

APPENDIX H Single-step Sulfur Recovery Process (SSRP): Proceedings of the
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Single-step Sulfur Recovery Process (SSRP)

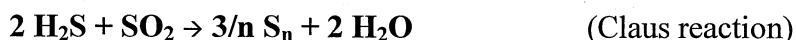
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The direct catalytic oxidation of H₂S in the presence of great excess (> 60%) H₂ and CO was examined on a commercial alumina catalyst at 125-160°C and 200-350psig. Total sulfur (H₂S + SO₂) conversions of 98.5% or higher were achieved, with the undesirable formation of carbonyl sulfide limited to below 40ppm. SO₂ is much more selective than oxygen for the catalytic oxidation of H₂S to high-purity sulfur by the Single-step Sulfur Recovery Process (SSRP).

INTRODUCTION

Gasification of heavy feeds (e.g., coal, pet coke, resid, biomass) produces a raw fuel gas that requires cleaning before its use to produce electricity and/or synthetic liquid fuels (e.g., using Fischer-Tropsch synthesis). The current commercial process for gas cleaning involves quenching the gas to remove particulates and trace contaminants. Then, a complex multi-step amine-based process to remove hydrogen sulfide (H₂S) follows. The fuel gas is first contacted by an amine solution using a gas-liquid scrubber. The spent amine is then regenerated using steam and the regeneration off-gas containing H₂S is sent to a Claus plant. An H₂S burner oxidizes 1/3 of H₂S to SO₂, which then reacts with the remaining H₂S to form sulfur:



The Claus reaction uses a series of up to three catalytic reactors, and yet its tail gas still contains about 2% of the inlet H₂S – SO₂ mixture, which is then sent to a tail gas treatment plant. To reduce the numerous steps in conventional sulfur removal and recovery processes, RTI with DOE/NETL funding is developing the **Single-step Sulfur Recovery Process (SSRP)**. The SSRP consists of injecting SO₂ directly into the quenched fuel gas to oxidize H₂S selectively on a suitable catalyst to both remove and recover sulfur in a single step. The key differences between SSRP and the traditional Claus process are: a) in SSRP the catalytic oxidation of H₂S by SO₂ (Claus reaction) occurs selectively in a highly reducing atmosphere containing the highly reactive H₂ and CO fuel gas components, and b) the reaction is carried out at the pressure of the fuel gas (300-1200 psig). The temperature of the SSRP reactor is within 125°C (257°F, where sulfur liquefies) and 160°C (320°F, where liquid sulfur viscosity starts to increase rapidly). The SSRP uses a catalyst that is highly selective for the oxidation of H₂S as opposed to the undesirable oxidation of H₂ and CO that are present in great excess in the fuel gas (ca. 60vol% vs. less than 1vol% H₂S).

A review of the literature did not identify any studies in which the Claus reaction was carried out in the presence of large concentrations of CO and H₂. Pearson (1976) studied the Claus reaction at temperatures between 135°C and 175°C using a Claus tail gas containing ca. 3vol% CO+H₂. Conversion of H₂S+SO₂ was 96 to 98% until his active alumina catalyst reached 60% sulfur loading in the pores. The conversion then declined rapidly to 31%.

The scope of this work is to determine the feasibility of the SSRP for the selective catalytic oxidation of H₂S in the presence of excess amounts (> 30vol%) of highly reactive gases such as H₂ and CO. Also, it is to evaluate the performance of commercial catalysts to selectively remove and recover high-purity sulfur under commercially applicable process conditions.

EXPERIMENTAL

The SSRP reaction was studied in a 0.5-inch fixed-bed micro-reactor at 125-160°C (257-320°F) and 200-350 psig, over a commercial high-surface-area (227m²/g) alumina catalyst. The stainless steel reactor was coated with silica to minimize reactions on its walls. The reactant feed consisted of a simulated Texaco coal gas stream containing 50.8% CO, 35.7% H₂, 12.5% CO₂, and 1.0% H₂S, and a 2.5% SO₂/N₂ stream. A syringe pump provided a constant flow of steam (through water evaporation) into the coal gas line. A typical reaction composition included ca. 8400ppm H₂S, ca. 4200ppm SO₂, 10% steam, and a balance of simulated Texaco gasifier gas (N₂, CO₂, H₂, and CO). The steam condensed into a condensation pot past the reactor outlet. A back-pressure-control valve, located downstream of the condenser, controlled the reactor and condenser pressure. The outlet gases were analyzed in a gas chromatograph with a thermal conductivity detector (TCD) and a flame photometric detector (FPD), for high (above 500ppm) and low (down to single-digit ppm) sulfur-gas concentrations, respectively. A schematic of the SSRP reaction system is shown in Figure 1.

