



Bureau of Mines Report of Investigations/1982

Methodology for Determining Occluded Gas Contents in Domal Rock Salt

By David M. Hyman



UNITED STATES DEPARTMENT OF THE INTERIOR

Bureau of Mines
Report of investigations 8700

METHODOLOGY FOR DETERMINING OCCLUDED GAS CONTENTS IN DOMAL ROCK SALT

By David M. Hyman

ERRATA

On page 10, the first equation in the left-hand column should read as follows:

$$\frac{(P_{bi} + P_{vi})(V_{gi})}{T_i} = \frac{(P)(V_i)}{T},$$

Report of Investigations 8700

Methodology for Determining Occluded Gas Contents in Domal Rock Salt

By David M. Hyman



UNITED STATES DEPARTMENT OF THE INTERIOR

James G. Watt, Secretary

BUREAU OF MINES

Robert C. Horton, Director

This publication has been cataloged as follows:

Hyman, D. M. (David M.)

Methodology for determining occluded gas contents in domal rock salt.

(Report of investigations / United States Department of the Interior, Bureau of Mines ; 8700)

Bibliography: p. 11.

Supt. of Docs. no.: I 28.23:8700.

1. Rock-salt--Analysis. 2. Methane. 3. Mine gases. I. Title. II. Series: Report of investigations (United States. Bureau of Mines) ; 8700.

TN23.U43 [TN900] 622s [622.1'8285] 82-600182 AACR2

CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	2
Acknowledgments.....	3
Background.....	3
Domal rock salt samples.....	4
Dissolution method.....	4
Experimental apparatus.....	5
Experimental procedure.....	6
Crushing method.....	8
Experimental apparatus.....	8
Experimental procedure.....	8
Summary and conclusions.....	10
References.....	11

ILLUSTRATIONS

1. Schematic of dissolution method apparatus.....	5
2. Schematic of crushing method apparatus.....	8

METHODOLOGY FOR DETERMINING OCCLUDED GAS CONTENTS IN DOMAL ROCK SALT

By David M. Hyman¹

ABSTRACT

The Bureau of Mines has developed two experimental designs for determining the volumes and relative proportions of the various gas species, particularly methane (CH_4), occluded in rock salt. To date, the rock salt samples analyzed have been relatively small (400- to 1,000-gram) grab samples from Louisiana Gulf Coast domal salt mines. The results obtained are comparable to results in Polish domal salt mines, in terms of occluded gas volumes per mass of rock salt. The notable difference between the Louisiana and Polish occluded gas mixtures is in the relative proportions of the individual gas species.

The two methods used by the Bureau are ballmill crushing and dissolution. Of the two, the dissolution method appears to be more versatile because it can be performed in situ. The relevance and applicability of data on the occluded gas contents of rock salt are dependent on sample size, sample collection method, geologic context of the sample, and the correlation with gas emissions that occur as a result of mining-induced fractures and pressure differentials.

¹Geologist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, Pa.

INTRODUCTION

The Bureau of Mines became interested in developing information concerning the occurrence and distribution of gases, particularly methane (CH_4), in the various salt dome lithologies, as a result of increased concern about potentially hazardous methane occurrences in Louisiana Gulf Coast domal salt mines. Basic information concerning the types of gases, their relative abundances, and the circumstances relating to their occurrences and distribution in North American domal salt mines is generally lacking in the literature. A notable exception is a study (5)² that was performed on gases contained in gas-enriched salt from a salt dome in central Louisiana. Methane and other gases have been reported to occur in the domal salt mines of Poland (3). Various gases, such as hydrogen, methane, nitrogen, and hydrogen sulfide have been found in the domal salt formations and bedded evaporite deposits of Louisiana, New Mexico, and Poland (1, 3, 5, 7).

Given the relatively impermeable nature of salt, the occluded gases generally are not released from their containment unless mining activities intercept (1) a gas-filled fissure zone, an area where the voids between the salt crystals are interconnected, (2) a mechanically unstable zone of gas-enriched salt that disaggregates, releasing its entrained gases (a blowout), or (3) some other relatively permeable geologic anomaly (1, 7). A simple illustration of the nature of gas occlusion in rock salt is seen when a piece of gas-enriched rock salt is immersed in water. The rock salt will "pop" sporadically, releasing gas bubbles as it dissolves. This simple demonstration is the foundation for one method of determining the gas content of a rock salt sample. The sometimes rather energetic "pops" as gases are released from a gas-enriched rock salt sample attest to the high pressures under

which the gases can be occluded. The pressures postulated for these occluded gases are lithostatic but could be higher depending on local stresses related to the low creep limits of rock salt (1), particularly around mine openings.

