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Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography



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Analysis for Natural Gas and Similar Gaseous Mixtures by Gas Chromatography

1. SCOPE

1.1 This method covers the determination of the chemical composition of natural gas and similar gaseous mixtures within the ranges listed in Table I.

1.2 Components sometimes associated with natural gases, i.e., helium, hydrogen sulfide, carbon monoxide and hydrogen are excluded from the main body of the method. These components are determined and made a part of the complete compositional data by following special techniques outlined in Appendix A.

Table I

Natural Gas Components and Range of Components Covered

Components	Conc. Range
	Mol. %
Helium	0.01 - 10
Oxygen	0.01 - 20
Nitrogen	0.01 - 100
Carbon Dioxide	0.01 - 20
Methane	0.01 - 100
Ethane	0.01 - 100
Hydrogen Sulfide	3.00 - 100
Propane	0.01 - 100
Isobutane	0.01 - 10
n-Butane	0.01 - 10
Isopentane	0.01 - 2
n-Pentane	0.01 - 2
Hexanes & Heavier	0.01 - 2

NOTE 1 — Hydrogen sulfide is eluted in a well defined peak between ethane and propane on the Silicone 200/500 column. Special procedures must be followed if precise values for hydrogen sulfide are required. An auxiliary method for determining hydrogen sulfide in place in the sample is outlined in Appendix A. The accuracy of chromatographic analysis for hydrogen sulfide has not been determined, therefore, it is not to be used as a referee method. For hydrogen sulfide below 3.0 mol %, measurement must be made at the source using GPA Standard 2377. Chromatographic results for hydrogen sulfide above 3.0 mol % can be confirmed at the source by the Tutweiler Method (C-1) in the GPA Plant Operations Test Manual.

2. SUMMARY OF METHOD

2.1 Components to be determined in a gaseous sample are physically separated by gas chromatography and compared to calibration data obtained under identical operating conditions. A fixed volume of sample in the gaseous phase is isolated in a suitable inlet sample system and entered onto the column.

2.1.1 The inert components, nitrogen and oxygen, are analyzed on an adsorption column. This analysis detects any air contamination that could be introduced in field and/or laboratory sampling. Failure to detect air contamination will result in erroneous data being used to calculate the properties of natural gas from compositional data.

2.1.2 Carbon dioxide in natural gas is difficult to determine accurately on the silicone 200-500 column due to inadequate resolution of the minor component (carbon dioxide) from the major component (methane). Results are acceptable if the

carbon dioxide in the reference standard matches closely the carbon dioxide in the unknown sample (within 20% in the 0.01 to 10% range). For this reason an alternate column system for determining carbon dioxide is included in the main body of this method. Samples containing less than 10% carbon dioxide can be analyzed on either column system by calibrating with a reference standard or the pure component that approximates the carbon dioxide expected in the unknown gas.

2.1.3 The components nitrogen/air, methane, carbon dioxide and ethane through n-pentane are eluted on forward flow of carrier gas through the partition column. The numerous heavy components of natural gas are grouped into a single peak using a precut column which is backflushed to elute the hexanes and heavier as the first peak in the chromatogram. This recommended approach to the hexanes and heavier separation has two distinct advantages: (1) better precision of measuring the peak area, and (2) a reduction in analysis time over the non-precut (single) column approach.

2.1.4 An alternate to the precut, two-column method is the single column method which separates nitrogen/air, methane, carbon dioxide and ethane through n-pentane with the reverse flow valve in the forward position. The numerous heavy end components of natural gas are grouped into irregular peaks by reversing the flow of the carrier gas to group them as hexanes and heavier.

2.1.5 The chromatograms are interpreted by comparing the areas of the components eluted in the forward position with the areas taken from response curves obtained using pure components, or from areas of corresponding peaks in the selected reference standard. The hexanes and heavier components may be interpreted by comparing the total area under the reverse flow peak with the corresponding area in a reference standard (whose hexanes and heavier composition closely resembles that of the hexanes and heavier composition of the sample being analyzed) or by comparing the total area under the reverse flow peak with the areas of the pentane peaks in the sample.

NOTE 2 — Modern technology has brought many advances in the way natural gas can be analyzed. These advances are now available for traditional laboratory as well as portable and on-line gas chromatographs. Any gas chromatograph is acceptable for the analysis of natural gas as long as the specifications for repeatability and reproducibility in Section 9 over the component ranges listed in Table 1 are met or exceeded.

3. APPARATUS

3.1 **Chromatograph**—Any chromatographic instrument may be used which has the following performance and characteristics:

3.1.1 **Detector**—The detector shall be a thermal conductivity type. It must be sufficiently sensitive to produce a deflection of at least 0.5 mv for 1 mol% n-butane in a 0.25 ml sample.

3.1.2 **Sample Inlet System**—Provision must be made to introduce into the carrier gas ahead of the analyzing column a

gas phase sample that has been entrapped in a fixed volume loop or tubular section. This fixed volume loop shall be so constructed that the total loop volume including dead space shall not normally exceed 0.5 ml at 760 mm Hg absolute. If increased accuracy of the hexanes and heavier portion of the analysis is required, a larger sample size should be used. The sample volume must be reproducible such that successive runs agree within $\pm 0.5\%$ on each major component peak area.

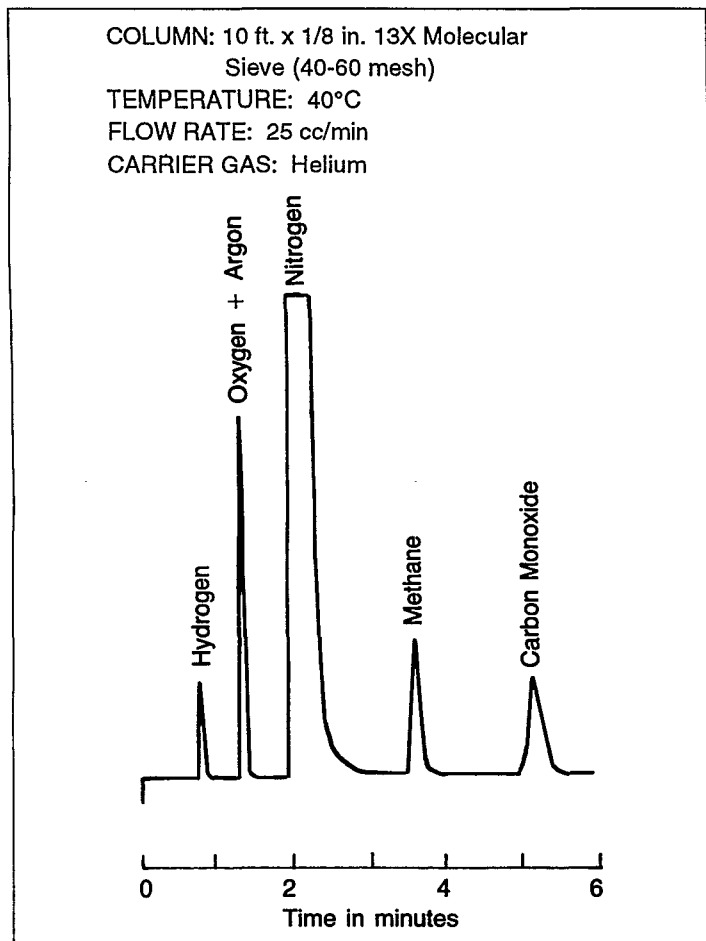


Figure 1 – Separation of Non-Condensable Gases on Molecular Sieve.

NOTE 3—The sample size limitation of 0.5 ml or smaller is selected relative to linearity of detector response and efficiency of column separation. Larger samples may be used to determine low-quantity components in order to increase measurement accuracy on the unattenuated peaks.

3.1.3 Adsorption Column—This column must completely separate oxygen, nitrogen and methane as indicated by return of the integrator/computer indicator to the baseline between each successive peak. Figure 1 shows an example chromatogram obtained using a suitable adsorption column.

NOTE 4—The preparation and arrangement of absorption columns found to meet the requirements of this method are described in Appendix B-1 and Figure B-1.

3.1.4 Porous Polymer Column—This column must completely separate methane, carbon dioxide and ethane as indicated by return of the integrator/computer indicator to the

baseline between each successive peak. Figure 2 shows an example chromatogram obtained using a suitable porous polymer column.

NOTE 5—The preparation and arrangement of porous polymer columns found to meet the requirements of this method are described in Appendix B-3 and Figure B-1.

3.1.5 Partition Column—This column must separate methane through pentanes and carbon dioxide. The integrator/computer indicator must return to baseline on propane and succeeding peaks, and on peaks eluted ahead of propane the integrator/computer indicator must return to within 2% of full scale deflection, measured at the attenuation of the peak. Separation of carbon dioxide must be sufficient so that a 0.25 ml sample containing 0.01 mol % carbon dioxide will produce a clearly measurable peak on the chromatogram. Time for completion of a partition column run should not exceed 30 minutes, including reversal of flow after n-pentane to give a composite peak for hexanes and heavier components. Figure 3 shows an example chromatogram of a natural gas mixture using the precut column for grouping the hexanes and heavier. The position of the hexanes and heavier peak to provide the best baseline for this peak is accomplished by inserting a lightly loaded (1 wt% Silicone 200/500) column between the detector inlet and the column switching/sampling valve (Figure 5, Column 3). This column is usually between 12 and 40 in. long. Figure 4 shows an example chromatogram obtained on a single partition column which separates oxygen and/or nitrogen from methane in addition to the separation of ethane through pentanes and carbon dioxide. Examples shown in Figures 3 and 4 provide a complete analysis if there is no requirement to separate oxygen from nitrogen.

