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THE MODIFIED DIRECT METHOD: A SOLUTION FOR OBTAINING ACCURATE COAL DESORPTION MEASUREMENTS

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ABSTRACT

The direct method test was developed for general mine safety applications by the U.S. Bureau of Mines in the early 1970's to measure the gas content of coal samples obtained from the relatively shallow depths of eastern U.S. coal mines. Over time, applications for gas content data evolved which required increasingly accurate desorption values. It became evident that some of the inherent weaknesses in the original direct method test could best be addressed by abandoning the water displacement based desorbed gas volume measurements. The ideal gas law based modified direct method (MDM) and associated desorbed gas volume measurement apparatus was developed to provide the most accurate desorption values possible for rock samples obtained from any gas-bearing strata. The MDM has a number of significant advantages, including: (1) increased accuracy, especially for low gas content samples, (2) a test apparatus with an integral sampling port to facilitate the collection of uncontaminated gas samples, (3) an inherent head space effect correction in the periodic MDM desorbed gas volume calculations, (4) measurement of positive and negative desorbed gas volumes, (5) elimination of differential gas solubility effects as a source of error inherent in the water displacement methods, and (6) a compact and rugged test apparatus that along with the elimination of the "glassware" required for the water displacement methods, facilitates its use in the field.

INTRODUCTION

The accumulation of methane in underground coal mines continues to be a safety problem in the United States and around the world. Measuring the quantity of methane contained within a coalbed and associated gas-bearing strata can be an important step in evaluating the potential severity of gas problems in new mines or in unmined areas of existing mines. Gas content testing can be included in the exploratory core drilling program that is usually conducted during the planning phase of mine development [1]. An early assessment of the potential for methane emission problems provides the greatest amount of lead time to incorporate longer term gas drainage techniques into the mine development plan [2]. Once mining is underway, gas content testing can be used periodically to assess gas conditions ahead of mining.

Whereas mine safety was initially the primary purpose for measuring the gas content of coalbeds, the potential for commercial coalbed methane production has resulted in an increased interest in this technology. Coalbed gas content data are used for the calculation of gas resources and as input data for reservoir models and production simulators to forecast gas production and to evaluate methane control options for underground coal mining.

GAS CONTENT COMPONENT PARTS

Gas is stored in coalbeds in a manner different from conventional reservoirs. Unlike the free gas existing in the porosity of conventional reservoir rock, Yee et al., [3] describe the gas in coal as existing primarily in a "condensed, near liquid-like state because of physical sorption". Due to the unique gas storage mechanism associated with coal, formation evaluation methods common in the conventional oil and gas industry can not be applied to coalbed reservoirs to determine the volume of gas in place. Thus, gas content determination methods have been developed to measure the volume of gas sorbed within the micropores of coalbed gas reservoirs.

To fully understand the development of NIOSH's modified direct method, it is important to first define the component parts of a rock sample's gas content, and some of the issues to be addressed to accurately determine these values. The most commonly used gas content determination methods [4], including the MDM, generally subdivide the total gas content of a coal sample into three parts: lost, desorbed, and residual gas. Each of these parts is generally measured or estimated by a different procedure, and then combined to yield the total gas content of the sample. Mavor et al. [5], McLennan et al. [6], and Mavor and Pratt [7] present comprehensive analyses of the possible errors associated with measurement of these gas content component parts by commonly used testing methodologies.

Lost Gas

The lost gas is that portion of the total gas that escapes from the sample during its collection and retrieval prior to being sealed into an airtight desorption canister. Lost gas volumes cannot be directly measured and therefore must be estimated from the subsequently measured desorbed gas volume data. Since the lost gas is an estimated quantity, it is generally considered to be the least reliable component of the total gas content.

The volume of gas lost prior to sealing a coal sample into a desorption canister generally depends on sample retrieval time, physical character of the sample, the type of drilling fluid, and water saturation/relative amount of free gas. Virtually all methods for estimating lost gas benefit from minimizing the lost-gas time over which measured desorption data must be extrapolated. Wireline core retrieval from coalbed depths of less than 610 m (2,000 ft), common in most mining areas in the United States, is relatively quick and generally requires only a few minutes to reach the surface. The retrieval time plus the time required to remove the sample from the core barrel, determine the depth interval of the coalbed and individual samples, inspect and describe the coal sample(s) to be tested, and finally sealing the sample(s) in the canister(s) can generally be accomplished in under one hour, and in many instances in less than 30 minutes. Under these conditions, the lost-gas time is relatively short, thus reducing the lost-gas volume and therefore, the potential error inherent in the estimation techniques.

