ENERGY

Conversion of Hydrogen Sulfide in Coal Gases to Liquid Elemental Sulfur with Monolithic Catalysts

Final Report

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For the Period October 1, 2004 to September 30, 2009

K. C. Kwon
Tel: (334) 727-8976, Fax: (334) 724-4188

December 2009

Work Performed Under Contract No
DE-FG26-04NT42129

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

By
Tuskegee University
Tuskegee, Alabama 36088

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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 power plants that produce electric power and clean transportation fuels with coal and natural gas. These plants will require highly clean coal gas with H_2S below 1 ppmv 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 power 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

In the Single-Step Sulfur Recovery Process (SSRP), 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 H_2 and CO components of syngas appear to behave as inert with respect to sulfur formed at the SSRP conditions. One problem in the SSRP process that needs to be eliminated or minimized is COS formation that may occur due to reaction of CO with sulfur formed from the Claus reaction.

The objectives of this research are to formulate monolithic catalysts for removal of H_2S from coal gases and minimum formation of COS with monolithic catalyst supports, γ-alumina wash coat, and catalytic metals, to develop a regeneration method for a deactivated monolithic catalyst, to measure kinetics of both direct oxidation of H_2S to elemental sulfur with SO_2 as an oxidizer and formation of COS in the presence of a simulated coal gas mixture containing H_2, CO, CO_2, and moisture, using a monolithic catalyst reactor. The task of developing kinetic rate equations and modeling the direct oxidation process to assist in the design of large-scale plants will be abandoned since formulation of catalysts suitable for the removal of H_2S and COS is being in progress. 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.

Experiments on conversion of hydrogen sulfide into elemental sulfur and formation of COS were carried out for the space time range of 46 – 570 seconds under reaction conditions to formulate catalysts suitable for the removal of H_2S and COS from coal gases and evaluate their

capabilities in reducing hydrogen sulfide and COS in coal gases. Simulated coal gas mixtures consist of 3,200 - 4,000 -ppmv hydrogen sulfide, 1,600 – 20,000- ppmv sulfur dioxide, 18 – 27 v% hydrogen, 29 – 41 v% CO, 8 – 12 v% CO_2, 0 -10 vol % moisture, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the reactor are 30 - 180 cm^3/min at 1 atm and 25°C (SCCM). The temperature of the reactor is controlled in an oven at 120 - 155°C. The pressure of the reactor is maintained at 40 – 210 psia. The molar ratio of H_2S to SO_2 in the monolithic catalyst reactor is maintained approximately 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 ppmv, 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 power 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 advanced power plants will require highly clean coal gas with H_2S below 1 ppmv 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 cleaned 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

$ZnO + H_2S \leftrightarrow ZnS + H_2O$ (HGD)

(ii) sorbent regeneration using air to produce SO_2

$ZnS + 3/_2 O_2 \leftrightarrow SO_2 + ZnO$ (regeneration)

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

$SO_2 + 2H_2$ (or $2CO$) $\leftrightarrow S + 2H_2O$ (or $2CO_2$) (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 co-produce 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 advanced power 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 40 to 220 psia and 125 to 155^oC. In the direct oxidation process, the Claus reaction is carried out over a selective monolithic catalyst in the presence of the major gas components at around 125 to 155^oC 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 Single-Step Sulfur Recovery Process (SSRP) consists of injecting sulfur dioxide (SO_2) directly into the quenched syngas in the presence of a monolithic catalyst at 125 to 160^oC (257 to 320^oF) to oxidize H_2S and recover elemental sulfur in a single step via the Claus reaction

($2\,H_2S + SO_2 \rightarrow 3/n\,S_n + 2H_2O$). The SO_2 needed is obtained by burning a portion of the produced sulfur in an external sulfur burner. The key differences between the above-mentioned SSRP process and the traditional Claus process are: (a) in the proposed SSRP process, the Claus reaction occurs in a highly reducing syngas atmosphere containing hydrogen (H_2) and carbon monoxide (CO) and (b) the reaction is carried out at the pressure of the syngas (40-1200 psia). Furthermore, in conventional low-temperature fixed-bed Claus processes e.g. SuperClaus, the catalyst is poisoned by sulfur plugging and must be regenerated by heating externally. In the proposed SSRP process, the liquid elemental sulfur formed from the H_2S removal reaction (Claus reaction) can be detached from the monolithic catalyst surface with the aid of the slip velocity (special flow pattern) of the gaseous reaction mixture at the interface between the thin liquid sulfur layer and the gaseous reaction mixture. The slip velocity, developed from a special flow pattern in monolithic catalyst support channels, induces the pressure difference between the solid catalyst surface and the liquid-sulfur interface by the venturi effect, thereby facilitating catalyst regeneration, sulfur recovery, and favorable shift in thermodynamic limitation on sulfur formation.

Work to date at various research organizations has shown the potential of SSRP to convert 99 + % of the H_2S at 40 – 220 psia to elemental sulfur with less than 40 ppmv COS slip. Differential kinetic experiments at Tuskegee University have shown significant increases in rate with pressure increase from 40 to 170 psia. Considering that the commercial SSRP plant will operate at up to 1200 psia, there is potential for complete sulfur removal and recovery. One problem in SSRP that needs to be eliminated or minimized is COS formation that may occur due to reaction of CO with sulfur formed from the Claus reaction.

The objectives of this research are to formulate monolithic catalysts for removal of H_2S from coal gases and minimum formation of COS with monolithic catalyst supports, γ-alumina wash coat, and catalytic metals, to develop a regeneration method for a deactivated monolithic catalyst, to measure kinetics of both direct oxidation of H_2S to elemental sulfur with SO_2 as an oxidizer and formation of COS in the presence of a simulated coal gas mixture containing, H_2, CO, CO_2, and moisture, using a monolithic catalyst reactor. The task of developing kinetic rate equations and modeling the direct oxidation process to assist in the design of large-scale plants will be abandoned since formulation of catalysts suitable for the removal of H_2S and COS is being in progress. 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.

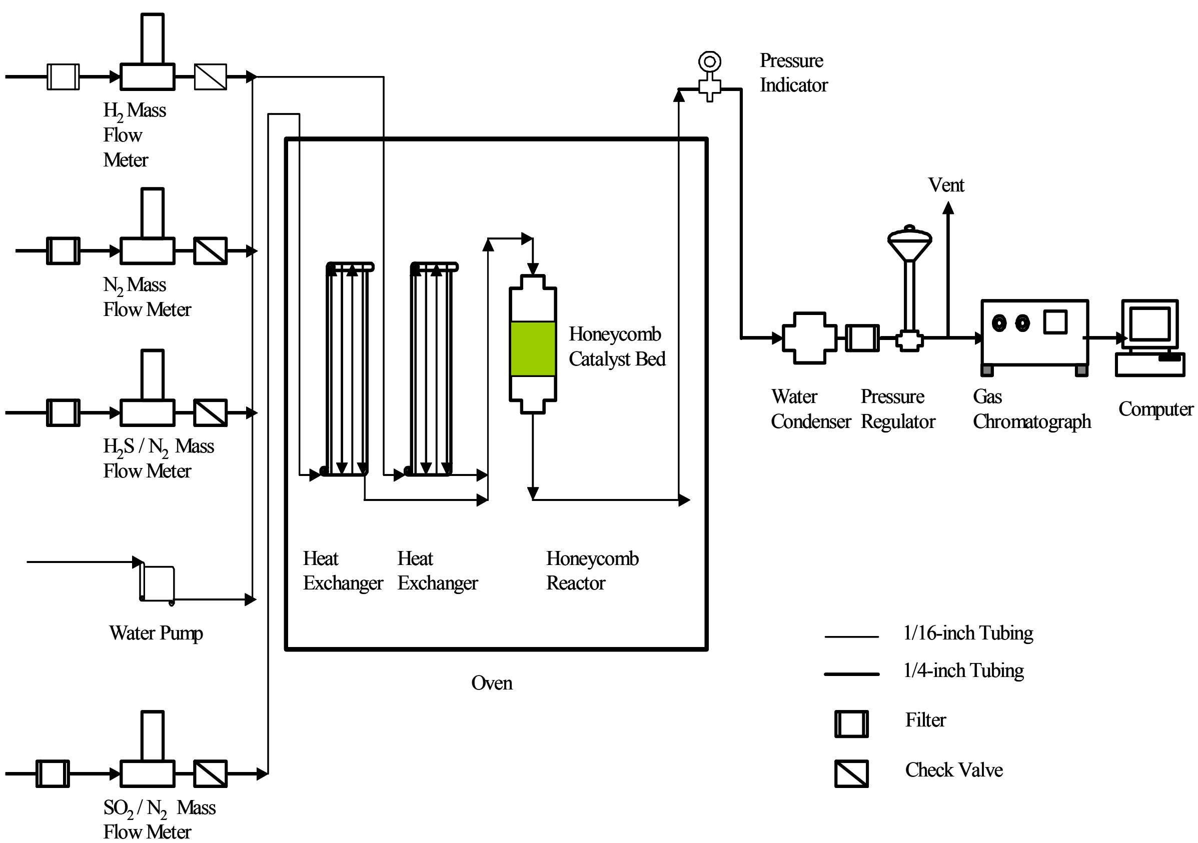
Experiments on conversion of hydrogen sulfide to elemental sulfur and formation of COS using a monolithic catalyst reactor were carried out for the space time range of 46 – 570 seconds at 120 - 155^{o}C and 40 – 210 psia to evaluate effects of active catalytic metal oxides impregnated into γ-alumina wash-coated monolithic catalyst supports on conversion of hydrogen sulfide to elemental sulfur and formation of COS. Simulated coal gas mixtures consist of 3,300 – 4,000 ppmv hydrogen sulfide, 1,600 – 2,000 ppmv sulfur dioxide, 18 – 27 v% hydrogen, 29 – 41 v% CO, 8 – 12 v% CO_2, 0 - 18 vol % moisture, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM. The molar ratio of H_2S to SO_2 in the monolithic catalyst reactor is maintained approximately at 2 for all the reaction experiment runs.

EXPERIMENTAL SETUPS

A monolithic catalyst reactor was fabricated with a 2.2-cm inside diameter and 15-cm long 316-stainless steel HPLC column. A -alumina wash-coated monolithic catalyst, 2-cm in the diameter and 15-cm long, 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 120 - 155^oC. Conversion of hydrogen sulfide to elemental sulfur was analyzed with the flame photometric detector (FPD) and the thermal conductivity detector (TCD) of a gas chromatograph. The range of space (residence) time of the reaction gas mixture in the reactor was 46 – 570 seconds under 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 Figure 1. The preheaters are made of 20-ft-long 1/16-inch Teflon tubing.

Figure 1. Schematic Diagram on a monolithic catalyst reactor assembly



Simulated coal gas mixtures are fed downward to a vertical monolithic catalyst reactor, as shown in Figure 1. The reactor was loaded with a γ-alumina-wash-coated monolithic catalyst in the vertical reactor. The vertical reactor, loaded with 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. The reaction conditions are shown in Table 1. The properties of the monolithic catalyst are shown in Table 2. The experimental data, shown in Tables 3 through 8 for the fifth year research, were used for drawing the Figures 5-2 through 5-7. The experimental data for the first year through fourth year research works shown in Appendixes I through IV were used for constructing Figures 1-2 through 4-10.

Table 1. Experimental conditions for the reaction of hydrogen sulfide with sulfur dioxide as an oxidant using a monolithic catalyst reactor.

Bulk Volume of the honeycomb catalyst bed, cm^3:	47
Temperature, °C:	120 – 155
Reaction Pressure, psia	40 – 210
Space Time under the reaction conditions, s:	46 – 570
Total Feed Rate, SCCM	30 –180
Concentration of H_2S, ppmv	3,300 – 4,000
Concentration of SO_2, ppmv	1,600 – 2,000
Carbon Monoxide, v%	29 – 41
Hydrogen, vol %	18 – 27
Carbon Dioxide, vol %	8 – 12
Moisture, vol %:	0 – 18
Nitrogen, vol %	Remainder

Table 2. Dimensions and properties of the monolithic catalyst

Diameter, cm	2
Length, cm	15
Flat Surface Area, cm^2	1,040
Wash Coat	$-Al_2O_3$
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 ($2MgO-2Al_2O_3-5SiO_2$)

Table 3. Conversion of H_2S to elemental sulfur and formation of COS with a 120 SCCM feed stream containing 3,600 ppmv H_2S, 1,800 ppmv SO_2 as an oxidant, 31.0 – 33.0 v% CO, 18.7 – 21.0 v% H_2, 8.5 – 9.1 v% CO_2, and 10-v% moisture at 125°C, 115 - 124 psia, and 138 – 148 s space time.

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product	Reaction Product
672	125	121.7	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9648	76	93	na
673	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9473	42	90	145
674	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8968	35	63	170
675	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9184	40	90	187
676	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9257	43	108	178
677	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9164	53	99	194
678	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9364	43	104	161
679	125	120.7	120	145	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9333	49	95	125
680	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9394	46	107	156
681	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9387	33	88	137
682	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9204	41	107	177
683	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7789	38	147	196
684	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9112	27	148	180
685	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.908	93	169	184
686	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7941	43	176	208
687	125	122.7	120	147	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8423	50	159	171
688	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8488	28	127	137
689	125	120.7	120	145	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7634	42	122	141
690	125	121.7	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.751	30	144	160
691	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8548	48	154	199
692	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9211	59	129	145
693	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9104	51	87	103
694	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9414	88	39	108
695	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9366	25	84	106
696	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9395	10	81	107
697	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9523	15	64	90
698	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9195	19	72	102
699	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.856	20	64	88
700	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9159	11	39	82
701	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9124	14	44	101
702	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8909	14	44	65
703	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8596	13	39	76
704	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9096	8	23	87
705	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8763	18	36	83
706	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7938	10	30	91
707	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9102	13	22	85
708	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8959	12	39	84
709	125	121.7	120	146	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.881	13	26	85
710	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8157	11	22	65
711	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8711	21	24	46

Table 3. Continued – 1

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product	Reaction Product
712	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8663	13	22	69
713	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6277	8	16	56
714	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.4934	10	19	40
715	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8554	5	14	42
716	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7733	4	19	56
717	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7968	6	18	56
718	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6596	6	28	66
719	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.5362	8	26	51
720	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7613	5	22	46
721	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.5745	6	21	56
722	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	1	5	38	32
723	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9429	4	29	68
724	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9235	6	20	61
725	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9458	6	19	64
726	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9252	6	20	74
727	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.892	6	14	52
728	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8927	8	12	60
729	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9243	5	15	48
730	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9311	6	23	56
731	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9323	6	20	51
732	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8825	5	18	46
733	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8345	8	16	58
734	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.827	4	1	66
735	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.916	6	13	43
736	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8668	6	12	53
737	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8458	8	17	41
738	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8927	5	9	35
739	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7539	7	18	39
740	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9489	4	13	74
741	125	121.7	120	146	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9489	8	51	101
742	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6777	6	21	78
743	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8718	6	24	73
744	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7729	6	22	48
745	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7276	7	17	53
746	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.816	7	20	48
747	125	115.7	120	139	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8236	7	18	46
748	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8289	7	13	46
749	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7754	6	12	38
750	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7662	7	14	39
751	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8166	8	17	35
752	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7491	9	16	36
753	125	121.7	120	146	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7743	8	17	35
754	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.721	8	17	32
755	125	115.7	120	139	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6678	8	14	33

Table 3. Continued – 2

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product	Reaction Product
756	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6934	9	14	45
757	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7135	9	25	45
758	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.75	9	21	50
759	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7223	8	18	49
760	125	115	120	138	0.36	0.18	32.06	20.55	10.00	8.92	27.93	1	9	11	26
761	125	117	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9403	8	14	44
762	125	120	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6906	11	16	44
763	125	117	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8367	3	34	59
764	125	116	120	139	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8243	7	41	57
765	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.9206	10	45	36
766	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.9125	26	33	32
767	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.724	12	12	29
768	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.5612	2	11	30
769	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8678	10	19	35
770	125	115.7	120	139	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.874	10	46	61
771	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7633	12	62	71
772	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7489	10	69	64
773	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7253	4	75	56
774	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6888	11	76	47
775	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.73	10	49	42
776	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7701	7	83	60
777	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7482	7	102	89
778	125	115.7	120	139	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7388	12	89	73
779	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7794	13	63	56
780	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7044	12	147	111
781	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6799	15	102	133
782	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6867	8	46	53
783	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6578	5	59	81
784	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6946	6	37	51
785	125	123.7	120	148	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6245	13	55	62
786	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6684	6	78	83
787	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6067	9	36	53
788	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6619	12	38	45
789	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.5795	7	63	40
790	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6351	6	45	65
791	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6856	11	40	45
792	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6803	10	61	69
793	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6704	8	48	47
794	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6764	6	41	46
795	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6219	11	88	69
796	125	122.7	120	147	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.621	7	47	40
797	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8743	18	58	66
798	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8352	17	60	68
799	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8408	15	59	69

Table 3. Continued – 3

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product	Reaction Product
800	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.774	8	56	65
801	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8289	8	56	68
802	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8065	7	51	48
803	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7885	8	46	56
804	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7897	11	46	50
805	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7359	11	47	54
806	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7481	9	49	52
807	125	122.7	120	147	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7661	10	53	61
808	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7573	8	51	58
809	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7087	6	54	54
810	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7335	10	51	58
811	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7134	8	50	52
812	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6575	8	50	53
813	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.698	9	50	51
814	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7138	8	48	50
815	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7357	8	42	52
816	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6566	10	48	52
817	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6882	8	47	48
818	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7737	9	54	61
819	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7305	8	50	48
820	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.9246	8	50	51
821	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8587	14	52	50
822	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8865	9	52	47
823	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.85	9	54	50
824	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.895	11	56	54
825	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8797	17	51	52
826	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8533	9	60	58
827	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8574	9	53	54
828	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8802	9	47	51
829	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8343	5	45	44
830	125	115.7	120	139	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8096	16	47	42
831	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8536	14	49	45
832	125	115.7	120	139	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8221	10	49	45
833	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7951	8	41	40
834	125	116.7	120	140	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8347	9	47	46
835	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.82	14	52	55
836	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8099	7	50	45
837	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7155	12	38	52
838	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7624	6	45	42
839	125	121.7	120	146	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7783	7	47	46
840	125	117.7	120	141	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7836	9	49	50
841	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7646	7	35	46
842	125	121.7	120	146	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.6745	8	44	46
843	125	117.7	120	141	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.777	10	42	43

Table 3. Continued – 4

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product	Reaction Product
844	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7439	11	42	44
845	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7979	12	42	43
846	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7812	7	44	42
847	125	115.7	120	139	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7599	7	39	42
848	125	114.7	120	138	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7241	7	42	41
849	125	114.7	120	138	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7526	6	47	44
850	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7674	8	39	43
851	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7423	5	45	41
852	125	117.7	120	141	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7149	7	37	38

*SCCM: standard cubic centimeters per minute, volumetric flow rates of gases measured at 1 atm and 25°C

Table 4. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 1-w% Cr aqueous solution and heated for 2 hrs at 400°C.

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
672	125	121.7	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9648	na	76	93	na	4-w% Zn soaked and heated for 2 hrs at 400°C, and 1-w% Cr soaked and heated for 2 hrs at 400°C
673	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9473	54	42	90	145	
674	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8968	108	35	63	170	
675	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9184	98	40	90	187	
676	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9257	69	43	108	178	
677	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9164	95	53	99	194	
678	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9364	58	43	104	161	
679	125	120.7	120	145	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9333	30	49	95	125	
680	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9394	49	46	107	156	
681	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9387	49	33	88	137	
682	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9204	70	41	107	177	
683	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7789	49	38	147	196	
684	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9112	32	27	148	180	
685	125	119.7	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.908	14	93	169	184	
686	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7941	31	43	176	208	
687	125	122.7	120	147	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8423	13	50	159	171	
688	125	117.7	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8488	10	28	127	137	
689	125	120.7	120	145	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7634	19	42	122	141	
690	125	121.7	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.751	16	30	144	160	
691	125	118.7	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8548	45	48	154	199	

*SCCM: standard cubic centimeters per minute, volumetric flow rates of gases measured at 1 atm and 25°C

Table 5. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 400°C.

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
692	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9211	16	59	129	145	4-w% Zn soaked and heated for 2 hrs at 400°C, and 2-w% Cr soaked and heated for 2 hrs at 400°C
693	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9104	15	51	87	103	
694	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9414	70	88	39	108	
695	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9366	22	25	84	106	
696	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9395	26	10	81	107	
697	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9523	25	15	64	90	
698	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9195	30	19	72	102	
699	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.856	24	20	64	88	
700	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9159	44	11	39	82	
701	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9124	56	14	44	101	
702	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8909	21	14	44	65	
703	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8596	37	13	39	76	
704	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9096	64	8	23	87	
705	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8763	47	18	36	83	
706	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7938	61	10	30	91	
707	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9102	62	13	22	85	
708	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8959	45	12	39	84	
709	125	121.7	120	146	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.881	59	13	26	85	
710	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8157	43	11	22	65	
711	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8711	23	21	24	46	
712	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8663	47	13	22	69	
713	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6277	40	8	16	56	
714	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.4934	21	10	19	40	
715	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8554	29	5	14	42	
716	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7733	37	4	19	56	
717	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7968	37	6	18	56	
718	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6596	38	6	28	66	
719	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.5362	25	8	26	51	
720	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7613	24	5	22	46	
721	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.5745	34	6	21	56	

Table 6. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 500°C.

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
722	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	1	-6	5	38	32	4-w% Zn soaked, heated for 2 hrs at 400°C and 2-w% Cr soaked, heated for 2 hrs at 500°C
723	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9429	39	4	29	68	
724	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9235	41	6	20	61	
725	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9458	45	6	19	64	
726	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9252	54	6	20	74	
727	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.892	38	6	14	52	
728	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8927	48	8	12	60	
729	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9243	33	5	15	48	
730	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9311	33	6	23	56	
731	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9323	31	6	20	51	
732	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8825	28	5	18	46	
733	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8345	42	8	16	58	
734	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.827	66	4	1	66	
735	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.916	30	6	13	43	
736	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8668	40	6	12	53	
737	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8458	24	8	17	41	
738	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8927	26	5	9	35	
739	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7539	21	7	18	39	
740	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9489	61	4	13	74	
741	125	121.7	120	146	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9489	51	8	51	101	
742	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6777	57	6	21	78	
743	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8718	49	6	24	73	
744	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7729	26	6	22	48	
745	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7276	35	7	17	53	
746	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.816	29	7	20	48	
747	125	115.7	120	139	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8236	28	7	18	46	
748	125	117.7	120	141	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8289	33	7	13	46	
749	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7754	26	6	12	38	
750	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7662	26	7	14	39	

Table 6. Continued – 1

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
751	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8166	17	8	17	35	
752	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7491	21	9	16	36	
753	125	121.7	120	146	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7743	18	8	17	35	
754	125	119.7	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.721	14	8	17	32	
755	125	115.7	120	139	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6678	19	8	14	33	
756	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6934	31	9	14	45	
757	125	120.7	120	145	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7135	19	9	25	45	
758	125	116.7	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.75	29	9	21	50	
759	125	118.7	120	142	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.7223	31	8	18	49	

Table 7. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 4-w% Cr aqueous solution and heated for 2 hrs at 400°C.

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
760	125	115	120	138	0.36	0.18	32.06	20.55	10.00	8.92	27.93	1	15	9	11	26	4-w% Zn soaked and heated for 2 hrs at 400°C, and 4-w% Cr soaked and heated for 2 hrs at 400°C
761	125	117	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.9403	29	8	14	44	
762	125	120	120	144	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.6906	28	11	16	44	
763	125	117	120	140	0.36	0.18	32.06	20.55	10.00	8.92	27.93	0.8367	26	3	34	59	
764	125	116	120	139	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8243	17	7	41	57	
765	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.9206	-9	10	45	36	
766	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.9125	-1	26	33	32	
767	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.724	16	12	12	29	
768	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.5612	19	2	11	30	
769	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8678	16	10	19	35	
770	125	115.7	120	139	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.874	14	10	46	61	
771	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7633	9	12	62	71	
772	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7489	-5	10	69	64	
773	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7253	-20	4	75	56	

Table 7. Continued – 1

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
774	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6888	-29	11	76	47	
775	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.73	-8	10	49	42	
776	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7701	-23	7	83	60	
777	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7482	-12	7	102	89	
778	125	115.7	120	139	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7388	-16	12	89	73	
779	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7794	-6	13	63	56	
780	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7044	-36	12	147	111	
781	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6799	31	15	102	133	
782	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6867	8	8	46	53	
783	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6578	22	5	59	81	
784	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6946	14	6	37	51	
785	125	123.7	120	148	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6245	7	13	55	62	
786	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6684	5	6	78	83	
787	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6067	17	9	36	53	
788	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6619	7	12	38	45	
789	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.5795	-23	7	63	40	
790	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6351	20	6	45	65	
791	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6856	4	11	40	45	
792	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6803	8	10	61	69	
793	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6704	-1	8	48	47	
794	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6764	5	6	41	46	
795	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6219	-19	11	88	69	
796	125	122.7	120	147	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.621	-7	7	47	40	
797	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8743	9	18	58	66	
798	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8352	8	17	60	68	
799	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8408	11	15	59	69	
800	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.774	10	8	56	65	
801	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8289	12	8	56	68	
802	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8065	-3	7	51	48	
803	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7885	10	8	46	56	
804	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7897	5	11	46	50	

Table 7. Continued – 2

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
805	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7359	7	11	47	54	
806	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7481	3	9	49	52	
807	125	122.7	120	147	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7661	8	10	53	61	
808	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7573	7	8	51	58	
809	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7087	0	6	54	54	
810	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7335	7	10	51	58	
811	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7134	1	8	50	52	
812	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6575	3	8	50	53	
813	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.698	0	9	50	51	
814	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7138	2	8	48	50	
815	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7357	10	8	42	52	
816	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6566	4	10	48	52	
817	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.6882	1	8	47	48	
818	125	120.7	120	145	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7737	6	9	54	61	
819	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.7305	-2	8	50	48	

Table 8. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 6-w% Cr aqueous solution and heated for 2 hrs at 400°C.