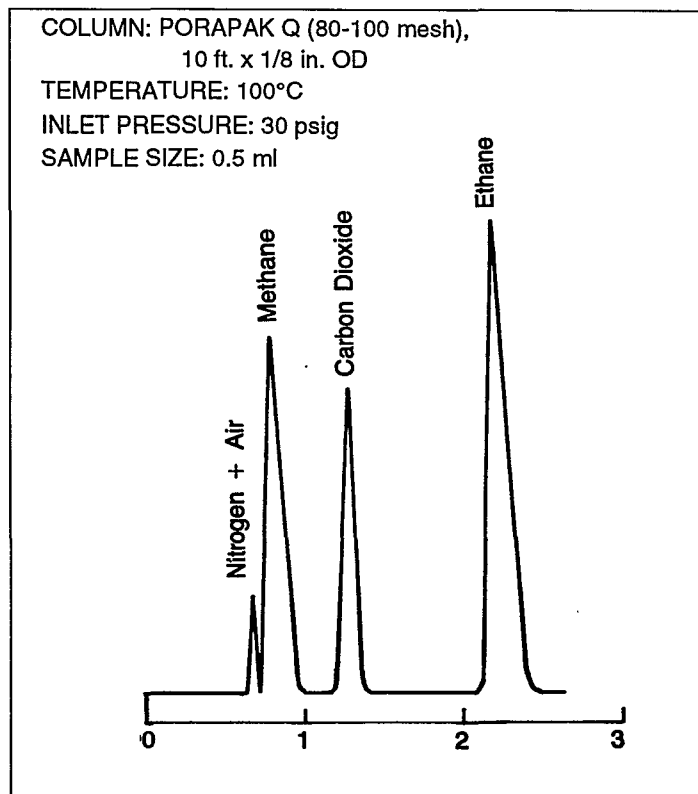


Figure 2 – Chromatogram of Carbon Dioxide Separation on Porous Polymer Column.

(Figure 5 shows a typical column switching/sampling valve arrangement).

NOTE 6—The preparations and arrangements of partition columns found to meet requirements of this method are described in Figure 5, Appendix B-2 and Figure B-1.

3.1.6 Temperature Control—The chromatographic columns and the detector shall be maintained at a temperature constant to $\pm 0.2^{\circ}\text{C}$ during the course of the sample and corresponding reference standard runs.

3.2 Carrier Gas—Pressure reducing and control devices shall be such as to provide a flow of helium or other suitable carrier gas through the chromatographic column at a rate that varies a maximum of $\pm 0.5\%$ during the course of the sample and corresponding reference standard runs.

3.3 Drier—Unless water is known not to interfere in the analysis, a drier must be provided in the sample entering system ahead of the sample valve. The drier must remove moisture without simultaneously removing selective components to be determined in the analysis.

NOTE 7—A procedure for the preparation of a drier found to meet the requirements of this method is described in Appendix B.

3.4 Integrator/Computer—Wide range, 0-IV/0-10V with both printing and plotting capability, baseline tracking and tangent skim peak detection.

3.5 Vacuum gage—Equipped with an accurately graduated and easily read scale covering the range 0 to 30 inches (0 to 760 mm) of Hg and having a $\pm 0.5\%$ accuracy rating.

3.5.1 A U-tube or well type manometer may be used in place of the vacuum gage. If used, caution should be used handling mercury because of its toxic nature. The user should be fully versed in safety practices for handling Hg.

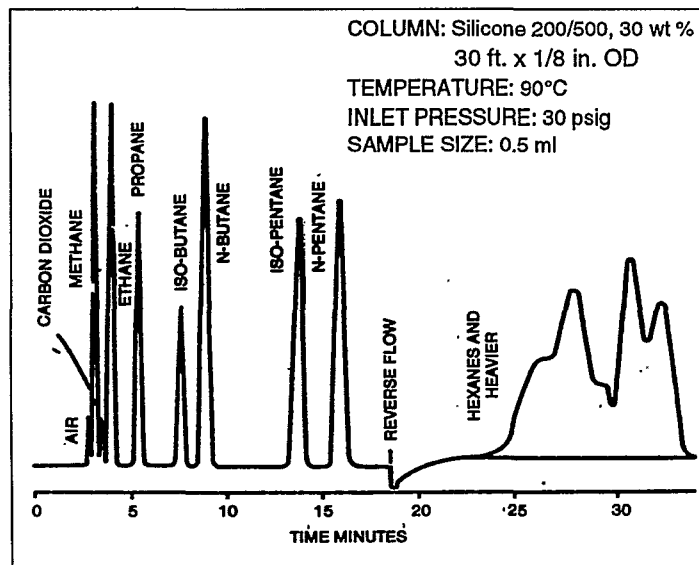


Figure 4 – Chromatogram of Natural Gas (Silicone 200/500).

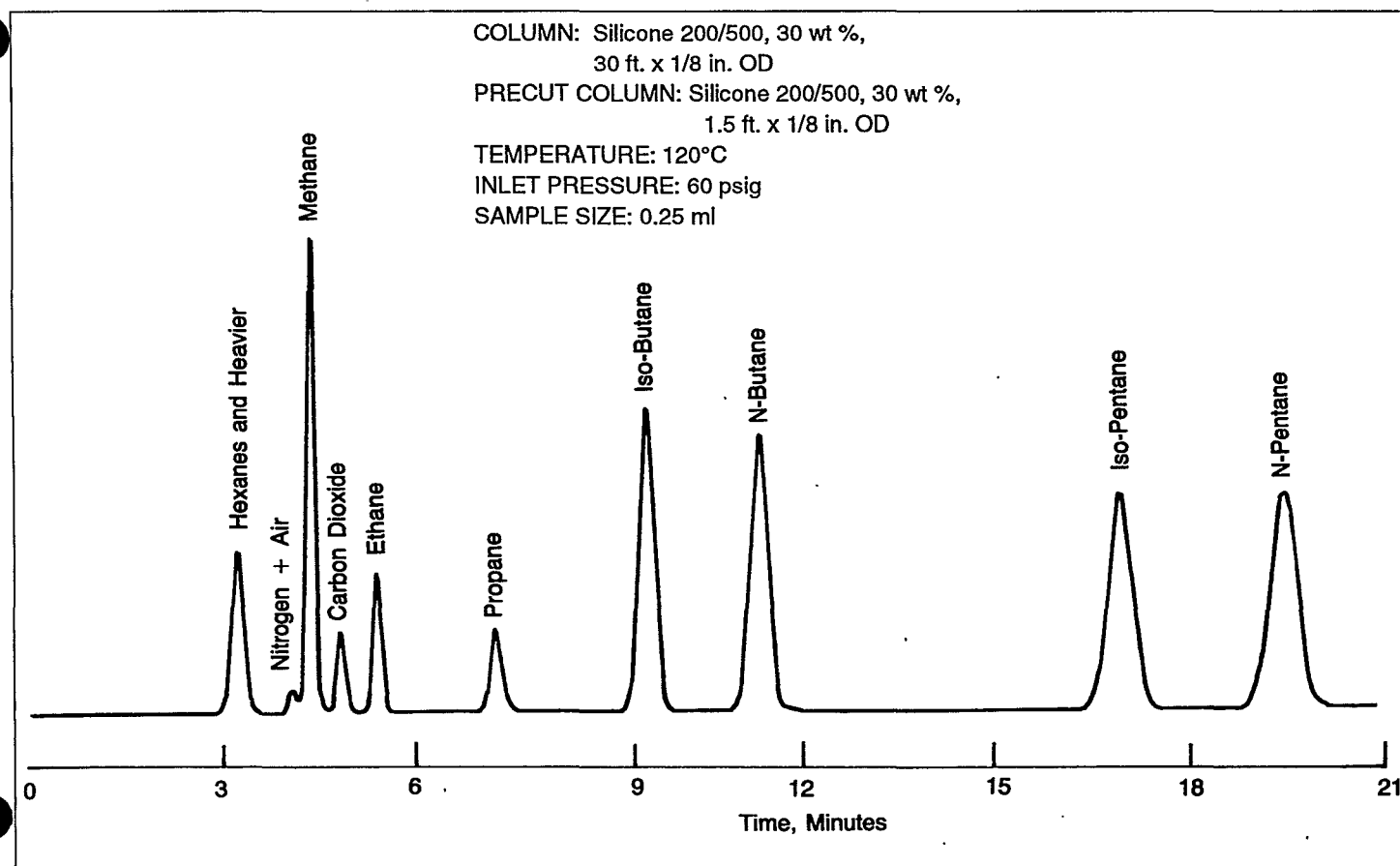


Figure 3 – Chromatogram of Natural Gas Mixture Using Precut Column for Grouping Hexanes and Heavier.