Lost gas estimation becomes a more significant issue under several circumstances most commonly associated with commercial production operations. Lost-gas times are generally longer (>1 hr) in many of the commercial coalbed methane applications where depths may be greater than those associated with mining, and/or conventional coring methods are utilized. Extended lost-gas times can increase any associated error by increasing the fraction of lost gas relative to the total gas content.

Kissell et al. [8] and McCulloch et al. [9] demonstrated that the physical character of the retrieved coal sample can influence the desorption rate and hence the volume of lost gas that must be estimated. Blocky coals which remain intact during coring and subsequent retrieval emit their adsorbed gas at a relatively slow rate. However, friable coals which tend to break apart into smaller fragments, release their adsorbed gas faster because of the shorter diffusion distances. The density of the drilling fluid influences the time, during sample retrieval, when desorption is assumed to begin, i.e., when the hydrostatic pressure of the drilling fluid equals the reservoir pressure of the coalbed.

The final factor influencing the accuracy of the lost gas estimation is the water saturation and associated level of free gas in the virgin coalbed from which the sample is obtained. Most estimation methods are based on the assumption that the lost gas is desorbed gas (behaving according Fick's law of diffusion) and all the measured gas volumes used in extrapolation are also desorbed gas. Many coalbeds are essentially water-saturated and contain only a relatively small volume of free gas. However, there are coalbed gas reservoirs that are not water-saturated, and, therefore, may contain larger volumes of free gas. Some portion of this free gas will escape during sample retrieval and will not be accounted for by lost gas estimation methodologies based on diffusion of desorbed gas.

Desorbed Gas

Once a coal sample is sealed in the desorption canister, the desorbing gas accumulates and can be measured directly, commonly by some variation of the water displacement method first described by Bertard et al. [10] and later refined as the USBM direct method by Kissell et al. [8]. A more accurate gas desorption volume method originally developed by the USBM to measure the low volumes of gas desorbed from samples of oil shale [11], has been furthered developed and patented by NIOSH researchers. The modified direct method, as will be discussed more completely later in this paper, is based on periodically measuring pressure differentials in the desorption canister as gas is released over time, and calculating the desorbed gas volume utilizing the ideal gas law.

Residual Gas

The volume of gas desorbing from a coal sample gradually declines with time. Desorption measurements are terminated at some point when a low desorption rate is reached. This termination rate is generally defined by the developer of a particular gas content determination methodology, or by the end user of the methodology. Friable coal samples generally desorb gas very quickly (within days or weeks), while blocky coals may desorb gas for several months. Generally, at the point when the desorption rate reaches the established termination point, some volume of gas still remains in the sample. Traditionally, this residual gas has been thought of as gas that is "trapped" within the coal structure due to slow diffusion rates. Bertard et al. [10] and Levine [12] suggest that the residual gas may not be diffusion dependent, but in part, represents gases remaining in equilibrium under approximately 1 atm of methane pressure in the desorption canister. The residual gas volume can be determined by crushing the sample in an airtight container and measuring the volume of gas released by the same method as that used for the desorbed gas [13].

Analysis of the gas content component parts for 1,500 coal samples from 250 coalbeds in the United States [13], shows that residual gas can comprise 40 to 50 percent of the total gas content, in particular for relatively low-rank (High volatile-A bituminous) blocky coalbeds. In contrast, friable, higher rank (Medium to Low volatile) bituminous coalbeds typically had less than 10 percent residual gas. Caution must be used in evaluating the resource recovery potential of coalbeds with a high residual gas content, since it may represent methane that will not readily flow to a methane drainage borehole under field conditions. Residual gas may also represent a portion of the total gas content that will not be admitted into a mine atmosphere either from migration to the mine openings from the surrounding coal, or from the mining of the coal at the face.

PRECURSORS OF THE NIOSH MODIFIED DIRECT METHOD

Bertard's Direct Method

The original direct method was developed in France by Bertard et al. [10], for the testing of drill cuttings collected from horizontal holes drilled in underground coal mines. Similar methods are still in general use for gas content testing in high gas emission underground coal mines in many European mining operations. The total gas content of a coal sample was separated into three component parts, but the sample had to be transferred to a different container for the measurement of each component by a different apparatus.

The methodology described by Bertard et al. [10] was based on experimental and theoretical studies on the sorption and diffusion of methane in coal. These studies included the finding that early in the desorption process the volume of gas released was proportional to the square root of time. This finding is the basis for determining the quantity of gas lost by the sample from the moment when it was extracted from the coalbed to when it was transferred into a transport container. A 10 g coal sample was collected from the borehole underground and immediately sealed in a glass flask connected by tubing to a U-tube manometer (collectively referred to as a desorption meter).

