United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
Research Triangle Park, NC 27711

Research and Development

EPA/600/SR-96/065 June 1996

EPA

Project Summary

Evaluation and Analysis of Gas Content and Coal Properties of Major Coal Bearing Regions of the United States

Sushma Masemore, Stephen Piccot, Eric Ringer, and William P. Diamond

The report presents a compilation of quality assured data on gas content and coalbed reservoir properties for 11 major coal bearing regions in the U.S. The primary source of these data is the U.S. Bureau of Mines (BOM) gas content measurements program conducted during the 1970's and 1980's. In order to enhance the utility of the BOM data, an evaluation was conducted to compile and quality assure the original data, and to adjust the data as needed to improve quality and representativeness. The report was compiled to provide access to these improved data at the basin level. Under this effort, the original raw data records for the core samples were provided by the BOM. The raw data were digitized to allow a computer to accurately and consistently perform routine quality assurance checks, consistently determine lost gas and total gas contents for each sample, and examine various corrections to the data. In addition, desorption constants for each coal sample were determined from time series desorption curves generated from the original data. Additional data presented include the results of equilibrium adsorption isotherm tests performed by the Department of Energy (DOE) in 1983 for approximately 100 of the BOM coal samples. These results give important, basin level information on the capacity of various coalbeds to store and release methane. In order to provide context and background, the report also characterizes the geology and coal and coalbed methane resources in each major U.S. coal basin.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. Environmental Protection Agency's (EPA) Air Pollution Prevention and Control Division (APPCD) has undertaken a study to identify the most practical and cost effective means to use coalbed methane control and utilization technologies to reduce methane emissions into the atmosphere. An initial phase of this study was to characterize methane gas content in minable coalbeds of active coal producing regions across the country. A joint evaluation with the U.S. Bureau of Mines (BOM) was conducted to compile and quality assure the data gathered from the BOM's gas content measurements program executed during the 1970's and 1980's. The result of this multi-tiered quality assurance and computational effort is a database titled the Refined Gas Content (RGC) database. This database and the results of gas content trend analysis are reported in the full report. The report presents a compilation of the gas content data and coalbed reservoir properties for major coal bearing regions of the U.S. The following paragraphs summarize the sources of data, data management and quality assurance activities, and key findings on a national level.

In 1972, the BOM developed the "Direct Method" (DM) for determining the gas content of coal cores. The DM is based on measurements of the gas volume evolved from coal cores sealed in airtight canisters, where the total gas content is obtained as the sum of three gas volume determinations identified as desorbed gas, residual gas, and lost gas. The desorbed gas volume is determined from cumulative volume measurements made over time as gas desorbs from the coal surfaces and microporous structure. A desorption rate curve may be developed from the cumulative desorbed gas volume versus time. This curve initially increases rapidly and eventually flattens out as gas sorbed onto the coal reaches equilibrium with atmospheric pressure and methane concentration. The residual gas content is defined as the gas volume that is released when the core is crushed to a fine powder. Lost gas is defined as the gas that evolves from the core samples from the time that the coalbed is first encountered by the drill to the time the sample is sealed in the desorption canister.

Since the development of the DM, several shortcomings have been identified that have raised questions about the quality of the original data. Examples of items not included in the DM are: accounting for oxygen sorption onto coal, accounting for liberation of other hydrocarbons in addition to methane, correcting the gas volumes for standard conditions, and correcting for ash and moisture content. The original DM data were compiled and calculated manually. This introduced some quality and consistency problems. In particular, the lost gas derivations were conducted somewhat inconsistently by different investigators and technicians over the years.

In response to these shortcomings, the BOM developed and tested a modified version of the DM known as the "Modified Direct Method" (MDM). The primary change in the MDM is that the composition of the desorbed and residual gas is determined and used to quantify the actual volume of methane released, and to correct for the oxygen sorption effect. This change accounts for most of the difference between DM and MDM results. Corrections are also made for ambient atmospheric conditions during sampling and testing, and for the ash and moisture content of the samples. The currently published BOM data are based only on the DM results, and do not include MDM data. Regardless of the shortcomings of the original method, the large and geographically representative data set compiled using the DM is valuable for conducting mine ventilation analyses, coal mine degasification analyses, coalbed methane development assessments, and methane emission inventory development studies.

Development of the RGC Database

The BOM obtained gas content data for 1511 coal samples. Original raw data files were available for 1100 of these samples. Many of the available BOM files were incomplete. Missing data included coring time parameters required to calculate lost gas, sample weights required to calculate gas content, and incomplete or missing pages from the records of the desorption experiment. Due to lack of pertinent data required to determine total gas content, complete calculations could not be performed with confidence on 423 of the samples. That is, complete data necessary for RGC analysis were available for 677 of the original 1511 BOM samples (about 45 %).

