.03 g catalyst and a 100-SCCM feed containing 7,430 - 7,620-ppm H_2S and 2,490 - 2,560 ppm SO_2 at 140°C and 61 - 64 psia.



Effects of catalyst loading on conversion of H_2S to elemental sulfur were examined at 140°C and 118 - 123 psia. The feed gas mixture to a micro bubble reactor contains 4,980-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2. The volumetric feed rate of the feed gas mixture to the micro bubble reactor is 100 SCCM. The amount range of fresh catalyst particles loaded in the micro bubble reactor is 0.02 – 0.08 g. Conversion of H_2S increases with catalyst loading. However, experimental reaction rate of H_2S (see Equation 3) is independent of catalyst loading, as shown in Figure 3-2. This result may indicate that both surface reaction rate k and equilibrium adsorption constant k_A of H_2S for conversion of H_2S with SO_2 to elemental liquid sulfur are not significantly affected by amount of catalyst particles loaded in the micro bubble reactor. These data also indicate that experimental reaction rate of H_2S with SO_2 be independent of space time of gaseous reaction mixtures in the micro bubble reactor, as shown in Figure 3-3.

Figure 3-2. Effects of catalyst loading on conversion of H_2S with 0.02 - 0.08 g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 118 - 123 psia and 140°C.

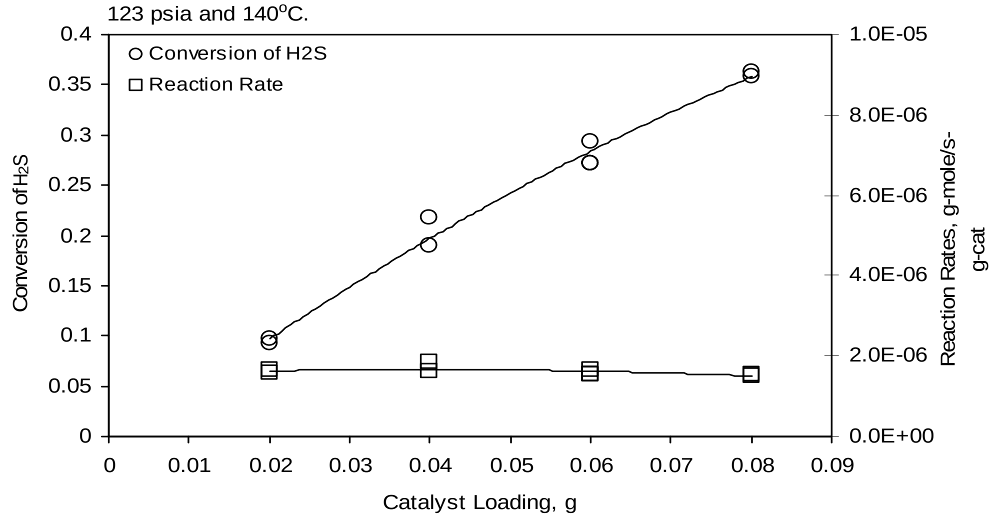
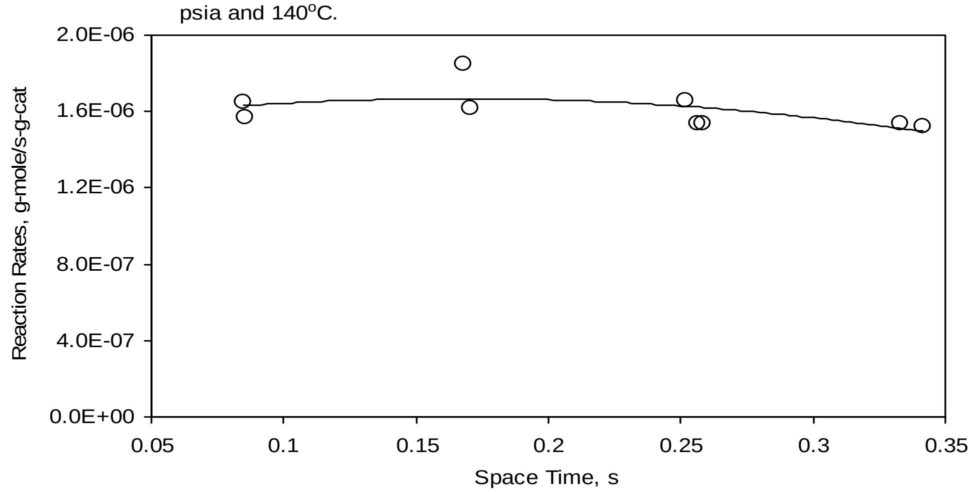
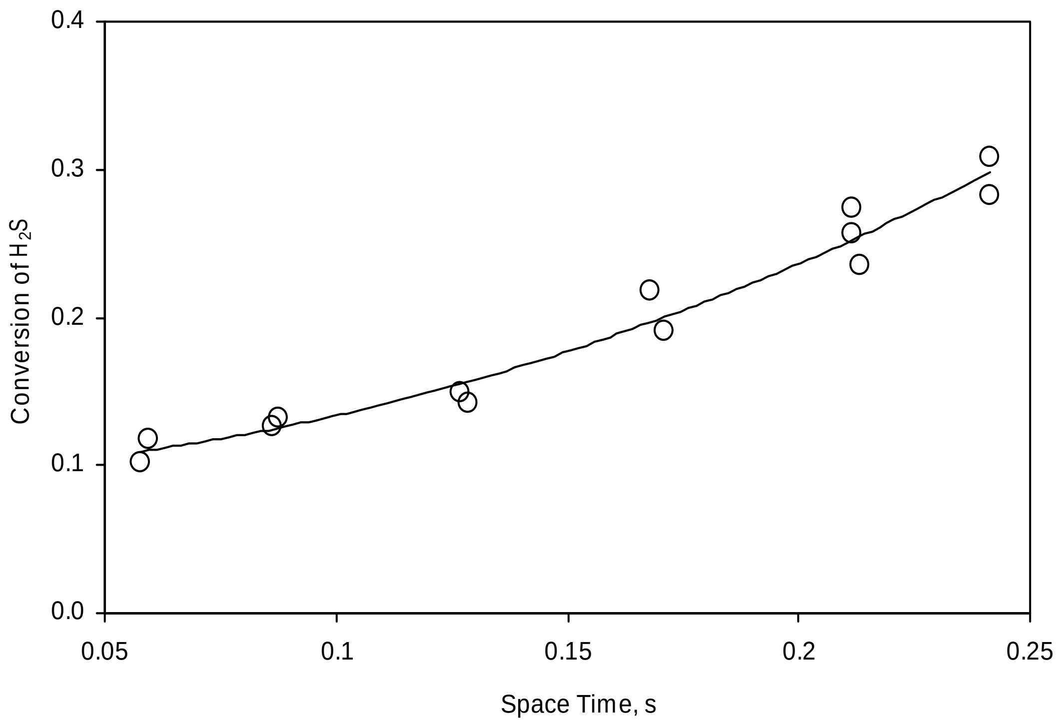


Figure 3-3. Effects of space time on reaction rates of H_2S with 0.02 - 0.08 g catalyst in a bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 118 - 123 psia and 140°C.



Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.04-g catalyst in a micro bubble reactor were carried out over the space time range of 0.06 – 0.24 s, which is developed by increasing total reaction pressure from 40 psia to 170 psia, to evaluate effects of space time on conversion of hydrogen sulfide to elemental sulfur at 140°C and 40 -170 psia. A gas mixture fed to a micro bubble reactor contains 70-v% hydrogen, 4,980-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of the gas mixture to the micro bubble reactor are 100 SCCM. Conversion of H_2S to elemental sulfur is 0.09 – 0.35. Space time affects significantly conversion of H_2S to elemental sulfur in the space time range of 0.06 – 0.24 s. Conversion of H_2S to elemental sulfur increases with space time over the space time range of 0.06 – 0.24 s (see Figure 3-4).

Figure 3-4. Effects of space time on conversion of H_2S with 0.04-g alumina catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 40 - 170 psia and 140°C.



Effects of space times on conversion of H_2S to elemental sulfur were examined over the space time range of 0.16 – 0.85 s at 140°C and 115 - 123 psia by varying catalyst loadings. The feed gas mixture to a micro bubble reactor contains 5,000-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, 70-v% H_2, and nitrogen as remainder. The volumetric feed rate of the feed gas mixture to the micro bubble reactor is 50 SCCM. The amount range of fresh catalyst particles loaded in the micro bubble reactor is 0.02 – 0.1 g. Experimental reaction rate of H_2S, obtained with Equation 3, decreases with increased space times over the space time range of 0.16 – 0.5 s by increasing catalyst loading from 0.02 g to 0.06 g, whereas experimental reaction rate of H_2S level off over the space time range of 0.5 – 0.85 s by increasing catalyst loading from 0.06 g to 0.1 g, as shown in Figure 4-1. These data indicate that experimental reaction rate of H_2S with SO_2 in the space time range of 0.05 –0.85 s be independent of space time of gaseous reaction mixtures in the micro bubble reactor.

Figure 4-1. Effects of space time on conversion and reaction rate of H_2S in a micro bubble reactor with a 50-SCCM feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 10-v% moisture, and 70-v% H_2 at 140°C and 120 psia.

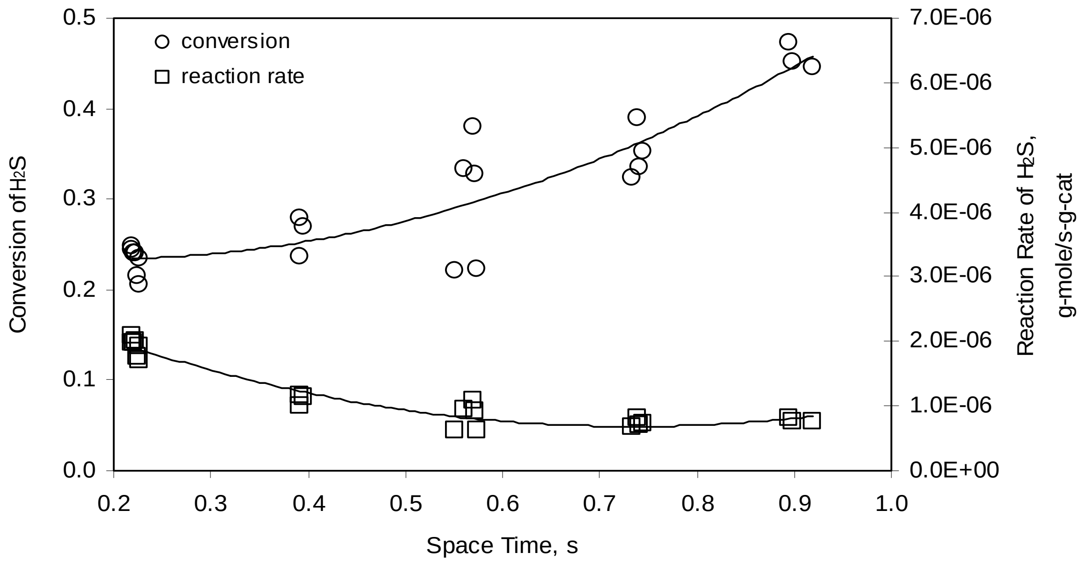
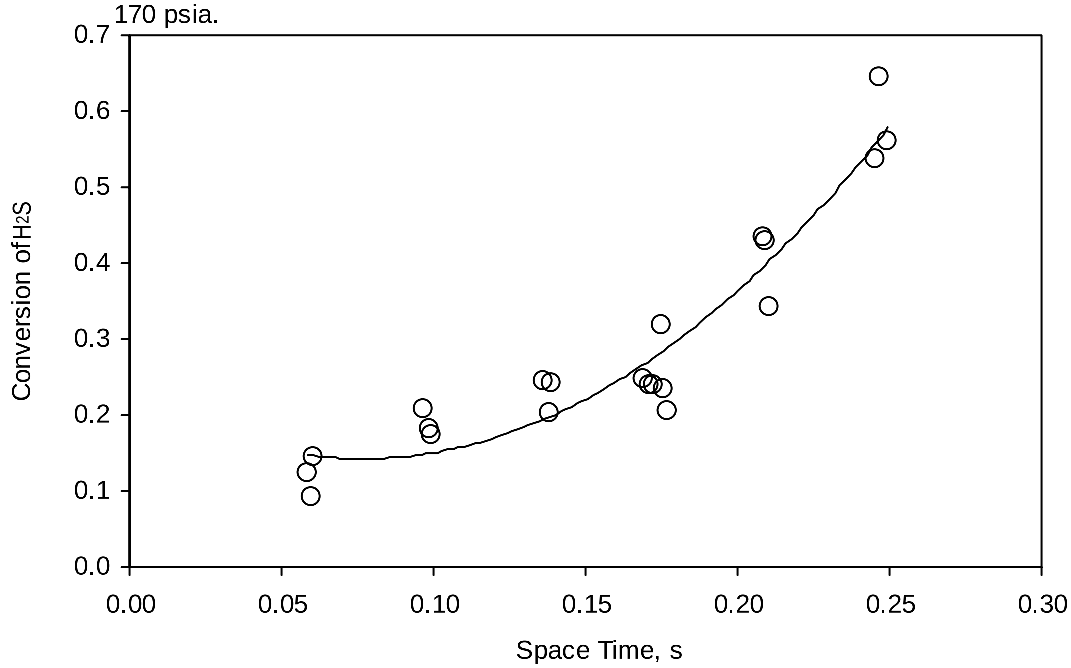


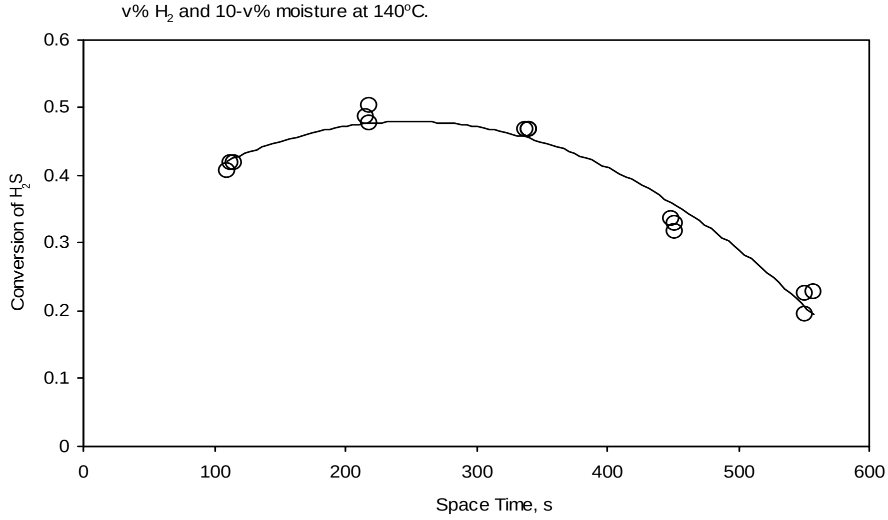
Figure 4-2. Effects of space time on conversion of H_2S with a 50 cc/min feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 10-v% moisture, 70-v% H_2, and 0.02-g catalyst in a micro bubble reactor at 140°C and 40 - 170 psia.



Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.02-g catalyst in a micro bubble reactor were carried out over the space time range of 0.059 – 0.25 s, which is developed by increasing total reaction pressure from 40 psia to 170 psia with the other reaction conditions fixed, to evaluate effects of space time on conversion of hydrogen sulfide to elemental sulfur at 140°C and 40 -170 psia. A gas mixture fed to a micro bubble reactor contains 70-v% hydrogen, 5,000-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of the gas mixture to the micro bubble reactor are 50 SCCM. Conversion of H_2S to elemental sulfur is 0.05 – 0.65. Space time affects significantly conversion of H_2S to elemental sulfur in the space time range of 0.059 – 0.25 s. Conversion of H_2S to elemental sulfur increases with space time over the space time range of 0.059 – 0.25 s (see Figure 4-2).

Experiments on conversion of hydrogen sulfide to elemental sulfur with a 2-cm-diameter 15-cm-long γ-alumina wash-coated 400-cells/inch^2 monolithic catalyst were carried out over the space time range of 110 – 560 s, which is developed by increasing total reaction pressure from 25 psia to 186 psia to evaluate effects of space time on conversion of hydrogen sulfide to elemental sulfur at 140°C and 25 -186 psia. A gas mixture fed to a monolithic catalyst reactor contains 70-v% hydrogen, 5,000-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of the gas mixture to the monolithic catalyst reactor are 50 SCCM. Conversion of H_2S to elemental sulfur is 0.19 – 0.51. Space time affects conversion of H_2S to elemental sulfur over the pressure range of 40 -170 psia. Conversion of H_2S to elemental sulfur increases slightly with space time over the space time of 110 -220 s (see Figure 5-2). Conversion of H_2S to elemental sulfur decreases with increased space time over the space time range of 220 – 560 s.

Figure 5-2 Effects of space time on conversion of H_2S in a momolithic catalyst reactor with a 50-SCCM feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 70-v% H_2 and 10-v% moisture at 140°C.



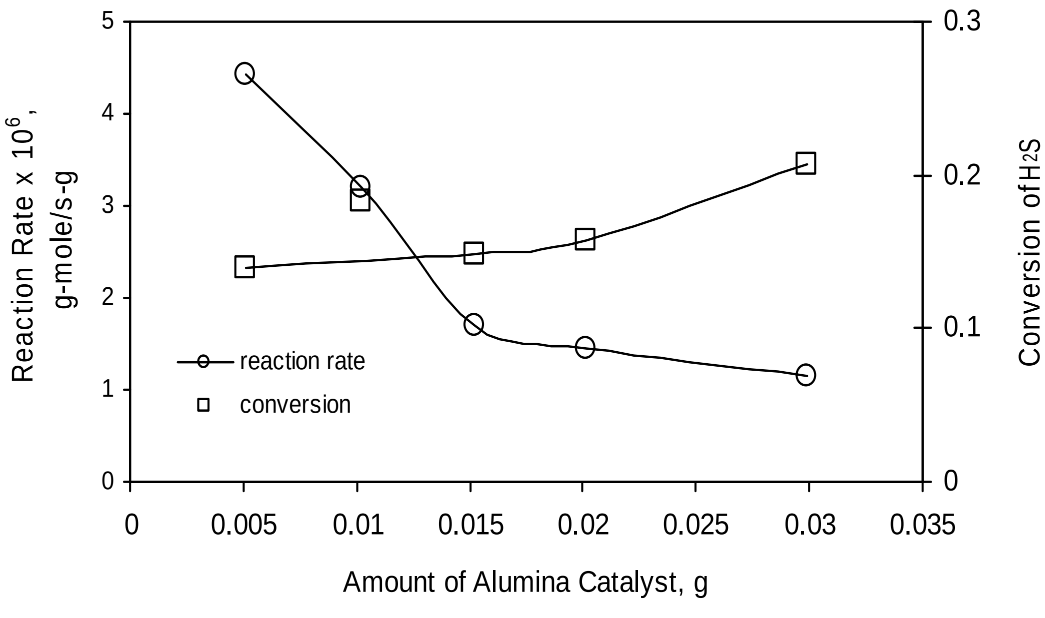
Conversion of H_2S in the micro packed-bed reactor and the micro bubble reactor increases with space time, whereas conversion of H_2S in the monolithic catalyst reactor decreases generally with increased space time. Reaction rates of H_2S in the micro packed-bed reactor and the micro bubble reactor decrease generally with increased space time.

Effects of Catalyst Amounts on Conversion of H_2S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.011 – 0.064 seconds (see Table 1-3) 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_2S, 2,490- 2,560 ppm SO_2, 5 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 101 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.14 – 0.21, whereas reaction rates for the conversion of H_2S into elemental sulfur are 1.15 – 4.41 $\times 10^{-6}$ g-mole/s-g-cat.

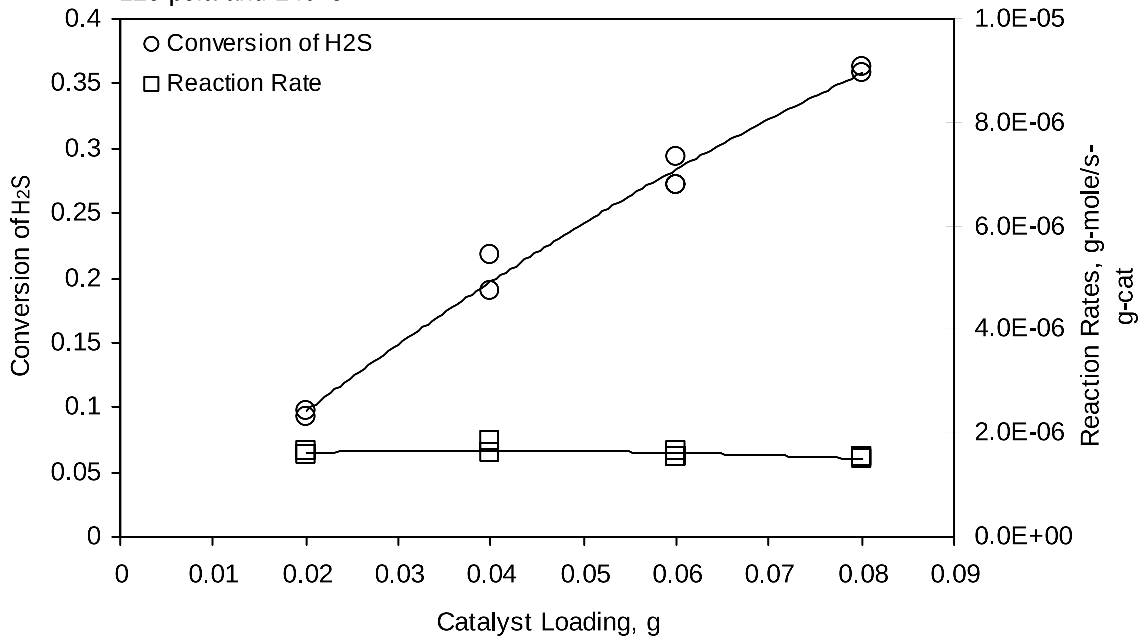
Catalyst loadings affect significantly conversion of H_2S into elemental sulfur and reaction rates for the conversion of H_2S into elemental sulfur (see Figure 1-2).

Figure 1-2. Effects of catalyst amounts on surface reaction rates and conversion of H_2S in a micro packed-bed reactor with a 100-SCCM feed containing 7,430 - 7,620 ppm H_2S, 2,490 - 2,560 ppm SO_2 and 5-v% moisture at 140°C and 61 - 64 psia.



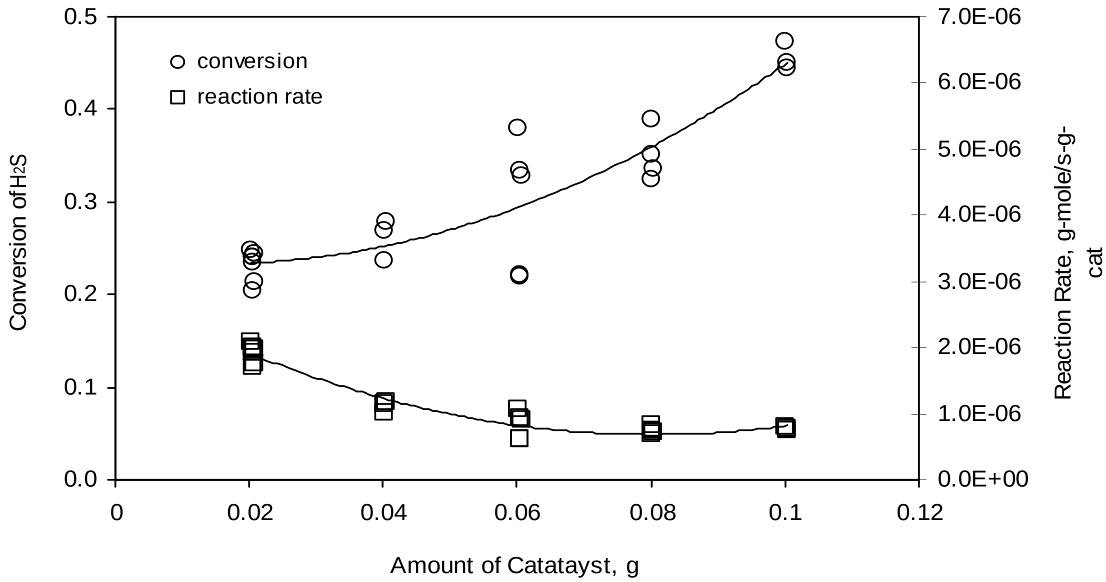
Effects of catalyst loading on conversion of H_2S to elemental sulfur were examined at 140°C and 118 - 123 psia. The feed gas mixture to a micro bubble reactor contains 4,980-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, 70-v% H_2, and nitrogen as remainder. The volumetric feed rate of the feed gas mixture to the micro bubble reactor is 100 SCCM. The amount range of fresh catalyst particles loaded in the micro bubble reactor is 0.02 – 0.08 g. Conversion of H_2S increases with catalyst loading. However, experimental reaction rate of H_2S (see Equation 3) is independent of catalyst loading, as shown in Figure 3-2. This result may indicate that both surface reaction rate *k* and equilibrium adsorption constant k_A of H_2S for conversion of H_2S with SO_2 to elemental liquid sulfur are not significantly affected by amount of catalyst particles loaded in the micro bubble reactor.

Figure 3-2. Effects of catalyst loading on conversion of H_2S with 0.02 - 0.08 g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 118 - 123 psia and 140°C.



Effects of catalyst loading on conversion of H_2S to elemental sulfur were examined at 140°C and 115 - 123 psia. The feed gas mixture to a micro bubble reactor contains 5,000-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, 70-v% H_2, and nitrogen as remainder. The volumetric feed rate of the feed gas mixture to the micro bubble reactor is 50 SCCM. The amount range of fresh catalyst particles loaded in the micro bubble reactor is 0.02 – 0.1 g. Conversion of H_2S increases with catalyst loading. However, experimental reaction rate of H_2S, obtained with Equation 3, decreases with increased catalyst loading over the catalyst loading range of 0.02 – 0.06 g, whereas experimental reaction rate of H_2S appears to be independent of catalyst loading over the catalyst loading range of 0.06 – 0.1 g, as shown in Figure 4-3. This result may indicate that both surface reaction rate *k* and equilibrium adsorption constant k_A of H_2S for conversion of H_2S with SO_2 to elemental liquid sulfur over the catalyst loading range of 0.06 – 0.1 g are not significantly affected by amount of catalyst particles loaded in the micro bubble reactor.

Figure 4-3. Effects of catalyst amount on conversion of H_2S in a micro bubble reactor with a 50-SCCM feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 10-v% moisture, and 70-v% H_2 at 140°C, 115 - 123 psia and 0.169 - 0.849 s space time.



Conversion of H_2S in the micro packed-bed reactor and the micro bubble reactor increases with catalyst loading. Reaction rate of H_2S in the micro packed-bed reactor and the micro bubble reactor decreases with increased catalyst loading.

Effects of Pressure on Conversion of H_2S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.023 – 0.041 seconds (see Table 1-1) 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_2S, 2,560- 2,610 ppm SO_2, 5 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 96 – 98 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.18 – 0.45, whereas reaction rates for the conversion of H_2S into elemental sulfur are 3.2 – 7.4 $x10^{-6}$ g-mole/s-g-cat.

Reaction pressures affect significantly both conversion of H_2S into elemental sulfur and reaction rates for the conversion of H_2S into elemental sulfur over the pressure range of 64 -113 psia (see Figures1-3 and 1-4).

Figure 1-3. Effects of reaction pressure on reaction rates and conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 96 - 98 SCCM feed stream containing 7,620 - 7,780 ppm H_2S, 2,560 - 2,610 ppm SO_2 and 5-v% moisture at 140°C.