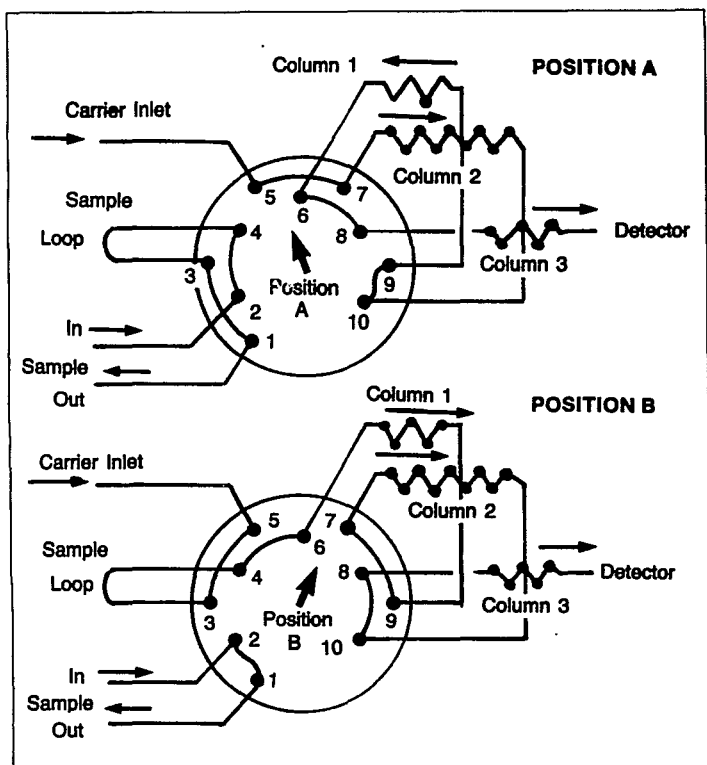


Figure 5 – Column Switching/Sampling Valve in Precut Column Arrangement.

3.6 **Vacuum Pump**—Must have the capability of producing a vacuum of 1 mm of mercury absolute or less.

4. LINEARITY CHECK

4.1 In order to establish linearity of response for the thermal conductivity detector, it is necessary to carry out the procedure outlined below:

4.2 The major component of interest (methane for natural gas) is charged to the chromatograph via the fixed size sample loop at partial pressures of 100-700 mm of Hg in increments of 100 mm. The peak area of the methane is plotted vs partial pressure. Any deviation from linearity indicates the fixed volume sample loop is too large. The sample size should be reduced until the pure major component is linear over the concentration range expected in the samples.

4.2.1 Connect the pure component source to the sample entry system. Evacuate the sample entry system and observe vacuum gage or manometer for any leaks. (See Figure 6 for a suggested manifold arrangement.) The sample entry system must be vacuum tight.

4.2.2 Carefully open needle valve to admit the pure component up to 100 mm of partial pressure.

4.2.3 Record exact partial pressure and actuate sample valve to place sample onto column. Record peak area of pure component.

4.2.4 Repeat 4.2.3 for 200, 300, 400, 500, 600, and 700 mm of mercury. Record peak area obtained at each pressure.

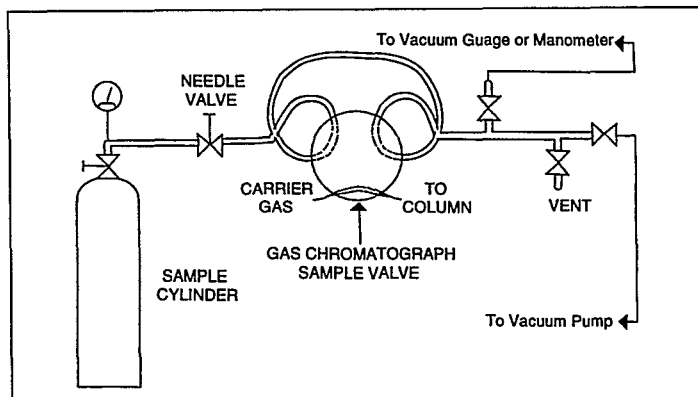


Figure 6 – Suggested Manifold Arrangement for Entering Vacuum Samples.

4.2.5 Plot the area data versus partial pressure on the x and y axes of linear graph paper as shown in Figure 7.

NOTE 8—Experience has shown that if the major component is linear over the expected concentration range in the sample, the lesser components will also be linear. Methane and ethane exhibit less than 1% compressibility at 760 mm Hg and are therefore the components of choice for linearity checks.

CAUTION: *n*-Butane at atmospheric pressure exhibits 3.5% compressibility, which, if the detector response is linear, will produce a non-linear response opposite to detector non-linearity.

5. CALIBRATION PROCEDURE

5.1 Response factors of the components of interest can be established in two ways. The routine method is to use a gas reference standard of known composition to determine response factors, provided all components in the reference standard and in the unknown samples lie within the proven linear range for a specific chromatography instrument. An acceptable non-routine method of determining response factors is to charge the pure components to the chromatograph. The latter method is described in Appendix A.

5.1.1 Connect the reference standard gas to the sample entry system. Evacuate the sample entry system and observe the vacuum gage or manometer for any leaks.

5.1.2 Carefully open the needle valve to admit reference standard gas up to some predetermined partial pressure.

NOTE 9—The use of some constant partial pressure below atmospheric pressure avoids variations in sample size due to changes in barometric pressure.

5.1.3 Record the partial pressure and operate the gas sampling valve to place the sample onto the column. Record the chromatogram, integrator/computer peak areas and peak retention times.

NOTE 10—It is recommended that the integrator/computer have the capability to print out retention times of peak maxima to aid in peak identification and to monitor instrument conditions for unknown changes.

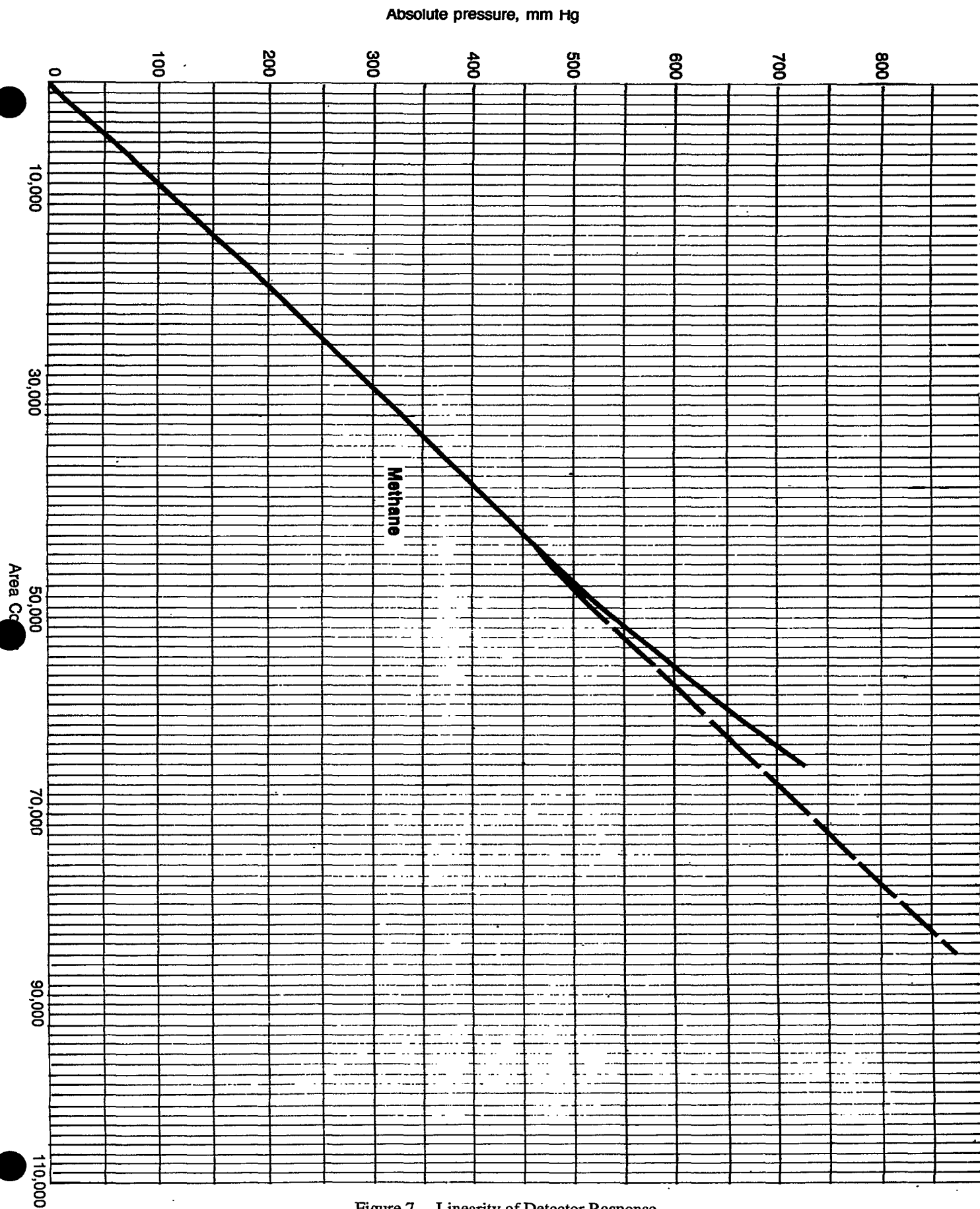


Figure 7 - Linearity of Detector Response.

