Effect Of The Presence Of Sour Gases On The Solubility Of Light Hydrocarbons In Aqueous Alkanolamine Solutions

I. Background

Introduction The solubility of hydrocarbons in aqueous alkanolamine solutions is of prime importance in the design of absorber/regenerator systems used to remove sour (acid) gases from hydrocarbon-rich gas streams typically found in natural gas processing plants, ethylene plants and refineries. Hydrocarbons in the feed to an amine absorber are absorbed to the extent of their physical solubility in the alkanolamine solution. For a typical sour gas stream containing H_2S, the H_2S-containing effluent gas from the regenerator overhead is usually sent to a Claus sulfur plant. It is common practice to reduce the pressure on the acid gas-rich solution from the amine absorber in a flash drum in order to vent off as much hydrocarbon vapor as possible before this stream enters the generator. Accurate prediction of these hydrocarbon losses in amine solutions is important in the design of such units.

Independent Study In 1998 Carroll and Mather (1) published a model for correlating the solubility of methane, ethane and propane in pure water and also aqueous solutions of alkanolamines. Their model considers the general case where it is possible to have three coexisting phases: (1) a vapor phase, (2) hydrocarbon-rich liquid, and (3) an aqueous-alkanolamine-rich liquid phase. The model in turn utilizes a form of Henry's law for the aqueous phase and an equation of state (Peng-Robinson equation) for the vapor and non-aqueous liquid phases.

The authors demonstrate that a relatively simple modification of the pure water model is required to extend the model for handling the solubility of the light hydrocarbons in alkanolamine solutions. They basically did this by using a parameter called the salting-in ratio, defined in terms of Henry's constants as follows:

$$\frac{H_{iw}}{H_{ia}} = S_{ia} > 1 \qquad (1)$$

The salting-in ratio is basically defined as the ratio of the Henry's law constant for the hydrocarbon i in water to the Henry's law constant for the hydrocarbon in the aqueous alkanolamine solution itself. The data sets that they correlated indicated that the solubility of the hydrocarbons, expressed in terms of mole fractions, is larger in the amine solution than it is in water. As a result, the Henry's constant for the amine solution is less than that for water, and hence S_{ia} is a number greater than unity.

This Study In the current literature the results of the measurement and correlation of systems involving the equilibrium solubility of light hydrocarbons and hydrogen in aqueous amine solutions have led to two basic generalized conclusions:

1. The solubility of light hydrocarbons in aqueous amine solutions is greater than they are in pure water.

2. The presence of sour gases such as H_2S and CO_2 lowers the hydrocarbon solubility in the aqueous amine solutions.

The obvious implication of these two opposing effects (conclusions) is that, for all practical purposes, we can simply consider that the solubility of light hydrocarbons in aqueous amine solutions containing significant concentrations of sour gases to be identical to the solubility in pure water.

The quantity of data in the existing literature which includes the presence of acid gases in aqueous amine solutions is not very plentiful. In addition, these few data include only methane and hydrogen as the principal solutes. The paper presented here attempts to analyze these data with the primary objective of verifying the more or less general solubility rule stated above.

II. Summary of Available Data

General Database Table 1 is a comprehensive list of source references of experimental data for the solubility of light hydrocarbons in various alkanolamine solutions. Table 2 covers the range of conditions covered by these data. The source references taken from Table 1 are listed here along with each of the corresponding data sets in Table 2. The light hydrocarbon solutes consist of hydrogen, methane, ethane, ethylene, acetylene, propane and n-butane. The alkanolamine species covered are MEA, DEA, TEA, MDEA and DGA. A rather broad range of alkanolamine concentrations in water are covered. The hydrogen data set includes solubility data for MEA concentrations as high as 91 weight percent. The complete temperature range is 59 deg. F to 302 deg. F. Hydrocarbon partial pressures vary from around atmospheric up to as high as 3000 psia.

Acid Gases Of the sources listed in Table 1, only references 1, 2 and 11 include a rather small amount of data which involve the presence of H_2S and CO_2 or both together dissolved in the aqueous amine solution. The range of conditions for these data are given in detail in Table 2. It is these data that we will be focusing on in the analysis to follow.

III. Analysis of the Data

<u>CH_4 in Aqueous DEA</u> Lawson and Garst (Table 1, Ref. 1) report an extensive set of data for the solubilities of methane and ethane in in aqueous MEA and DEA solutions for temperatures between 100 deg. F and 250 deg. F and amine concentrations up to 40 weight percent. However, these authors report only nine points which cover the solubility of methane in 25 weight percent DEA containing either H_2S and CO_2 at temperatures of 100 and 150 deg. F. As a result, we focused our attention on the CH_4/ aqueous DEA system here and the subsequent effect of the presence of the two acid gases on CH_4 solubility.

In the original paper, Lawson and Garst express liquid phase hydrocarbon solubility as lbmoles of HC/ 100,000 lbs of solution. We converted these values to mole fraction HC in our analysis. An example of this conversion is illustrated below:

The solubility of CH_4 in 25 wt. % DEA is reported to be 3.20 lbmoles of CH_4/ 100,000 lbs of solution at 100 deg. F for a methane partial pressure of 510 psia. The conversion to mole fraction methane is as follows:

$$Molecular\ weight\ of\ DEA = 105.14$$

$$Molecular\ weight\ of\ the\ solution: \qquad M_{soln} = \frac{100}{\frac{25}{105.14} + \frac{75}{18.02}} = 22.728$$

$$Lbmoles\ of\ soln = \frac{100,000}{22.728} = 4399.82$$

$$Therefore \qquad x_{HC}, mole\ fr. = \frac{3.20}{4399.82} = 0.0007273$$

Figure 1 shows the effect of DEA concentration on the solubility of CH_4 at 150 deg. F with no acid gases present. It is quite apparent here that the methane solubility increases with increasing amine concentration for a fixed CH_4 partial pressure. Figure 2 demonstrates the effect of temperature on gas solubility for a fixed DEA concentration of 25 wt. percent. At fixed CH_4 partial pressure and starting at 100 deg. F, we observe that the gas solubility starts to decrease with an increase in temperature. Then as we proceed to increase the temperature further, the gas solubility starts to increase. As a result, the

various isotherms tend to intersect. This behavior indicates that, for a given gas partial pressure, a plot of gas solubility versus temperature should exhibit a minimum point.