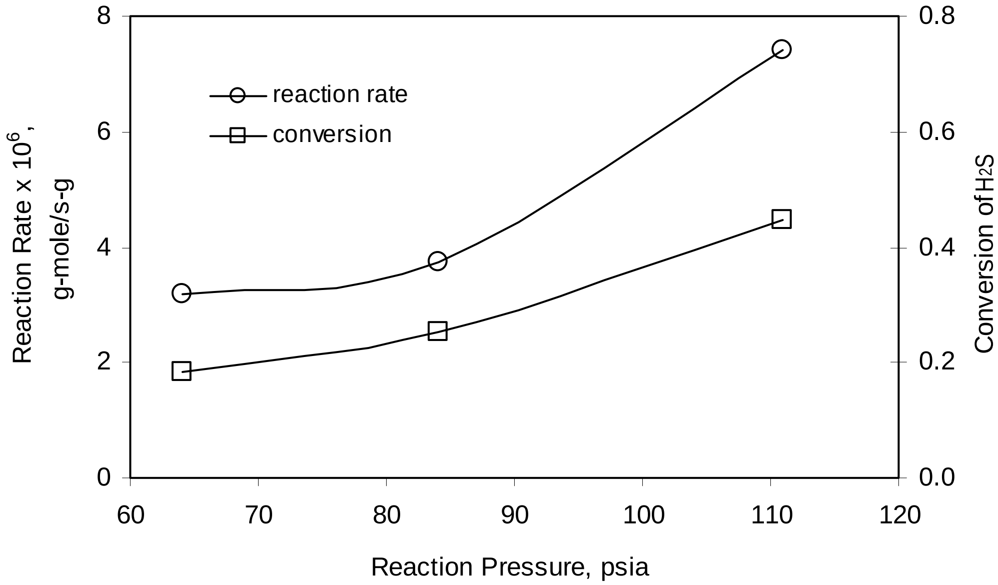
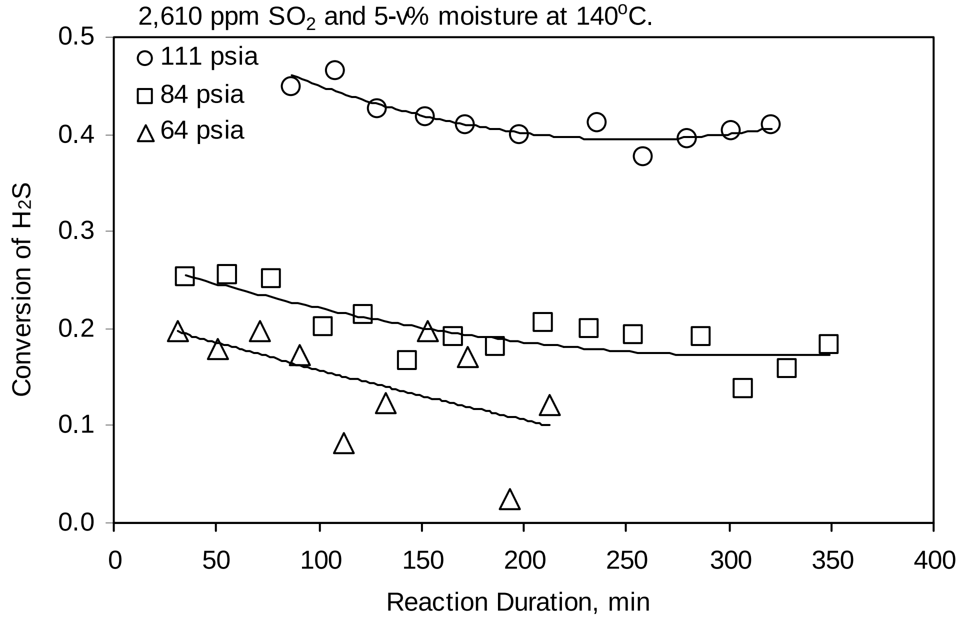
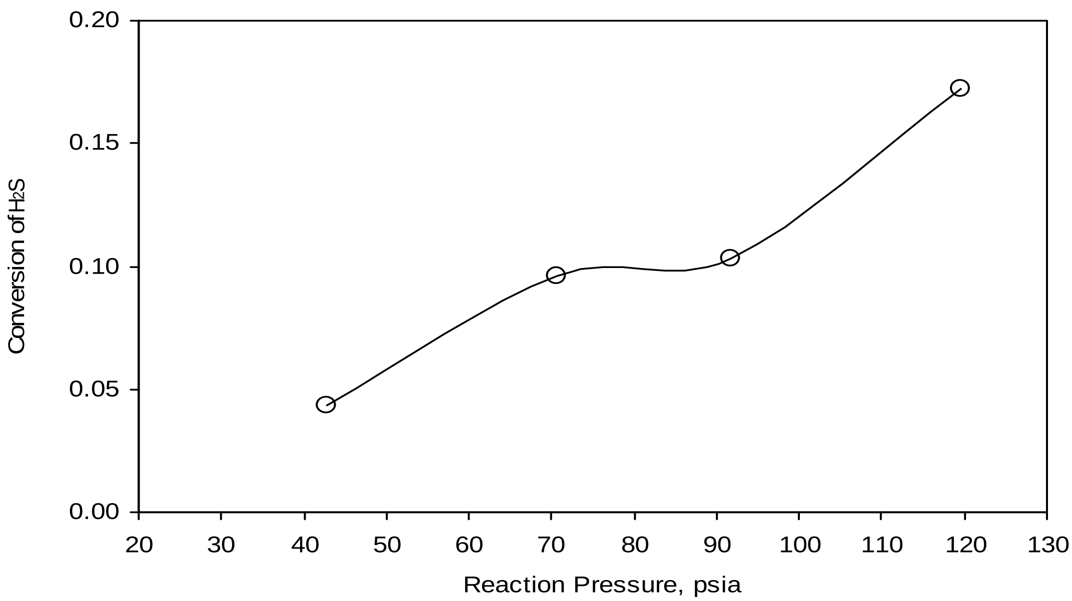


Figure 1-4. Effects of pressure on conversion of H_2S into elemental sulfur with 0.01-g catalyst in a micro packed-bed reactor and a 96 - 98 SCCM feed stream containing 7,620 - 7,780 ppm H_2S, 2,560 - 2,610 ppm SO_2 and 5-v% moisture at 140°C.



Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.015 – 0.044 seconds (see Table 2-6) to evaluate effects of reaction pressures on conversion of hydrogen sulfide into elemental sulfur at 140°C and 43 -123 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 9,000-ppmv H_2S, 1,800-ppmv SO_2, and 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 100 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.04 – 0.17. Reaction pressures affect significantly conversion of H_2S into elemental sulfur over the pressure range of 43 -123 psia. Conversion of H_2S into elemental sulfur increases with reaction pressure over the pressure range of 43 - 123 psia (see Figure 2-6).

Figure 2-6. Effects of reaction pressure on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 9,000-ppm H_2S, 1,800-ppm SO_2, 5-v% moisture, and 70-v% H_2 at 140°C.



Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.014 – 0.045 seconds (see Table 2-5) to evaluate effects of reaction pressures on conversion of hydrogen sulfide into elemental sulfur at 140°C and 38 -123 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 7,500 - 7,600 ppmv H_2S, 2,500-ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 99 -100 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.06 – 0.24. Reaction pressures affect significantly conversion of H_2S into elemental sulfur over the pressure range of 71 - 123 psia. Conversion of H_2S into elemental sulfur increases with reaction pressure over the pressure range of 71 - 123 psia (see Figure 2-7). However, conversion of H_2S is lowest at 71 psia.

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.015 – 0.044 seconds (see Table 2-4) to evaluate effects of reaction pressures on conversion of hydrogen sulfide into elemental sulfur at 140°C and 43 -122 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 3,500-ppmv H_2S, 4,500-ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 100 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.14 – 0.33. Reaction pressures affect significantly conversion of H_2S into elemental sulfur over the pressure range of 43 -122 psia. Conversion of H_2S into elemental sulfur increases with reaction pressure over the pressure range of 43 -122 psia (see Figure 2-8).

Figure 2-7. Effects of reaction pressure on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 7,500 - 7,600 ppm H_2S, 2,500-ppm SO_2, 5-v% moisture, and 70-v% H_2 at 140°C.

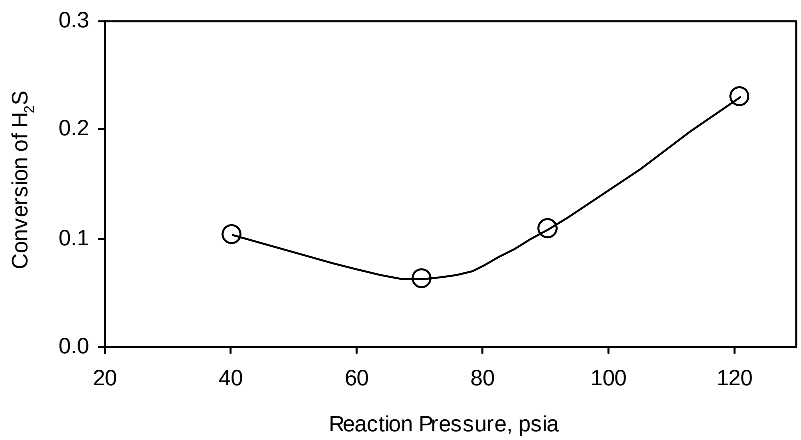
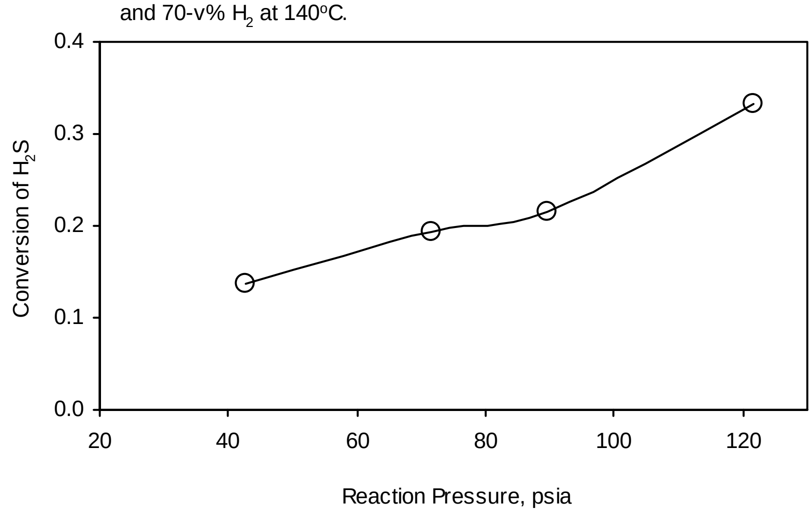
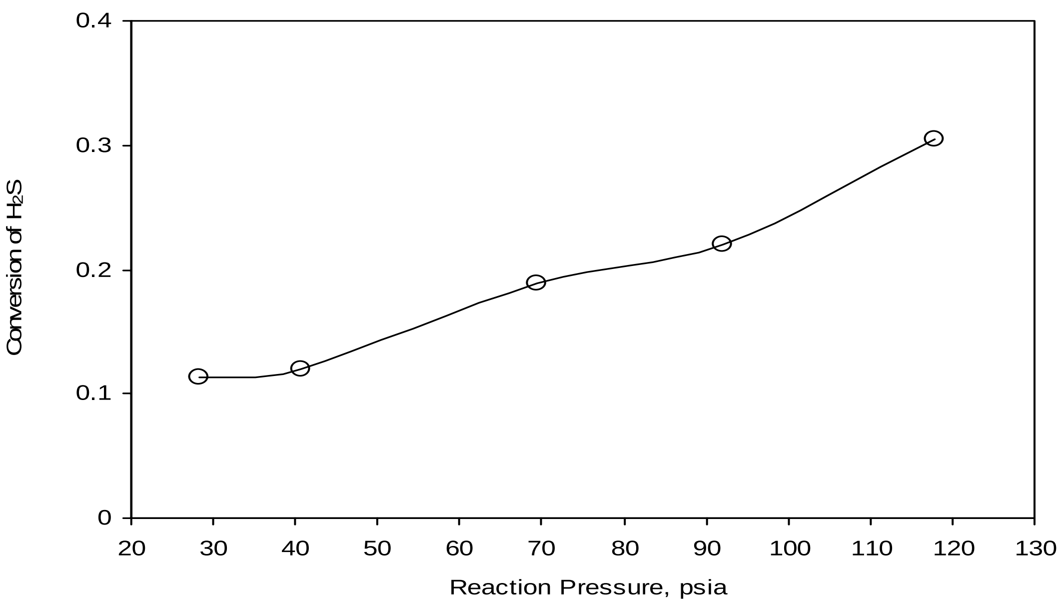


Figure 2-8. Effects of reaction pressure on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 3,500-ppm H_2S, 4,500-ppm SO_2, 5-v% moisture, and 70-v% H_2 at 140°C.



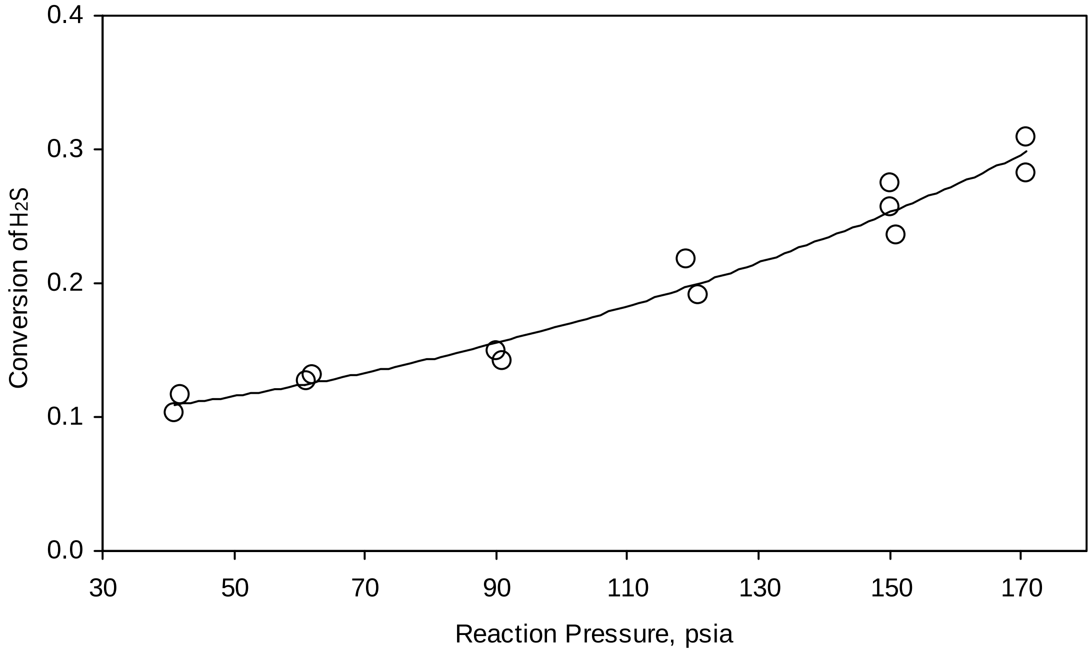
Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.010 – 0.044 seconds (see Table 2-3) to evaluate effects of reaction pressures on conversion of hydrogen sulfide into elemental sulfur at 140°C and 28 -122 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 4,900 - 5,000-ppmv H_2S, 3,800-ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 99 - 101 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.10 – 0.32. Reaction pressures affect significantly conversion of H_2S into elemental sulfur over the pressure range of 28 -122 psia. Conversion of H_2S into elemental sulfur increases with reaction pressure over the pressure range of 28 -122 psia (see Figure 2-9).

