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Methane Accumulations in Coal Mine Roof Cavities

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METHANE ACCUMULATIONS IN COAL MINE ROOF CAVITIES

by

Robert P. Vinson,[1] Edward D. Thimons,[2] and Fred N. Kissell[3]

ABSTRACT

The Bureau of Mines investigated the presence and extent of methane accumulations in mine roof cavities using a full-scale mine model. Methane was released at a constant rate into the roof of a cavity built onto a 700-ft wind tunnel. Two box-shaped roof cavities were used in the study: one had a volume of 114.7 cu ft; and the other had a volume of 57.3 cu ft. Methane concentration was measured at 28 sampling points in the cavities using 21 different combinations of gas emission rates and air velocities. Brattice hung in the cavity helped reduce methane concentrations without auxiliary ventilation. It was also found that the effective ventilation rate increased by a factor of 40 in the large cavity and by a factor of 20 in the small cavity when air velocity was increased from 100 to 600 fpm.

INTRODUCTION

Any location in a coal mine where 5 pct or more of methane is present constitutes a potential site for an explosion and roof cavities are likely locations. Unfortunately, little is known about the buildup of methane in roof cavities. Some research has been done using scale models where no air flows past the cavity so that methane disperses only by diffusion (5),[4] a rare situation in mines.

No known cavity-model investigations have been made that simulate air and methane flow conditions normally encountered underground. These Bureau of Mines studies were undertaken to determine the extent and manner of methane buildups in coal mine roof cavities with air velocities in the range normally found in coal mines and with various methane emission rates.

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[1] Physicist.

[2] Supervisory physicist.

[3] Physical research scientist.

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

TEST FACILITIES

Studies were conducted at the Mining Enforcement and Safety Administration (MESA) Technical Support wind tunnel at Bruceton, Pa. The tunnel is 700 ft long, 8 ft wide, and 5 ft high. A roof cavity was simulated by a wooden, box-shaped structure built onto the top of the tunnel. Initially, this box was 8 ft wide, 4 ft long, and 4 ft high (fig. 1). The top 5 inches of the box was used as a gas chamber into which gas was fed through eight equally spaced gas-dispersing pipes. A 4- by 8-ft section of pegboard separated this gas chamber from the cavity. Fifteen equally spaced 1/16-in-diameter holes were kept open in the pegboard; the remainder were sealed shut. This arrangement allowed gas to disperse evenly through the roof of the cavity. Gas issuing from these holes into the cavity was deflected 90° by small baffles placed directly in front of the holes to prevent gas jets from disturbing the established air current in the cavity (fig. 2).

The initial inner height of the cavity was 43 inches, giving a total cavity volume of 114.7 cu ft. Later, the height was reduced to 21.5 inches, resulting in a cavity volume of 57.3 cu ft. Both cavities had plastic blowout

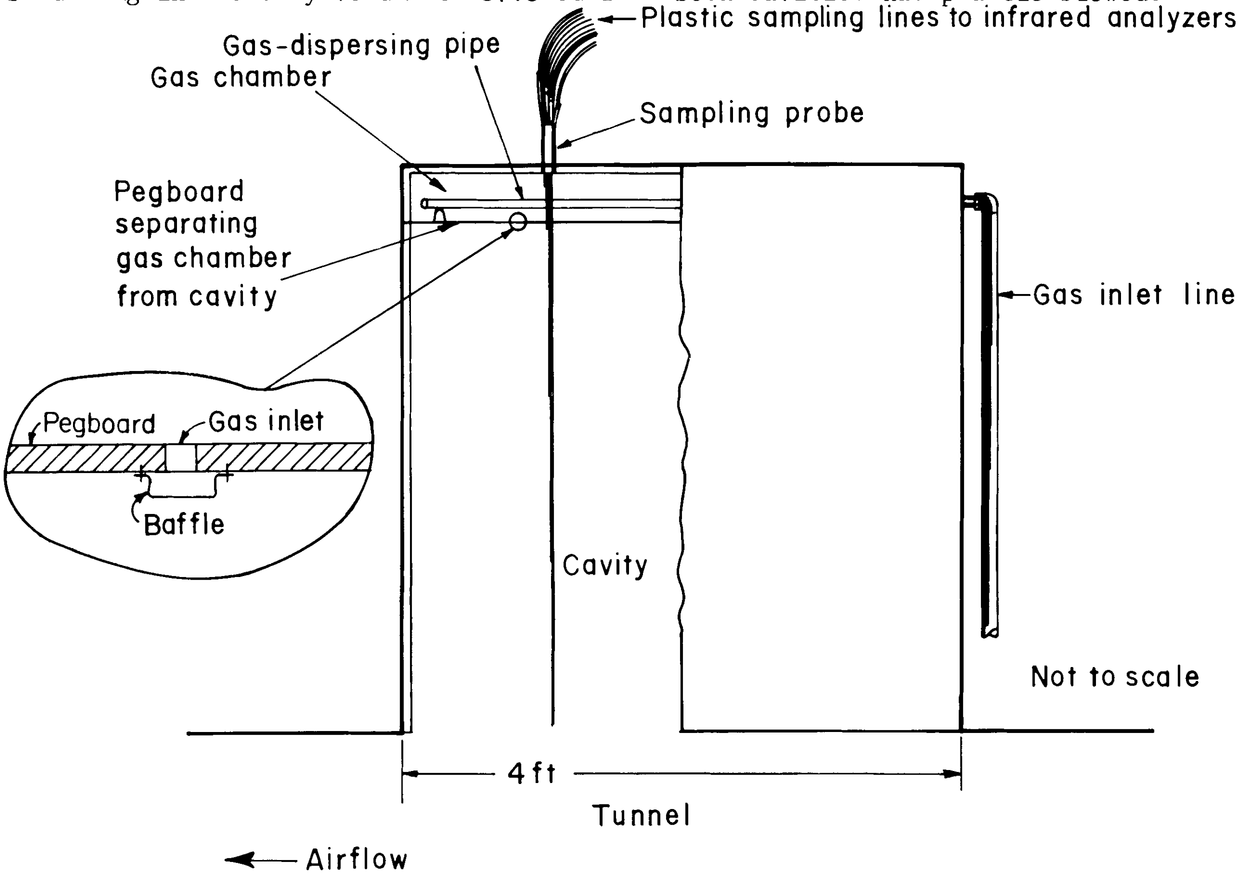


FIGURE 1. - Roof cavity.

