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UNITED STATES DEPARTMENT OF THE INTERIOR

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Donald Paul Hodel, Secretary

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	m	meter
cm/min	centimeter per minute	mL	milliliter
cm^3	cubic centimeter	min	minute
dB	decibel	pct	percent
g	gram		

GAS CONTENT DETERMINATIONS OF SALT SAMPLES USING ACOUSTIC RESPONSES

By Thomas E. Marshall[1] and Gerald L. Finfinger[2]

ABSTRACT

The Bureau of Mines has developed a practical methodology for determining occluded gas contents of domal rock salt samples. The method, which is portable and fieldworthy, provides results in 5 min or less and does not require a laboratory environment or specially trained personnel to obtain meaningful results. The results can be used to identify gas-enriched zones, and thus may aid mine operators in production planning or ventilation design.

The test method is based on the relationship between gas content and the acoustic response of salt samples as they are dissolved in water. The relationship is defined by an equation, and the results are repeatable. The equation was derived by testing a series of rock salt samples collected from domal salt mines in Louisiana.

[1]Engineering technician.
[2]Supervisory geologist.
Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The release of hydrocarbon gases from subsurface strata into underground mine workings has long been problematic to the mineral industry. In particular, methane emissions have been directly responsible for many disasters which have resulted in the loss of life and property (1).[3] While methane control guidelines and procedures are well known to the underground coal mining industry, workable methods for the domal salt industry are still being devised. The mechanisms that govern the occurrence and subsequent release of in situ gases in domal salt formation differ significantly from the environments associated with coal-bearing strata.

Most coal mining operations experience a relatively steady emission of methane into the underground workings (2-7). As a result, the ventilation requirements to dilute the methane to safe levels can be identified and easily implemented during the mining operation. However, methane emission in domal salt mines is not always a steady continuous flow, but instead tends to occur as sudden and rapid releases (8). As a result, the ventilation needs cannot always be met and the potential for hazardous conditions to form is increased.

To achieve a safer work environment for the underground domal salt mining industry, the Bureau of Mines has been conducting research to develop predictive techniques for identifying gas-enriched zones and outburst-prone areas. Earlier Bureau investigators have determined methods for quantifying gas-enriched zones and have correlated the zones to observed physical conditions such as salt quality, banding, and impurities (9-13). Based on data collected from three domal salt mines in southern Louisiana, a correlation has been established between increased gas content and outburst occurrences (12). The gas content measurements were obtained using a dissolution and gas chromatography technique (9). This technique is quite simple, but requires a laboratory environment and trained personnel to obtain accurate results.

Additional studies were undertaken to provide the industry with a rapid and fieldworthy method for estimating gas contents. It was observed during field studies and dissolution testing that a popping or cracking sound was discernible as the salt samples were dissolved in water. A laboratory test was conducted to determine if the emitted sounds were related to the gas content of the salt sample. Results from the test indicated an excellent correlation between the two parameters. Procedures and results of the test are discussed in this report.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the personnel of the Cote Blanche, New Iberia, LA, Bell Isle, Franklin, LA, Weeks Island, New Iberia, LA, and Avery Island, New Iberia, LA, domal salt mines for their assistance and support. They provided samples from active mining areas and assisted in verifying the test. Special recognition is given to Timothy McCue, production supervisor, and Patricia Olivier, chemist, of the Cote Blanche Mine. Mr. McCue was instrumental in identifying outburst areas and collecting salt samples from underground production faces. Ms. Olivier performed all of the acoustic tests at the Cote Blanche Mine site and provided the results. Without their dedication and cooperation, the project goals couls not have been achieved.

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

TEST DESCRIPTION

The test methodology was designed around the concepts of simplicity, field-worthiness, and real time results. The system is intended to be used at a mine site; it does not require a laboratory environment, but a relatively quiet area is necessary.

TEST APPARATUS

To provide a buffer from outside noise interference a portable sound-resistant chamber was obtained with inside dimensions of 0.6 by 0.6 by 0.6 m (fig. 1). This size was selected to test

FIGURE 1.—Portable sound-resistant chamber.