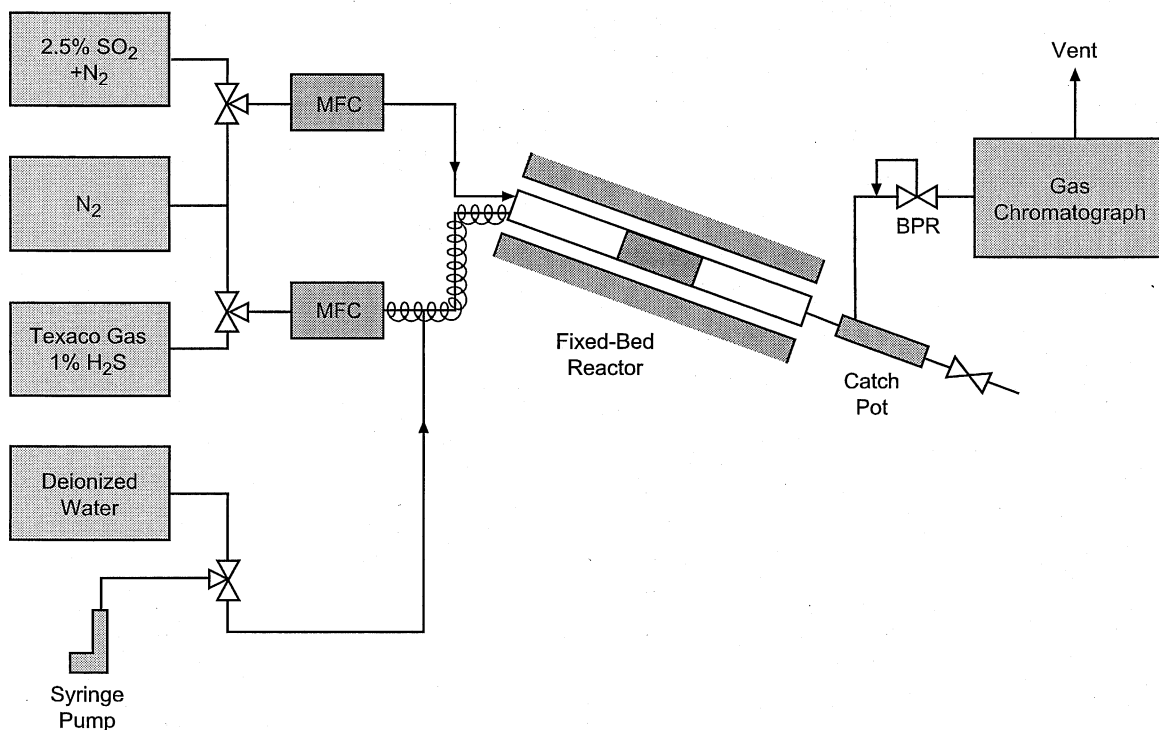


Figure 1. Schematic of the SSRP reaction system

RESULTS AND DISCUSSION

The SSRP reaction experiments were conducted by loading the silica-coated reactor with 5 cm³ of alumina catalyst, then heating to 154°C (309°F) and pressurizing to 200psig (14.4 bar) under an inert gas flow of 100sccm. 15sccm SO₂/N₂ (corresponding to ca. 3800ppm SO₂) were fed into the reactor, followed by feeding 10sccm steam, substituting an equal flow of N₂. Upon reaching a pseudo steady state, simulated coal gas with H₂S was fed into the reactor (giving ca. 8400ppm H₂S), at a constant total feed flow of 100sccm. The total sulfur (H₂S+SO₂) conversion was 86.5%, with less than 20ppm COS (carbonyl sulfide) formation.

The effect varying the inlet SO₂ concentration was examined by increasing the SO₂/N₂ flow from 15 to 18 to 20sccm while keeping the coal gas and steam flows constant, thus increasing the total flow from 100 to 103 to 105sccm, respectively. The results are shown in Figure 2. Upon increasing the SO₂ inlet concentration the conversion of H₂S increased up to 99.5%, while the conversion of SO₂ decreased from essentially 100% down to ca. 87%. Thus the H₂S+SO₂ conversion showed a maximum at an intermediate SO₂ concentration. This implies reaction of SO₂ with H₂S only, and not with H₂ or CO which are in great excess, at least to any appreciable rate. The COS formation was only about 20ppm.

The effect of space velocity was studied by varying the total feed flow from 100sccm to 500sccm while keeping the other reaction parameters (temperature, pressure, feed composition) constant. A fivefold increase in space velocity resulted in only a minor decrease (from 98.5% to 96%) in H₂S+SO₂ conversion (Figure 3). The formation of COS was again only about 20ppm. Thus the SSRP reaction is very active and selective even at significantly small contact times.

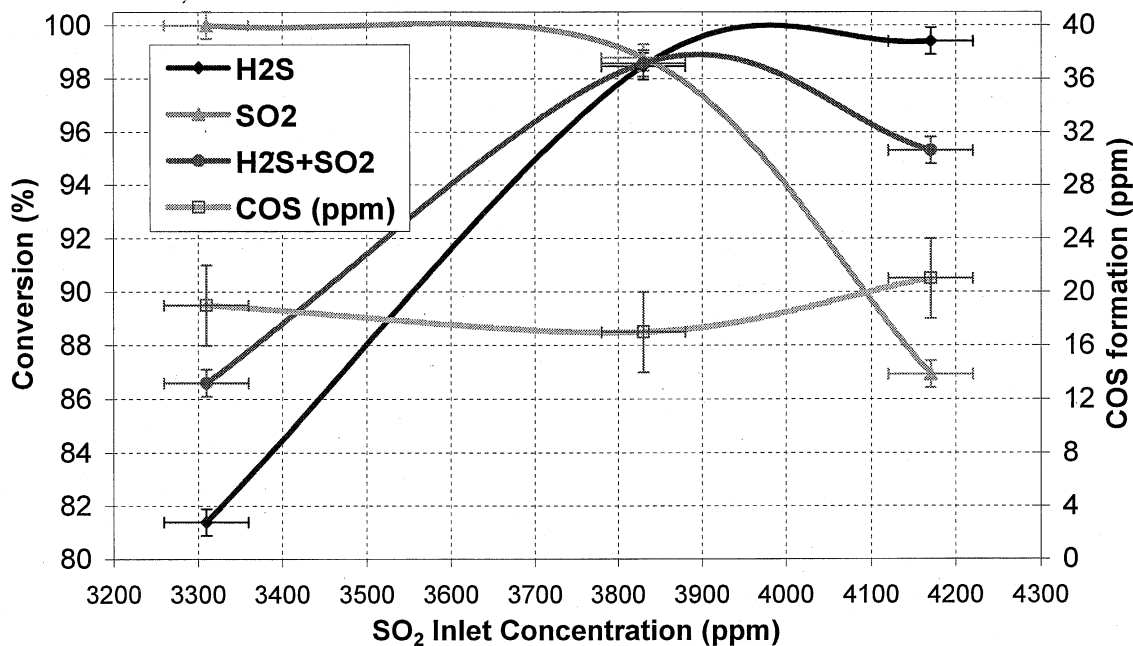


Figure 2. Effect of SO₂ inlet concentration on H₂S, SO₂, and H₂S+SO₂ conversion, and COS formation, for SSRP on alumina; T: 154°C, P: 200psig; SV: 1200 (1230) (1260) h⁻¹; H₂S: 8400-8000ppm; steam: 10%