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
820	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.9246	0	8	50	51	4-w% Zn soaked and heated for 2 hrs at 400°C, and 6-w% Cr soaked and heated for 2 hrs at 400°C
821	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8587	-3	14	52	50	
822	125	121.7	120	146	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8865	-4	9	52	47	
823	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.85	-4	9	54	50	
824	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.895	-2	11	56	54	
825	125	116.7	120	140	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8797	1	17	51	52	
826	125	117.7	120	141	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8533	-3	9	60	58	
827	125	118.7	120	142	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8574	1	9	53	54	

Table 8. Continued - 1

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time s	Feed Composition, v%							Conversion of H_2S	COS, ppm				Remark
					H_2S	SO_2	CO	H_2	H_2O	CO2	N_2		COS Formation	Cylinder Feed	Blank Product	Reaction Product	
828	125	119.7	120	144	0.36	0.18	32.92	21.02	10.00	9.13	26.39	0.8802	4	9	47	51	
829	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8343	-1	5	45	44	
830	125	115.7	120	139	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8096	-5	16	47	42	
831	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8536	-4	14	49	45	
832	125	115.7	120	139	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8221	-4	10	49	45	
833	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7951	-1	8	41	40	
834	125	116.7	120	140	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8347	-2	9	47	46	
835	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.82	3	14	52	55	
836	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.8099	-5	7	50	45	
837	125	119.7	120	144	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7155	14	12	38	52	
838	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7624	-3	6	45	42	
839	125	121.7	120	146	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7783	-1	7	47	46	
840	125	117.7	120	141	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7836	1	9	49	50	
841	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7646	10	7	35	46	
842	125	121.7	120	146	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.6745	2	8	44	46	
843	125	117.7	120	141	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.777	2	10	42	43	
844	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7439	3	11	42	44	
845	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7979	1	12	42	43	
846	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7812	-1	7	44	42	
847	125	115.7	120	139	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7599	3	7	39	42	
848	125	114.7	120	138	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7241	-1	7	42	41	
849	125	114.7	120	138	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7526	-2	6	47	44	
850	125	118.7	120	142	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7674	3	8	39	43	
851	125	120.7	120	145	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7423	-5	5	45	41	
852	125	117.7	120	141	0.36	0.18	31.01	18.67	10.00	8.52	31.27	0.7149	1	7	37	38	

*SCCM: standard cubic centimeters per minute, volumetric flow rates of gases measured at 1 atm and 25°C

CALCULATIONS

Concentrations of H_2S and COS in the outlet stream from a monolithic catalyst reactor are analyzed by using a gas chromatograph equipped with a flame photometric detector (FPD) and a thermal conductivity detector (TCD), and a calibration curve. A calibration curve for H_2S is developed with three H_2S samples in different concentrations such as 4,980 ppmv, 996 ppmv, and 249 ppmv, whereas a calibration curve for COS is developed with three COS samples in different concentrations such as 45 ppmv, 30 ppmv, and 15 ppmv.

Each experimental reaction run proceeds after a blank run, which is carried out in the absence of moisture and monolithic catalyst in a reactor. Conversions of H_2S are obtained with concentrations of H_2S from a reaction run and those from its blank run, as shown in the following equation.

$$x = \frac{(C_B - C_R)}{C_B} \qquad (1)$$

where x: conversion of H_2S.
C_B: concentration of H_2S in the outlet stream for a blank run.
C_R: concentration of H_2S in the outlet stream for a reaction run

Formation of COS is calculated by subtracting concentration of COS in the outlet stream for a blank run from concentration of COS in the outlet stream for a reaction run.
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Elemental sulfur is formed with the following reversible stoichiometric reaction formula, as shown in Equation (2). COS is formed in the presence of moisture and catalyst according to the reversible stoichiometric reaction formula, as shown in Equation (3) and Equation (4), which is obtained by adding Equation (2) to Equation (3) multiplied by 3, whereas COS is formed in the absence of moisture and catalyst according to the reversible stoichiometric reaction formula, as shown in Equation (5).

$$2H_2S + SO_2 \leftrightarrow 3S + 2H_2O \qquad (2)$$
$$CO + S \leftrightarrow COS \qquad (3)$$
$$2H_2S + SO2 + 3CO \leftrightarrow 3COS + 2H_2O \qquad (4)$$
$$CO + H_2S \leftrightarrow COS + H_2 \qquad (5)$$

FIRST YEAR RESULTS AND DISCUSSION

Experiments on conversion of hydrogen sulfide into element sulfur were carried out over the space time range of 90 – 560 seconds to evaluate effects of catalyst age, space time, moisture concentration, and reaction temperature on conversion of hydrogen sulfide into elemental sulfur and formation of COS, as shown in Appendix I. Simulated coal gas mixtures consist of 3,600 - 4,000 ppmv hydrogen sulfide, 1,800 - 2,000 ppmv sulfur dioxide, 36 – 41 v% CO, 23 – 27 v% hydrogen, 0 – 10 vol % moisture, 10 – 12 v% CO_2, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to a monolithic catalyst reactor are 30 - 180 cm^3/min at room temperature and atmospheric pressure (SCCM). The temperature of the reactor is controlled in an oven at 140 - 155^oC. The pressure of the reactor is maintained at 118 - 124 psia.

Effects of space time on conversion of H_2S into elemental sulfur and formation of COS

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 90 – 560 s, which is developed by increasing total volumetric flow rate of gaseous feed mixture to a monolithic catalyst reactor from 30 SCCM to 180 SCCM to evaluate effects of space time on both conversion of hydrogen sulfide to elemental sulfur and formation of COS at 140^oC and 118 -123 psia. A gas mixture fed to the monolithic catalyst reactor contains 3,600-ppmv H_2S, 1,800-ppmv SO_2, 37-v% CO, 24-v% hydrogen, 10-v% moisture, 10-v% CO_2, and nitrogen as remainder.

Conversion of H_2S to elemental sulfur is 0.41 – 0.83. Concentration of COS in the outlet stream from the catalyst-loaded reactor is 26 – 213 ppmv, whereas concentration of COS in the outlet stream from the reactor in absence of the catalyst and moisture is 26 – 119 ppmv. Space time affects conversion of H_2S to elemental sulfur, and formation of COS for both the reaction runs and the blank runs over the pressure range of 118 -123 psia, as shown in Figures 1-2 through 1-4. Conversion of H_2S to elemental sulfur and formation of COS for both the reaction runs and the blank runs increase with space time. However, formation of COS for the reaction runs is higher than that for the blank runs over the space time range of 90 – 560 s. The difference of COS formation between the reaction runs and the blank runs increases with space time, as shown in Figure 1-3. Formation of COS for the reaction runs increases with conversion of H_2S to elemental sulfur over the space time range of 90 – 560 s, as shown in Figure 1-4. In other words, formation of COS for the reaction runs increases with formation of elemental sulfur over the space time range of 90 – 560 s. These data may suggest that COS in the reaction runs are formed mainly by reacting CO with elemental sulfur vapor produced from conversion of H_2S with SO_2 in addition to reacting CO with H_2S in the bulk gaseous mixture in the monolithic catalyst reactor. These data may indicate that COS in the blank runs be formed mainly by reacting CO with H_2S.

Figure 1-2. Effects of space time on conversion of H_2S to elemental sulfur and formation of COS with a 30 - 180 SCCM feed stream containing 3600-ppm H_2S, 1800-ppm SO_2 as an oxidant, and 10-v% moisture at 140^oC, 118 - 123 psia, and 90 -560 s space time.

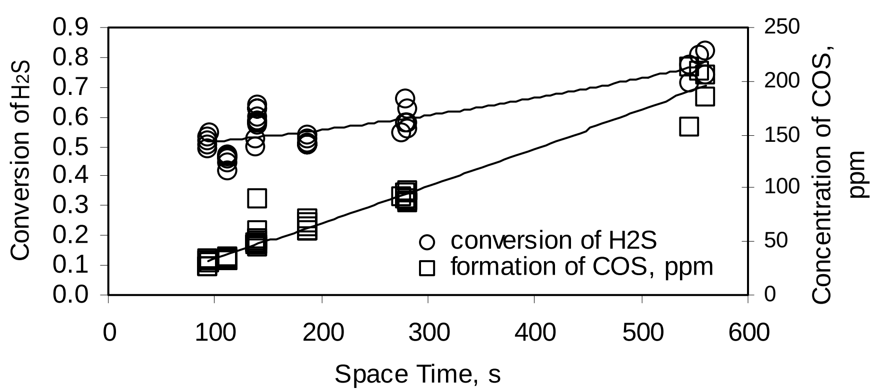


Figure 1-3. Effects of space time on formation of COS with a 30 - 180 SCCM feed stream containing 3,600-ppm H_2S, 1,800-ppm SO_2 as an oxidant, and 10-v% moisture at 140°C, 118 - 123 psia, and 90 -560 s space time..

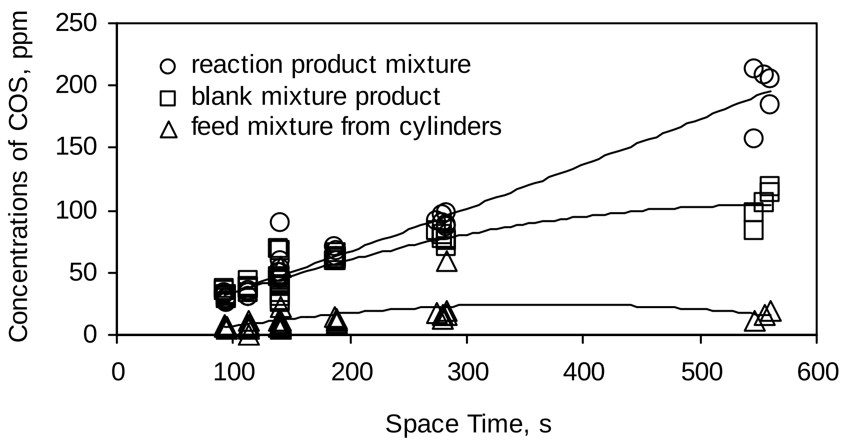
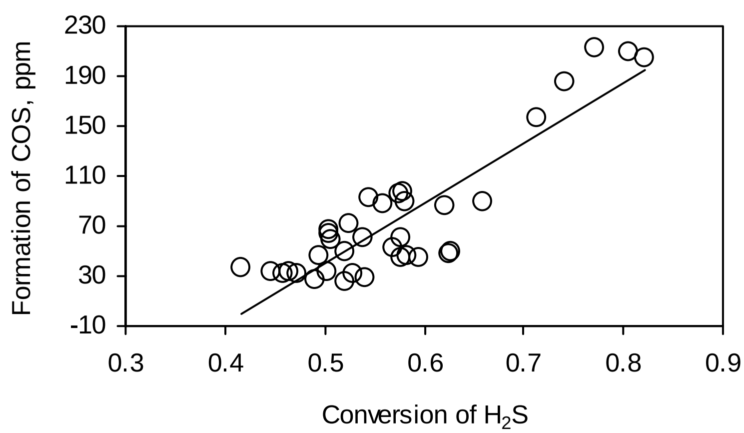


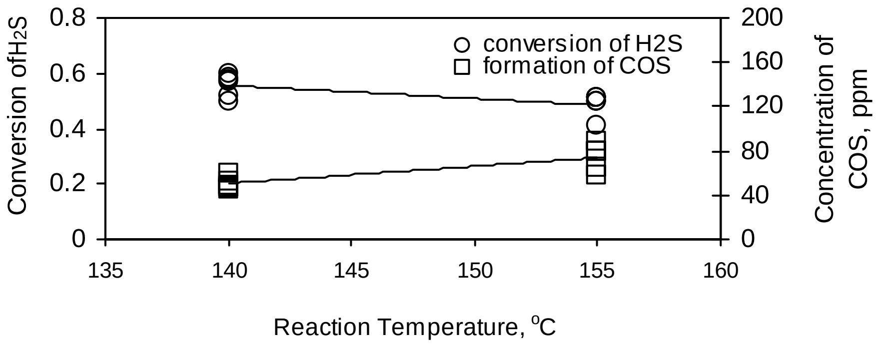
Figure 1-4. Effects of conversion of H_2S on formation of COS with a 30 - 180 SCCM feed stream containing 3,600-ppm H_2S, 1,800-ppm SO_2 as an oxidant, and 10-v% moisture at 140°C, 118 - 123 psia, and 90 – 560 s space time.



Effects of temperature on conversion of H_2S into elemental sulfur and formation of COS

Experiments on conversion of hydrogen sulfide to elemental sulfur and formation of COS 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 136 - 142 s to evaluate effects of reaction temperature on conversion of hydrogen sulfide to elemental sulfur and formation of COS at 140 - 155°C and 121 – 122 psia. Gas mixtures are fed to a monolithic catalyst reactor containing 3,600-ppmv H_2S, 1,800 ppmv SO_2, 37-v% CO, 24-v% hydrogen, 10-v% moisture, 10-v% CO_2, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the monolithic catalyst reactor are 120 SCCM. Conversion of H_2S to elemental sulfur is 0.49 – 0.6.

Figure 1-5. Effects of temperature on conversion of H_2S to elemental sulfur and formation of COS with a feed stream containing 3,600-ppm H_2S, 1,800-ppm SO_2 and 10-v% moisture at 121-122 psia and 136 - 142 s space time.

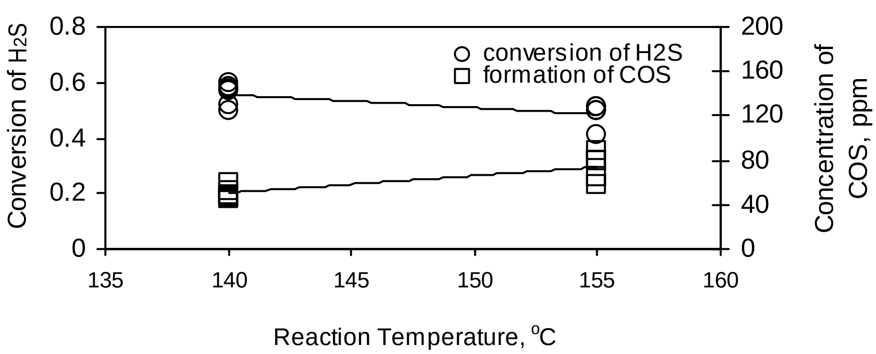


Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation. Reaction temperature affects conversion of H_2S to elemental sulfur. Conversion of H_2S to elemental sulfur decreases with increased reaction temperature (see Figure 1-5). However, formation of COS increases with increased reaction temperature. The experimental data may indicate that increased reaction temperature decrease formation of element sulfur and increase formation of COS. Vapor pressure of liquid elemental sulfur increases with reaction temperature. These facts may indicate that increased vapor pressure of liquid elemental sulfur increase formation of COS according to the reversible stoichiometric reaction formula ; $CO(g) + S(g) \leftrightarrow COS(g)$.

Effects of moisture on conversion of H_2S into elemental sulfur and formation of COS

Concentration of moisture in a 108 – 120 SCCM feed stream containing 3,600 – 4,000 ppmv H_2S and 1,800 – 2,000 ppmv SO_2 affects conversion of H_2S to elemental sulfur over the moisture range of 0 - 10 v% in a simulated coal gas mixture at 118 – 123 psia (see Figure 1-6) and 140°C. Conversions of H_2S to elemental sulfur and formation of COS in a monolithic catalyst reactor decreases with increased concentration of moisture. These data may indicate that increased moisture shift equilibrium formation of both liquid elemental sulfur and COS in disfavor of their formation according to the reversible stoichiometric reaction formulas; $2H_2S + SO_2 \leftrightarrow 3S + 2H_2O$ and $2H_2S + SO_2 + 3CO \leftrightarrow 3COS + 2H_2O$.

Figure 1-6. Effects of moisture on conversion of H_2S to elemental sulfur and formation of COS with a 108 – 120 SCCM feed stream containing 3,600 - 4,000 ppm H_2S, 1,800 - 2,000 ppm SO_2, and 10-v% moisture at 140°C and 118 - 123 psia.



.Effects of catalyst age on conversion of H_2S into elemental sulfur and formation of COS

Effects of catalyst age on conversion of H_2S to elemental sulfur and formation of COS were examined at 140°C, 119 -124 psia, and 139 – 143 s space time over the reaction time of 230 – 2670 min. The feed gas mixture to a monolithic catalyst reactor contains 3,600-ppmv H_2S, 1,800-ppmv SO_2, 37-v% CO, 24-v% H_2, 10-v% moisture, 10-v% CO_2, and N_2 as remainder. The volumetric feed rate of the feed gas mixture is 120 SCCM. Conversion of H_2S to elemental sulfur decreases linearly with increased catalyst age, whereas formation of COS increases with increased catalyst age, as shown in Figure 1-7. Each reaction experimental run proceeds after a blank experimental run, which is carried out in the absence of moisture and a monolithic catalyst. Formation of COS for the blank runs is higher than that for the reaction runs, as shown in Figure 1-8. Formation of COS decreases generally with increased conversion of H_2S, as shown in Figure 1-9. In other words, formation of COS decreases with decreased catalyst age, and increased formation of elemental sulfur.

Figure 1-7. Effects of catalyst age on conversion of H_2S to elemental sulfur and formation of COS with a 120 SCCM feed stream containing 3,600-ppm H_2S, 1,800-ppm SO_2 as an oxidant, and 10-v% moisture at 140°C, 119 -124 psia, and 139 – 143 s space time.

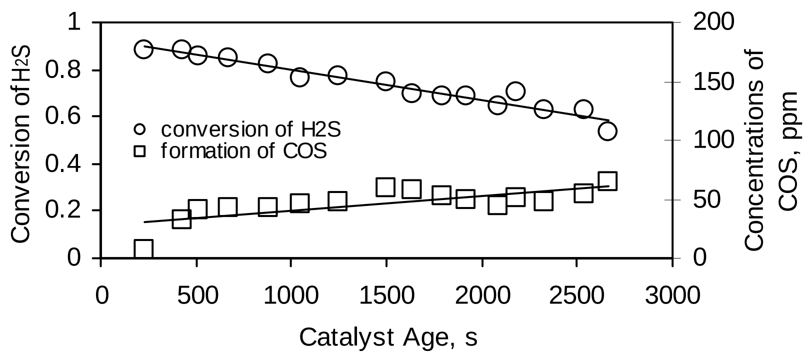
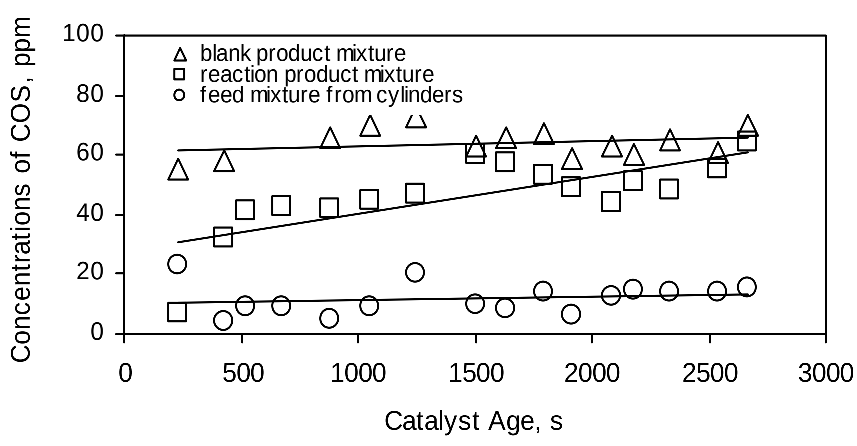
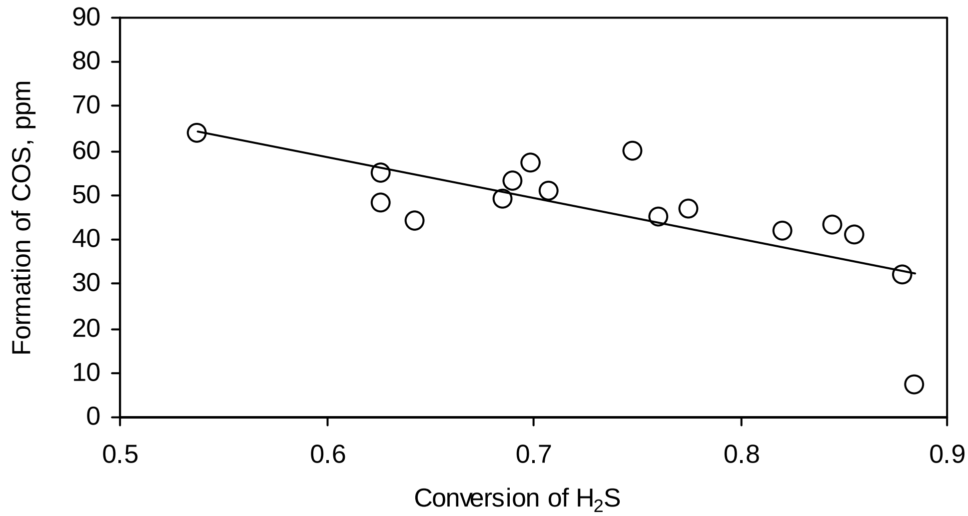


Figure 1-8. Effects of catalyst age on formation of COS with a 120 SCCM feed stream containing 3,600-ppm H_2S, 1800-ppm SO_2 as an oxidant, and 10-v% moisture at 140°C, 119 - 124 psia, and 139 – 143 s space time.



These observations may suggest that COS for the reaction runs be formed by reacting CO with elemental sulfur produced from conversion of H_2S in addition to reacting CO with H_2S itself in the bulk gaseous mixture. These data may indicate that COS for the blank runs be formed by reacting CO with H_2S in the bulk gaseous mixture. Sulfur vapor released from used catalyst increases with catalyst age, where used catalyst is never regenerated. Thus, formation of COS for both the reaction of CO with elemental sulfur vapor and the reaction of CO with H_2S in the bulk gaseous mixture may increase with catalyst age. Elemental sulfur is formed catalytically, whereas COS is formed non-catalytically or thermally for both reaction runs and blank runs.

Figure 1-9. Effects of conversion of H_2S to elemental sulfur on formation of COS with a 120 SCCM feed stream containing 3,600-ppm H_2S, 1,800-ppm SO_2 as an oxidant, and 10-v% moisture at 140°C, 119 -124 psia, 139 – 143 s space time, and 230 – 2670 s catalyst age.



FIRST YEAR CONCLUSIONS

The following conclusions were drawn based on the experimental data generated from the monolithic catalyst reactor system, and their interpretations. Each reaction experimental run proceeds after a blank experimental run, which is carried out in the absence of moisture and a monolithic catalyst.

Conversion of H_2S to elemental sulfur and formation of COS for both the reaction runs and the blank runs increase with space time. However, formation of COS for the reaction runs is higher than that for the blank runs over the space time range of 90 – 560 s. The difference of COS formation between the reaction runs and the blank runs increases with space time. Formation of COS for the reaction runs increases with conversion of H_2S to elemental sulfur over the space time range of 90 – 560 s. In other words, formation of COS for the reaction runs increases with formation of elemental sulfur over the space time range of 90 – 560 s. These data may suggest that COS in the reaction runs is formed mainly by reacting CO with elemental sulfur vapor produced from conversion of H_2S with SO_2 in addition to reacting CO with H_2S in the bulk gaseous mixture in the monolithic catalyst reactor. These data may indicate that COS in the blank runs be formed mainly by reacting CO with H_2S.

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 with increased reaction temperature. However, formation of COS increases with increased reaction temperature. The experimental data may indicate that increased reaction temperature decrease formation of element sulfur and increase formation of COS. Vapor pressure of liquid elemental sulfur increases with reaction temperature. These facts may indicate that increased vapor pressure of liquid elemental sulfur increase formation of COS according to the reversible stoichiometric reaction formula ; $CO(g) + S(g) \leftrightarrow COS(g)$.