Figure 2-9. Effects of reaction pressure on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 99 - 101 SCCM feed stream containing 5,000-ppm H_2S, 3,800-ppm SO_2, 5-v% moisture, and 70-v% H_2 at 140°C.



Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.04-g catalyst were carried out over the space time range of 0.06 – 0.24 s to evaluate effects of reaction pressure on conversion of hydrogen sulfide to elemental sulfur at 140°C and 40 -170 psia. A gas mixture fed to a micro bubble reactor contains 70-v% hydrogen, 4,980-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of the gas mixture to the micro bubble reactor are 100 SCCM. Conversion of H_2S to elemental sulfur is 0.09 – 0.35. Reaction pressure affects significantly conversion of H_2S to elemental sulfur over the pressure range of 40 -170 psia. Conversion of H_2S to elemental sulfur increases with reaction pressure over the pressure range of 40 -170 psia (see Figure 3-5).

Figure 3-5. Effects of reaction pressure on conversion of H_2S with 0.04-g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 140°C and 0.06 - 0.24 s space time.



Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.02-g catalyst were carried out over the space time range of 0.059 – 0.25 s to evaluate effects of reaction pressure on conversion of hydrogen sulfide to elemental sulfur at 140°C and 40 -170 psia. A gas mixture fed to a micro bubble reactor contains 70-v% hydrogen, 5,000-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of the gas mixture to the micro bubble reactor are 50 SCCM. Conversion of H_2S to elemental sulfur is 0.05 – 0.65. Reaction pressure affects significantly conversion of H_2S to elemental sulfur over the pressure range of 40 -170 psia. Conversion of H_2S to elemental sulfur increases with reaction pressure over the pressure range of 40 -170 psia (see Figure 4-4). Conversion of H_2S to elemental sulfur increases moderately with increased total reaction pressure over the pressure range of 40 – 120 psia, whereas conversion of H_2S to elemental sulfur increases sharply with increased total reaction pressure over the pressure range of 120 – 170 psia.

Experiments on conversion of hydrogen sulfide to elemental sulfur with a 2-cm-diameter 15-cm-long γ-alumina wash-coated 400-cells/inch^2 monolithic catalyst were carried out over the space time range of 69 – 513 s to evaluate effects of reaction pressure on conversion of hydrogen sulfide to elemental sulfur at 140°C and 25 -186 psia. A gas mixture fed to the monolithic catalyst reactor contains 70-v% hydrogen, 5,000-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of the gas mixture to the monolithic catalyst reactor are 50 SCCM. Conversion of H_2S to elemental sulfur is 0.19 – 0.51. Reaction pressure affects conversion of H_2S to elemental sulfur over the pressure range of 40 -170 psia. Conversion of H_2S to elemental sulfur increases with reaction pressure over the pressure range of

25 - 64 psia (see Figure 5-3). Conversion of H_2S to elemental sulfur decreases with increased total reaction pressure over the pressure range of 64 – 186 psia.

Figure 4-4. Effects of pressure on conversion of H_2S in a micro bubble reactor with a 50 cc/min feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 10-v% moisture, 70-v% H_2, and 0.02-g catalyst at 140°C and 0.059 - 0.25 s space time.

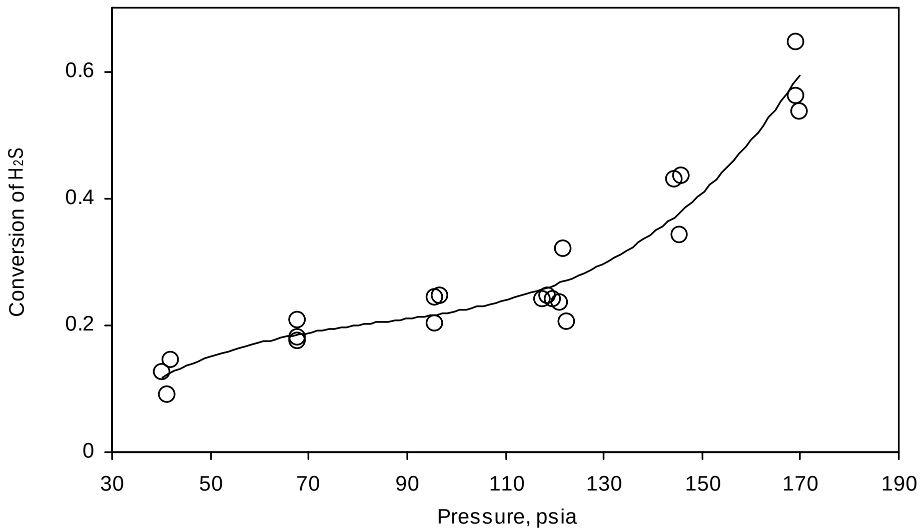
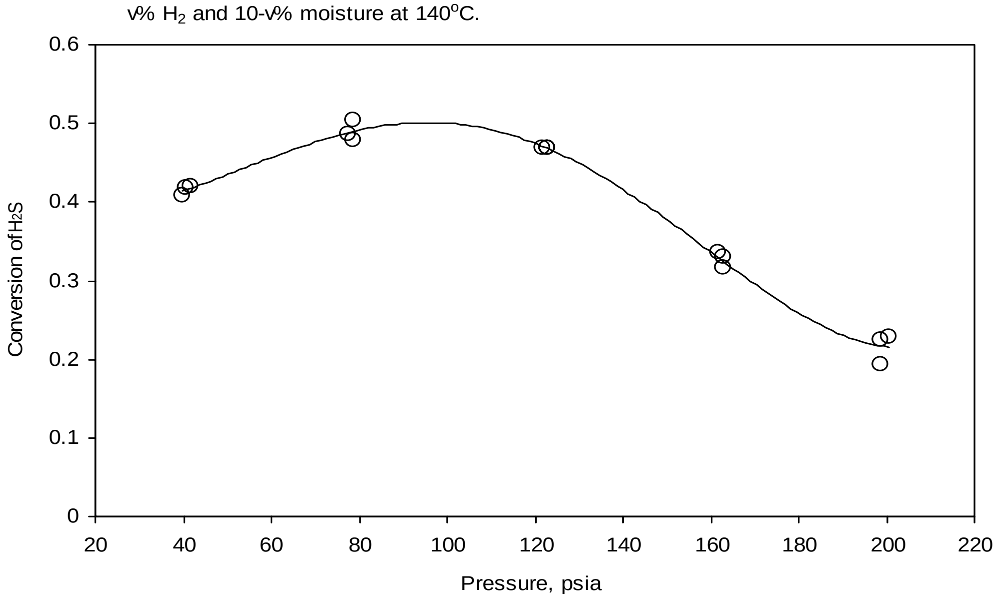


Figure 5-3 Effects of pressure on conversion of H_2S in a momolithic catalyst reactor with a 50-SCCM feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 70-v% H_2 and 10-v% moisture at 140°C.

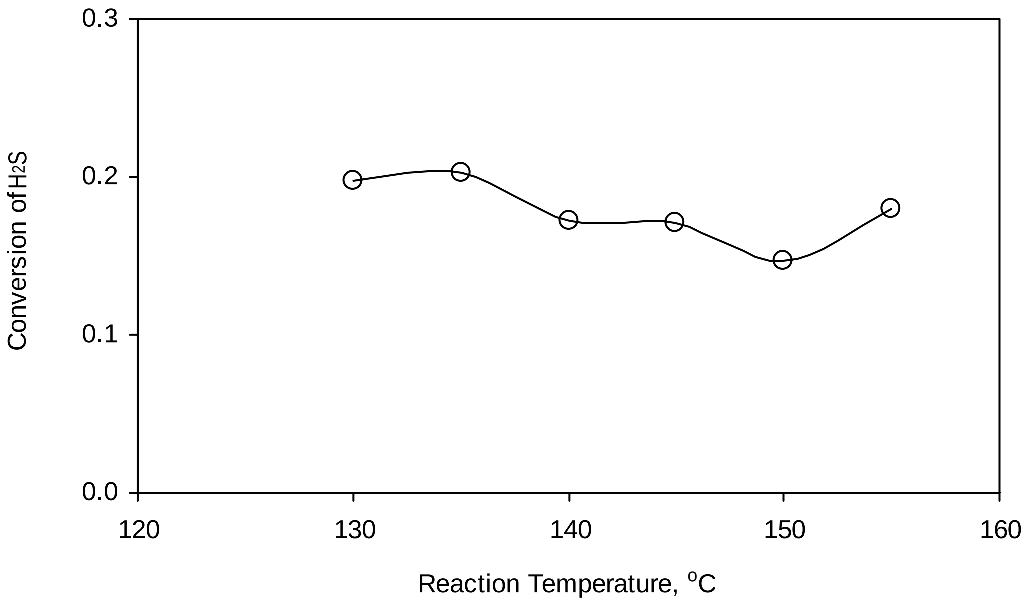


Conversion of H_2S in the micro packed-bed reactor and the micro bubble reactor increases with reaction pressure, whereas conversion of H_2S in the monolithic catalyst reactor decreases generally with increased reaction pressure.

Effects of Reaction Temperature on Conversion of H_2S into Elemental Sulfur

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.043 – 0.046 seconds (see Table 2-6) to evaluate effects of reaction temperature on conversion of hydrogen sulfide into elemental sulfur at 130 - 155^oC and 119 – 122 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 9,000-ppmv H_2S, 1,800-ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the reactor are 100 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.16 – 0.20. Reaction temperatures affect conversion of H_2S into elemental sulfur. Conversion of H_2S into elemental sulfur decreases with increased reaction temperature over the temperature range of 130 – 150^oC (see Figure 2-10).

Figure 2-10. Effects of reaction temperature on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 9,000-ppm H_2S, 1,800-ppm SO_2, 5-v% moisture, and 70-v% H_2 at 120 psia.



Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.043 – 0.046 seconds (see Table 2-5) to evaluate effects of reaction temperature on conversion of hydrogen sulfide into elemental sulfur at 125 - 155^oC and 120 – 125 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 7,500-ppmv H_2S, 2,500-ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the reactor are 100 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.05 – 0.29. Reaction temperatures affect significantly conversion of H_2S into elemental sulfur. Conversion of H_2S into elemental sulfur decreases with increased reaction temperature (see Figure 2-11), as opposed to the Arrhenius' equation.

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.042 – 0.046 seconds (see Table 2-4) to evaluate effects of reaction temperature on conversion of hydrogen sulfide into elemental sulfur at 125 - 155°C and 120 – 122 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 3,500-ppmv H_2S, 4,500-ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the reactor are 100 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.33 – 0.53. Reaction temperatures affect slightly conversion of H_2S into elemental sulfur. However, conversion of H_2S into elemental sulfur is lowest at 140°C (see Figure 2-12).

Figure 2-11. Effects of reaction temperature on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 7,500-ppm H_2S, 2,500-ppm SO_2, 5-v% moisture, and 70-v% H_2 at 120 psia.

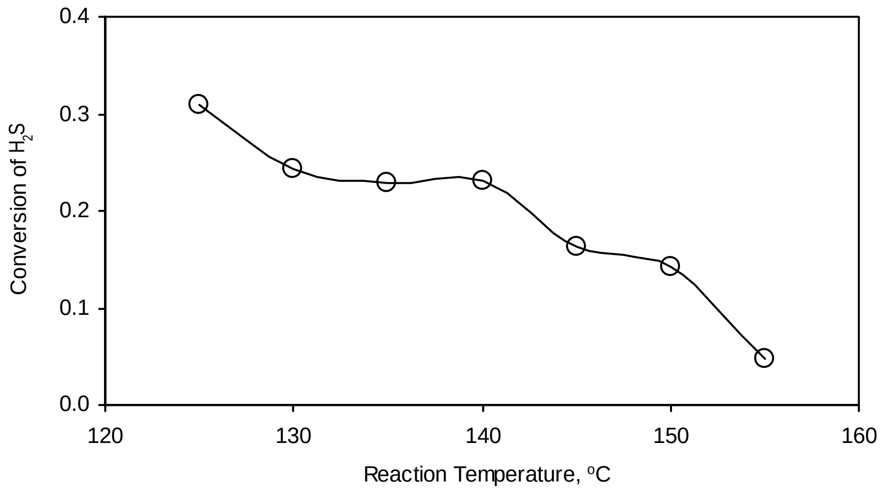


Figure 2-12. Effects of reaction temperature on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 3,500-ppm H_2S, 4,500-ppm SO_2, 5-v% moisture, and 70-v% H_2 at 120 psia.