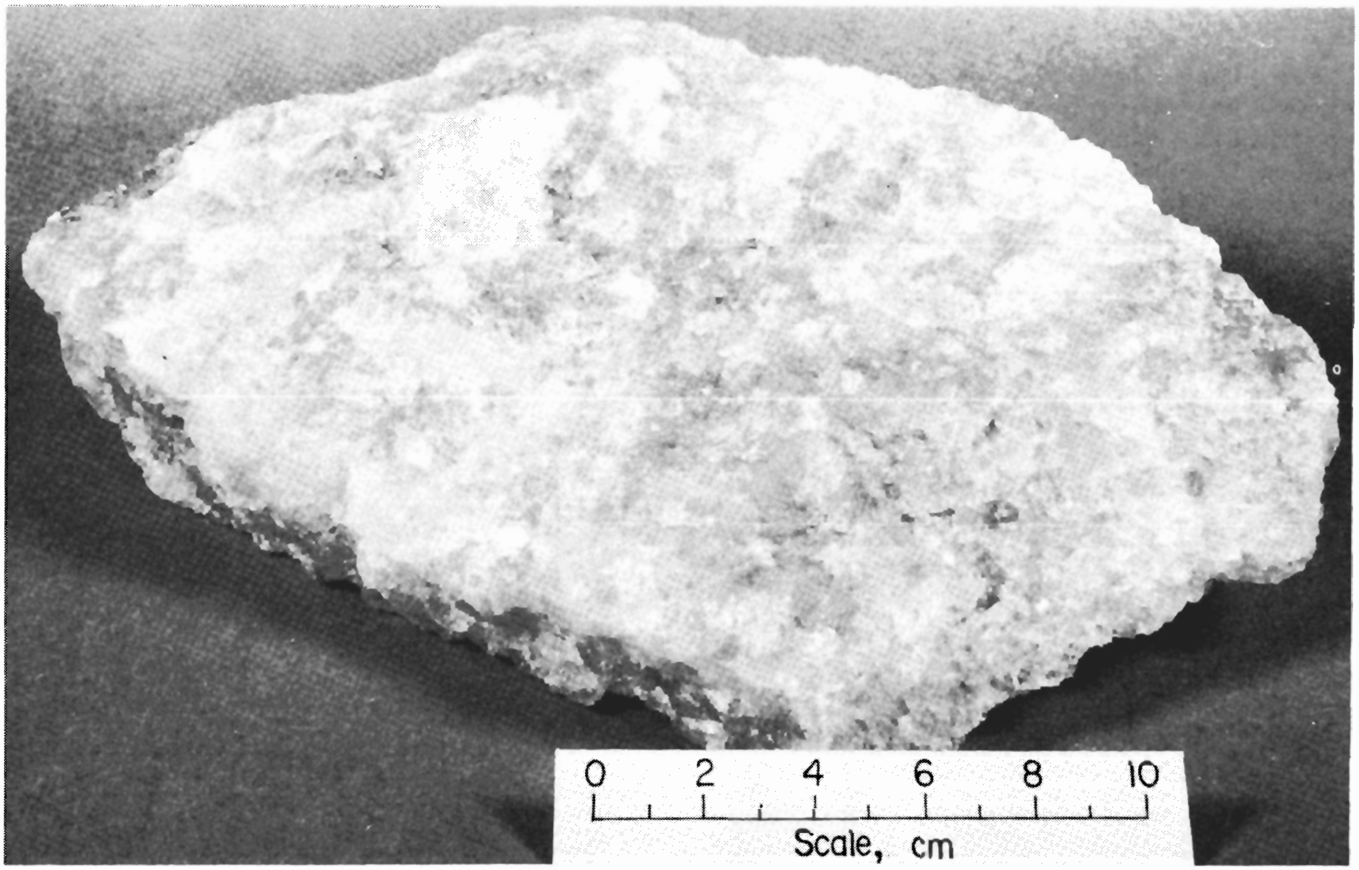

FIGURE 2.—Small grab sample of rock salt.

primarily small grab samples (fig. 2) collected from within the mine. The chamber is equipped with a magnetic door seal and has an instrumentation receptacle built in for strip-chart recorder and microphone outputs.