Conversions of H_2S to elemental sulfur and formation of COS in a monolithic catalyst reactor decreases with increased concentration of moisture. These data may indicate that increased moisture shift equilibrium formation of both liquid elemental sulfur and COS in disfavor of their formation according to the reversible stoichiometric reaction formulas; $2H_2S + SO_2 \leftrightarrow 3S + 2H_2O$ and $2H_2S + SO_2 + 3CO \leftrightarrow 3COS + 2H_2O$.

Conversion of H_2S to elemental sulfur decreases linearly with increased catalyst age, whereas formation of COS increases with increased catalyst age. Formation of COS for the blank runs is higher than that for the reaction runs. Formation of COS decreases generally with increased conversion of H_2S. In other words, formation of COS decreases with decreased catalyst age, and increased formation of elemental sulfur. These observations may suggest that COS for the reaction runs be formed by reacting CO with elemental sulfur produced from conversion of H_2S in addition to reacting CO with H_2S itself in the bulk gaseous mixture. These data may indicate that COS for the blank runs be formed by reacting CO with H_2S in the bulk gaseous mixture. Sulfur vapor released from used catalyst increases with catalyst age, where used catalyst is never regenerated. Thus, formation of COS for both the reaction of CO with elemental sulfur vapor and the reaction of CO with H_2S in the bulk gaseous mixture may increase with catalyst age. Elemental sulfur is formed catalytically, whereas COS is formed non-catalytically or thermally for both reaction runs and blank runs.

SECOND YEAR RESULTS AND DISCUSSION

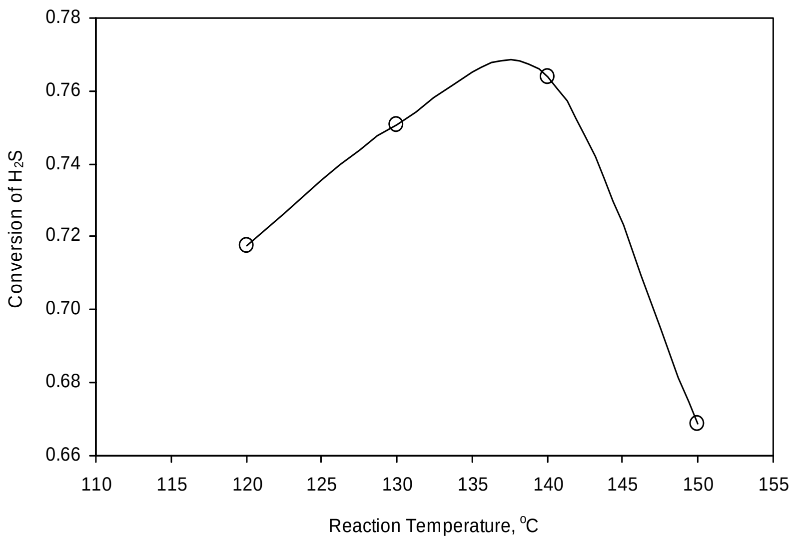
Experiments on conversion of hydrogen sulfide into element sulfur were carried out over the space time range of 46 – 570 seconds to evaluate effects of catalyst age, space time, pressure, and reaction temperature on conversion of hydrogen sulfide into elemental sulfur and formation of COS, as shown in Appendix II. Simulated coal gas mixtures consist of 3,500 - 4,000 ppmv hydrogen sulfide, 1,800 - 2,000 ppmv sulfur dioxide, 36 – 41 v% CO, 23 – 27 v% hydrogen, 0 – 12 vol % moisture, 10 – 12 v% CO_2, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to a monolithic catalyst reactor are 30 - 180 cm^3/min at room temperature and atmospheric pressure (SCCM). The temperature of the reactor is controlled in an oven at 120 - 150^oC. The pressure of the reactor is maintained at 40 - 210 psia. Monolithic catalyst is regenerated with nitrogen at 140^oC overnight. Multiple experimental data (e.g.: triple, quadruple, quintuple) were obtained and averaged at a given experimental condition to interpret them.

Effects of temperature on conversion of H_2S into elemental sulfur and formation of COS

Experiments on conversion of hydrogen sulfide to elemental sulfur and formation of COS 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 137 - 150 s to evaluate effects of reaction temperature on conversion of hydrogen sulfide to elemental sulfur and formation of COS at 120 - 150°C and 120 – 123 psia. Gas mixtures are fed to a monolithic catalyst reactor containing 3,600-ppmv H_2S, 1,800 ppmv SO_2, 37-v% CO, 24-v% hydrogen, 10-v% moisture, 10-v% CO_2, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the monolithic catalyst reactor are 120 SCCM. Conversion of H_2S to elemental sulfur is 0.60 – 0.84.

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 increases with increased reaction temperature over the temperature range of 120 -140°C (see Figure 2-2), whereas conversion of H_2S to elemental sulfur decreases with increased reaction temperature over the temperature range of 140 -150°C.

Figure 2-2. Effects of temperature on conversion of H_2S to elemental sulfur with a 120-SCCM feed stream containing 3,600-ppmv H_2S, 1,800-ppmv SO_2, 37-v% CO, 24-v% H_2, 10-v% CO_2 and 10-v% moisture at 120 – 150°C, 120- 123 psia and 137 - 150 s space time.



Formation of COS for the reaction runs levels off and is minimum over the temperature range of 120 -130°C, increases with increased reaction temperature over the temperature range of 130 -140°C, and decreases with increased reaction temperature over the temperature range of 140 -150°C, as shown in Figure 2-3. Formation of COS for the blank runs levels off over the temperature range of 120 -130°C, and increases with increased reaction temperature over the temperature range of 130 -150°C. Formation of COS for the reaction runs is higher than that for the blank runs. Figure 2-4 indicates that catalytic formation of COS is lowest over the H_2S conversion range of 0.72 – 0.75 and also over the temperature range of 120 – 130°C.

Figure 2-3. Effects of temperature on formation of COS with a 120-SCCM feed stream containing 3,600-ppmv H_2S, 1,800-ppmv SO_2, 37-v% CO, 24-v% H_2, 10-v% CO_2 and 10-v% moisture at 120 – 150°C, 120- 123 psia and 137 - 150 s space time.

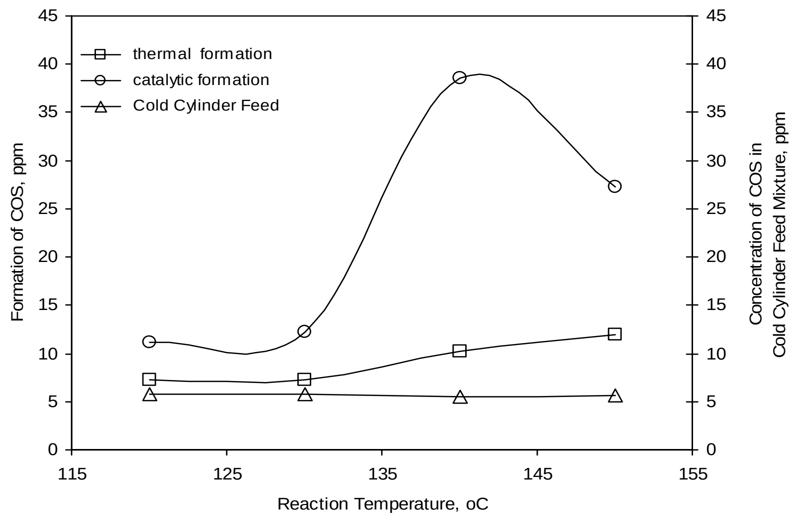
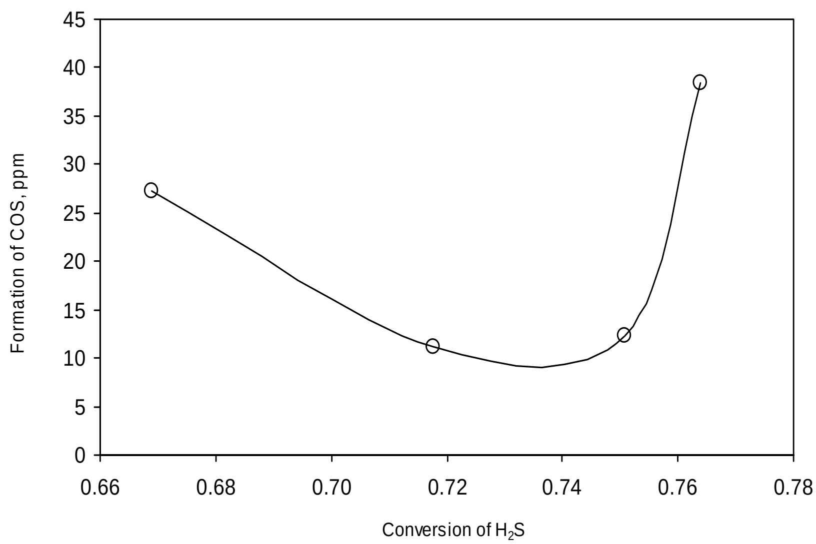


Figure 2-4. Effects of conversion of H_2S on formation of COS with a 120-SCCM feed stream containing 3,600-ppmv H_2S, 1,800-ppmv SO_2, 37-v% CO, 24-v% H_2, 10-v% CO_2 and 10-v% moisture at 120 – 150°C, 120- 123 psia and 137 - 150 s space time.

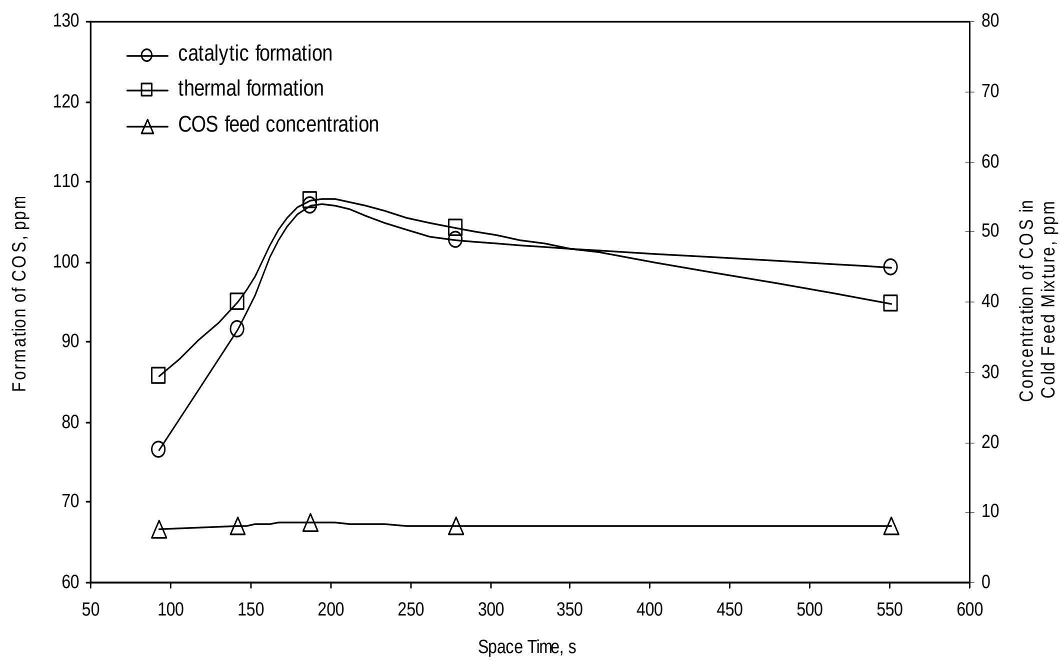


Effects of space time on conversion of H_2S into elemental sulfur and formation of COS

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 90 – 570 s, which is developed by increasing total volumetric flow rate of gaseous feed mixture to a monolithic catalyst reactor from 30 SCCM to 180 SCCM to evaluate effects of space time on both conversion of hydrogen sulfide to elemental sulfur and formation of COS at 140^{o}C and 117 -124 psia. A gas mixture fed to the monolithic catalyst reactor contains 3,500-ppmv H_2S, 1,800-ppmv SO_2, 37-v% CO, 24-v% hydrogen, 10-v% moisture, 10-v% CO_2, and nitrogen as remainder.

Conversion of H_2S to elemental sulfur is 0.27 – 0.86. Concentration of COS in the outlet stream from the catalyst-loaded reactor is 36 – 147 ppmv, whereas concentration of COS in the outlet stream from the reactor in absence of the catalyst and moisture is 73 – 172 ppmv. Space time affects conversion of H_2S to elemental sulfur, and formation of COS for both the reaction runs and the blank runs over the pressure range of 117 -124 psia, as shown in Figures 2-5 and 2-6.

Figure 2-5. Effects of space time on formation of COS with 30 - 180 SCCM feed streams containing 3500-ppmv H_2S, 1800-ppmv SO_2, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v% moisture at 140^{o}C, and 117 -124 psia and 90 – 570 s space time.



Conversion of H_2S to elemental sulfur increases with space time, as shown in Figure 2-6. Formation of COS for both the reaction runs and the blank runs increases with space time over the space time range of 90 – 190 s and decreases with increased space time over the space time range of 190 – 550 s. Formation of COS for the reaction runs is slightly lower than formation of COS for the blank runs over the space time range of 140 – 280 s. Formation of COS for the reaction runs is much lower than that for the blank runs at the space time 90 s, whereas catalytic formation of COS for the reaction runs is much higher than thermal formation of COS for the blank runs at the space time 550 s.

Formation of COS for the reaction runs appears to be independent of conversion of H_2S to elemental sulfur over the space time range of 90 – 570 s, as shown in Figure 2-7. These facts may suggest that COS be formed by reacting H_2S with CO ($CO + H_2S \rightarrow COS + H_2$)

Figure 2-6. Effects of space time on conversion of H_2S with 30 - 180 SCCM feed streams containing 3500-ppmv H_2S, 1800-ppmv SO_2, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v% moisture at 140°C, 117 -124 psia and 90 – 570 s space time.

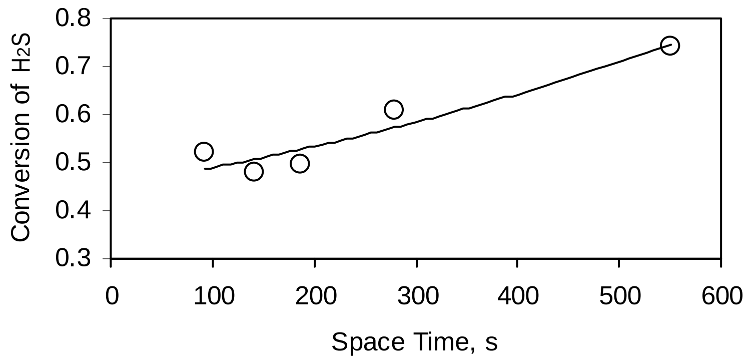
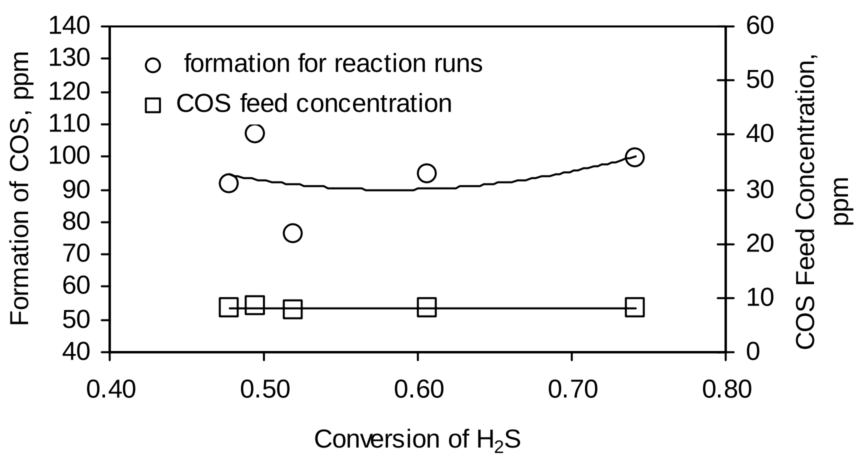


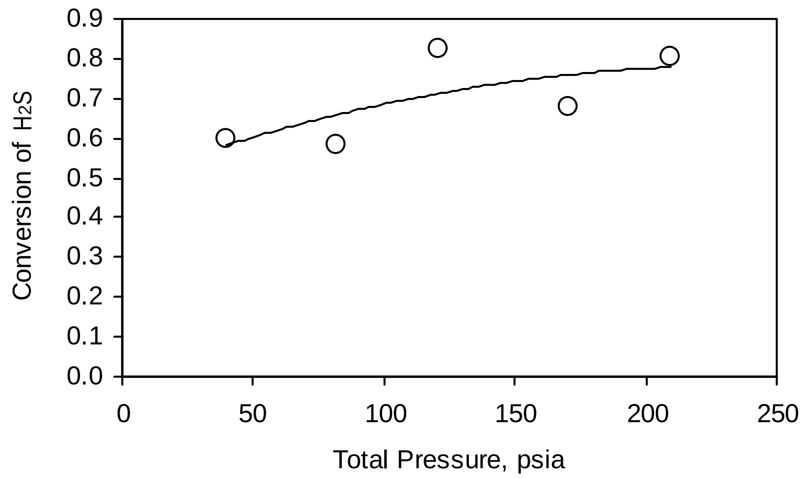
Figure 2-7. Effects of conversion of H_2S on formation of COS with 30 - 180 SCCM feed stream containing 3500-ppmv H_2S, 1800-ppmv SO_2, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v % moisture at 140°C, 117 -124 psia, and 90 - 570 s space time.



Effects of total pressure on conversion of H_2S into elemental sulfur and formation of COS

Experiments on conversion of hydrogen sulfide to elemental sulfur and formation of COS 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 46 - 243 s to evaluate effects of total pressure on conversion of hydrogen sulfide to elemental sulfur and formation of COS at 140°C and 40 – 210 psia. Gas mixtures are fed to a monolithic catalyst reactor containing 3,500 – 3600 ppmv H_2S, 1,800 ppmv SO_2, 37-v% CO, 24-v% hydrogen, 10-v% moisture, 10-v% CO_2, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the monolithic catalyst reactor are 120 SCCM. Conversion of H_2S to elemental sulfur is 0.53 – 0.86.

Figure 2-8. Effects of total pressure on conversion of H_2S with a 120-SCCM feed stream containing 3500 - 3600 ppmv H_2S, 1800-ppmv SO_2, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v% moisture at 140°C, 40 – 210 psia and 46 - 243 s space time.



Conversion of H_2S increases with increased total pressure, as shown in Figure 2-8. Formation of COS for reaction runs and formation of COS for blank runs increase with increased total pressure. Formation of COS is not significantly different from that for the blank runs at 140°C and 40 – 210 psia, as shown in Figure 2-9. Formation of COS is independent of H_2S conversion over the H_2S conversion range of 0.68 – 0.83, as shown in Figure 2-10.

Figure 2-9. Effects of total pressure on formation of COS with a 120-SCCM feed stream containing 3500 - 3600 ppmv H_2S, 1800-ppmv SO_2, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v% moisture at 140°C, 40 -210 psia and 46 - 243 s space time.

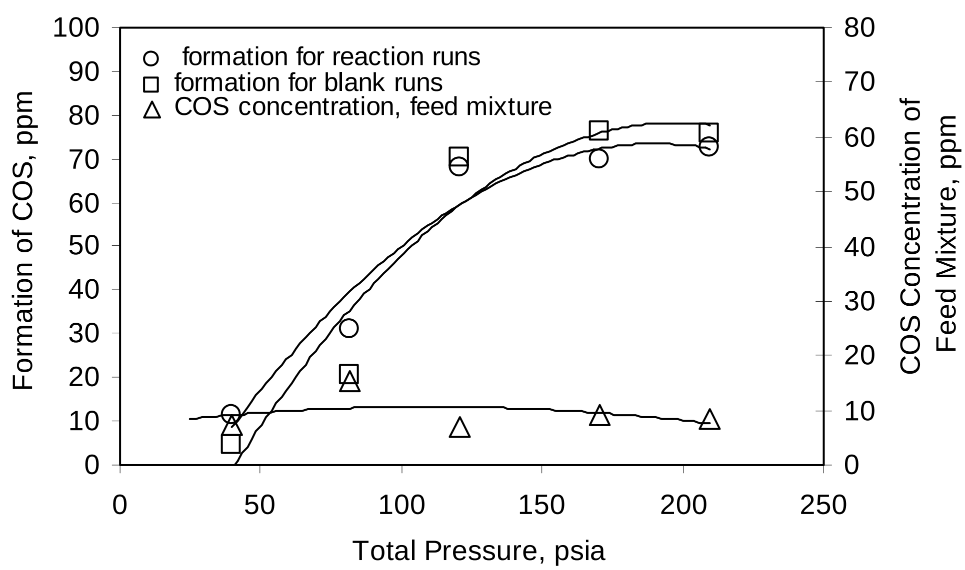
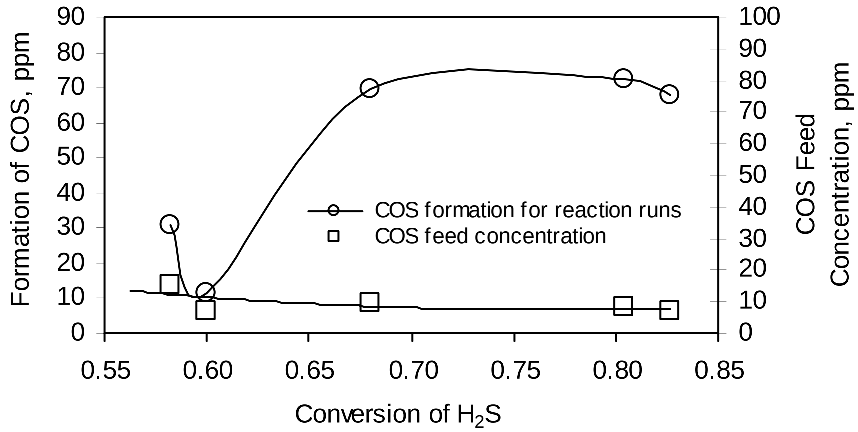


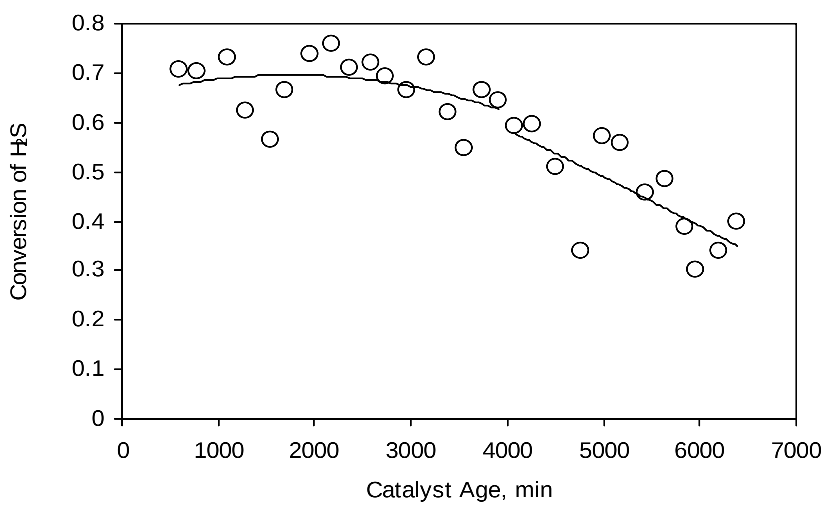
Figure 2-10. Effects of conversion of H_2S on formation of COS with a 120-SCCM feed stream containing 3500 - 3600 ppmv H_2S, 1800-ppmv SO_2, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v% moisture at 140°C, 40 - 210 psia and 46 - 243 s space time.



Regeneration of catalyst for conversion of H_2S into elemental sulfur and formation of COS

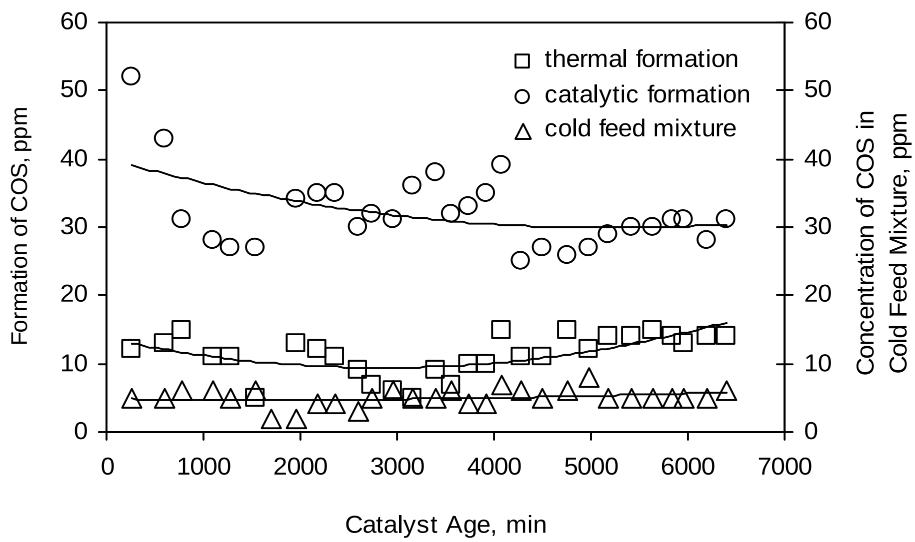
Effects of catalyst age on conversion of H_2S to elemental sulfur and formation of COS were examined at 140°C, 119 -123 psia, and 138 – 142 s space time. The feed gas mixture to a monolithic catalyst reactor contains 3,600-ppmv H_2S, 1,800-ppmv SO_2, 37-v% CO, 24-v% H_2, 10-v% moisture, 10-v% CO_2, and N_2 as remainder. The volumetric feed rate of the feed gas mixture is 120 SCCM. The monolithic catalyst is regenerated with nitrogen at 140°C overnight. Conversion of H_2S to elemental sulfur does not decrease significantly with increased catalyst age up to 3900 hr catalyst age, as shown in Figure 2-11.