6. ANALYTICAL PROCEDURE

6.1 *General*—The full range analysis of a gaseous sample requires first a run on an adsorption column to determine oxygen and nitrogen; second, a run on a partition column to determine methane, carbon dioxide, ethane and heavier hydrocarbons. If carbon dioxide content is critical in the unknown samples and does not closely match the carbon dioxide in the reference standard, a third run must be made using a porous polymer column. If helium and/or hydrogen are to be determined, a fourth run is needed using an adsorption column with nitrogen or argon as the carrier gas. These runs are independent and may be made in any order, or may be made separately to obtain less than the full range analysis.

6.1.1 Response factors or response curves derived from proven calibration data are essential to accurately determine the composition of an unknown sample. Response factors, determined from gas reference standards of known composition, are acceptable for most routine analyses. The gas reference standard and the unknown must be run using identical instrument operating conditions. As long as this stipulation is met, numerous samples can be calculated from a single gas reference standard run. It is, however, considered good operating practice to run a gas reference standard or a gas check standard at the beginning of each operating day to verify that response factors are not changing.

6.2 *Apparatus Preparation*—Connect columns to the column switching/sampling valve and mount the valve in the chromatograph oven so that it can be actuated manually or automatically. Adjust the instrument conditions to the optimum for the selected column arrangement.

NOTE 11—Most modern chromatographs have valve ovens that can be temperature controlled. It is strongly recommended in the absence of valve ovens to mount the gas sampling valve in the chromatograph oven and operate at the column temperature.

6.3 Determine response factors as outlined in Section 5, Calibration Procedure, and in Section 7.1, Calculations. Peak areas for the sample component must agree to within $\pm 0.5\%$ on repeat runs. The average of two repeat runs may be used to compute response factors.

6.4 *Preparation and Introduction of Sample*—Samples must be equilibrated in the laboratory at 20-50°F above the source temperature of the field sampling. The higher the temperature the shorter the equilibration time (approximately two hours for small sample containers of 300 ml or less). This analysis method assumes field sampling methods have removed entrained liquids.

NOTE 12—To insure representative samples in the field, select appropriate sampling method from GPA Publication 2166.

6.4.1 Connect the sample outlet valve to the sample entry system via a phosphorous pentoxide or magnesium perchlorate tube (unless gas samples are known to be moisture free, a dryer should be used). This dryer and the transport line must be maintained at the same elevated temperature (20-50°F) above the highest expected field sampling temperature. Sample

connections to the sample entry system of the chromatograph should be accomplished by using metal, teflon, nylon or some other non-absorbing materials. Rubber and plastic tubing (Tygon) should be avoided since both materials readily absorb hydrocarbons.

6.4.2 Evacuate sample entry system, including sample loop, back to valve on sample cylinder to 1 mm of mercury absolute. Close valve to vacuum source and carefully meter gas from sample cylinder until sample loop is filled to the same predetermined partial pressure as used for the reference standard. Operate chromatograph sample valve to place sample onto column. The evacuation method of sample entry at the chromatograph is preferred if hexanes and heavier concentration exceeds 0.3 mol%.

6.4.3 As an alternate to 6.4.2, if samples are known to contain a relatively small amount of hexanes and heavier, the purge technique is satisfactory. In using this technique, open the sample cylinder outlet valve and carefully purge the sample through the entry system, including the sample loop. Pass outlet from the sample loop through a tube extended just below the surface of water held in a beaker or other suitable container to indicate the rate of sample flow. Adjust the flow to one or two bubbles per second. Flush for three minutes or more. Close sample cylinder outlet valve. Remove bubble tube from water, operate chromatograph sample valve to place sample onto column.

6.4.4 *Precut Method for Nitrogen, Carbon Dioxide, Methane, and Heavier Hydrocarbons*—Using the exact instrument conditions that were used in the calibration run, inject exactly the same volume of sample. Obtain a chromatogram through n-pentane with hexanes and heavier eluting as the first peak in the chromatogram. The latter is accomplished by the column switching/sampling valve shown in Figure 5. In position A, sample is loaded into the sample loop and carrier gas is flowing through Column 2, Column 1, and Column 3 in series and in that order. In position B, sample is injected and carrier gas is flowing through Column 1, Column 2, and Column 3 in series and in that order. Still in position B, the light end components of the sample through n-pentane move through Column 1 and into Column 2. The valve is returned to position A before any hexanes and heavier material exit Column 1. The valve is left in position B for approximately two minutes, but it must be determined for each instrument. In Position A, Column 1 is placed in series down-stream of Column 2 and with carrier flow in the opposite direction of Position B. This puts the hexanes and heavier portion of the sample at a position in the column series ahead of all the light components still moving through Column 2, so it is the first peak eluted from the series of columns. The sole purpose of Column 3 is to position the hexanes and heavier peak to provide the best baseline for measurement of this peak. If oxygen and nitrogen separation is required, a second run is necessary on an adsorption column. If carbon dioxide in the unknown gas does not match closely the carbon dioxide in the reference standard, a third run is necessary on the porous polymer column.

6.4.5 Adsorption Column Run for Oxygen (Including Argon) and Nitrogen—Using the exact instrument conditions that were used in the adsorption column calibration, inject exactly the same volume of sample. Obtain chromatogram through methane and reverse carrier flow to remove remaining components from the column; argon will be included in the oxygen peak. Grade 13X molecular sieve has proven by experiment to be a satisfactory adsorbent for this separation.

6.4.6 Porous Polymer Column Run for Carbon Dioxide—Using the exact instrument conditions that were used in the porous polymer column calibration, inject exactly the same volume of sample. Obtain a chromatogram through ethane and reverse carrier flow to remove remaining components from the column.

7. CALCULATIONS FOR STANDARD BLEND WITHOUT C₆⁺ FRACTION

7.1 Response factors are calculated for each peak from nitrogen through n-pentane (Table II) using the peak area from chromatogram (5.1.3) of the reference standard in accordance with the following relationship:

$$K = M / P$$

where

K - Response factor

M - Mol% of component in reference standard

P - Peak area in arbitrary units (millimeters, square inches, counts, etc.) corrected to maximum sensitivity

Table II
Example of Response Factors Determined
from Reference Standard

Component	Response Factors
Nitrogen	$\frac{2.03}{3140} = .0006465$
Methane	$\frac{89.75}{106874} = .0008398$
Carbon Dioxide	$\frac{0.53}{1174} = .0004514$
Ethane	$\frac{3.08}{6389} = .0004821$
Propane	$\frac{1.90}{4944} = .0003843$
Isobutane	$\frac{0.97}{2962} = .0003275$
n-butane	$\frac{0.97}{3038} = .0003193$
Isopentane	$\frac{0.30}{1053} = .0002849$
n-Pentane	$\frac{0.29}{1098} = .0002641$

NOTE 13—Most integrators/computers have internal programs to calculate external response factors from a reference standard run.

7.2 Calculate mol% of each component in unknown sample.

7.2.1 Determine peak area of each component nitrogen through n-pentane from the chromatogram of the unknown sample using the same arbitrary units as in 7.1.

7.2.2 Calculate the concentration for each of these components in accordance with the following relationship:

$$M = P \times K$$

where

M - Mol% of component in unknown

P - Peak area of each component in unknown sample

K - Response factor as determined in 7.1.

7.3 Determine mol% of the precut hexanes and heavier portion of the unknown sample.

7.3.1 Determine area of the hexanes and heavier peak from chromatogram of the unknown sample in arbitrary units.

7.3.2 Determine the total area of the pentane peaks from the chromatogram of the unknown sample in the same arbitrary units.

7.3.3 To correct the hexanes and heavier (backflush) area to a mole % basis, proceed according to the following relationship:

$$\text{Corrected C}_6^+ \text{ Area} = \text{Measured C}_6^+ \text{ Area}$$

$$\times \frac{\text{Mol wt of normal C}_5}{\text{Mol wt of C}_6^+}$$

If the average molecular weight of the hexanes and heavier portion is not known, use the value found in Table IV as an acceptable approximation.

7.3.4 Calculate mol% of hexanes and heavier in the sample by the following relationship:

$$\text{Mol \% C}_6^+ \text{ in sample} = (\text{Mol \% i-C}_5 + \text{Mol \% n-C}_5)$$

$$\times \frac{\text{Corr. C}_6^+ \text{ Area}}{\text{i-C}_5 + \text{n-C}_5 \text{ Area}}$$

Tabulate this result together with the values determined for nitrogen through n-pentane. The sum of these component mol% gives the unnormalized total.