Bertard et al. [10] estimated the lost gas volume using desorption meter data and a derived formula that they considered valid, as long as the lost gas volume represented less than 20 percent of the total gas content, necessitating the speedy recovery and sealing of the drill cuttings into the desorption meter. At the end of the lost gas determination procedure, the sample was transferred to a second container for transport out of the mine to the laboratory, where it was then transferred to a third container for crushing to determine the volume of gas remaining in the coal. Gas volumes were measured in a graduated cylinder suspended over a pan of water into which the gas released by crushing was collected. The total gas content of the sample was then the total of the three component parts, expressed in cm^3/g.

Bertard et al. [10] noted that the final results could be presented either in terms of the temperature and pressure conditions of the underground sampling site for the site-specific mining application, or at STP conditions for a "stricter comparison of the desorbable concentrations of different seams." It was also noted that the "desorbable concentration is always referred to pure coal" necessitating a correction for contained mineral matter content. Bertard et al. [10] also recognized the potential for using this methodology with core samples, but emphasized the importance of short sample recovery time to ensure accurate lost gas estimates.

U.S. Bureau of Mines Direct Method

The coalbed gas content testing procedure commonly referred to as the USBM direct method [8] was an adaptation and simplification of the method developed by Bertard et al. [10]. The initial purpose of the USBM method was to determine the gas content of virgin coal core samples for use in estimating ventilation requirements for new mines. Laboratory experiments confirmed that lost gas assumptions for coal cuttings proposed by Bertard et al. [10] could also be applied to the larger sized coal core samples that would have a longer sample recovery (lost gas) time.

The USBM direct method eliminated the multiple sample containers and associated measurement techniques used by Bertard et al. [10] to determine the component parts of the total gas content. Standard desorption canisters were constructed from 0.3-m (1.0-ft) long sections of 10.2-cm (4.0-in) diameter aluminum pipe (Fig. 1). All gas volume measurements were made by periodically releasing the accumulated gas into a water filled inverted graduated cylinder (Fig. 1).

Kissell et al. [8] proposed two alternate approaches to estimate time zero and cumulative lost gas time. If the hole was cored with water or drilling mud, desorption was assumed to begin when the sample was halfway to the surface. The cumulative lost gas time (t_{lg}) would then be:

$$t_{lg} = (t_4 \,!\, t_3) + (t_3 \,!\, t_2) \ni 2,$$

where: t_2 = time core retrieval begins,
t_3 = time core reached surface,
t_4 = time core sealed in desorption canister.

If the hole was cored by air or mist, pressure release and gas desorption were assumed to begin at the first penetration of the coalbed by the core barrel. In this case, t_{lg} would be:

$$t_{lg} = t_4 \,!\, t_1,$$

where: t_1 = time coalbed first penetrated.

A graphical technique was proposed to estimate the lost gas volume (Q_l) based on several early direct measurements of desorbed gas after the sample was sealed into the desorption canister. Measurements of the desorbed gas volume are made every 15 to 20 minutes for the first several hours. These data are then plotted on a graph of cumulative desorbed gas versus the square root of desorption time. The initial linear portion of the desorption curve is extrapolated through the point on the x-axis representing the lost-gas time (e.g., /15 min, Fig. 2) to estimate the lost-gas volume.

The desorbed portion (Q_d) of the total gas content is measured periodically by the water displacement technique described above. At some point, gas desorption slows to a rate at which essentially little gas is emitted. McCulloch et al. [9] proposed that desorption measurements be discontinued when daily emissions were less than 0.05 cm^3/g for five consecutive days, which was subsequently revised by Diamond and Levine [14] to an average of 10 cm^3 of gas desorption per day for one week for samples in the standard [0.3-m (1.0 ft long)] canisters. Both of these guidelines are arbitrary; but whatever cutoff point is used, it should be applied uniformly to all samples. At the point when the periodic measurement of desorbed gas is discontinued, the residual gas (Q_r) is determined by crushing as much of the desorption sample as possible to a powder (-200 mesh) to release the remaining in situ gas.

The volume of gas released is measured by the water displacement method after the sample cools to ambient temperature. The gas volume released by crushing is attributed only to the portion of the sample crushed to a powder. The total gas content of the sample is then:

$$Q_t = (Q_l + Q_d) \ni M_t + Q_r \ni M_c, \tag{1}$$

where: M_t = total air-dried mass (weight) of the sample,
M_c = air-dried mass (weight) of the sample crushed to a powder in the ball mill.

The value Q_t is calculated in cm^3/g, but is commonly converted to ft^3/st (= $cm^3/g \times 32$) in the United States for ease in making gas resource calculations.