However, a gas pressure was estimated by melting a gas-enriched salt sample in a sealed container and back-calculating the occluded gas. This calculated value was 500 to 1,000 atm (at 0° C) and occurred in "bubbles" within the salt crystals of domal rock salt that had been ejected from a blowout at a depth of about 244 m (800 feet) (5). The lithostatic load corresponding to this sample was calculated to be about 50 to 60 atm. It is possible that this difference between the gas pressure and the lithostatic load was due to gross experimental or sampling error, locally high stress concentrations in the mine structure where the blowout occurred, or some other mechanism(s) not considered.

As part of its program to promote mine safety, the Bureau of Mines has undertaken two main areas of research in order to assess the species of gases released during mining, their modes of occurrence, their quantities, and their characteristics of emission into mine openings. The first area concerns the reservoir characteristics (volume, permeability, etc.) of fissure and anomalous zones or other areas of significantly interconnected void spaces in domal rock salt, where any gases present will migrate in response to a pressure gradient. The second area concerns the quantities of the various gases occluded in the rock salt itself. In this mode of occurrence, the gases will be released when the rock salt mass is mechanically disturbed or dissolved.

This report addresses the second area of research. It presents two methods developed by the Bureau's Pittsburgh Research Center for determining the gas contents of rock salt, as well as some preliminary data on small samples from Louisiana Gulf Coast domal salt mines.

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

ACKNOWLEDGMENTS

The author wishes to acknowledge gratefully the technical contributions of David C. Oyler and Patricia M. Erickson of the Methane Control Group and the Environmental Control Group, respectively, at the Pittsburgh Research Center. Sylvester Sudduth, Steven Schatzel, and Deborah Burse, of the Methane Control Group, participated in the development of the ballmill crushing method, and Helen Lang of the Fire and Explosions Group in the development of the dissolution method. The personnel of the Louisiana

Gulf Coast Five Islands Salt Mines (Jefferson Island, Avery Island, Weeks Island, Cote Blanche, and Belle Isle) permitted access and sampling and contributed their time, information, experiences, and cooperation toward this and related research efforts in understanding the nature and effects of gases in domal salt mines. The sum of these persons' efforts, along with others, has made this study and, it is hoped, future studies possible.

BACKGROUND

A number of gases are occluded in varying proportions in rock salt. Some results of occluded gas contents analyses performed on rock salt samples from Polish salt domes are reported in reference 3. One suite of analyses using an undescribed dissolution technique yielded mean contents of $2.85 \text{ cm}^3 \text{ N}_2$, $0.23 \text{ cm}^3 \text{ CO}_2$, $0.10 \text{ cm}^3 \text{ H}_2$, and $0.06 \text{ cm}^3 \text{ CH}_4$ per 100 grams NaCl. In one Polish mine, nitrogen was the dominant gas occluded in salt, with up to $10.65 \text{ cm}^3 \text{ N}_2$ per 100 grams NaCl reported. The maximum occluded methane content given for this mine was 0.38 cm^3 per 100 grams NaCl. Another Polish domal salt mine reported maximum occluded gas contents in rock salt samples (dissolved in water) of $5.17 \text{ cm}^3 \text{ H}_2$, $1.18 \text{ cm}^3 \text{ CO}_2$, and $0.03 \text{ cm}^3 \text{ CH}_4$ per 100 grams NaCl. Data in reference 5 portray a carbon dioxide-dominant gas mixture occluded in the "popping" salt from a blowout. The carbon dioxide and methane concentrations were 46.9 pct and 1.5 pct, respectively. No data for gas content per mass of salt were given for this analysis.

