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GASOLINE FROM NATURAL GAS BY SULFUR PROCESSING

Quarterly Technical Progress Report #2
10/01/93 - 12/31/93
Final Version

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EXECUTIVE SUMMARY

This report presents the work performed at the Institute of Gas Technology(IGT) during the second program quarter from October 1, 1993 to December 31, 1993, under Department of Energy(DOE) Contract No. DE-AC22-93PC92114. This program has co-ordinated funding for Task 1 from IGT's Sustaining Membership Program(SMP), while DOE is funding Tasks 2 through 8. Progress in all tasks will be reported here.

The overall objective of this research project is to develop a catalytic process to convert natural gas to liquid transportation fuels. The process consists of two steps that each utilize catalysts and sulfur containing intermediates: 1) to convert natural gas to CS_2 , and 2) to convert CS_2 to gasoline range liquids. Experimental data will be generated to demonstrate the potential of catalysts and the overall process.

During this quarter, progress in the following areas has been made. An existing unit at IGT was modified to accommodate the sulfur feedstocks and the higher temperatures($>1300^\circ\text{K}$) required for studying the reactions of hydrogen sulfide and methane as proposed in Tasks 2 through 5. An HP 5890 gas chromatograph with a TCD(thermal conductivity detector) for detecting fixed gases including hydrogen and an FPD(flame photometric detector) for detecting sulfur compounds was purchased using SMP funds and has been installed and calibrated. A total of seventy runs on MoS_2 , WS_2 , ZrS_2 catalysts as well as quartz wool were performed. As high as 61% H_2S conversion was observed.

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INTRODUCTION

Natural gas is an abundant resource in various parts of the world. The major component of natural gas is methane, often comprising over 90% of the hydrocarbon fraction of the gas. The expanded use of natural gas as fuel is often hampered because of difficulties in storage and handling a gaseous fuel. This is especially true for natural gas in remote areas such as the North Slope of Alaska. The successful implementation of a gas to gasoline process would decrease dependence on imported oil for transportation fuels. These factors make it very desirable to convert natural gas to more valuable liquids.

There are commercial processes for converting natural gas to gasoline range liquids. These processes such as Fischer-Tropsch synthesis and Mobil's MTG(Methanol To Gasoline) start with the steam reforming of methane. Steam reforming of methane requires the removal of sulfur compounds present in natural gas down to less than 0.1 ppm. This additional gas clean up step which means extra cost is necessary because the catalysts are quickly poisoned by sulfur compounds.

In this program IGT is investigating a two step process that utilizes H_2S as a reactant to convert natural gas to gasoline range liquids. In the first step of the process methane is converted to CS_2 plus hydrogen. In the second step CS_2 is hydrogenated to gasoline range hydrocarbon liquids. For the proposed process a sulfur removal step down to 0.1 ppm with associated guard beds is not necessary. Sulfur which has been considered as a poison is used as a reactant. This method of methane conversion utilizes H_2S to convert methane to CS_2 . Then CS_2 plus hydrogen can be catalytically converted to gasoline range hydrocarbons. All the H_2S generated during the CS_2 to gasoline reaction is recycled. An additional advantage of the proposed process is that the hydrogen required for the process is produced in step one without using a steam reformer.

The proposed process has the potential for improving the overall economics of natural gas conversion which could result in much more natural gas being used to make liquid fuels and decrease the US dependence on foreign sources of oil.

ACHIEVEMENTS

Task 1. Catalyst Preparation(SMP funded)

Preparation of catalysts for H_2S decomposition reaction are continuing. Based on IGT's proprietary technique, additional several new high surface area and high temperature stable catalysts have been prepared. The chemicals such as cerium sulfide, chromium sulfide and zirconium sulfide were received in this quarter. These chemicals will be used for making high surface area sulfides catalysts.

Task 2. Experimental Studies of H_2S Decomposition Reaction

Experimental Studies. A new HP 5890 gas chromatograph has been calibrated with hydrogen, nitrogen as well as hydrogen sulfide during this quart. The calibration results are given in Figure 1 to 3.