A cylindrical aluminum canister is bolted inside the chamber to provide additional insulation from outside noise interferences. A 2,000-mL glass beaker, filled with approximately 1,800 mL of water, is placed inside the canister. An inverted 250-mL glass beaker is placed inside the larger beaker and is used as a platform to hold the salt sample during testing (fig. 3). Sound emissions are monitored by a noise dosimeter attached to the aluminum canister. The dosimeter is connected to the inside jack of the instrumentation receptacle. A strip-chart recorder is connected to the dosimeter through the outside jack of the instrumentation receptacle. The recorder operates at a chart speed of 3 cm/min.

TEST PROCEDURE

A collected salt sample (approximately 50 g) is submerged in the water-filled 2,000-mL beaker. The chamber door is closed and sealed, and the strip-chart recorder is activated. Sound emissions are recorded for five min. The relative gassiness of the sample can be readily determined by examining the strip-chart recording at the end of the test. Visual inspection of the strip-chart recordings does not provide gas content values, but does provide relative values of gassiness such as low, medium, and high. Figure 4 shows the recorded output from three salt samples with different amounts of occluded gas. The gas contents of the three samples tested were no gas

FIGURE 3.—Test setup inside chamber.

(fig. 4*A*), cm^3 per 100 g (fig. 4*B*), 8 cm^3 per 100 g (fig. 4*C*), as determined by the dissolution method.

Additional testing was performed to determine if the acoustic test method could be used to ascertain actual gas content values. The results of this testing are detailed in the following section.

TEST RESULTS

A series of tests was conducted to determine the degree of correlation between the gas content of domal salt samples and the acoustic response of the samples as they are dissolved in water. The tests included an analysis of the impact of sample size on the test results.

CORRELATION TESTING

Correlation testing was accomplished by collecting 20 grab samples from within operating domal salt mines in southern Louisiana. The samples were collected from areas that had and had not experienced methane emissions during mining.