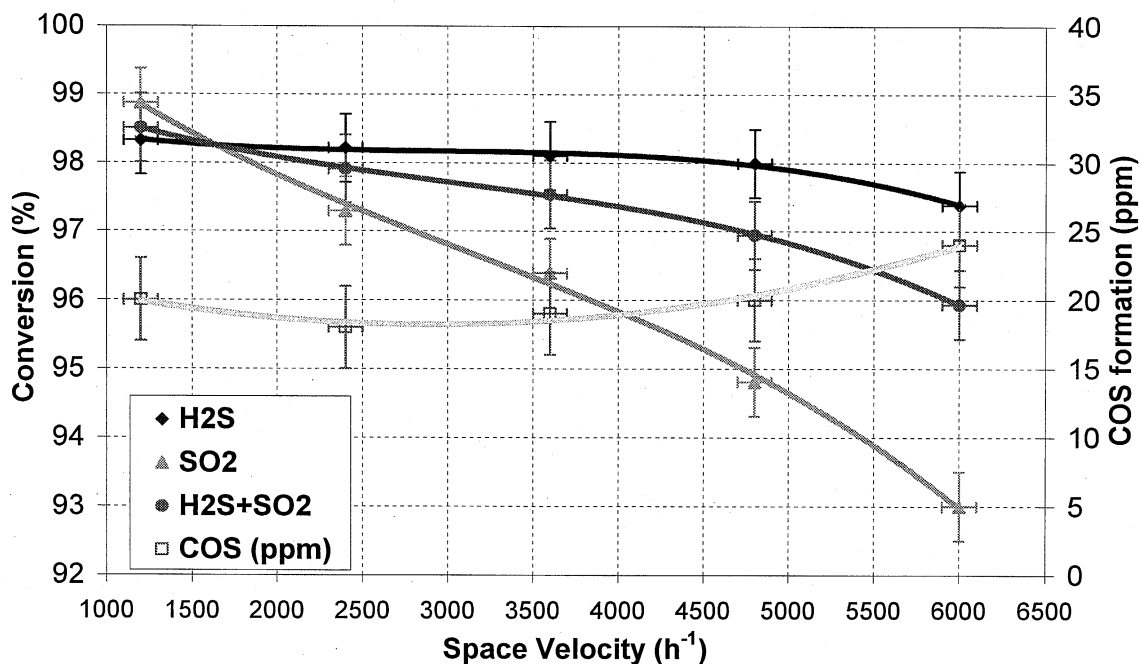


Figure 3. Effect of space velocity on H₂S, SO₂, and H₂S+SO₂ conversion, and COS formation, for SSRP on alumina; T: 154°C, P: 200psig; H₂S: 8400ppm; SO₂: 4200ppm; steam: 10%

The effect of pressure was examined by increasing the reaction pressure from 200psig (12.4 bar) to 350psig (25.8 bar) at a total feed flow of 300scm while keeping the other reaction parameters (temperature, feed composition) constant. The results are given in Table 1. The combined H₂S+SO₂ conversion was found to increase up to 99.0%. Higher pressures favor the reaction in terms of thermodynamic equilibrium, so they would be expected to further increase the measured conversion. The amount of formed COS was below 40ppm.

Table 1. Effect of pressure on H₂S, SO₂, and H₂S+SO₂ conversion, and COS formation, for SSRP on alumina; T: 154°C, H₂S: 8400ppm; SO₂: 4200ppm; steam: 10%

Pressure (psig)	Conversion (%)			COS formation (ppmv)
	H ₂ S	SO ₂	H ₂ S+SO ₂	
200	98.9	97.3	98.4	34
240	98.9	98.4	98.7	34
300	99.0	99.0	99.0	36
350	98.8	99.3	99.0	38

The effect of catalytically oxidizing H₂S in the presence of excess H₂ and CO by an oxidant other than SO₂ (such as O₂) was also examined on alumina at 154°C, 200psig, and a total flow of 100scm. After addition of 10% steam for 30min, 2%O₂/N₂ was fed into the reactor,

producing ca. 4300ppm O₂ in the feed, at a total flow of 105sccm. Then, coal gas was fed to get a ratio of H₂S/O₂ of ca. 2 and the reaction reached a pseudo steady state. Finally, the O₂ flow was substituted by a flow of SO₂ producing ca. 4300ppm of SO₂ in the feed (H₂S/SO₂ ratio of ca. 2) and the reaction reached a new pseudo steady state.

The results for the effect of O₂ vs. SO₂ in the feed are given in Figure 4. Oxygen is much less selective for the oxidation of H₂S compared to SO₂ and also allows for enhanced undesirable formation of COS. There appears to be a clear unselective consumption of O₂ by the H₂ and/or CO of the coal gas, thus limiting its availability for the desirable selective reaction with H₂S.

The sulfur that was generated on the catalyst during the SSRP was retained within the catalyst pores (the collected water condensate was clear). Normally in low temperature fixed-bed Claus-type processes, the catalyst is reversibly poisoned by the sulfur plugging its pores, as shown by Pearson (1975). The catalyst would have to be heated to high temperatures to remove the sulfur.

A commercial embodiment of the SSRP involving a liquid phase of molten sulfur with dispersed catalyst in a slurry bubble column reactor (SBCR) is currently under development (Gangwal et al, 2002). A schematic of this embodiment is given in Figure 5. The sulfur that is generated during the SSRP dissolves into the molten sulfur, in analogy to the wax formed and removed by the liquid wax medium in a slurry-bubble column Fischer-Tropsch reactor. Therefore, recovery of the product sulfur as well as a shift in thermodynamic equilibrium limitations on sulfur formation can be accomplished.