In Figure 3 we have plotted the ratio of CH_4 solubility in 25 wt. % DEA to the CH_4 solubility in pure water versus gas partial pressure for isotherms of 100 and 150 deg. F. In any case, no acid gases are present here. The methane solubilities in pure water were read from Figure 9A2.1 of the Data Book of the American Petroleum Institute (2). At 100 deg. F, the gas solubility in the amine solution appears to be about 20 percent higher than it would be in pure water. At 150 deg. F, this percentage increases to around 27 percent.

Next we did an analysis of the nine data points that Lawson and Garst reported which included the presence of either H_2S or CO_2. This analysis resulted in a plot involving the solubility ratio of CH_4 in 25 wt. % DEA with acid gases present relative to the gas solubility in pure water. This plot is illustrated as Figure 4. Here we have plotted the solubility ratio against dissolved CO_2 or H_2S concentration or liquid phase loading between 0.2 and 1.1 moles of CO_2 or H_2S per mole of DEA. Most of the data points covered a liquid phase loading between 0.2 and 0.27 moles acid gas/ mole DEA. In this range there appears to be a fair degree of scatter where the solubility ratio varies between about 0.94 to nearly 1.08. At a loading of 1.1, the solubility ratio is close to one. This scatter is probably well within the degree of uncertainty in the experimental measurement of solubility. Based on this data analysis alone, we could easily conclude that the gas solubility in amine solutions with acid gases present is basically the same as it would be in pure water alone.

As we approach zero acid gas loading, the solubility ratio must show a significant increase. The dashed curve shown in Figure 4 is just an estimate and is based on the curves or lines plotted in Figure 3.

<u>CH_4 in Aqueous MEA</u> In the Third Edition of their book "Gas Purification", Kohl and Riesenfeld (Table 1, Ref. 2, Page 120) published a graph showing the solubility of methane in aqueous MEA for the following fixed conditions:

Moles total acid gases/mole MEA = 0.47
CO_2/H_2S = 0.9
25.3 wt. % MEA in water

This figure consists of a plot of total system pressure (psia) versus methane solubility in solution expressed as volume methane (60 deg. F, 14.7 psia) / volume solution. Two curves are shown for temperatures of 160 deg. F and 80 deg. F respectively.

We read a host of points from these graphs and then proceeded to convert the liquid solubility of methane from volume ratio to mole fraction. A sample calculation for a specific data point is given below:

At 160 deg. F and a total pressure of 280 psia, we read a CH_4 solubility value of 0.26 cc gas/ cc solution.

At 1 atm and 60 deg. F (288.72 deg. K) 1 gmole of gas (assumed to be ideal) occupies:

$$\frac{(82.06)(288.72)}{(1)} = 23,692.4\ cc$$

Mason and Dodge (3) report that aqueous MEA solutions with concentrations up to 12.5 N have a specific gravity that is essentially 1.00 at 25 deg. C.

The molecular weight of the solution (on a CH_4 free basis) must also be computed.

Breakdown of the liquid phase aid gas loading:

$$\frac{Mols\ acid\ gases}{Mol\ MEA} = 0.47 \quad with \quad \frac{CO_2}{H_2S} = 0.9$$

$$H_2S + 0.9\,H_2S = 0.47 \quad or \quad H_2S = 0.247\ mols\,H_2S\,/\,mol\,MEA$$

$$CO_2 = 0.47 - 0.247 = 0.223\ mols\,CO_2\,/\,mol\ MEA$$

In the liquid phase solution:

$$Let\ \ x_a = mole\ \ fraction\ a\min e\ (MEA)$$

Then

$$x_w = m.f.\ water = \left(\frac{74.7}{25.3}\right)\left(\frac{61.09}{18.02}\right)x_a$$

$$x_{H_2S} = 0.247\,x_a \quad and \quad x_{CO_2} = 0.223\,x_a$$

As a result we can write:

$$x_a + \left(\frac{74.7}{25.3}\right)\left(\frac{61.09}{18.02}\right)x_a + 0.47\,x_a = 1.$$

or

$$x_a + 10.01\,x_a + 0.47\,x_a = 1.$$

$$x_a = \frac{1}{11.480} = 0.0871\ m.f.\ MEA$$

$$x_w = (10.01)(0.0871) = 0.8720\ m.f.\ H_2O$$

$$x_{H_2S} = (0.247)(0.0871) = 0.0215\ m.f.\ H_2S$$

$$x_{CO_2} = (0.223)(0.0871) = 0.0194\ m.f.\ CO_2$$

$$\overline{}$$

$$1.0000$$

The molecular weight of the solution is therefore:

$$M_{so\ln} = (0.0871)(61.09) + (0.8720)(18.02) + (0.0215)(34.08) + (0.0194)(44.01) = 22.621$$

