GAS SWEETENING; DETERMINATION OF EQUILIBRIUM DISTRIBUTION COEFFICIENTS FOR HYDROGEN SULFIDE, CARBON DIOXIDE AND METHANE IN METHANOL

By

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PREFACE

Equilibrium distribution coefficients for hydrogen sulfide, carbon dioxide and methane in methanol were determined for a pressure range of 100 psi - 1000 psi and room temperature. An equilibrium cell was used and vapor molar fractions were determined by gas chromatograph.

I am truly grateful to Dr. R. N. Maddox for serving as my adviser and for his guidance and concern. I would like to thank Mr. Ali Maadah for his valued help, and Mr. E. E. McCroskey for his help in procuring equipment. My thanks to all the faculty, staff and students of the School of Chemical Engineering at Oklahoma State University who extended their help during the course of this work.

Finally, with love and appreciation, I thank my wife Mary. Her constant support and encouragement helped me through the moments of hardship.

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NOMENCLATURE

K - equilibrium distribution coefficient

mV - milli volt

n - number of moles, lb mole

P - pressure, psia

P_c - critical pressure, psia

P_{pc} - Pseudo critical pressure, psia

R - ideal gas constant, $\frac{(\text{psia ft}^3)}{(\text{lb mole R}^o)}$

T - temperature, R^o

T_c - critical temperature, R^o

T_{pc} - Pseudo critical temperature, R^o

y - vapor molar fraction

x - liquid molar fraction

Z - compressibility factor

Greek Letters

ε - Pseudo critical temperature adjustment factor, R^o

CHAPTER I

INTRODUCTION

Gas sweetening means the removal of hydrogen sulfide and carbon dioxide from natural gas. The need to remove this from natural gas is due to health and safety considerations plus the desire to reduce corrosion in natural gas pipelines. The gas usually contains CO_2 (carbon dioxide) and water vapor. The removal of CO_2 from the gas is important due to the fact it is an acid gas (1).

Natural gas was simulated in this experiment by mixing methane, CO_2, and H_2S in specified proportions. Solvent was introduced and the mixture was allowed to reach equilibrium. The equilibrium composition of the vapor and liquid phases was determined by measuring the concentration of the components in the gas phase using gas chromotography.

The equilibrium distribution coefficient for H_2S, CO_2 and methane in the solvent (methanol) was then determined at room temperature and different total pressure.

CHAPTER II

LITERATURE SURVEY

The gas and petroleum industry has given importance to the means of estimating the composition of coexisting phases in heterogeneous systems. The work of Katz and Hachmuth (2) was one of the early works to experimentally determine the equilibrium constant developed by Souders, Selheimer and Brown (8). Katz and Hachmuth investigated a naturally occurring mixture, crude oil - natural gas. Their investigation was carried out at pressures ranging from atmospheric to above 3000 pounds per square inch, and at temperatures ranging from 40^{o} to 200^{o}F. Equilibrium was obtained in an equilibrium bomb, and samples of the liquid and vapor phases were obtained and analyzed in fractionating columns.

Sage and Reamer (3) presented a discussion of the minimum experimental data required for the establishment of the phase behavior. They divided the data required into two categories; the first is the direct measurement of the composition of the coexisting phases, while the second requires sufficient data to permit an evaluation of chemical potential and enthalpy so as to permit the calculation of the composition. In discussing the first category they stated that the principle involves only bringing together the requisite components at the desired state, determining the prevailing pressure and, temperature and measuring the composition of each of the phases.

Muhlbauer and Monaghan (4) determined equilibrium data for CO_2 and H_2S in methanolamine solution. They established equilibrium by bubbling the gas through a bath of the solution and collecting it in gas sampling bombs. Liquid samples were taken and analyzed by chemical methods. Gas samples were analyzed using a mass spectrometer.

CHAPTER III

EQUIPMENT

The equipment used consisted of two main components; an experimental apparatus (Figure 1) consisting of an equilibrium cell with gas and solvent feed lines in which known amounts of components were mixed, and a gas chromotograph which was used to obtain mole fractions compositions of the gas phase.

Experimental Apparatus

The major components of the experimental apparatus are the following:

1. Equilibrium cell
2. Pressure transducer system
3. Gas feed system
4. Liquid feed system
5. Auxiliary equipment

Equilibrium Cell

The equilibrium cell (MGM, Bartlesville, OK) is made of stainless steel and has a 1000 ml volume. The volume was calibrated by displacement of liquid at constant temperature.

The cell has a fluid driven magnetic stirrer, a connection for a pressure transducer, a connection for a gas/solvent feed line, and a

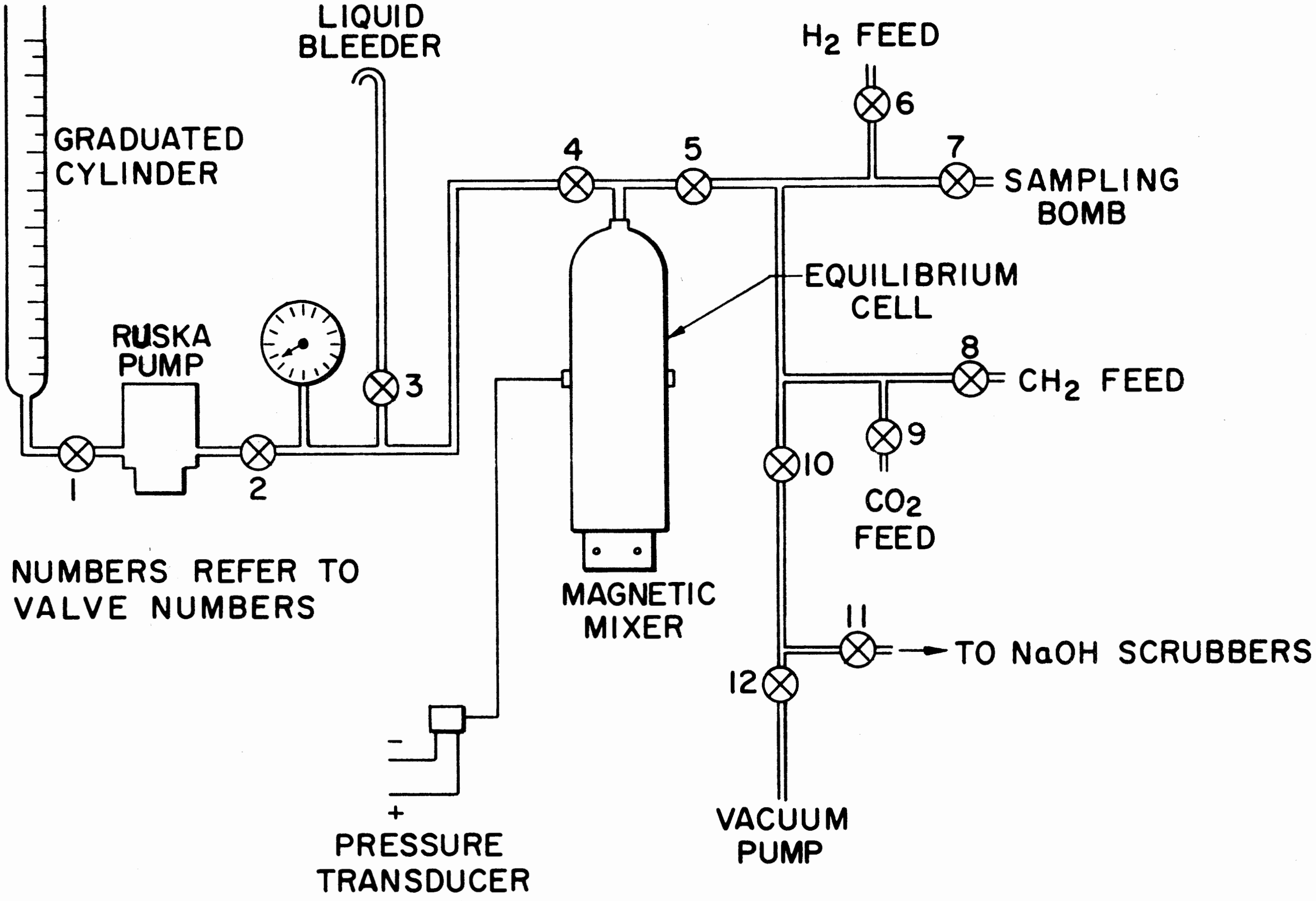

Figure 1. Experimental Apparatus

solvent drainage line. All connections and lines are stainless steel and 1/8 inch O.D.