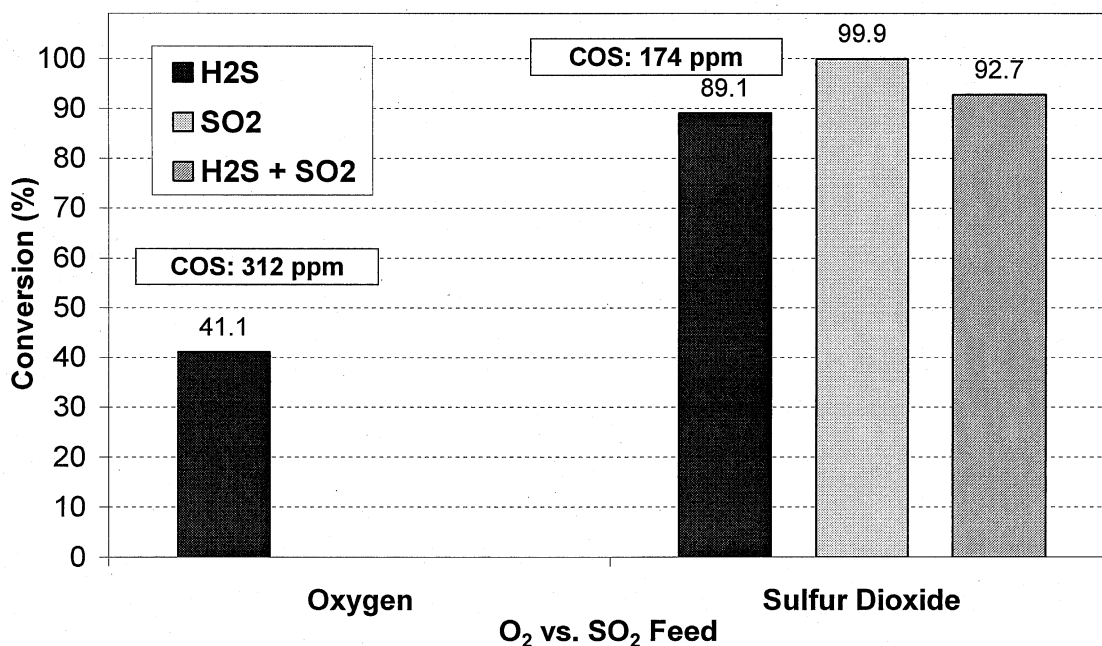


Figure 4. Effect of O₂ vs. SO₂ feed on H₂S, SO₂, and H₂S+SO₂ conversion, and COS formation, for SSRP on alumina; T: 125°C, P: 200psig; H₂S: 8400ppm; O₂ (SO₂): 4300ppm; steam: 10%

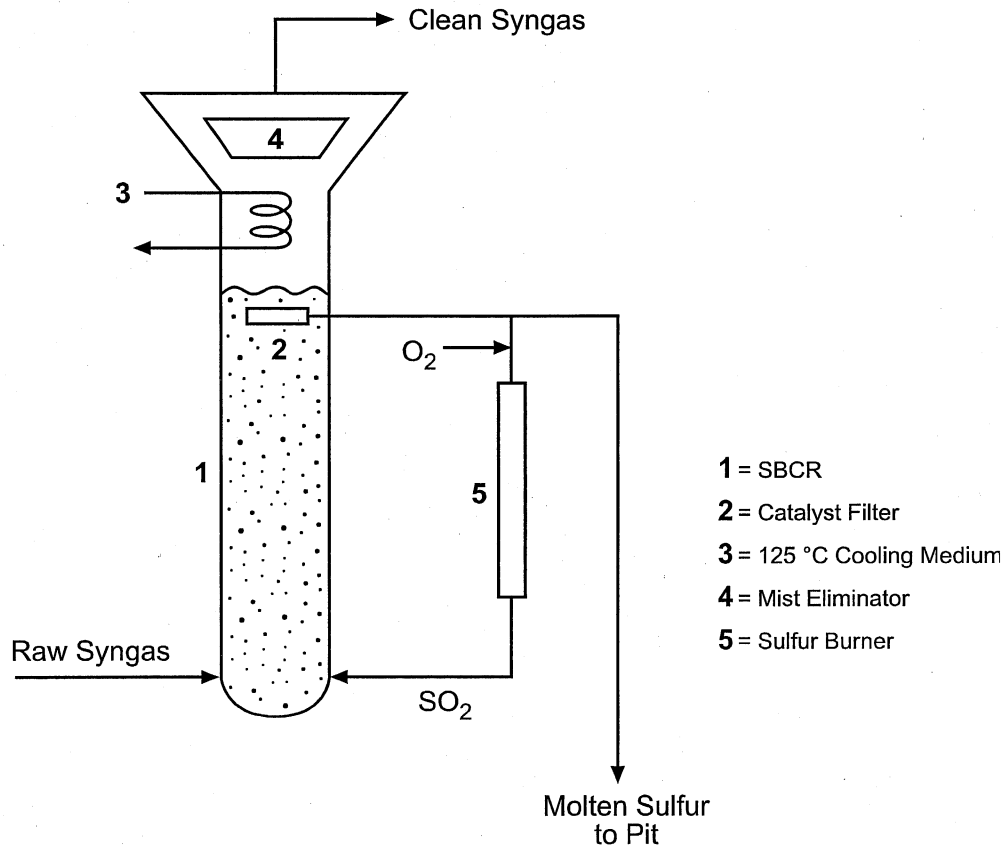


Figure 5. Proposed commercial embodiment of the Single-step Sulfur Recovery Process (SSRP)

CONCLUSIONS

The results of this work have clearly demonstrated that the direct catalytic oxidation of H_2S by SO_2 can be successfully performed even in the presence of great excess of highly reactive reducing species such as H_2 and CO . The combined H_2S+SO_2 conversion on an alumina catalyst is 98.5% at 154°C and 200psig and further increases with increasing pressure (99% at 300psig), being limited only by thermodynamic equilibrium from attaining 100%. Furthermore, higher pressures would shift the equilibrium limitations towards higher conversion, thus the SSRP is favored by using high-pressure fuel gas (300-1200psig). SO_2 is a much more selective oxidant compared to oxygen for selectively oxidizing H_2S in the presence of excess H_2 and CO . Under the examined experimental conditions, the undesirable formation of COS was limited to 40ppm or lower.

REFERENCES

- Gangwal, S.K., Nikolopoulos, A.A., and Dorchak, T.P., "Method of Removing and Recovering Elemental Sulfur from Highly Reducing Gas Streams Containing Sulfur Gases", US Patent applied for, July 2002.
- Pearson, M.J., "Catalyst Performance in Low-Temperature Claus Process", Energy Processing/Canada, July-August 1976, 38-42.