Preliminary analysis has been done by the Bureau of Mines on Gulf Coast Louisiana domal salt. This study of the composition of gas mixtures occluded in rock salt ejected from blowouts has yielded a maximum of 8 to $10 \text{ cm}^3 \text{ CH}_4$ per 100 grams rock salt, with lesser quantities of other gas species. The minimum occluded methane content was less than $0.1 \text{ cm}^3 \text{ CH}_4$

per 100 grams of rock salt. The occluded methane contents for the "popping" rock salt analyzed to date range from about 0.6 to $10 \text{ cm}^3 \text{ CH}_4$ per 100 grams rock salt. Conversion of these determinations to 100 grams NaCl does not significantly change these values, owing to a very high assay of NaCl for the rock salt samples tested. In terms of volumes of occluded gases per mass of rock salt, the results of the Bureau's work are comparable to the values published in reference 3. The apparent differences are in the relative proportions of the gas species occluded in the salt.

An important consideration is that these occluded gas contents of rock salt may not represent the gas mixtures released during a blowout, emitted through boreholes penetrating interconnected void systems, or emitted through fissure systems intercepted by mining. The potential relationship of the occluded gas to gas released or emitted during mining is currently being explored by the Bureau, with comparisons between occluded gas contents of cored samples and corehole gas emissions. Data on these occluded gas contents will be useful if they can be correlated to a significant degree with mine atmospheres, blowout-prone zones, or gas emissions from drill holes in conventional mining operations. As the sampling process improves in terms of representative sample size and representative in situ

conditions through sophisticated core drilling techniques and reservoir mechanics analysis, the probability of useful application of these data should increase.

The gas emissions during mining should depend on the characteristics of the occluded gas contents of a representative

sample combined with the reservoir characteristics of the interconnected void spaces and fissure systems. To build a data base for use in predicting in-mine emissions, the Bureau has initiated a program to analyze systematically a variety of domal salt lithologies with respect to gas contents, geochemistry, and geologic context.

DOMAL ROCK SALT SAMPLES

To date, the rock salt samples have been gathered from mine faces, ribs, and salt piles of known origin. These are essentially grab samples with a maximum mass of about 3.5 kg (7.7 pounds), which have lost any gases not occluded within the salt crystals and/or confined in intergranular void spaces. The exposure of these salt samples to the mine atmosphere has allowed the rock mass to "loosen" over time along grain boundaries and fractures because of the effects of humidity and loss of original in situ confining pressure. Thus, the gas contents of this suite of samples represent "residual" occluded gas contents. Although this residual gas represents only a portion of the gases in domal salt, this is the current state of the art. This residual gas content of rock salt is not directly analogous to the residual gas in coal (4), owing to

different entrainment modes. Methane has no real affinity for or interaction with pure salt; however, the presence of bitumen changes this (2).

The state of the art will advance with the acquisition of larger (with respect to grain size) core drilled samples that are maintained under in situ pressure and sealed from atmospheric effects until analyzed. As these cored samples are recovered, gas pressure measurements and gas samples should be taken from the corehole to characterize the interconnected void spaces and their gases and thus maximize the information presented by the corehole. In short, the reliability of a gas content determination depends upon the size and physical integrity of the sample analyzed, along with its geologic context and in situ conditions.

DISSOLUTION METHOD

Two methods are used by the Bureau of Mines to determine the gas contents of rock salt samples. One is based on the dissolution of the rock salt mass in a sealed chamber with distilled and degassed water, in a helium atmosphere. Occluded gases are released during dissolution and collected for analysis by gas chromatography. This method allows the gas volume to be normalized to either the mass of the rock salt or to the mass of the water-soluble NaCl. There are two major advantages to this dissolution method. One is the relatively inexpensive nature of the apparatus. The other is that this test can be performed at any scale, from single crystal samples to a solution mining operation.

The dissolution chamber can range in size from a laboratory 10-ml test tube to a commercially available desiccator to an aircraft fuel tank bladder (in the extreme). All that is minimally required is that the opening for introducing the salt sample be airtight when closed and that there be two valve fittings (or at least one if the dissolution chamber is a flexible bladder type).

This dissolution method can also be performed in situ. A borehole can be cased with an annular pipe arrangement for injecting water and extracting the resulting brine and/or gases. These released gases would represent both occluded and fissure-interconnected void

space gases. The pipe set should be cemented and able to withstand a pressure test to at least the hydrostatic pressure for that depth. Provisions should be made for collecting gas and shutting off gas flows. During and after the solution process and cavity development, the cavity can be monitored for brine and/or gas flows from any intercepted fissure-interconnected void zones. A core sample from the solution cavity salt should be extracted and analyzed for occluded gas content prior to dissolution.

