

CHARACTERIZATION OF GAS FLOW IN LONGWALL GOBS: PITTSBURGH COALBED, PA

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ABSTRACT

The National Institute for Occupational Safety and Health, Office for Mine Safety and Health Research, is investigating the geologic and mining factors influencing the migration of longwall gob gas. One goal of these studies is to optimize methane drainage strategies to reduce the volume of gob gas that reaches the underground workplace. As part of this research effort, longwall gob gas flow paths in a mine operating in the Pittsburgh Coalbed, PA, were investigated using SF₆ tracer gas. Tracer gas released into the ventilation airflow underground generally stayed in the bleeder system and was vented at the associated bleeder fan shafts. Tracer gas injected into an inactive (intaking) gob gas venthole migrated to the two inby producing ventholes on the study panel, indicating that all three ventholes were in communication. The tracer gas that was injected into the gob generally stayed in the gob and only migrated to the ventilation system in response to the venthole on the study panel closest to the injection hole going off production. Tracer gas flow velocities in the longwall gob reservoir and factors influencing the production performance of gob gas ventholes in the study area are also discussed.

INTRODUCTION

As part of its Mine Safety and Health research program, the National Institute for Occupational Safety and Health's Pittsburgh Research Laboratory is investigating methane emissions associated with underground coal mining. The current focus of this research program is to develop a better understanding of the influence of geology, mining and ventilation practices, and methane drainage on the release and migration of methane gas during longwall mining [1-5]. The objective of the current phase of the study is to measure gas migration characteristics associated with longwall gobs using a tracer gas to simulate methane flows. The knowledge gained from this research will be used to optimize longwall methane control strategies to intercept a larger portion of the gob gas before it enters the underground workplace.

Research completed to date includes seven tracer gas releases into underground ventilation airways between mined-out longwall panels. Additionally, one release, which is the focus of this paper, was made into an inactive (intaking) gob gas venthole. This combination of release modes allowed for a complete evaluation of the interaction (or lack thereof) between gob gas ventholes and the ventilation system and between individual gob gas ventholes on the same longwall panel.

STUDY AREA

The study mine operates in the Pittsburgh Coalbed in Greene County, PA. Longwall panels in the study area (Fig. 1) were generally 253 m (830 ft) wide initially (Panels A+ through E) and increased to 305 m (1,000 ft) starting with F Panel. Panel length generally increased with each successive panel. G Panel at the southern end of the study area where the SF₆ borehole injection experiment was conducted had a mined length of approximately 32,713 m (8,900 ft) (Fig. 2). Overburden depths ranged between 152 and 274 m (500 and 900 ft).

Methane control for the study area includes bleeder fan shafts and gob gas ventholes. Bleeder exhaust fans (BF2 and BF3), located at the top of 1.8-m (6-ft) -diameter air shafts, are designed to remove a portion of the gas liberated

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during active mining on the current panel, as well as gas released in the large gob area formed by the previously mined-out panels (Fig. 1). Commonly, three gob gas ventholes are located on the tailgate side of each panel in the near-margin configuration developed in earlier research efforts [2]. The gob gas ventholes are equipped with exhausters powered by the produced gas.

TEST PROCEDURES AND EQUIPMENT

General

The general concept of the gas flow characterization experiments is to release a defined volume of tracer gas into the ventilation airflow or longwall gob and subsequently monitor (collect gas samples) all potential exit points for the gas. The tracer gas selected for use in these studies was sulfur hexafluoride (SF_6). SF_6 is a nontoxic, colorless, odorless, nonflammable gas commonly used in underground mine ventilation studies [6-8]. It is chemically and thermally stable, but is heavier than air, requiring its dispersal and mixing to a low concentration (<100 ppm of SF_6 in air) to simulate the movement of the host air stream.

By determining the tracer gas concentration (if any) in the periodic gas samples taken at the various monitoring locations and measuring the associated airflow rate, the volume of tracer gas passing through each monitoring site can be calculated. Thus, the relative distribution of tracer gas flow to the various outlet points (bleeder fan shafts, producing gob gas ventholes, underground ventilation system) can be determined. The velocities associated with the identified gas flow pathways can be calculated knowing the path length and travel times for tracer gas flow to each monitoring location. These basic gob gas flow characterization data will be used to model gob gas reservoirs and optimize methane control strategies.