APPENDIX I SSRP Micro-Reactor Processed Data

Norton Alumina

NAL01		W+G+S	D'			
In (ppm):		9200	4350			
F (cc/min)	P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y
101	70	5850	2650	36.4	39.1	1
101	50	6450	2950	29.9	32.2	1

NAL02		W+G+S	D'			
In (ppm):		9100	4000			
F (cc/min)	P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y
100	80	5350	2150	41.2	46.3	1
150	80	6475	2600	28.8	35.0	1
100	70	5750	2400	36.8	40.0	1
50	70	2000	800	78.0	80.0	3

NAL06
H2S in: 9100
SO2 in: 4000
F (cc/min) 100
G+W+S C'

NAL03		G+W+S	C'			
In (ppm):		9000	3900			
F (cc/min)	P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y
100	60	6000	2400	33.3	38.5	1
100	90	4800	1900	46.7	51.3	1
100	105	4100	1500	54.4	61.5	2

NAL04		S+W+G	C	W+S+G	D	NAL05		
H2S in (ppm)	SO2 in (ppm)	P (psig):	95	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS
9000	3900	H2S (ppm)	4650	48.3	55.1	1	50.4	70
8900	4400	SO2 (ppm)	2200	50.6	50.0	1	50.4	65
8700	4850		2500	54.6	48.5	3	52.4	80
8550	5200		2850	55.0	45.2	3	51.3	110

NAL04		NAL05				
H2S in (ppm)	SO2 in (ppm)	P (psig):	95	DH2S/2	Delta SO2	Error-Y
9000	3900	H2S (ppm)	4650	2175.0	2150.0	100
8900	4400	SO2 (ppm)	2200	2250.0	2200.0	100
8700	4850		2500	2375.0	2350.0	100
8550	5200		2850	2350.0	2350.0	100

F (cc/min)	SV (h-1)	P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y
50	600	70	2000	800	78.0	80.0	3
100	1200	75	5650	2400	38.1	41.8	3
150	1800	80	6475	2600	28.8	35.0	1

F (cc/min)	P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y
101	50	6450	2950	29.9	32.2	1
100	60	6000	2350	33.3	38.5	1
100	70	5800	2525	36.6	40.0	1
100	80	5350	2150	41.2	46.3	1
100	90	4800	1900	46.7	51.3	1
100	105	4100	1500	54.4	61.5	2

E-alumina

EAL02 125°C

H2S in (ppm)	SO2 in (ppm)	P (psig): 200		D(H2S)/2	D(SO2)	Error-Y
		H2S (ppm)	SO2 (ppm)			
9350	3400	2300	0	3525	3400	100
9100	3900	500	50	4300	3850	100
8900	4400	150	550	4375	3850	100
8700	4850	100	950	4300	3900	100
8550	5200	0	1650	4275	3550	100

EAL04 125°C

H2S in (ppm)	SO2 in (ppm)	P (psig): 200		P (psig): 300		Error-Y	X(tot)%
		H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%		
9300	3900	90	550	99.0	85.9	0.2	95.2
9200	4200	100	350	98.9	91.7	0.2	96.6
9100	4500	180	150	98.0	96.7	0.2	97.6
9100	4500	150	25	98.4	99.4	0.2	98.7

125°C

P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%
200	190	150	97.9	96.7	0.5	97.5
250						
300	150	25	98.4	99.4	0.5	98.7

EAL05 125°C

139°C

H2S in (ppm)	SO2 in (ppm)	P (psig): 300		X(H2S)%	X(SO2)%	Error-Y	X(tot)%
		H2S (ppm)	SO2 (ppm)				
9100	4500	200	150	97.8	96.7	0.2	97.4
9100	4500	300	100	96.7	97.8	0.2	97.1

EAL06 139°C

F (cc/min)	In (ppm):		H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%
	9100	4500						
86	200		650	0	92.9	100.0	0.2	95.2
86	250		550	0	94.0	100.0	0.2	96.0
86	300		400	0	95.6	100.0	0.2	97.1

139°C

P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%
200	650	0	92.9	100.0	0.5	95.2
250	550	0	94.0	100.0	0.5	96.0
300	350	50	96.2	98.9	1	97.1

Blank (no catalyst)

BLN01	156°C	High W	22.5%	W+G+S		D'		
	In (ppm):	9300	4500					
F (sccm)	P (psig)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
100	200	2800	1100	69.9	75.6	1	71.7	350
100	250	1950	800	79.0	82.2	1	80.1	450
100	300	1500	550	83.9	87.8	1	85.1	550

BLN01	86sccm	Low W	10%	W+G+S		D'		
	In (ppm):	9300	4500					
P (psig)	T (°C)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
300	156	1650	700	82.3	84.4	1	83.0	550
300	140	1450	700	84.4	84.4	1	84.4	300
300	125	1050	700	88.7	84.4	1	87.3	200

BLN02	86sccm	Low W	10%	S+W+G		C		
	In (ppm):	9300	4500					
P (psig)	T (°C)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
200	125	2490	1190	73.2	73.6	1	73.3	130
250	125	1700	870	81.7	80.7	1	81.4	500
300	125	1360	780	85.4	82.7	1	84.5	600
300	140	1395	735	85.0	83.7	2	84.6	730

BLN03	200psig	77/86sccm	S+G	A	S+G+W	B	Low W	10%	
	In (ppm):	9300	4500		9300	4500			
Parameter	T (°C)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)	H2O
-W -H	125	7625	3675	18.0	18.3	1	18.1	50	0%
-H2O	125	5100	2330	45.2	48.2	1	46.2	100	0%
+H2O	125	2800	1380	69.9	69.3	1	69.7	1300	10%

BLN04	200psig	86sccm	W+O+G	O	W+G+S	D'	Low W	10%
	In (ppm):	9500	4500					
Parameter	T (°C)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
Oxygen	140	6050	0	37.1		1		150
Sulfur Dioxide	140	3400	920	63.4	79.6	1	68.7	240