Several data processing, screening, and calculational steps were completed to assure the quality of the data, make necessary corrections and modifications, and develop total gas content and sorption time information for the samples. Examples of some of the exercises conducted include: digitization of the data which automated error checking and calculations; screening the data for completeness of information necessary for calculation of total gas content; developing time series desorption curves and screening graphical data to identify outliers that might indicate errors in the original data; calculating lost gas values, using a standardized, computer assisted routine to ensure consistent results; and determining sorption times from desorption curves and Langmuir isotherm constants from DOE adsorption data. In addition, the gas content on an ash/moisture free basis was calculated for samples where coal analysis data were available, and the effect of corrections for site barometric pressure and temperature conditions was examined using available national weather service data for a substantial subset of the samples.

Desorbed gas volume versus time plots (defined as desorption curves) can be used to determine rate constants such as sorption time. Time constants are important in defining coalbeds which have the potential to quickly outgas the largest quantities of gas. Sorption time is defined as the amount of time required to release 63% of the total gas contained in the coal at atmospheric pressure. Sorption time has been identified as an effective measure of the diffusion rate and is used in coalbed methane reservoir simulator modeling. Sorption rate constants are useful to both coal mining and coalbed methane recovery operations.

Adsorption isotherm data were generated by the U.S. Department of Energy (DOE) for approximately 100 coal samples collected by the BOM. The volume of gas adsorbed was reported at five pressure stages ranging from 5 to 50 atm.* The DOE data were used to develop adsorption isotherms (a plot of total gas adsorbed as a function of pressure) according to the Langmuir adsorption model. The isotherm curve relates the gas storage capacity as a function of coalbed reservoir pressure and is used to predict gas production potential as reservoir pressure is reduced. The equation for this isotherm curve is described by two constants: Langmuir volume and Langmuir pressure.

Initial Corrections to BOM Gas Content Data: Some errors and inconsistencies were found in the original desorbed and lost gas values. Residual gas results were determined directly from BOM laboratory experiments, and there was no need for corrections in the RGC data. Errors in the original desorbed gas values resulted from incorrect data entry, calculation errors, and failure to include all of the incremental desorbed gas volumes in the cumulative result. Errors in original lost gas values resulted mainly from imprecise application of DM procedures used to determine lost gas values.

Since the lost gas volume cannot be quantified directly, it is inferred from an empirical relationship between time and desorbed volume. This relationship is that, within the first hours after a core is exposed, the desorbed volume is a linear function of the square root of time. Some errors in lost time calculations in the original data were found and corrected. In the RGC analysis, lost time calculations were automated, and a computerized linear regression was executed on the first 10 desorbed gas volumes to determine lost gas.

The impact of the corrections and refinements that were made is most significant for the lost gas values. On average,

(*) 1 atm = 98 kPa.

RGC lost gas values are about 24% less than the published BOM values. RGC lost gas values are lower in each of the basins, ranging from -37 to -4% at the basin level. The largest differences were for the Arkoma and Raton Mesa Basins (-35 and -37%, respectively); however, the overall average is driven by the large number of samples from the Northern Appalachian Basin where the average difference was -22%. RGC desorbed gas values range from -9 to +19% at the basin level, but the overall average difference is zero. The relatively large increase evident for samples from the Greater Green River Basin (+19%) is notable. Except for samples from the Greater Green River Basin, there is little overall difference in total gas content between the published BOM and the RGC samples. Since lost gas values typically make up less than 5% of the total gas, relatively small increases in the corrected desorbed gas values tend to offset the larger decreases in lost gas values.

Corrections for Ash and Moisture Content: The BOM conducted coal analyses on a selected number of the original coal samples. The BOM's original publication presented ash content and apparent coal rank for each sample, and the remaining data were not published. These data are presented in the full report. Since it is generally true that methane is not adsorbed onto non-coal material, ash and moisture values can be used to make appropriate corrections on the total measured gas contents. Total gas values for ash and moisture content were corrected for RGC samples. The ash and moisture weight percent distribution for the RGC samples is used to determine changes in total gas content when ash and moisture are corrected. Ash/moisture free gas contents are higher than the as received gas content by +9 to +34% at the basin level with an overall average of +21%.