The solution cavity, if of sufficient size, can possibly be used to initiate the disaggregation of mechanically unstable gassy salt and/or to drain intercepted fissure zones, provided the resulting flow of gases can be controlled at the drill hole collar. A

disadvantage is that brine-soluble gas determinations can become complicated unless the gas solubilities in brine are known. When the dissolution has been completed, the brine can be subjected to geochemical analysis and the water-insoluble residues can be filtered, weighed, and examined. Any liquid hydrocarbon can be separated and analyzed.

Experimental Apparatus

The dissolution method essentially captures gases released from a weighed sample of rock salt as it dissolves in a sealed chamber that has had degassed, distilled water introduced into it. Figure 1 is a schematic representation of the experimental apparatus. The desiccator serves as the reaction vessel and gas collection chamber. It must have at least two fittings on the top for hoses

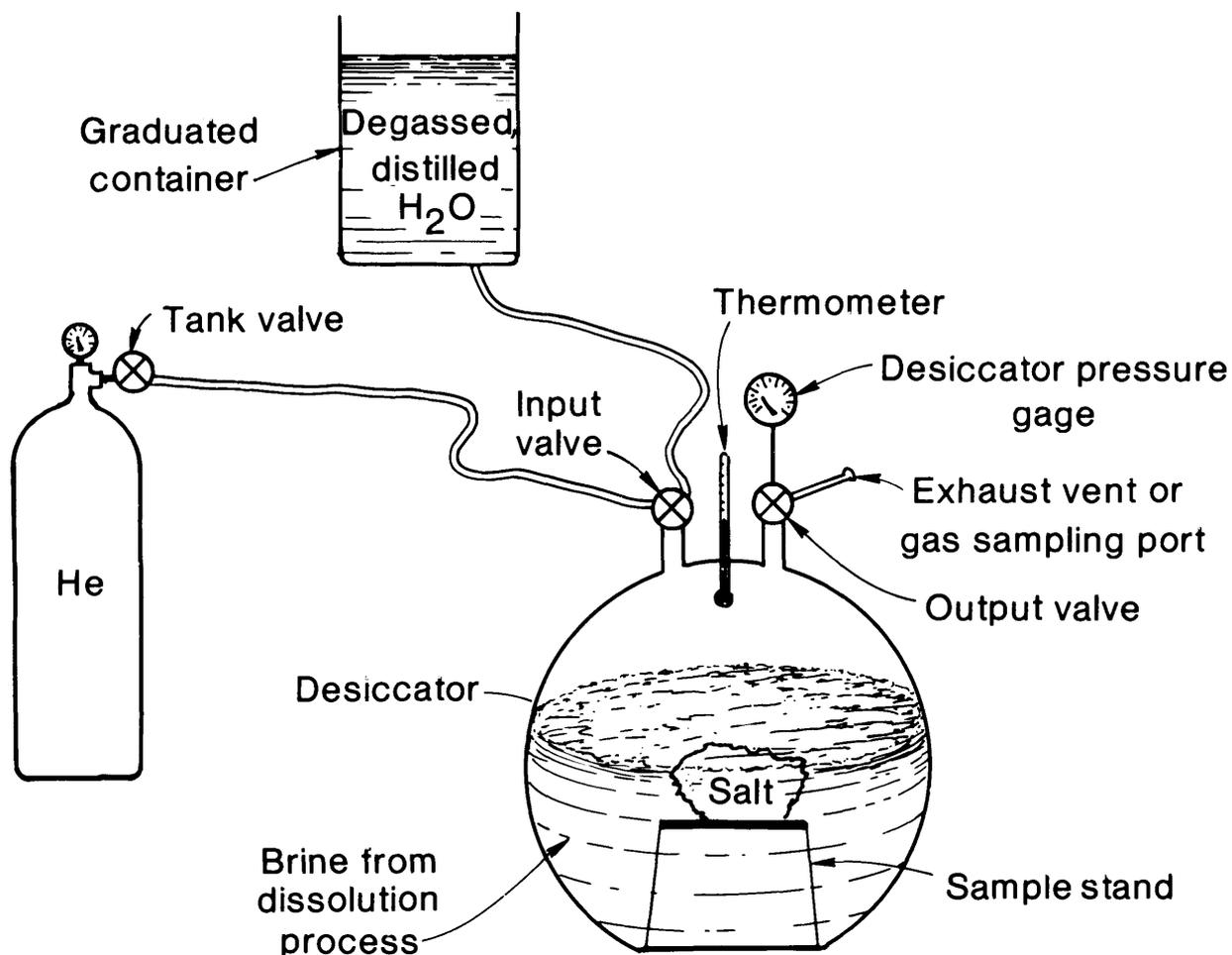


FIGURE 1. - Schematic of dissolution method apparatus.

and/or valves and a provision for a temperature probe (thermometer) if the distilled water is not at room temperature.