7.3.5 Sample calculation shown in Table III.

Table III
Calculation of Unknown Sample Using Response Factors

Component	Peak Area	Calibration Factor	Unnormalized Mol %	Normalized Mol %
Nitrogen	1050	.0006465	0.679	0.68
Methane	95153	.0008398	79.909	79.87
Carbon Dioxide	1255	.0004514	0.567	0.57
Ethane	21470	.0004821	10.351	10.35
Propane	13623	.0003843	5.235	5.23
Isobutane	2253	.0003275	0.738	0.74
n-Butane	4324	.0003193	1.381	1.38
Isopentane	1398	.0002849	0.398	0.40
n-Pentane	1321	.0002641	0.349	0.35
Hexanes Plus	2080*		0.442**	0.44
			100.049	100.00

* Corrected C_6^+ Area = $2080 \times \frac{72}{93.19} = 1607$

**Mol % $C_6^+ = (.398 + .349) \times \frac{1607}{1398 + 1321} = 0.442$

NOTE 14—The unnormalized total should not vary more than $\pm 1.0\%$ from 100%. If so, check for possible error or change in operating conditions of instrument between sample and reference standard run.

7.3.6 The calculation of the physical properties of natural gas is accomplished using the physical constant tables in GPA 2145 for hydrocarbons through n-pentane and inert gases. These data shown in Table IV are suggested values for the hexanes and heavier grouping. These values in Table IV should only be used if actual values are not determined by extended analysis (GPA 2286-95).

Table IV
Physical Constants for Hexanes and Heavier

	Molecular Mass	Summation Factor, b	Z Factor ¹	Relative Density of Ideal Gas	Cubic Feet Ideal Gas/ Gallon Liquid ²	Btu/Cubic Foot, Fuel as Ideal Gas ³
Hexanes & Heavier	93.191	0.0915	0.8769	3.2177	22.975	5129.3
¹ Compressibility Factor Z, at 60°F, 1 atm						
² This factor is used to calculate GPM (gallons liquid per 1000 cu ft gas)						
³ Gross, Dry, 14.696 psia, 60°F						

NOTE 15—These physical constants were calculated based on a 60:30:10 molar mixture of n-hexane, n-heptane, and n-octane. The values obtained have been found to represent hexanes and heavier fraction adequately.

8. CALCULATIONS FOR STANDARD BLEND WITH C_6^+ FRACTION.

8.1 Response factors are calculated for each peak from nitrogen through hexanes plus (Table IIA) using peak areas from chromatogram (5.1.3) of the reference standard in accordance with the following relationship:

$$K = M / P$$

where:

K - Response factor

M - Mol% of component in reference standard

P - Peak area in arbitrary units (millimeters, square inches, counts, etc.) corrected to maximum sensitivity.

NOTE: See note 13

8.2 Calculate mol% of each component in unknown sample.

Table IIA
Example of Response Factors Determined from Reference Standard with Hexanes Plus

Component	Response Factors
	2.03
Nitrogen	$\frac{3140}{2.03} = .0006465$
	89.75
Methane	$\frac{106874}{89.75} = .0008398$
	0.53
Carbon Dioxide	$\frac{1174}{0.53} = .0004514$
	3.08
Ethane	$\frac{6389}{3.08} = .0004821$
	1.90
Propane	$\frac{4944}{1.90} = .0003843$
	0.97
Isobutane	$\frac{2962}{0.97} = .0003275$
	0.97
n-Butane	$\frac{3038}{0.97} = .0003193$
	0.30
Isopentane	$\frac{1053}{0.30} = .0002849$
	0.29
n-Pentane	$\frac{1098}{0.29} = .0002641$
	0.18
Hexanes Plus	$\frac{749}{0.18} = .0002403$

8.2.1 Determine peak area of each component nitrogen through hexanes plus from the chromatogram of the unknown sample using the same arbitrary units as in 8.1.

8.2.2 Calculate the concentration for each of these components in accordance with the following relationship:

$$M = P \times K$$

where:

M - Mol% of component in unknown

P - Peak area of each component in unknown sample

K - Response factor as determined in 8.1.

8.3 Sample calculation shown in Table IIIA.

Table IIIA
Calculation of Unknown Sample Using Response Factors

Component	Peak Area	Calibration Factor	Unnormalized Mol %	Normalized Mol %
Nitrogen	1050	.0006465	0.679	0.68
Methane	95153	.0008398	79.909	79.81
Carbon Dioxide	1255	.0004514	0.567	0.57
Ethane	21470	.0004821	10.351	10.34
Propane	13623	.0003843	5.235	5.23
Isobutane	2253	.0003275	0.738	0.74
n-Butane	4324	.0003193	1.381	1.38
Isopentane	1398	.0002849	0.398	0.40
n-Pentane	1321	.0002641	0.349	0.35
Hexanes Plus	2080	.0002403	0.500	0.50
Total			100.107	100.00

NOTE: See note 14

8.3.1 The calculation of the physical properties of natural gas is accomplished using the physical constant tables in GPA 2145 for hydrocarbons through n-pentane and inert gases. The data shown in Table IV are suggested values for the hexanes and heavier grouping based on the procedure in Note 14. These values should only be used if actual values are not determined by extended analysis (GPA 2286-95).

9. PRECISION

The repeatability and reproducibility statements for this method are from the statistical data obtained in a GPA cooperative test program completed in 1982. The testing program included six samples analyzed by 21 laboratories. The method as revised in 1986 has not been statistically evaluated.

Component	Mol % Range	Percent Relative	
		Repeatability	Reproducibility
Nitrogen	1.0 - 7.7	2	7
Carbon Dioxide	0.14 - 7.9	3	12
Methane	71.6 - 86.4	.2	.7
Ethane	4.9 - 9.7	1	2
Propane	2.3 - 4.3	1	2
Isobutane	0.26 - 1.0	2	4
n-Butane	0.6 - 1.9	2	4
Isopentane	.12 - .45	3	6
n-Pentane	.14 - .42	3	6
C ₆ ⁺	.10 - .35	10	30

Repeatability is the expected precision within a laboratory using the same equipment and same analyst. Reproducibility is the expected precision when the same method is used by different laboratories using different equipment and different analysts.

APPENDIX A Supplementary Procedures

A-1. Response Factors Using Pure Components

Once linearity has been established for the instrument as described in Section 4, main text, response factors for each component to be measured in the unknown sample can be determined by using pure components.

Attach the pure component to the sample entry system and evacuate the entry system to less than 1 mm of mercury. Using the partial pressure suggested in Table A-1, inject duplicate samples of each pure component and record the peak areas. If areas on duplicate runs agree within $\pm 0.5\%$, average the areas and calculate the response factor as follows:

Table A-1
Suggested Sample Sizes for Pure Component Calibration

Component	Partial Press.	Baro. Press.	Pi/Po (100)
	mm of Hg (Pi)	mm of Hg (Po)	
Oxygen	100	750	13.33
Nitrogen	100	750	13.33
Methane	500	750	66.67
Carbon Monoxide	100	750	13.33
Carbon Dioxide	100 (650)*	750	13.33
Ethane	200 (450)*	750	26.67
Propane	100 (200)*	750	13.33
Isobutane	100 (100)*	750	13.33
n-Butane	100 (100)*	750	13.33
Isopentane	50 (50)*	750	6.67
n-Pentane	50 (50)*	750	6.67

* Partial pressures in parentheses are the maximum pressures to be used to determine response factors. Exceeding these pressures could result in low response factors caused by compressibility of the pure component.

$$K = \frac{(P_i)(100)}{(P_o)(A)}$$

where

K = Response factor

P_i = Partial pressure in mm of mercury of pure component to nearest 0.5mm

P_o = Barometric pressure in mm of mercury to nearest 0.5 mm

A = Peak area in arbitrary units (usually integrator/computer counts) of pure component

A-2. Single-Run Analysis for Carbon Dioxide, Ethane and Heavier Components

Occasionally the analysis of extremely light hydrocarbon systems such as residue gases may yield peaks in the propane and heavier components that are too small to measure accurately. In this case, it is satisfactory to use a sample volume up to 3 ml, depending on the individual basic sensitivity of the chromatograph, for the determination of the components that are too small to be obtained by regular method.

A sample similar in size to the reference standard should also be charged to the chromatograph and the peak areas of the ethane and heavier components measured. Make calculations of the ethane and heavier components in the same manner as outlined for the routine procedure. If a separation between inerts and methane is not necessary, methane and lighter may be expressed as the difference between 100% and the sum of the rest of the components (valid for all GPA sampling methods except "Helium Pop").

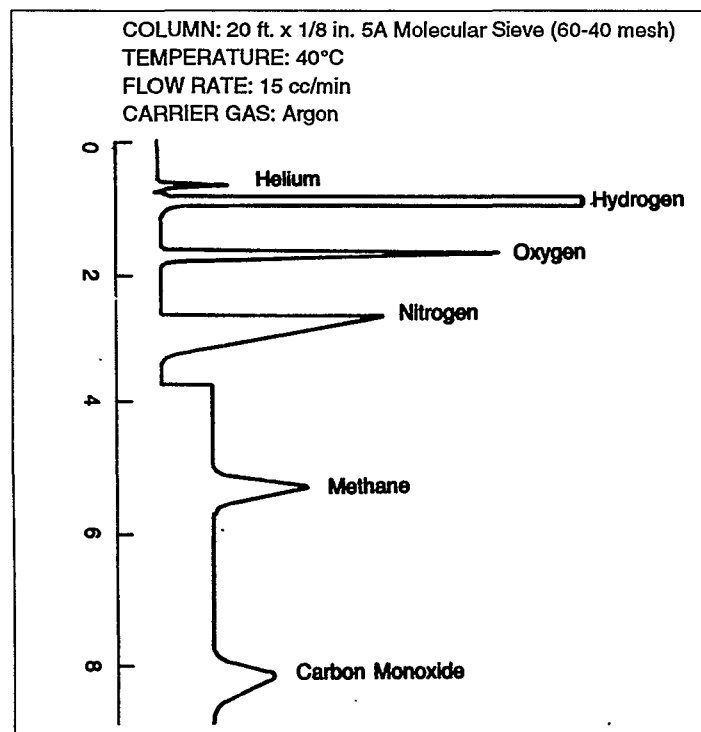


Figure A-1 – Separation of Non-Condensable Gases including Hydrogen and Helium.