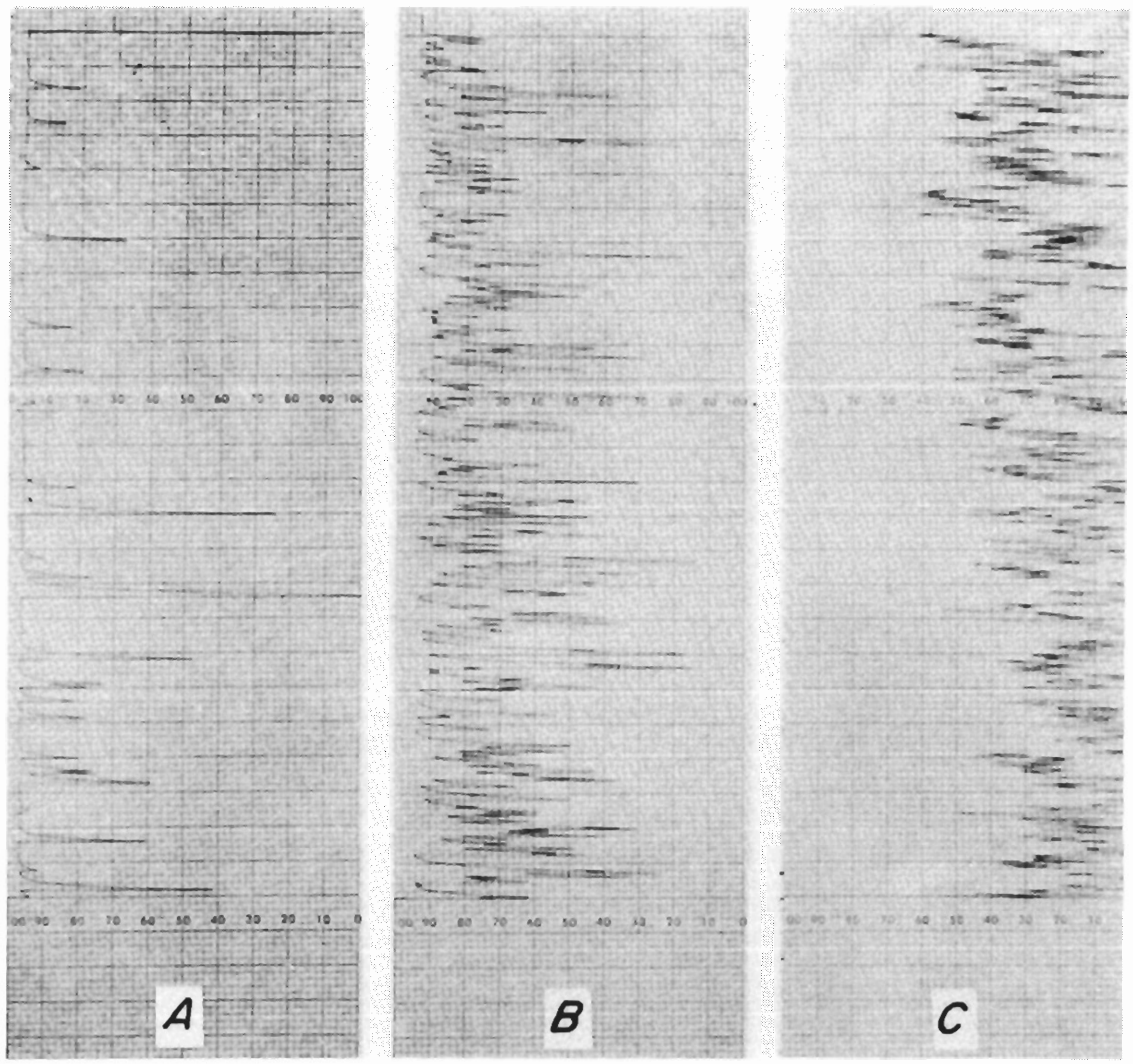

FIGURE 4.—Strip-chart recordings of relative acoustic responses from three samples with different gas contents. *A*, **No gas;** *B*, **4 cm^3 per 100 g;** *C*, **8 cm^3 per 100 g.**

Each sample collected was large enough to allow for multiple testing. After the samples were returned to the laboratory, a split of each one was subjected to the dissolution test to determine the actual gas content. A remaining portion from each sample was then dissolved in water, and its average acoustic response was recorded.

Results from the two test series are listed in table 1. Gas contents of the samples ranged from 0 to 8.6030 cm^3 per 100 g, while the acoustic responses ranged from 50 to 76 dB. Figure 5 shows the gas content versus acoustic response data for the samples collected and indicates the correlation coefficient, or r^2 value (14, pp. 229-249) was 0.97.

Using the established correlation shown in figure 5, gas content values for domal salt samples can be estimated from the following equation:

$$Y = -0.0127(X^2) + 1.9285(X) - 64,9316,$$

where Y = estimated total gas content, cm^3 per 100 g,

and X = average acoustic response, dB.