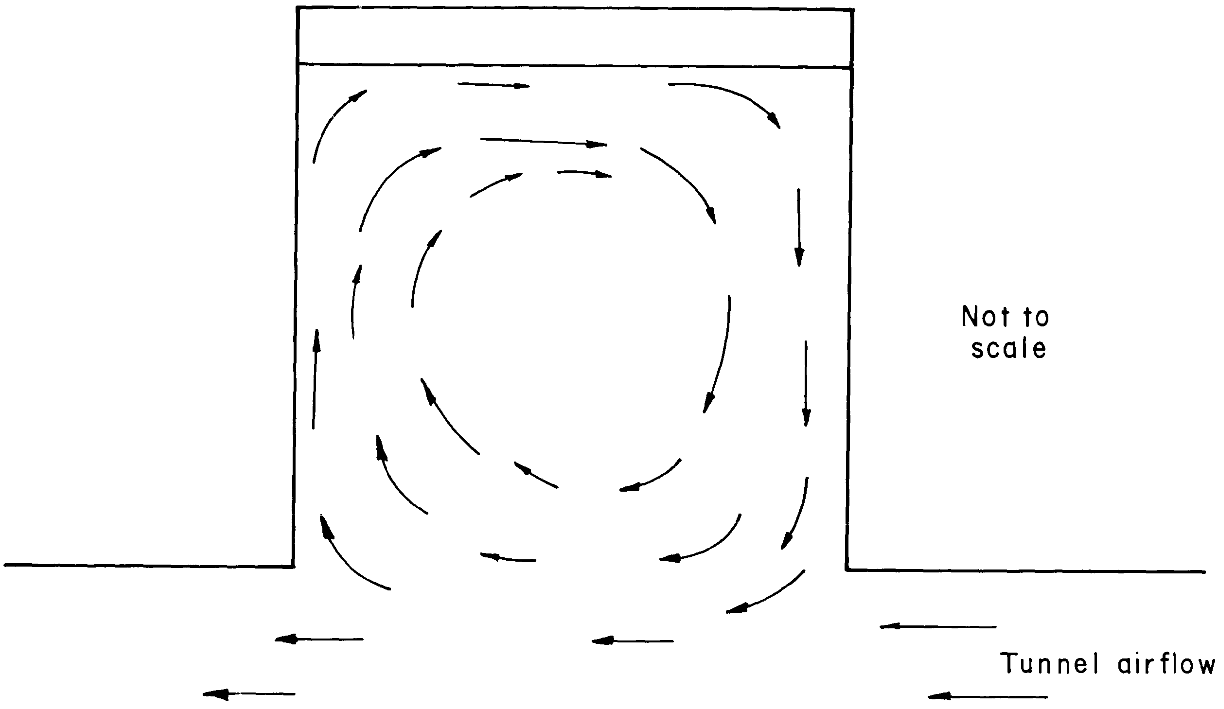


FIGURE 2. - Airflow in cavity.

windows in case of an explosion. Gas flows into the cavity from 2 to 8 cfm were measured with a rotameter. Gas flows less than 2 cfm were measured with a wet-test meter. Airflow through the tunnel was adjusted by a regulator near the exhaust fan. Tunnel air velocity was determined from anemometer traverses.

Gas concentrations in the cavity were measured with two five-point probes, each constructed of five lengths of 1/4-inch copper tubing. An air pump pulled gas samples from the gas chamber and cavity into the probes, through 1/4-inch plastic tubing, and into an infrared analyzer. Two analyzers were used to measure methane: one in the zero- to 2-pct range; and the other in the zero- to 100-pct range. The point in the cavity to be sampled and the analyzer to be used were determined by opening and closing the appropriate valves.

EXPERIMENTAL PROCEDURE

The test procedure consisted of establishing the air velocity through the tunnel at 100, 300, or 600 fpm. Gas was then released into the gas chamber at a controlled constant rate. While gas was released, air samples were taken through the probe permanently placed in the center of the cavity. Gas measurements were taken at five levels: one in the gas chamber and four in the cavity at equidistant depths. Gas samples were taken from these five points periodically to determine when the methane-air mixture in the cavity reached steady-state conditions. Once steady state was reached, the second probe was positioned at one of six other sampling locations (fig. 3). This probe also took a sample from the gas chamber and at four depths in the cavity. With seven sampling locations and four sampling depths in the cavity, 28 gas measurements were made in the cavity for each gas emission and airflow combination. A wide range of methane concentrations in the cavities was obtained by varying the CH_4 flow rates. Smoke was used to observe airflow patterns in the cavity (fig. 2).

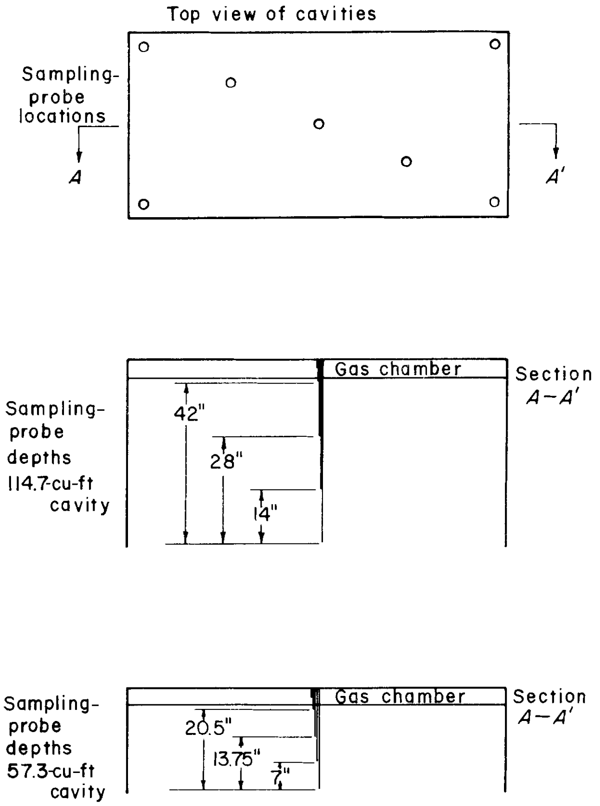


FIGURE 3. - Sampling probe locations and depths.