Pressure Transducer System

The pressure transducer system consists of:

1. Pressure transducer (Bell and Howell Type 4-317-0001)
2. A potentiometer (Leeds and Northrup Co. CAT. NO. 8690)
3. A regulated supply source (Dressen-Barnes Model 22-115A)

Gas Feed System

The gas feed system consists of three gas cylinders that supply H_2S, CO_2, and CH_4. Each cylinder is fitted with a regulator valve and has a 1/8 inch valve leading to the gas feed system. The system is connected to a vacuum pump (Welch Duo-Seal, 1/3 horsepower).

Liquid Feed System

The liquid feed system consists of a displacement pump connected on one side to a graduated cylinder (Kimax 500 ml), and to the equilibrium cell on the other. A liquid bleed line is connected between the pump and the cell in order to allow for careful bleeding of the lines.

Auxiliary Equipment:

1. Sample bomb (MGM Bartlesville, OK)
2. Flasks for the sodium hydroxide scrubber
3. Balance (Mettler Instrument Company)
4. Valves and fittings (autoclave)

Gas Chromatograph

Two different types of gas chromatographic equipment were used, one to obtain the CO_2, CH_4 mole fraction in the gas phase, the other to obtain the H_2S, CH_4 mole fraction. For the latter, samples were taken to the Chemistry Department and were analyzed by using a n-octanol/poracite column.

For the CO_2 analysis, a Tractor MT-150 gas chromotograph was used with an ultrasonic detector. The column used was 1 ft. 6 inches 1/4 in. O.D. stainless steel packed with grade 950 60-100 mesh silica gel.

CHAPTER IV

EXPERIMENTAL PROCEDURE

Pressure Transducer Calibration

The calibration of the pressure transducer was carried out using a Ruska Model 2400 HL Deadweight Pressure System. Potentiometer readings were obtained at known weights. During experimental work the transducer went out of calibration. It was recalibrated. The calibration curves and data are presented in Appendix A.

Gas Chromatograph Calibration

Since two gas chromatographs were used in this experiment, two calibration curves were obtained by different procedures. The first calibration was done for the CO_2/CH_4 system. Mixtures with known mole fractions were analyzed using a Tracor MT 150 Gas Chromatograph. several samples were taken and the peaks cut and weighed. A ratio of CO_2 peaks weight to total peaks weight was obtained. The results of the average ratio are shown in Appendix A.

For the H_2S calibration, known samples were taken to the Department of Chemistry at Oklahoma State University for analysis. The heights of the peaks obtained were measured.

A ratio of the length times the attenuation for the H_2S peaks over the total sum was obtained. These results and the rough data are in Appendix A.

Operating Procedure for Experimental Apparatus

Instructions for operating the apparatus:

1. Select the total pressure desired and the composition of the gases. Determine the partial pressure of the components.
2. Check the potentiometer reading for atmospheric pressure.
3. Evacuate the cell and the gas feed lines.
4. Introduce the gas for which the determination is being made (CO_2 or H_2S) until the required partial pressure is achieved.
5. Introduce methane until the required total pressure is achieved.
6. Wait 2 minutes and check the total pressure. Repeat until consistent values are obtained.
7. Add the required solvent to the gas mixture in the cell and start the stirrer. For best results allow 24 hrs. for equilibrium.
8. Evacuate the sample bomb and take a sample of the vapor phase for analysis.
9. Vent the remaining gas through the scrubber system.
10. Detach the equilibrium cell and pour the liquid into a graduated cylinder. It should be about the same as the amount introduced.
11. Attach the equilibrium cell again. Check for leaks, and repeat 1 through 10.

All results obtained are in Appendix B. A sample calculation for the K value of H_2S in methanol is shown in Appendix C.

CHAPTER V

EXPERIMENTAL RESULTS AND DISCUSSION

The equilibrium distribution coefficients were determined for carbon dioxide, hydrogen sulfide and methane with methanol as solvent. Since there is no data available for these values, the degree of accuracy is hard to measure. The following assumptions were made in obtaining the results:

1. The solvent introduced is 100 ml. This assumption is reasonable since the displacement pump is connected to a graduated cylinder and the difference of the liquid height was taken as the amount introduced. The line was bled repeatedly before introducing the liquid into the cell so as to insure that 100 ml of solvent were introduced into the cell.
2. The amount of liquid at equilibrium in the cell is 100 ml.

This is a harder assumption to prove. Two factors are involved:

1. The increase of volume due to the solute
2. The decrease of volume due to pressure.

With regard to the first factor, the volume of the solution was measured carefully in a graduated cylinder and was 100 ml $\mp$ 1.0 in each run.

With regard to the second factor, the compressibility of methanol is so very small (6) that the assumption of methanol as an incompressible fluid seems valid.

3. For the calculation of the K-values for H_2S and CO_2 an assumption was made that no CH_4 dissolved in the methanol. Lannung and Gjaldbaek (9) reported the mole fraction methane in methanol to be $8.71x10^{-4}$ at atmospheric pressure. The K-value of methane in methanol at 904.7 psia was 65.79 while for CO_2 and H_2S the K-values were 0.36 and 0.21 respectively. Clearly, when methane is present with H_2S and CO_2 it can be safely assumed that methane is insoluble for the purpose of calculating the K-values for H_2S and CO_2.

4. The final assumption made is that when a sample is drawn from the equilibrium cell into the sample bomb the equilibrium concentration in the vapor phase is the same as at equilibrium.

The whole operation is almost instantaneous and thus the equilibrium concentration in the sample tends to be the same as at equilibrium.

The K-values obtained were plotted as functions of total pressure on log-log scale (Figures 2, 3, and 4). As expected, K-values decrease as pressure increases.

The value for K_{CO_2} at 575.7 psia was obtained as a check point after the curve was drawn. It is very close to the values predicted by the curve.

In the case of H_2S, the value at 1021.7 was obtained as a check point. Its deviation can be due to the fact that in the calibration of the gas chromatograph the results y_{H_2S} = 0.1302 (taken at 920 psia) were inconsistent.

TABLE I

EQUILIBRIUM DISTRIBUTION COEFFICIENTS (K) FOR CO_2 IN METHANOL

Total Pressure Psia	K	$K_{average}$
120.7	15 17.74	16.37
420.7	1.717 1.243	1.48
575.7*	.423	.423
974.7	.27 .38	.325

* Indicates a check point.