Gas Sampling Procedures and Equipment

The periodic gas samples necessary to determine the presence (or absence) of the released tracer gas at the monitoring stations were collected in 20-ml glass sample tubes. Gas samples were obtained in two ways during the experiments. Primary sampling was accomplished with an automated gas sampling (AGS) system (Fig. 3). The automated system was supplemented with manual sampling during critical time periods, primarily just after a tracer gas release, to better identify the first arrival of the tracer gas at a monitoring site.

Operationally, the complete AGS system consisted of the automated gas sampling device sealed inside an air-tight housing and a permissible, programmable air sampling pump external to the sealed container (Fig. 3). The intake side of the pump was connected via tubing to the AGS housing, which in turn was connected to the mine air/gas production point to be monitored, i.e., either the bleeder fan housing or the surface piping system of a gob gas venthole. Thus, when the air sampling pump was on, the atmosphere inside the AGS housing was evacuated, pulling the mine air/gob gas to be sampled into the container. SF_6 concentration data were obtained by gas chromatography (GC).

UNDERGROUND RELEASES

General

The locations for the seven underground SF_6 releases were chosen to assess a complete geographic distribution of gas flows within the study area (Fig. 1). The releases were conducted at the completion (west) ends of the panels because the ventilation airflow for this part of the mine was directed towards the back (east) ends of the panels where the two bleeder fan shafts are located. Prior to the underground tracer gas releases, ventilation surveys were conducted to determine the airflow volumes and velocities in the vicinity of the proposed release sites. These data were used to design each individual release, including tracer gas volume and release method, i.e., fast versus slow. The ventilation surveys were also used to determine potential locations where tracer gas might flow out by the release points to the main return airways, which would necessitate underground monitoring for the presence of tracer gas.

Release Specifications

Two methods of tracer gas release (fast or slow) are generally used for underground airflow studies [6-8]. A fast release would empty a standard 0.04-m³ (1.3-ft³) lecture bottle in as little as 30 seconds, producing a high peak

concentration in the air stream at the release point and, subsequently, a short-duration, high-concentration peak at the monitoring locations. The results of the development work for this study determined that an air velocity of about 10.2 m/s (2,000 ft/min) was generally the minimum airflow acceptable for a successful fast release of tracer gas. Most of the releases in this series of experiments were fast.

The slower release method is generally used in low airflow conditions to ensure the mixing of the SF₆ in the airstream. A slow release is expected to produce a longer duration, lower concentration peak at the monitoring locations than would be observed with a fast release. The slow release method empties a standard lecture bottle in about 20 minutes. The slow release method was required for only one underground release (Test 2-0).

Results

The SF₆ recovery percentage for monitoring locations where tracer gas from each underground release was detected is summarized in Table 1. Data relative to the SF₆ concentration curves for each release, including first arrival time, duration (time interval from first to last measurable SF₆ concentration value), and the highest measured concentration are summarized in Table 2.

Most of tracer gas released into the underground ventilation airflow stayed in the ventilation system and the flow paths were in by the release points, i.e., towards the back (start-up) end of the panels, where it was vented at one of the bleeder fan shafts. On three occasions (Tests 2-0, 2-3, and 2-5), tracer gas released into the underground ventilation airflow was detected at a gob gas venthole. All tracer gas recoveries (percent of total release volume) at gob gas ventholes were low, with the highest being only 0.7% at hole G2 during Test 2-5 (Fig. 2). The trace amount recovered at gob gas venthole A+1 during Test 2-3 consists of only two samples with SF₆ over the 0.12 ppb lowest detection limit (LDL) for the GC, and the results from Test 2-0 (holes G2 and G3) consist of only a single sample over the LDL. On two occasions (Tests 2-4 and 2-5, Fig. 1, Table 1), a small amount of tracer gas was diverted from the release location back towards the main mine fan.