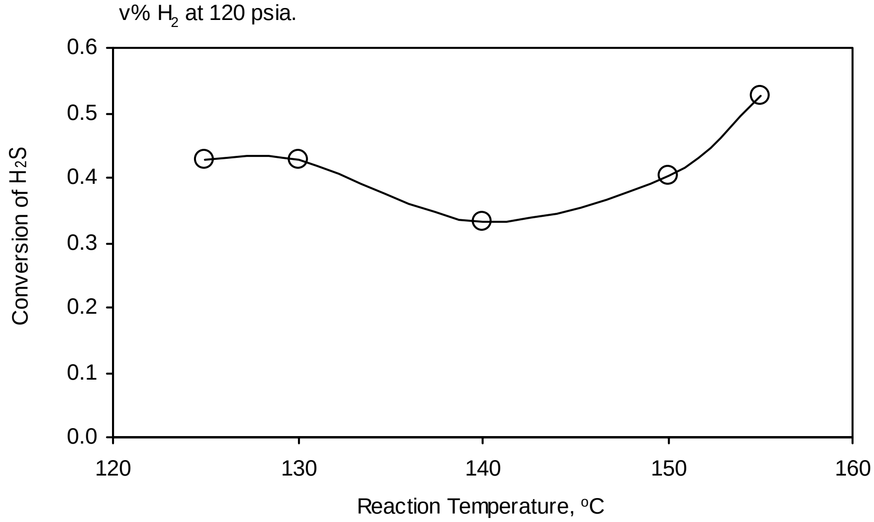
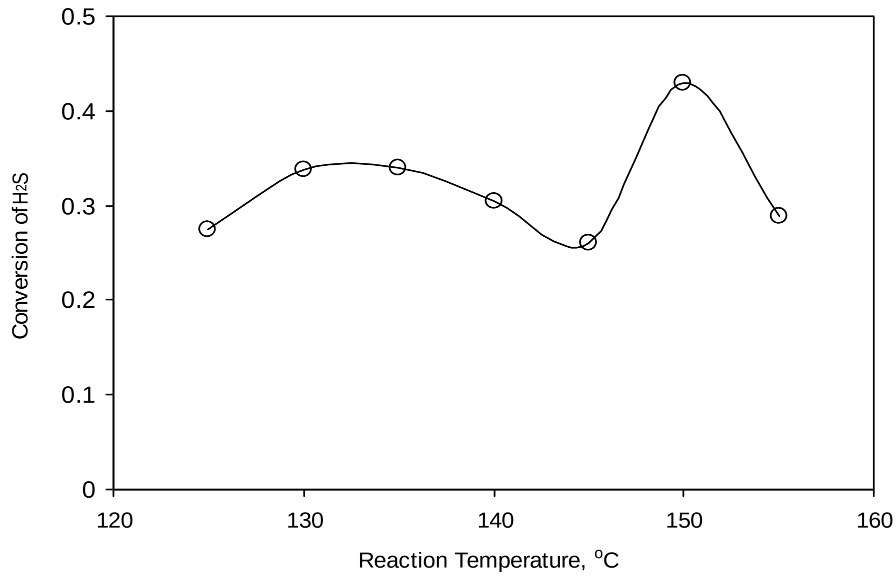


Figure 2-13. Effects of reaction temperature on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 99 - 101 SCCM feed stream containing 4,900 - 5,100 ppm H_2S, 3,700 - 3,800 ppm SO_2, 5-v% moisture, and 70-v% H_2 at 120 psia.



Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.041 – 0.046 seconds (see Table 2-1) to evaluate effects of reaction temperature on conversion of hydrogen sulfide into elemental sulfur at 125 - 155°C and 112 – 123 psia. Gas mixtures fed to the reactor contain 69 – 71 v% hydrogen, 4,900 - 5,100-ppmv H_2S, 3,700 - 3,800 ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 99 - 101 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.27 – 0.44. Reaction temperatures affect slightly conversion of H_2S into elemental sulfur. However, conversion of H_2S into elemental sulfur is highest at 150°C (see Figure 2-13).

Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.04-g catalyst were carried out over the space time range of 0.162 – 0.174 s to evaluate effects of reaction temperature on conversion of hydrogen sulfide to elemental sulfur at 125 - 155°C and 119 – 122 psia. Gas mixtures are fed to a micro bubble reactor containing 70-v% hydrogen, 4,980-ppmv H_2S, 2,500 ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the micro bubble reactor are 100 SCCM . Conversion of H_2S to elemental sulfur is 0.09 – 0.22. Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation. Reaction temperature affects conversion of H_2S to elemental sulfur. However, conversion of H_2S to elemental sulfur is highest at 140°C, while conversion of H_2S to elemental sulfur is lowest at 145°C over the reaction temperature range of 125 – 155°C (see Figure 3-6). Conversion of H_2S to elemental sulfur decreases with increased reaction temperature over the temperature ranges of 125 – 130°C, 140 – 145°C, and 150 – 155°C, whereas conversion of H_2S to elemental sulfur increases with increased reaction temperature over the temperature ranges of 130 – 140°C and 145 – 150°C.

Figure 3-6. Effects of temperature on conversion of H_2S with 0.04-g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S and 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 at 120 psia and 0.162 - 0.174 s space time.

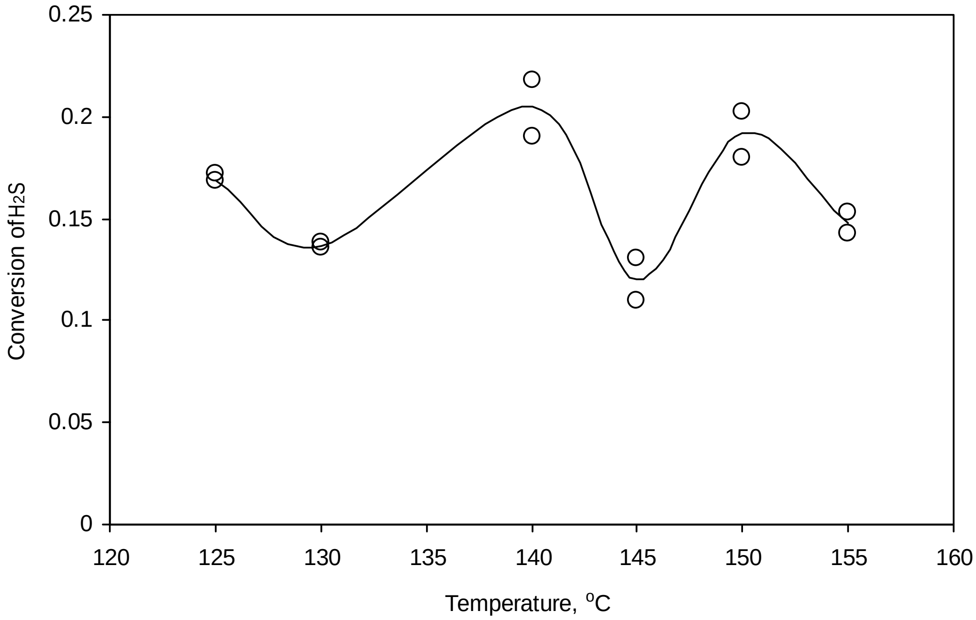
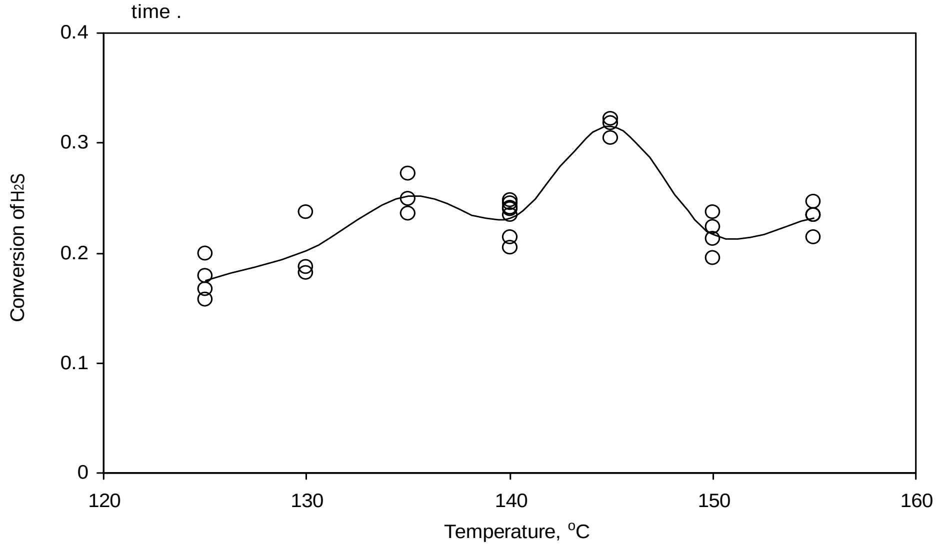


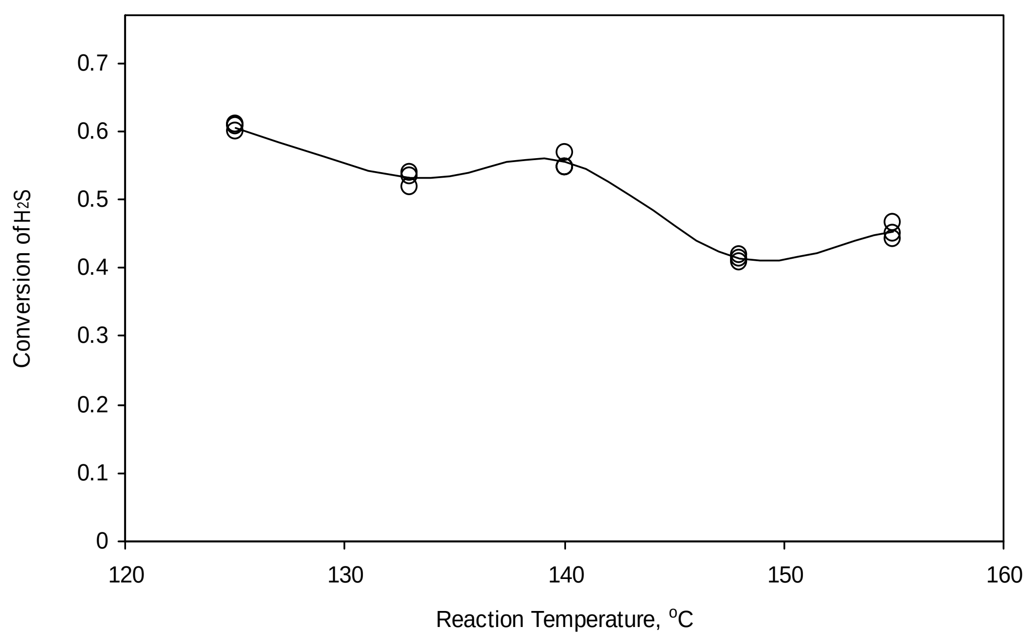
Figure 4-5. Effects of temperature on conversion of H_2S in a micro bubble reactor with a 50 cc/min feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 10-v% moisture, 70-v% H_2, and 0.02-g catalyst at 117 - 122 psia and 0.161 - 0.183 s space time .



Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.02-g catalyst were carried out over the space time range of 0.082 – 0.183 s to evaluate effects of reaction temperature on conversion of hydrogen sulfide to elemental sulfur at 125 - 155°C and 117 – 122 psia. Gas mixtures are fed to a micro bubble reactor containing 70-v% hydrogen, 5,000-ppmv H_2S, 2,500 ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the micro bubble reactor are 50 SCCM . Conversion of H_2S to elemental sulfur is 0.1 – 0.44. Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation. Reaction temperature affects conversion of H_2S to elemental sulfur. However, conversion of H_2S to elemental sulfur is highest at 145°C, while conversion of H_2S to elemental sulfur is lowest at 125°C over the reaction temperature range of 125 – 155°C (see Figure 4-5). Conversion of H_2S to elemental sulfur increases with increased reaction temperature over the temperature ranges of 125 – 135°C, 140 – 145°C, and 150 – 155°C, whereas conversion of H_2S to elemental sulfur decreases with increased reaction temperature over the temperature ranges of 135 – 140°C and 145 – 150°C.

Experiments on conversion of hydrogen sulfide to elemental sulfur with a 2-cm-diameter 15-cm-long γ-alumina wash-coated 400-cells/inch² monolithic catalyst were carried out over the space time range of 309 - 344 s to evaluate effects of reaction temperature on conversion of hydrogen sulfide to elemental sulfur at 125 - 155°C and 119 – 123 psia. Gas mixtures are fed to a monolithic catalyst reactor containing 70-v% hydrogen, 5,000-ppmv H_2S, 2,500 ppmv SO_2, 10-v% moisture, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the monolithic catalyst reactor are 50 SCCM. Conversion of H_2S to elemental sulfur is 0.40 – 0.61. Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation. Reaction temperature affects conversion of H_2S to elemental sulfur. Conversion of H_2S to elemental sulfur decreases generally with increased reaction temperature (see Figure 5-4).

Figure 5-4. Effects of reaction temperature on conversion of H_2S in a momolithic catalyst reactor with a 50-SCCM feed stream containing 5000-ppm H_2S, 2500-ppm SO_2, 70-v% H_2 and 10-v% moisture at 116 -123 psia.



Reaction rate of H_2S is proportional to conversion of H_2S with inlet molar flow rates of H_2S and amounts of catalyst held constant, as shown in Equations 3 and 4. Conversion of H_2S in the micro packed-bed reactor, the micro bubble reactor, and the monolithic catalyst reactor does not follow Arrhenius' equation. Conversion of H_2S in the micro packed-bed reactor decreases with increased reaction temperature over the H_2S-to-SO_2 feed ratio range of 3 – 5, whereas conversion of H_2S in the micro packed-bed reactor appear to fluctuate independently of reaction temperature over the low H_2S-to-SO_2 feed ratio range of 0.8 – 1.3. Conversion of H_2S in the micro bubble reactor appear to fluctuate independently of reaction temperature at the H_2S-to-SO_2 feed ratio range of 2, whereas conversion of H_2S in the monolithic catalyst reactor decrease with increased reaction temperature at the H_2S-to-SO_2 feed ratio range of 2.

Effects of Concentrations H_2S and SO_2 on Conversion and Reaction Rates of H_2S with SO_2

Reaction rates of hydrogen sulfide with 0.01-g catalyst in a micro packed-bed reactor were calculated over the space time range of 0.040 – 0.047 seconds with Equation 3 to evaluate effects of concentrations of H_2S and SO_2 on reaction rates of hydrogen sulfide in the presence of 2.5 – 13.6 v% moisture at 140°C and 120 – 123 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 3,500 - 9,000-ppmv H_2S, 1,800- 4,500 ppmv SO_2, 2.5 – 13.6 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 98 - 110 cm^3/min at room temperature and atmospheric pressure (SCCM). Reaction rates of H_2S with SO_2 are 0.35×10^{-5} – 1.17×10^{-5} g-mole/s/g-cat, as shown in Figure 2-14. Concentrations of both H_2S and SO_2 affect reaction rates of H_2S with SO_2. Reaction rates of H_2S slightly decrease with increased concentration of moisture.