If $$\beta = \frac{cc\ of\ CH_4\ gas\ at\ 60^o F\ and\ 1\ atm}{cc\ solution}$$

Then $$x_{CH_4}\ in\ sol\text{n}. = \frac{\beta M_{sol\text{n}}}{23,692.4\ \ SG_{sol\text{n}}}$$

$$= \frac{(0.26)(22.621)}{(23,692.4)(1.00)} = 0.0002483\ m.f.\ CH_4$$

In Figure 5 we have plotted the solubility ratio (ratio of solubility of CH_4 in aqueous MEA with H_2S/CO_2 present to the corresponding solubility of CH_4 in water) versus CH_4 partial pressure for the two isotherms reported in Kohl and Riesenfeld's book. At 80 deg. F the solubility ratio varies from around 0.70 at a partial pressure of 200 psia to nearly 1.00 at a partial pressure approaching 1000 psia. At 160 deg. F the curve is much flatter and produces an approximate average solubility ratio of around 0.90 over the full range of methane partial pressures. These results basically show that the solubility of CH_4 in water is somewhat higher than it would be in the entire solution containing both 25.3 wt. % MEA and 0.47 moles of acid gases/ mole MEA.

<u>H_2/CH_4 in Aq. DGA</u> Dingman (Table 1, Ref. 11) has measured and reported solubility data for basically three sets of conditions:

1. Hydrogen solubility in 50 wt. % DGA in water at 150, 170 and 190 deg. F and total system pressures ranging between 500 and 3000 psia.

2. Methane solubility in 50 wt. % DGA in water at 170 deg. F and total system pressures ranging from 500 to 3000 psia.

3. Three data points only, showing the simultaneous solubility of H_2 and CH_4 in 50 wt. % DGA/H_2O solutions loaded with 0.35 moles H_2S/ mole DGA at 170 deg. F with a vapor mixture consisting of 79.2 mol % H_2 and 20.8 mol % CH_4 and total system pressures from 2000 to 3000 psia.

4. A few data points are also reported for the above three systems at temperatures around ambient for pressures of 500 and 1000 psia.

In all the measurements above, the solubilities were reported in units of mole percent.

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Figure 6 consists of a plot of the solubility ratio for either H_2 or CH_4 versus total pressure for the first three data sets described above at a single temperature of 170 deg. F. In calculating these ratios, we used H_2 solubilities in pure water read from Figure 9A7.4 of the API Technical Data Book (2) and CH_4 solubilities in pure water from Figure 9A2.1 of the same source.

For H_2 alone in acid gas free aqueous DGA, the solubility ratio averages around 1.65. With CH_4 in the acid gas free DGA solution, the ratio varies from 2.5 to about 2.75. For the case where the H_2S loading is 0.35 moles/ mole DGA, H_2 solubility ratio varies between 1.25 and 1.3. For CH_4, over the same range of pressure, the ratio ranges between about 1.5 to 1.65. The comparison here clearly shows that the effect of the presence of H_2S in solution suppresses the solubility of H_2 and CH_4. However, the data also imply that the solute solubilities in pure water are significantly lower than they are in the acid gas loaded DGA solutions.

The table below summarizes the solubility ratio results for the ambient temperature data with H_2S present in solution relative to pure water.

Temp. ^oF	Press. Psia	Soly. Ratio H_2	Soly. Ratio CH_4
79	500	0.900	1.13
79	1000	0.947	0.914

Conclusion The experimental data of Lawson and Garst for CH_4 in 25 wt. % DEA with varying concentrations of H_2S or CO_2 in solution strongly imply that the solubility of a light hydrocarbon in an aqueous amine solution containing a significant concentration acid gases is the same as its solubility in pure water at the same temperature and HC partial pressure.

The data sets of Kohl and Riesenfeld for CH_4 dissolved in 25.3 wt. % MEA with 0.47 mols acid gases/ mol MEA and of Dingman for H_2 and CH_4 in 50 wt. % DGA with 0.35 mols H_2S/ mol DGA do not allow us to draw such a clear cut conclusion.

However, considering that the magnitude of the HC solubilities reported are of the order of 10^{-4} mole fraction, we might also expect that the observations made in this study may also have to be assessed in the light of measurement error or uncertainty.

In any case, within the scope of normal required engineering accuracy for design, the general solubility rule posed or proposed in this study should be a very reasonable one to follow.

General References

1. Carroll, J. J. and Mather, A.E., "A Model for the Solubility of Light Hydrocarbons in Water and Aqueous Solutions of Alkanolamines", Chemical Engineering Science, Vol. 52, No. 4, Pages 545-552 (June 29, 1998).

2. American Petroleum Institute (API) Division of Refining, Technical Data Book, Refining Division (Figures 9A2.1 and 9A7.4, June 1980).

3. Mason, J.W. and Dodge, B.F., Trans. Amer. Inst. of Chem. Engrs., Vol. 32, Page 27 (1936).

Table 1 File: SOLYTAB.DOC

Literature Sources of Experimental Data Used in the Correlation

1. Lawson, J.D. and A.W. Garst, "Hydrocarbon Gas Solubility in Sweetening Solutions: Methane and Ethane in Aqueous MEA and DEA", Jr. of Chem. and Engr. Data, 21 No. 1, (1976) Pages 30-32.

2. Kohl, A.L. and F.C. Riesenfeld, "Gas Purification", Third Edition, Gulf Publishing Co. (1979) Page 120 (Unpublished data from the Fluor Corporation).

3. Sada, E., Kumazawa, H. and M.A. Butt, "Solubilities of Gases in Aqueous Solutions of Amine", Jr. of Chem. and Engr. Data, 22, No. 3 (1977), Pages 277-278.