Corrections for Ambient Temperature and Pressure: It has been recommended that the volume of gas measured at ambient or atmospheric conditions in the field be corrected for standard temperature and pressure. In the original BOM data, only the volume of gas at ambient conditions was used to determine total gas content of coal cores. Unfortunately, temperature and pressure at the sampling sites and during desorption analysis were not recorded, so the correction to standard conditions could not be applied.

In order to examine the effect of ambient pressure and temperature variations on gas content data, temperature and pressure for the BOM sampling sites and sampling dates were obtained from National Weather Service data. Temperature and pressure data for 395 of the RGC coal samples were obtained, and conversion from actual to standard conditions (defined as 60°F* and 1 atm) was applied to these samples. The analysis may be limited somewhat by the fact that ambient conditions during desorption testing may not be reflected if the samples were transported away from the site for testing. However, during the BOM sampling program, samples often remained at or near the site during much of the desorption testing. Thus, these corrections may be considered reasonably representative overall.The corrections to total gas content values ranged from -3 to -21% at the basin level with an overall average of -6%.

Data Summary and Trends

The BOM/RGC database was reviewed and analyzed to examine (1) representativeness of the data in terms of U.S. coal production, and (2) basin level trends in terms of gas content, gas content relationships (e.g., with depth, coal rank), and reservoir properties (sorption time, and gas carrying capacity).

The BOM/RGC database provides broad geographic coverage of major coal producing regions in the U.S. Nearly 90% of 1992 U.S. coal production is in the 11 major coal basins that are the focus of the full report. The BOM samples represent coals from 81 counties in 17 states. Some of the counties represented in the original data are no longer producing coal. In 1992, only 59 of the 81 counties represented in the original data were still producing coal. In 1992, there were 247 counties producing coal in the U.S. Approximately 55% of 1992 production is in counties represented by BOM/RGC samples. Within each of the basins, gas content data for many different coalbeds are available.

Gas Content Summary: The aggregated RGC and "as-published" BOM data were used to develop a range of commonly encountered gas content values for each of the 11 basins. The data were grouped into five categories: 500 - 709, 300 - 499, 100 - 299, 50 - 99, and less than 50 ft^3/ton.* The full report presents the number of coal samples within each of these ranges in each basin and the average sample depth.

Total gas content can vary widely across a given basin and within a given coalbed depending on depth, rank, and other factors; however, some trends are evident. Coalbeds in the Arkoma, Black Warrior, Central Appalachian, Northern Appalachian, Greater Green River, and Raton Basins can contain very high levels of gas. Within these basins, the Mary Lee coalbed in Black Warrior, the Pocahontas No. 3 coalbed in Central Appalachian, the Williams Fork coalbed in Greater Green River, and the Peach Mountain coalbed in Northern Appalachian have coals which contain the highest gas contents; over 600 ft^3/ton. The Arkoma and Black Warrior Basins exhibit the most consistently high gas contents. Samples from the Central Appalachian Basin are evenly distributed across the full range of gas contents. Most Northern Appalachian Basin samples have gas contents less than 300 ft^3/ton, with most between 100 and 300 ft^3/ton. Most Illinois Basin coal samples have gas contents less than 100 ft^3/ton. Samples from the Greater Green River Basin also exhibit the full range of gas contents, including some of the highest values represented; however, many samples have low gas content and are associated with relatively shallow coal. San Juan and Raton Basin samples generally contain less than 300 ft^3/ton, and are more concentrated at the lower gas content levels (less than 100 ft^3/ton). Piceance Basin samples cover a broad range, but with most samples containing less than 100 ft^3/ton. Powder River Basin coalbeds contain the least gas (generally less than 50 ft^3/ton).

The relationship of total gas content to coalbed depth and coal rank was examined based on the complete RGC/BOM data set. In general, gas content is thought to increase with both depth and coal rank. Higher rank coals are associated with increased gas generation, and deeper coalbeds are associated with increased methane adsorption (due to higher pressures) and a higher probability of gas containment. Gas content has been observed to increase more rapidly at shallower depths, then level off with increasing depth. A logarithm curve (*i.e.,* Gas Content = a* ln (depth) + b, where a and b are constants) provides a simple mathematical description of this general relationship. This functional form is used to represent the relationship of gas content with depth throughout the report.

The relationship of increasing gas content with coalbed depth and rank is evident in the RGC/BOM data. Gas content

(*) °C = 5/9 (°F - 32).
(*) 1 ft^3/ton = 3.1218 x 10^{-5} m^3/kg.

is seen to increase with depth, and low volatile coals are associated with the highest gas contents, followed by medium and high volatile coals. In addition, the logarithm model appears to describe the data reasonably. There are also clear differences at the basin level in the relationship of gas content and depth, both in overall gas content and in the rate of increase of gas content with depth.