A-3. Determination of Carbon Monoxide

This component is encountered in association with oxygen, nitrogen, carbon dioxide and the conventional hydrocarbons in the effluent streams from combustion processes such as insitu combustion, manufactured gas and many varied types of stack gases. No extra equipment is necessary to determine carbon monoxide since it elutes shortly after methane on the molecular sieve run. If a calibration gas is available containing carbon monoxide, obtain a response factor as for methane on the molecular sieve column. However, should a gas blend not be available, a calibration curve should be developed using pure carbon monoxide to determine the extent of the nonlinearity, if present. Figure A-1 shows a typical separation of non-condensable gases on the molecular sieve column using argon carrier gas.

A-4. Determination of Hydrogen and Helium

If hydrogen is to be separated from helium, a 20 ft molecular sieve 5A column using nitrogen or argon as a carrier gas may be used (Figure A-1). Low temperature, 40°C or less is necessary to effect this separation.

If hydrogen is present, it will elute on the standard molecular sieve run, using helium as a carrier gas, just before oxygen. The hydrogen response is downscale (negative) rather than upscale (positive). Signal polarity must be reversed for the hydrogen peak to be recorded upscale. The sensitivity and precision of measurement will be poor under these conditions due to similar thermal conductivity values for hydrogen and helium. If a calibration gas blend is available containing hydrogen and helium, it should be used to obtain response factors. However, this not being the case, the pure components, hydrogen and helium, may be used to develop response factors in the manner set forth in A-1.

A-5. Determination of Hydrogen Sulfide

As indicated earlier in this text, to be absolutely sure of the hydrogen sulfide content of a gas, determinations should be made at the sample source. However, in the case where a field measurement has not been made and although corrosion of the sample bottle may have resulted in some loss of hydrogen sulfide, a measurement of the in-place component may be made by gas chromatography. It is necessary to charge a sample of pure hydrogen sulfide to the column prior to charging the unknown gas. As soon as the pure hydrogen sulfide has cleared the column, the unknown gas should be charged. (All calibrations should be done the same way, that is, each partial pressure charge of pure hydrogen sulfide must be preceded by a full sample loop of pure hydrogen sulfide.)

A column that has proved satisfactory for this type of analysis is the Silicone 200/500 column. It is most convenient since this is the recommended column for determining the hydrocarbons in a natural gas analysis. Hydrogen sulfide elutes between ethane and propane with good resolution. **Extreme care must be taken when working with hydrogen sulfide due to the very toxic nature of the gas. The best ventilation possible must be maintained in the laboratory.**

The Maximum Allowable Concentration that a person may be exposed to without approved respiratory protection equipment is 10 ppm for an eight hour working period.

Concentrations as low as 15 ppm may cause severe irritation to the eyes and respiratory tract if the exposure lasts through the working day. Exposure of 800 to 1,000 ppm may be fatal in a few minutes. As mentioned, the nose cannot be depended upon to detect the presence of hydrogen sulfide, as 2-15 minutes of exposure will cause the loss of smell.

APPENDIX B

Preparation of Equipment

B-1 Linde Molecular Sieve Column

Clean a 10 ft. (3.05 meter) length of 1/8 in. (3.2 mm) tubing (copper, aluminum or stainless steel that is inert to the system in use), with acetone and dry with a stream of clean dry air or inert gas. Plug one end of the tubing with about 1/2 in. of glass wool.

Attach a small funnel to the other end and fill the tubing with Type 13X, 40-60 mesh, dry Linde Molecular Sieve. Continuously vibrate the tubing while filling by moving an electric vibrator up and down the length of the tubing. When completely full, remove about 1/2 in. (10 to 15 mm) of the packing and replace with glass wool. Shape the finished column to mount conveniently in the chromatograph.

This column will separate hydrogen, oxygen, nitrogen, methane and carbon monoxide. About 10 psig carrier gas pressure at the inlet will give suitable flow rate.

B-2 Silicone 200/500 Column

Clean a 30 ft. (9.15 meter) length of 1/8 in. (3.2 mm) tubing with acetone and dry with a stream of clean dry air or inert gas. Bend into a U-shape for filling.

Dilute 17 grams of silicone 200/500 with about 150 grams of ethyl ether in a filter flask and add 40 grams of 80-100 mesh Chromosorb P. Shake the flask to disperse the solvent. Connect a vacuum line to the flask to aid in solvent removal. Swirl the flask gently several times while removing the solvent to avoid concentration of the silicone oil in the upper layer.

Admit the packing into both ends of the tubing, using a small funnel and electric vibrator continuously to completely fill the column. Plug each end with 1/2 in. (10-15 mm) of glass wool. Shape the column into approximately a 9 in. diameter coil (no smaller than 4 in. diameter) and with zero volume fittings, mount the column at ports #7 and #10 of the column switching/sampling valve. This column will separate air, methane, carbon dioxide, ethane, hydrogen sulfide, propane, isobutane, n-butane, isopentane, n-pentane, and other natural gas hydrocarbons as described in the method.

B-2.1 Clean a 1.5 ft. (0.46 meter) length of 1/8 in. (3.2 mm) tubing with acetone and dry with a stream of clean dry air or inert gas. Fill this column with the same packing used in B-2. Plug the ends with glass wool and mount the column at ports #6 and #9 of the column switching sampling valve.

B-2.2 Clean a 20 in. (0.51 meter) length of 1/8 in. (3.2 mm) tubing with acetone and dry with a stream of clean dry air or inert gas.

Dilute 0.25 grams of silicone 200/500 with about 75 grams of ethyl ether in a filter flask and add 20 grams of 80-100 mesh Chromosorb P. Shake the flask to disperse the solvent. Connect

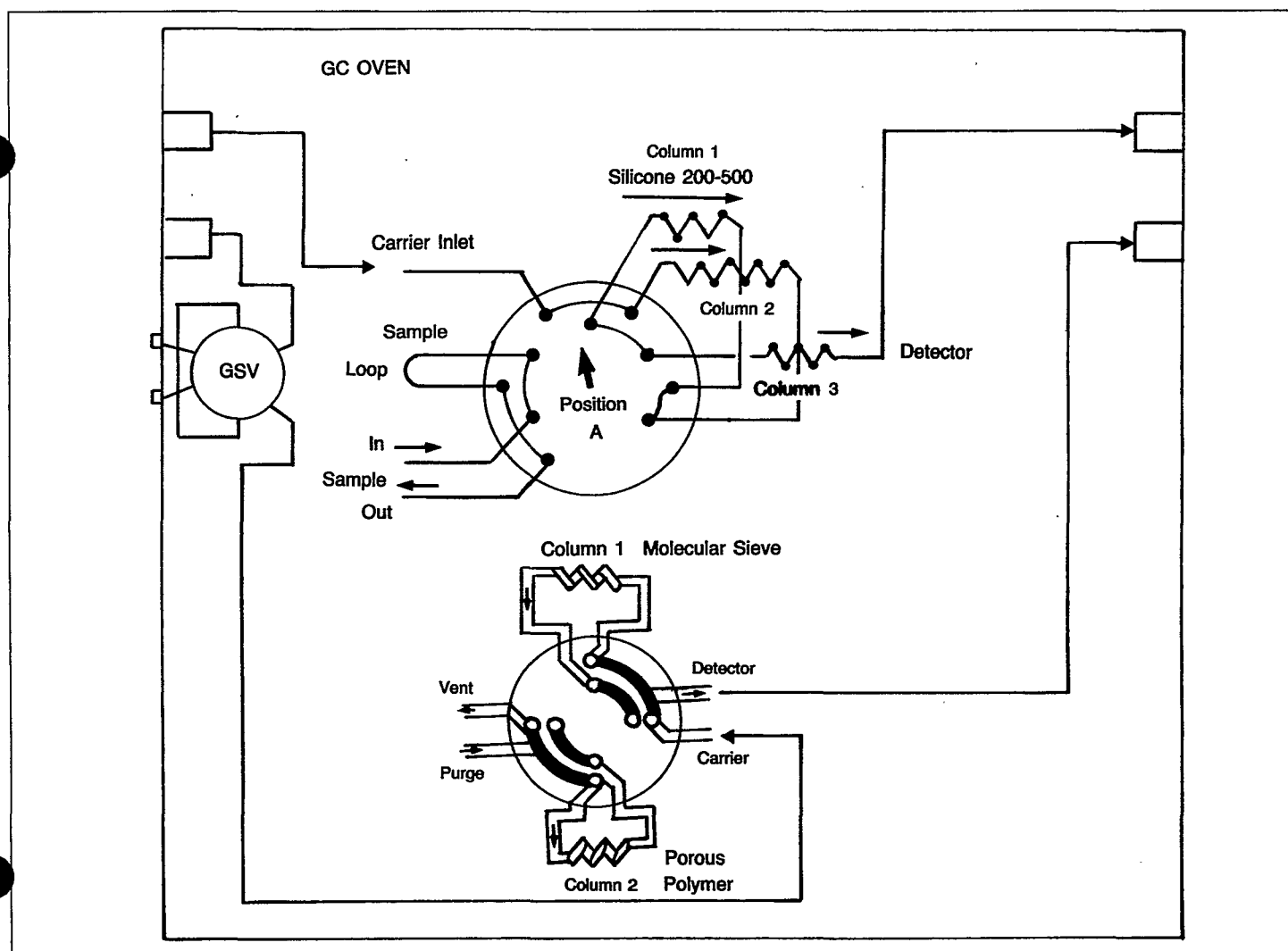


Figure B-1 – Column Arrangement for Natural Gas Analysis Using One Gas Chromatograph.

a vacuum line to the flask to aid in solvent removal. Swirl the flask gently several times while removing the solvent to avoid concentration of the silicone oil in the upper layer.