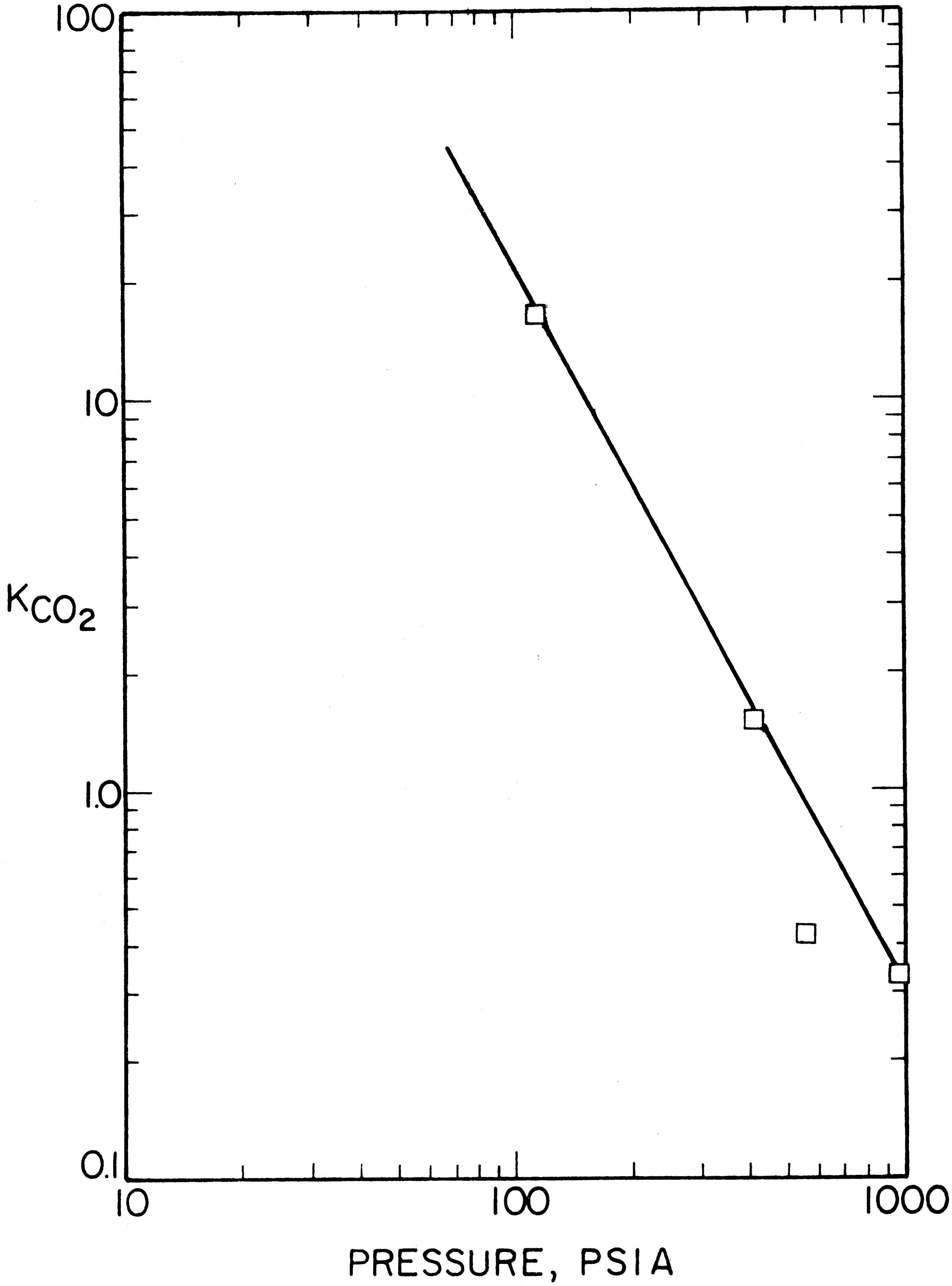

Figure 2. Equilibrium Distribution Coefficient (K) for Carbon Dioxide in Methanol

TABLE II

EQUILIBRIUM DISTRIBUTION COEFFICIENTS (K) FOR H_2S IN METHANOL

Total Pressure Psia	K	$K_{Average}$
114.7	5.95 9.30	7.625
514.7	.27 .59	.43
724.7	.2536	.2536
1021.7*	.36	.36

* Indicates a check point.

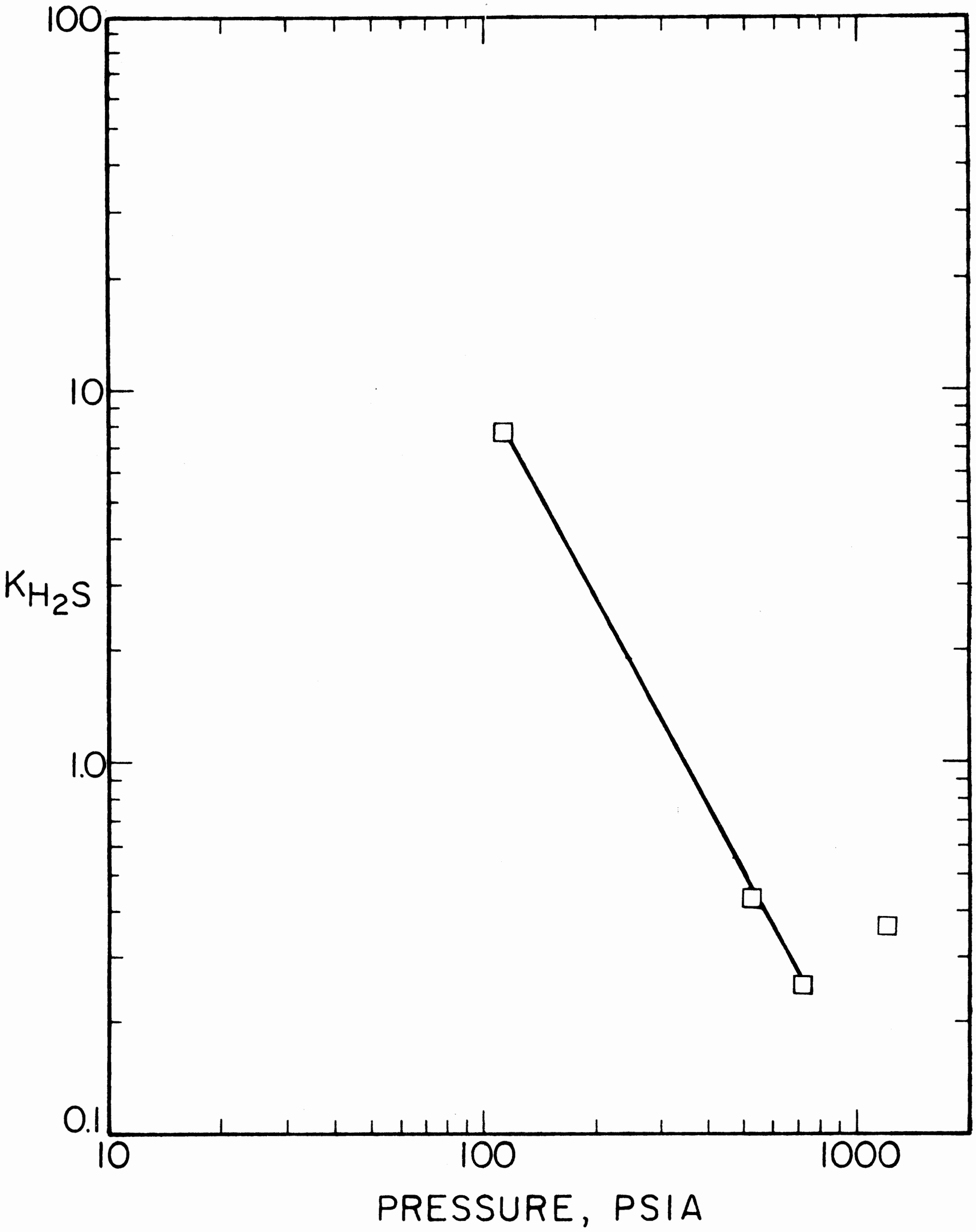

Figure 3. Equilibrium Distribution Coefficient (K) for Hydrogen Sulfide in Methanol

TABLE III

EQUILIBRIUM DISTRIBUTION COEFFICIENTS (K) FOR CH_4 IN METHANOL

Total Pressure Psia	K	$K_{Average}$
114.7	352.11	352.11
514.7	78.125	78.125
904.7	65.79	65.79