The high temperature furnace requires much more power than the previous furnace. The furnace runs on 106 volts @34 amps and requires a current limiting device for control. After IGT electricians installed a 34 amp circuit breaker/control device, experimental work began in Task 2.

The catalyst test unit has been modified to accommodate the flows, temperatures and reactants for this project. Figure 4. shows the schematic diagram of catalysis reactor system. The feed gas hydrogen sulfide, nitrogen and methane flow rate are controlled by mass flow controllers(Brooks Instruments 5850). The gas flows are measured by a dry test meter(SINGLE, American Meter Company). The gas from mass flow controllers are mixed before flowing into a custom made quartz adapter. There are two openings in the adapter. One is for mixed feed gas, another is for a ceramic thermowell. The feed gas flows through the adapter into 42 inch long, 22 mm I.D. and 25 mm O.D. quartz reactor. The joint which connects with adapter and quartz reactor are sealed by vacuum grease. There are three indents around quartz reactor at 26 inch from the top. The catalyst are held above the indents. The pressure of reactor system is measured by a pressure gauge. The temperature of catalyst reactor is measured by a type R high temperature thermocouple which protected by 1/4 inch O.D ceramic thermowell. The heat is provided by a 2 inch I.D. 32 inch long split tube high temperature furnace with maximum temperature 1540°C. (Series 3420, APPLIED TEST SYSTEMS, Inc). The product gas from the catalyst reactor flow into a knock-out condenser. The condenser is placed into a ice bath. The sulfur is cooled and condensed in condenser. The remaining gas is analyzed by GC then it flow into a 30% Hydrogen peroxide and 6M Sodium hydro-oxide solution to scrub hydrogen sulfide. The composition of gas from the scrubber is

analyzed by GC. The gas flow rate is measured by a wet test meter(PRECISION WET TEST METER, Precision Scientific Co) before release it into the vent system.

The gas sample is analyzed by Gas Chromatograph (HP5890) with a thermal conductivity detector (TCD) and a flame photometric sulfur detector (FPD). A 1/8-inch diameter 10-ft long HayeSep C 80/100 column(SUPELCO Inc.) is used for gas separation. In order to measure hydrogen in the TCD detector, argon is used as the carrier gas.

Catalyst activity tests were performed during this quarter. A total of seventy tests on three catalysts were performed. MoS_2 stabilized on ZrO_2 , pure WS_2 and pure ZrS_2 catalysts as well as quartz wool were used in these tests. Preliminary experimental results indicated that as high as 61% H_2S conversion was reached for WS_2 catalyst at 1131°C temperature.

For the first sixteen runs, no catalyst was put in the reactor. Only a plug of quartz wool was inserted. The quartz wool will be used in each run for holding the catalyst in place. The objective of these runs is to develop background data for future comparisons. The experimental conditions are given in Table 1. Nitrogen was used as a diluent. The feed gas compositions were 99% N_2 , 1% H_2S . The detailed experimental results for these runs are given in appendix A.

Table 1. TEST MATRIX FOR H_2S THERMAL DECOMPOSITION REACTION

Temperature, °C	Pressure, Atm	Flow rate, liter/min	Resident Time (Sec.)
600,700,800,900,1000,1060	1	0.28	5
600,700,800,900,1000,1060	1	0.44	3
800,900,1000,1060	1	1.08	1

Figure 5. shows the H_2S conversion for these sixteen runs. As indicated in Figure 5, the very low H_2S conversion below 800°C temperature. Significant amount of H_2S was converted at higher temperature. The maximum H_2S conversion, 54%, was reached at 1060°C temperature. Increasing feed gas flow rate appeared to reduce H_2S conversion.

The second group of runs were performed with a MoS_2 catalyst prepared by IGT proprietary

technique. A total of 24.49 g(20 ml volume) of catalyst was put into the reactor. The experimental conditions are given in Table 2.