G3 BOREHOLE INJECTION

General

The final tracer gas release experiment conducted at the test site in 1997 was an injection into gob gas venthole G3. Venthole G3 is located on the completion (west) end of G Panel, approximately 76 m (250 ft) off the centerline [tailgate side of the 305 m (1,000 ft) wide panel], 381 m (1,250 ft) from the longwall recovery room and 2,332 m (7,650 ft) from the start-up end (Fig. 2). Structurally, the Pittsburgh Coalbed at the injection hole (G3) was about 1.2 m (4 ft) and 21 m (69 ft) higher than at holes G2 and G1, respectively. It was anticipated that an injection of tracer gas directly into the gob and subsequent monitoring of probable outlet points would provide significant insight into the migration of gas through the gob. At the time of the release on July 21, 1997, it had been approximately 5 months since hole G3 had been mined through, and 3.6 months since G Panel had been completed. The adjoining H panel longwall face was approximately 701 m (2,300 ft) east of hole G3 and 55 m (180 ft) west of hole G2 at the time of the injection (Fig. 2). Hole G3 was inactive at the time of the injection, and had not produced gob gas for 2.3 months. The hole was shut in, but when opened, it would intake into the gob. These conditions were ideal for dispersal of the tracer gas into the gob.

All well-head equipment, except for the gate valve, was removed from gob gas venthole G3 prior to the injection experiment. A new well-head assembly (Fig. 4) was installed on G3 to facilitate the tracer gas injection and subsequent monitoring of the shut-in pressure. Depth to the Pittsburgh Coalbed at the G3 site was approximately 191 m (628 ft). The borehole (Fig. 5) was originally drilled to a depth of 179 m (588 ft), and 17.8-cm (7-in) casing with 61 m (200 ft) of slotted pipe on the bottom was installed. The pipe above the slotted casing was cemented in place. The slots were approximately 5.1 cm × 0.3 m (2 in × 1 ft), oriented vertically, with four rows (two slots/row) for each 6 m (20 ft) length of pipe in the 61-m (200-ft) slotted interval. Approximately 12 m (40 ft) of strata were present between the bottom of casing and the top of the Pittsburgh Coalbed prior to this location being intercepted by mining and the subsequent collapse of the overburden into the mine void.

Release Specifications

The original concept for the borehole injection experiment was to inject the tracer gas into the borehole via tubing at a point near the bottom of the borehole. However, an obstruction was encountered at 42 m (137 ft), limiting the depth for the release. Two 0.3-cm (1/8-in) -ID polyethylene lines were installed in the hole, one to a

depth of 37 m (120 ft) to release the tracer gas and the other to a depth of 34 m (110 ft) for periodic monitoring of the SF₆ concentration after the release. G3 was open and intaking [at approximately 0.03 m³/s (66 cfm)] for a short time before and after the SF₆ release to aid in dispersing the tracer gas into the gob. After the injection into G3 was completed, the hole was shut in. A 0 to 6,089 kPa (0 to 1 psi) range pressure transducer was attached (at the surface) to the polyethylene line installed to the 37-m (120-ft) depth to continuously monitor the shut-in pressure at the G3 location (Fig. 4).

The tracer gas release into gob gas venthole G3 was the largest (by volume) of the study, with 0.27 m³ (9.6 ft³) (STP) of SF₆ being released over a 25-min time interval. Underground tracer gas releases into areas of low airflow velocity (as was expected at the release point in G3) had produced relatively low recovery rates. In an attempt to enhance the recovery of the SF₆ during the borehole injection experiment, the decision was made to significantly increase the volume of the tracer gas released compared to that of the prior underground releases and to utilize the slow release mode.

Monitoring

The monitoring strategy for the borehole injection experiment included sampling all outlet points for the most likely migration path(s) for gas released into the gob from the G3 gob gas venthole location. The probable migration pathways were determined by evaluating a combination of factors, including ventilation surveys, methane drainage system configuration, and results from the previous underground releases. The available data indicated that the most likely direction of flow for the tracer gas released into G3 was towards the back (start-up) end of the panel, primarily due to the influence of the two bleeder fan shafts and the two producing gob gas ventholes on the panel (Figs. 1 and 2). The two producing gob gas ventholes on G Panel (G2 and G1), as well as producing gob gas venthole F1 on the adjoining F Panel, and the two bleeder fan shafts (BF2 and BF3) were equipped with AGS systems. In addition, monitoring stations (FR and GR) were established underground (Fig. 2) in the event that any of the tracer gas was diverted back towards the main mine fan.