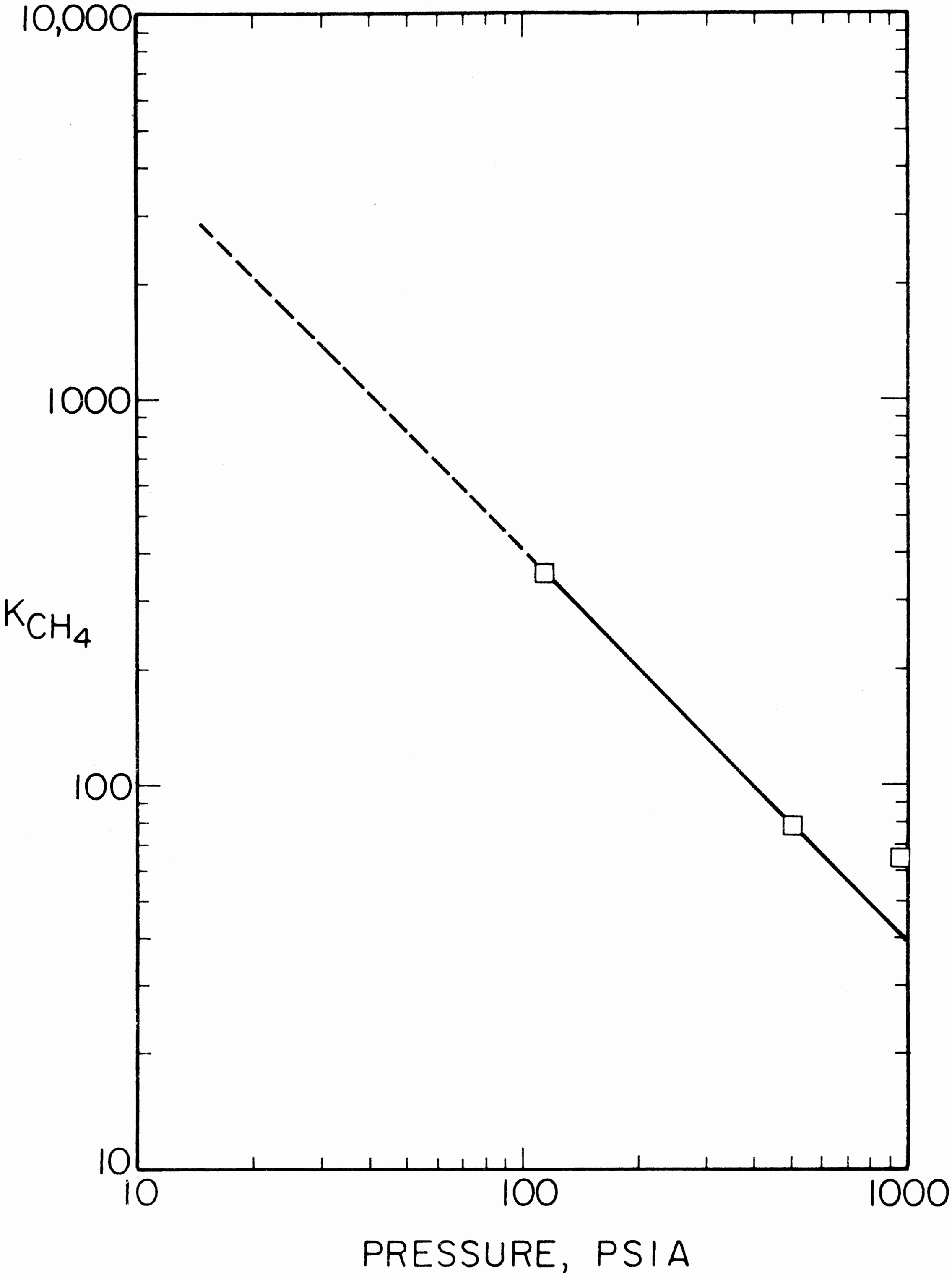

Figure 4. Equilibrium Distribution Coefficient (K) for Methane in Methanol

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

1. This experimental procedure seems to work for obtaining K-values. The results obtained, taking into account the assumptions made, are reasonably consistent.
2. Methanol is a more effective solvent for H_2S at low pressure than for CO_2.
3. Methanol is an effective solvent for both at high pressure ($\approx$ 1000 psia).
4. In order to substantiate these results the experiment has to be repeated using the same procedure and equipment.
5. The following are some recommendations for the improvement of the experiment:
   a. Liquid phase samples should be analyzed and either used as check points for the calculations or used directly in obtaining K-values.
   b. The gas chromatograph used for the carbon dioxide K-values is too sensitive for H_2S analysis. It should not be used. A flame type detector seems to work better, as in the case of H_2S analysis.

c. Calibration should be done on basis of mole fraction plus total pressure. For example a calibration at $y = 0.05$ should be done at 100, 500, 1000 psia total pressure, to ascertain the accuracy of the calibration curves.

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APPENDIX A

CALIBRATION DATA

TABLE IV

CALIBRATION DATA FOR PRESSURE TRANSDUCER*

Pressure (Psig)	Potentiometer Reading mV			
	1	2	3	4
106	-.980	-.99	-1.00	-1.00
206	-.100	-.100	- .100	
306	.780	.780	.780	.780
406	1.68	1.7	1.72	
506	2.6	2.62	2.61	2.58
606	3.54	3.52	3.52	
706	4.38	4.4	4.42	4.38
806	5.30	5.3	5.3	
906	6.18	6.16	6.18	6.2
1006	7.06	7.06	7.06	

* Calibration (1)

TABLE V

PRESSURE TRANSDUCER CALIBRATION*

Pressure Psig	Reading mv
106	- 1.0
206	- 0.1
306	+ 0.78
406	1.70
506	2.61
606	3.52
706	4.40
806	5.30
906	6.18
1006	7.06

* Calibration (1)