The intake valve has two switchable inputs with one outlet to the reaction vessel. One of the inputs is for the inert gas (helium) that is used to purge (or at least strongly dilute) the air atmosphere in the desiccator. The purpose of purging the reaction vessel atmosphere is to reduce the background interference of the various gases in air. This is essential, owing to the relatively small volumes of various gases released from the rock salt sample in comparison with the volumes of atmospheric gases in the vessel atmosphere. The other input on this valve is used to introduce the degassed, distilled water from a graduated container (buret or graduated cylinder) into the reaction vessel.

The output valve on the other port of the desiccator top has the same type of valve as the input but configured as one inlet from the reaction vessel to two switchable outputs. The first output goes to a pressure gage for monitoring gas pressure in the vessel. The second is used to sample the gases in the vessel atmosphere and also as an exhaust vent to release displaced gases when the vessel atmosphere is purged.

A sample of the vessel atmosphere should be taken before the degassed, distilled water is introduced, to obtain background or baseline measurements of the gases in the vessel. The occluded gases released from the rock salt will be superimposed on this background during the dissolution process. When the degassed, distilled water is introduced into the vessel, an expansion chamber of known volume can be attached to the exhaust vent to collect the displaced atmosphere and the first release of occluded gases.

The rock salt sample is elevated from the bottom of the vessel by a sample stand so that it will be exposed to

relatively "fresh," unreacted water. This is because the brine that results from the dissolved portion of the salt is denser than the fresh, unreacted water and settles to the bottom of the vessel. Without a sample stand, the rock salt sample will be in contact with brine, which will inhibit dissolution unless the solution in the vessel is frequently agitated.

Experimental Procedure

The procedure, with some typical values, for the Bureau prototype apparatus is as follows:

1. The rock salt sample (300 to 1,000 grams) is weighed and placed on the sample stand in a reaction vessel with an internal volume (V_v) of about 3,000 to 6,500 cm^3 .

2. The top of the reaction vessel is greased, installed, sealed, and secured. The top must be secured to withstand an applied differential positive pressure (1 to 30 mm Hg) used to preclude leakage from outside the reaction vessel.

3. The exhaust vent and inlet valve for helium are opened. The tank valve is opened, with tank regulator set at about 69 kPa (10 psig), and helium is flowed through the reaction vessel. The time of flow should be experimentally determined for the vessel used. For a 3,310- cm^3 vessel, 6 minutes of flow at about 69 kPa diluted the nitrogen concentration in the vessel atmosphere from about 78 pct to about 1 to 2 pct. The purging is stopped by closing the helium tank valve, the inlet valve, and the exhaust vent.

4. After purging the sampling circuit with helium and just prior to the introduction of the degassed, distilled water to the reaction vessel, temperature (T_i), barometric pressure (P_{bi}), and vessel internal pressure (P_{vi}) measurements are made, and two gas samples are taken through the sampling port. This establishes the "before" condition of the experiment.

5. Because the solubility of NaCl in room-temperature water is about 37 grams NaCl in 100 grams H₂O, the volume of degassed, distilled water to be prepared can be estimated from the sample weight. The appropriate volume of water is introduced into the reaction vessel by opening the inlet valve and then the exhaust port as desired to run the experiment at either atmospheric or positive pressure conditions. Liberal volumes of distilled water are recommended to insure complete dissolution of the salt. The final volume of water in the vessel is V_w.

6. When the dissolution of the rock salt sample is complete, the reaction vessel temperature (T_f), barometric pressure (P_{bf}), and vessel internal pressure (P_{vf}) measurements are made, and two gas samples are taken through the sampling port. This establishes the "after" condition of the experiment.