While the increasing trend of gas content with depth and coal rank is evident in the data, this simple relationship does not fully explain the variability observed in the RGC/BOM gas content data. Regression (using the logarithm model) of total gas content versus depth is generally weak ($r^2 < 0.5$), even when the data are segregated by rank. More robust relationships are sometimes observed locally within specific coalbeds or counties, indicating that changes in local coal properties are important. For example, it has been found that the microporous structure of coal is related to methane storage capacity. This is discussed in more detail below. Local relationships of gas content with depth are examined within basin level discussion of the full report.

Sorption Time: Sorption time was computed from the time series desorption curves for each RGC coal sample. Sorption time can vary significantly within a given basin; however, there are clear differences in sorption time among basins. The median sorption time across all basins is about 30 days, and this value can be used as a benchmark for identifying regions with high, low, and average sorption times. By this measure, Northern Appalachian and San Juan Basin coals can be characterized as slow desorbers, while Powder River and Raton Mesa coals desorb most rapidly. Coals in the remaining basins can be considered "average" desorbers. Several figures in the full report compare the average sorption time of the basins.

Sorption time indicates how rapidly initial desorption from coal takes place, but does not describe diffusion through the coal matrix. Thus, sorption time alone cannot be used as an indicator of coalbed gas production. However, sorption time is a useful indicator of direct gas emissions from a coal mining operation, and from post-mining coal handling operations. Mines producing coal with high gas content and low sorption time will likely produce significant quantities of gas as coal is continually exposed by mining operations. Run-of-mine coal emerging from such mines will continue to emit significant quantities of gas to the atmosphere during storage, handling, and transport operations prior to consumption.

Gas Storage Capacity: The Langmuir adsorption isotherm is a model describing the gas storage capacity of coal as a function of pressure at a constant temperature. Generally, gas storage capacity increases with increasing pressure; increasing rapidly at first, and then leveling off to a maximum. For the full report, Langmuir adsorption coefficients (Langmuir volume and pressure) were calculated from the DOE results. These data are summarized in the full report.

Langmuir volume varies considerably across the samples analyzed (ranging from 300 to over 3000 ft^3/ton), but is symmetrically distributed with an average of about 1075 ft^3/ton. There is some variability among basins; however, variability within basins is equally significant. That is, there seems to be no clear trend for coals from one basin to have significantly more or less adsorptive capacity than coals from another basin. Langmuir volume also seems largely independent of coal rank and depth.

Gas content and desorption data are available for 36 of the 100 samples analyzed by DOE. DOE did not specifically examine the relationship of gas content and sorption rate to Langmuir adsorption. Since the Langmuir curve represents the maximum gas storage capacity at a given pressure, the measured gas content should be less than or equal to the volume indicated by the Langmuir curve. Based on generalized information on the hydrostatic gradient (psi/foot) at the basin level and sample depth, it is possible to obtain a rough idea of the fraction of the volume indicated by the Langmuir curve represented by the measured gas content. The gas volume predicted by the Langmuir model appears to be about a factor of 2 to 3 higher than the measured gas volume (corrected for ash/moisture content). This is based on calculations for a limited number of samples at pressures exceeding 200 psi* from the Black Warrior, Central Appalachian, Northern Appalachian, and Raton Mesa Basins, and appears to be fairly consistent across basins. For some shallow samples from the Northern Appalachian Basin (less than about 200 psi bed pressure, or about 500 ft** deep), the measured gas content is near, and sometimes exceeds the Langmuir model prediction. This may be an artifact of the pressure gradient's being non-representative at shallow depths, or may be related to the rapid increase of Langmuir model predictions at low pressures.

(*) 1 psi = 6.89 kPa.
(**) 1 ft = 0.30 m.

Sushma Masemore, Stephen Piccot, and Eric Ringer are with Southern Research Institute, Chapel Hill, NC 27514; and William Diamond is with the U.S. Bureau of Mines, Pittsburg Research Center, Pittsburgh, PA 15236
***David A. Kirchgessner** is the EPA Project Officer (see below).*
The complete report, entitled "Evaluation and Analysis of Gas Content and Coal Propertries of Major Coal Bearing Regions of the United States," (Order No. PB96-185 491; Cost: $38.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection Agency
National Risk Management Research Laboratory (G-72)
Cincinnati, OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Official Business
Penalty for Private Use $300

EPA/600/SR-96/065