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The Composition of Coalbed Gas

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THE COMPOSITION OF COALBED GAS

by

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ABSTRACT

Samples of gas were obtained directly from the coalbed during drilling of horizontal and vertical boreholes in six different formations. The samples were analyzed by gas chromatography for C_1 to C_5 hydrocarbons and for O_2, N_2, H_2, He, and CO_2. Methane in the gas varied from 63 to 99 percent; carbon dioxide from 0.1 to 15 percent. The CH_4/CO_2 ratio varied and showed no apparent correlation with age, rank, or bed. The majority of samples contained ethane, propane, and butane; hydrogen and helium were found in some samples. Oxygen and nitrogen were usually present, possibly as a result of air contamination. A more extensive sampling program would be necessary to establish relationship between the amount and composition of the gas in the coalbed and other factors.

INTRODUCTION

The existence of gas in coal and its release during mining has been common knowledge, probably since the beginning of coal mining. Until about the middle of the 20th century coalbed gas was considered a mixture of methane (firedamp) and carbon dioxide (blackdamp). Ethane, when detected, was attributed to contamination from natural gas horizons below the coal (14).[2] More recent analyses of coalbed gas have shown it to be a complex mixture, containing in addition to methane and CO_2, higher homologs of methane and other inorganic gases (8, 11).

GAS IN COAL: THEORY

Coalification involves a series of biochemical and geochemical reactions that transform plant material into a combustible, carbonaceous solid. The rank designations, lignite, bituminous, and anthracite are roughly equivalent to different stages in a sequential transformation. Low molecular-weight hydrocarbons and carbon dioxide are gaseous byproducts of coalification. Aliphatic hydrocarbons can form by removal of alkyl side chains from aromatic

[1] Chemist.

[2] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

molecules, by decomposition of longer straight-chain molecules, or by condensation of straight-chain molecules into ring structures. Carbon dioxide is produced by oxidation of organic material, primarily during early stages of coalification. The ratio of methane to carbon dioxide is believed to increase during coalification. Hydrogen is also thought to be a product of the coal-forming process. Oxygen and nitrogen are occluded during the deposition of the organic sediment. They may also be introduced into the coalbed by percolating ground water. Most of the oxygen is consumed by the formation of CO_2. Helium is a product of radioactive decay (3-5).

The postdepositional history also affects the gas contained in the coal. Coal is a highly porous solid with two distinct pore systems. The macropore system consists of cracks and fractures; the micropores have an average diameter of 5 to 20 Å. Gases can exist as free gases in the macropores or be adsorbed on the surface of the micropores. The amount of gas in the bed depends on temperature, pressure, degree of fracturing, and permeability of coal and adjacent strata (1, 12-13).

PROCEDURES

During studies on the use of horizontal and vertical boreholes in methane emission control (2, 7), Bureau personnel collected gas samples directly from six coalbeds. The gas samples were obtained by inserting a sealed evacuated gas sampling bottle with a capacity of about 250 ml into the borehole. The tip of the bottle was broken and the bottle was allowed to fill with the coalbed gas. Then the tip was capped with a wax-filled cartridge. Contamination with air was a serious problem. Generally a sample containing more than 8 percent N_2 and 2 percent O_2 was considered to be highly contaminated and not included in calculation of gas composition.

The gas samples were analyzed by gas chromatography in the Bureau gas analysis laboratory. Samples are introduced into the sample loop of the gas chromatograph through a mercury displacement valve. A 1-ml sample is split between two parallel columns--molecular sieve 5A column and a porous polymer (or silica gel) column. The molecular sieve column leads to thermal conductivity and flame ionization detectors in series which detect O_2, N_2, and hydrocarbons, methane through pentane. Carbon dioxide is separated by the second column and is detected by thermal conductivity detector. Temperature of the columns is 100° C; helium is the carrier gas (6).

A second 1-ml sample was used to determine hydrogen and helium. The gases were separated on a molecular sieve 5A column at room temperature; thermal conductivity detector and argon carrier gas were used. The sensitivity of analysis was 0.0001 percent for hydrocarbons and 0.01 percent for O_2, N_2, H_2, He, and CO_2. The accuracy of analysis is generally ±1 percent of the amount present.

GASES IN COAL: DATA

Table 1 gives coalbeds and locations where gases were sampled, as well as the type of borehole and the number of gas samples used to calculate the average composition of the gas. The results of the analyses are summarized in tables 2 and 4 through 6. The average percentage and standard deviation are given for each component of the gas.