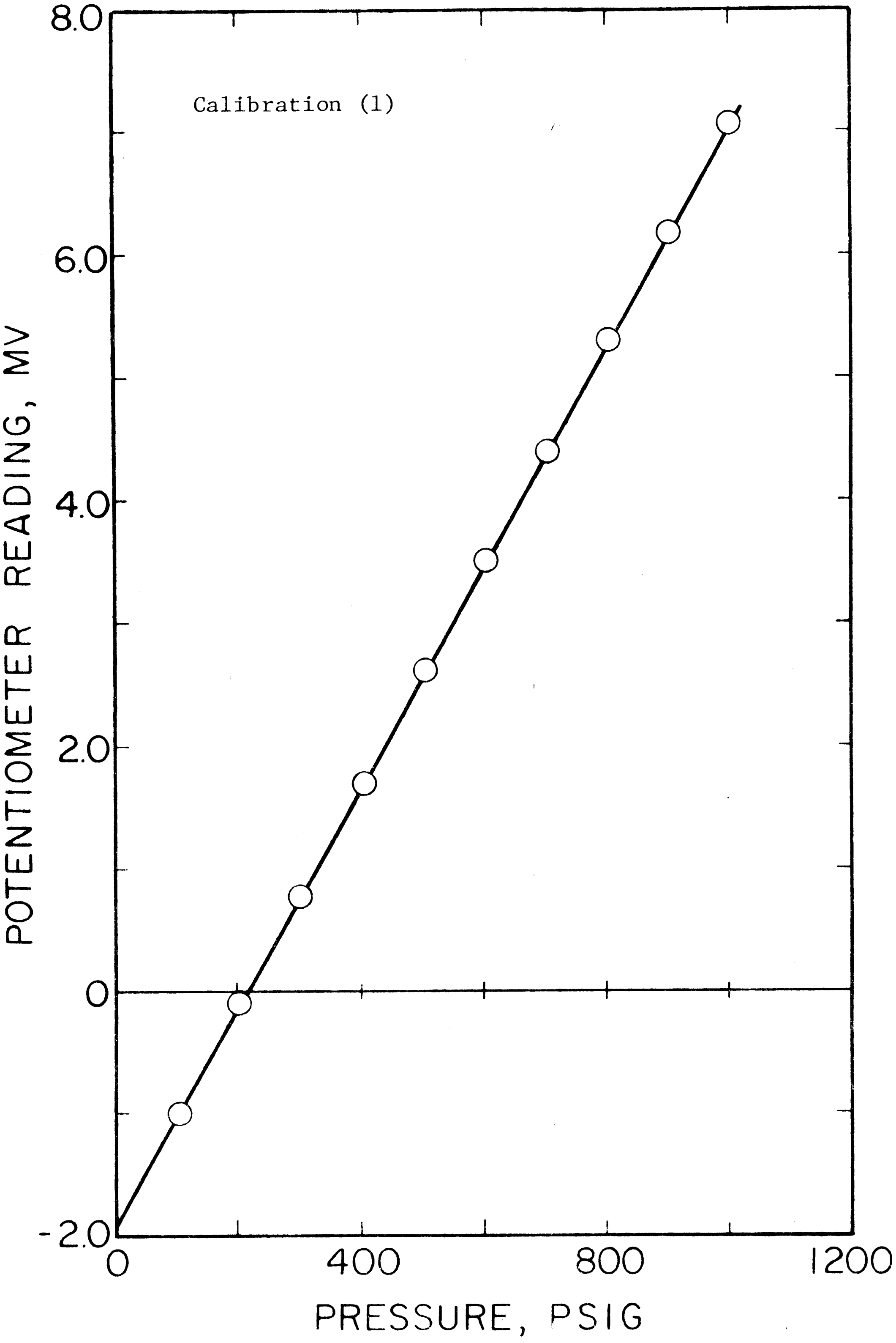

Figure 5. Pressure Transducer Calibration

TABLE VI

CALIBRATION DATA FOR PRESSURE TRANSDUCER*

Pressure (Psig)	Potentiometer Reading mV		
	1	2	3
106	-1.68	-1.66	-1.68
206	- .73	- .74	- .75
306	.15	.16	.14
406	1.02	1.04	1.03
506	1.92	1.92	1.92
606	2.815	2.82	2.82
706	3.7	3.7	3.7
806	4.6	4.6	4.61
906	5.5	5.5	5.5
1006	6.4	6.4	6.4

* Calibration (2)

TABLE VII

PRESSURE TRANSDUCER CALIBRATION*

Pressure Psi	Reading mv
106	- 1.67
206	- .74
306	+ .15
406	1.03
506	1.92
606	2.82
706	3.7
806	4.6
906	5.5
1006	6.4

* Calibration (2)

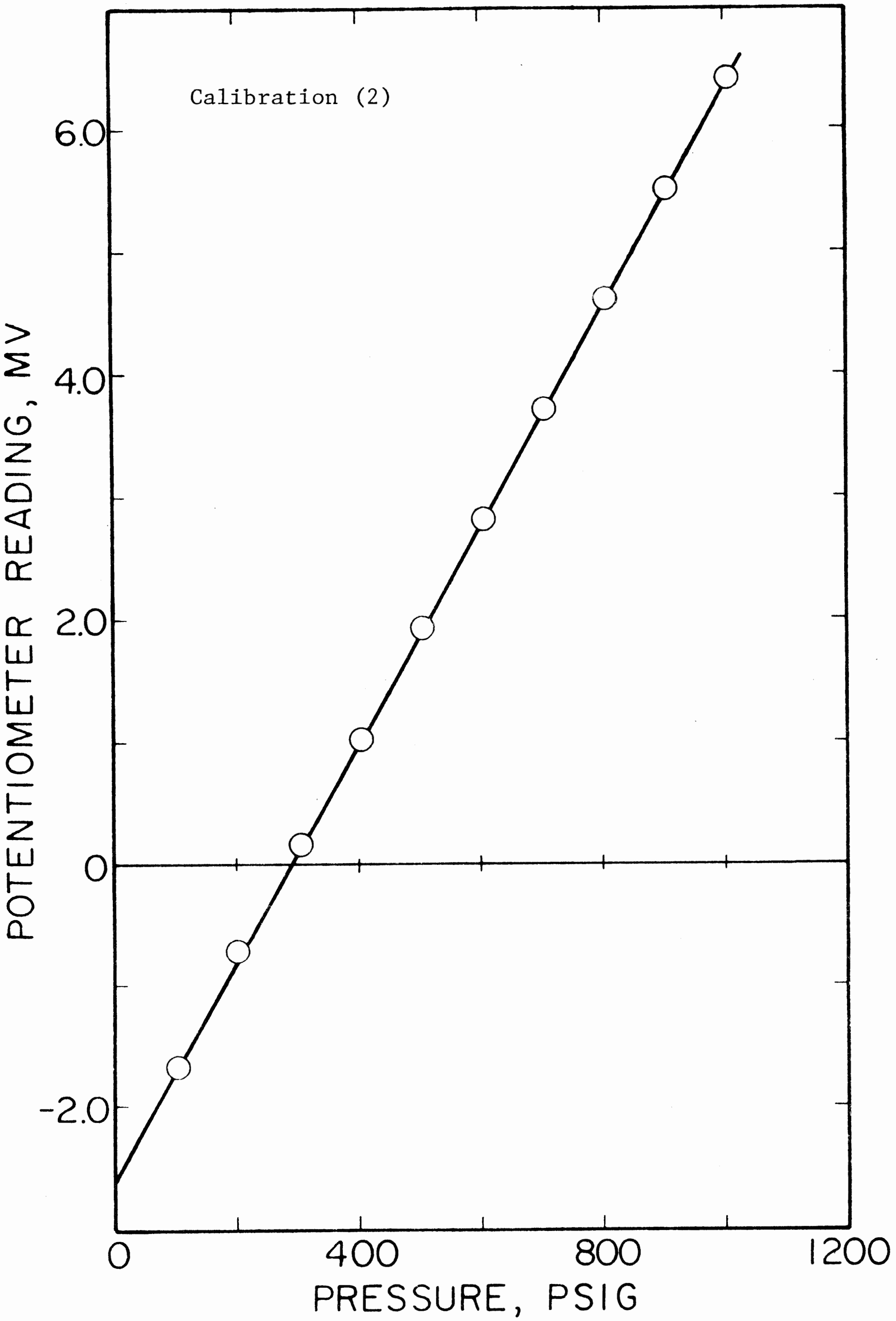

Figure 6. Pressure Transducer Calibration

TABLE VIII

CALIBRATION DATA FOR GAS CHROMATOGRAPH FOR CO_2 KNOWN LOADING

Run No.	CO_2 Loading mV	Total Loading mV	Transducer Calibration
5	-1.15	.28	1
6	-1.56	1.36	1
7	-1.5	3.10	1
8	-1.16	2.17	1
9	-1.63	.9	1
10	-1.6	1.08	1
11	-1.56	+1.36	1

TABLE IX

GAS CHROMATOGRAPH CALIBRATION DATA FOR CO_2

Run No.	Weight of Peak gm				
	CO_2	CH_4	Total	CO_2/Total	Avg.
5	.380	.2134	.5934	.640	
	.4063	.1815	.5878	.691	
	.3728	.210	.5828	.640	
	.3695	.2074	.5769	.630	
	.3765	.1820	.5585	.674	
	.3248	.206	.5308	.612	.648
6	.1555	.2400	.3955	.393	
	.146	.2744	.4204	.347	
	.145	.2446	.3896	.372	
	.121	.2730	.394	.3071	
	.1432	.2477	.3909	.366	
	.1365	.2420	.3785	.3606	.358
7	.0661	.2158	.2819	.2345	
	.0607	.2618	.3225	.2559	
	.074	.2725	.3465	.2136	
	.0782	.243	.3212	.2435	
	.0633	.2636	.3269	.1936	
	.0715	.277	.3485	.2052	.2244
8	.1539	.1927	.3466	.444	
	.122	.19	.312	.391	
	.1565	.2227	.3792	.421	
	.1605	.233	.3935	.4078	
	.132	.206	.338	.3609	.4031
9	.1295	.2007	.3302	.392	
	.128	.2295	.3575	.358	
	.1295	.2296	.3591	.2606	
	.128	.2135	.3415	.3748	
	.095	.189	.284	.3345	
	.1159	.186	.3019	.3839	
	.109	.217	.326	.334	.3626
10	.1157	.2056	.3213	.36	
	.0943	.230	.3243	.29	
	.0894	.2125	.3019	.296	
	.0835	.2400	.3235	.258	
	.0835	.2129	.2964	.281	
	.0918	.98	.296	.33	.3025
11	.0613	.15045	.21175	.2895	
	.0632	.15745	.22065	.2864	
	.06595	.15965	.22560	.2923	.2894