Figure 2-11. Effects of catalyst regeneration on conversion of H_2S to elemental sulfur with a 120-SCCM feed stream containing 3600-ppmv H_2S, 1800-ppmv SO_2, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v% moisture at 140°C, 119 - 123 psia and 138 – 142 s space time, regenerating the monolithic catalyst with N_2 overnight at 140°C.



Formation of COS for the reaction runs decreases with increased catalyst age, as shown in Figure 2-12. Each reaction experimental run proceeds after a blank experimental run, which is carried out in the absence of moisture and a monolithic catalyst. Formation of COS for the blank runs is lower than that for the reaction runs, as shown in Figure 2-12. This observation may indicate that COS be formed in the presence of catalyst and moisture by reacting CO with elemental sulfur vapor, which is produced from the removal reaction of H_2S.

Figure 2-12. Effects of catalyst age on formation of COS with a 120 SCCM feed stream containing 3,600-ppmv H_2S, 1800-ppmv SO_2 as an oxidant, 37-v% CO, 10-v% CO_2, 24-v% H_2 and 10-v% moisture at 140°C, 119 -123 psia, and 138 – 142 s space time, regenerating the monolithic catalyst with N_2 overnight at 140°C.



SECOND YEAR CONCLUSIONS

The following conclusions were drawn based on experimental data generated from the monolithic catalyst reactor system, and their interpretations. Each reaction experimental run proceeds after a blank experimental run, which is carried out in the absence of moisture and a monolithic catalyst.

Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation. Conversion of H_2S to elemental sulfur increases with increased reaction temperature over the temperature range of 120 -140°C, whereas conversion of H_2S to elemental sulfur decreases with increased reaction temperature over the temperature range of 140 -150°C. Formation of COS for the reaction runs levels off and is lowest over the temperature range of 120 -130°C, increases with increased reaction temperature over the temperature range of 130 -140°C, and decreases with increased reaction temperature over the temperature range of 140 -150°C. Formation of COS for the blank runs is minimal over the temperature range of 120 -130°C, and increases with increased reaction temperature over the temperature range of 130 -150°C. Formation of COS for the reaction runs is higher than that for the blank runs. Formation of COS for the reaction runs is minimal over the H_2S conversion range of 0.72 – 0.75 and also over the temperature range of 120 – 130°C.

Formation of COS for both the reaction runs and the blank runs increases with space time over the space time range of 90 – 190 s and decreases with increased space time over the space time range of 190 – 550 s. Formation of COS for the reaction runs is slightly lower than that for the blank runs over the space time range of 140 – 280 s. Formation of COS for the reaction runs is much lower than that for the blank runs at the space time 90 s, whereas formation of COS for the reaction runs is much higher than that for the blank runs at the space time 550 s. Conversion of H_2S to elemental sulfur increases with space time. Formation of COS for the reaction runs appears to be independent of conversion of H_2S to elemental sulfur over the space time range of 90 – 570 s. These facts may suggest that COS be formed by reacting H_2S with CO ($CO + H_2S \rightarrow COS + H_2$)

Conversion of H_2S increases with increased total pressure. Formation for reaction runs of COS and formation of COS for blank runs also increase with increased total pressure. Formation of COS is not significantly different from that for the blank runs at 140°C and 40 – 210 psia. Formation of COS is independent of H_2S conversion over the H_2S conversion range of 0.68 – 0.83.

Conversion of H_2S to elemental sulfur does not decrease significantly with increased age of 140°C-nitrogen regenerated catalyst up to 3900 hr catalyst age. Formation of COS for the reaction runs decreases with increased age of regenerated catalyst. Formation of COS for the blank runs is lower than that for the reaction runs. This observation may suggest that COS is formed in the presence of catalyst and moisture by reacting CO with elemental sulfur vapor from the removal reaction of H_2S.

THIRD YEAR RESULTS AND DISCUSSION

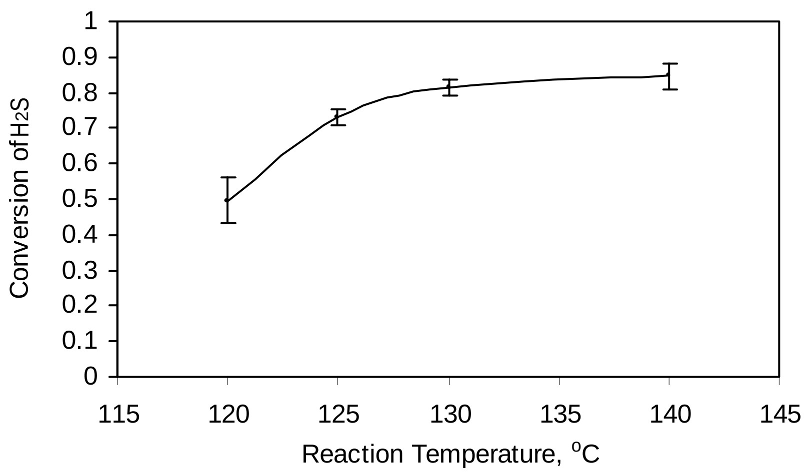
Experiments on conversion of hydrogen sulfide into element sulfur were carried out over the space time range of 130 – 156 seconds to formulate catalysts suitable for the removal of H_2S and COS from coal gases, evaluate removal capabilities of hydrogen sulfide and COS from coal gases with formulated catalysts, and develop an economic regeneration method of deactivated catalysts, as shown in Appendix III. Catalysts were formulated by soaking γ-alumina wash-coated monolithic catalyst supports in catalytically active additive aqueous solutions followed by heating them under air environment at elevated temperatures. Simulated coal gas mixtures consist of 3,300 - 3,800 ppmv hydrogen sulfide, 1,600 - 1,900 ppmv sulfur dioxide, 29 – 34 v% CO, 18 – 21 v% hydrogen, 5 – 18 vol % moisture, 8 – 10 v% CO_2, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to a monolithic catalyst reactor are 130 - 156 cm^3/min at room temperature and atmospheric pressure (SCCM). The temperature of the reactor is controlled in an oven at 120 - 140°C. The pressure of the reactor is maintained at 116 - 129 psia. Elemental sulfur deposited on a monolithic catalyst is removed with nitrogen at 140 - 270°C overnight.

Effects of temperature on conversion of H_2S into elemental sulfur and formation of COS

Experiments on conversion of hydrogen sulfide to elemental sulfur and formation of COS 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 135 - 149 s to evaluate effects of reaction temperature on conversion of hydrogen sulfide to elemental sulfur and formation of COS at 120 - 140^{o}C and 117 – 124 psia, using quadruple experimental data. Gas mixtures are fed to a monolithic catalyst reactor containing 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 20-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the monolithic catalyst reactor are 120 SCCM. Conversion of H_2S to elemental sulfur is 0.50 – 0.82.

Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation, although conversion of H_2S to elemental sulfur increases with increased reaction temperature over the temperature range of 120 -140^{o}C (see Figure 3-2).

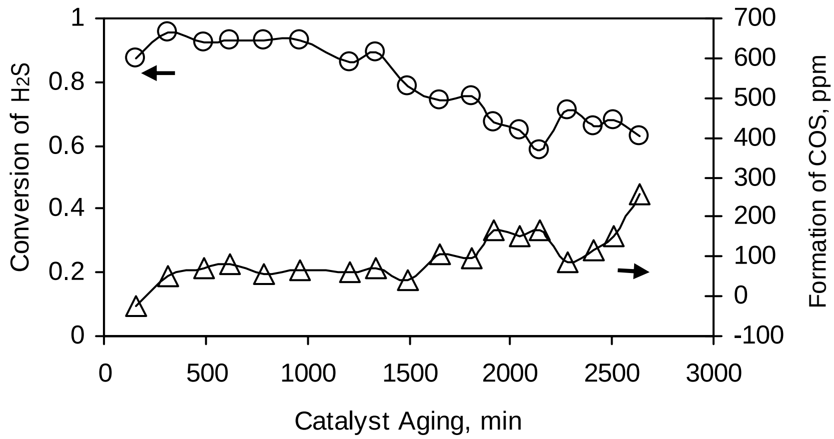
Figure 3-2. Effects of temperature on conversion of H_2S to elemental sulfur and formation of COS with a 120-SCCM feed stream containing 3,600-ppmv H_2S, 1,800-ppmv SO_2, 32-v% CO, 20-% H_2, 9-v% CO_2 and 10-v% moisture at 120 – 140^{o}C, 117- 124 psia and 135 - 149 s space time, removing elemental sulfur from a γ-alumina wash-coated monolithic catalyst with N_2 overnight.



Effects of catlayst age on conversion of H_2S into elemental sulfur and formation of COS

Experiments on conversion of hydrogen sulfide to elemental sulfur and formation of COS with a 2-cm-diameter 15-cm-long .-alumina wash-coated 400-cells/inch^2 monolithic catalyst were carried out over the space time range of 130 - 154 s to evaluate effects of catalyst aging on conversion of hydrogen sulfide to elemental sulfur and formation of COS at 125^{o}C and 116 – 122 psia. Gas mixtures are fed to a monolithic catalyst reactor containing 3,300 - 3,800-ppmv H_2S, 1,600 – 1,900 ppmv SO_2, 29 - 34-v% CO, 18 - 21-v% hydrogen, 5 -18-v% moisture, 8 -10 v% CO_2, and nitrogen as remainder. Volumetric feed rates of gas mixtures to the monolithic catalyst reactor are 114 - 132 SCCM. A γ-alumina wash-coated 400-cells/inch^2 monolithic catalyst is soaked in 1-w% Zn aqueous solution and heated for 4 hours at 450^{o}C.
Elemental sulfur was removed from the catalyst with N_2 at 140^{o}C overnight. Conversion of H_2S to elemental sulfur is 0.58 – 0.95.

Figure 3-3. Effects of catalyst aging on conversion of H_2S and formation of COS with a γ-alumina wash-coated catalyst soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C, removing elemental sulfur from the catalyst with N_2 overnight at 140°C.

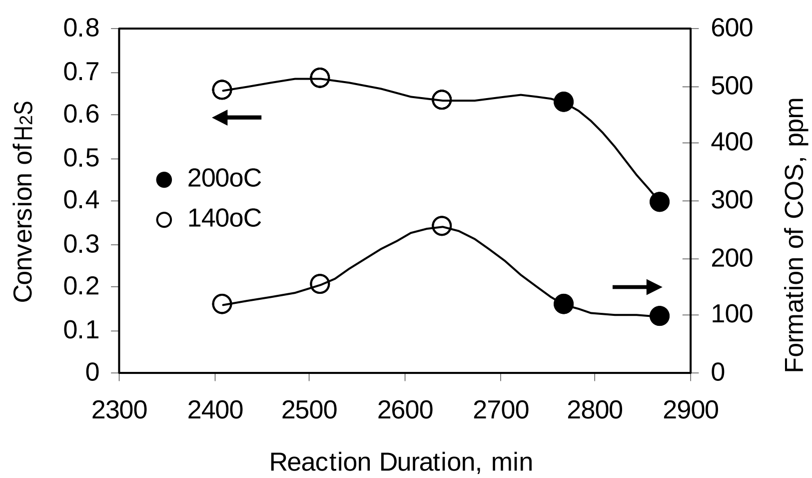


Conversion of H_2S into elemental sulfur and formation of COS are constant up to 1,400-min catalyst aging. Thereafter, conversion of H_2S into elemental sulfur decreases with increased catalyst aging, while formation of COS increases with increased catalyst aging, as shown in Figure 3-3.

Temperature effects of removing elemental sulfur from a catalyst on conversion of H_2S and formation of COS.

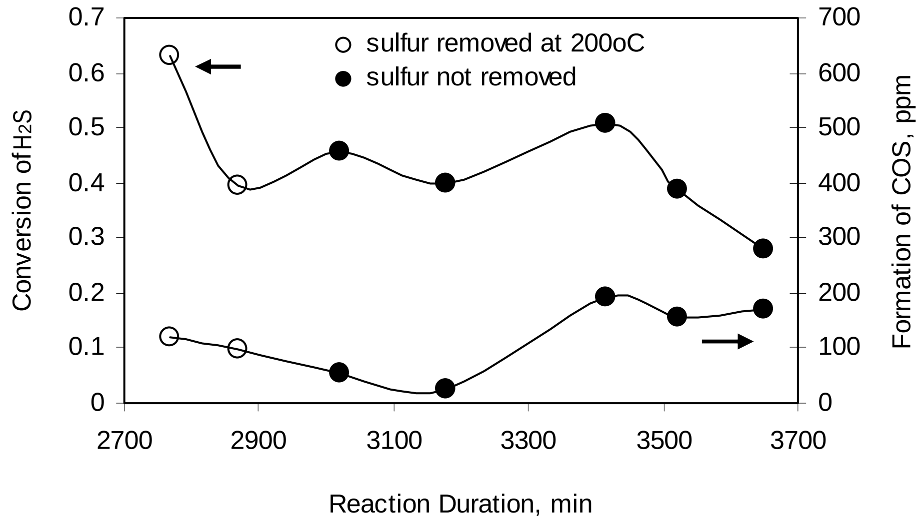
Conversion of H_2S into elemental sulfur and formation of COS decrease with increased temperature at which elemental sulfur is removed from the catalyst soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C (see Figure 3-4).

Figure 3-4. Effects of removal temperature of elemental sulfur attached to a γ-alumina wash-coated catalyst on conversion of H_2S and formation of COS with the monolithic catalyst soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C, removing elemental sulfur from the catalyst with N_2 overnight.



Effects of sulfur removal from a Zn-treated monolithic catalyst on conversion of H_2S and formation of COS

Figure 3-5. Effects of sulfur removal from a γ-alumina wash-coated monolithic catalyst on conversion of H_2S and formation of COS with the catalyst soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C, removing elemental sulfur from the catalyst with N_2 at 200°C overnight.



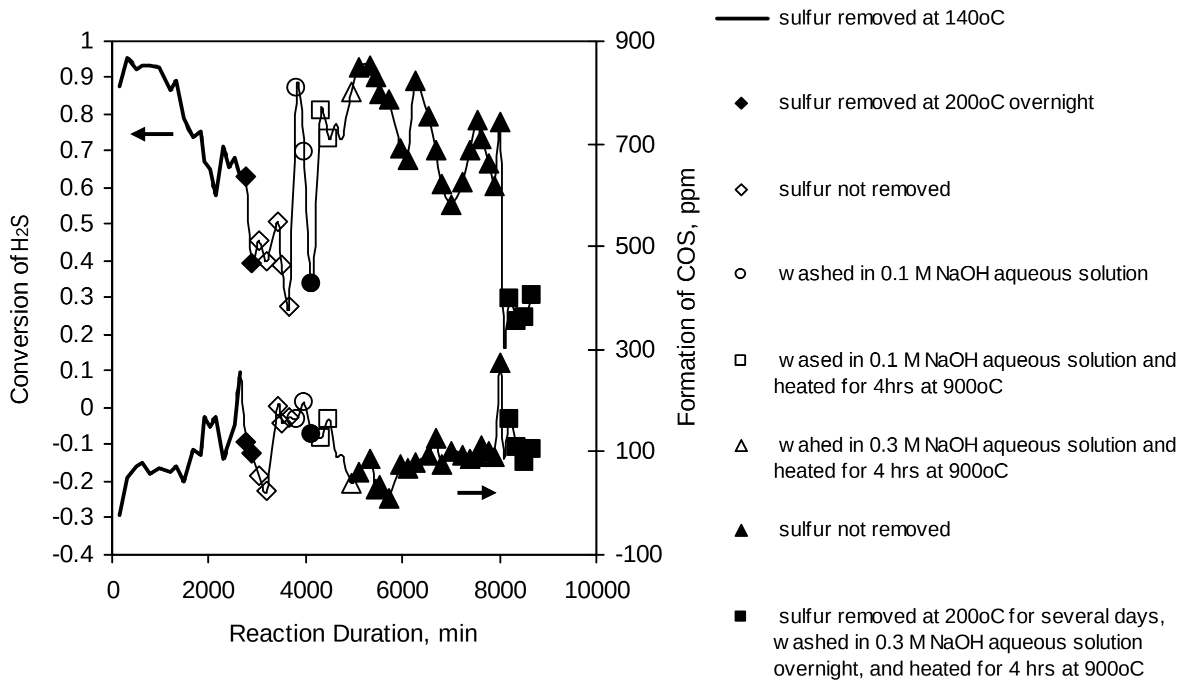
A γ-alumina wash-coated catalyst was soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C to increase conversion of H_2S into elemental sulfur and decrease formation of COS. Elemental sulfur was removed from the catalyst by heating the catalyst with N_2 at 200°C overnight. Conversion of H_2S into elemental sulfur seems to be higher on removing elemental sulfur from the catalyst than leaving elemental sulfur on the catalyst. Formation of COS seems to lower on removing elemental sulfur from the catalyst than leaving elemental sulfur on the catalyst.

Effects of soaking a Zn-treated catalyst in NaOH aqueous solution on conversion of H_2S and formation of COS

A γ-alumina wash-coated catalyst was soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C to increase conversion of H_2S into elemental sulfur and decrease formation of COS. Conversion of H_2S into elemental sulfur decreases and formation of COS increases with increased catalyst aging, although elemental sulfur was removed from the catalyst by heating the catalyst with N_2 at either 140 or 200°C overnight.

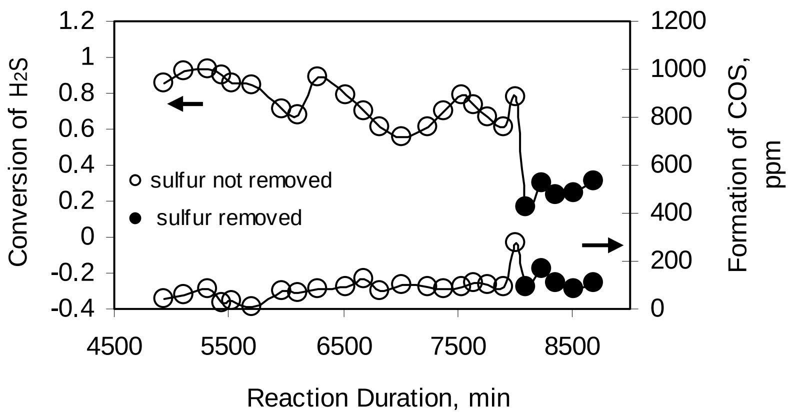
The catalyst was washed in 0.1-M NaOH aqueous solution overnight followed by heating it for 4 hrs at 450°C and then washed in 0.3-M NaOH aqueous solution overnight followed by heating it for 4 hrs at 900°C for the regeneration of the deactivated catalyst. Effects of washing the catalyst in NaOH aqueous solution overnight followed by heating it for 4 hrs at 450°C and then for 4 hrs at 900°C on conversion of H_2S into elemental sulfur are pronounced and long-lived, although elemental sulfur was not removed from the catalyst by heating it overnight, as shown in Figure 3-6.

Figure 3-6. Effects of soaking a catalyst in NaOH aqueous solution on conversion of H_2S and formation of COS with the γ-alumina wash-coated monolithic catalyst soaked in 1-w% Zn aqueous solution followed by heating it for 4 hrs at 450°C



Effects of removing elemental sulfur from a Zn-treated and NaOH-regenerated catalyst on conversion of H_2S and formation of COS.

Figure 3-7. Effects of removing elemental sulfur from a catalyst on conversion of H_2S and formation of COS with the γ-alumina wash-coated catalyst soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C, and washed in 0.3 M NaOH aqueous solution followed by heating it for 4 hrs at 900°C, removing sulfur from the catalyst with N_2 at 200°C overnight.



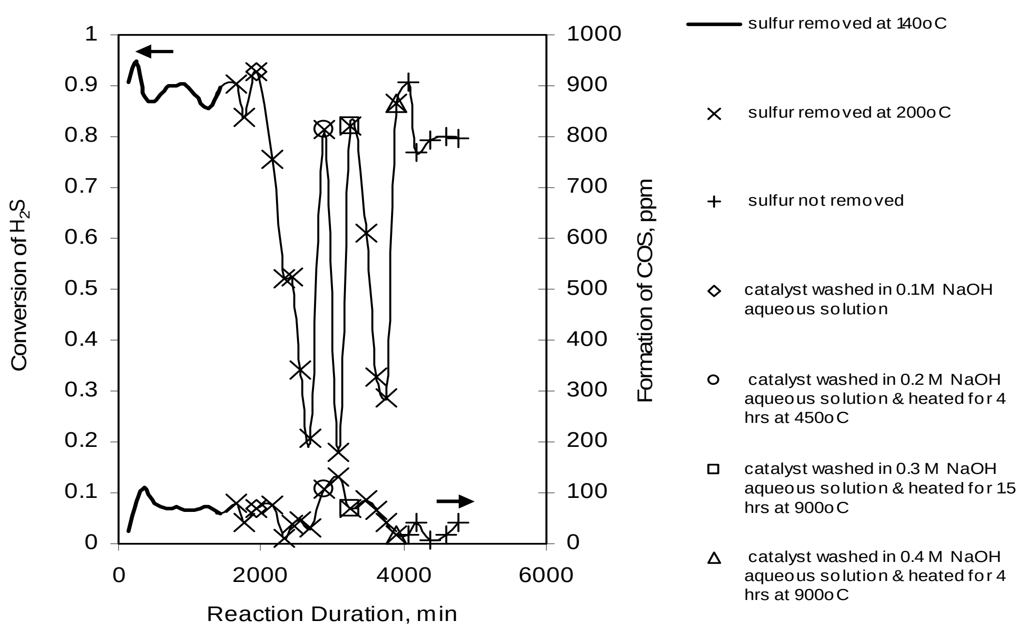
A catalyst washed in 0.1-M NaOH aqueous solution overnight followed by heating it for 4 hrs at 450°C and then washed in 0.3-M NaOH aqueous solution overnight followed by heating it for 4 hrs at 900°C for the regeneration of the catalyst was used for the removal of H_2S without removing elemental sulfur from the catalyst overnight by heating it for the 8,000 min reaction duration. Thereafter, elemental sulfur was removed from the catalyst by heating it overnight at 200°C. Conversion of H_2S into elemental sulfur decreases drastically upon removing elemental sulfur from the catalyst, as shown in Figure 3-7. This observation may suggest that the elemental sulfur deposited on the catalyst play a catalytic role in removing H_2S from the catalyst.

Effects of washing a catalyst in NaOH aqueous solution on conversion of H_2S and formation of COS

Catalysts are mainly deactivated by liquid elemental sulfur deposition below the dew temperature of elemental sulfur, carbon deposition, aluminum sulfate formation, and catalyst aging. Catalysts are washed in NaOH aqueous solutions to dissolve alumina sulfate or other water-soluble substances on catalyst surfaces. Catalysts are heated at elevated temperatures to remove elemental sulfur from catalysts by vaporizing it.

Effects of washing a γ-alumina wash-coated catalyst in 0.1-M NaOH aqueous solution, washing the catalyst in 0.2-M NaOH aqueous solution followed by heating it for 4 hrs at 450°C, and washing the catalyst in 0.3-M NaOH aqueous solution followed by heating it for 1.5 hrs at 900°C on conversion of H_2S into elemental sulfur are short-lived. However, effects of washing the catalyst in 0.4-M NaOH aqueous solution followed by heating it for 4 hrs at 900°C on conversion of H_2S into elemental sulfur is long-lived, as shown in Figure 3-8.

Figure 3-8. Effects of washing a γ-alumina wash-coated monolithic catalyst in NaOH aqueous solution on conversion of H_2S and formation of COS.



Effects of soaking a catalyst in Zn aqueous solution and then KOH aqueous solution on conversion of H_2S and formation of COS

A γ-alumina catalyst was soaked in 4-w% Zn aqueous solution followed by heating it for 4 hrs at 600°C, and then soaked in 4-w% KOH aqueous solution followed by heating it for 4 hrs at 550°C to increase conversion of H_2S and reduce formation of COS. Elemental sulfur deposited on the catalyst is not removed. Effects of soaking the catalyst with Zn and KOH aqueous solutions on conversion of H_2S seem to be good initially. However, effects of soaking the catalyst in Zn and KOH aqueous solutions on formation of COS seem to be short-lived by changing formation of COS from negative to positive, as shown in Figure 3-9.