Table 2. TEST MATRIX FOR H₂S THERMAL DECOMPOSITION FOR MoS₂ CATALYST

Temperature, °C	Pressure, Atm	Flow rate, liter/min	Resident Time (Sec.)
600,700,800,900,1000	1	0.28	5
600,700,800,900,1000	1	0.44	3
600,700,800,900,970,1032	1	1.08	1

Figure 6. shows the H₂S conversion for this catalyst. The detailed experimental results are given in Appendix A. The preliminary results indicate that the reaction rate for this catalyst was significantly increased over the quartz wool run. Hydrogen was detected at 600°C, which is 300°C lower than results of quartz wool tests. Significant amount of hydrogen sulfide conversion was observed at 700°C temperature. As high as 60% hydrogen sulfide conversion was observed at higher temperature.

The third group runs were performed with WS₂ catalyst. A total 28.6 g(20 ml volume) of catalyst was put into the reactor. The experimental conditions are given in Table 3. Nitrogen was used as a diluent. The feed gas composition were 99% N₂, 1% H₂S. The detailed experimental results for these runs are given in appendix A.

Table 3. TEST MATRIX FOR H₂S THERMAL DECOMPOSITION FOR WS₂ CATALYST

Temperature, °C	Pressure, Atm	Flow rate, liter/min	Resident Time (Sec.)
600,700,800,900,1000,1131	1	0.28	5
600,700,800,900,1000	1	0.44	3
600,700,800,850,1000,1050	1	1.08	1

Figure 7. shows H₂S conversion results for WS₂ catalyst. As indicated from this figure, as high as 61% H₂S conversion was obtained at 1131°C temperature.

The remaining runs were performed with a ZrS₂ catalyst. A total of 24.64 g(20 ml volume) of

catalyst was put into the reactor. The experimental conditions are given in Table 5. Nitrogen was also used as diluents.

Table 5. TEST MATRIX FOR H₂S THERMAL DECOMPOSITION FOR ZrS₂ CATALYST

Temperature, °C	Pressure, Atm	Flow rate, liter/min	Resident Time (Sec.)
600,700,800,900,1033,1100	1	0.28	5
600,700,800,900,1000,1133	1	0.44	3
600,700,800,900,1000,1120	1	1.08	1

Figure 8. shows H₂S conversion results for these runs. As indicated from these figure, the ZrS₂ catalyst has the lower catalytic activity than WS₂. The maximum H₂S conversion was 31%, which was about 30% lower than the WS₂ catalyst's under the same conditions.

For above all tests, a significant amount of yellow colored solid was found in product condenser which was cooled by ice bath.

A comparison of catalyst activity for these catalyst for feed flow rate from 0.28 to 1.08 L/min are given in Figure 9 to 11. From these figures, it is indicated that the MoS₂ has the highest catalytic activity, especially at 600 to 800°C. The rank of catalytic activity is:

However, at 1000°C and the lowest flow rate, 0.28 L/min(5 second residence time), there appears to be little difference in conversion between MoS₂, WS₂ and the quartz wool run. The conversion reach near equilibrium according to our preliminary calculations. We will report more on equilibrium conversion calculations in future reports.

However, at the higher flow rates, 0.44 and 1.028 L/min, the MoS₂ and the WS₂ catalysts showed significantly higher activity for H₂S conversion than the quartz wool. Quartz wool is used to support the catalyst samples for each run. The ZrS₂ catalyst appears to have an inhibitory effect on H₂S decomposition because H₂S conversion is lower than quartz wool alone at all flow rates studied.

The purpose for studying these catalysts as well as the quartz wool can be explained as follows.

As this project began, a search of the literature found that no catalyst exists for the conversion of $\text{H}_2\text{S} + \text{CH}_4$ to CS_2 and H_2 . The purpose of this project was to build a catalyst by using catalyst development techniques. One particularly effective method for catalyst development is to combine catalytic surfaces that are active for two separate reactions into one catalyst. This technique has been used successfully in developing catalysts for Fischer-Tropsch alcohols synthesis, reforming of hydrocarbons, and the ammoxidation of propylene.

The reaction of H_2S and CH_4 can be broken down into simpler reactions. The study of these simpler reaction provides valuable information that may not be discovered if the entire reaction was studied at first. For example, the reaction may be broken down into the following two reactions:

A catalyst that has high activity for reaction 1 may not have activity for reaction 2 and vice versa. Thus, by studying the separate reactions one may be able to incorporate an active catalyst for reaction 1 with an active catalyst for reaction 2 to obtain a catalyst that is active for the overall reaction. Where studying only the overall reaction might eliminate such catalysts from further consideration.