Due to the changing uses of the gas content data in the United States beginning in the early 1980's, several modifications to the USBM direct method were proposed. One of these modifications was designed to eliminate volumetric measurement errors due to the differential heads between the water level in the graduated cylinder and the pan (Fig.1) by adjusting the water level in a separate reservoir vessel to that in the measurement vessel. Relative errors due to these differential pressures has been estimated to range up to about 4 percent [15]. Two examples of these alternative manometric apparatuses are shown in Figure 3.

Another potential problem with direct method testing methods is related to the volume of head space (free space) left in the canister after the sample is inserted. Changes in ambient pressure and temperature on the head space volume between subsequent desorption readings can influence the resultant volumetric measurement. These changes can be either positive or negative depending on the net effects of both temperature and pressure changes between readings. Since these changes in gas volume due to the head space effect tend to cancel themselves out over time, corrections for this problem were not included in the original USBM direct method test procedure. However, it was recommended that the head space volume in the canisters be minimized by filling the canisters as full as possible to reduce possible errors associated with this problem.

An even better solution to the head space issue is to customize the canisters to the diameter of the core and length of the sample to be collected. The other recommended practice is to transport the samples as soon as possible after collection to a laboratory environment where the ambient temperature can be controlled. For those concerned with the loss of accuracy due to the head space effect, it is relatively easy to add a correction factor based on the ideal gas law. Circumstances of extreme variations in atmospheric pressure (e.g., elevation difference between collection location and laboratory) or temperature may necessitate head space effect corrections.

Ulery and Hyman [16] concluded that if the USBM direct method is conducted according to the recommended specifications and practices, reasonably accurate STP results can be obtained. The most substantial loss of accuracy occurred with the direct method when small, low gas content samples were placed into a large container resulting in a large free space volume. Errors of up to 100 pct were reported for low gas content samples when the ratio between the desorbed gas volume and the free space in the canister was less than 2:1.

NIOSH MODIFIED DIRECT METHOD

In the early 1980's, the USBM initiated basic research on the occurrence and migration of gas associated with oil shale mining. Early mine development experience in the industry suggested that significant quantities of methane could be released during mining. Preliminary assessment of the low volumes of gas sorbed within the organic matter associated with oil shale indicated that the existing USBM direct method technique was not sufficiently precise nor accurate for this application. A new gas content testing methodology was developed to more accurately measure the expected low gas volumes of oil shale samples. This new method also provided increased accuracy for determining the gas content of coal and other rocks where sorption is the primary gas storage mechanism.

The modified direct method test procedure relies on the measurement of differential pressures (pressure buildup between readings) and the ideal gas law to calculate the volume of gas released into the desorption canister at STP conditions [11]. The primary improvement achieved with the MDM testing apparatus was the abandonment of the water displacement techniques for measuring desorbed gas volumes. The MDM measurement apparatus (U.S. patent No. 5,741,959, "Portable Tester for Determining Gas Content Within a Core Sample") utilizes pressure transducers with digital readouts that offer superior resolution when compared to other instrumentation incorporated in conventional direct method gas content testing apparatuses. The inclusion of two pressure transducers permits a choice of overlapping pressure ranges for increased accuracy within each transducer's optimal range. The small size and ruggedness of the apparatus (Fig. 4) facilitates its use in the field, as well as in the laboratory.

An integral gas sampling port included on the MDM apparatus allows for collection of uncontaminated gas samples. It is important to periodically collect samples of the gas desorbed to determine the actual constituents of the measured gas volume. In most cases, the desorbed gas is predominantly methane; however, other constituents are present. Kim [17] reported that the largest constituent in coalbed gas after methane is usually CO_2 or N_2. In the United States, CO_2 has most commonly been found in the Pittsburgh Coalbed in the east [17] and several coalbeds in the west, including the Fruitland Coalbed [18]. Rice [18] also reports high concentrations of CO_2 for coalbeds in The Peoples Republic of China, Australia, and Poland. Other constituents of coalbed gas may include minor amounts of higher hydrocarbons (primarily ethane), H_2, and He [17].

An additional innovation developed as part of the MDM is the use of canisters constructed of polyvinyl chloride (PVC) pipe. The internal diameter of the canister is sized as close as possible to the external diameter of the core samples. The canister is partially constructed and pressure tested in the laboratory with only one end cap. The other end cap (fitted with the quick-disconnect valve assembly, as illustrated in Fig. 4) is glued in place after the pipe is cut to size in the field to match the length of the actual coal sample. Customizing the desorption canisters to the actual size of the sample greatly reduces the head space volume in the canister.