RESULTS AND DISCUSSION

The objective of this study was to measure methane accumulations in roof cavities and to observe the effect of cavity size, air velocity, and methane emission on these accumulations by varying these three parameters. Methane concentrations were sampled at four depths in both cavities and at seven

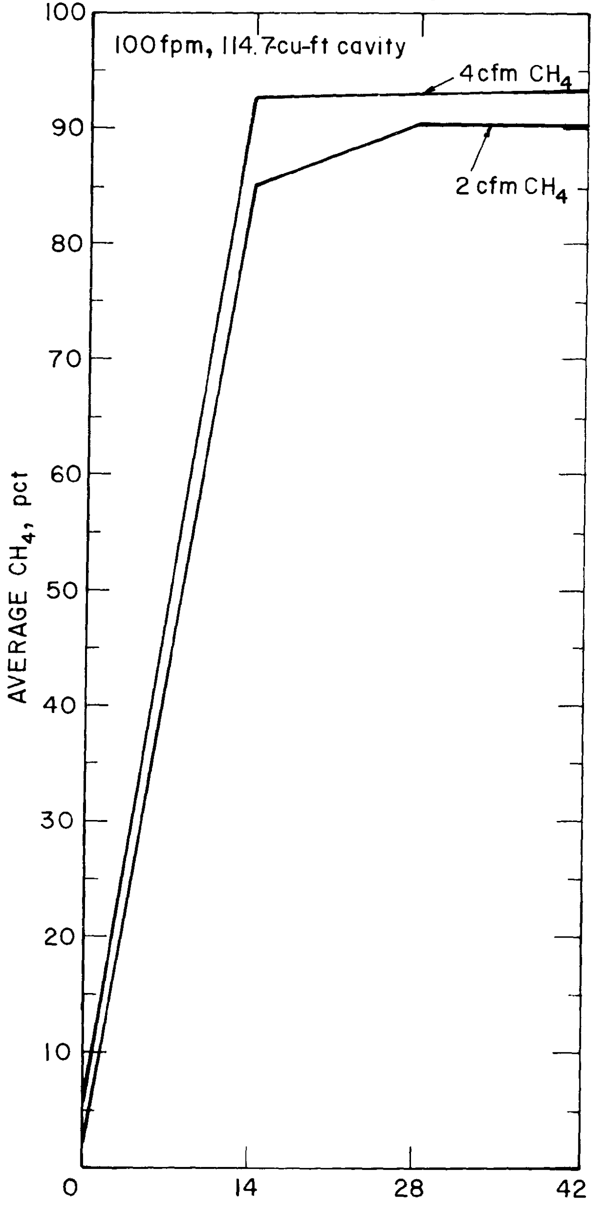


FIGURE 4. - Methane concentrations in 114.7-cu-ft cavity at 100-fpm air velocity.

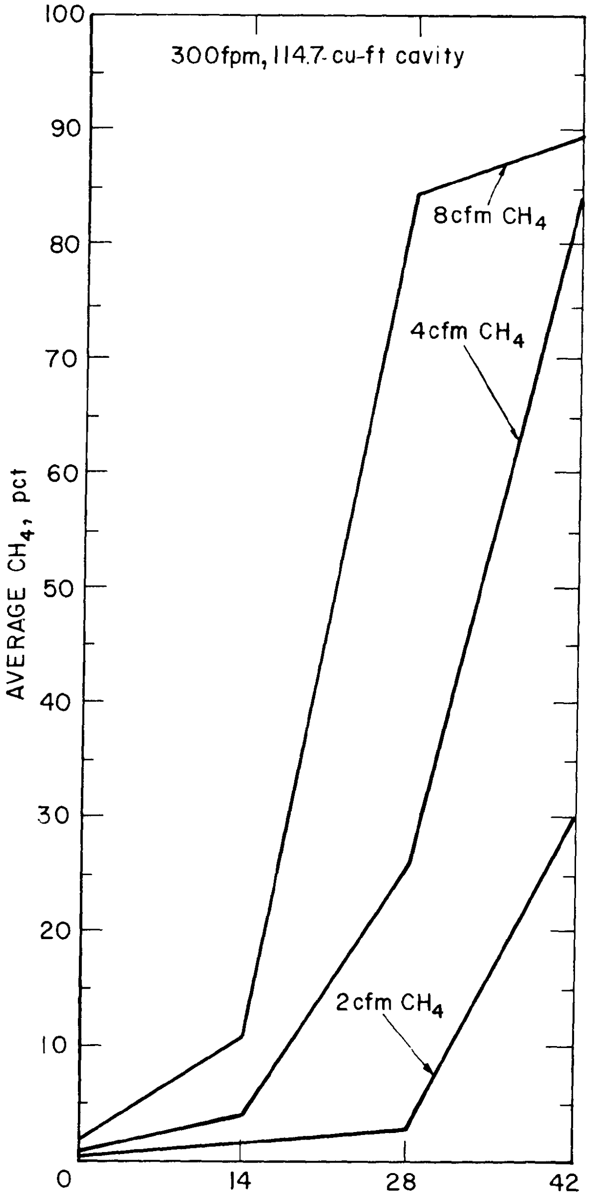


FIGURE 5. - Methane concentrations in 114.7-cu-ft cavity at 300-fpm air velocity.