Fill this column with packing in the same manner as used in B-2. 1. Plug the ends with glass wool and mount the column at port #8 of the column switching/ sampling valve and at the inlet to the detector.

B-3. Porous Polymer Column

Clean a 10 ft. (3.05 meter) length of 1/8 in. (3.2 mm) tubing with acetone and dry with a stream of clean dry air or inert gas. Bend into a U-shape for filling. Fill the column as described in B-2. Plug the ends with glass wool and shape the column as described in B-2, to mount in the chromatograph.

NOTE 15—By selecting the proper lengths of columns for oxygen and nitrogen separation on the molecular sieve column, and for methane, carbon dioxide, and ethane, on the porous polymer column, a single chromatograph can be equipped to make the compositional analysis described in this method. Hydrogen, helium, and carbon monoxide must be done at operating temperatures of 40° C or less. Recommended column lengths for operating temperatures of 100-140 °C for the

molecular sieve column and for the porous polymer column are 25 and 15 ft. respectively. A suitable instrument/valve arrangement for single instrument operation is shown in Figure B-1.

B-4. Preparation of Dryer

Fill a glass or stainless steel tube about 1/2 inch (10-15 mm) diameter by 3 inch (7.5 cm) long with an indicating moisture absorbent containing phosphorous pentoxide or with granular magnesium perchlorate and plug both ends of the tube with glass wool. Mount as required to dry the sample stream and replace as necessary before drying agent becomes total saturated and ineffective.

B-5. Preparation of a Reference Standard by Weight

Material required:

- 5 gallon cylinder.
- 2,000 gram balance, sensitivity 10 mg.
- 100 ml pressure cylinder,
- Pure components, methane through n-pentane and carbon dioxide.

All materials except methane, carbon dioxide, and possibly ethane, will be added as liquid.

The pure components should be 99+% pure. Run chromatogram on each component to check the purity.

Evacuate the five gallon cylinder for several hours. Connect the 100 ml cylinder to a source of pure n-pentane with a metal connection of calculated length to contain approximately the amount of n-pentane to be added. Flush the connection with the n-pentane by loosening the fitting at the 100ml cylinder valve.

Tighten the fitting. Close the n-pentane valve and open the 100 ml cylinder valve to admit the n-pentane from the connection and then close. Disconnect and weigh the 100 ml cylinder to obtain the weight of n-pentane added.

Similarly, using connections of suitable length for each component, add isopentane, n-butane, isobutane, propane, ethane, and carbon dioxide as desired to include in the reference standard. Weigh the 100 ml cylinder after each addition to obtain weight of component added.

Connect the 100 ml cylinder to the five gallon cylinder using as short a connection as possible. Open valves on both cylinders to transfer the sample. Disconnect and weigh the 100 ml cylinder to obtain weight of sample not transferred. Analyze the material remaining in the 100 ml cylinder and calculate the weight of all components transferred into the five gallon cylinder.

Weigh a one quart cylinder containing pure methane at about 1500 pounds pressure. Transfer the methane to the five gallon cylinder until the pressure equalizes. Weigh the one quart cylinder to determine the weight of methane transferred.

Thoroughly mix the contents of the five gallon cylinder by heating at the bottom by convenient means such as hot water or heat lamp and leaving in vertical position for six hours or longer.

From the weights and purities of all components added, calculate the composition and convert the weight % to mol %.

APPENDIX C

Precautions to Avoid Common Cause of Errors

C-1. Hexanes and Heavier Content Change

The amounts of heavy-end components in natural gas are easily changed during handling and entering of samples to give seriously erroneous low or high values.

Concentration of these components has been observed to occur in a number of cases due to collection of heavier components in the sample loop during purging of the system. The surface of small diameter tubing acts as a separating column and therefore must be heated to the column temperature when used in the sampling and entering system.

An accumulation of oily film in the sampling system greatly aggravates the collection of heavier components in the sample entry system. Also, the richer the gas the worse the problem.

This trouble has been experienced with some inlet systems even when clean and with the specified loop size. A safeguard then is to install a vacuum system so that the sample can be

entered into an evacuated holder instead of by purging. For very rich gases, heat tracing of all sample entry lines may be necessary.

C-2. Acid Gas Content Change

The carbon dioxide and hydrogen sulfide contents of gas are easily altered during sampling and handling. It is usually advisable to determine these components at the sampling source. If samples containing carbon dioxide and/or hydrogen sulfide are to be taken, use completely dry sample cylinders, connections, and lines, as moisture will selectively absorb appreciable amounts of the acid gases. If hydrogen sulfide is present, use stainless steel, or other materials inert to hydrogen sulfide for the cylinder, valves, lines, and connections.

C-3. Sample Inlet System

Do not use rubber or plastic that may preferentially absorb sample components. Keep the system short and the dryer small to minimize purging required.

C-4. Sample Size Reproducibility

Varying back pressures on the sample loop may impair sample size repeatability when using the purge technique for sample entry. Keep the outlet tube from the sample loop just below the water level in the beaker or remove it entirely from the water before manipulating the sampling valve.

C-5. Backflush

Be sure the inlet dryer is in good condition. Moisture on the column will enlarge the backflush peak.

Be sure the column is clean by making a blank run each morning to clear the column of any residual or spurious materials.

Installation of the short column between the detector inlet and the switching/sampling valve has two distinct advantages: (1) It properly locates the hexanes and heavier peak for best baseline treatment, and (2) It quite often reduces baseline upset due to valve actuation.

C-6. Reference Standard

It is recommended that a Natural Gas Reference Standard be heated to a minimum of 125° F (51.7° C) or 20° F (11° C) above its hydrocarbon dew point, whichever is greater, for at least 12 hours before attempting to analyze. The heating element should be installed at the bottom of the cylinder to assure complete vaporization and convective mixing occurs. Insulation of the cylinder is required to minimize heat loss (see GPA-2198-98).

C-7. Miscellaneous

Moisture in the carrier gas that would cause trouble on the backflush may be safeguarded against by installing a cartridge of molecular sieves in the carrier gas line ahead of the instrument. Usually a 300 ml cylinder filled with activated molecular sieves (3A, 4A, 5A, 13X) is adequate if changed twice a year.

Use electrical contact cleaner on attenuator if noisy contacts are indicated.

Appendix D

Calculations Performed in Association with Gas Analyses

PREFACE

All physical constants used in these calculations should come from the most recent edition of GPA 2145. The constants used in the examples that follow are from GPA 2145-95.

The following physical constants not listed in GPA 2145 have been used in some of the calculations:

0.25636 = vapor pressure of H₂O (psia) @ 60°F (reference: U.S. Bureau of Standards)

1230 = vapor pressure of CO₂ (psia) @ 100°F

5000 = vapor pressure of N₂ (psia) @ 100°F

\bar{R} = Gas Constant = 10.7316 (psia • cu.ft.)/(°R • lb – mol)

Cu.ft./lb – mol of any gas at 14.696 psia and 60°F = $\frac{V}{n} = \frac{\bar{R}T}{P}$

$$= \frac{(10.7316)(459.67 + 60)}{(14.696)}$$

$$= 379.48357$$

Constant values for hexanes plus (C₆⁺) or heptanes plus (C₇⁺) if not actually determined by extended analysis should be mutually agreed upon by all concerned parties.

For ease of hand calculations in the examples shown the number of significant figures does not match those shown in GPA-2145. Precision of numbers in computer generated calculations should match that of GPA-2145. Rounding of numbers can cause some differences in final results. Computer generated calculations should only round those final numbers displayed on analyses, not numbers generated in intermediate calculations.

For those calculations that are pressure dependent, the mathematics should be carried out using the constants at a pressure base of 14.696 and the final result converted to the desired pressure base after all other mathematical functions are completed. Conversion of the physical constants to equivalent values at other pressure bases or the use of generated secondary factors prior to performing calculations is not recommended.

It is further recommended that computer software be written to follow these methods and recommendations and that hardbound documentation of the software programs be maintained and available at all times.

For use in these calculations, mol fraction shall be equal to: mol%/100.

Calculation of Physical Properties from Mol Fraction

D.1 Calculation of Heating Value (Btu), Relative Density (Specific Gravity) and Compressibility Factor (Z).