Figure 3-9. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst, soaked in 4-w% Zn aqueous solution followed by heating it for 4 hrs at 600°C, and then soaked in 4-w% KOH aqueous solution followed by heating it for 4 hrs at 550°C.

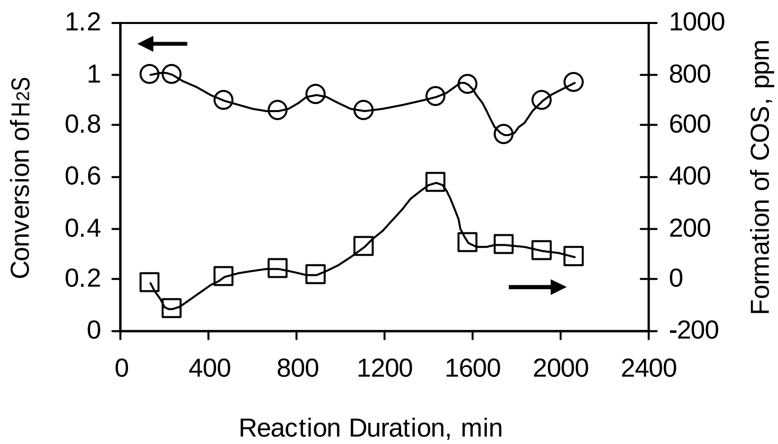
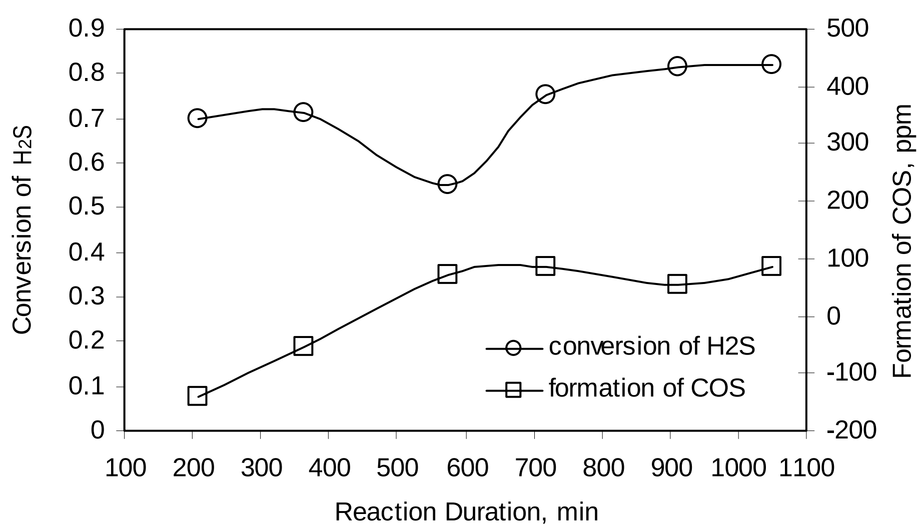


Figure 3-10. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% KOH aqueous solution followed by heating it for 4 hrs at 550°C



A catalyst was soaked in 4-w% KOH aqueous solution followed by heating it for 4 hrs at 550°C. Effects of soaking the catalyst in KOH aqueous solutions on conversion of H_2S are good initially. However, favorable effects of soaking the catalyst in KOH aqueous solution on formation of COS seem to be short-lived, as shown in Figure 3-10. Conversion of H_2S into elemental sulfur is much higher with the catalyst soaked in Zn and KOH aqueous solutions than that in KOH aqueous solution only (see Figures 3-9 and 3-10).

Effects of soaking a catalyst in Fe^{3+} Aqueous solution on Conversion of H_2S and formation of COS

A γ-alumina wash-coated catalyst was soaked in 2-w% Fe^{3+} aqueous solution followed by heating it for 4 hrs at 550°C. Conversion of H_2S drastically decreases with increased reaction duration with removing sulfur from the catalyst with N_2 at 270°C, as shown in Figure 3-11.

Figure 3-11. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 2-w% Fe^{3+} aqueous solution followed by heating it for 4 hrs at 450°C, removing elemental sulfur from the catalyst with N_2 at 270°C.

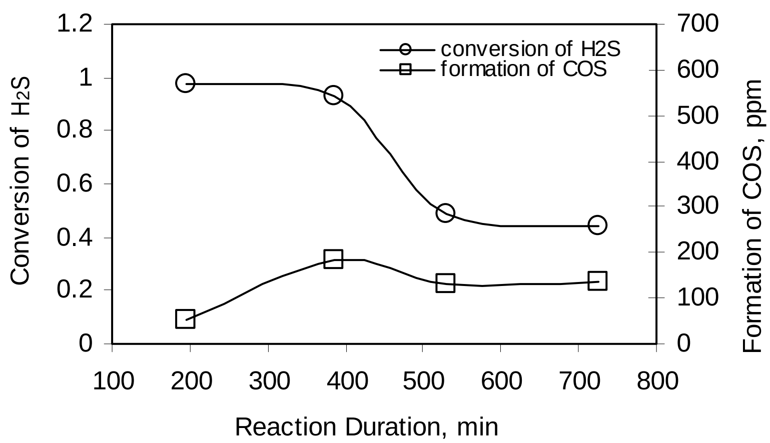
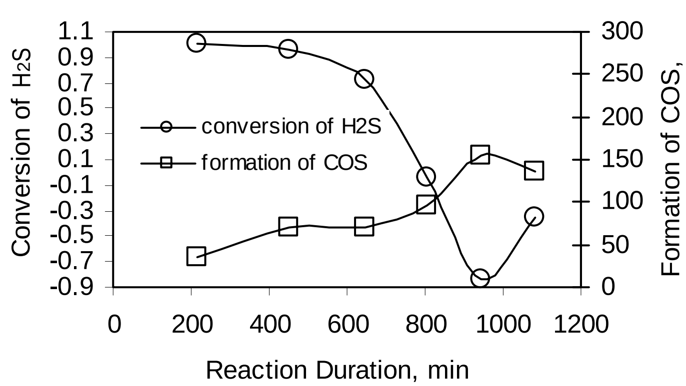


Figure 3-12. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 2-w% Fe^{3+} aqueous solution followed by heating it for 4 hrs at 450°C, removing sulfur from the catalyst with N_2 at 200°C overnight.

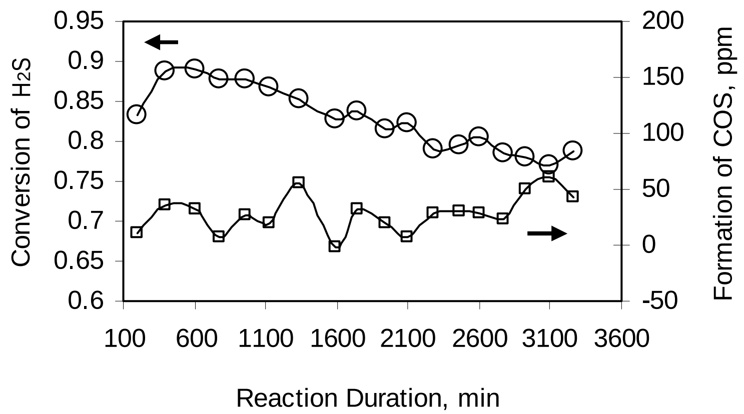


Conversion of H_2S drastically decreases and becomes negative with increased reaction duration with removing sulfur from the 2-w% Fe^{3+} treated catalyst with N_2 at 200°C, as shown in Figure 3-12. This fact may suggest that H_2S be produced rather than removed from the simulated coal gas. Formation of COS is very high with the catalyst soaked in 2-w% Fe3+ aqueous solution followed by heating it for 4 hrs at 550°C.

Effects of soaking a catalyst in NaOH, KOH, and $MgCl_2$ aqueous solutions on conversion of H_2S and formation of COS

A γ-alumina wash-coated monolithic catalyst was soaked in 0.6-M NaOH aqueous solution followed by heating it for 4 hrs at 950°C, soaked in 4-w% KOH followed by heating it for 2 hrs at 550°C, and soaked in 0.5-w% $MgCl_2$ aqueous solution followed by heating it for 2 hrs at 550°C. Conversion of H_2S decreases and formation of COS increases with increased reaction duration, although elemental sulfur is removed from the catalyst throughout experiments.

Figure 3-13. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst, soaked in 0.6-M NaOH aqueous solution followed by heating it for 4 hrs at 950°C, soaked in 4-w% KOH followed by heating it for 2 h at 550°C, and soaked in 0.5-w% $MgCl_2$ aqueous solution by heating it for 2 hrs at 550°C, removing no sulfur.



THIRD YEAR CONCLUSIONS

The following conclusions were drawn based on experimental data generated from the monolithic catalyst reactor system, and their interpretations. Each reaction experimental run proceeds after a blank experimental run, which is carried out in the absence of moisture and a monolithic catalyst.

Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation, although conversion of H_2S to elemental sulfur increases with increased reaction temperature over the temperature range of 120 -140°C. Conversion of H_2S into elemental sulfur and formation of COS decrease with increased temperature at which elemental sulfur is removed from the catalyst soaked in 1-w% Zn aqueous solution followed by heating it for 4 hours at 450°C.

Conversion of H_2S into elemental sulfur and formation of COS are constant up to 1,400-min aging of the 1-w% Zn-treated γ-alumina wash-coated catalyst. Thereafter, conversion of H_2S into elemental sulfur decreases with increased catalyst aging, while formation of COS increases with increased catalyst aging. However, conversion of H_2S into elemental sulfur decreases and formation of COS increases with increased aging of the other 1-w% Zn-treated catalyst, although elemental sulfur was removed from the catalyst by heating the catalyst with N_2 at either 140 or 200°C overnight.

Effects of washing the deactivated Zn-treated catalyst in NaOH aqueous solution overnight followed by heating it for 4 hrs at 900°C on conversion of H_2S into elemental sulfur are pronounced and long-lived, although elemental sulfur was not removed from the catalyst by heating it overnight. Effects of washing the deactivated γ-alumina wash-coated support itself in 0.4-M NaOH aqueous solution followed by heating it for 4 hrs at 900°C on conversion of H_2S into elemental sulfur also is long-lived.

Conversion of H_2S into elemental sulfur decreases drastically upon removing elemental sulfur from the catalyst treated with NaOH and Zn aqueous solutions. This observation may suggest that the elemental sulfur deposited on the catalyst play a catalytic role in removing H_2S from the catalyst.

Effects of soaking the catalyst with Zn and KOH aqueous solutions on conversion of H_2S seem to be good initially. However, effects of soaking the catalyst with Zn and KOH aqueous solutions on formation of COS seem to be short-lived by changing formation of COS from negative to positive. Effects of soaking the catalyst in KOH aqueous solution only on conversion of H_2S are good initially. However, favorable effects of soaking the catalyst in KOH aqueous solution on formation of COS seem to be short-lived. Conversion of H_2S into elemental sulfur is much higher with the catalyst soaked in Zn and KOH aqueous solutions than that in KOH aqueous solution only. Conversion of H_2S decreases and formation of COS increases with increased reaction duration with the catalyst treated with NaOH, KOH, and $MgCl_2$, although Elemental sulfur deposited on the catalyst is not removed throughout experiments.

Conversion of H_2S drastically decreases with increased reaction duration with removing sulfur from the 2-w% Fe^{3+} treated catalyst with N_2 at 270°C. Conversion of H_2S drastically decreases and becomes negative with increased reaction duration with removing elemental sulfur from the 2-w% Fe^{3+} treated catalyst with N_2 at 200°C. This fact may suggest that H_2S be produced rather than removed from the simulated coal gas. Formation of COS is very high with the catalyst soaked in 2-w% Fe^{3+} aqueous solution followed by heating it for 4 hrs at 550°C

FOURTH YEAR RESULTS AND DISCUSSION

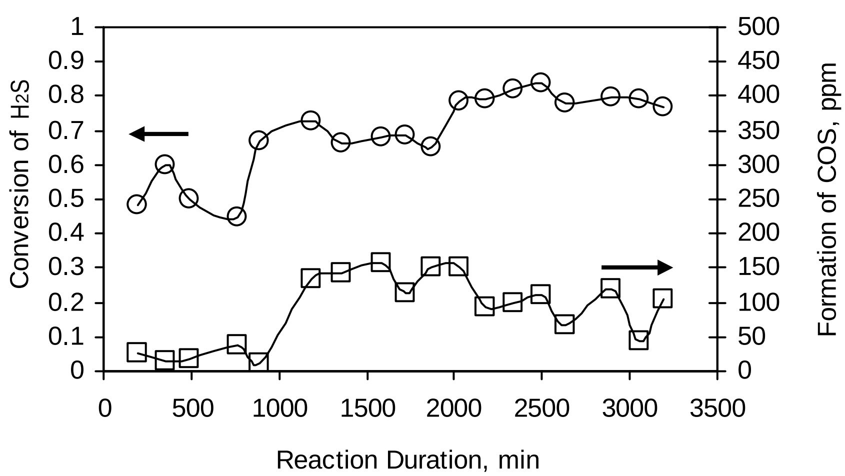
Experiments on conversion of hydrogen sulfide into element sulfur were carried out over the space time range of 131 – 148 seconds to evaluate effects of catalytic metals impregnated into γ-alumina wash-coated monolithic catalysts on conversion of hydrogen sulfide into elemental sulfur and formation of COS, as shown in Appendix IV. Simulated coal gas mixtures consist of 3, 500 - 3,600 ppmv hydrogen sulfide, 1,800 ppmv sulfur dioxide, 31.7 – 32.1 v%

CO, 20.4 – 20.6 v% hydrogen, 10 vol % moisture, 8.7 – 9.1 v% CO_2, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to a monolithic catalyst reactor are 120 cm^3/min at room temperature and atmospheric pressure (SCCM). The temperature of the reactor is controlled in an oven at 125°C. The pressure of the reactor is maintained at 110 - 124 psia. Zinc oxide and γ-alumina were chosen for the removal of H_2S from coal gases, whereas chromium oxide and potassium oxide were selected for the removal of COS. Na and P were used as stabilizers for formulated catalysts.

γ-Alumina wash-coated monolithic catalyst soaked in Na, Zn, and K aqueous solutions.

A Na aqueous solution was prepared by dissolving sodium hydroxide in water at room temperature so that the Na aqueous solution contains 1-N Na. A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 6-w% Zn. A K aqueous solution was prepared by dissolving potassium hydroxide in water at room temperature so that the K aqueous solution contains 6 w% K. A γ-alumina wash-coated monolithic catalyst was soaked in 1-N Na aqueous solution and heated for 4 hrs at 950°C, soaked in 6-w% Zn aqueous solution and heated for 4 hrs at 600°C, and then soaked in 6-w% K aqueous solution and heated for 2 hrs at 550°C. The γ-alumina wash-coated monolithic catalyst impregnated with Na, Zn and K for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 118 – 122 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,500 - 3,600 ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 20-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 141 – 146 s space time. Average conversion of H_2S to elemental sulfur is 0.69, whereas average formation of COS is 89 ppmv over the 3,192 - min reaction duration, as shown in Figure 4-2.

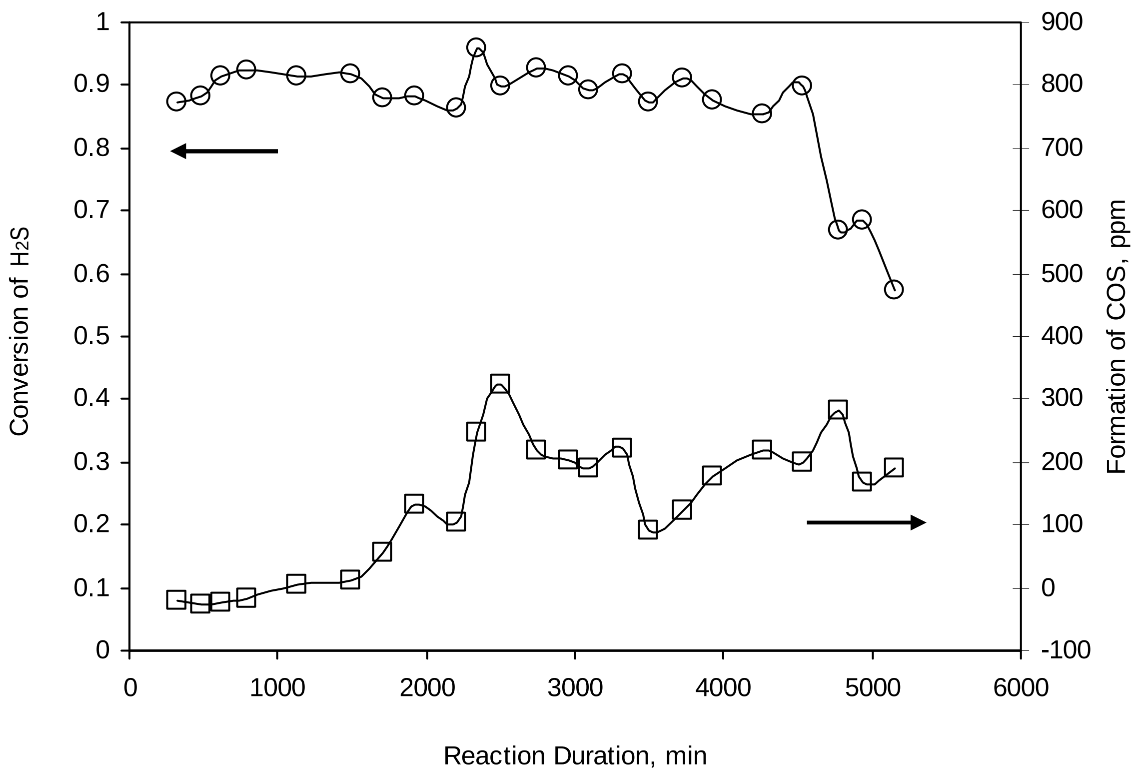
Figure 4-2. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 1 N NaOH aqueous solution and heated for 4 hrs at 950°C, soaked in 6-w% Zn aqueous solution and heated for 4 hrs at 600°C, and soaked in 6-w% K aqueous solution and heated for 2 hrs at 550°C.



γ-Alumina wash-coated monolithic catalyst soaked in Zn and K aqueous solutions

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 6-w% Zn, whereas a K aqueous solution was prepared by dissolving potassium hydroxide in water at room temperature so that the K aqueous solution contains 6-w% K. A γ-alumina wash-coated monolithic catalyst was soaked in 6-w% Zn aqueous solution and heated for 4 hrs at 600°C, and then soaked in 6-w% K aqueous solution and heated for 2 hrs at 550°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and K for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 117 – 124 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,500-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 140 – 148 s space time. Average conversion of H_2S to elemental sulfur is 0.86, whereas average formation of COS is 178 ppmv over the 5,151 - min reaction duration, as shown in Figure 4-3.

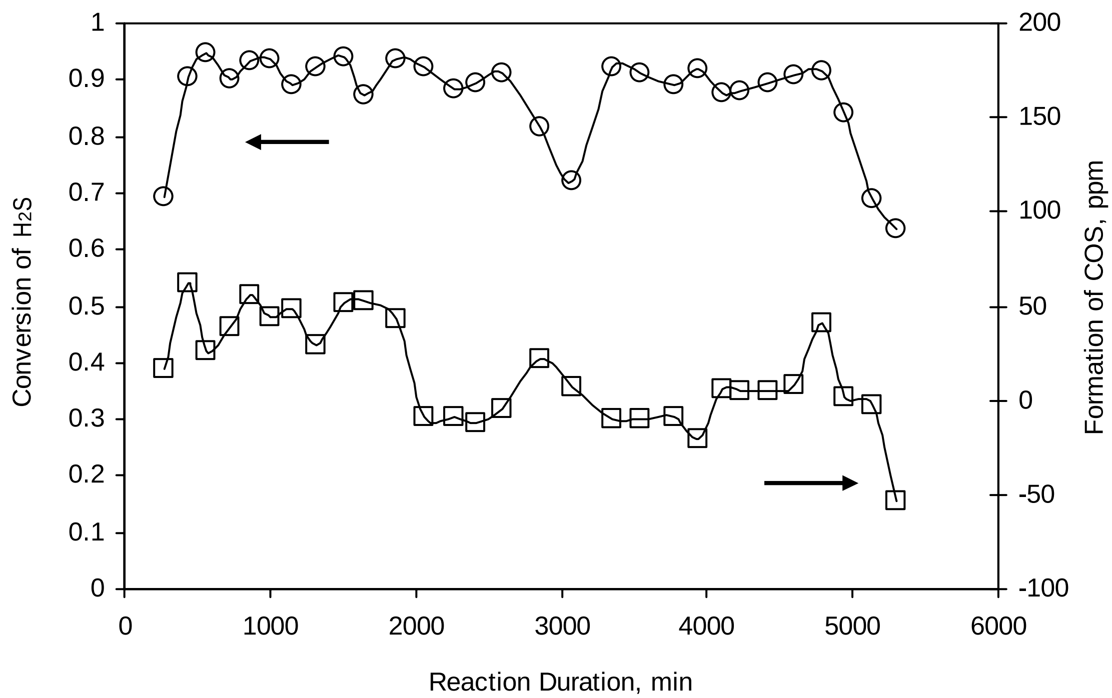
Figure 4-3. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 6-w% Zn aqueous solution and heated for 4 hrs at 600°C, and soaked in 6-w% K aqueous solution and heated for 2 hrs at 550°C.



γ-Alumina wash-coated monolithic catalyst soaked in Zn and Cr aqueous solutions

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas a Cr aqueous solution was prepared by dissolving chromium nitrate in water at room temperature so that the Cr aqueous solution contains 2-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600^oC, and then soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 550^oC. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125^oC and 116 – 123 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,500-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 139 – 147 s space time. Average conversion of H_2S to elemental sulfur is 0.88, whereas average formation of COS is 14 ppmv over the 5300- min reaction duration, as shown in Figure 4-4.

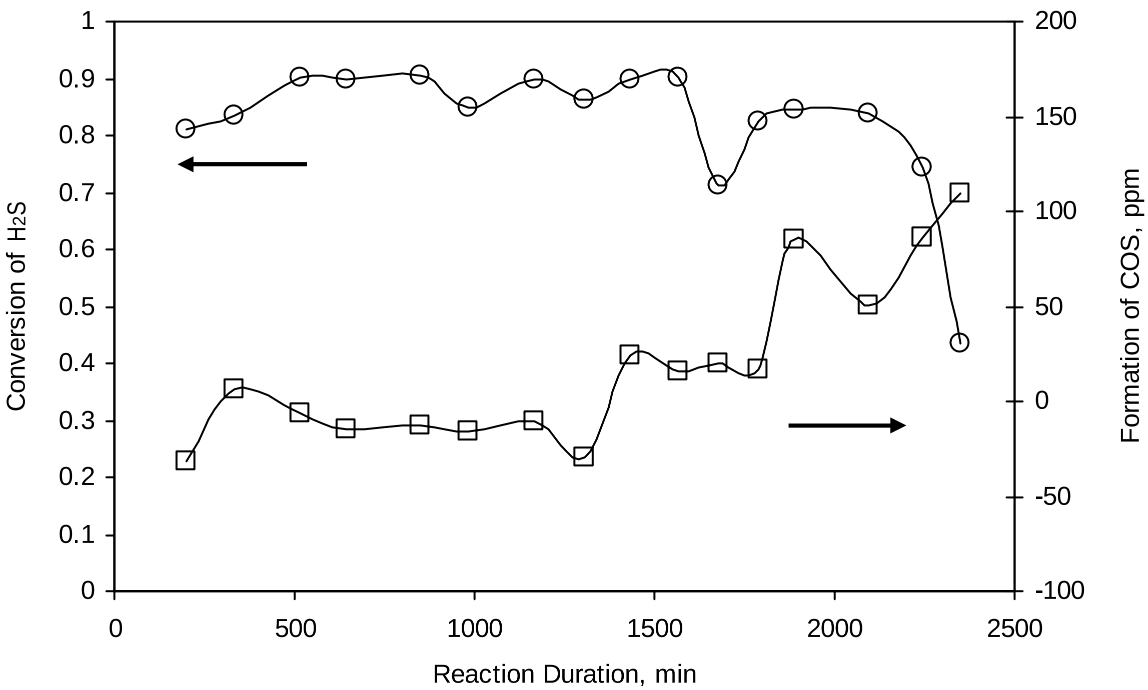
Figure 4-4. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600^oC, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 550^oC.