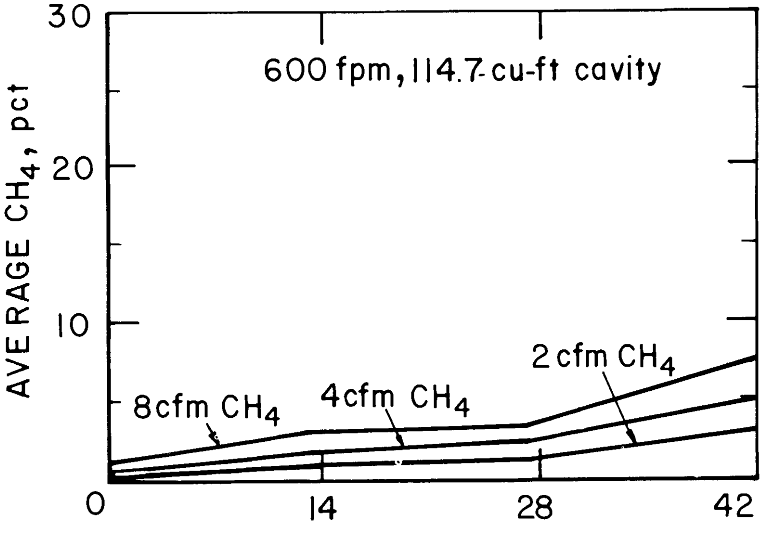


FIGURE 6. - Methane concentrations in 114.7-cu-ft cavity at 600-fpm air velocity.

locations at each depth (fig. 3). An unweighted arithmetic mean of the concentrations at each depth was calculated.

The mean methane concentrations in the 114.7-cu-ft cavity and in the 57.3-cu-ft cavity are shown in figures 4 through 6 and figures 7 through 9. Steady-state methane concentrations were higher in the large cavity than in the small cavity at air velocities of 100 and 300 fpm. This is shown graphically in figure 10, which is a typical methane profile as measured in both cavities. Figure 10 also shows the effect of the circular air current in the cavity. This is seen at the bottom of the downstream side of the cavity where the concentration profile is bent up, which indicates that fresh air is entering the cavity in this area. This agrees with the circular air current in figure 2. The effect of the cavity air current is much stronger in the shallow cavity because the concentration profile is bent up from the base to the roof of the cavity on the downstream side. In the large cavity, however, the effect of the air current is not as strong because only the bottom portion of the profile is bent up. The concentration profile near the roof on the downstream side of the large cavity is actually bent down. This may be the result of either a dead space of no airflow or a small, reverse, circular air current induced by the main airflow in the cavity.

At an air velocity of 600 fpm, methane concentrations in the small cavity were slightly higher, but no special significance is attached to this less-than-1-pct increase.

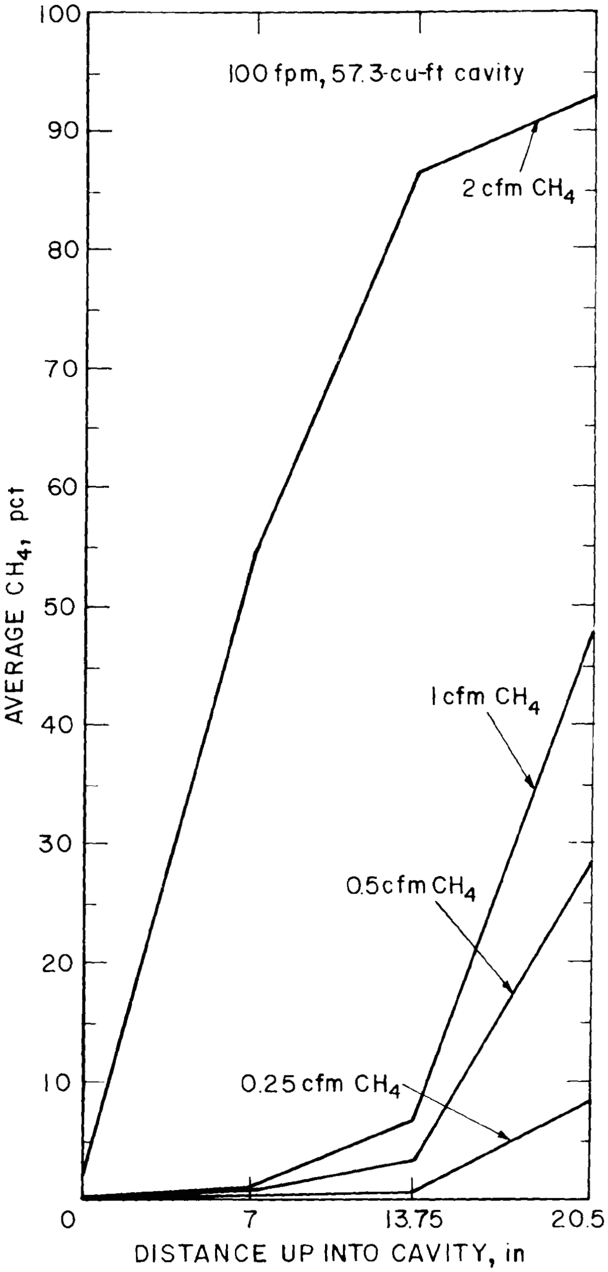


FIGURE 7. - Methane concentrations in 57.3-cu-ft cavity at 100-fpm air velocity.