4. Sada, E., Kumazawa, H., and M.A. Butt, "Solubility and Diffusivity of Gases in Aqueous Solutions of Amines", Jr, of Chem. and Engr. Data, 23, No. 2 (1978) Pages 161-163.

5. Sada, E. and S. Kito, Kagaku Kogaku 36, (1972) Pages 218-221.

6. Kling, G and G. Maurer, "Solubility of hydrogen in Aqueous Ethanolamine Solutions at temperatures between 323 and 423 K", Jr. of Chem. and Engr. Data, 36, No. 4 (1991) pages 390-394.

7. Jou, F.Y., Otto, F.D. and A.E. Mather, "Solubility of Ethane in Aqueous Solutions of Triethanolamine (TEA)", Jr. Chem.. Engr. Data, 41, No. 4 (1996) Pages 794-795

8. Jou, F.Y., Carroll, J.J., Mather, A.E. and F.D. Otto, "Solubility of Methane and Ethane in Aqueous Solutions of Methyldiethanolamine (MDEA)", Jr. Chem. Engr. Data , 43, No. 5 (1998), Pages 781-784.

9. Carroll, J.J., Jou, F.Y., Mather, A.E., and F.D. otto, "Phase Equilibria in the System Water- MDEA – Propane", AIChE Jr., 38, No. 4 (1992) Pages 511-520.

10. Jou, F.Y., Carroll, J.J., Mather, A.E., and F.D. Otto, "Phase Equilibria in the System n-butane – Water – MDEA", Fluid Phase Equilibria, 116 (1996) Pages 407 – 413.

11. Dingman, J.C., Texaco Chemical Co.,"Don't Blame Hydrocarbon Solubility for Entrainment Problems in Amine treating Systems", a paper presented at the 1986 Annual AIChE meeting in Miami Beach, Florida, Nov. 2-7, 1986.

Table 2

Range of Conditions Covered by the Experimental Data

* Data Source	Temp. deg. F	Alkanol-amine Type	Wt. % Alk.	Hydrocarbon Solute	Partial Press. Hydrocarbon Psia	Mole fract. Hydrocarbon in the Liquid	Acid Gas in the mols/mol H2S	Loading Liquid Alkan. CO2
Lawson and Garst (1)	100 to 250	DEA	5 to 40	Methane	498 to 982	0.00052 to 0.0017	-	-
	100 to 250	MEA	15 to 40	Methane	498 to 993	0.00062 to 0.0020	-	-
	100 to 150	DEA	5 to 25	Ethane	480 to 972	0.0005 to 0.0011	-	-
	100 to 150	MEA	15 to 40	Ethane	491 to 955	0.00063 to 0.0016	-	-
	100 to 150	DEA	25	Methane	456 to 973	0.00046 to 0.0012	0.19 to 1.1	-
	100 to 150	DEA	25	Methane	489 to 970	0.00054 to 0.0011	-	0.25 to 0.27
Kohl and Riesenfeld (2)	80 to 160	MEA	25.3	Methane	113 to 993	0.000086 to 0.0013	0.247	0.223
Sada et.al. (3)	77	DEA	0 to 31.7	Ethylene	14.7	0.000089 to 0.000116	-	-
	77	TEA	2.9 to 37.0	Ethylene	14.7	0.000093 to 0.000119	-	-
Sada et.al. (4)	77	MEA	0 to 19.3	Acetylene	14.7	0.00076 to 0.00091	-	-
	77	DEA	4.7 to 29.5	Acetylene	14.7	0.0008 to 0.00093	-	-
	77	TEA	4.0 to 41.0	Acetylene	14.7	0.0008 to 0.0011	-	-
Sada and Kito (5)	59 to 77	MEA	0 to 34.8	Ethylene	14.7	0.000089 to 0.000136	-	-
Kling and Maurer (6)	122 to 302	MEA	53.1 to 91.1	Hydrogen	272 to 2786	0.00062 to 0.00789	-	-

* Detailed references are cited in Table 1

Table 2 Cont.

Range of Conditions Covered by the Experimental Data

* Data Source	Temp. deg. F	Alkanol-amine Type	Wt. % Alk.	Hydrocarbon Solute	Partial Press. Hydrocarbon Psia	Mole fract. Hydrocarbon in the Liquid	Acid Gas in the mols/mol H2S	Loading Liquid Alkan. CO2
Jou, Otto and mather (7)	77 to 257	TEA	28.6 to 67.45	Ethane	8.8 to 2900	0.000047 to 0.0089	-	-
Jou, Carroll, Mather and Otto (8)	77 to 266	MDEA	34.7	Methane	13.4 to 1916	0.0000418 to 0.00326	-	-
Jou, Carroll, Mather and Otto (8)	77 to 266	MDEA	34.7	Ethane	13.5 to 1954	0.0000535 to 0.00352	-	-
Carroll, Jou, Mather and Otto (9)	32 to 302	MDEA	34.7	Propane	11.9 to 2727	0.0000371 to 0.00309	-	-
Jou, Carroll, Mather and Otto (10)	77 to 302	MDEA	34.7	n-butane	15.5 to 544	0.000049 to 0.00141	-	-

* Detailed references are cited in Table 1.