γ-Alumina wash-coated monolithic catalyst soaked in Zn aqueous soluition, and soaked twice in Cr aqueous solution

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas a Cr aqueous solution was prepared by dissolving chromium nitrate in water at room temperature so that the Cr aqueous solution contains 2-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 550°C, and then soaked again with 2-w% Cr aqueous solution and heated for 2 hrs at 550°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 117 – 122 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,500-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 140 – 146 s space time. Average conversion of H_2S to elemental sulfur is 0.84, whereas average formation of COS is 15 ppmv over the 2,350 - min reaction duration, as shown in Figure 4-5.

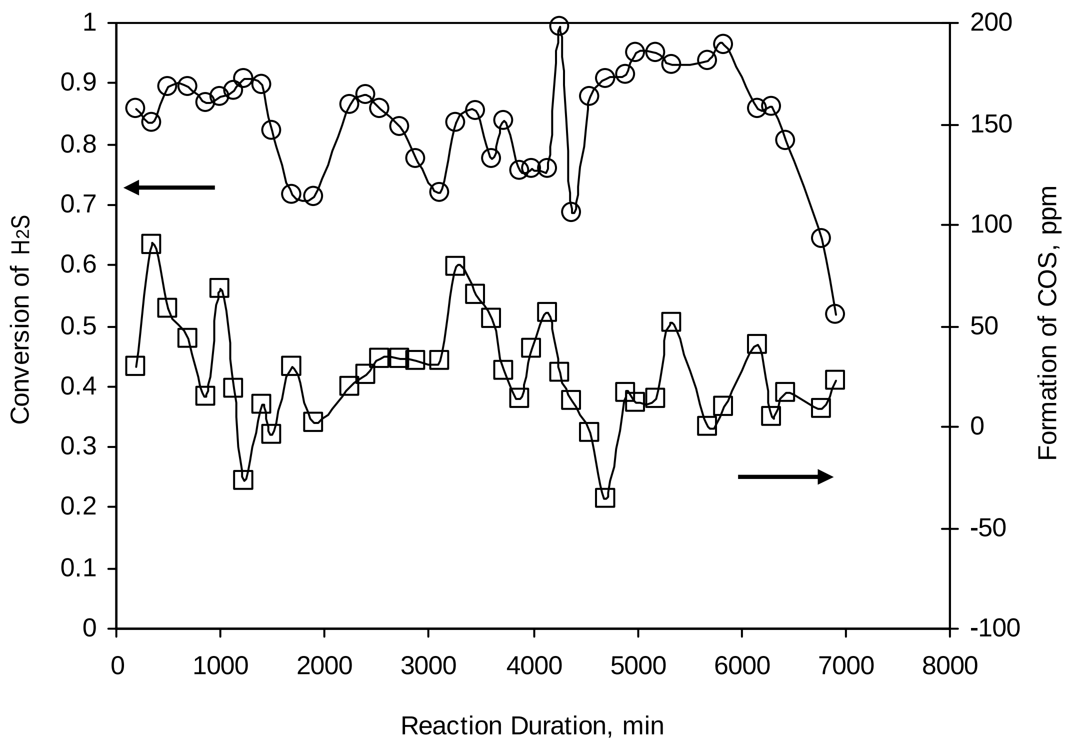
Figure 4-5. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, and soaked twice with 2-w% Cr aqueous solution and then heated for 2 hrs at 550°C.



γ-Alumina wash-coated monolithic catalyst soaked in Zn and Cr aqueous solutions, heating at 600°C.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas a Cr aqueous solution was prepared by dissolving chromium nitrate in water at room temperature so that the Cr aqueous solution contains 2-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, and then soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 600°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 110 – 123 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,500 – 3600 ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 131 – 147 s space time. Average conversion of H_2S to elemental sulfur is 0.84, whereas average formation of COS is 26 ppmv over the 6,910 - min reaction duration, as shown in Figure 4-6.

Figure 4-6. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 600°C.

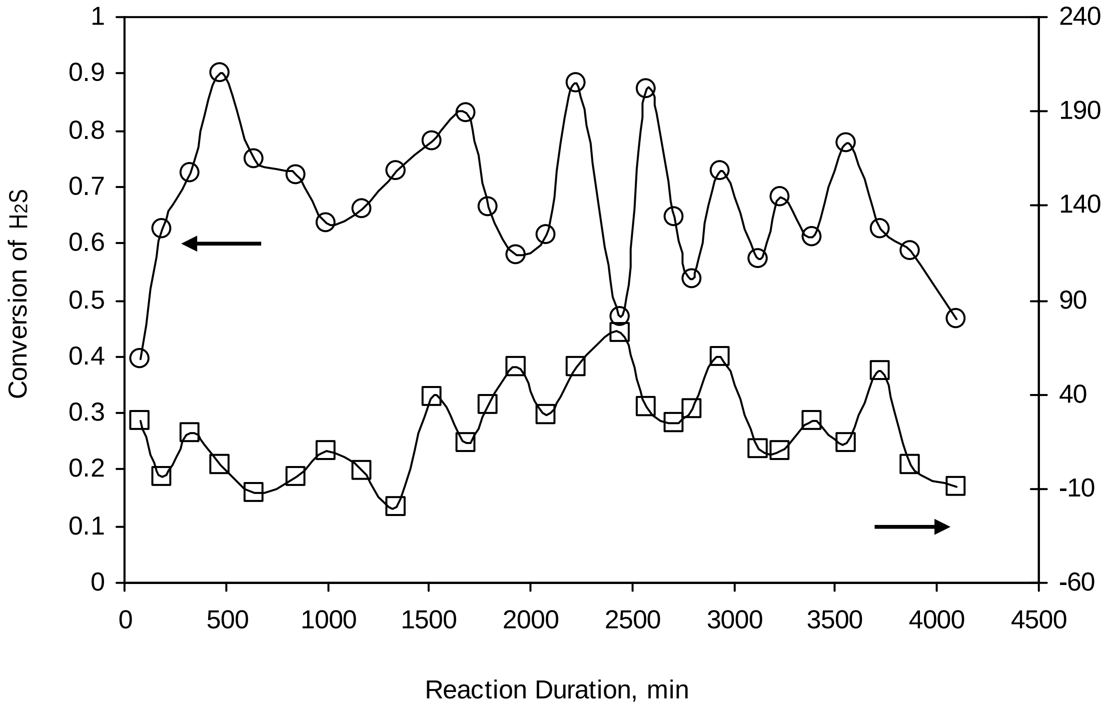


γ-Alumina wash-coated monolithic catalyst soaked in Zn, K, and P aqueous solutions.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas an aqueous solution containing K and P was prepared by dissolving potassium phosphate monobasic in water at room temperature so that the potassium phosphate monobasic aqueous solution contains 2.8-w% K and 2.2-w% P. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, soaked in the aqueous solution containing 2.8-w% K and 2.2-w% P, and heated for 2 hrs at 550°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn, K, and P for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 115 – 122 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 137 – 146 s space time.

Average conversion of H_2S to elemental sulfur is 0.68, whereas average formation of COS is 21 ppmv over the 4,093 - min reaction duration, as shown in Figure 4-7.

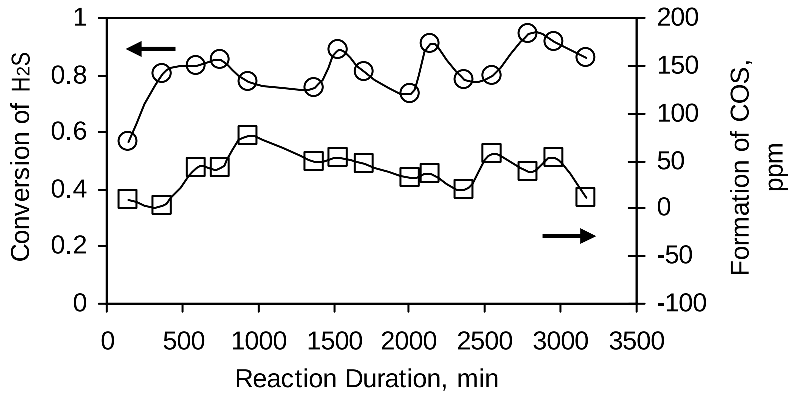
Figure 4-7. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, and soaked in 2.8-w% K and 2.2-w% P aqueous solution and heated for 2 hrs at 550°C.



γ-Alumina wash-coated monolithic catalyst soaked in Zn, Cr, and K aqueous solutions.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn. A Cr aqueous solution was prepared by dissolving chromium nitrate in water at room temperature so that the Cr aqueous solution contains 2-w% Cr. A K aqueous solution was prepared by dissolving potassium hydroxide in water at room temperature so that the K aqueous solution contains 4-w% K. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 550°C, and then soaked in 4-w% K aqueous solution and heated for 2 hrs at 550°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn, Cr, and K for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 118 – 123 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 141 – 147 s space time. Average conversion of H_2S to elemental sulfur is 0.82, whereas average formation of COS is 41 ppmv over the 3,170 - min reaction duration, as shown in Figure 4-8.

Figure 4-8. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C, and soaked in 2-w% Cr and 4-w% K aqueous solution and heated for 2 hrs at 550°C.



γ-Alumina wash-coated monolithic catalyst soaked in Zn aqueous solution, and Cr and K from potassium chromate aqueous solution.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas an aqueous solution containing K and Cr was prepared by dissolving potassium chromate in water at room temperature so that the aqueous solution contains 2-w% Cr and 3-w% K. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and then soaked in the aqueous solution containing 2-w% Cr and 3-w% K, and heated for 2 hrs at 400°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn, Cr, and K for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 117 – 122 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 140 – 146 s space time. Average conversion of H_2S to elemental sulfur is 0.79, whereas average formation of COS is 50 ppmv over the 3,060 - min reaction duration, as shown in Figure 4-9.

Figure 4-9. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 2-w% Cr and 3-w% K aqueous solution and heated for 2 hrs at 400°C.

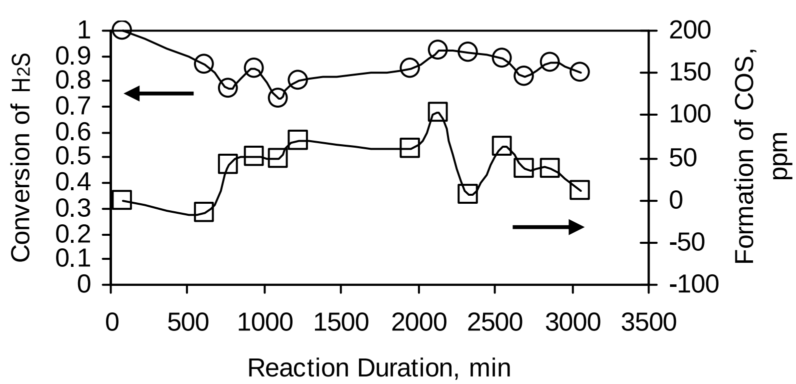
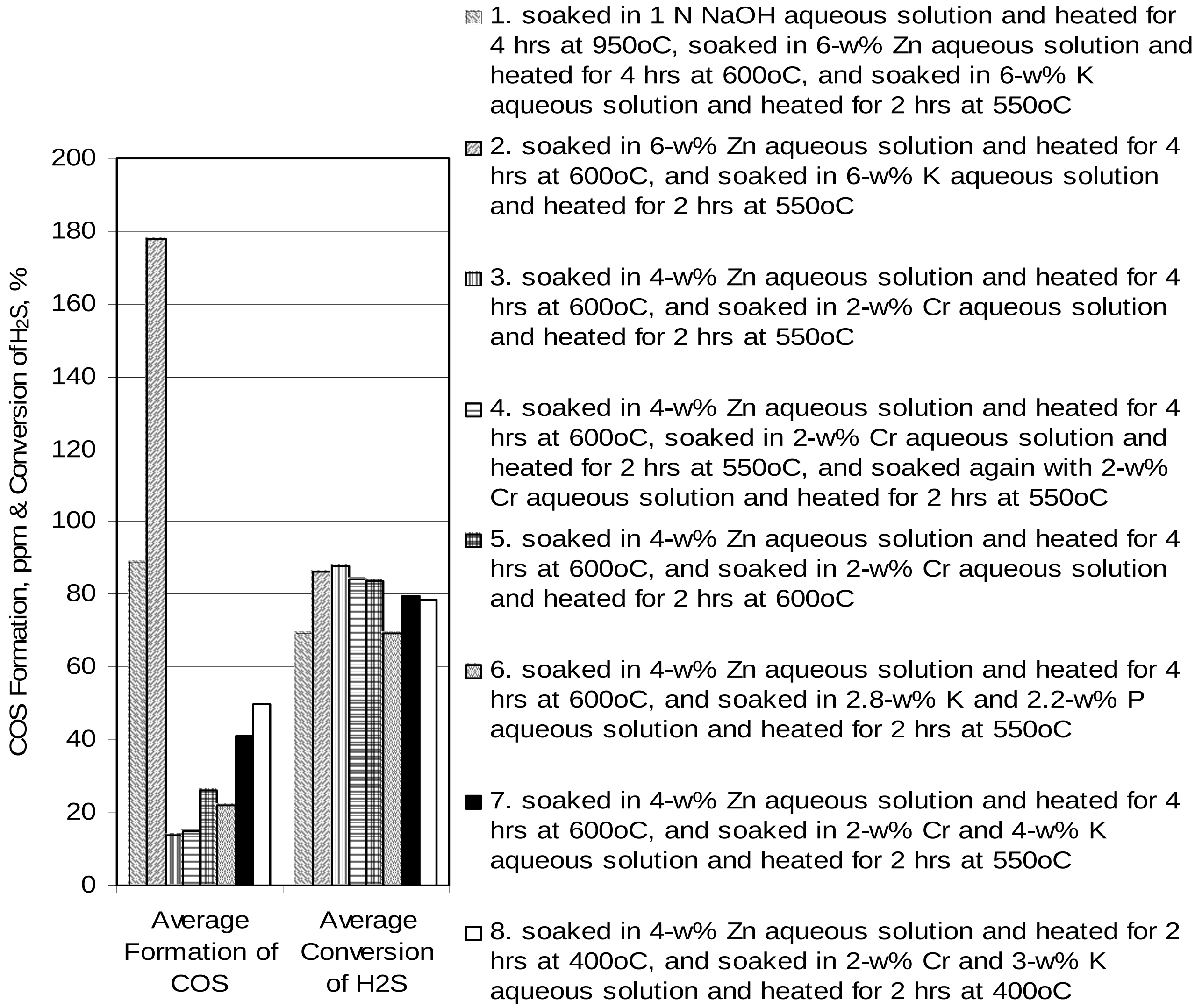


Figure 4-10. Average conversion of H_2S and average formation of COS with formulated catalysts



FOURTH YEAR CONCLUSIONS

The following conclusions were drawn based on experimental data generated from the monolithic catalyst reactor system, and their interpretations. Each reaction experimental run proceeds after a blank experimental run, which is carried out in the absence of moisture and a monolithic catalyst.

- NaOH treatment decreases removal of H_2S and formation of COS, when a γ-alumina wash-coated catalyst is soaked in 6-w% Zn and K aqueous solutions (see Formulated Catalysts 1 and 2 in Figure 4-10).

- Increased Cr loading decreases slightly removal of H_2S and increases formation of COS, when a γ-alumina wash-coated catalyst is soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 600°C (see Formulated Catalysts 3 and 4 in Figure 4-10).

- P decreases removal of H_2S and formation of COS, when a γ-alumina wash-coated catalyst is soaked in 4-w% aqueous Zn and 2.8-w% K aqueous solutions (see Formulated Catalysts 6 in Figure 4-10).

- Heating temperature does not affect removal of H_2S and formation of COS over 400 – 600°C, when a γ-alumina wash-coated catalyst is soaked in 4-w% Zn, 2-w% Cr, and 3 - 4 K aqueous solutions (see Formulated Catalysts 7 and 8 in Figure 4-10).

- Removal of H_2S decreases and formation of COS increases as heating temperature of Cr increases, when a γ-alumina wash-coated catalyst is soaked in Zn and Cr aqueous solutions (see Formulated Catalysts 3 and 5 in Figure 4-10).

- K decreases removal of H_2S and increases formation of COS, when a γ-alumina wash-coated catalyst is soaked in Zn and Cr aqueous solutions (see Formulated Catalysts 3 and 7 in Figure 4-10).

FIFTH YEAR RESULTS AND DISCUSSION

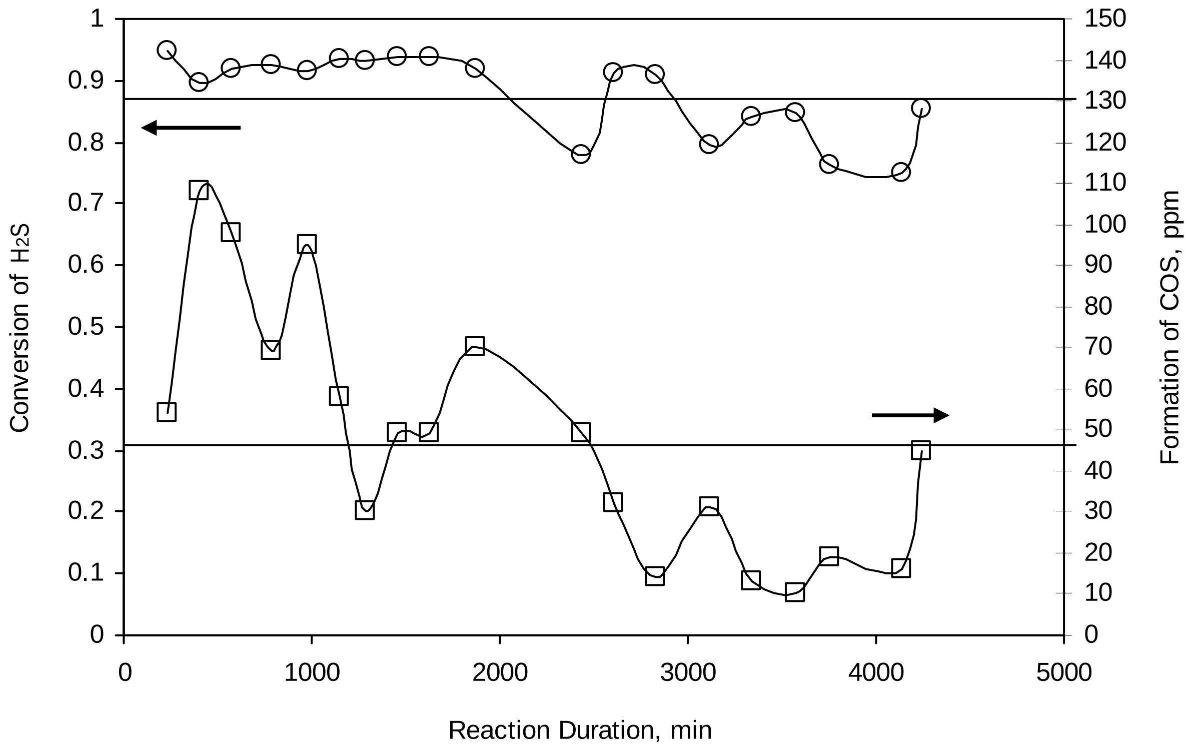
Experiments on conversion of hydrogen sulfide into element sulfur were carried out over the space time range of 138 – 148 seconds under the reaction conditions (see Table 3) to evaluate effects of catalytic metals impregnated into γ-alumina wash-coated monolithic catalysts on conversion of hydrogen sulfide into elemental sulfur and formation of COS. Simulated coal gas mixtures consist of 3,600 ppmv hydrogen sulfide, 1,800 ppmv sulfur dioxide, 31.0 – 33.0 v% CO, 18.7 – 21.0 v% hydrogen, 10 vol % moisture, 8.5 – 9.1 v% CO_2, and nitrogen as remainder. Volumetric feed rates of a simulated coal gas mixture to a monolithic catalyst reactor are 120 cm^3/min at room temperature and atmospheric pressure (SCCM). The temperature of the reactor is controlled in an oven at 125°C. The pressure of the reactor is maintained at 115 - 124 psia. Zinc oxide and γ-alumina were chosen for the removal of H_2S from coal gases, whereas chromium oxide only is selected for the removal of COS.

γ-Alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 1-w% Cr aqueous solution and heated for 2 hrs at 400°C.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas an aqueous solution containing Cr was prepared by dissolving chromic nitrate in water at room temperature so that the aqueous solution contains 1-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and then soaked in the aqueous solution containing 1-w% Cr and heated for 2 hrs at 400°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 118 – 123 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-

v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 141 – 147 s space time. Average conversion of H_2S to elemental sulfur is 0.89, whereas average formation of COS is 48 ppmv over the 4,200 - min reaction duration, as shown in Figure 5-2.

Figure 5-2. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C,and soaked in 1-w% Cr aqueous solution and heated for 2 hrs at 400°C.

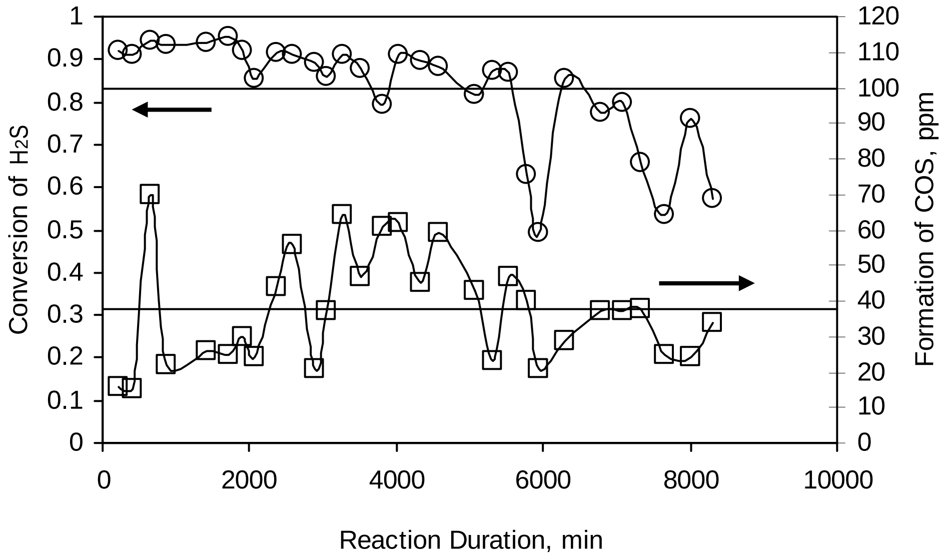


γ-Alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 400°C.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas an aqueous solution containing Cr was prepared by dissolving chromic nitrate in water at room temperature so that the aqueous solution contains 2-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and then soaked in the aqueous solution containing 2-w% Cr, and heated for 2 hrs at 400°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 117 – 122 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the

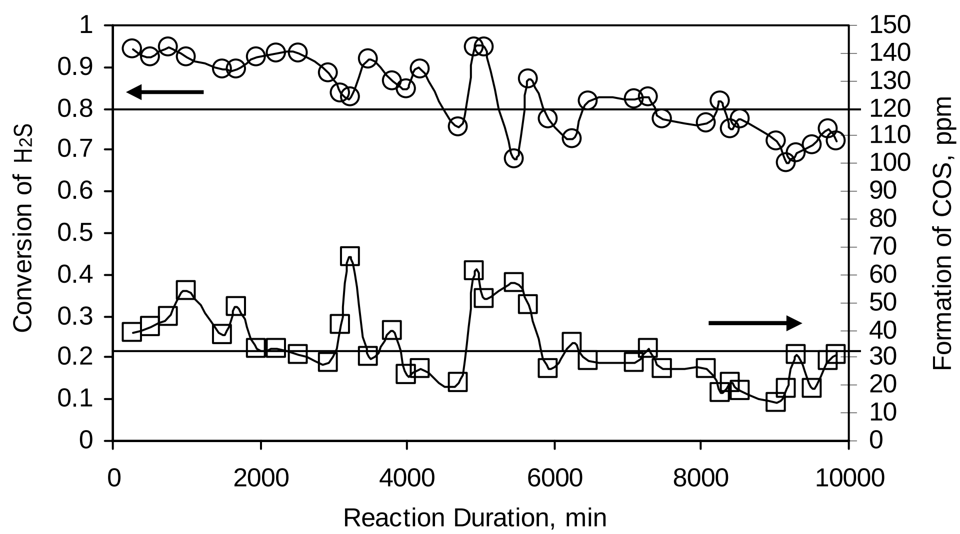
140 – 146 s space time.   Average conversion of H_2S to elemental sulfur is 0.83, whereas average formation of COS is 37 ppmv over the 8,300 - min reaction duration, as shown in Figure 5-3.

Figure 5-3.   Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400^{o}C, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 400^{o}C.



γ-Alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400^{o}C, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 500^{o}C.

Figure 5-4. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 4 hrs at 400^{o}C, and soaked in 2-w% Cr aqueous solution and heated for 2 hrs at 500^{o}C.