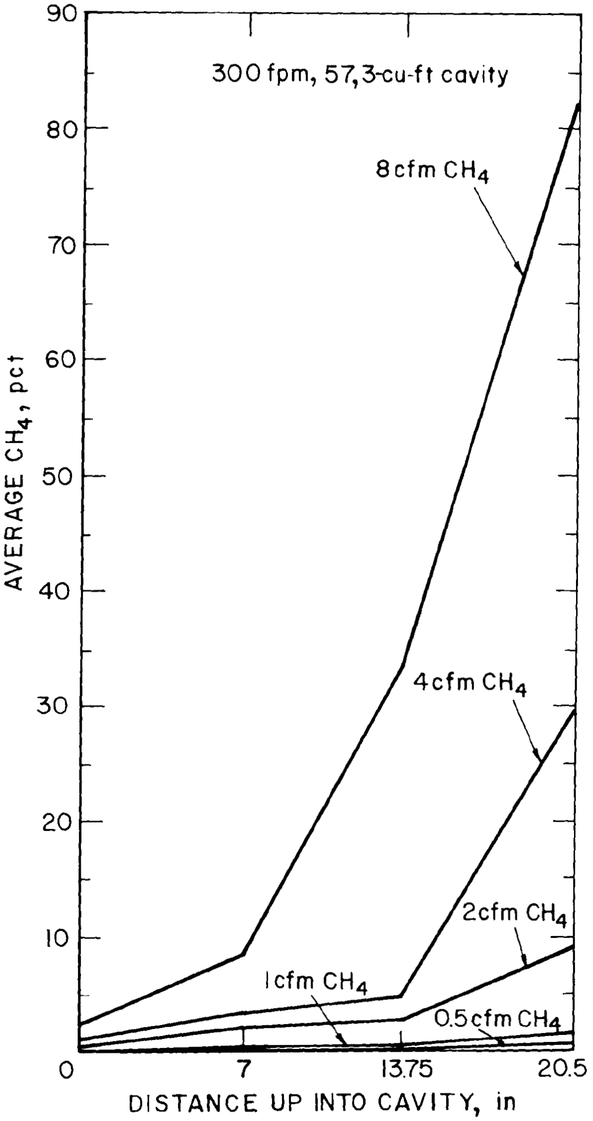


FIGURE 8. - Methane concentrations in 57.3-cu-ft cavity at 300-fpm air velocity.

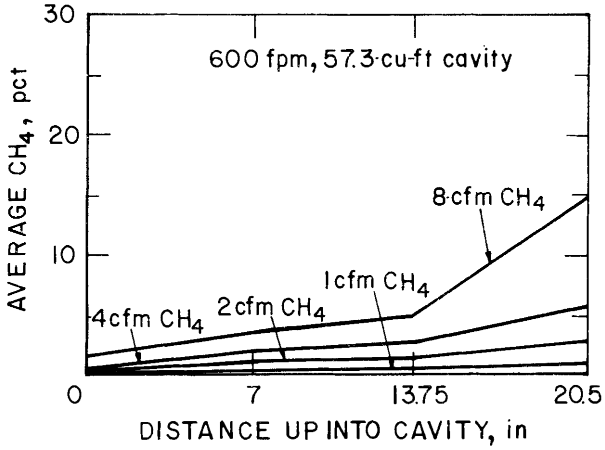


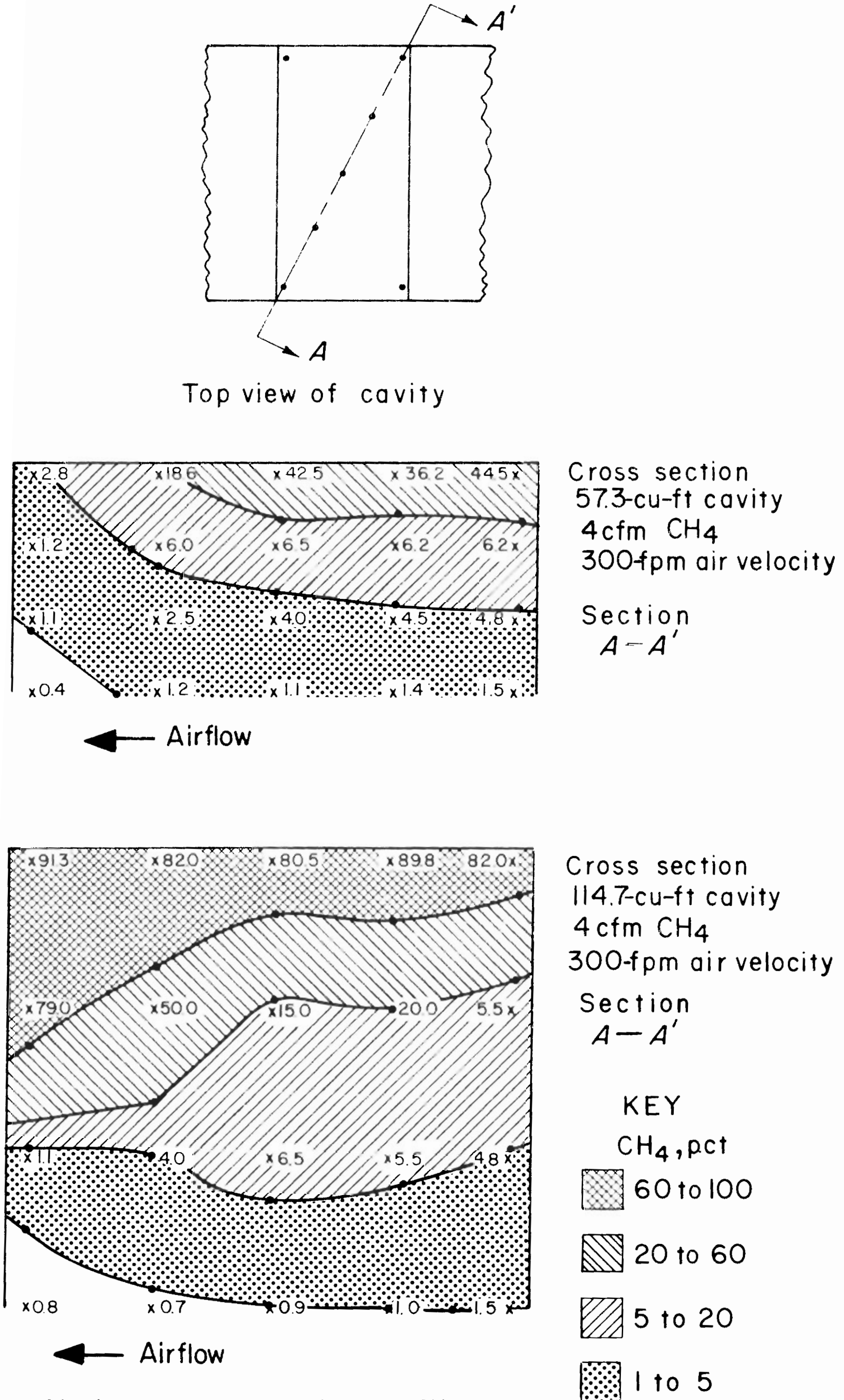
FIGURE 9. - Methane concentrations in 57.3-cu-ft cavity at 600-fpm air velocity.