Reaction rates of hydrogen sulfide with 0.01-g catalyst in a micro packed-bed reactor were calculated over the space time range of 0.041 – 0.046 seconds with Equation 3 to evaluate effects of concentrations of H_2S and SO_2 on reaction rates of hydrogen sulfide at 125 - 155°C and 112 – 123 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 3,500 - 9,000-ppmv H_2S, 1,800- 4,500 ppmv SO_2, 5- v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 112 - 125 cm^3/min at room temperature and atmospheric pressure (SCCM). Reaction rates of H_2S with SO_2 are 0.24×10^{-5} – 1.56×10^{-5} g-mole/s/g-cat, as shown in Figure 2-15. Concentrations of both H_2S and SO_2 appear to affect reaction rates of H_2S with SO_2. However, reaction rates of H_2S with SO2 appear to decrease with increased reaction temperatures over the temperature range of 135 - 145°C.

Reaction rates of hydrogen sulfide with 0.01-g catalyst in a micro packed-bed reactor were calculated over the space time range of 0.010 – 0.045 seconds with Equation 3 to evaluate effects of concentrations of H_2S and SO_2 on reaction rates of hydrogen sulfide at 140°C and 28 – 123 psia. Gas mixtures fed to the reactor contain 70-v% hydrogen, 3,500 - 9,000-ppmv H_2S, 1,800- 4,500 ppmv SO_2, 5-v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 99 – 101 cm^3/min at room temperature and atmospheric pressure (SCCM). Reaction rates of H_2S with SO_2 are 0.27×10^{-5} – 1.17×10^{-5} g-mole/s/g-cat, as shown in Figure 2-16. Concentrations of both H_2S and SO_2 appear to affect reaction rates of H_2S with SO_2. Reaction rates of H_2S with SO_2 increase with increased reaction pressures over the pressure range of 28 – 123 psia.

Figure 2-14. Effects of concentrations of H_2S and SO_2 on reaction rate of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 70-v% H_2 and 2.5 -14.6 v% moisture at 119 - 123 psia and 140°C.

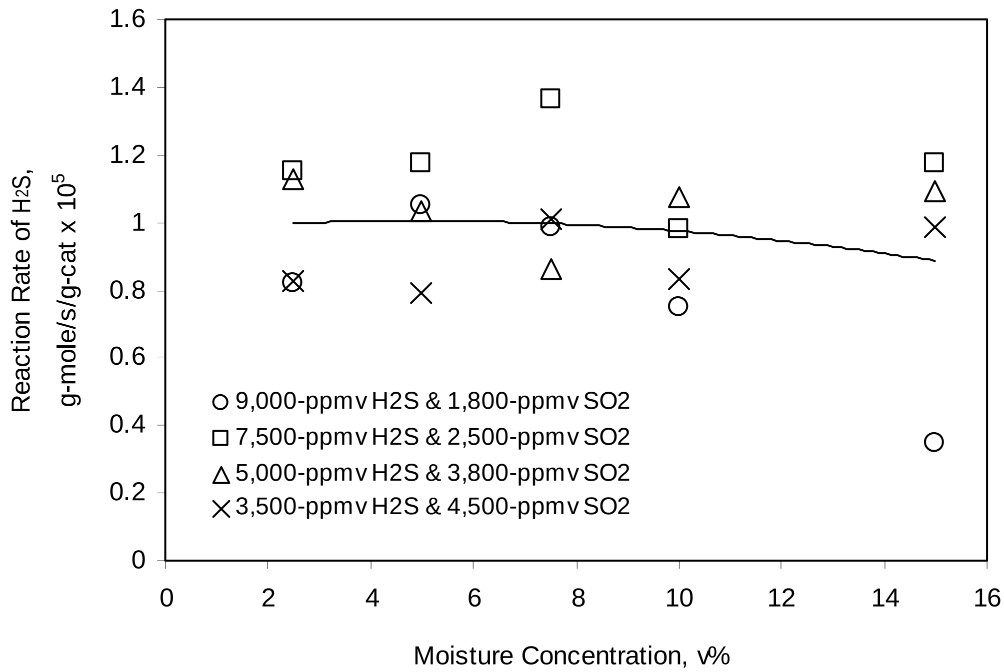


Figure 2-15. Effects of concentrations of H_2S and SO_2 on reaction rate of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 100-SCCM feed stream containing 70-v% H_2 and 5-v% moisture at 120 psia and 125 - 155°C.

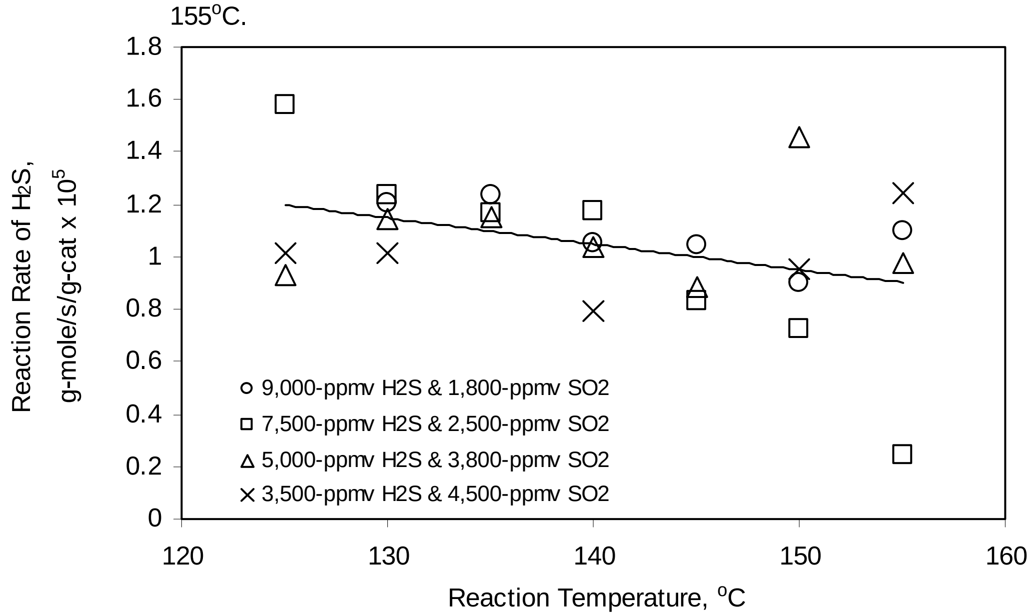
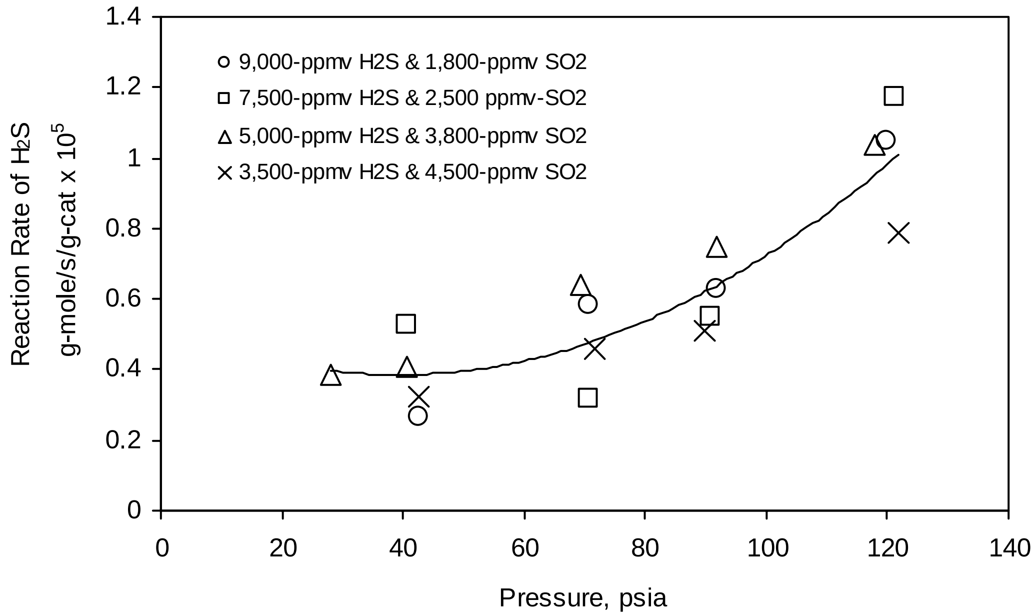


Figure 2-16. Effects of concentrations of H_2S and SO_2 on reaction rate of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 99 - 101 SCCM feed stream containing 70-v% H_2 and 5-v% moisture at 23 - 121 psia and 140°C.



Experiments on conversion of hydrogen sulfide to elemental sulfur with 0.02-g catalyst were carried out over the space time range of 0.168 – 0.178 s to evaluate effects of H_2S concentration on conversion of hydrogen sulfide to elemental sulfur at 140°C and 115 – 123 psia. A gas mixture consisting of 62 - 78 v% hydrogen, 3,000 – 7,000-ppmv H_2S, 1,500 – 3,500 ppmv SO_2, 10 v% moisture, and nitrogen as remainder is fed to a micro bubble reactor. Volumetric feed rates of the gas mixture to the micro bubble reactor are 50 SCCM. Conversion of H_2S to elemental sulfur is 0.11 – 0.30.

Concentration of H_2S in the presence of 10-v% moisture and 62 - 78 v% H_2 affects conversion of H_2S to elemental sulfur in the H_2S concentration range of 3,000 - 7,000 ppmv in a simulated coal gas mixture at 115 – 123 psia (see Figure 4-6). Conversion of H_2S to elemental sulfur increases with increased concentrations of both H_2S and SO_2.

Experiments on conversion of hydrogen sulfide to elemental sulfur with 2-cm diameter, 15-cm long γ-alumina 400 cells/in^2 wash-coated monolithic catalysts were carried out over the space time range of 332 – 343 s to evaluate effects of H_2S concentration on conversion of hydrogen sulfide to elemental sulfur at 140°C and 119 – 123 psia. A gas mixture consisting of 50 - 78 v% H_2, 3,000 – 10,000-ppmv H_2S, 1,500 – 5,000 ppmv SO_2, 10 v% moisture, and nitrogen as remainder is fed to the monolithic catalyst reactor. Volumetric feed rates of the gas mixture to the monolithic catalyst reactor are 50 SCCM. Conversion of H_2S to elemental sulfur is 0.43 – 0.78.

Figure 4-6. Effects of initial H_2S concentration on conversion of H_2S in a micro bubble reactor with a 50 cc/min feed stream containing 62-78 v-% H_2, 10-V% moisture, and 0.02-g catalyst at 140^oC and 115 -123 psia

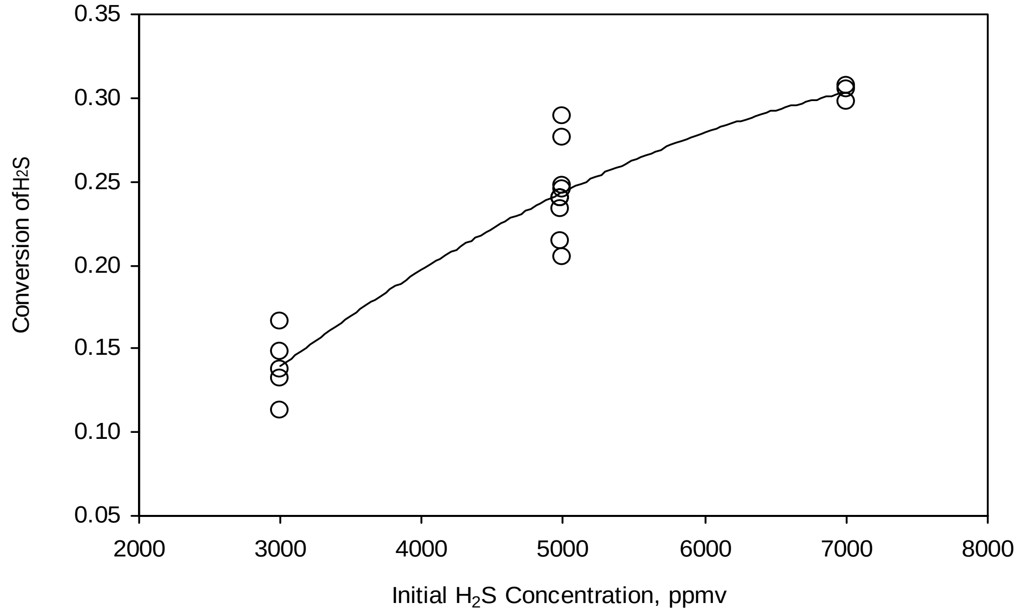
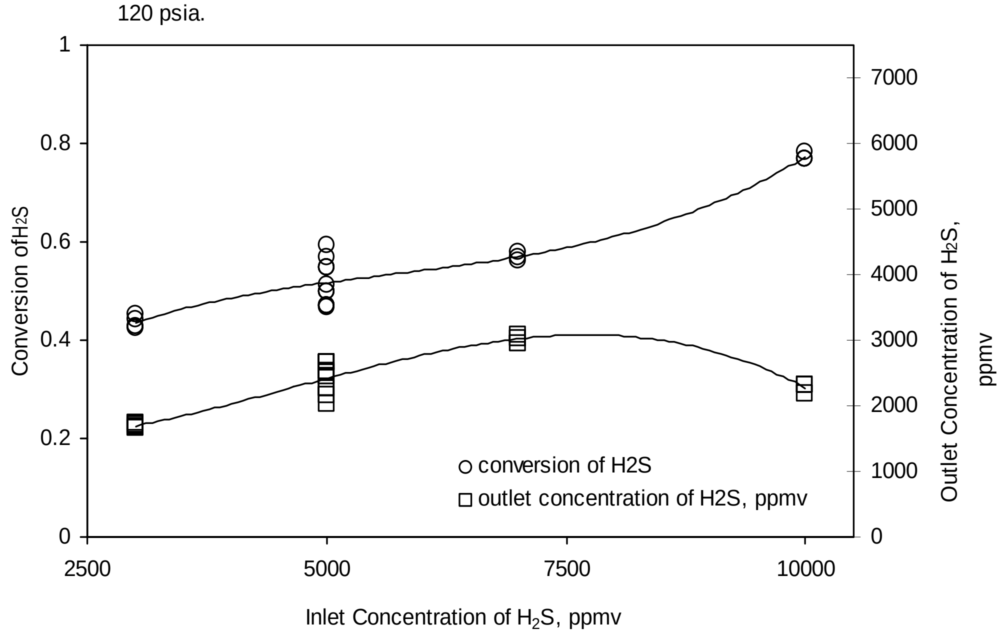


Figure 5-5 Effects of H_2S concentration on conversion of H_2S in a momolithic catalyst reactor with a 50-SCCM feed stream containing 3,000 - 10,000-ppmv H_2S, 1,500 - 5,000 ppmv SO_2, 10-v% moisture, and 50 - 78-v% H_2 at 140^oC and 120 psia.