7. The reaction vessel is opened, and samples of the brine are taken for geochemical analysis. The water-insoluble residues are washed out of the vessel, filtered, weighed, and preserved for geochemical and/or mineralogic analysis.

8. The reaction vessel is washed in distilled water.

The data reduction method is presented below.

The volume that the gases occupy before the distilled water is added--the volume of gases initially (V_{gi})--is

$$V_{gi} = V_v - V_{\text{salt}},$$

where V_v = internal volume of desiccator (and expansion chamber if used) with sample stand,

and V_{salt} = volume of salt = (sample weight)/(density of rock salt).

To approximate the density of rock salt, a value of 2.16 g/cm³ was chosen because it represented the median of a range of values (2.12 to 2.204 g/cm³) presented in references 2, 5-6. More explicit methods

to determine the density or volume of rock salt can be used.

The value for V_{gi} is corrected to standard temperature and pressure (STP) conditions (V_i) by

$$\frac{(P_{bi} + P_{vi})(V_{gi})}{T_i} = \frac{(P)(V_i)}{T},$$

where P_{bi} = initial barometric pressure,

P_{vi} = initial vessel internal pressure,

T_i = initial temperature,

P = 760 mm Hg,

and T = 273 K.

The gases under consideration for the pressures and temperatures quoted in this report behave essentially as ideal gases.

To obtain the background individual gas species volumes, the concentrations of each gas, as determined by analysis of the "before" gas samples, are multiplied by the V_i.

The volume that the gases occupy after dissolution (V_{gf}) is

$$V_{gf} = V_v - (V_w + V_d),$$

where V_w = volume of water,

and V_d = volume of salt dissolved = (V_{salt}) (100 pct - percent volume decrease).

The percent volume decrease of a saturated aqueous solution of NaCl at 0° C is about 25.9 pct; at 25° C, 20.4 pct; at 50.4° C, 17.9 pct (2, 6). For less than saturated solutions, the molar concentration must be calculated and the corresponding volume decrease value found in the aforementioned references.

The volume V_{gf} is then adjusted to STP conditions (V_f), as was done in the "before" case, to include water vapor pressure correction. The "after" volume

of the individual gas species or groups of species are similarly calculated and the "after" minus "before" represents the

STP volumes of gases released by the rock salt. The gas volumes can be normalized to 100 grams NaCl or 100 grams rock salt.

CRUSHING METHOD

The second method used by the Bureau of Mines for gas content determination is the crushing method. In this method the salt sample is mechanically crushed in a ballmill. The rock salt sample is reduced to a powder that is on the order of 0.420 mm (40 mesh, 0.0165 inch), although the size distribution of the crushed salt can be altered. An advantage of this method is that the degree of crushing can be controlled to match the end use of the data. Disadvantages of the crushing method are that the size of the ballmill governs the maximum size of the sample to be analyzed, and the ballmill interior volume can be relatively large, introducing sometimes considerable experimental error, owing to mechanical efficiency requirements.

Experimental Apparatus

This method essentially captures occluded gases released when the rock salt sample is mechanically crushed to powdered form. The stainless steel ballmill is analogous to the desiccator (reaction vessel) used in the dissolution method. Figure 2 is a schematic of the crushing method apparatus. The design of the Bureau ballmill is described in

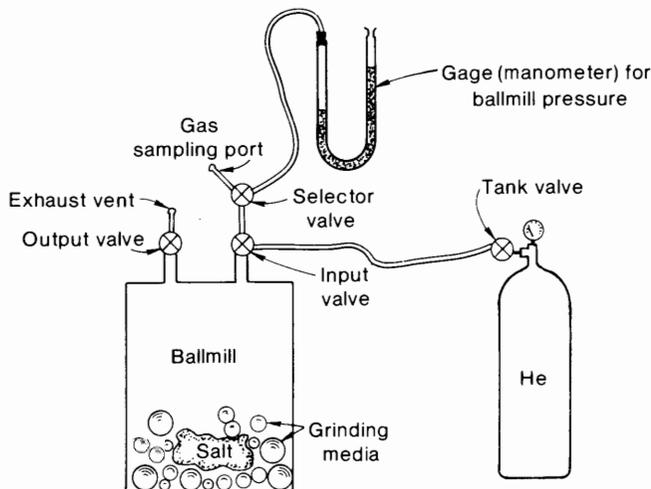


FIGURE 2. - Schematic of crushing method apparatus.

reference 4; however, any commercially available airtight crushing mill could be used.