E-alumina

EAL03 200 psig 154°C 10% W

F(SO₂) In (ppm): 8500

(cc/min)	SO ₂ (ppm)	H ₂ S (ppm)	SO ₂ (ppm)	X(H ₂ S)%	X(SO ₂)%	Error-Y	X(tot)%	COS (ppm)	H ₂ O
15	3310	1582	0	81.4	100.0	0.5	86.6	19	10%
18	3830	130	46	98.5	98.8	0.5	98.6	17	10%
20	4170	50	545	99.4	86.9	0.5	95.3	21	10%

EAL04 200 psig 154°C 10% W

In (ppm): 8965 4430

F (sccm)	SV (h-1)	H ₂ S (ppm)	SO ₂ (ppm)	X(H ₂ S)%	X(SO ₂)%	Error-Y	X(tot)%	COS (ppm)	H ₂ O
100	1200	150	50	98.3	98.9	0.5	98.5	20	10%
200	2400	160	120	98.2	97.3	0.5	97.9	18	10%
300	3600	170	160	98.1	96.4	0.5	97.5	19	10%
400	4800	180	230	98.0	94.8	0.5	96.9	20	10%
500	6000	235	310	97.4	93.0	0.5	95.9	24	10%

EAL05 154°C 10% W

In (ppm): 8550 4358

F (sccm)	P (psig)	H ₂ S (ppm)	SO ₂ (ppm)	X(H ₂ S)%	X(SO ₂)%	Error-Y	X(tot)%	COS (ppm)	H ₂ O
300	200	94	116	98.9	97.3	0.5	98.4	34	10%
300	240	98	71	98.9	98.4	0.5	98.7	34	10%
300	300	89	45	99.0	99.0	0.5	99.0	36	10%
300	350	106	30	98.8	99.3	0.5	98.9	38	10%
300	200	104	86	98.8	98.0	0.5	98.5	46	10%

EAL06 200 psig 10% W

In (ppm): 8550 4275

F (sccm)	T (°C)	H ₂ S (ppm)	SO ₂ (ppm)	X(H ₂ S)%	X(SO ₂)%	Error-Y	X(tot)%	COS (ppm)	H ₂ O
300	154	111	68	98.7	98.4	0.5	98.6	85	10%
300	140	70	113	99.2	97.4	0.5	98.6	45	10%
300	125	90	163	98.9	96.2	0.5	98.0	31	10%
300	154	137	112	98.4	97.4	0.5	98.1	86	10%

EAL09 200 psig 154°C 10% W

In (ppm): 8500 4300

F (sccm)	Oxidizer	H ₂ S (ppm)	SO ₂ (ppm)	X(H ₂ S)%	X(SO ₂)%	Error-Y	X(tot)%	COS (ppm)	H ₂ O
100	Oxygen	5009	0	41.1		0.5		312	10%
100	Sulfur Dioxide	928	3	89.1	99.9	0.5	92.7	174	10%

P3-alumina

P3AL01 200 psig 154°C G+S A' G+S+W B'
 In (ppm): 8500 4350

H2O	F (sccm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
0%	270	8450	0	0.6	100.0	0.5	34.2	1950
10%	300	6470	0	23.9	100.0	0.5	49.6	5300

P3AL02 200 psig 154°C W+S+G D
 In (ppm): 8500 4350

H2S	F (sccm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
8500	300	750	950	91.2	78.2	0.5	86.8	250
8550	305	890	650	89.6	85.1	0.5	88.0	380

P3AL03 300sccm 154°C W+S+G D
 In (ppm): 8500 4350

P (psig)	F (sccm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
200	300	65	560	99.2	87.1	0.5	95.1	235
290	300	50	230	99.4	94.7	0.5	97.8	310

P3AL04 300sccm 154°C S+W+G C
 In (ppm): 8500 4600

P (psig)	F (sccm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
200	300	40	530	99.5	88.5	0.5	95.6	45
275	300	20	400	99.8	91.3	0.5	96.8	45

200psig 300sccm 154°C S+W+G C
 In (ppm):

Alumina	F (sccm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS(ppm)
P	300			99.5	88.5	0.5	95.6	45
E	300			98.9	97.3	0.5	98.4	34

Sulfided Iron Oxide

FeS01 200 psig 154°C 10% W

F In (ppm): Out(ppm):

(cc/min)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS (ppm)
300	8500	0	4282	0	49.6	#DIV/0!	0.5	49.6	303
300	8500	4300	208	0	97.6	100.0	0.5	98.4	8578
295	8650	4000	352	0	95.9	100.0	0.5	97.2	8868
285	8950	3300	1020	0	88.6	100.0	0.5	91.7	7594
265	9600	1750	3457	0	64.0	100.0	0.5	69.5	4130
265	9600	0	6667	0	30.6	#DIV/0!	0.5	30.6	798

Procedure	SUM In	SUM Out	Delta S	Effic. (%)
W+G	8500	4585	3915	46.1
W+G+S	12800	8786	4014	31.4
W+G+S	12650	9220	3430	27.1
W+G+S	12250	8614	3636	29.7
W+G+S	11350	7587	3763	33.2
W+G	9600	7465	2135	22.2

FeS02 200 psig 154°C 10% W

F In (ppm): Out(ppm):

(cc/min)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS (ppm)
300	8500	0	7099	0	16.5	#DIV/0!	0.5	16.5	706
300	8500	4300	913	0	89.3	100.0	0.5	92.9	13139
310	8250	4900	264	140	96.8	97.1	0.5	96.9	13705
320	7950	5500	158	580	98.0	89.5	0.5	94.5	14190
340	7500	6550	49	1679	99.3	74.4	0.5	87.7	14215
340	0	6550	0	5124	#DIV/0!	21.8	0.5	21.8	13

Procedure	SUM In	SUM Out	Delta S	Effic. (%)
W+G	8500	7805	695	8.2
W+G+S	12800	14052	-1252	-9.8
W+G+S	13150	14109	-959	-7.3
W+G+S	13450	14928	-1478	-11.0
W+G+S	14050	15943	-1893	-13.5
W+S	6550	5137	1413	21.6