Concentration of H_2S in the presence of 10-v% moisture and 50 - 78 v% H_2 affects conversion of H_2S to elemental sulfur over the H_2S concentration range of 3,000 - 10,000 ppmv in a simulated coal gas mixture at 119 – 123 psia (see Figure 5-5). Conversion of H_2S to elemental sulfur increases with increased concentrations of both H_2S and SO_2. Outlet concentrations of H_2S from the reactor range from 1,650 to 3,070 ppmv, whereas inlet concentrations of H_2S range from 3,000 to 10,000 ppmv. Outlet concentrations of H_2S increase with inlet concentrations of H_2S over the inlet H_2S concentration range of 3,000 – 7, 000 ppmv, whereas outlet concentrations of H_2S decrease with increased inlet concentrations of H_2S over the inlet H_2S concentration range of 7,000 – 10,000 ppmv.

Concentrations of H_2S and SO_2 in the packed-bed reactor affect reaction rates of H_2S with SO_2 in the presence of various concentrations of moisture, where reaction rates of H_2S with SO_2 decrease slightly with increased concentration of moisture. Concentrations of H_2S and SO_2 in the packed-bed reactor affect reaction rates of H_2S with SO_2 at various reaction pressures and temperatures, where reaction rates of H_2S with SO_2 decrease generally with increased reaction temperature and increase generally with total reaction pressure.

Effects of H_2S and SO_2 Partial Pressures on Reaction Rates of H_2S

A reaction rate equation (see Equation 6) was developed with the following surface reaction mechanisms, using experimental data from a micro bubble reactor. Gaseous hydrogen sulfide is attached to active sites on the surface of catalyst particles, and then the H_2S attached to active sites on the surface of catalyst particles is reacted with gaseous SO_2 from a bulk gaseous reaction mixture to produce liquid elemental sulfur and water. Water produced from the reaction of H_2S with SO_2 is mostly evaporated into the gaseous reaction mixture.

$$-r_A' = \frac{kP_A^2 P_B}{(1+k_A P_A)^2} \tag{6}$$

where $-r_A'$: surface reaction rates of H_2S
k: surface reaction rate constant
k_A: equilibrium adsorption constant of H_2S on active sites of catalyst particles
P_A: partial pressure of H_2S
P_B: partial pressure of SO_2

Rearranging Equation 6 produces Equation 7. Experimental data in Table 3-5 obtained from a micro bubble reactor at 140°C, 40 – 170 psia, 0.06 – 0.24 s space time and 100 SCCM feed rate are applied to Equation 7 to determine the surface reaction rate constant k and the equilibrium adsorption constant k_A of H_2S.

$$\left(\frac{P_A^2 P_B}{-r_A'}\right)^{0.5} = \frac{1}{k^{0.5}} + \frac{k_A}{k^{0.5}} P_A \tag{7}$$

Partial pressures of H_2S and experimental surface reaction rates of H_2S determined with experimental data in Table 3-5 are applied to Equation 7. Left-side values of Equation 7 are plotted against partial pressures of H_2S, as shown in Figure 3-7. The value of a surface reaction rate constant k can be calculated from the intercept value of a linear regression line in Figure 3-7, whereas the value of an equilibrium adsorption constants k_A of H_2S on active sites of catalyst particles can be obtained from the slope value of the linear regression line in Figure 3-7. The value of the surface reaction rate constant k of H_2S and the value of the equilibrium adsorption constant k_A of H_2S, determined with the experimental data in Table 3-5, are 1.4376×10^{-3} g-mole/s-g-(psia)^3 and 11.3187 psia^{-1}, respectively. The developed reaction model suggests that H_2S is strongly adsorbed onto active sites of catalyst particles, and the reaction for conversion of H_2S to elemental sulfur is second order with respect to partial pressure of H_2S and first order with respect to partial pressure of SO_2.

Figure 3-7. Left-side values of Equation 7 vs. partial pressures of H_2S with conversion of 3500 - 6500 ppmv H_2S with 1750 – 3250 ppmv SO_2 in the presence of 70 v-% H_2, 10-v % moisture, and 0.04-g catalyst in a bubble reactor at 140 °C and 40 - 170 psia

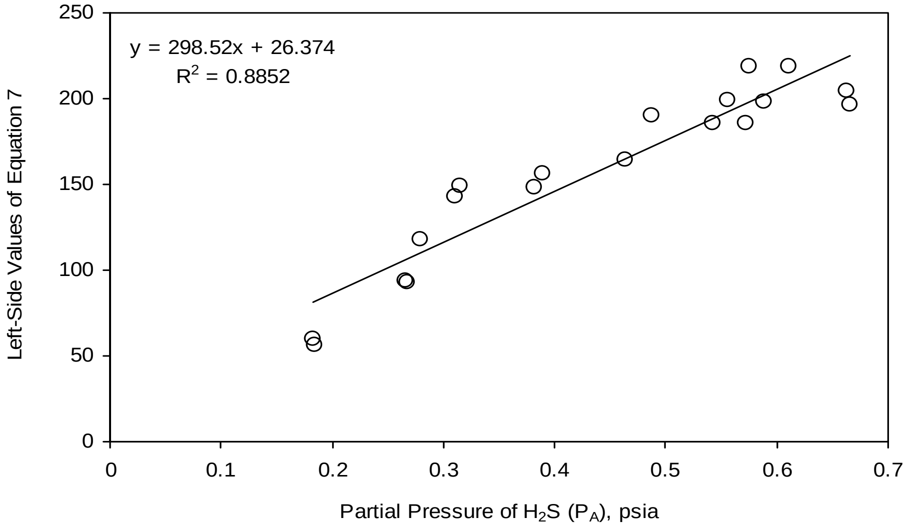
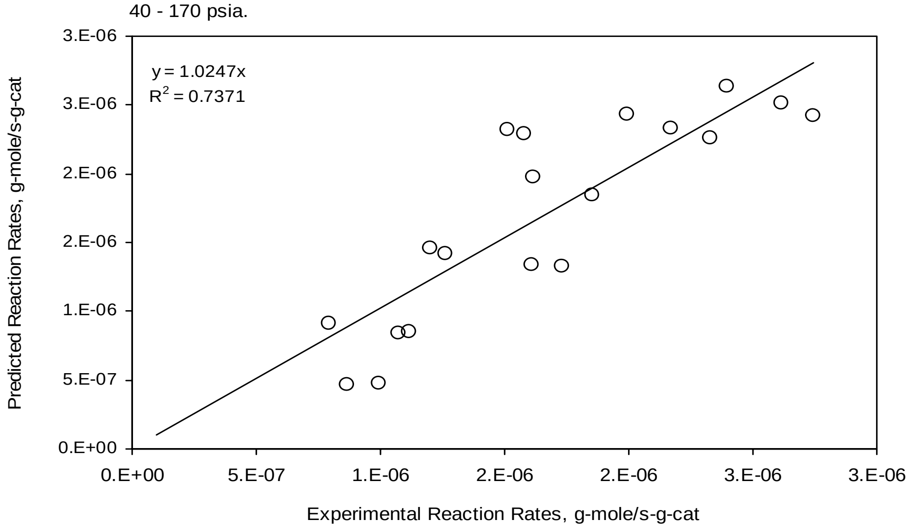


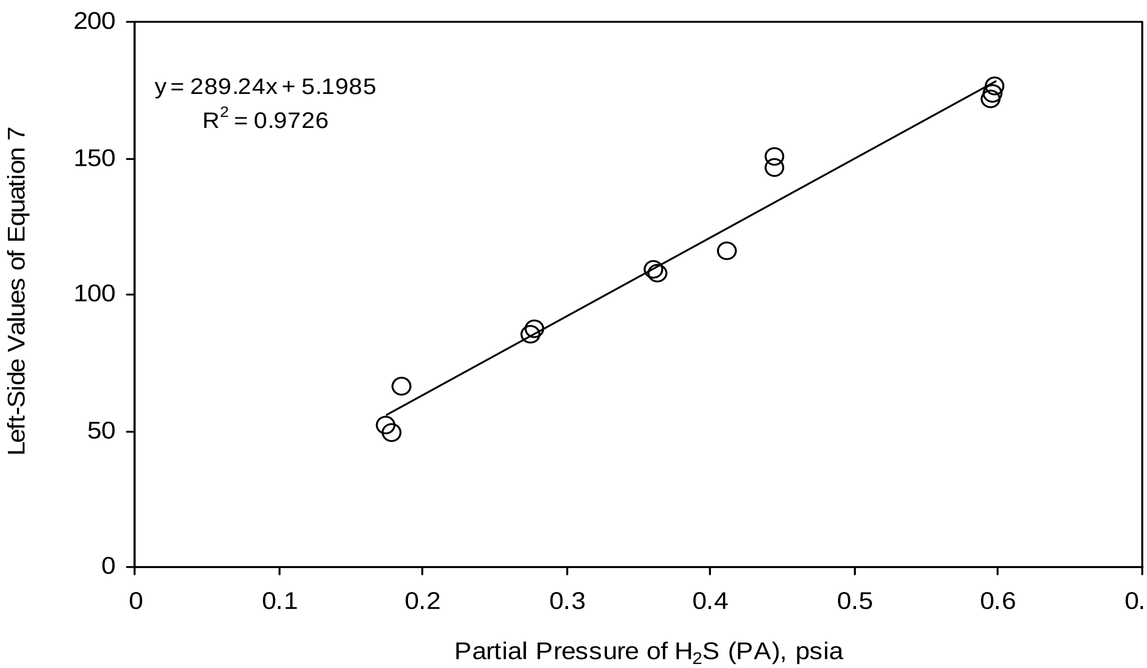
Figure 3-8. Predicted reaction rates vs. experimental reaction rates with conversion of 3500 - 6500 ppmv H_2S with 1750 – 3250 ppmv SO_2 in the presence of 70 v-% H_2, 10-v % moisture, and 0.04-g catalyst in a bubble reactor at 140°C and 40 - 170 psia.



Predicted surface reaction rates for conversion of H_2S to elemental sulfur were calculated with the surface reaction rate constant *k* and the equilibrium absorption constant k_A of H_2S determined by applying experimental data in Table 3-6 to the reaction model. Predicted surface reaction rates for conversion of H_2S to elemental sulfur were compared with experimental surface reaction rates for conversion of H_2S to elemental sulfur calculated with experimental data of conversion of H_2S, catalyst amount, and molar feed rate of H_2S, as shown in Figure 3-8.

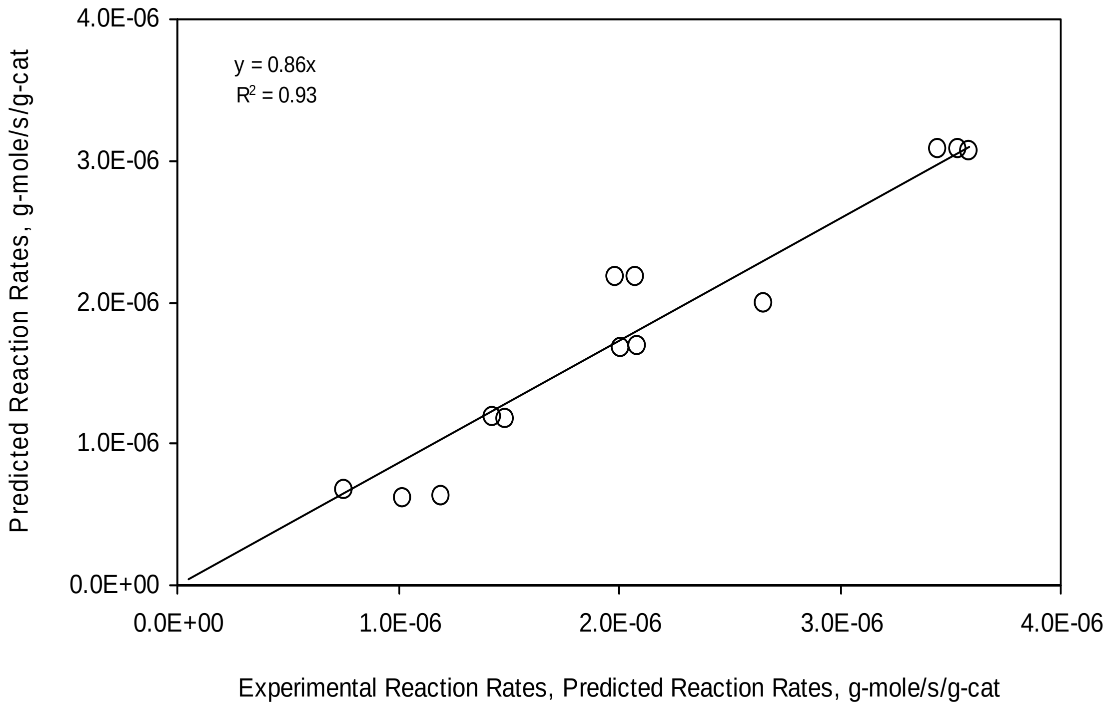
Partial pressures of H_2S and experimental surface reaction rates of H_2S determined with experimental data obtained over the reaction pressure range of 40 – 123 psia at 140^{o}C, as shown in Tables 4-4 and 4-5, are applied to Equation 7. Left-side values of Equation 7 are plotted against partial pressures of H_2S, as shown in Figure 4-7. The value of a surface reaction rate constant *k* can be calculated from the intercept value of a linear regression line in Figure 4-7, whereas the value of an equilibrium adsorption constants k_A of H_2S on active sites of catalyst particles can be obtained from the slope value of the linear regression line. The value of the surface reaction rate constant *k* of H_2S and the value of the equilibrium adsorption constant k_A of H_2S, determined with the experimental data in Tables 4-4 and 4-5, are 0.037 g-mole/s-g-(psia)^3 and 55.64 psia^{-1}, respectively. The developed reaction model suggests that H_2S is strongly adsorbed onto active sites of catalyst particles in the preference over SO_2, and the reaction for conversion of H_2S to elemental sulfur is second order with respect to partial pressure of H_2S and first order with respect to partial pressure of SO_2. In other words, this reaction may be called element reaction.