The top of the mill has two fittings for the valves. One fitting is for the input valve, which has two switchable inputs and one outlet into the ballmill. One of the inputs is from the helium tank. The other is the input to the selector valve, which has two switchable outlets for a pressure gage (for example, water manometer) and a gas sampling port. The second fitting is for the output valve which has one inlet from the ballmill and one output for the exhaust vent. As discussed in the section "Dissolution Method," the air atmosphere is purged with helium to allow background subtraction.

Experimental Procedure

The procedure, with some typical values, for the Bureau prototype apparatus is as follows:

1. The rock salt sample (600 to 1,000 grams) is weighed and placed in a ballmill with a 3,340-cm³ internal volume (V_v).

2. The grinding media (ball bearings, rods, etc.) of known volume (about 725 cm³) are added. Glass wool is placed inside the fittings in the top of the mill, and the top is secured to the body of the mill. The glass wool acts as a filter to prevent salt dust from plugging the fittings and valves.

3. The output valve-exhaust vent and the input valve are opened; the selector valve is closed; and the tank valve is opened to allow helium at a pressure of about 69 kPa (10 psig) to flow into the ballmill to purge the air atmosphere. For a 3,340-cm³ ballmill, about 6 minutes of purging is required to lower the

nitrogen concentration in the atmosphere from about 78 pct to about 1 to 2 pct.

4. The output valve-exhaust vent is closed while the helium tank valve is slowly turned off. This step applies a slight positive pressure to the interior of the ballmill. The two main reasons for this positive pressure are to avoid inflowing contamination from outside the ballmill and to aid in gas sample extraction. The selector valve is switched to obtain the internal pressure (Pvi), using a water manometer. This differential pressure is in the 34- to 52-cm water gage (W.G.) (13- to 20-inch W.G.) range. A mercury manometer could be used with a corresponding differential pressure range of 25 to 38 mm Hg. A barometric pressure measurement is also made at this time, along with temperature (Ti).

5. The selector is switched to the gas sampling port. After the sampling circuit input valve, selector valve, and gas sampling port are flushed with helium, two gas samples of the ballmill atmosphere are taken (using 20-ml evacuated containers). The ballmill internal pressure is remeasured. Two 20-ml evacuated containers are used for gas sample collections, and the differential pressure decreases by about 7.8 to 25.4 cm W.G. (3 to 10 inches W.G.). The second manometer (Pvi) reading added to the barometric pressure (Pbi) (with temperature correction) represents the "before" character of the interior of the ballmill.

6. The ballmill is disconnected from the valve assemblies and placed on the roller machine to rotate for about 1 hour and crush the salt.

7. After crushing, the ballmill is removed from the roller machine and allowed to equilibrate with the room temperature. A thermometer is set on top of the mill to insure that the ball-

mill and contents come to room temperature.

8. When the ballmill has reached room temperature, the sampling circuit is again flushed with helium, and the valve assemblies are reconnected to the mill. A ballmill differential pressure measurement is made with the manometer (Pvf), along with barometric pressure (Pbf) and temperature (Tf) measurements. Two gas samples of the ballmill atmosphere are taken. These measurements and samples represent the "after" character of the interior of the ballmill. A postsampling manometer reading of the remaining differential pressure is taken to insure that the "after" gas samples were satisfactorily extracted. Any remaining differential pressure in the ballmill is then removed by opening the output valve-exhaust vent.

9. The ballmill top is removed, and the salt and grinding media are emptied into a sieve stack with pan. A typical sieve stack made of stainless steel is composed of 1/2-inch (12.7-mm), 10-mesh (2-mm), 20-mesh (841- μ m), and 40-mesh (420- μ m) sieves and pan. The sieve fractions are weighed separately. The sieve analysis is required to characterize the degree of efficiency of the crushing. These data are also required to determine the exact weight of crushed salt that releases its occluded gases. Normally the minus 20-mesh salt is used to normalize the gas contents to salt mass.

10. A representative fraction of the crushed salt is submitted for geochemical analysis.

The data reduction method is presented below.

The volume that the gases occupy before the rock salt is crushed (Vgi) is

$$V_{gi} = V_v - (V_{\text{salt}} + V_{\text{grinding media}}),$$

where

V_v = internal volume
of ballmill
(3,340 cm³),

V_{salt} = (sample weight)/
(density of
rock salt),

and $V_{\text{grinding media}}$ = volume of grind-
ing media.