TABLE X

CALIBRATION DATA FOR GAS CHROMATOGRAPH FOR H_2S KNOWN LOADING

Run No.	Sample Bottle No.	H_2S Loading mV	Total Loading mV	Transducer Calibration
1	11 6	-2.0	2.8	2
2	7 8	-2.1	5.56	2
3	9 10	-2.35	3.0	2
4	13 14	-2.4	3.0	2

TABLE XI

GAS CHROMATOGRAPH CALIBRATION DATA FOR CO_2

Mole Fraction CO_2	$\frac{CO_2 \text{ Peak Area}}{\text{Total Peak Area}}$
.40	.648
.142	.358
.103	.2244
.21	.4031
.146	.3626
.146	.3025
.142	.2894

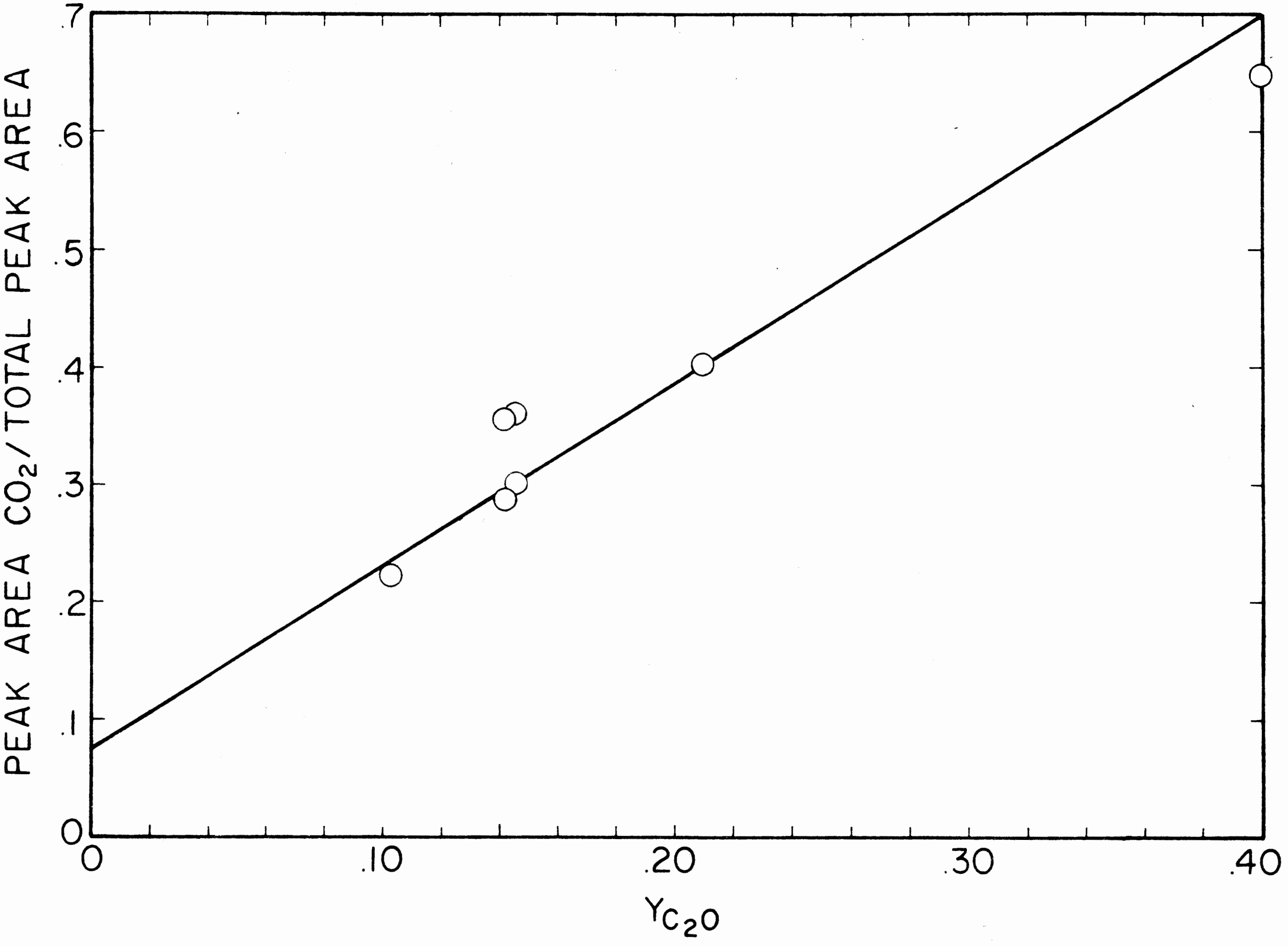

Figure 7. Gas Chromatograph Calibration for CO_2

TABLE XII

CALIBRATION DATA FOR GAS CHROMATOGRAPH ANALYSIS FOR H_2S

Run No.	Average	Sample Bottle No.	Length of H_2S Peak	Attenuation	L x Att.	Length of Peak cm	Attenuation	L x Att.	$\frac{(L \times A)_{H_2S}}{\text{Total}}$
1	.03455	11	17.7	16	283.2	10.55	512	5401.6	.04982
			16.7	16	267.2	10.5	512	5376.0	.04734
		6	8	16	128	10.4	512	5324.8	.02347
			6.4	8	51.2	5.6	512	2867.2	.01754
2	.016665	7	3.25	32	104	10.5	512	5376	.01898
			3.0	32	96	10.5	512	5376	.01754
		8	5.3	16	84.8	10.75	512	5504	.01517
			10.3	8	82.4	10.6	512	5427.2	.01496
3	.02231	9	7.55	16	120.8	10.5	512	5376	.02198
			6.9	16	110.4	10.3	512	5273.6	.02051
		10	8.1	16	129.6	10.5	512	5376	.02354
			7.5	16	120.0	11.3	512	5785.6	.2032

TABLE XII (Continued)

Run No.	Average	Sample Bottle No.	Length of H_2S Peak	Attenuation	L x Att.	Length of Peak cm	Attenuation	L x Att.	$\frac{(L \times A)_{H_2S}}{\text{Total}}$
4	.01552	13	11.7	8	93.6	10.55	512	5401.6	.0170
			9.8	8	78.4	10.55	512	5401.6	.0143
		14	11.1	8	88.8	10.5	512	5376	.0762
			10.1	8	80.8	10.5	512	5376	.0148

TABLE XIII

GAS CHROMATOGRAPH CALIBRATION DATA FOR H_2S

Mole Fraction H_2S	$\frac{\text{Area of } H_2S \text{ Peak}}{\text{Total Area}}$	Average
.1302	0.04858 0.0205	.03455
.08	.01826 .01507	.016715
.0707	.02125 .02199	.02162
.0544	.01565 .0155	.15575