Figure 4-7. Left-side values of the rearranged reaction model vs. partial pressures of H_2S with a 50 cc/min feed stream containing 10-V% moisture, and 0.02-g catalyst in a micro bubble reactor at 140^{o}C.



Predicted surface reaction rates for conversion of H_2S to elemental sulfur were calculated with the surface reaction rate constant *k* and the equilibrium absorption constant k_A of H_2S determined by applying experimental data in Table 4-5 to the reaction model. Predicted surface reaction rates for conversion of H_2S to elemental sulfur were compared with experimental surface reaction rates for conversion of H_2S to elemental sulfur, calculated with experimental data of conversion of H_2S, catalyst amount, and molar feed rate of H_2S, as shown in Figure 4-8.

Figure 4-8. Predicted reaction rates vs. experimental reaction rates with a 50 cc/min feed stream containing 10-V% moisture, and 0.02-g catalyst in a micro bubble reactor at 140°C.



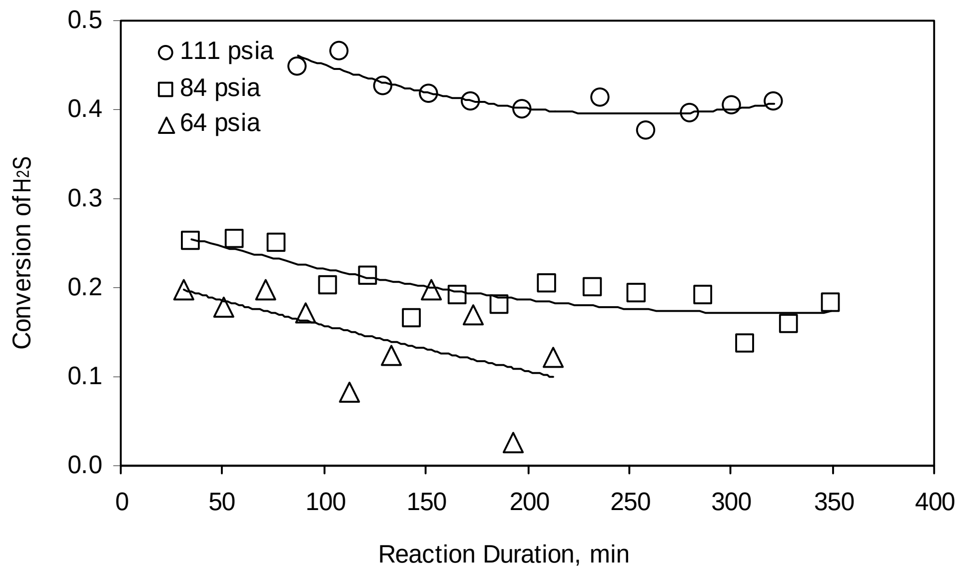
A reaction rate equation was developed with the following surface reaction mechanisms Gaseous hydrogen sulfide is attached to active sites on the surface of catalyst particles, and then the H_2S attached to active sites on the surface of catalyst particles is reacted with gaseous SO_2 from a bulk gaseous reaction mixture to produce liquid elemental sulfur and water. Water produced from the reaction of H_2S with SO_2 is mostly evaporated into the gaseous reaction mixture.

The value of the surface reaction rate constant *k* of H_2S and the value of the equilibrium adsorption constant k_A of H_2S, determined with the experimental data having 100-SCCM feed stream, are 1.4376×10^{-3} g-mole/s-g-(psia)^3 and 11.3187 psia^{-1}, respectively. The value of the surface reaction rate constant *k* of H_2S and the value of the equilibrium adsorption constant k_A of H_2S, determined with the experimental data having 50-SCCM feed stream,, are 0.037 g-mole/s-g-(psia)^3 and 55.64 psia^{-1}, respectively.

Effects of reaction duration on catalyst activities

Experiments on conversion of hydrogen sulfide into element sulfur with 0.01-g catalyst in a micro packed-bed reactor were carried out over the space time range of 0.023 – 0.041 seconds (see Table 1-1) to evaluate effects of reaction duration and 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_2S, 2,560- 2,610 ppm SO_2, 5 v% moisture, and nitrogen as remainder. Volumetric feed rates of a gas mixture to the reactor are 96 – 98 cm^3/min at room temperature and atmospheric pressure (SCCM). Conversions of H_2S into elemental sulfur are 0.18 – 0.45, whereas reaction rates for the conversion of H_2S into elemental sulfur are 3.2 – 7.4 $\times 10^{-6}$ g-mole/s-g-cat.

Figure 1-5. Effects of reaction duration on conversion of H_2S with 0.01-g catalyst in a micro packed-bed reactor and a 96 - 98 SCCM feed stream containing 7,620 - 7,780 ppm H_2S, 2,560 - 2,610 ppm SO_2 and 5-v% moisture at 140°C and 64 - 111 psia.



Reaction duration affects conversion of H_2S into elemental sulfur over the pressure range of 64 -113 psia (see Figure 1-5). Conversion of H_2S decreases gradually with increased reaction duration. This observation suggests that catalytic activities decrease with increased reaction duration.

Effects of reaction duration on conversion of H_2S to elemental sulfur were examined at 130°C and 120 psia. The feed gas mixture to a micro bubble reactor contains 4,980-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2. The volumetric feed rate of the feed gas mixture is 100 SCCM. The amount of fresh catalyst particles in the bubble reactor is 0.04 g. Initially, conversion of H_2S to elemental sulfur decreases drastically with increased reaction duration. Conversion of H_2S to elemental sulfur levels off, as reaction duration increases further, as shown in Figure 3-9. These observations may suggest that initially reaction takes place on both internal surface and external surface of porous catalyst particles, and then porous catalyst particles are plugged up with produced liquid elemental sulfur, as reaction duration increases further. These observations also indicate that reaction may occur mainly on external surface of catalyst particles rather than internal surface of catalyst particles, when conversion of H_2S levels off.

Figure 3-9. Effects of reaction duration on conversion of H_2S with 0.04-g catalyst in a micro bubble reactor and a 100-SCCM feed stream containing 4,980-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 for 25 - 274 min at 130°C and 120 psia.

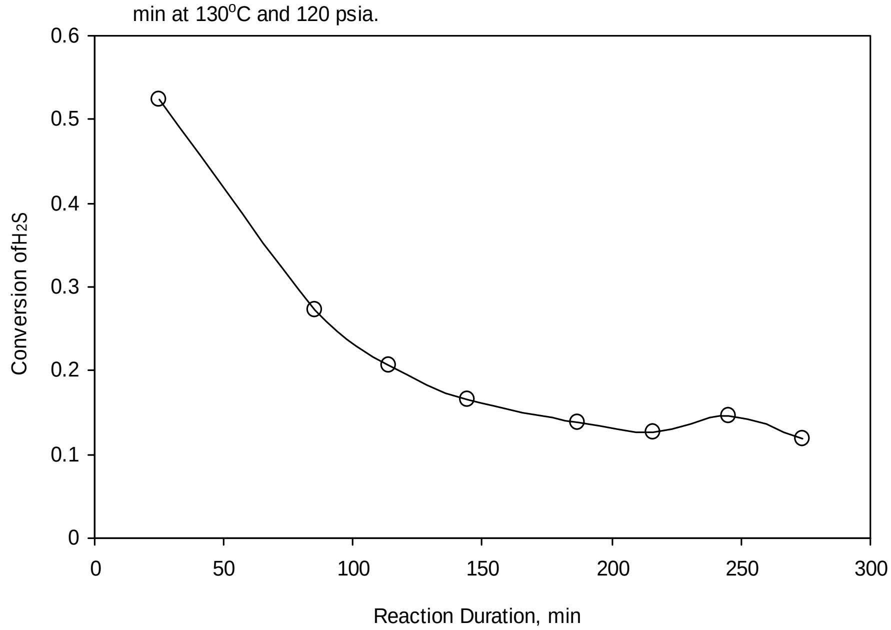
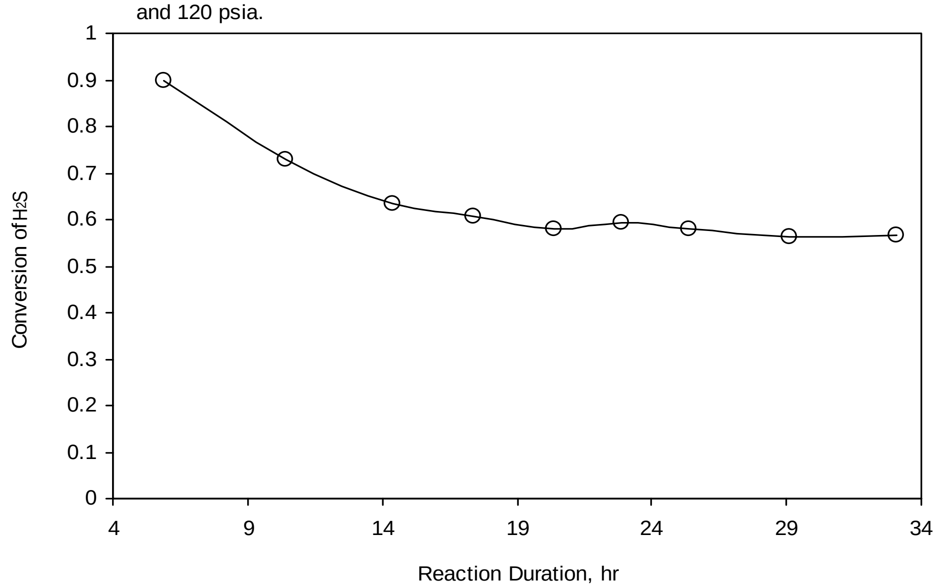


Figure 5- 6. Effects of reaction duration on conversion of H_2S in a momolithic catalyst reactor with a 50-SCCM feed stream containing 4,980 - 5,000 ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2 for 6 - 3 3 hrs at 140°C and 120 psia.



Effects of reaction duration on conversion of H_2S to elemental sulfur were examined at 140°C and 120 psia. The feed gas mixture to a monolithic catalyst reactor contains 5,000-ppmv H_2S, 2,500-ppmv SO_2, 10-v% moisture, and 70-v% H_2. The volumetric feed rate of the feed gas mixture is 50 SCCM. Initially, conversion of H_2S to elemental sulfur decreases gradually with increased reaction duration. Conversion of H_2S to elemental sulfur levels off, as reaction duration increases further, as shown in Figure 5-6. These observations may suggest that initially reaction takes place on both internal surface and external surface of the porous monolithic catalyst, and then the porous monolithic catalyst are plugged up with produced liquid elemental sulfur, as reaction duration increases further. These observations also indicate that reaction may occur mainly on external surface of monolithic catalyst rather than internal surface of monolithic catalyst, when conversion of H_2S levels off.

Conversion of H_2S in the micro packed-bed reactor and the monolithic catalyst reactor decreases gradually with increased catalyst age, while conversion of H_2S in the micro bubble reactor decreases drastically with increased catalyst age (reaction duration).

CONCLUSIONS

The following results were obtained from experimental data generated with the micro packed-bed reactor system, the micro bubble reactor system, and the monolithic catalyst reactor. The following conclusions were drawn based on the experimental data from the reactor systems, and their interpretations.

- Concentrations of moisture in the micro packed-bed reactor and the micro bubble reactor affect slightly conversion of H_2S. Conversion of H_2S in the monolithic catalyst reactor decrease with increased concentrations of moisture.
- Conversion of H_2S in the micro packed-bed reactor and the micro bubble reactor increases with space time, whereas conversion of H_2S in the monolithic catalyst reactor decreases generally with increased space time. Reaction rates of H_2S in the micro packed-bed reactor and the micro bubble reactor decrease generally with increased space time.
- Conversion of H_2S in the micro packed-bed reactor and the micro bubble reactor increases with catalyst loading. Reaction rate of H_2S in the micro packed-bed reactor and the micro bubble reactor decreases with increased catalyst loading.
- Conversion of H_2S in the micro packed-bed reactor and the micro bubble reactor increases with reaction pressure, whereas conversion of H_2S in the monolithic catalyst reactor decreases generally with increased reaction pressure.
- Reaction rate of H_2S is proportional to conversion of H_2S with inlet molar flow rates of H_2S and amounts of catalyst held constant. Conversion of H_2S in the micro packed-bed reactor, the micro bubble reactor, and the monolithic catalyst reactor does not follow Arrhenius' equation. Conversion of H_2S in the micro packed-bed reactor decreases with increased reaction temperature over the H_2S-to-SO_2 feed ratio range of 3 – 5, whereas conversion of H_2S in the micro packed-bed reactor appear to fluctuate independent of reaction temperature over the low H_2S-to-SO_2 feed ratio range of 0.8 – 1.3. Conversion of H_2S in the micro

bubble reactor appear to fluctuate independently of reaction temperature at the H_2S-to-SO_2 feed ratio range of 2, whereas conversion of H_2S in the monolithic catalyst reactor decrease with increased reaction temperature at the H_2S-to-SO_2 feed ratio range of 2.

- Concentrations of H_2S and SO_2 in the packed-bed reactor affect reaction rates of H_2S with SO_2 in the presence of various concentrations of moisture, where reaction rates of H_2S with SO_2 decrease slightly with increased concentration of moisture. Concentrations of H_2S and SO_2 in the packed-bed reactor affect reaction rates of H_2S with SO_2 at various reaction pressures and temperatures, where reaction rates of H_2S with SO_2 decrease generally with increased reaction temperature and increase generally with total reaction pressure.

- The value of the surface reaction rate constant k of H_2S and the value of the equilibrium adsorption constant k_A of H_2S, determined with the experimental data having 100-SCCM feed stream, are $1.4376x10^{-3}$ g-mole/s-g-$(psia)^3$ and 11.3187 $psia^{-1}$, respectively. The value of the surface reaction rate constant k of H_2S and the value of the equilibrium adsorption constant k_A of H_2S, determined with the experimental data having 50-SCCM feed stream,, are 0.037 g-mole/s-g-$(psia)^3$ and 55.64 $psia^{-1}$, respectively.

- Conversion of H_2S in the micro packed-bed reactor and the monolithic catalyst reactor decreases gradually with increased catalyst age, while conversion of H_2S in the micro bubble reactor decreases drastically with increased catalyst age (reaction duration).

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PUBLICATIONS AND PRESENTATIONS

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