The application of the MDM to coal samples, as described by Ulery and Hyman [16], includes the determination of lost (Q_l), desorbed (Q_d), and residual (Q_r) gas components of a sample. As with the original USBM direct method, the lost gas (Q_l) is estimated by extrapolating early time periodic measured gas volumes to time zero, as shown in Figure 2. The individual data points of desorbed gas volume (V_{dp}) at STP conditions are determined by the formula:

$$V_{dp} = V_i \,!\, V_f$$

where: V_i =gas volume in the desorption canister at the end of a desorption volume measurement time interval,
V_f =volume of gas in the canister after releasing the accumulated desorbed gas volume.

V_i and V_f are calculated at STP conditions according to the ideal gas law:

$$V_i \text{ (or } V_f) = (P_{amb} T_{std} V_{amb}) \ni (P_{std} T_{amb}),$$

where: P_{amb} = ambient pressure of gas in canister,
P_{std} = standard pressure,
T_{amb} = ambient temperature of gas in canister,
T_{std} = standard temperature,
V_{amb} = free space volume at T_{amb} and P_{amb}.

An advantage of the MDM gas volume measurement and calculation technique is that the head space effect correction is inherent in the calculation. Negative V_{dp} values, as well as positive values, are also easily measured with the MDM technique. This is not the case with the water displacement gas volume techniques where a negative pressure in the canister can draw water into the tubing connecting the measurement apparatus and the canister. A further advantage of eliminating the water displacement method of gas volume measurements is the elimination of gas dissolution problems associated with gases that have higher solubilities in water than methane, such as CO_2 and N_2.

Desorption in the canisters is generally allowed to continue until the cutoff point previously defined for the USBM direct method test is reached. The desorbed gas volume (Q_d) is then the sum of the periodic gas measurements (V_{dp}). Prior to removing the coal sample from the canister the head space volume is measured, either with water or helium. However, to calculate apparent gas volumes as the desorption process is underway, an estimated head space volume is calculated by subtracting the estimated volume of the coal sample from the estimated internal volume of canister. A portion of the sample is crushed and the residual gas volume (Q_r) measured by the MDM. The final gas content of the sample (Q_t) is calculated according to equation (1). The final results are reported at a defined STP, gas species, and coal compositional (as-received versus ash- or mineral- matter-free) basis.

A common problem occurring in the desorption canisters are oxygen depletions, either through oxidation or perhaps adsorption [16,19]. Gas samples are obtained for each MDM desorption measurement. Without these gas compositional analyses, the net change in volume between oxygen depletion and methane desorption would underestimate the true desorbed methane volume. Alternatively, the oxygen depletion problem can be eliminated by purging the sample containers with an inert gas, but this entails added expense, as well as an additional complication to the testing procedure in the field. Even if the canisters are purged in the field with an inert gas, it is recommended that desorption readings be accompanied by a gas compositional analysis to determine volumetric changes in gas species desorbed over the duration of testing.

OTHER GAS CONTENT TESTING ISSUES

Direct vs. Indirect Gas Content Determination Methods

The gas content of a coal sample can be determined by several available direct measurement techniques. These techniques can generally be divided into quick-crushing and extended desorption determination methods. The quick-crushing techniques are most commonly used for mine safety applications outside the United States to assess gas conditions ahead of the active production face. The coal samples are usually obtained from underground drill holes. Instead of waiting for months to obtain results, total gas yield is available within a matter of days. While quick crushing methods are appropriate for the mining applications for which they were intended, they preclude determination of the relative amounts of desorbed and residual gas, and the sorption time (time to release 63 percent of total sorbed gas) commonly used in coalbed gas reservoir models [20].

The extended desorption gas content measurement techniques allow for a sample to desorb gas until a low desorption rate cutoff point is reached. The sample may then be crushed to a powder to quickly release any gas remaining within the coal. These techniques are most common in the United States and are used for both mining, coalbed methane resource recovery applications, and basic research applications. The coal samples to be tested are generally fresh core or drill cuttings obtained from boreholes drilled from the surface.

Pressure coring is an alternative direct measurement method used to obtain a coal sample at reservoir pressure, thus eliminating the need for determining lost gas [21]. Pressure cores are generally considered the standard against which other gas content determination methods are evaluated. However, pressure cores are not without their own problems, including high cost.

Gas contents can be estimated indirectly based on sorption isotherm data [22] or empirical estimation curves of measured gas content results plotted against other measurable variables such as coalbed depth and coal rank [23, 24]. Laboratory derived sorption isotherms describe the quantitative relationship between adsorbed methane at varying pressures and a constant temperature, and provide a measure of the maximum methane sorption or storage capacity of the coal sample. Thus, gas content estimates based on sorption isotherm data do not necessarily result in accurate in situ gas content values. Since all coalbeds are not necessarily fully saturated with methane, especially those at shallow depths or in areas of geologic anomalies [25], the isotherm-based methods may overestimate the actual gas content.