The reader is referred to GPA 2172 for the proper method of calculation for these properties.

D.2 Calculation of GPM (Liquid Volume Equivalent Expressed as Gallons per 1000 cu. ft. of Gas) of Natural Gas.

Component	Column 1	Column 2	Column 3	Column 4
	<u>Mol Fraction</u>	<u>Cu. Ft./Gallon</u> <u>@ 14.696 psia</u> GPA-2145	<u>GPM @ 14.696 psia</u> (Col. 1 x 1000)/Col. 2	<u>GPM @ 14.650 psia</u> Col. 3 x $\frac{14.650}{14.696}$
Nitrogen	0.0068	91.413		
Methane	0.7987	59.135		
Carbon Dioxide	0.0056	58.807		
Ethane	0.1034	37.476	2.759	2.7504
Propane	0.0523	36.375	1.438	1.4335
Isobutane	0.0074	30.639	0.242	0.2412
n-Butane	0.0138	31.791	0.434	0.4326
Isopentane	0.0040	27.380	0.146	0.1455
n-Pentane	0.0035	27.673	0.126	0.1256
Hexanes Plus	0.0045	23.235*	0.194	0.1934
Totals	1.0000	C ₂ ⁺ GPM = C ₃ ⁺ GPM = IC ₅ ⁺ GPM =	5.339 2.580 0.466	5.3222 2.5718 0.4645

* Arbitrarily assumed value (used if average value not determined).

Note: It is recommended that this calculation be carried out using cu.ft./gallon constants at a pressure base of 14.696 psia until the final calculation at which time GPM can be converted to any desired pressure base as shown. Conversion of or manipulation of constants prior to performing the calculation is not recommended.

D.3 Calculation of 26-70 Gasoline Content of Natural Gas.

Component	Column 1	Column 2	Column 3
	<u>Mol Fraction</u>	<u>Vapor Pressure</u> GPA-2145	<u>Partial Pressure</u> Col. 1 x Col. 2
Isopentane	0.0040	20.450	0.0818
n-Pentane	0.0035	15.580	0.0545
Hexanes Plus	0.0045	3.683*	0.0166
Total	A = 0.0120		B = 0.1529

* Arbitrarily assumed value (used if average value not determined).

Note: The reader is directed to the GPSA Engineering Data Book, Vol. I, Section 6 (Storage), Figure 6-4 for conversion of Reid Vapor Pressure to True Vapor Pressure.

Mol Fraction of nC_4 Required to Produce 26 PSI Gasoline:

$$[(27.5 \times A) - B] \div 24.22 = \text{mol fraction of } nC_4 \text{ required}$$

$$[(27.5 \times 0.012) - 0.1529] \div 24.22 = 0.0073$$

Where: 27.5 = True Vapor Pressure (psia) required to obtain an ASTM Reid Vapor Pressure of 26 psi.

24.22 = nC_4 Vapor Pressure (51.72) - required pressure (27.5)

A = Sum of mol fractions of C_5^+ components.

B = Sum of Partial Pressures of C_5^+ components.

Component	Column 1	Column 2	Column 3
	Mol Fraction	Cu. Ft./Gallon	GPM @ 14.696 psia
		GPA-2145	Col. 1 x 1000 Col. 2
n-Butane	0.0073	31.791	0.2296
Isopentane	0.0040	27.380	0.1461
n-Pentane	0.0035	27.673	0.1265
Hexanes Plus	0.0045	23.235*	0.1937

* Arbitrarily assumed value (used if average value not determined).

D.4 Calculation of 14 psi Reid Vapor Pressure Gasoline Content of Natural Gas.

14 psi Reid Vapor Pressure Gasoline content is calculated in exactly the same manner as 26 psi Gasoline with the following two changes:

- (1) 15.25 is used in place of 27.5 as the required True Vapor Pressure to obtain a correct reading of 14 psi Reid.
- (2) 36.47 is used in place of 24.22 as the difference between NC_4 True Vapor Pressure and required pressure.

D.5 Calculation of Actual Btu (Based on Field Determined H_2O Content) of Natural Gas.

$$\text{Actual Btu/cu. ft.} = \text{Dry Btu @ PB} \times \left[\left(1 - \frac{\text{Pounds}}{1000000} \times \frac{1000 \text{ cu. ft.}}{47.473^* \text{ lb. mol per 1000 cu. ft.}} \times \frac{14.696}{\text{PB}} \right) \right]$$

Where: PB = Pressure Base (psia) of Dry Btu

Pounds = Field determined H_2O Content in pounds per MMcf

* From GPA 2145 latest version

D.6. Calculation of Btu per pound of Natural Gas.

D.6a Calculation of Weight Fraction.

Component	Column 1	Column 2	Column 3	Column 4
	Mol Fraction	Molecular Wt.	Comp. Pounds	Weight Fraction
		GPA-2145	Col. 1 x Col. 2	Col. 3 Sample Mol. Wt.
Nitrogen	0.0068	28.013	0.1905	0.0091
Methane	0.7987	16.043	12.8135	0.6144
Carbon Dioxide	0.0056	44.010	0.2465	0.0118
Ethane	0.1034	30.070	3.1092	0.1491
Propane	0.0523	44.097	2.3063	0.1106
Isobutane	0.0074	58.123	0.4301	0.0206
n-Butane	0.0138	58.123	0.8021	0.0385
Isopentane	0.0040	72.150	0.2886	0.0138
n-Pentane	0.0035	72.150	0.2525	0.0121
Hexanes Plus	0.0045	92.489*	0.4162	0.0200
Total	1.0000	Sample Mol. Wt. = 20.8555		1.0000

* Arbitrarily assumed value (used if average value not determined).

D.6b Calculation of Btu/lb.

Component	Column 1	Column 2	Column 3
	Weight Fraction	Btu/lb. Mass	Comp. Btu/lb.
		GPA-2145	Col. 1 x Col. 2
Nitrogen	0.0091	—	0
Methane	0.6144	23891	14679
Carbon Dioxide	0.0118	—	0
Ethane	0.1491	22333	3330
Propane	0.1106	21653	2395
Isobutane	0.0206	21232	437
n-Butane	0.0385	21300	820
Isopentane	0.0138	21043	290
n-Pentane	0.0121	21085	255
Hexanes Plus	0.0200	20899*	418
Total	1.0000	Btu/lb. mass = 22624	

* Arbitrarily assumed value (used if average value not determined).

- Notes: 1. Btu/lb. mass constants from GPA-2145 are fuel as ideal gas.
 2. Since mass is not pressure dependent the final sample Btu/lb. mass should not be adjusted for any pressure base corrections.

D-7. Conversion of Known Btu Value to Btu Value at Different Condition.

Btu Conversion Factors

Conditions of Known Btu		Required Btu Conditions									
		14.650 psia		14.696 psia		14.730 psia		14.735 psia		15.025 psia	
		Dry	Sat	Dry	Sat	Dry	Sat	Dry	Sat	Dry	Sat
Multiply By:											
14.650 psia	Dry	1.000	0.9825	1.0031	0.9856	1.0055	0.9880	1.0058	0.9883	1.0256	1.0081
	Sat	1.0178	1.0000	1.0210	1.0032	1.0234	1.0056	1.0237	1.0059	1.0439	1.0261
14.696 psia	Dry	0.9969	0.9794	1.0000	0.9826	1.0023	0.9849	1.0027	0.9852	1.0224	1.0049
	Sat	1.0146	0.9968	1.0178	1.0000	1.0201	1.0024	1.0205	1.0027	1.0405	1.0228
14.730 psia	Dry	0.9946	0.9772	0.9977	0.9803	1.0000	0.9826	1.0003	0.9829	1.0200	1.0026
	Sat	1.0122	0.9945	1.0154	0.9977	1.0177	1.0000	1.0181	1.0003	1.0381	1.0204
14.735 psia	Dry	0.9942	0.9768	0.9974	0.9800	0.9997	0.9823	1.0000	0.9826	1.0197	1.0023
	Sat	1.0118	0.9941	1.0150	0.9973	1.0174	0.9997	1.0177	1.0000	1.0377	1.0200
15.025 psia	Dry	0.9750	0.9580	0.9781	0.9610	0.9804	0.9633	0.9807	0.9636	1.0000	0.9829
	Sat	0.9920	0.9746	0.9951	0.9777	0.9974	0.9800	0.9977	0.9804	1.0174	1.0000

Note: Sat (saturation) assumes that the gas contains all of the water vapor it can hold at 60°F and the indicated pressure base.

Formulas Used to Derive Btu Conversion Factors

1. Dry to Dry: $\frac{\text{PB Required}}{\text{Known Dry Btu PB}} \times \text{Known Dry Btu}$
2. Dry to Sat: $\frac{\text{PB Required} - 0.25636}{\text{Known Dry Btu PB}} \times \text{Known Dry Btu}$
3. Sat to Dry: $\frac{\text{PB Required}}{\text{Known Sat Btu PB} - 0.25636} \times \text{Known Sat Btu}$
4. Sat to Sat: $\frac{\text{PB Required} - 0.25636}{\text{Known Sat Btu PB} - 0.25636} \times \text{Known Sat Btu}$

Where: PB = pressure base (psia)