(cc/min)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	Error-Y	X(tot)%	COS (ppm)
340	7500	6550	49	1679	99.3	74.4	10	87.7	14215
320	7950	5500	158	580	98.0	89.5	10	94.5	14190
310	8250	4900	264	140	96.8	97.1	10	96.9	13705
300	8500	4300	208	0	97.6	100.0	1300	98.4	10858.5
295	8650	4000	352	0	95.9	100.0	10	97.2	8868
285	8950	3300	1020	0	88.6	100.0	10	91.7	7594
265	9600	1750	3457	0	64.0	100.0	10	69.5	4130
265	9600	0	6667	0	30.6		10	30.6	798

Procedure	SUM In	SUM Out	Delta S	Effic. (%)
W+G+S	14050	15943	-1893	-13.5
W+G+S	13450	14928	-1478	-11.0
W+G+S	13150	14109	-959	-7.3
W+G+S	12800	11067	1734	13.5
W+G+S	12650	9220	3430	27.1
W+G+S	12250	8614	3636	29.7
W+G+S	11350	7587	3763	33.2
W+G	9800	7465	2335	23.8

FeS02	200 psig	154°C	10% W						
1750 ppm	9600	1750	3457	0	64.0	100.0	0.5	69.5	4130
0 ppm	9600	0	6667	0	30.6		0.5		798
					Procedure	SUM In	SUM Out	Delta S	Effic. (%)
					W+G+S	11350	7587	3763	33.2
					W+G	9800	7465	2335	23.8

Silica gel

SIL01	300sccm	154°C		10% W		W+G+S		D'	
		In (ppm)		Out (ppm)					
	P (psig)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	H2S-2SO2	X(tot)%
W+G	200	8200		7787		5.0		413	5.0
W+G+S	200	8200	4400	736	847	91.0	80.8	358	87.4
W+G+S	250	8200	4400	213	442	97.4	90.0	71	94.8
W+G+S	300	8200	4400	130	351	98.4	92.0	-28	96.2
W+G	300	8200		7603		7.3		597	7.3

COS (ppm)	SUM In	SUM Out	Delta S	Effic. (%)
47	8200	7834	366	4.5
172	12600	1755	10845	86.1
146	12600	801	11799	93.6
159	12600	640	11960	94.9
85	8200	7688	512	6.2

SIL02	200psig	154°C		10% W		W+S+G		D	W+S+O	O	W+G+S		D'
		In (ppm)		Out (ppm)									
		H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	H2S-2SO2	X(tot)%				
W+S			4450		4458		-0.2	16	-0.2				
Sulfur Dioxide		8200	4450	506	669	93.8	85.0	132	90.7				
Oxygen		8200		5593		31.8		2607					
Sulfur Dioxide		8200	4450	597	743	92.7	83.3	189	89.4				
W+G		8200		7375		10.1		825	10.1				

COS (ppm)	SUM In	SUM Out	Delta S	Effic. (%)
0	4450	4458	-8	-0.2
138	12650	1313	11337	89.6
512	8200	6105	2095	25.5
183	12650	1523	11127	88.0
125	8200	7500	700	8.5

SIL11	200psig	154°C		0/10% W		G+S		A'	G+S+W	B'	G+W		G'
		In (ppm)		Out (ppm)									
	H2O	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	H2S-2SO2	X(tot)%				
G		8200		7827		4.5		373					
G+S	0%	8200	4400	284	833	96.5	81.1	782	91.1				
G+S+W	10%	8200	4400	598	877	92.7	80.1	556	88.3				
G+W		8200		7954		3.0		246					

COS (ppm)	SUM In	SUM Out	Delta S	Effic. (%)
293	8200	8120	80	1.0
80	12600	1197	11403	90.5
114	12600	1589	11011	87.4
87	8200	8041	159	1.9

SIL12	100psig	154°C		0/10% W		G+S		A'	G+S+W	B'	G+S	A'
		In (ppm)				Out (ppm)						
	H2O	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	H2S-2SO2	X(tot)%			
G		8200		7838		4.4		362				
G+S	0%	8200	4400	719	1072	91.2	75.6	825	85.8			
G+S+W	10%	8200	4400	1445	1325	82.4	69.9	605	78.0			
G+S	0%	8200	4400	1036	1181	87.4	73.2	726	82.4			
G		8200		7700		6.1		500				

COS (ppm)	SUM In	SUM Out	Delta S	Effic. (%)
298	8200	8136	64	0.8
116	12600	1907	10693	84.9
135	12600	2905	9695	76.9
116	12600	2333	10267	81.5
110	8200	7810	390	4.8

Silica	Procedure	300sccm		154°C		10% W		200psig	
		In (ppm)				Out (ppm)			
		H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	H2S-2SO2	X(tot)%
W+G+S	D'	8200	4400	736	847	91.0	80.8	358	87.4
W+S+G	D	8200	4450	506	669	93.8	85.0	132	90.7
W+G+S	D'	8200	4450	597	743	92.7	83.3	189	89.4
G+S+W	B'	8200	4400	598	877	92.7	80.1	556	88.3
Avg						92.6	82.3	309	89.0

COS (ppm)	SUM In	SUM Out	Delta S	Effic. (%)
172	12600	1755	10845	86.1
138	12650	1313	11337	89.6
183	12650	1523	11127	88.0
114	12600	1589	11011	87.4
Avg	12625	1545	11080	88

Catalyst	Procedure	300sccm		154°C		10% W		200psig	
		In (ppm)				Out (ppm)			
		H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	X(H2S)%	X(SO2)%	H2S-2SO2	X(tot)%
Silica	D'	8200	4400	736	847	91.0	80.8	358	87.4
E-Alumina	D'	8550	4350	70	68	99.2	98.4	-84	98.9

COS (ppm)	SUM In	SUM Out	Delta S	Effic. (%)
172	12600	1755	10845	86.1
85	12900	223	12677	98.3

APPENDIX J SSRP Micro-Bubbler Processed Data

Molten Sulfur + E-alumina

MSAL01 150 psig 60/120scc 10% W W+G+S D'