An explicit determination of the den-
sity of rock salt or the volume is pref-
erable to using an assumed density of
2.16 g/cm³ as discussed in the section
"Dissolution Method."

The volume V_{gi} is corrected to standard
temperature and pressure (STP) conditions
(V_i):

$$\frac{(P_{bi} + V_{gi})(V_{gi})}{T_i} = \frac{(P)(V_i)}{T},$$

where P_{bi} = initial barometric pressure,

P_{vi} = initial ballmill internal
pressure,

T_i = initial temperature,

P = 760 mm Hg,

and T = 273 K.

As in the dissolution method, the STP
volumes of the individual gas concentra-
tion and V_i are calculated.

The volume that the gases occupy after
crushing (V_{gf}) is

$$\frac{(P_{bf} + P_{vf})(V_{gf})}{T_f} = \frac{(P)(V_f)}{T}$$

where P_{bf} and P_{vf} = final barometric and
ballmill pressures,
respectively,

T_f = final temperature,

and V_f = STP adjusted final
gas volume.

The volumes of gases are then calcu-
lated using V_f and gas concentrations
determined from the "after" gas sam-
ples. After subtracting background
(the "before" conditions), the STP vol-
umes of individual or groups of gases
(for example, hydrocarbons) are normal-
ized to the mass of the appropriate
sieve fraction (for example, minus
20 mesh) of rock salt or NaCl under
consideration.

SUMMARY AND CONCLUSIONS

The Bureau of Mines has developed two
methodologies to determine the occluded
gas contents of domal rock salt, although
these methods are not necessarily
restricted to domal rock salt samples.
The usefulness of the occluded gas con-
tent data from either the dissolution
method or the crushing method is deter-
mined by the size and collection method
of the subject sample and the correlation
of the occluded gas content data with gas
emissions into the mine atmosphere as a
result of mining activities. Of the two
methods, the dissolution method appears
to be more versatile because it can
be performed either in situ, through an
exploratory drill hole, or on a sample

the size of which is limited only by the
size of the dissolution chamber.

The results of occluded gas determina-
tions can be applied to further studies
on the correlation of occluded gas with
gas emissions into the mine atmosphere
during the mining of rock salt for which
the occluded gas contents and drill hole
gas emission characteristics have been
determined. This correlation will allow
the mapping of gas emission characteris-
tics as a function of geology and thus
provide a prediction model of gas occur-
rences in a salt dome through use of the
results of these laboratory procedures.

REFERENCES

1. Baar, C. A. Applied Salt-Rock Mechanics. Elsevier Scientific Publishing Co., Amsterdam, v. 1, 1977, 294 pp.
2. Baxter, G. P., and C. C. Wallace. Changes in Volume Upon Solution in Water of the Halogen Salts of the Alkali Metals II. J. ACS, v. 38, 1916, pp. 70-105.
3. Cybulski, W., C. Gorol, T. Gotkowski, and J. Sobala. Charakterystyka Zagrozenia Metanowego w Polskich Kopalniach Soli (Characteristic Features of Methane Hazard in Polish Salt Mines). Pr. Gl. Inst. Gorn., Komun., No. 567, 1972, 20 pp. (Safety in Mines Research Establishment Transl. No. 6344.)
4. Diamond, W. P., and J. R. Levine. Direct Method Determination of the Gas Content of Coal: Procedures and Results. BuMines RI 8515, 1981, 36 pp.
5. Hoy, R. B., R. M. Foose, and B. J. O'Neill, Jr. Structure of Winnfield Salt Dome, Winn Parish, Louisiana. Am. Assoc. Pet. Geol. Bull., v. 46, No. 8, 1962, pp. 1444-1459.
6. Kaufmann, D. W. Sodium Chloride. Reinhold Publishing Corp., New York, 1960, pp. 592, 623.
7. Kupfer, D. H. Problems Associated With Anomalous Zones in Louisiana Salt Stocks, USA. Paper in Fifth Symposium on Salt, Hamburg, Germany, 1979. Northern Ohio Geological Society, Inc., Case Western Reserve Univ., Cleveland, Ohio, v. 1, 1980, pp. 119-134.