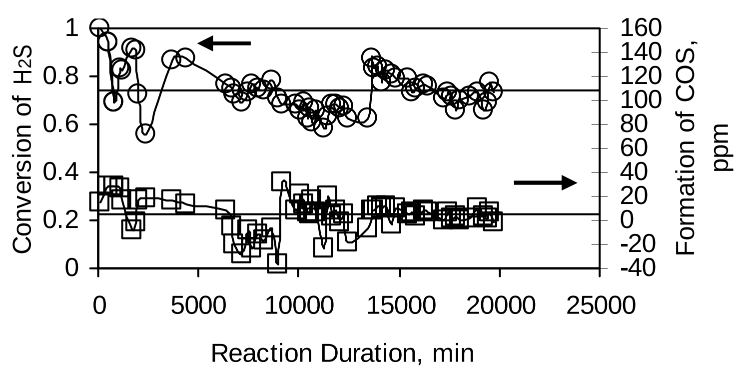


A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas an aqueous solution containing Cr was prepared by dissolving chromic nitrate in water at room temperature so that the aqueous solution contains 2-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400^{o}C, and then soaked in the aqueous solution containing 2-w% Cr, and heated for 2 hrs at 500^{o}C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125^{o}C and 116 – 122 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32-v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 139 – 146 s space time. Average conversion of H_2S to elemental sulfur is 0.83, whereas average formation of COS is 33 ppmv over the 9,840 - min reaction duration, as shown in Figure 5-4.

γ-Alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400^{o}C, and soaked in 4-w% Cr aqueous solution and heated for 2 hrs at 400^{o}C.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas an aqueous solution containing Cr was prepared by dissolving potassium chromate in water at room temperature so that the aqueous solution contains 4-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400^{o}C, and then soaked in the aqueous solution containing 4-w% Cr, and heated for 2 hrs at 400^{o}C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125^{o}C and 115 – 124 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 32 – 33 -v% CO, 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 138 – 148 s space time. Average conversion of H_2S to elemental sulfur is 0.74, whereas average formation of COS is 17 ppmv over the 19,740 - min reaction duration, as shown in Figure 5-5.

Figure 5-5 Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400^{o}C, and then soaked in 4-w% Cr aqueous solution and heated for 2 hrs at 400^{o}C.



γ-Alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and soaked in 6-w% Cr aqueous solution and heated for 2 hrs at 400°C.

A Zn aqueous solution was prepared by dissolving zinc acetate in water at room temperature so that the Zn aqueous solution contains 4-w% Zn, whereas an aqueous solution containing Cr was prepared by dissolving chromic nitrate in water at room temperature so that the aqueous solution contains 6-w% Cr. A γ-alumina wash-coated monolithic catalyst was soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and then soaked in the aqueous solution containing 6-w% Cr, and heated for 2 hrs at 400°C. The γ-alumina wash-coated monolithic catalyst impregnated with Zn and Cr for the removal of H_2S and COS was tested in the presence of a simulated coal gas at 125°C and 115 – 122 psia. Simulated coal gas mixtures fed to a monolithic catalyst reactor contain 3,600-ppmv H_2S, 1,800 ppmv SO_2, 31 – 33 -v% CO, 19 - 21-v% hydrogen, 10-v% moisture, 9-v% CO_2, and nitrogen as remainder. Volumetric feed rates of simulated coal gas mixtures to the monolithic catalyst reactor are 120 SCCM with the 138 – 146 s space time. Average conversion of H_2S to elemental sulfur is 0.80, whereas average formation of COS is 0.061 ppmv over the 9,140 - min reaction duration, as shown in Figure 5-6.

Figure 5-6. Conversion of H_2S and formation of COS with a γ-alumina wash-coated monolithic catalyst soaked in 4-w% Zn aqueous solution and heated for 2 hrs at 400°C, and then soaked in 6-w% Cr aqueous solution and heated for 2 hrs at 400°C.

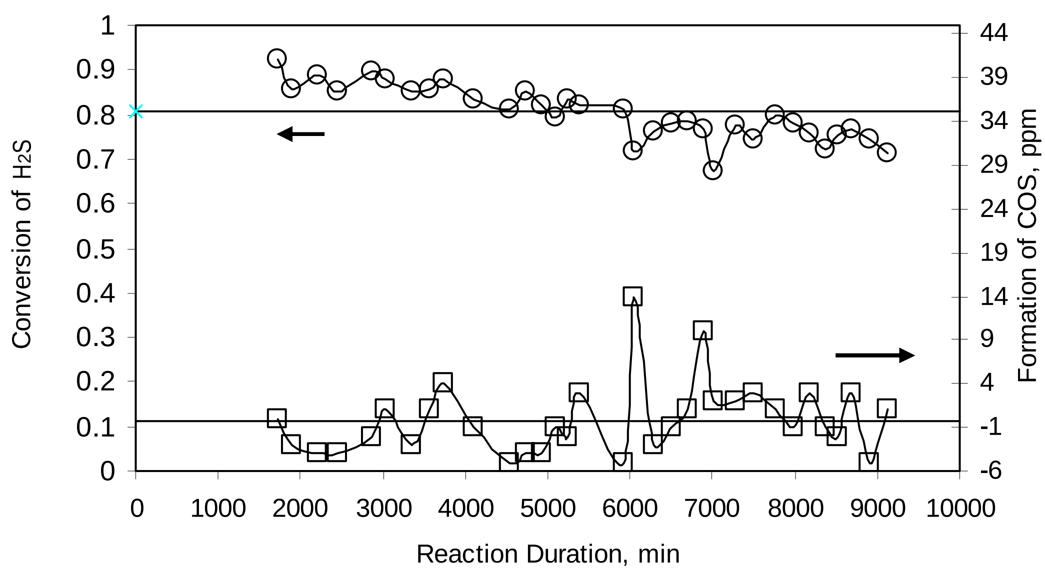
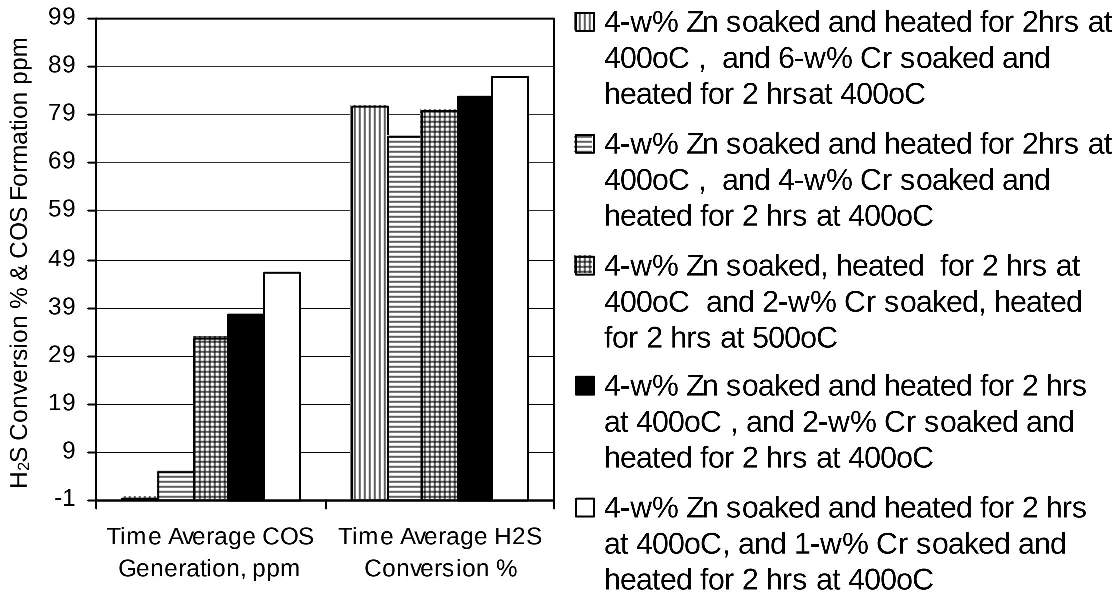


Figure 5-7. Average conversion % of H_2S and formation of COS at 125^{o}C and 115 - 124 psia, using formulated catalysts



FIFTH YEAR CONCLUSIONS

- Removal of H_2S decreses slightly with increased loading Cr onto the 4-w%-Zn treated catalyst.

- Formation of COS decreases drastically with increased loading Cr onto the 4-w%-Zn treated catalyst.

OVERALL CONCLUSIONS

The following conclusions were drawn based on the experimental data generated from the monolithic catalyst reactor system, and their interpretations. Each reaction experimental run proceeds after a blank experimental run, which is carried out in the absence of moisture and a monolithic catalyst.

Temperature

Conversion of H_2S to elemental sulfur does not follow the Arrhenius' equation. Conversion of H_2S to elemental sulfur increases with increased reaction temperature over the temperature range of 120 -140^{o}C, whereas conversion of H_2S to elemental sulfur decreases with increased reaction temperature over the temperature range of 140 -150^{o}C. Formation of COS for the reaction runs levels off and is lowest over the temperature range of 120 -130^{o}C, increases with increased reaction temperature over the temperature range of 130 -140^{o}C, and decreases with increased reaction temperature over the temperature range of 140 -150^{o}C. Formation of COS for both the blank runs and the reaction runs is minimal over the temperature range of 120 - 130^{o}C, and increases with increased reaction temperature over the temperature range of 130 - 150^{o}C. Formation of COS for the reaction runs is higher than that for the blank runs.

Pressure

Conversion of H_2S increases with increased total pressure. Formation of COS for both reaction runs and blank runs increase with increased total pressure. Formation of COS is not significantly different from that for the blank runs at 140°C and 40 – 210 psia. Formation of COS appears to be independent of H_2S conversion.

Moisture

Conversion of H_2S to elemental sulfur and formation of COS in a monolithic catalyst reactor decrease with increased concentration of moisture. These data may indicate that increased moisture shift equilibrium formation of both liquid elemental sulfur and COS in disfavor of their formation according to the reversible stoichiometric reaction formulas; $2H_2S + SO_2 \leftrightarrow 3S + 2H_2O$ and $2H_2S + SO_2 + 3CO \leftrightarrow 3COS + 2H_2O$.

Space Time

Formation of COS for both the reaction runs and the blank runs increases with space time over the space time range of 90 – 190 s and decreases with increased space time over the space time range of 190 – 550 s. Formation of COS for the reaction runs is slightly lower than that for the blank runs over the space time range of 140 – 280 s. Formation of COS for the reaction runs is much lower than that for the blank runs at the space time 90 s, whereas formation of COS for the reaction runs is much higher than that for the blank runs at the space time 550 s. Conversion of H_2S to elemental sulfur increases with space time. Formation of COS for the reaction runs appears to be independent of conversion of H_2S to elemental sulfur. These facts may suggest that COS be formed by reacting H_2S with CO ($CO + H_2S \rightarrow COS + H_2$)

Catalyst Age

Conversion of H_2S to elemental sulfur decreases with increased catalyst age, whereas formation of COS increases with increased catalyst age. Formation of COS for the blank runs is higher than that for the reaction runs. Formation of COS decreases generally with increased conversion of H_2S. In other words, formation of COS decreases with decreased catalyst age, and increased formation of elemental sulfur. These observations may suggest that COS for the reaction runs be formed by reacting CO with elemental sulfur produced from conversion of H_2S in addition to reacting CO with H_2S itself in the bulk gaseous mixture. These data may indicate that COS for the blank runs be formed by reacting CO with H_2S in the bulk gaseous mixture. Sulfur vapor released from used catalyst increases with catalyst age, where used catalyst is never regenerated. Thus, formation of COS for both the reaction of CO with elemental sulfur vapor and the reaction of CO with H_2S in the bulk gaseous mixture may increase with catalyst age. Elemental sulfur is formed catalytically, whereas COS is formed non-catalytically or thermally for both reaction runs and blank runs.

Conversion of H_2S to elemental sulfur does not decrease significantly with increased age of 140°C-nitrogen regenerated catalyst up to 3900 hr catalyst age. Formation of COS for the reaction runs decreases with increased age of the regenerated catalyst. Formation of COS for the blank runs is lower than that for the reaction runs.

Regeneration

Effects of washing the deactivated Zn-loaded catalyst with NaOH aqueous solution overnight and then heating it for 4 hrs at 900°C on conversion of H_2S into elemental sulfur are pronounced and long-lived, although elemental sulfur was not removed from the catalyst by heating it overnight during testing the NaOH-washed regenerated catalyst. Effects of washing the deactivated γ-alumina wash-coated support itself with 0.4-M NaOH aqueous solution and then heating it for 4 hrs at 900°C on conversion of H_2S into elemental sulfur also is long-lived.

Effects of Calcining Temperature on Removal of H_2S and Formation of COS

Calcining temperature of formulated catalysts does not affect removal of H_2S and formation of COS over 400 – 600°C, when a γ-alumina wash-coated catalyst is impregnated with Zn, Cr, and K.

Effects of Sulfur on Removal of H_2S

Conversion of H_2S into elemental sulfur decreases drastically upon removing elemental sulfur from the catalyst impregnated with NaOH and Zn. This observation may suggest that the elemental sulfur deposited on the catalyst play a catalytic role in removing H_2S from the catalyst. Conversion of H_2S also drastically decreases with increased reaction duration with removing sulfur from the Fe^{3+} impregnated catalyst with N_2. Conversion of H_2S drastically decreases and becomes negative with increased reaction duration with removing elemental sulfur from the Fe^{3+} impregnated catalyst with N_2. This fact may suggest that H_2S be produced rather than removed from the simulated coal gas.

Effects of Potassium on Removal of H_2S and Formation of COS

Effects of impregnating a catalyst with both Zn and KOH on conversion of H_2S seem to be good initially. However, effects of impregnating the catalyst with Zn and KOH on formation of COS seem to be short-lived. Effects of impregnating a catalyst with KOH only on conversion of H_2S also are good initially. However, favorable effects of impregnating the catalyst with KOH only on formation of COS also seem to be short-lived. Conversion of H_2S into elemental sulfur is much higher with the catalyst impregnated with Zn and KOH than that with KOH only.

Effects of Fe on Formation of COS

Formation of COS is very high with a catalyst impregnated with Fe^{3+} followed by calcining it for 4 hrs at 550°C

Effects of Phosphate on Removal of H_2S and Formation of COS

Removal of H_2S and formation of COS decrease with a γ-alumina wash-coated catalyst impregnated with phosphate

Effects of Cr on Removal of H_2S and Formation of COS

Removal of H_2S decreases slightly and formation of COS decreases drastically with increased loading Cr onto the 4-w%-Zn impregnated catalyst.

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PUBLICATIONS AND PRESENTATIONS

1. Deactivation of Catalysts in Removal of Hydrogen Sulfide in Coal Gases as Liquid Sulfur, presented at the AIChE Annual Meeting, Cincinnati, OH, November 2, 2005.

2. Removal of Hydrogen Sulfide in Coal Gases using a Monolithic Catalyst Reactor, presented at the AIChE Annual Meeting, Cincinnati, OH, November 1, 2005

3. Conversion of Hydrogen Sulfide in Coal Gases to Liquid Elemental Sulfur with Monolithic Catalysts, presented at the 2006 DOE/NETL HBCU/OMI Contractors Review Conference, June 8, 2006

4. Cleanup of Coal Gases by Removing Hydrogen Sulfide in the Form of Liquid Elemental Sulfur, presented at the 2006 AIChE National Meeting, San Francisco, November 14, 2006

5. Removal of Hydrogen Sulfide from Coal Gases, Using a Monolithic Catalyst Reactor, presented at the AIChE National Meeting, Salt Lake City, 559e, 10:10 am, November 8, 2007

6. Effects of Regenerated Monolithic Catalysts on Removal of Hydrogen Sulfide in Coal Gases, presented at the AIChE National Meeting, Salt Lake City, 281g, 530 pm, November 4 - 9, 2007

7. Dual-Mode Monolithic Catalysts Formulated for Removal of Hydrogen Sulfide and Reduced Formation of COS in Coal Gases, presented at the 2008 AIChE National Meeting, Philadelphia, November 17, 2008

8. Monolithic Catalysts for the Cleanup of Coal Gases, presented at the 2009 AIChE National Meeting, Nashville, November 12, 2009

STUDENTS ASSIGNED FOR THIS PROJECT

Claudell Burnell, Laneddye Carter, Tikia Allen, Tara Johnson, Brittany Williams, Shicociya Townsend, Chadwick Corbett, Tikia Allen, and Valerie Gordon

Appendix I. Experimental data for the first year annual report

Table 3. Conversion of H_2S to elemental sulfur and formation of COS with a 30 - 180 SCCM feed stream containing 3,600 - 4,000 ppmv H_2S, 1,800 - 2,000 ppmv SO_2 as an oxidant, and 0 - 10-v% moisture at 140 - 155°C, 118 - 124 psia, and 90 – 560 s space time.

Run	Temp.	Press.	Total Feed	Space	Feed Composition, v%							Conversion	COS, ppmv		
#	°C	psia	Rate, SCCM	Time, s	H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2	H_2S	Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
1	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.6355	na	na	na
2	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.625	23	27	47
3	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5824	na	30	46
4	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5771	na	34	45
5	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.6274	54	26	50
6	140	121	30	560	0.36	0.18	36.59	23.92	10.00	10.08	18.87	0.7417	na	119	185
7	140	120	30	555	0.36	0.18	36.59	23.92	10.00	10.08	18.87	0.8056	15	106	209
8	140	118	30	546	0.36	0.18	36.59	23.92	10.00	10.08	18.87	0.7711	12	83	213
9	140	121	30	560	0.36	0.18	36.59	23.92	10.00	10.08	18.87	0.8226	20	114	205
10	140	118	30	546	0.36	0.18	36.59	23.92	10.00	10.08	18.87	0.7127	na	98	157
11	140	122	60	282	0.36	0.18	36.60	23.92	10.00	10.09	18.85	0.5797	60	77	97
12	140	121	60	280	0.36	0.18	36.60	23.92	10.00	10.09	18.85	0.6595	16	77	90
13	140	122	60	282	0.36	0.18	36.60	23.92	10.00	10.09	18.85	0.622	16	75	86
14	140	122	60	282	0.36	0.18	36.60	23.92	10.00	10.09	18.85	0.5584	19	71	88
15	140	119	60	275	0.36	0.18	36.60	23.92	10.00	10.09	18.85	0.5453	18	83	92
16	140	121	60	280	0.36	0.18	36.60	23.92	10.00	10.09	18.85	0.5754	13	80	96
17	140	121	90	187	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5252	15	59	71
18	140	122	90	188	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5076	11	59	59
19	140	122	90	188	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5393	10	61	60
20	140	122	90	188	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5053	11	62	63
21	140	122	90	188	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5047	13	66	67
22	140	122	150	113	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4459	0	38	33
23	140	122	150	113	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4156	12	33	36
24	140	122	150	113	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4643	6	38	34
25	140	122	150	113	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4726	8	37	31
26	140	122	150	113	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4581	5	44	31
27	140	121	180	93	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5021	6	37	33
28	140	122	180	94	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4913	5	31	27
29	140	123	180	95	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5414	6	32	29
30	140	122	180	94	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5202	6	29	26
31	140	121	180	93	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5286	8	35	32
32	140	119	120	138	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.494	7	47	46
33	140	120	120	139	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5215	11	69	49
34	140	118	108	152	0.40	0.20	40.67	26.58	0.00	11.21	20.96	0.9012	11	60	85
35	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5957	6	38	45
36	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5817	10	68	90
37	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5763	5	40	60
38	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5698	12	43	53
39	155	123	120	137	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5092	10	65	80
40	155	123	120	137	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4976	9	35	65
41	155	122	120	136	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5006	5	73	79
42	155	122	120	136	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4096	9	94	89
43	155	122	120	136	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5097	5	28	57

Table 3. Continued – 1

Run	Temp.	Press.	Total Feed	Space	Feed Composition, v%							Conversion	COS, ppmv		
#	°C	psia	Rate, SCCM	Time, s	H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2	H_2S	Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
44	155	122	108	151	0.40	0.20	40.67	26.58	0.00	11.21	20.96	0.8525	8	38	89
45	155	122	120	136	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4604	8	38	60
46	155	122	120	136	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4792	9	44	57
47	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4885	26	32	37
48	140	122	108	157	0.40	0.20	40.67	26.58	0.00	11.21	20.96	0.8944	9	32	53
49	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.516	10	29	35
50	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5742	9	36	37
51	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5387	10	49	43
52	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4992	9	44	50
53	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4673	14	61	50
54	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5179	9	60	45
55	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5156	18	59	40
56	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.4752	9	56	36
57	140	123	108	158	0.40	0.20	40.67	26.58	0.00	11.21	20.96	0.8912	9	56	71
58	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	NA	na	na	na
59	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.2390	20	62	58
60	140	123	108	158	0.40	0.20	40.67	26.58	0.00	11.21	20.96	0.8822	9	52	65
61	140	123	108	158	0.40	0.20	40.67	26.58	0.00	11.21	20.96	0.8443	54	56	70
62	140	123	108	158	0.40	0.20	40.67	26.58	0.00	11.21	20.96	0.8277	16	58	70
63	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.2339	10	51	54
64	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.5149	10	42	36
65	140	124	120	143	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.2294	12	35	40
66	140	124	120	143	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.8847	23	55	7
67	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.8785	4	58	32
68	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.8553	9	41	41
69	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.8454	9	53	43
70	140	120	120	139	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.8211	5	66	42
71	140	119	120	138	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.7605	9	70	45
72	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.775	20	73	47
73	140	120	120	139	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.7479	10	63	60
74	140	122	120	141	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.6991	9	66	57
75	140	123	120	142	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.6899	14	67	53
76	140	120	120	139	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.6851	6	59	49
77	140	120	120	139	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.6432	12	63	44
78	140	124	120	143	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.7073	15	60	51
79	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.6266	14	65	48
80	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.627	14	61	55
81	140	121	120	140	0.36	0.18	36.60	23.92	10.00	10.09	18.86	0.538	16	70	64

*SCCM: standard cubic centimeters per minute, volumetric flow rates of gases measured at 1 atm and 25°C
*na: not available

Appendix II. Experimental data for the second year annual report

Table 3. Conversion of H_2S to elemental sulfur and formation of COS with 30 – 180 SCCM feed streams containing 3,500 – 4,000 ppmv H_2S, 1,800 – 2,000 ppmv SO_2 as an oxidant, 36 – 41 v% CO, 23 – 27 v% H_2, 10 – 12 v% CO_2 and 0 – 10-v% moisture at 120 – 150°C, 40 – 210 psia, and 46 – 570 s space time, regenerating the monolithic catalyst with N_2 at 140°C overnight.