Reaction 1 is the decomposition of H_2S . Reaction 2 is the reaction of methane and sulfur to form CS_2 . Methane and sulfur are the reactants for the commercial production of CS_2 . However, the main commercial by-product is H_2S , rather than H_2 . The commercial reaction may be written as:

Our purpose for studying the H_2S decomposition reaction is to find catalytic surfaces that are active for reaction 1. Such a catalyst would favor reaction 2 over reaction 3.

Another reason for studying the H_2S decomposition reaction is that in Task 3 we will be studying

the conversion of methane. The objective is to find a surface that converts methane without becoming covered with unreactive carbon. At temperatures above 700°C methane will convert to carbon and hydrogen at equilibrium. Thus, our purpose is to find catalytic surfaces that will either not form carbon or if carbon is formed, the carbon remains reactive and can be converted to CS₂ or other desirable products.

In previous work we found that a stabilized MoS₂ maintained hydrogenation activity without laying down carbon. Chemisorption of hydrocarbons to form surface carbon did not occur. This matches our needs for this project. In addition to not laying down carbon, it is desirable to have catalytic phases that are thermally stable up to 1300°C. These are the criteria for choosing the catalysts in Task 2. Moreover, we wanted to see how a nondescript surface such as quartz wool could perform. Quartz wool was studied as well.

Literature Studies. The search and review of literature related with this project are continuing.

Task 3. Carbon Deposition Studies

This task was inactive this quarter. This task will start up after the unit modifications are complete.

Task 4. Experimental Studies of the Methane Hydrogen Sulfide Reaction

Experimental Studies. The catalyst test unit has been modified to accommodate the flows, temperatures and reactants for this project.

Literature Studies. The search and review of literature related with this project are continuing during this quarter.

Task 5. Experimental Studies of CS₂ to Liquid Hydrocarbons

This task was inactive this quarter.

Task 6. Proof of Concept Testing

This task was inactive this quarter.

Task 7. Environmental Reporting

This task was inactive this quarter.

Task 8. Project Management and Technology Transfer

Dr. Erikson attended DOE higher Alcohols Synthesis Workshop and gave a presentation on alcohols synthesis.

Figure 1. Hydrogen Calibration Results

Figure 2. Nitrogen Calibration Results

Figure 3. H₂S Calibration Results

Figure 4. SCHEMATIC DIAGRAM OF CATALYSIS REACTOR SYSTEM

Figure 5. H₂S CONVERSION FOR CATALYSTS QUARTZ WOOL

Figure 6. H₂S CONVERSION FOR CATALYST MoS₂

Figure 7. H₂S CONVERSION FOR CATALYST WS2

Figure 8. H₂S CONVERSION FOR CATALYST ZrS₂

Figure 9. H₂S CONVERSION FOR CATALYSTS AT FLOW RATE:0.28 L/MIN

Figure 10. H₂S CONVERSION FOR CATALYSTS AT FLOW RATE:0.44L/MIN

Figure 11. H₂S CONVERSION FOR CATALYSTS AT FLOW RATE:1.082 L/MIN

Appendix A.

PROJECT	DE-AC22-93PC92114
CATALYST	QUARTZ WOOLS
DATE	12/09/93
REACTOR	1"

CAT.WT	8.43 G
CAT.VOLUME	14 ML

TIME	1450	1508	1535	1603	1637	1649
TEMP	600	700	800	900	1000	1030
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE (L/MIN)	0.2802	0.2802	0.2802	0.2802	0.2802	0.2802

GC ANALYS						
H2S	14.97	14.61	13.63	9.14	6.76	6.73
N2	1939	1937	1929	1927	1926	1924
H2	0	0	0	66.29	97	100.97

MOLE FRACTION						
H2S	0.01	0.009772	0.00916	0.006144	0.004545	0.004529
N2	0.99	0.990228	0.99084	0.990014	0.989831	0.989612
H2	0	0	0	0.003842	0.005624	0.005859
H2S	1	1	1	1	1	1