Efforts to estimate the gas content of coalbeds utilizing wireline geophysical logging tools have also been attempted [26]. The wireline logging method does not directly measure the gas content of the coalbeds exposed in the wellbore. It is essentially an empirical estimation curve technique. Algorithms relating gas content to apparent coal rank are derived from actual gas content and coal proximate analysis data from cores obtained in the geographical area of interest. Log-derived coal property data are then used to estimate gas content as a function of coal rank and depth.

Indirect methods can serve as a preliminary assessment tool for mine planning purposes or targeting potential areas for commercial coalbed methane exploration. Whenever possible, however, engineering and/or economic decisions should include data from actual direct measurement tests.

Sampling Strategies

The coal samples to be used for gas content testing are commonly obtained from wireline or conventional cores, and drill cuttings from production wells or test boreholes. Core samples or drill cuttings may also be obtained from boreholes drilled underground. In general, coal cores are preferable to cuttings. Due to their larger size and lower ratio of surface area to volume, cores typically have slower initial desorption rates, effectively reducing the amount of gas lost during sample retrieval. Gas content values obtained from drill cuttings should generally be considered minimum values because of the difficultly in applying lost gas estimation techniques to this type of sample.

An issue that frequently arises at the drill site is how to select samples for gas content testing. It is not uncommon for gas contents to vary over the length of a coal core due to coal compositional changes, primarily due to variations in mineral matter content. If samples are obtained from cores, it is preferable to test the entire recovered coal section. However, it is generally good practice to divide the coal core into several samples instead of placing the entire coal section into a single desorption canister. When multiple samples are tested from the same coal core, it is recommended that the samples be selected relative to obvious, naturally occurring breaks in the coalbed, such as shale partings.

Reporting of Results

Historically, gas content data have been reported on various bases, and in many cases, without any defined basis. All volumetric readings should be corrected to standard temperature and pressure (STP) conditions. Gas industry convention for STP conditions, 15.6° C and 760 mm Hg (60° F and 14.70 psia), are most commonly used for reporting coalbed gas content data. However, chemistry STP conditions, 0 °C and 760 mm Hg (32 ° F and 14.70 psia), are occasionally used. The STP conditions applied to a particular data set should be clearly defined. The methodology and type of coal sample tested (e.g., core or drill cuttings) should also be specified.

The coal compositional basis for the gas content values is another important data-reporting issue. Raw (as-received) gas content results are commonly corrected to an ash-free value to aid in the comparison of results on a normalized basis. While an ash-free basis for reporting gas content values is desirable from a standpoint of comparing results, it can lead to confusion when calculating gas resource estimates. Gas resource calculations should always be made with gas content values and coal resource data corrected to the same basis [27, 28]. Ash-free gas content values should not be applied directly to raw tons of coal in place for calculation of gas resources because an inflated value for the gas resource results.

Calculation of gas content on a volume-to-mass (weight) ratio, i.e., cm^3/g (ft^3/st) is inherited from the mining industry where coal reserves are calculated on a weight basis. As an alternative to expressing gas content values as a volume-to-mass (weight) ratio, they can be expressed as a volume-to-volume ratio, i.e., m^3 (ft^3) of gas/m^3 (ft^3) of sample [27]. This volumetric expression of gas content values has been used effectively in the calculation of gas in place for studies related to longwall gob gas, where the gas is contained not only in coalbeds, but also in other rock types for which a volume-to-mass ratio has little meaning, and is awkward for gas in place calculations [29].

Several other types of information should be provided to enhance the use and interpretation of reported gas content values. The depth of the sample should be included for each individual gas content value. If data from multiple samples from a single coalbed are combined for a single gas content value, they should be normalized by mass or volume, as opposed to calculating a simple arithmetic average [27]. Any shale partings excluded from the sample(s) sealed into the desorption canister(s) should be indicated on any stratigraphic sections or for stated coalbed thickness values associated with the gas content values. It is also helpful to include either an inferred coal rank calculated from a coal proximate analysis and Btu data [30] or a coal rank estimated from vitrinite reflectance measurements. Finally, any extenuating circumstance in the collection of the sample or its location relative to outcrop or mining that could have a bearing on the interpretation of the results should be noted.

SUMMARY

Coalbed gas content determination methods require varying levels of equipment sophistication, auxiliary test data, and data reduction complexity to arrive at a final gas content value. Selection of a gas content testing method should be determined by the particular application of the gas content data and the degree of accuracy required. For mining applications where the data are to be used for estimation of emission rates, as is common outside the United States, the various quick-crushing methods are generally sufficient.