Table 2 Cont.-

Range of Conditions Covered by the Experimental Data

I. Solubility Data for Hydrogen and Methane in Aqueous DGA Vapor-aq. Liquid Region Only

* Data Source	Temp. deg. F	Alkanol-amine Type	Wt. % Alk.	Hydrocarbon Solute	System Press. Psia	Mole Fract. Hydrocarbon in the Aq. Liq.	Acid Gas in the mols/mol H2S	Loading Liquid Alkan. CO2
J.C. Dingman Ref. (11)	150 to 190	DGA	50	Hydrogen	500 to 3000	0.0027 to 0.00457	-	-
	72	DGA	50	Hydrogen	500	0.00054	-	-
	170	DGA	50	Methane	500 to 3000	0.00122 to 0.00547	-	-
	73 to 76	DGA	50	Methane	500 to 1000	0.00112 to 0.00198	-	-
	170	DGA	50	Hydrogen/Methane *	2000 to 3000		0.35	-
				Hydrogen		0.001825 to 0.002741		
				Methane		0.000666 to 0.000919		
	79	DGA	50	Hydrogen/Methane *	500 to 1000		0.35	-
				Hydrogen		0.00036 to 0.00071		
				Methane		0.00017 to 0.00032		

*For these two sets of data (H2/CH4) in 50 wt. % DGA with 0.35 mols H2S/mol DGA, the dry gas contains 79.2 mole % H2 and 20.8 mole % CH4.

FIGURE 1

SOLUBILITY OF METHANE IN AQUEOUS DEA SOLUTIONS AT 150°F

DATA SOURCE: LANSON & GARST (TABLE 1, REF. 1)

NO ACID GASES PRESENT

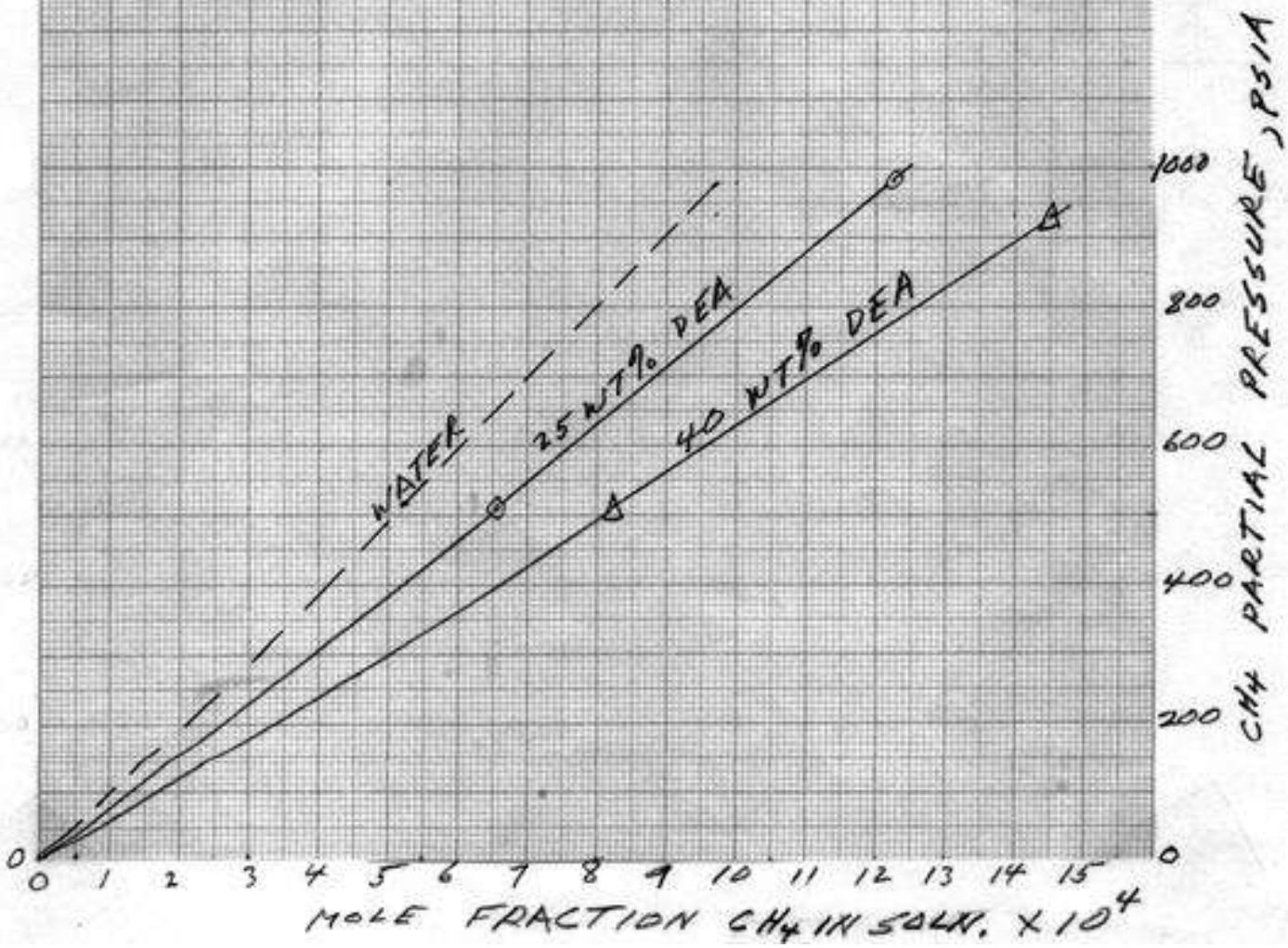

FIGURE 2

EFFECT OF TEMPERATURE ON THE SOLUBILITY OF CH_4 IN 25 WT % DEA

DATA SOURCE: LANSON & GARST (TABLE 1, REF. 1)