CONVERSION						
H2S	0	2.281525	8.401568	38.56346	54.546	54.71068

BALANCE						
H	1	0.975952	0.910488	0.992385	1.01029	1.031153

PROJECT	DE-AC22-93PC92114
CATALYST	QUARTZ WOOLS
DATE	12/09/93
REACTOR	1"

CAT.WT	8.43 G
CAT.VOLUME	14 ML

TIME	1126	1238	1305	1316	1335	1406
TEMP	700	800	900	930	1000	1043
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE (L/MIN)	0.441	0.441	0.441	0.441	0.441	0.441

GC ANALYS						
H2S	13.98	13.2	9.57	8.19	7.26	6.33
N2	1895	1897	1898	1932	1947	1937
H2	0	15.13	65.81	84.85	103.7	108.1

MOLE FRACTION						
H2S	0.010272	0.009686	0.007017	0.005901	0.005189	0.004549
N2	0.989728	0.989475	0.989333	0.989476	0.989205	0.989575
H2	0	0.00084	0.00365	0.004624	0.005606	0.005876
H2S	1	1	1	1	1	1

CONVERSION						
H2S	0	3.142152	29.82512	40.99273	48.11035	54.50682

BALANCE						
H	1	1.026059	1.040581	1.044875	1.08033	1.037611

PROJECT	DE-AC22-93PC92114
CATALYST	QUARTZ WOOLS
DATE	12/10/93
REACTOR	1"

CAT.WT	8.43
CAT.VOLUME	14

TIME	915	1003	1021	1040	1100
TEMP	600	800	900	1000	1060
H2S	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1
FLOW RATE (L/MIN)	1.082	1.082	1.082	1.082	1.082

GC ANALYS					
H2S	14.23	13.38	12.24	10.17	9.04
N2	1923	1909	1901	1893	1918
H2	0	0	17.28	36.72	54.26

MOLE FRACTION					
H2S	0.01	0.009477	0.008704	0.007265	0.006374
N2	0.99	0.990523	0.99035	0.990715	0.990681
H2	0	0	0.000946	0.002019	0.002945
H2S	1	1	1	1	1

CONVERSION					
H2S	0	5.233662	12.95835	27.3462	36.26281

BALANCE					
H	1	0.940267	0.953639	0.913342	0.928824

PROJECT	DE-AC22-93PC92114
CATALYST	MoS2
DATE	12/15/93
REACTOR	1"

CAT.WT	24.7 G
CAT.VOLUME	20 MI.

TIME	1619	1630	1640	1650	1702	956
TEMP	1000	900	800	700	600	25
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE (L/MIN)	0.2802	0.2802	0.2802	0.2802	0.2802	0.2802

GC ANALYS						
H2S	5.76	7.04	10.13	11.96	13.68	13.98
N2	1863	1879	1891	1851	1887	1814
H2	71.08	63.6	48.14	27.88	12.89	0

MOLE FRACTION						
H2S	0.00419	0.005075	0.007247	0.008737	0.009801	0.01042
N2	0.991792	0.991361	0.990077	0.98968	0.989481	0.98958
H2	0.004019	0.003564	0.002677	0.001583	0.000718	0
H2S	1	1	1	1	1	1

CONVERSION						
H2S	58.10336	49.25105	27.53374	12.62874	1.989887	0

BALANCE						
H	0.807222	0.857193	0.992265	1.010521	1.050209	1

PROJECT	DE-AC22-93PC92114
CATALYST	MoS2
DATE	12/15/93
REACTOR	1"

CAT.WT	24.7 G
CAT.VOLUME	20 ML

TIME	1345	1358	1411	1422	1433	956
TEMP	1000	900	800	700	600	25
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE (L/MIN)	0.44	0.44	0.44	0.44	0.44	0.44

GC ANALYS

H2S	5.44	6.77	9.51	11.66	13.67	13.98
N2	1945	1925	1907	1886	1881	1814
H2	86.3	76.95	55.07	32.35	14.75	0

MOLE FRACTION

H2S	0.003896	0.004897	0.006938	0.008597	0.010101	0.010714
N2	0.991299	0.990777	0.98994	0.989548	0.989052	0.989286
H2	0.004805	0.004326	0.003123	0.001854	0.000847	0
H2S	1	1	1	1	1	1