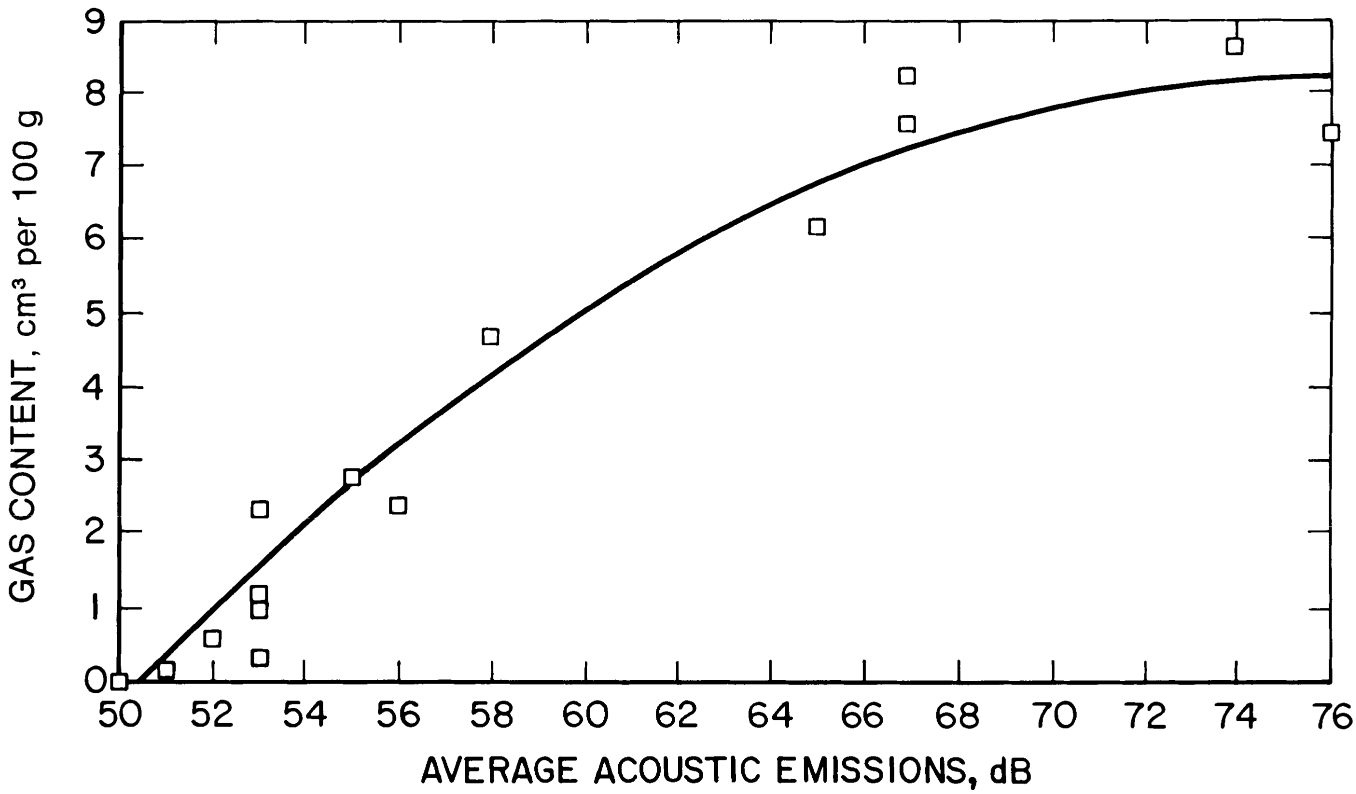

FIGURE 5.—Relationship between gas content and acoustic responses of salt samples.

TABLE 1. - Gas content and acoustic response test results

Test	Gas content, cm^3 per 100 g	Av acoustic response, dB
1..........	0.0000	50
2..........	.0013	50
3..........	.0000	50
4..........	.0000	50
5..........	.0101	50
6..........	.0000	50
7..........	.1520	51
8..........	.6010	52
9..........	1.1536	53
10..........	.9734	53
11..........	2.3036	53
12..........	.3224	53
13..........	2.7570	55
14..........	2.3690	56
15..........	4.6878	58
16..........	6.1427	65
17..........	8.2040	67
18..........	7.5615	67
19..........	8.6030	74
20..........	7.4248	76

REPEATABILITY OF RESULTS

The repeatability of an individual gas content estimation using the acoustic method was investigated for two different domal salt samples: one sample, collected from an outburst area, was expected to contain a large quantity of gas, while the other sample was collected from a relatively gas-free area. Each sample was large enough to be divided into 20 equal splits, and each split was tested using the acoustic method.