The low methane concentrations in both cavities at 600 fpm were due to the strong circular air current in the cavity (fig. 2); a less pronounced circular air current also existed at 100 and 300 fpm.

The effect of this circular air current in the cavity is shown in figure 11, which is a plot of the air velocity and the effective ventilation rate. The effective ventilation rate is the quotient of the methane flow divided by the average methane concentration in the cavity. In the 114.7-cu-ft cavity, the average effective ventilation rate increased by a factor of 40 when the air velocity was raised from 100 to 600 fpm. In the 57.3-cu-ft cavity, the average effective ventilation rate increased by a factor of 20 when the air velocity was raised from 100 to 600 fpm.

Although the methane concentrations decreased substantially at 600 fpm, the concentrations in both cavities were above 5 pct when methane flows were 4 and 8 cfm.

Comparison of methane concentrations measured at the same air velocity and different methane inputs with methane concentrations measured at the same methane input and different air velocities shows that air velocity in the tunnel has more influence on methane concentration than does methane input. High air velocities substantially reduce the possibility of dangerous methane concentrations in roof cavities.



Methane concentration profile

FIGURE 10. - Methane profiles in 114.7- and 57.3-cu-ft cavities.

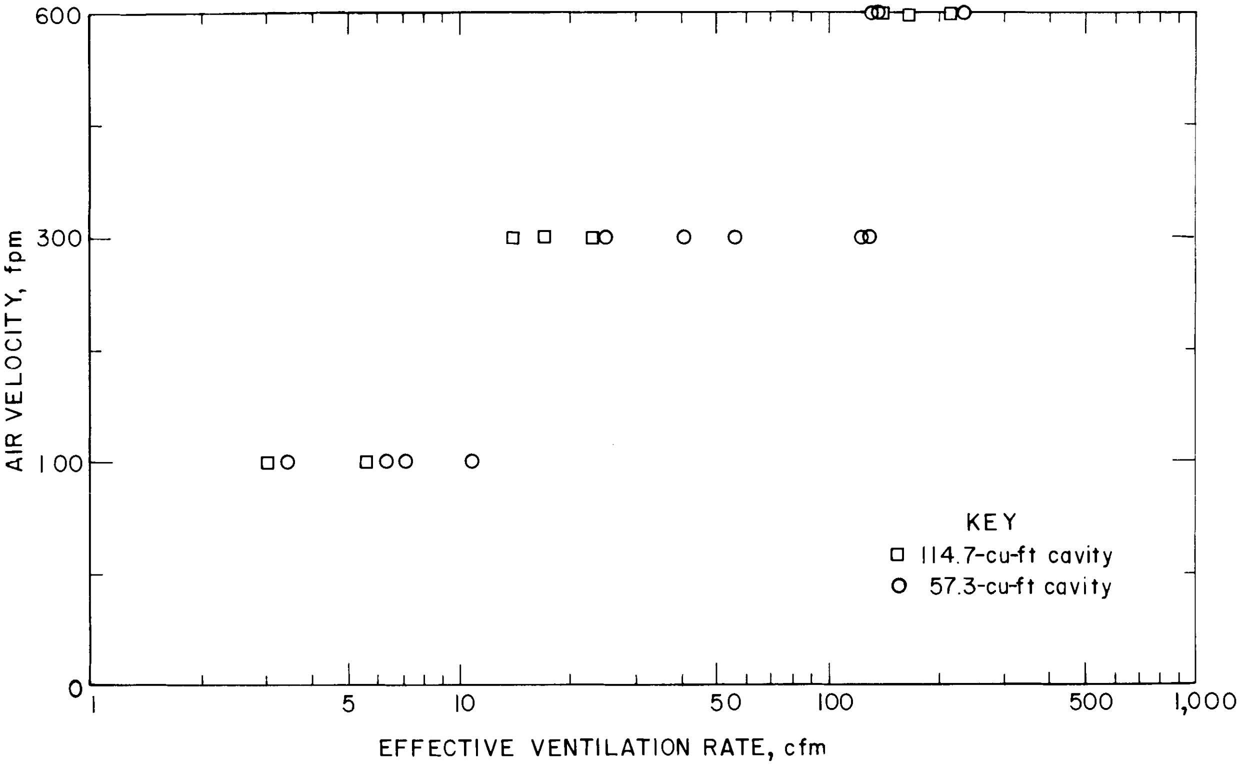


FIGURE 11. - Air velocity versus effective ventilation rate.

BRATTICE AID IN VENTILATION CAVITIES

When cavities occur in main haulageways or main intake airways provisions are normally made to ventilate them. Common practice is to run a section of ventilation tubing from the cavity roof into a return airway that has a lower air pressure. Cavities in return airways can be kept free of methane by placing a baffle in the cavity, which forces the air to sweep out the cavity.

An experiment was conducted to determine if the simulated cavities could be kept at nonflammable methane concentrations by a brattice sheet hung the full width of the cavity (fig. 12). Gas samples were taken from the center probe and compared with samples from the same location but without the

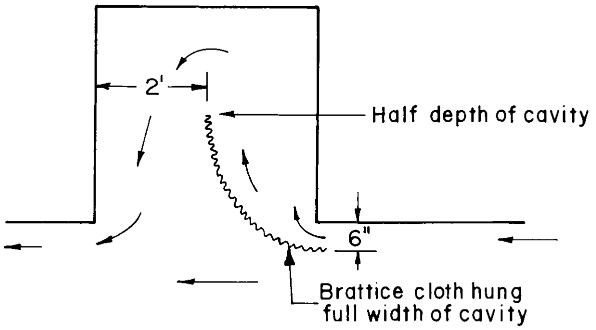


FIGURE 12. - Airflow with brattice hung in cavity.