NO ACID GASES PRESENT

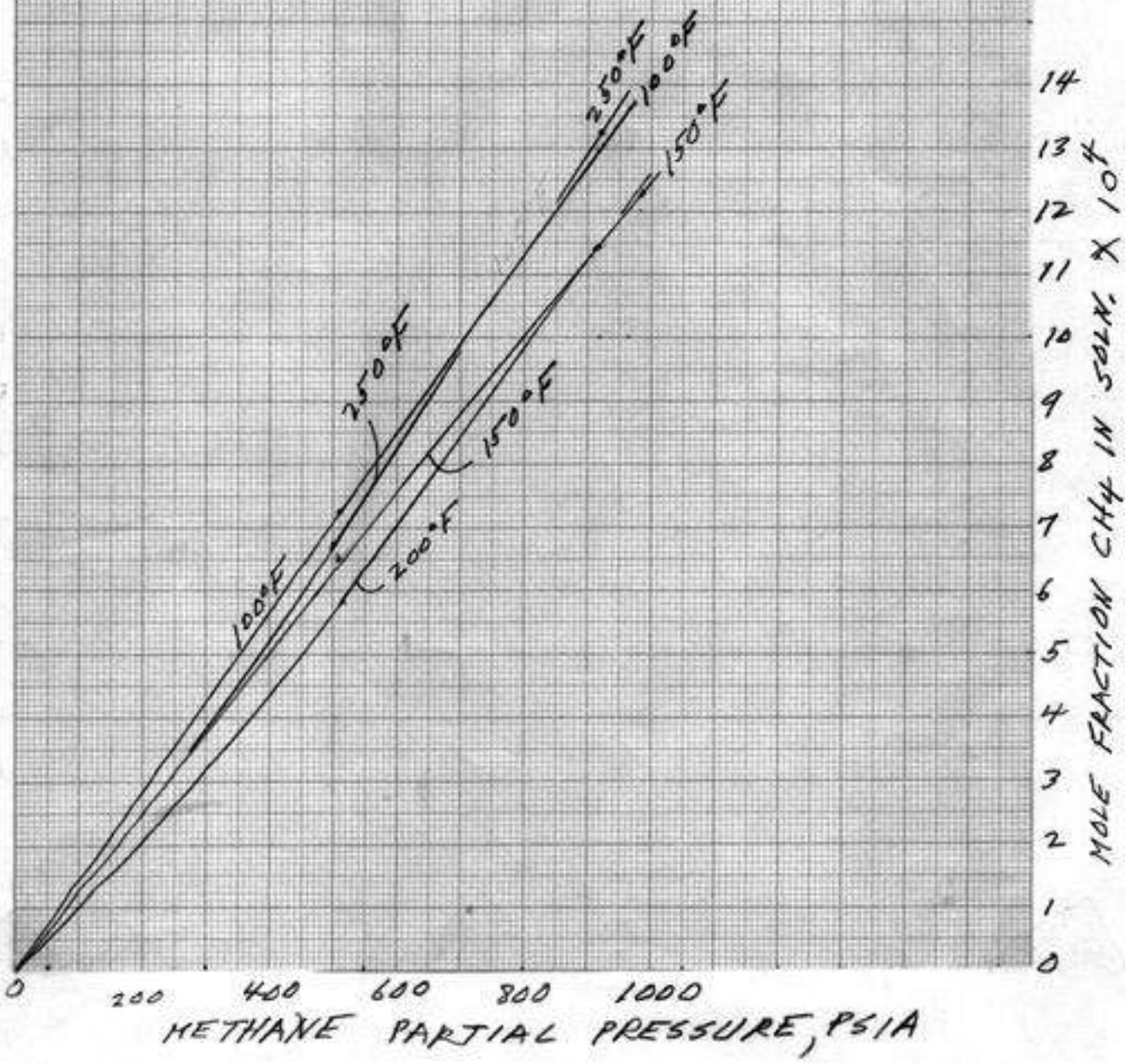

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FIGURE 3

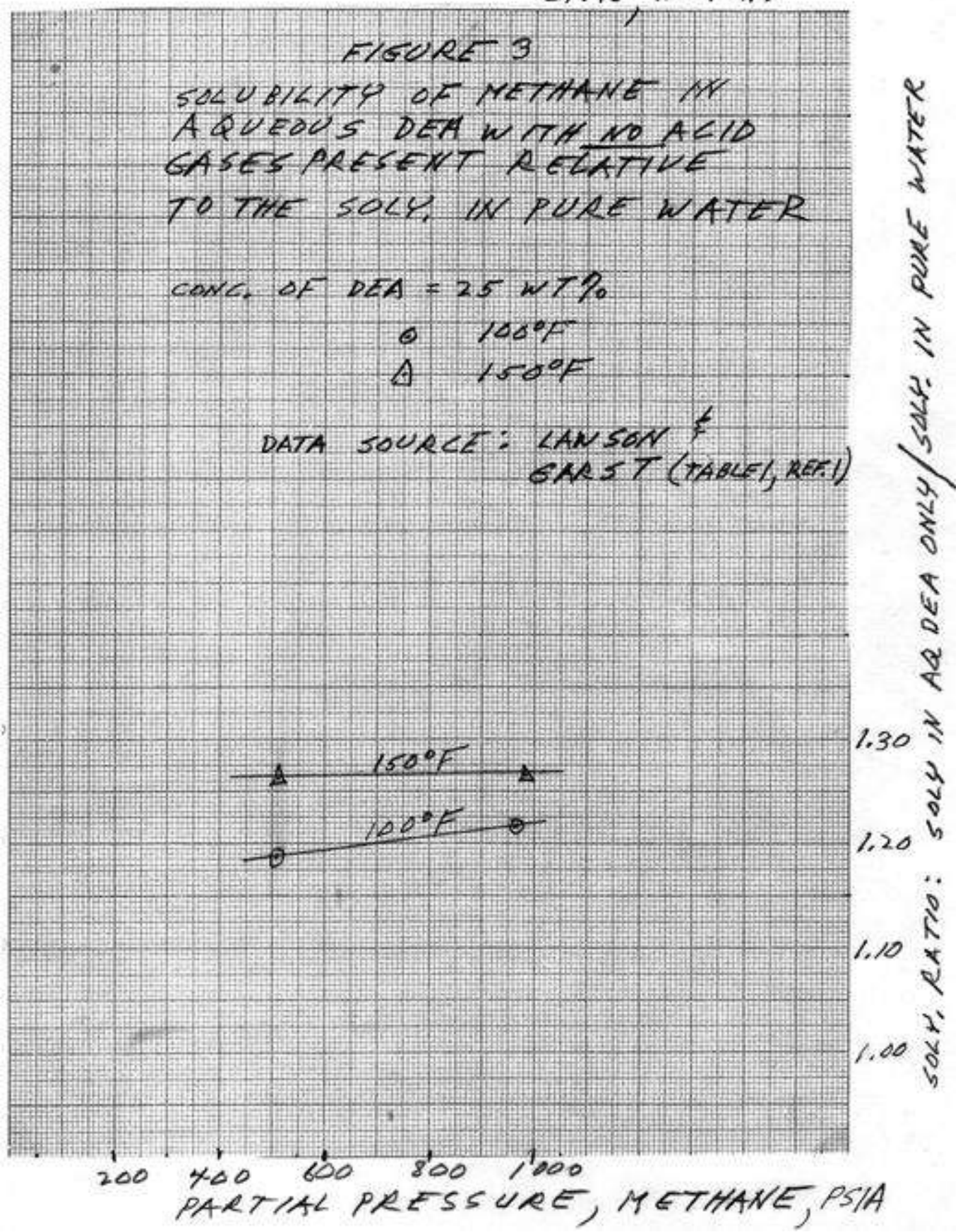
SOLUBILITY OF METHANE IN AQUEOUS DEA WITH NO ACID GASES PRESENT RELATIVE TO THE SOLY. IN PURE WATER

CONC. OF DEA = 25 WT%

⊙ 100°F

△ 150°F

DATA SOURCE: LANSON & GARST (TABLE I, REF. 1)



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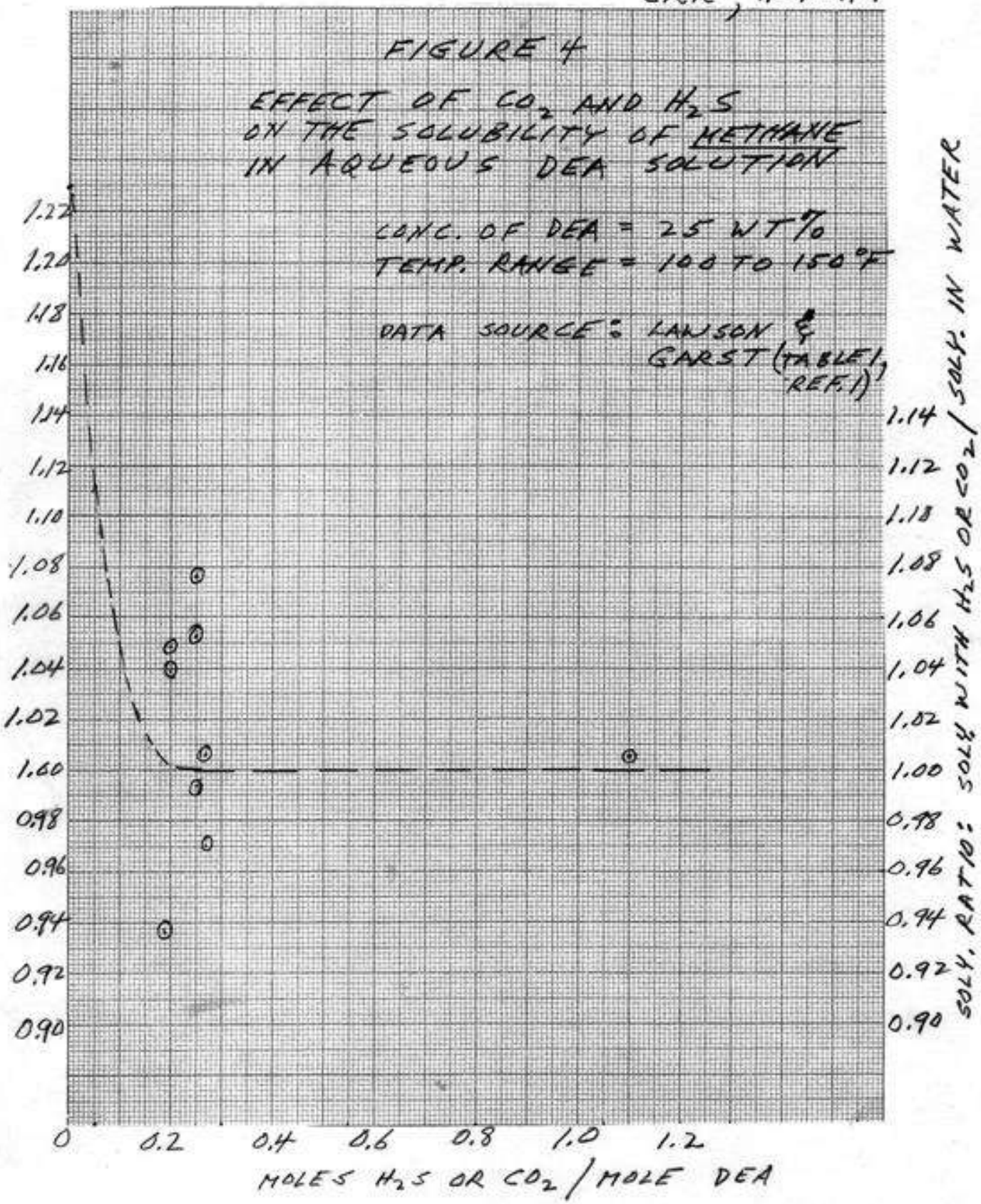
FIGURE 4
EFFECT OF CO_2 AND H_2S ON THE SOLUBILITY OF METHANE IN AQUEOUS DEA SOLUTION
CONC. OF DEA = 25 WT%
TEMP. RANGE = 100 TO 150°F
DATA SOURCE: LAWSON & GARST (TABLE 1, REF. 1)
1.22
1.20
1.18
1.16
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0
0.2
0.4
0.6
0.8
1.0
1.2
MOLES H_2S OR CO_2 / MOLE DEA
SOLY. RATIO: SOLY. WITH H_2S OR CO_2 / SOLY. IN WATER