TABLE 1. - Coalbeds sampled

Site number	Coalbed	Location	Average depth[1] of overburden (feet)	Coal[1] thickness (inches)	Type of borehole	Number of samples
1	Pocahontas No. 3.	Dismal Creek, Buchanan County, Va.	1,162	54	Horizontal	32
2	.......do........	Keen Mountain, Buchanan County, Va.	1,925	54	....do....	17
3	.......do........	Grundy, Buchanan County, Va.	1,925	54	....do....	2
4	.......do........	Van Sant, Buchanan County, Va.	1,925	54	....do....	9
5	Pittsburgh.......	Bobtown, Greene County, Pa.	225	56	....do....	4
6	.......do........	Marianna, Washington County, Pa.	399	60	....do....	3
7	.......do........	Fairview, Marion County, W. Va.	721	96	....do....	2
8	.......do........	..........do..........	721	96	Vertical..	2
9	Upper Kittanning.	Ebensburg, Cambria County, Pa.	753	42	Horizontal	3
10	.......do........	..........do..........	753	42	Vertical..	3
11	B Seam, Mesaverde Formation.	Carbondale, Pitkin County, Colo.	(0-2,500)	81	Horizontal	3
12	Lower Hartshorne.	Heavener, LeFlore County, Okla.	350	39	....do....	2
13	Mary Lee.........	Oak Grove Area, Jefferson County, Ala.	1,070	63	Vertical..	2

[1]Methane Emission From U.S. Coal Mines (9).

TABLE 2. - Composition of gas from Pocahontas No. 3 coal

Site	No. 1[1]		No. 2		No. 3		No. 4	
component	Percent	±	Percent	±	Percent	±	Percent	±
CH_4..........	97.07	1.75	95.93	1.70	63.1	2.4	97.61	0.24
C_2H_6.........	1.25	0.58	1.59	0.5	0.85	0.07	1.32	0.23
C_3H_8.........	0.0011	0.0021	0.0109	0.0337	-	-	0.0027	0.0012
C_4H_{10}[2].......	0.0001	0.0003	0.0010	0.0013	-	-	0.0013	0.0005
C_5H_{12}[2].......	-	-	Tr[3]	-	-	-	-	-
CO_2..........	0.20	0.31	0.57	0.21	0.06	0.01	0.30	0.14
O_2..........	0.16	0.24	0.31	0.40	-	-	0.04	0.05
N_2..........	2.79	1.74	1.61	1.52	35.96	2.48	0.70	0.12
H_2..........	0.02	0.02	ND[4]	-	0.005	0.0	-	-
He..........	0.05	0.02	ND[4]	-	0.03	0.0	0.02	0.02

[1]Numbers refer to table 1.
[2]All isomers.
[3]Tr: Trace, less than 1 ppm.
[4]ND: Not determined.

The samples from the Pocahontas No. 3 coalbed were taken from horizontal boreholes drilled in four mines within one county. The composition of the gas from three of the drilling sites (1, 2, and 4) is relatively constant. Gas obtained at site No. 3 contains an exceptionally high percentage of nitrogen, which cannot be attributed to air contamination (table 2). Gases from Pocahontas No. 3 commonly contain higher hydrocarbons-ethane, with smaller amounts of propane and butanes. If only hydrocarbon gases are considered, the calculated composition of the gas from all four sites shows close agreement (table 3). Hydrogen and helium are frequently detected in gas samples from this bed.

TABLE 3. - Hydrocarbons from Pocahontas No. 3 coal

(Percent)

Site component	No. 1	No. 2	No. 3	No. 4
CH_4	98.73	98.36	98.67	98.66
C_2H_6	1.27	1.63	1.33	1.33
C_3H_8	0.0011	0.0112	-	0.0027
C_4H_{10}	0.0001	0.0010	-	0.0013
C_5H_{12}	-	Trace	-	-

Analyses of gas samples from the Pittsburgh coalbeds are summarized in table 4. Sites No. 5 and No. 6 were located in Pennsylvania, approximately 30 miles apart. Samples were obtained from horizontal boreholes, but contain substantially different amounts of methane and CO_2. Site No. 7 was a vertical borehole and No. 8 was a horizontal borehole, drilled at the same location in West Virginia. The percentage of CO_2 in samples obtained from No. 8 is substantially higher than in samples from No. 7. Samples from three of the sites contained ethane, but no other higher hydrocarbons. No hydrogen or helium was detected in any of the samples.

TABLE 4. - Composition of gas from Pittsburgh coal

Site component	No. 5		No. 6		No. 7		No. 8	
	Percent	±	Percent	±	Percent	±	Percent	±
CH_4	88.91	0.99	95.86	1.02	93.85	0.35	84.4	0.85
C_2H_6	0.04	0.02	1.08	0.23	0.04	0.0	-	-
C_3H_8	-	-	-	-	-	-	-	-
C_4H_{10}	-	-	-	-	-	-	-	-
C_5H_{12}	-	-	-	-	-	-	-	-
CO_2	10.97	0.97	2.54	0.93	4.75	0.78	14.75	0.35
O_2	0.04	0.03	0.06	0.09	0.5	0.0	0.2	0.28
N_2	0.05	0.04	0.46	0.47	1.2	0.0	0.65	0.92
H_2	-	-	-	-	-	-	-	-
He.............	ND[1]	-	-	-	-	-	-	-

[1] ND: Not determined.

The composition of gas from the Kittanning coalbeds is summarized in table 5. Site No. 9 was a horizontal borehole drilled in the Upper Kittanning coalbed; site No. 10 was a vertical borehole through the Upper and Middle Kittanning coalbeds in the same area. The composition of the gases from both boreholes is similar. Methane was the only hydrocarbon; hydrogen and helium were not present.