In (ppm):			Out (ppm):						
T(°C)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	H2O
154	8900	0	11119	0	1825	-24.9	#DIV/0!	-24.9	10%
154	8900	4200	3141	0	2644	64.7	100.0	76.0	10%
140	8900	4200	2130	69	2012	76.1	98.4	83.2	10%

MSAL01 150 psig 140°C 10% W

In (ppm):		Out (ppm):							
F (sccm)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	H2O
60	8900	4200	2130	69	2012	76.1	98.4	83.2	10%
120	8900	4200	2694	641	1331	69.7	84.7	74.5	10%

MSAL09 300 psig 154°C 0/10% W S+C S+C+W S+W

In (ppm):		Out (ppm):							
Switch	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	H2O
-CO	0	5850	0	5810	0		0.7	0.7	0%
+CO	0	5850	0	5880	230		-0.5	-0.5	0%
+CO	0	4500	0	4580	420		-1.8	-1.8	0%
+CO	0	4500	0	4520	440		-0.4	-0.4	10%
+CO	0	5850	0	5420	200		7.4	7.4	10%
-CO	0	5850	0	5450	12		6.8	6.8	10%
-CO	0	5850	0	5900	3		-0.9	-0.9	0%

MSAL02 150 psig 140°C 10% W W+(G+S) D*

MSAL05 150 psig 140°C 10% W W+(G+S) D*

In (ppm):		Out (ppm):							
F(SO2)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	H2O
20	8900	3800	2826	630	424	68.2	83.4	72.8	10%
24	8630	4420	1869	783	441	78.3	82.3	79.7	10%
25	8565	4570	1633	894	395	80.9	80.4	80.8	10%
26	8500	4720	1590	969	422	81.3	79.5	80.6	10%
27	8440	4860	1494	1248	407	82.3	74.3	79.4	10%
27.5	8400	4940	1453	1554	430	82.7	68.5	77.5	10%

MSAL05 127 sccm 140°C 10% W

In (ppm):		Out (ppm):							
P (psig)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	H2O
150	8400	4900	1494	1048	407	82.2	78.6	80.9	10%
200	8400	4900	1108	808	416	86.8	83.5	85.6	10%
250	8400	4900	839	502	459	90.0	89.8	89.9	10%
300	8400	4900	640	318	475	92.4	93.5	92.8	10%

MSAL06 300 psig 140°C 10% W W+(G+S) D*

In (ppm):		Out (ppm):							
F(sccm)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	SV (h-1)
64	8400	5300	316	465	1062	96.2	91.2	94.3	3840
128	8400	5300	550	578	662	93.5	89.1	91.8	7680
192	8400	5300	584	684	639	93.0	87.1	90.7	11520
256	8400	5300	857	1135	414	89.8	78.6	85.5	15360

MSAL07 300 psig 140/154°C 0/10% W W+S+G D S+G S+G+W B
 In (ppm): Out (ppm):

T (°C)	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	H2O
140	0	5850	0	5849	0	#DIV/0!	0.0	0.0	10%
140	8400	5850	950	981	360	88.7	83.2	86.4	10%
154	8400	5850	465	358	1330	94.5	93.9	94.2	10%
154	8400	5850	439	235	1632	94.8	96.0	95.3	0%
154	8400	5850	611	100	780	92.7	98.3	95.0	10%

MSAL08 300 psig 154°C 0% W C+S
 In (ppm): Out (ppm):

Switch	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	X(tot)%	H2O
-SO2	0	0	92	0	10900				0%
+SO2	0	5850	0	5870	1250		-0.3	-0.3	0%

Blank (no Molten Sulfur, no catalyst)

BLN0	300 psig	154°C	10% W		S+W	S+W+C	S+W		
In (ppm):		Out (ppm):							
Switch	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	F (sccm)	X(tot)%
-H2O	0	5850	0	5850	0		0.0	128	0.0
-CO	0	5850	0	5800	0		0.9	128	0.9
+CO	0	5850	0	5600	70		4.3	128	4.3
-CO	0	5850	0	5800	0		0.9	128	0.9
-CO	0	4400	0	4350	0		1.1	125	1.1

BLN1	300 psig	154/140°C	10% W		S+W	S+W+G			
In (ppm):		Out (ppm):							
Switch	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	T (°C)	X(tot)%
-H2O	0	5850	0	5900	0		-0.9	154°C	-0.9
+H2O	0	5850	0	5850	0		0.0	154°C	0.0
+G	8800	5850	166	1036	400	98.1	82.3	154°C	91.8
+G	9000	5300	225	643	400	97.5	87.9	154°C	93.9
+G	9000	5300	220	634	410	97.6	88.0	140°C	94.0

BLN2	300 psig	140/154°C	10/0% W		W+G	W+G+S	G+S	G		
In (ppm):		Out (ppm):								
Switch	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	T (°C)	X(tot)%	
-SO2	8800	0	8461	0	289	3.9		140°C	3.9	
+SO2	8800	5300	329	579	691	96.3	89.1	140°C	93.6	
+SO2	8800	5300	399	763	881	95.5	85.6	154°C	91.8	
+SO2-W	8800	5300	498	831	1077	94.3	84.3	154°C	90.6	
-SO2	8800	0	8307	0	588	5.6	#DIV/0!	154°C	5.6	

BLN3	300 psig	154/140°C	0/10% W		S+G	S+G+W			
In (ppm):		Out (ppm):							
Switch	H2S (ppm)	SO2 (ppm)	H2S (ppm)	SO2 (ppm)	COS (ppm)	X(H2S)%	X(SO2)%	Variable	X(tot)%
-H2O	0	5500	0	5496	0		0.1	154°C	0.1
+G	8800	5500	752	899	1003	91.5	83.7	154°C	88.5
+G	8800	5500	899	962	985	89.8	82.5	140°C	87.0
+G	8800	5500	899	962	985	89.8	82.5	300 psig	87.0
+G	8800	5500	2884	2379	893	67.2	56.7	200 psig	63.2
+G	8800	5500	899	962	985	89.8	82.5	125 sccm	87.0
+G	8800	5500	7345	5301	546	16.5	3.6	250 sccm	11.6
+H2O	8800	5500	3392	2253	466	61.5	59.0	250 sccm	60.5