CRK, 11-7-11

FIGURE 5

EFFECT OF CO_2 AND H_2S ON THE SOLUBILITY OF METHANE IN AQUEOUS MEA SOLUTION

CONC. OF MEA = 25.3 WT%

⊙ 80°F

△ 160°F

DATA SOURCE: KOHL & RIESENFELD

MOLS (H_2S+CO_2)/MOLE MEA = 0.47

(TABLE 1, REF. 2) CO_2/H_2S = 0.90

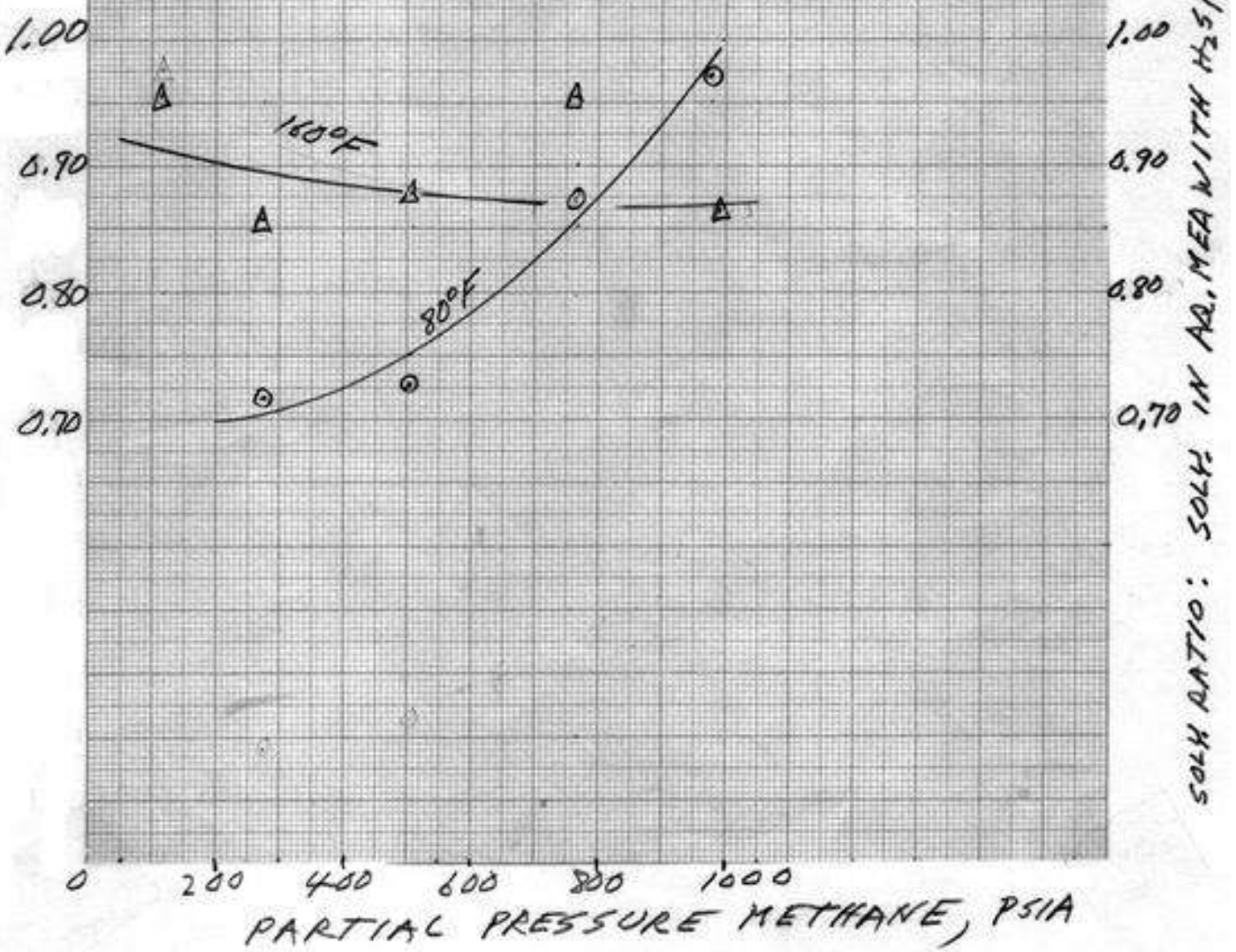

FIGURE 6

EFFECT OF THE PRESENCE OF H_2S ON SOLY. OF H_2 AND CH_4 IN AQ. DGA SOLUTIONS. TEMP. = 170°F