Run	Temp.	Press.	Total Feed Rate, SCCM	Space	Feed Composition, v%							Conversion	COS, ppmv		
#	°C	psia		Time, s	H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2	H_2S	Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
82	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6658	86	46	49
83	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6657	13	54	46
84	140	124	120	143	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5871	5	21	38
85	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5889	17	31	49
86	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5942	5	35	39
87	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6385	6	30	37
88	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6132	5	28	31
89	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.658	5	21	31
90	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.628	5	19	28
91	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6143	8	17	25
92	140	123	120	142	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5833	5	17	25
93	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6248	5	14	23
94	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5808	7	12	26
95	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5556	5	15	31
96	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5322	5	9	31
97	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5108	7	10	30
98	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5283	5	12	31
99	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4706	6	13	28
100	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3804	6	20	33
101	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4226	5	26	38
102	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4367	5	28	37
103	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.46	5	20	34
104	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4586	6	23	32
105	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4819	6	24	34
106	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3965	6	25	34
107	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4122	6	22	32
108	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3687	7	25	32
109	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3467	5	20	31
110	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.1439	5	20	14
111	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4539	5	16	30
112	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3546	4	16	29
113	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3369	5	16	30
114	140	122	108	157	0.40	0.20	40.76	26.42	0.00	11.21	21.01	0.6944	5	17	37
115	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3791	5	17	33
116	140	124	120	143	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.255	5	17	33
117	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.277	5	17	31
118	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4745	5	17	57
119	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7071	5	18	48
120	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7043	6	21	37
121	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7316	6	17	34
122	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6234	5	16	32

Table 3. Continued – 1

Run #	Temp. °C	Press. psia	Total Feed Rate, SCCM	Space Time, s	Feed Composition, v% H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2	Conversion H_2S	COS, ppmv Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
123	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5652	6	11	33
124	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.666	2	3	3
125	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7365	2	15	36
126	140	123	120	142	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7583	4	16	39
127	140	123	120	142	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7105	4	15	39
128	140	119	120	138	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7196	3	12	33
129	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6919	5	12	37
130	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6659	6	12	37
131	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7311	5	10	41
132	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6198	5	14	43
133	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5458	6	13	38
134	140	119	120	138	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6643	4	14	37
135	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6456	4	14	39
136	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.592	7	15	39
137	140	120	120	139	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.597	6	11	25
138	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5103	5	11	27
139	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3405	6	15	26
140	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5704	8	12	27
141	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5582	5	14	29
142	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4586	5	14	30
143	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4864	5	15	30
144	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3877	5	14	31
145	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3019	5	13	31
146	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3382	5	14	28
147	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3989	6	14	31
148	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3598	6	15	33
149	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3219	5	14	29
150	140	119	120	138	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3677	5	13	28
151	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6641	6	16	48
152	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.8322	6	14	50
153	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.8098	5	14	46
154	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7591	5	17	44
155	140	122	120	141	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7328	5	16	38
156	140	121	120	140	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7852	6	17	38
157	120	121	120	147	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7608	6	16	19
158	120	121	120	147	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7479	5	11	17
159	120	123	120	150	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6058	6	16	16
160	120	121	120	147	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7152	5	10	15
161	120	123	120	150	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7584	7	12	18
162	130	122	120	145	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7549	5	12	18
163	130	120	120	142	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7644	5	14	19
164	130	121	120	143	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7445	7	14	20
165	130	121	120	143	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7396	6	12	15
166	150	121	120	137	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7012	5	18	34
167	150	121	120	137	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6718	6	18	32

Table 3. Continued – 2

Run #	Temp. °C	Press. psia	Total Feed Rate, SCCM	Space Time, s	Feed Composition, v% H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2	Conversion H_2S	COS, ppmv Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
168	150	121	120	137	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6336	6	17	33
169	140	207	120	239	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.7199	6	20	27
170	140	208	120	241	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6891	6	18	27
171	140	209	120	242	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.6742	6	17	27
172	140	40	120	46	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.4122	3	15	18
173	140	40	120	46	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3738	8	14	19
174	140	42	120	49	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.3088	6	10	11
175	140	41	120	47	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.2483	5	10	11
176	140	41	120	47	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.2544	7	10	11
177	140	119	120	138	0.36	0.18	36.69	23.77	10.00	10.09	18.91	0.5056	6	12	17
178	140	121	120	140	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.8562	6	23	17
179	140	121	120	140	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.8544	7	14	64
180	140	121	120	140	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.8375	7	14	60
181	140	122	120	141	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.8142	7	14	40
182	140	119	120	138	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.7993	7	14	39
183	140	41	120	47	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.657	7	12	22
184	140	42	120	49	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.614	7	12	19
185	140	40	120	46	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.5954	7	12	19
186	140	40	120	46	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.65	7	11	20
187	140	40	120	46	0.36	0.18	36.60	23.72	10.00	10.06	19.08	0.5387	8	13	17
188	140	82	120	95	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6263	8	20	45
189	140	82	120	95	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5387	23	52	48
190	140	210	120	243	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.8553	9	77	79
191	140	209	120	242	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7948	8	83	81
192	140	209	120	242	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.824	7	82	79
193	140	210	120	243	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.8023	9	83	79
194	140	210	120	243	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7943	9	89	84
195	140	172	120	199	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7723	10	81	76
196	140	170	120	197	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7291	9	80	74
197	140	170	120	197	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7162	10	81	73
198	140	171	120	198	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6956	8	86	78
199	140	170	120	197	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6879	11	88	84
200	140	170	120	197	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6212	8	87	81
201	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.8545	8	85	36
202	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7049	9	87	86
203	140	123	120	142	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5886	9	84	78
204	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6938	9	88	81
205	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.8143	8	83	76
206	140	119	120	138	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7235	9	73	77
207	140	120	120	139	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.8134	8	80	73
208	140	119	120	138	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7924	16	79	82
209	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7812	8	73	76
210	140	121	30	560	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.567	9	106	114
211	140	121	30	560	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.2793	8	103	113
212	140	119	30	551	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.8063	8	112	119

Table 3. Continued – 3

Run #	Temp. °C	Press. psia	Total Feed Rate, SCCM	Space Time, s	Feed Composition, v% H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2	Conversion H_2S	COS, ppmv Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
213	140	122	30	564	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.8068	8	86	94
214	140	119	30	551	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.634	7	88	91
215	140	119	30	551	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.703	8	97	109
216	140	120	30	555	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7831	9	125	125
217	140	118	30	546	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7292	9	110	113
218	140	117	30	541	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.7271	8	102	101
219	140	119	30	551	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6473	9	172	147
220	140	121	60	271	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6674	9	151	143
221	140	117	60	271	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.611	9	97	96
222	140	122	60	282	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6619	8	80	82
223	140	122	60	282	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4787	9	131	129
224	140	120	60	278	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6045	9	94	92
225	140	121	60	280	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6633	7	113	112
226	140	120	60	278	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5664	7	105	107
227	140	119	90	184	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5664	10	95	94
228	140	123	90	190	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4503	8	101	105
229	140	123	90	190	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5049	8	120	122
230	140	120	90	185	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5256	8	149	144
231	140	121	90	187	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4973	8	125	118
232	140	123	90	190	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4222	9	107	110
233	140	124	180	96	0.35	0.18	36.69	23.74	10.00	10.04	19.00	0.3858	9	87	91
234	140	121	180	93	0.35	0.18	36.69	23.74	10.00	10.04	19.00	0.4107	8	104	79
235	140	121	180	93	0.35	0.18	36.69	23.74	10.00	10.04	19.00	0.6036	7	104	85
236	140	120	180	93	0.35	0.18	36.69	23.74	10.00	10.04	19.00	0.5829	7	96	70
237	140	119	180	92	0.35	0.18	36.69	23.74	10.00	10.04	19.00	0.559	7	79	85
238	140	119	180	92	0.35	0.18	36.69	23.74	10.00	10.04	19.00	0.576	8	90	95
239	140	119	120	138	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.6186	8	148	131
240	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5767	8	108	108
241	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.5133	9	109	111
242	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4976	8	122	116
243	140	123	120	142	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.525	8	101	99
244	140	122	120	141	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.3917	8	100	95
245	140	124	120	143	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4292	7	99	96
246	140	123	120	142	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4137	8	102	91
247	140	121	120	140	0.35	0.18	36.69	23.74	10.00	10.04	19.01	0.4717	9	84	82

*SCCM: standard cubic centimeters per minute, volumetric flow rates of gases measured at 1 atm and 25°C

Appendix III. Experimental data for the third year annual report

Table 3. Conversion of H_2S to elemental sulfur and formation of COS with 114 – 132 SCCM feed streams containing 3,300 – 3,800 ppmv H_2S, 1,600 – 1,900 ppmv SO_2 as an oxidant, 29 – 34 v% CO, 18 – 21 v% H_2, 8 – 10 v% CO_2 and 5 – 18-v% moisture at 120 – 140oC, 116 – 129 psia, and 130 – 156 s space time, regenerating the monolithic catalyst with N_2 at 140 - 270^{o}C overnight.

Run #	Temp. ^{o}C	Press. psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
283	130	118.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	-0.04	10	75	88
284	130	118.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.1223	22	68	103
285	130	120.7	120	143	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8095	13	76	47
286	130	120.7	120	143	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8066	8	69	108
287	130	117.7	120	140	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8103	11	89	105
288	130	120.7	120	143	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8599	9	94	105
289	130	122.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7929	9	112	116
290	130	121.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8034	10	110	108
291	130	120.7	120	143	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8168	10	104	130
292	125	119.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7797	11	98	94
293	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7635	10	106	104
294	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7152	10	108	112
295	125	118.7	120	142	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7455	10	108	107
296	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7171	10	107	111
297	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7171	11	120	117
298	120	120.7	120	147	0.36	0.18	32.02	20.26	10	9.07	28.11	0.639	10	115	125
299	120	118.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.5667	11	101	107
300	120	120.7	120	147	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4911	11	26	63
301	120	119.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4098	11	29	68
302	120	118.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.5135	11	43	89
303	120	120.7	120	147	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3223	12	86	93
304	120	120.7	120	147	0.36	0.18	32.02	20.26	10	9.07	28.11	0.176	12	93	106
305	120	122.7	120	149	0.36	0.18	32.02	20.26	10	9.07	28.11	0.2094	11	86	114
306	125	122.7	120	147	0.36	0.18	32.02	20.26	10	9.07	28.11	0.1639	12	133	121
307	130	121.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.1398	12	124	129
308	140	120.7	120	140	0.36	0.18	32.02	20.26	10	9.07	28.11	0.1607	13	119	130
309	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8925	12	125	119
310	140	119.7	120	138	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8552	12	122	109
311	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8332	12	118	112
312	140	120.7	120	140	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8075	13	115	111
313	140	117.7	120	136	0.36	0.18	32.02	20.26	10	9.07	28.11	0.448	12	115	108
314	120	117.7	120	143	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7617	12	74	88
315	120	120.7	120	147	0.36	0.18	32.02	20.26	10	9.07	28.11	0.6981	13	61	99
316	120	119.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.5888	13	77	101
317	120	118.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.5506	13	96	5
318	120	119.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.465	13	75	113
319	120	117.7	120	143	0.36	0.18	32.02	20.26	10	9.07	28.11	0.6981	13	65	104
320	140	116.7	120	135	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4799	14	128	118
321	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4297	14	138	130
322	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3554	13	120	103

Table 3. Continued-1

Run #	Temp. ^oC	Press. psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
323	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3777	13	121	106
324	140	119.7	120	138	0.36	0.18	32.02	20.26	10	9.07	28.11	0.2955	13	110	110
325	140	119.7	120	138	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3816	15	109	90
326	140	121.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3009	14	96	91
327	140	120.7	120	140	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3179	14	101	103
328	140	123.7	120	143	0.36	0.18	32.02	20.26	10	9.07	28.11	0.2225	15	97	94
329	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.223	15	118	119
330	140	117.7	120	136	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3355	15	114	103
331	140	119.7	120	138	0.36	0.18	32.02	20.26	10	9.07	28.11	0.2711	15	99	88
332	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.976	15	94	149
333	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9331	16	102	286
334	140	119.7	120	138	0.36	0.18	32.02	20.26	10	9.07	28.11	0.485	16	102	235
335	140	118.7	120	137	0.36	0.18	32.02	20.26	10	9.07	28.11	0.363	18	101	218
336	125	117.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4461	16	64	200
337	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9584	17	81	44
338	125	119.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8188	18	87	120
339	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.6118	17	81	99
340	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4529	17	76	100
341	125	118.7	120	142	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4419	19	94	116
342	125	119.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.4014	18	105	96
343	125	117.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3348	17	100	89
344	140	121.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.3155	18	124	120
345	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	na	18	100	135
346	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9649	18	100	171
347	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7282	18	124	196
348	125	116.7	120	140	0.36	0.18	32.02	20.26	10	9.07	28.11	-0.044	0 18	126	221
349	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	-0.835	8 19	29	184
350	125	122.7	120	147	0.36	0.18	32.02	20.26	10	9.07	28.11	-0.357	1 18	26	161
351	125	116.7	120	140	0.36	0.18	32.02	20.26	10	9.07	28.11	0.1906	19	34	75
352	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9057	18	49	74
353	125	119.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9479	19	52	134
354	125	117.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8795	19	48	157
355	125	117.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8676	19	43	121
356	125	123.7	120	148	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8974	18	38	107
357	125	116.7	120	140	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9005	19	58	130
358	125	118.7	120	142	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9034	19	58	125
359	125	119.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8823	19	58	123
360	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8568	19	47	119
361	125	118.7	120	142	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8965	19	65	123
362	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.876	19	53	25
363	125	117.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9529	19	67	117
364	125	120.7	120	145	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9231	20	58	128
365	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9331	20	49	128
366	125	121.7	120	146	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9326	19	56	114
367	125	115.7	120	139	0.36	0.18	32.02	20.26	10	9.07	28.11	0.9285	20	56	122
368	125	118.7	120	142	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8644	20	71	133

Table 3. Continued-2

Run #	Temp. ^oC	Press. psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
369	125	118.7	120	142	0.36	0.18	32.02	20.26	10	9.07	28.11	0.8942	20	62	135
370	125	118.7	120	142	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7891	21	92	135
371	125	119.7	120	144	0.36	0.18	32.02	20.26	10	9.07	28.11	0.7402	21	89	193
372	125	117.7	120	141	0.36	0.18	32.02	20.26	10	9.07	28.11	0.752	21	109	204
373	125	118.7	132	130	0.33	0.16	29.11	18.42	18	8.25	25.55	0.6703	20	169	336
374	125	121.7	132	133	0.33	0.16	29.11	18.42	18	8.25	25.55	0.6499	25	152	302
375	125	118.7	132	130	0.33	0.16	29.11	18.42	18	8.25	25.55	0.582	24	154	320
376	125	118.7	114	150	0.38	0.19	33.71	21.32	5.3	9.55	29.59	0.7115	24	152	237
377	125	121.7	114	154	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.6578	10	64	183
378	125	121.7	114	154	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.6821	7	61	216
379	125	118.7	114	150	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.6316	7	75	330
380	125	119.7	114	151	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.6298	6	74	193
381	125	119.7	114	151	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.3957	6	89	187
382	125	120.7	114	152	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.4566	6	94	147
383	125	120.7	114	152	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.3991	6	99	124
384	125	120.7	114	152	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.5082	6	62	253
385	125	123.7	114	156	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.3885	5	76	231
386	125	121.7	114	154	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.2779	5	52	221
387	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9044	4	62	141
388	125	122.7	114	155	0.38	0.19	33.61	21.45	5.3	9.54	29.57	0.8395	3	85	128
389	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8731	5	57	220
390	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9287	5	71	141
391	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6987	4	52	248
392	125	122.7	120	147	0.36	0.18	31.93	20.38	10	9.07	28.09	0.341	5	51	184
393	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7553	6	63	139
394	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.521	5	123	133
395	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.5254	5	142	179
396	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.3428	6	53	99
397	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.2062	6	89	121
398	125	117.7	120	141	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8108	5	79	207
399	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7348	5	59	224
400	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7744	5	72	163
401	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8154	5	53	161
402	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.1779	5	62	193
403	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7339	5	45	138
404	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8201	5	48	119
405	125	123.7	120	148	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6095	4	68	153
406	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.327	5	70	137
407	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.2864	6	80	121
408	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8602	7	69	106
409	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9269	5	60	121
410	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9309	4	59	145
411	125	122.7	120	147	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9027	4	148	178
412	125	122.7	120	147	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8547	5	125	161
413	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.841	4	177	188
414	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7072	4	116	190

Table 3. Continued-3

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
415	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6785	4	97	165
416	125	122.7	120	147	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8935	4	110	191
417	125	122.7	120	147	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7925	4	121	216
418	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7027	4	122	248
419	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6082	5	157	231
420	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.5535	5	116	215
421	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6156	4	116	209
422	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7023	4	101	187
423	125	116.7	120	140	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7857	4	110	202
424	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7343	4	111	223
425	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6678	4	142	243
426	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6056	5	129	218
427	125	115.7	120	139	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7794	4	129	402
428	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8661	5	131	148
429	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9073	5	98	115
430	125	117.7	120	141	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7673	5	99	142
431	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7929	5	120	128
432	125	128.7	120	154	0.36	0.18	31.93	20.38	10	9.07	28.09	1	5	119	103
433	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.1718	5	108	200
434	125	115.7	120	139	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6977	4	142	2
435	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7108	4	118	64
436	125	117.7	120	141	0.36	0.18	31.93	20.38	10	9.07	28.09	1	4	121	2
437	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8961	4	126	140
438	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.299	4	18	182
439	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.2383	5	37	147
440	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.5517	4	20	90
441	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7503	4	14	100
442	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8165	4	48	103
443	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8213	4	30	114
444	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8004	4	21	39
445	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7956	4	26	66
446	125	123.7	120	148	0.36	0.18	31.93	20.38	10	9.07	28.09	0.2445	5	58	138
447	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.3075	5	31	137
448	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8316	5	41	51
449	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8884	4	32	67
450	125	116.7	120	140	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8906	4	29	62
451	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8764	5	72	79
452	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8779	4	57	84
453	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8677	3	70	88
454	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8517	4	75	131
455	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.647	4	79	104
456	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.6484	4	166	128
457	125	116.7	120	140	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8283	5	93	92
458	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.837	5	63	96
459	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8139	5	77	96
460	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8213	5	83	92

Table 3. Continued-4

Run #	Temp. °C	Press. psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
461	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7894	5	74	102
462	125	122.7	120	147	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7943	5	90	121
463	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.804	6	69	97
464	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7853	5	84	107
465	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7803	18	77	127
466	125	121.7	120	146	0.36	0.18	31.93	20.38	10	9.07	28.09	0.77	5	91	151
467	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7879	12	75	118
468	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8565	5	68	107
469	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9181	5	112	129
470	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8565	5	80	207
471	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9087	5	84	460
472	125	118.7	120	142	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9584	5	54	199
473	125	117.7	120	141	0.36	0.18	31.93	20.38	10	9.07	28.09	0.7669	5	58	196
474	125	119.7	120	144	0.36	0.18	31.93	20.38	10	9.07	28.09	0.8941	4	53	164
475	125	120.7	120	145	0.36	0.18	31.93	20.38	10	9.07	28.09	0.9626	6	73	159

*SCCM: standard cubic centimeters per minute, volumetric flow rates of gases at 1 atm and 25°C

Appendix IV. Experimental data for the fourth year annual report.

Table 3. Conversion of H_2S to elemental sulfur and formation of COS with a 120 SCCM feed stream containing 3,500 - 3,600 ppmv H_2S, 1,800 ppmv SO_2 as an oxidant, 31.7 – 32.1 v% CO, 20.4 – 20.6 v% H_2, 8.7 – 9.1 v% CO_2, and 10-v% moisture at 125^{o}C, 110 - 124 psia, and 131 – 148 s space time.

Run #	Temp. ^{o}C	Press. Psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
476	125	118	120	141	0.36	0.18	31.93	20.38	10.00	9.07	28.09	0.4803	6	108	97
477	125	119	120	142	0.36	0.18	31.93	20.38	10.00	9.07	28.09	0.5964	6	102	128
478	125	121	120	144	0.36	0.18	31.93	20.38	10.00	9.07	28.09	0.4988	5	109	126
479	125	121	120	144	0.36	0.18	31.93	20.38	10.00	9.07	28.09	0.4486	5	73	91
480	125	121	120	144	0.36	0.18	31.93	20.38	10.00	9.07	28.09	0.7813	5	83	121
481	125	119	120	142	0.36	0.18	31.93	20.38	10.00	9.07	28.09	0.7382	5	76	123
482	125	118	120	141	0.36	0.18	31.93	20.38	10.00	9.07	28.09	0.6701	21	83	95
483	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.2529	14	128	248
484	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7265	78	183	316
485	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6634	219	202	343
486	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6818	41	149	306
487	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6846	30	164	277
488	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6503	25	169	319
489	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7826	24	157	306
490	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7895	16	129	223
491	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8178	60	164	262
492	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8392	32	152	262
493	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7817	16	118	186
494	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.4866	27	139	229
495	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7938	28	152	271
496	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7883	65	125	170
497	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7689	33	138	242
498	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.0405	22	40	128
499	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8732	26	37	19
500	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8812	22	34	6
501	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9133	33	32	9
502	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9221	28	30	14
503	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9152	27	30	34
504	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6161	22	44	81
505	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9176	22	86	28
506	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8792	28	57	112
507	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8828	28	57	189
508	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8637	35	49	153
509	125	123	120	147	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9579	25	45	292
510	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8979	16	37	301
511	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9281	26	41	262
512	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9130	26	32	234

Table 3. Continued – 1

Run #	Temp. °C	Press. Psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
513	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8929	25	33	223
514	125	117	120	140	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9179	28	55	277
515	125	117	120	140	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8735	25	161	253
516	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9104	27	141	263
517	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8771	24	54	231
518	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6897	28	67	1079
519	125	124	120	148	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8538	36	37	254
520	125	123	120	147	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8995	32	37	237
521	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6692	24	54	336
522	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6835	30	58	225
523	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.5732	28	38	227
524	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	na	33	59	68
525	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6913	67	135	152
526	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9049	48	86	148
527	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9464	35	140	166
528	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9008	31	125	164
529	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.932	27	86	143
530	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9369	43	97	140
531	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8921	29	72	120
532	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9226	32	68	97
533	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9396	36	74	126
534	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8712	30	74	127
535	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9348	42	74	117
536	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9224	46	137	129
537	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8834	28	159	150
538	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8953	41	152	141
539	125	123	120	147	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9112	29	174	169
540	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8149	29	115	137
541	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7198	46	141	149
542	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9239	35	151	141
543	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9133	32	162	152
544	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8904	33	201	192
545	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9188	38	222	202
546	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8765	36	177	183
547	125	116	120	139	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8811	55	145	150
548	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8943	39	144	149
549	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9066	35	114	122
550	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9158	40	171	21
551	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.842	37	135	137
552	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6894	33	118	115
553	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.6348	46	193	140
554	125	117	120	140	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8092	25	141	109
555	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8364	33	99	105

Table 3. Continued – 2

Run #	Temp. ^oC	Press. Psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
556	125	117	120	140	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9031	29	99	93
557	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8992	32	109	94
558	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9069	28	100	87
559	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8504	33	114	98
560	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8994	35	106	94
561	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8622	40	154	125
562	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8993	23	96	120
563	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9035	40	113	130
564	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7118	47	135	155
565	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8253	33	136	153
566	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8455	41	118	203
567	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8375	34	114	165
568	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7441	41	87	173
569	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.4346	40	57	167
570	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8585	34	85	115
571	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8359	30	61	151
572	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8945	32	72	131
573	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8941	37	94	137
574	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8682	30	111	126
575	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8793	40	131	200
576	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8874	45	172	192
577	125	123	120	147	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.9086	38	169	142
578	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8966	39	157	168
579	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8229	42	107	104
580	125	118	120	141	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7162	43	96	126
581	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7142	39	90	93
582	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.3848	40	82	113
583	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8651	46	99	119
584	125	122	120	146	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8818	34	86	112
585	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8587	46	117	151
586	125	121	120	144	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8290	42	97	131
587	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7747	40	101	134
588	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7186	49	113	146
589	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8362	47	122	201
590	125	119	120	142	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.8551	45	95	160
591	125	120	120	143	0.35	0.18	31.71	20.52	10.00	8.71	28.53	0.7771	35	87	140
592	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8368	90	171	199
593	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7563	66	65	79
594	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7586	41	93	133
595	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7579	28	65	121
596	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9943	24	68	96
597	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6875	44	61	74
598	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8780	33	71	69

Table 3. Continued – 3

Run #	Temp. °C	Press. Psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
599	125	123	120	147	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9081	33	174	138
600	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9131	25	75	92
601	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9507	55	113	125
602	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9517	36	132	146
603	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9300	28	73	124
604	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9525	152	1044	1300
605	125	117	120	140	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9370	11	66	66
606	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9643	26	63	74
607	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9368	26	133	412
608	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8583	51	110	151
609	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8621	39	104	109
610	125	123	120	147	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8053	24	54	70
611	125	110	120	131	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7281	39	75	244
612	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6440	31	67	77
613	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.5174	20	75	97
614	125	116	120	139	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.3971	28	82	108
615	125	115	120	137	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6265	28	94	90
616	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7243	25	92	110
617	125	117	120	140	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9015	27	108	111
618	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7480	34	94	82
619	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7215	29	98	94
620	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6347	134	114	124
621	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6624	122	102	102
622	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.5656	34	119	129
623	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8048	99	384	386
624	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8292	31	109	151
625	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8564	26	104	146
626	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7736	37	124	201
627	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.0264	25	179	169
628	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7580	33	135	185
629	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8901	38	134	187
630	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8118	40	120	166
631	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7374	30	61	93
632	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9058	39	88	125
633	125	123	120	147	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7803	31	103	123
634	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	na	146	93	na
635	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	na	35	127	3
636	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8650	23	99	84
637	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7723	28	123	165
638	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8515	34	112	164
639	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7316	25	93	142
640	125	117	120	140	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8036	28	107	178
641	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.5381	25	98	149

Table 3. Continued – 4

Run #	Temp. °C	Press. Psia	Total Flow Rate, SCCM	Space Time, s	Feed Composition, v%							Conversion of H_2S	COS, ppm		
					H_2S	SO_2	CO	H_2	H_2O	CO_2	N_2		Cylinder Feed	Blank Product Mixture	Reaction Product Mixture
642	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8491	26	106	166
643	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9197	25	105	208
644	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9134	24	150	157
645	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8898	29	149	211
646	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8153	27	130	168
647	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8764	27	106	142
648	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8381	25	135	145
649	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7274	44	136	116
650	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7826	31	105	144
651	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8291	27	100	114
652	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6635	29	87	121
653	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.5798	30	75	130
654	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6151	39	185	215
655	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8845	33	76	131
656	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.4682	41	74	146
657	125	118	120	141	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8741	29	64	97
658	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6467	28	66	91
659	125	116	120	139	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.5355	45	79	111
660	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7284	32	76	136
661	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.5735	42	94	106
662	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6818	33	97	107
663	125	120	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6110	29	69	95
664	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7768	34	89	102
665	125	117	120	140	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.6265	29	55	107
666	125	119	120	142	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.5878	27	105	108
667	125	121	120	144	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.4651	32	117	109
668	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.7962	27	83	141
669	125	122	120	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9444	35	71	108
670	125	105	120	143	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.9126	61	90	144
671	125	107	122	146	0.36	0.18	32.12	20.59	10.00	8.76	27.99	0.8613	44	124	135

*SCCM: standard cubic centimeters per minute, volumetric flow rates of gases measured at 1 atm and 25°C