For general purpose applications, the original USBM direct method and its water displacement based variants are a good choice. These methods should include the generally accepted data correction factors (STP, differential water heads, and head space). One important operational practice that will generally increase the accuracy of most gas content testing methods, especially for low gas content samples, is to fill the canisters as completely as possible with coal to minimize problems associated with a large free space.

The NIOSH modified direct method provides a significant level of increased accuracy and sophistication, and eliminates the logistical and technical problems associated with the common water displacement techniques. Complicated and cumbersome apparatuses with fragile glassware are not required for measuring desorbed gas volumes. The MDM eliminates the problem of losing water soluble gases to the water column in the manometric devices, does not require an apparatus to correct for differential water heads, and the head space effect is directly compensated for in the test methodology.

It is recognized that cost is a consideration when selecting a gas content testing methodology. The quick-crushing gas content testing methods are generally at the low end of the cost scale; however, a determination of the true residual gas content is lost. This may not be a serious limitation for the traditional mining applications for these methods or for coalbeds where the residual gas contents have been shown to be relatively low. The original USBM direct method and similar water displacement methods are also a relatively low-cost choice, even with the inclusion of the basic correction factors. The NIOSH modified direct method has a higher initial cost for equipment than most of the traditional water displacement based techniques, and the increased level of accuracy may not be necessary for some data applications. However, for large scale sampling programs, the higher initial equipment costs can be amortized over a large number of samples and several years of operation.

No single technique is necessarily appropriate for all applications for which coalbed gas content data are utilized. It is up to the user to select the methodology that best addresses the intended application of the data at an acceptable level of accuracy and cost. However, no matter what gas content determination method is used, applying good experimental method and laboratory practices is essential to maximize the inherent accuracy of any test procedure. Adhering to the reporting guidelines for gas content data will enhance the value of the results while minimizing the potential for erroneous conclusions or use of the data.

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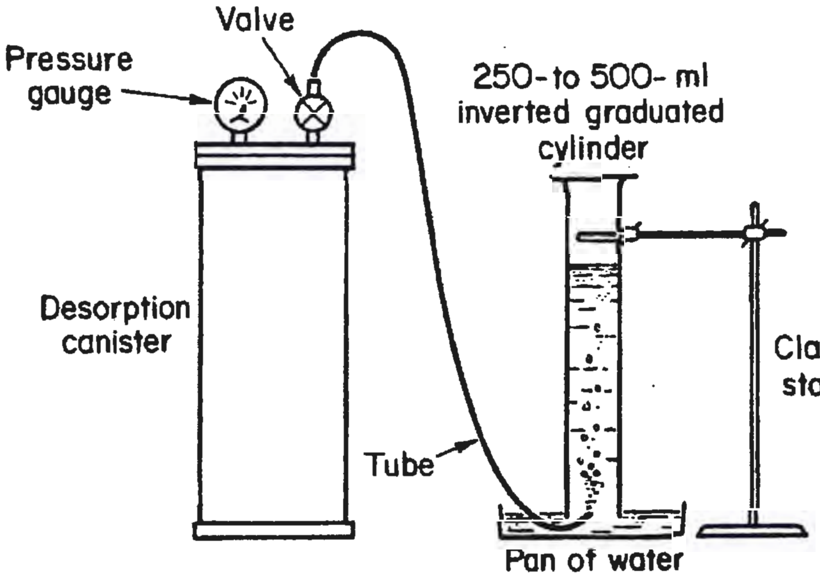

Figure 1. – USBM direct method gas volume measurement apparatus.

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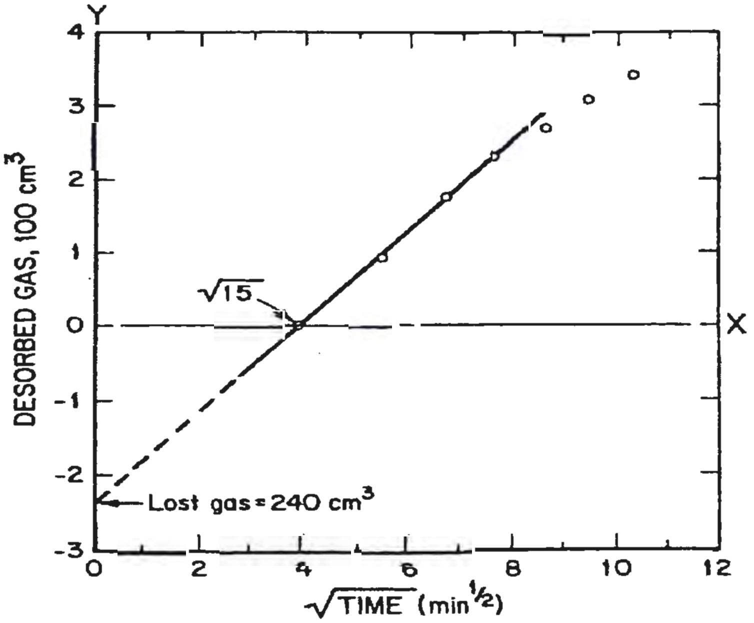