Table 2 lists the test results from the sample collected in the area that contained no gas. The acoustic responses when the 20 individual splits were tested ranged from 50 to 53 dB. The spread of the data can probably be attributed to differing gas contents within individual splits and differences in the results of the two tests. Table 2 also lists the test results from the sample collected from the outburst area. The average acoustic response from the 20 individual splits ranged from 69 to 75 dB. Overall, any individual test result is probably accurate to only ±10 pct.

TABLE 2. - Repeatability test results

(Av acoustic response, decibel)

Test	Sample with no gas	Sample from outburst prone area
1.........	51	72
2.........	52	73
3.........	51	73
4.........	51	72
5.........	53	73
6.........	52	74
7.........	52	75
8.........	53	73
9.........	51	73
10........	52	75
11........	51	70
12........	51	69
13........	50	75
14........	51	75
15........	52	73
16........	53	72
17........	51	74
18........	50	71
19........	51	74
20........	53	75

IMPACT OF SAMPLE SIZE

An experiment was conducted to determine the impact of sample size on the acoustic test method. A large domal salt mine sample was split into 10 smaller samples that ranged in size from 10 to 100 g, and each of the samples was subject to the acoustic test (table 3). Assuming each split contained like quantities of gas, the average acoustic responses were not affected by sample size. Therefore, the test method does not require careful selection of samples of equal size to ensure meaningful results.

TABLE 3. - Sample size test results

Test	Sample weight, g	Av acoustic response, dB
1...............	10	72
2...............	20	71
3...............	30	72
4...............	40	69
5...............	50	70
6...............	60	71
7...............	70	69
8...............	80	70
9...............	90	69
10..............	100	69

APPLICATION OF TEST RESULTS

Various observable features in domal salt mines have been correlated with the occurrence of gas-enriched zones and outburst-prone areas. The features include increased crystal size, occluded gas bubbles, contorted cleavage surfaces, and disking of core samples (11). These features are not consistent from mine to mine, and often they are observed only after the gas-enriched zone is intercepted by mining. Since the gas content of outburst-prone salt samples is usually high, the acoustic test method can be used for advance identification of these zones and areas.

Each active face within the mine can be sampled on a daily basis, and the results can be obtained before production begins. Core samples from horizontal holes could also be tested to provide gas content information in advance of mining. Where mining is to advance in a gas-enriched area, additional precautions can be implemented to reduce the hazards associated with methane emissions. Supplementary ventilation capabilities and increased awareness of the potential problem can prevent production delays and lessen the hazards associated with mining in gas-enriched and outburst-prone areas.

CONCLUSIONS

The Bureau of Mines has developed a fieldworthy method for determining gas contents of domal rock salt samples. The method is based on the relationship between occluded gas contents and acoustic responses as the samples are dissolved in water. The relationship was determined by performing a power curve regression on collected samples from three domal salt mines in Louisiana. The actual gas content of the samples was determined by the dissolution test method and ranged from no gas to 8.6030 cm^3 per 100 g NaCl. The correlation coefficient (r^2) of the established relationship is 0.97.

Multiple testing of large domal rock salt samples was conducted to determine the repeatability of the acoustic results. Two separate samples were tested to evaluate repeatability at both low and high gas content values. The acoustic responses from the low and high gas content samples ranged from 50 to 53 dB and 69 to 75 dB, respectively.

The impact of sample size on the acoustic test was determined by splitting a large salt block into 10 individual splits that ranged in size from 10 to 100 g. The average acoustic emissions from the 10 splits ranged from 69 to 72 dB.

The results of the acoustic test method can be used by mine operators to aid in identifying gas-enriched zones prior to their interception by mining if coreholes are used. Using grab samples, the method can also be used to verify areas of high gas content. Since areas with higher occluded gas contents can be expected to experience higher methane emissions during mining, the test can aid in determining additional ventilation needs. Data from the test can be obtained in 5 min or less, and a laboratory environment is not necessary to ensure meaningful results.

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