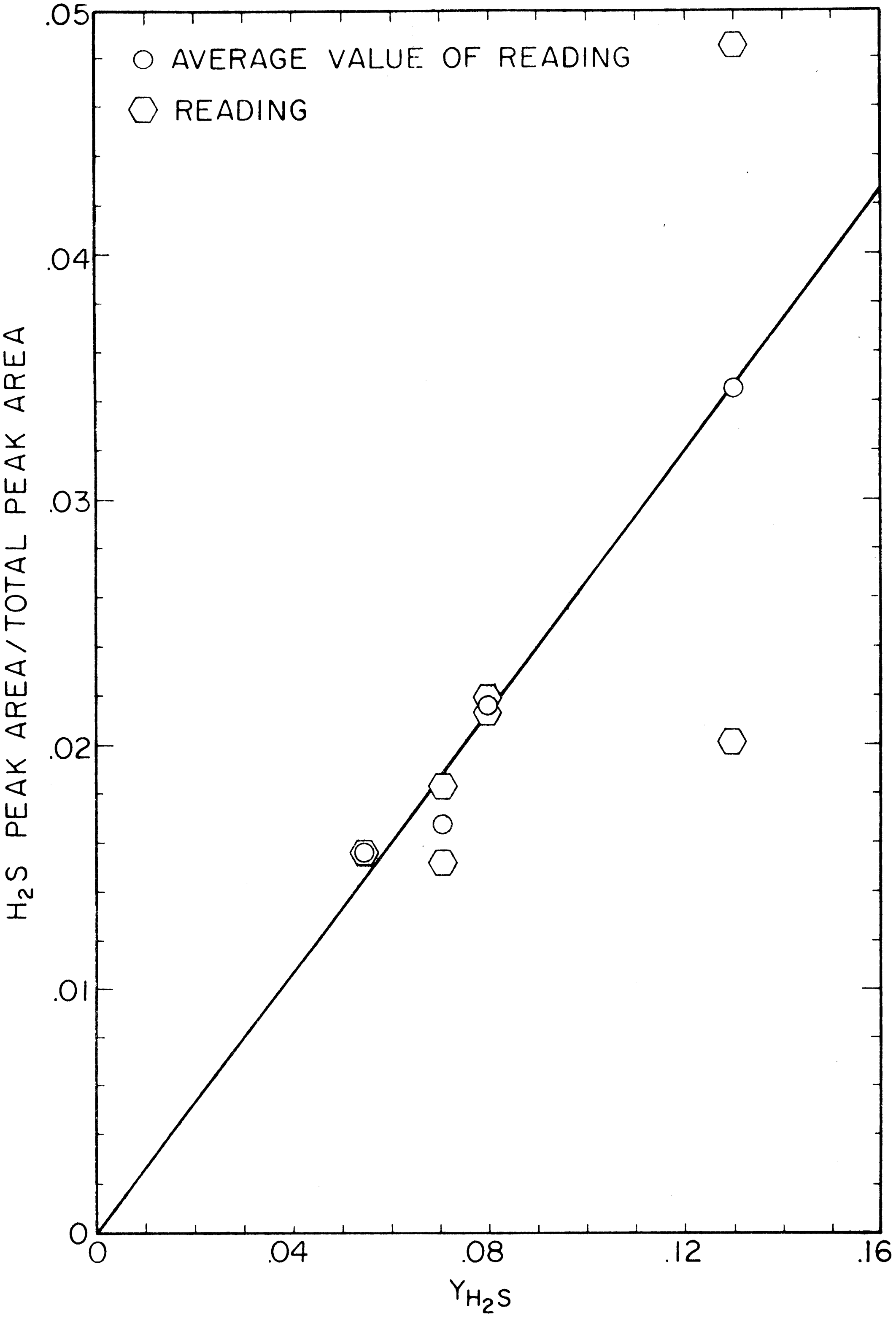

Figure 8. Gas Chromatograph Calibration for H_2S

APPENDIX B

EXPERIMENTAL DATA

TABLE XIV

LOADING FOR CO_2 EQUILIBRIUM DISTRIBUTION COEFFICIENT

Run No.	CO_2 Loading mV	Total Loading mV	Liquid Level, ml Initial	Liquid Level, ml Final	Transducer Calibration
14	-1.135	+6.76	201	301	1
15	-1.135	+6.76	302	402	1
16	-1.6	+1.7	301	401	1
17	-1.6	+1.7	200	300	1
18	-1.9	-1.00	352	452	1
19	- .19	-1.00	395	495	1
20	- .19	-1.00	300	400	1
21	-2.13	+2.381	250	350	2

TABLE XV

GAS CHROMATOGRAPH ANALYSIS DATA FOR CO_2-CH_4 IN METHANOL

Run No.	CO_2 Peak Area Weight gm	CH_4 Peak Area Weight gm	Total Weight gm	CO_2 Peak Area Weight / Total Weight	Avg.
14	.02323	.15755	.18078	.1285	
	.02030	.17370	.19400	.1046	
	.02045	.17252	.19297	.1060	
	.01575	.17590	.19165	.0822	.1130
15	.02565	.17016	.19581	.131	
	.02565	.17145	.19710	.130	
	.02375	.17610	.19985	.1188	
	.02245	.17175	.19420	.1156	.1239
16	.03163	.1489	.18053	.1752	
	.02905	.14625	.17530	.1663	
	.02668	.14164	.16832	.15850	
	.03055	.14365	.17420	.1754	.1689
17	.02795	.15766	.18561	.1506	
	.02700	.16835	.18535	.1457	
	.02535	.14590	.17125	.1480	.1481
19	.05077	.1441	.19487	.2605	
	.04965	.15115	.2008	.2473	
	.05010	.11874	.16884	.2967	.2682
20	.05500	.14565	.20065	.2727	
	.05564	.14185	.19749	.2832	
	.05800	.15282	.21082	.2715	.277
21	.01660	.18131	.19791	.0843	
	.015052	.1691	.184152	.0817	
	.0261	.1815	.2076	.1259	
	.02778	.16275	.19053	.1458	
	.0284	.1665	.1949	.1459	.1160

TABLE XVI

LOADING FOR H_2S EQUILIBRIUM DISTRIBUTION COEFFICIENT

Run No.	Sample Bottle No.	H_2S Loading mV	Total Loading mV	Liquid Level, ml		Transducer Calibration
				Initial	Final	
5	15 16	-1.65	6.42	250	350	2
6	17 18	-1.65	6.42	350	450	2
7	19 20	-2.1	+1.9	250	350	2
8	21 22	-2.1	+1.9	350	450	2
9	23 24	-2.45	+1.7	250	350	2
10	25 26	-2.45	+1.70	350	450	2
11	27 28	-1.9	+3.75	200	300	2
12	SG1 SG2	-1.9	+3.75	301	401	2

TABLE XVII

GAS CHROMATOGRAPH ANALYSIS DATA FOR H_2S-CH_4 IN METHANOL

		CH_4			H_2S				
Run No.	Sample Bottle No.	Length of Peak cm	Atten- uation	L x Atten.	Length of Peak cm	Atten- uation	L x Atten.	$\frac{(L \times Att.)_{H_2S}}{Total}$	Average
5	15	10.6	512	5427.2	2.9	16	46.4	.0085	
		4.0	512	2048.0	2.7	4	10.8	.0053	
	16	10.6	512	5427.2	3.7	16	59.2	.0108	
		10.5	512	5376	3.4	16	54.4	.0100	.1005
6	17	10.55	512	5401.6	4.9	16	78.4	.0143	
		10.5	512	5376	4.45	16	71.2	.0131	
	18	10.6	512	5427.2	4.1	16	65.6	.0119	
		5.5	512	2816	2.4	8	19.2	.0068	
7	19	10.65	512	5452.8	2.4	16	38.4	.007	
		4.3	512	2201.6	2.6	4	10.4	.0047	

TABLE XVII (Continued)