CONVERSION

H2S	61.03621	51.03215	30.62296	14.0252	0	0
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BALANCE

H	0.868955	0.912105	0.986447	1.013915	1.059835	1
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PROJECT	DE-AC22-93PC92114
CATALYST	MoS2
DATE	12/15/93
REACTOR	1"

CAT.WT	24.7 G
CAT.VOLUME	20 ML

TIME	1451	1511	1526	1541	1554	1607
TEMP	600	700	800	900	970	1032
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE (L/MIN)	1.077	1.077	1.077	1.077	1.077	1.077

GC ANALYS

H2S	12.88	11.23	10.34	7.29	6.63	6.1
N2	1849	1837	1885	1846	1844	1861
H2	14.75	28.3	34.82	64.86	75.8	79.48

MOLE FRACTION

H2S	0.010184	0.008942	0.008028	0.005783	0.005264	0.004801
N2	0.988981	0.989445	0.990036	0.990533	0.990426	0.99072
H2	0.000835	0.001614	0.001936	0.003684	0.00431	0.004479
TOTAL	1	1	1	1	1	1

CONVERSION

H2S	0	10.58253	19.7176	42.17374	47.3577	51.99409
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BALANCE

H	1.08201	1.029242	0.996394	0.926615	0.9362	0.915511
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PROJECT DE-AC22-93PC92114
 CATALYST WS2
 DATE 1/10/94
 REACTOR 1"

CAT.WT 28.6 G
 CAT.VOLUME 20 ML

TIME	1035	1056	1114	1131	1149	1224
TEMP	600	700	800	900	1000	1131
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE	0.2802	0.2802	0.2802	0.2802	0.2802	0.2802

GC ANALYS						
H2S	14.34	13.59	11.65	9.3	7.19	5.5
N2	1941	1939	1953	1957	1955	1958
H2	10.63	17.14	44.02	69.83	91.36	116.52

MOLE FRACTION						
H2S	0.010081	0.009565	0.00814	0.006486	0.005021	0.003834
N2	0.989324	0.989473	0.989408	0.989631	0.989892	0.989689
H2	0.000596	0.000962	0.002452	0.003883	0.005087	0.006476
TOTAL	1	1	1	1	1	1

CONVERSION						
H2S	0	4.352389	18.59946	35.13751	49.78907	61.65778

BALANCE						
H	1.059103	1.042997	1.057164	1.03679	1.009356	1.031394

PROJECT	DE-AC22-93PC92114
CATALYST	WS2
DATE	1/10/94
REACTOR	1"

CAT.WT	28.6 G
CAT.VOLUME	20 ML

TIME	1254	1308	1327	1347	1400
TEMP	1100	1000	800	700	600
H2S	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1
FLOW RATE (L/MIN)	0.441	0.441	0.441	0.441	0.441

GC ANALYS

H2S	5.66	8.04	12.2	14.01	14.65
N2	1962	1946	1946	1950	1934
H2	79.93	58.74	40.7	16.69	0

MOLE FRACTION

H2S	0.00387	0.00554	0.00839	0.009617	0.010143
N2	0.991678	0.991164	0.98933	0.98945	0.989857
H2	0.004452	0.003297	0.00228	0.000933	0
H2S	1	1	1	1	1

CONVERSION

H2S	61.29969	44.60319	16.09571	3.833536	0
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BALANCE

H	0.830759	0.8754	1.059057	1.04911	1
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PROJECT	DE-AC22-93PC92114
CATALYST	WS2
DATE	1/10/94
REACTOR	1"

CAT.WT	28.6 G
CAT.VOLUME	20 ML

TIME	1415	1432	1449	1504	1526	1545
TEMP	600	700	800	850	1000	1050
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776

GC ANALYS						
H2S	14.61	13.83	12.22	11.31	10.1	9.45
N2	1954	1967	1961	1950	1944	1960
H2	0	24.18	31.26	32.97	63.11	70.52