Figure 2. – USBM direct method lost gas estimation graph

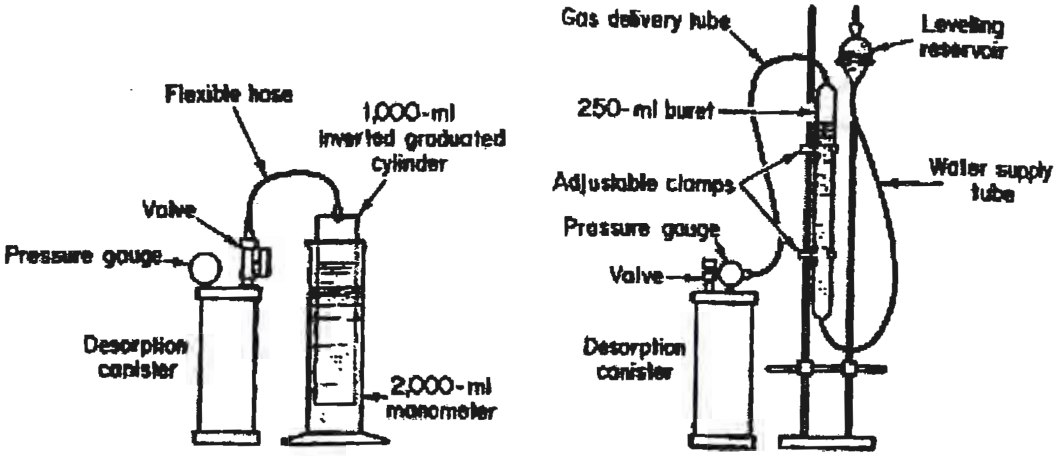

Figure 3. – Examples of manometric gas volume measurement apparatuses.

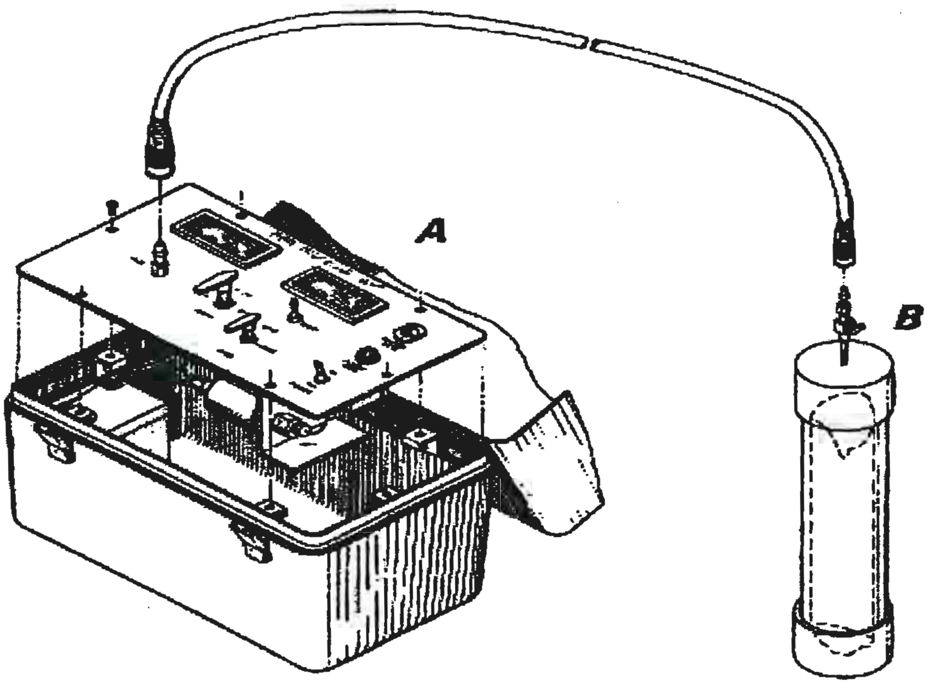

Figure 4. – (A) NIOSH modified direct method testing apparatus, and (B) field customized PVC desorption canister.