TABLE 5. - Composition of gas from Kittanning coalbeds

Site component	No. 9		No. 10	
	Percent	±	Percent	±
CH_4	95.47	0.95	99.17	0.47
C_2H_6	-	-	0.02	0.0
C_3H_8	-	-	-	-
C_4H_{10}	-	-	-	-
C_5H_{12}	-	-	-	-
CO_2	0.10	0.0	0.18	0.09
O_2	0.47	0.30	-	-
N_2	3.97	0.65	0.64	0.56
H_2	-	-	-	-
He................	-	-	-	-

In table 6, sites No. 11 and No. 12 were horizontal boreholes drilled in Western coals. The higher percentage of CO_2 in samples from site No. 11 is believed to be related to igneous activity which heated the coal and caused extensive oxidation. The higher hydrocarbons, ethane, propane, and butane, were found in samples from this site, but hydrogen and helium were not detected. Samples from site No. 12 contained ethane, but no other higher hydrocarbons, no hydrogen or helium, and a very small percentage of CO_2. Site No. 13 was located in Southern Appalachia. The samples, obtained from a vertical borehole contained a small amount of ethane, but no other higher hydrocarbons. They contained helium and a trace of hydrogen.

TABLE 6. - Composition of gas from Western and Southern coals

Site component	No. 11		No. 12		No. 13	
	Percent	±	Percent	±	Percent	±
CH_4	87.84	3.64	99.22	0.0	96.05	0.21
C_2H_6	0.05	0.05	0.01	0.0	0.01	0.0
C_3H_8	0.0046	0.0092	-	-	-	-
C_4H_{10}	0.0011	0.0022	-	-	-	-
C_5H_{12}	-	-	-	-	-	-
CO_2	11.99	3.6	0.06	0.01	0.1	0.0
O_2	-	-	0.1	0.0	0.05	0.07
N_2	0.09	0.11	0.6	0.0	3.5	0.14
H_2	-	-	-	-	Trace	-
He............	-	-	-	-	0.27	0.01

Because the relative amount of methane and CO_2 are believed to be influenced by the extent of coalification the ratio of methane to CO_2 in the gas from each site was calculated (table 7). There was considerable variation in the ratio (from <10 to >1,000); even for a single coalbed, it was not constant, and no correlation could be made between the ratio of methane to CO_2 and age or rank of the coals, location or type of borehole. The high percentage of hydrocarbons in gas drained from coal makes it suitable for use as a fuel (16). The heat of combustion of the gas obtained from each site was calculated (table 8) and for most samples was comparable to the heat of combustion of natural gas. The heat of combustion for samples which contained a high percentage of CO_2 would be higher if the CO_2 were removed prior to use.

TABLE 7. - Ratio of CH_4 to CO_2

Site No.	Coalbed	CH_4/CO_2
1	Pocahontas No. 3..	495
2	........do........	168
3	........do........	1,051
4	........do........	325
5	Pittsburgh........	8
6	........do........	38
7	........do........	20
8	........do........	6
9	Upper Kittanning..	955
10	........do........	550
11	B Seam, Mesaverde Formation.	7
12	Lower Hartshorne..	1,654
13	Mary Lee..........	961

TABLE 8. - Heat of combustion of coalbed gas and natural gas

Gas	Heat of combustion, Btu/ft^3	Heat of combustion CO_2 free, Btu/ft^3
Site No.:		
1..............	[1]1,058	1,061
2..............	1,053	1,031
3..............	689	689
4..............	1,066	1,069
5..............	949	1,043
6..............	1,043	1,046
7..............	1,001	1,011
8..............	900	1,015
9..............	1,019	1,019
10..............	1,059	1,060
11..............	938	1,066
12..............	1,058	1,059
13..............	1,024	1,026
Natural gas......	[2]950	-
Natural gas......	[3]1,035	-

[1]Calculated from Heat of Combustion for Organic Compounds, Handbook of Chemistry and Physics (17).
[2]Fuels and Combustion Handbook (10).
[3]Energy in the American Economy, 1850-1975 (15).

SUMMARY

The data in tables 2 and 4 through 6 show that the gas in coals sampled is a variable mixture of C_1 to C_6 hydrocarbons and inorganic gases, with methane as the predominant component. There are significant variations in gas composition even for samples obtained at different locations in the same bed. The greatest variation was in the relative amounts of methane and carbon dioxide, which displayed no apparent correlation with age or rank, location, or type of borehole. Ethane was found in the majority of samples; propane and butane were not as common. Hydrogen and helium were found consistently only in samples from the Pocahontas No. 3 coal.

The small number of beds sampled and the limited number of samples per bed precludes drawing general conclusions about the composition of coalbed gas or about the effect of factors such as age, rank, permeability, and degree of fracturing. A much more extensive sampling program, with respect to the number of beds sampled and number of samples per bed, will be necessary to determine the significance of variations in the ratio of methane to CO_2, the prevalence of ethane and other higher hydrocarbons, the prevalence of hydrogen and helium. Other factors that should be considered are drilling techniques and their effect on the composition of the gas; and variations in the composition of samples from a single borehole with time and with changes in reservoir gas pressure.

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