MOLE FRACTION						
H2S	0.010066	0.009458	0.008389	0.007811	0.006991	0.006489
N2	0.989934	0.989198	0.989868	0.990339	0.98946	0.989578
H2	0	0.001343	0.001743	0.00185	0.003548	0.003933
TOTAL	1	1	1	1	1	1

CONVERSION						
H2S	0	5.415472	16.11391	21.88566	30.08948	35.11492

BALANCE						
H	1	1.081053	1.010219	0.957441	1.042199	1.038908

PROJECT DE-AC22-93PC92114
 CATALYST ZrS2
 DATE 1/14/94
 REACTOR 1"

CAT.WT 24.64 G
 CAT.VOLUME 20 ML

TIME	957	1013	1028	1044	1104	1117
TEMP	600	700	800	900	1033	1100
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
Flow rate(L/min)	0.2802	0.2802	0.2802	0.2802	0.2802	0.2802

GC ANALYS						
H2S	17.07	15.76	14.98	13.96	13.23	11.57
N2	1924	1914	1913	1937	1963	1947
H2	0	10.65	11	30.99	40.17	49.87

MOLE FRACTION						
H2S	0.010201	0.009468	0.009008	0.008288	0.007751	0.006836
N2	0.989799	0.989925	0.990364	0.989966	0.990016	0.990367
H2	0	0.000607	0.000628	0.001746	0.002233	0.002797
TOTAL	1	1	1	1	1	1

CONVERSION						
H2S	0	5.317885	9.916922	17.12419	22.49436	31.63792

BALANCE						
H	1	0.982471	0.938723	0.990113	0.998389	0.955075

PROJECT DE-AC22-93PC92114
 CATALYST ZrS2
 DATE 1/14/94
 REACTOR 1"

CAT.WT 24.64 G
 CAT.VOLUME 20 ML

TIME	1436	1514	1534	1606	1647	1700
TEMP	600	700	800	900	1000	1133
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE (L/min)	0.441	0.441	0.441	0.441	0.441	0.441

GC ANALYS

H2S	15.6	15.15	14.5	12.66	11.89	10.77
N2	1912	1943	1915	1951	1934	1922
H2	15.95	19.97	24.17	44.94	47.24	54.35

MOLE FRACTION

H2S	0.010193	0.009743	0.009462	0.00811	0.007686	0.007007
N2	0.988903	0.989143	0.98917	0.989392	0.989665	0.989925
H2	0.000904	0.001114	0.001368	0.002497	0.002649	0.003067
TOTAL	1	1	1	1	1	1

CONVERSION

H2S	0	2.569175	5.3833	18.89596	23.1381	29.92514
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BALANCE

H	1.088682	1.082187	1.063872	1.061405	1.024834	0.992571
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PROJECT DE-AC22-93PC92114
 CATALYST ZTS2
 DATE 1/14/94
 REACTOR 1"

CAT.WT 24.64 G
 CAT.VOLUME 20 ML

TIME	1130	1145	1323	1335	1348	14.18
TEMP	1120	1000	900	800	700	600
H2S	0.01	0.01	0.01	0.01	0.01	0.01
N2	0.99	0.99	0.99	0.99	0.99	0.99
PRESSURE(ATM)	1	1	1	1	1	1
FLOW RATE(L/min)	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776

GC ANALYS						
H2S	10.74	11.28	11.66	13.27	14.16	14.29
N2	1932	1951	1935	1940	1933	1928
H2	52.13	50.85	45.98	39.97	37.54	22.34

MOLE FRACTION						
H2S	0.007586	0.007888	0.00822	0.009324	0.00998	0.010105
N2	0.989489	0.989287	0.989204	0.988444	0.987918	0.988639
H2	0.002925	0.002825	0.002576	0.002231	0.002102	0.001255
TOTAL	1	1	1	1	1	1

CONVERSION						
H2S	24.14261	21.12054	17.79593	6.758065	0.197383	0

BALANCE						
H	1.041417	1.072089	1.071604	1.150855	1.199625	1.12421

DATE

FILMED

5 / 31 / 94

END