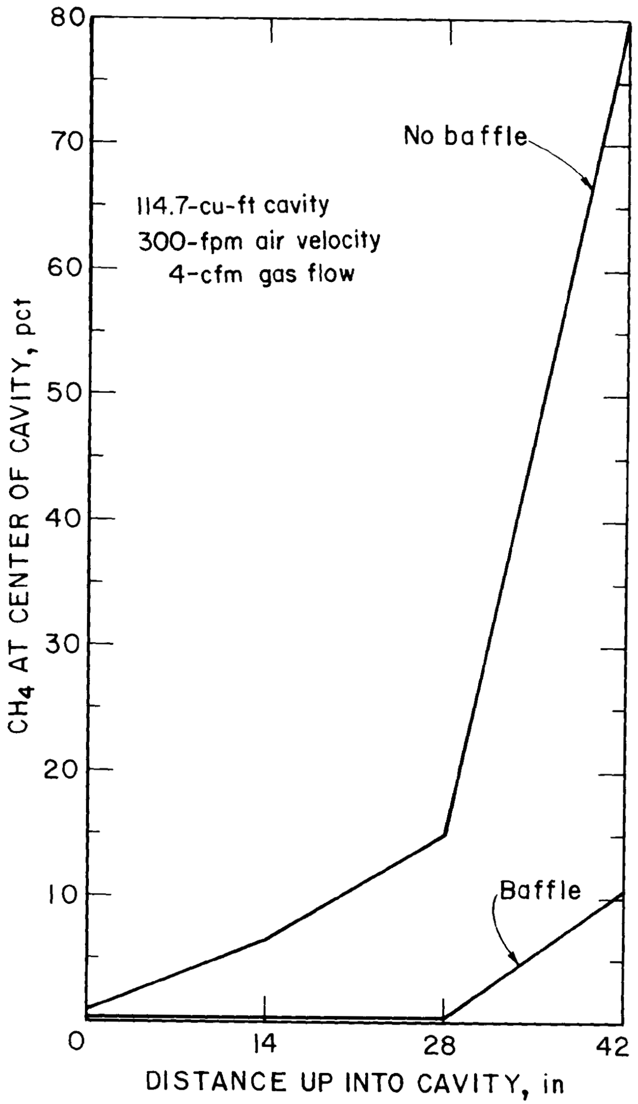


FIGURE 13. - Effect of brattice in 114.7-cu-ft cavity.

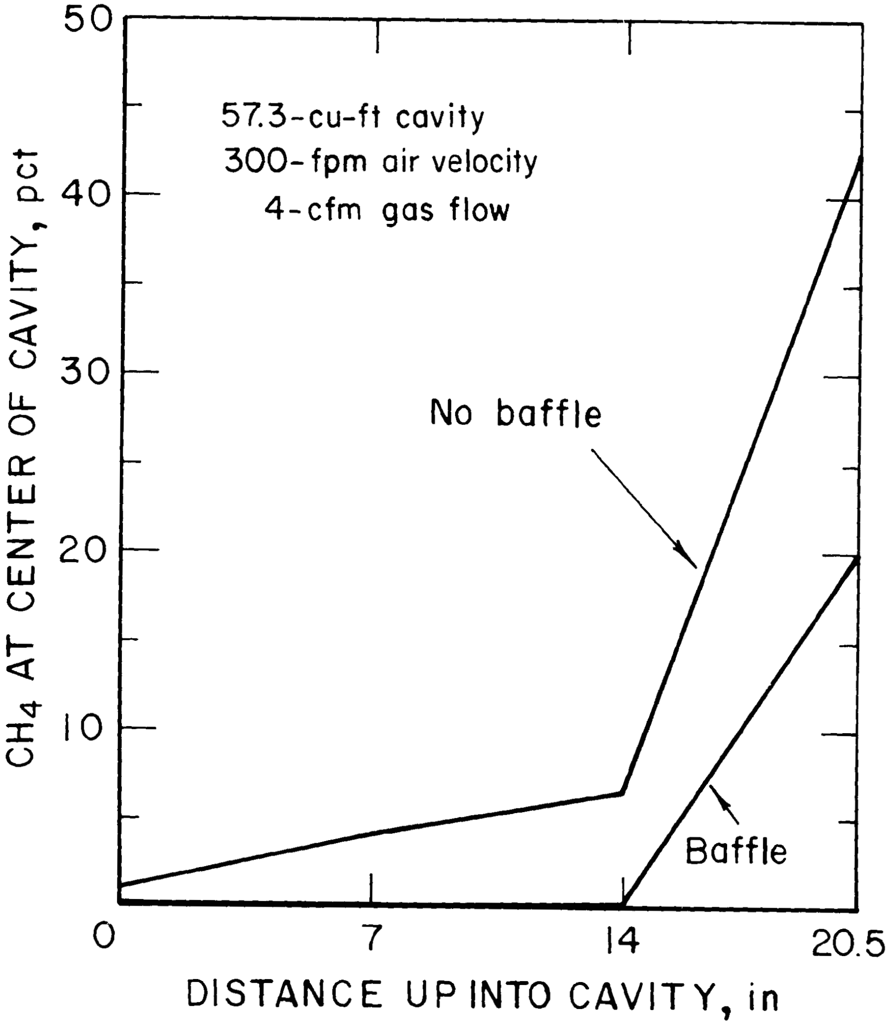


FIGURE 14. - Effect of brattice in 57.3-cu-ft cavity.

brattice in the cavity. Both sets of gas samples were taken with a tunnel air velocity of 300 fpm and a gas input of 4 cfm. The comparisons for both cavities (figs. 13-14) show a dramatic reduction in methane concentration with the use of brattice.

The volumes of gas at 5 pct or greater concentration were calculated by gas samples taken from the center probe. When the brattice was hung in the small cavity, this volume was reduced from 31.5 to 7.2 cu ft; when it was hung in the large cavity, volume was reduced from 88 to 18 cu ft. These concentrations might have been reduced further if the brattice had been hung nearer the roof of the cavity.