Run No.	Sample Bottle No.	CH_4 Length of Peak cm	CH_4 Atten- uation	CH_4 L x Atten.	H_2S Length of Peak cm	H_2S Atten- uation	H_2S L x Atten.	$\frac{(L \times Att.)_{H_2S}}{Total}$	Average
	20	10.65	512	5452.8	1.5	16	24	.0044	
		10.62	512	5437.44	6.5	4	26	.0047	.0072
8	21	10.7	512	5478.4	3.2	16	51.2	.0093	
		10.7	512	5478.4	3.3	16	52.8	.0095	
	22	10.7	512	5478.4	3.2	16	51.2	.0093	
		10.6	512	5427.2	3.0	16	48.0	.0087	
9	23	10.55	512	5401.6	13.75	16	220	.0391	
		10.6	512	5427.2	13.4	16	214.4	.038	
	24	10.7	512	5478.4	11.9	16	190.4	.0336	
		10.62	512	5437.44	11.2	16	179.2	.0319	.040175

TABLE XVII (Continued)

Run No.	Sample Bottle No.	Length of Peak cm	Atten-uation	L x Atten.	Length of Peak cm	Atten-uation	L x Atten.	$\frac{(L \times Att.)_{H_2S}}{Total}$	Average
10	25	10.5	512	5376	14.1	16	225.6	.0403	
		10.6	512	5427.2	13.2	16	211.2	.0375	
	26	10.65	512	5452.8	18.5	16	296.0	.0515	
		10.6	512	5427.2	17.7	16	283.2	.0496	
11	27	10.6	512	5427.2	1.8	16	28.8	.0053	.0061
		- - - - - - - - - - - - Failed to get second reading - - - - - - - - - - - - -							
	28	10.6	512	5427.2	4.65	8	37.2	.0068	
		10.6	512	5427.2	2.3	16	36.8	.0063	

TABLE XVIII

LOADING FOR CH_4 EQUILIBRIUM DISTRIBUTION COEFFICIENT

Run No.	CH_4 Loading mV	Liquid Level, ml Initial	Final	Final Trans. Reading
1	1.92	07	107	2.28
2	1.92	207	307	2.28
3	5.35	100	200	6.06
4	5.35	200	300	6.06
5	-1.7	300	400	-1.64
6	-1.7	100	200	-1.64

APPENDIX C

SAMPLE CALCULATION

SAMPLE CALCULATIONS

Run No. 5, 6

TABLE XIX

PHYSICAL PROPERTIES OF THE GASES

Gas	P_c psia	T_c °R
H_2S	1306	672.7
CH_4	667.8	343.37

Note: Source Reference 7

TABLE XX

PRESSURE OF THE COMPONENTS IN THE CELL

Component	Loading mV	Pressure* psig	Pressure psia
H_2S	-1.65	105	119.7
Total	6.42	1007	1021.7

* From Figure 3

1. Moles of H_2S introduced in the cell

For H_2S

$$Tr = \frac{533}{672.7} = 0.792$$

$$Pr = \frac{119.7}{1306} = 0.09165.$$

From Figure 2.13a reference (1)

$$Z = 0.933$$

$$n_{H_2S} = \frac{P\,v}{ZRT}$$

$$= \frac{119.7 \text{ psia} \times 1 \text{ liter} \times 0.03532 \ (ft^3/\text{liter})}{0.933 \times 10.73 \text{ psia } (ft^3/\text{lb mole } {}^oR) \times 533 \ R^o}$$

$$= 7.9233 \times 10^{-4} \text{ lb mole}$$

2. Moles of CH_4 added

Assuming gas composition of

$$y_{H_2S} = \frac{119.7 \text{ psia}}{1021.7 \text{ psia}} = 0.117$$

$$y_{CH_4} = 0.883$$

$$P_{pc} = (y_j \ P_{cj}) + (y_i \ P_{ci})$$

$$T_{pc} = (y_j \ T_{cj}) + (y_i \ T_{ci})$$

$$P_{pc} = 0.117 \times 1306 + .883 \times 667.8 = 787.4394 \text{ psia}$$

$$T_{pc} = 0.117 \times 672.7 + .833 \times 343.37 = 405.095 \ R^o$$

Adjusting the Pseudo critical temperature for the presence of H_2S natural gas

$$T'_{pc} = T_{pc} - \varepsilon$$

from Figure 2.14 reference (1)

$\rho\ y_{H_2S} = 0.117$ $\varepsilon = 18.5R^o$

$T'_{pc} = 386.595\ R^o$

$$Pr = \frac{1021.7}{787.4394} = 1.297$$

$$Tr = \frac{533}{386.595} = 1.379$$

From Figure 2.13a reference (1)

$Z = 0.85$

$$n_{total} = \frac{1021.7}{0.85} \times \frac{\text{psia x 1 liter x .03532 (ft}^3\text{/liter)}}{\text{10.73 psia (ft}^3\text{/lb mole R}^o)533R^o}$$

$= 7.4233 \times 10^{-3}$ lb mole

$y_{H_2S} = n_{H_2S} / n_{total}$

$= 0.1067$

Assume $y_{H_2S} = 0.106$

$y_{CH_4} = 0.894$

Repeating previous procedure

$P_{pc} = 735.4492$ psia

$T_{pc} = 378.27898\ R^o$

$\varepsilon = 17.5\ R^o$

$T'_{pc} = 360.78$

$Pr = 1.3892$

$Tr = 1.48$

$Z = 0.88$

$n_{total} = 7.1703 \times 10^{-3}$ lb mole

$$y_{H_2S} = \frac{n_{H_2S}}{n_{total}} = .1105$$

Assume $y_{H_2S} = .111$

$y_{CH_4} = .889$

$P_{pc} = 738.64$ psia

$T_{pc} = 379.92\ R^o$

$\varepsilon = 17.8\ R^o$

$T'_{pc} = 362.12$

$Pr = 1.38$

$Tr = 1.47$

$Z = .88$

$n_{total} = 7.1703 \times 10^{-3}$

$y_{H_2S}\ \ n_{H_2S} / n_{total} = .1105 \simeq .111$

$n_{CH_4} = n\ total - n_{H_2S} = 6.37797 \times 10^{-3}$

TABLE XXI

EQUILIBRIUM COMPARISON

Component	No. of Moles lb mole	y
H_2S	7.9233×10^{-4}	0.111
CH_4	6.37797×10^{-3}	0.889
Total	7.1703×10^{-3}	1.000

No. of moles of methanol added =

$$100 \text{ ml} \times 0.7914 \frac{\text{gm}}{\text{ml}} \times \frac{\text{g}_{\text{mole}}}{32.04 \text{ gm}} \times \frac{\text{lb mole}}{454 \text{ g mole}}$$

$$= 5.441 \times 10^{-3} \text{ lb mole}$$

For Run 5 and 6 the result of analysis from Table XVI

$$\frac{\text{Ratio of } H_2S \text{ peak}}{\text{total ratio}} = 0.01005$$

From Figure 7

$$y_{H_2S} = 0.0375$$

Assuming no CH_4 in methanol

$$y_{H_2S} = \frac{n_{H_2S}}{n_{CH_4} + n_{H_2S}}$$

$$0.0375 = \frac{n_{H_2S}}{n_{H_2S} + 6.37797 \times 10^{-3} \text{ lb mole}}$$

n_{H_2S} in vapor phase = 2.485×10^{-4}

n_{H_2S} in liquid phase = $7.9233 \times 10^{-4} - 2.485 \times 10^{-4}$ lb mole

$$X_{H_2S} = \frac{5.4383 \times 10^{-4}}{5.4383 \times 10^{-4} + 5.441 \times 10^{-3}} = \frac{5.4383 \times 10^{-4} \text{ lb mole}}{5.9885 \times 10^{-3} \text{ lb mole}}$$

$$= 0.091$$

$$K_{H_2S} = \frac{.0375}{.09111} = .412$$

VITA

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