LAYERING NUMBER

When methane flows into a mine entry from the roof, it tends to remain concentrated at the roof (1). This phenomenon, known as layering, has been the subject of many theoretical and practical studies (1-4). "As a phenomenon, layering depends on a dimensionless combination of independent variables, such as velocity, gravitational acceleration, density, density difference, volume of fluid, and width of roof" (1).

To better understand layering, a dimensionless number using these variables has been derived by Bakke and Leach (1). For methane in air, it is

$$L = \frac{U}{37\sqrt[3]{V/D}},$$

where L = layering number, dimensionless;

U = ventilation velocity, fpm;

V = methane input, cfm;

and D = width of layer (same as width of tunnel), feet.

This number gives an estimate of the propensity to layer. The higher the layering number, the lower the probability that layering will occur. A horizontal entry with a layering number of 5 or more is generally considered safe; that is, layering will not be a problem.

Although it is not related to roof cavities, the layering expression was applied to determine what value of L would correspond to safe methane concentrations (below 5 pct) in the cavities used in this study. Quite often, as in this investigation, the point of methane emission is the roof of the cavity. Figure 15 is a plot of average percent methane in the cavity versus layering number for all the tests run, both in the large and small cavities.

The graph shows that as L increases, the methane concentration decreases. The layering number reached 20 before gas concentrations in the cavity approached safe levels; however, it should not be assumed that the layering number can be used to determine methane accumulations in cavities. In three

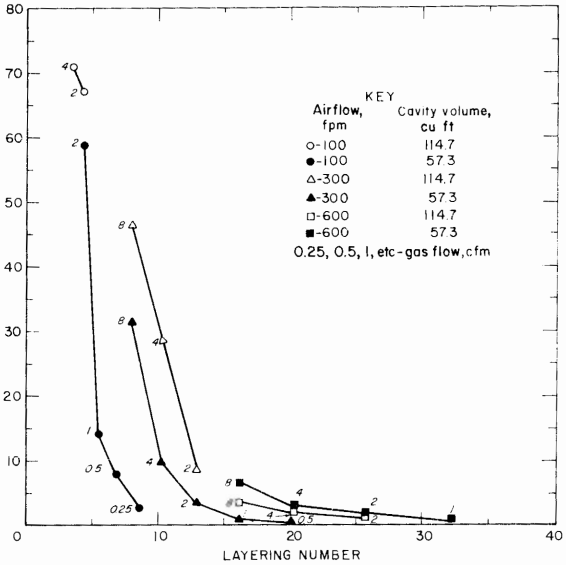


FIGURE 15. - Layering number versus average methane concentration.

comparisons shown in table 1, there is a drastic difference in average methane concentrations although the calculated layering numbers are about the same.

TABLE 1. - Layering number and methane concentration in 57.3-cu-ft cavity

Layering No.	CH_4 in cavity, pct	Air velocity, fpm	CH_4 emission, cfm
20.4	2.81	600	4
20.2	.41	300	.52
16.2	6.19	600	8
16.2	.78	300	1
8.1	31.7	300	8
8.6	2.34	100	.25

The length of a methane layer extends from the point of emission to that point downstream in the entry where the methane is completely dispersed. For practical purposes, however, layer length is usually defined as the distance from the point of methane emission to the place at the mine roof where the mean concentration is 5 pct. Based on this definition of layer length, no layering occurred in the tunnel downstream from the cavity. Figure 16 shows that the highest methane concentration at the roof was 4 pct. This was at the downstream edge of the cavity, which was considered to be the point of methane emission into the tunnel. Fifty ft downstream from the cavity, methane concentrations were less than 1 pct at the roof.

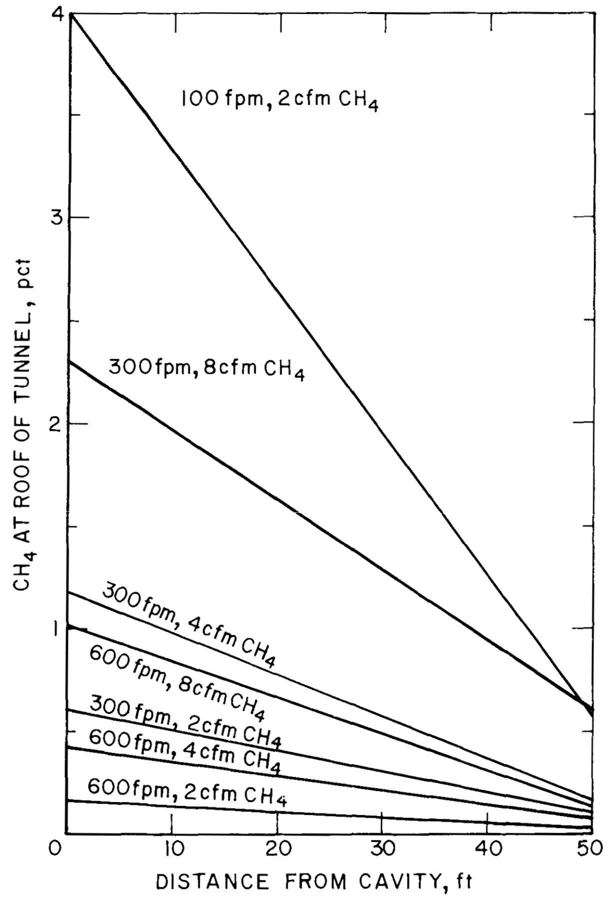


FIGURE 16. - Methane concentrations at roof of tunnel.

CONCLUSIONS

This study demonstrated that methane accumulates in coal mine roof cavities into which methane flows from the roof regardless of the air velocity, and that the methane concentrations are a function of the air velocity in the airway below the cavity. Higher air velocities produce pronounced circular air currents in the cavities, which, in turn, reduce the methane concentrations. It was found that this velocity effect is more important in determining the methane concentrations that will exist in a cavity than the rate of flow of methane into the cavity. This conclusion is supported by the layering-number theory. Higher than normal layering numbers are needed to maintain safe methane concentrations in an airway if the airway has roof cavities. Higher layering numbers can most readily be obtained by increasing the air velocity in the airway. It was also found that brattice hung in the cavity reduced methane concentrations without auxiliary ventilation.

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