Results

Tracer gas was not detected at either of the underground monitoring locations or at gob gas venthole F1. The first arrival of tracer gas after the release into gob gas venthole G3 was at gob gas venthole G2, the closest inby producing hole on the same panel (Fig. 2). Tracer gas was first detected 1.1 days (27 h) after the release at concentrations of 0.54 ppb (Fig. 6). The velocity (first arrival) of tracer gas flow from the release point in G3 to the measurement point at the surface on hole G2 is 0.012 m/s (2.40 ft/min). The path length (for the velocity calculations) includes the distances traveled vertically down the injection borehole, the horizontal distance (straight line) through the gob, and the vertical distance up the monitored boreholes. Peak concentration was 1,308.59 ppb, 7.1 days after the release. As can be seen on Figure 6, hole G2 was taken off production on day 25 before tracer gas had completely cleared this location. The hole was shut in due to insufficient methane concentrations to run the methane fueled engine that powered the exhauster. At the time that hole G2 was taken off production, 23.9 days after the SF₆ tracer gas was first detected, 75.3% of the injected gas had been recovered at this location (Fig. 7, Table 1), and the SF₆ concentration was still at 110.85 ppb (Fig. 6).

The second monitored location where SF₆ tracer gas was detected was gob gas venthole G1, the next inby producing hole on the same panel (Fig. 2). Tracer gas was first detected 15.3 days after the release at concentrations of 0.43 ppb (Fig. 8). Peak SF₆ concentration was 43.65 ppb, 25.1 days after the release. The significantly lower peak concentration level as compared to that at hole G2, is an indication that the injected gas had become much more widely dispersed in the gob atmosphere as it migrated inby past hole G2. Flow velocity (first arrival) to this location was 0.002 m/s (0.36 ft/min), which is significantly slower than the 0.012 m/s (2.40 ft/min) calculated for flow to G2. It is important to note that the exhauster on hole G1 stopped running late on the first day of the release due to mechanical problems and was not back on production until day 9. It seems likely that if gob gas venthole G1 had been on production the entire time, tracer gas would have migrated to this location in a shorter time. Total SF₆ recovery (287.8 days duration) from G1 was 3.2% (Fig. 7, Table 1).

The only other confirmed location to which tracer gas migrated from the G3 borehole injection experiment was bleeder fan shaft 2 (Fig. 1). Tracer gas arrived at this location on day 30 after the release (Fig. 9, Table 2). Tracer gas was detected at BF2 only 5 days after gob gas venthole G2 went off production on day 25 of the test. The tracer gas probably migrated out of the gob into the mine's ventilation system because of the disruption of the primary gob gas flow path towards the diminishing low pressure sink of G2 after this hole went off production. Peak SF₆

concentration at BF2 was only 0.25 ppb on day 35, or about 2× the analytical lab's detection limit. The low concentration level at the bleeder fan shaft, compared to the gob gas ventholes, is due to the significantly larger volume of ventilation air in which the tracer gas volume is diluted. At the time of the borehole injection experiment in July 1997, the total airflow from BF2 ranged from about 60 to 75 m³/s (120,000 to 150,000 cfm), compared to only about 0.17 m³/s (330 cfm) at G2 and G1. The duration of tracer gas at BF2 was 9.2 days, for a total recovery of 4.5% (Fig. 7, Table 2).

Discussion of Borehole Injection Test Results

The primary findings from the borehole injection experiment were: (1) most of the tracer gas that was injected into the gob stayed in the gob and was recovered from the ventholes in by the injection borehole, and (2) all three gob gas ventholes on the test panel were in communication with each other. Eighty-three percent of the tracer gas injected into gob gas venthole G3 was recovered (Fig. 7). Only 4.5% of the released tracer gas was recovered at a location (BF2) outside the longwall panel. Tracer gas was first observed at BF2 approximately 5 days after gob gas venthole G2 went off production.

It is speculated that the presence of tracer gas in the ventilation system (BF2) is a direct result of G2 going off production. In addition to the time coincidence factor noted above, the close proximity of the gob gas venthole locations to the gate roads (ventilation system) on the tailgate side of the panel provides additional support for a connection between the arrival of the tracer gas at BF2 shortly after the loss of active gas production at G2. Injection hole G3 is only about 76 m (250 ft) from the gate roads on the tailgate side of the panel, a considerably shorter flow path than the 762 m (2,500 ft) between G3 and G2 (Fig. 2). If the pressure sink created by active gob gas production (aided by the exhausters) at G2 had not been so dominating, it would seem likely that tracer gas would have been able to flow the 76 m (250 ft) to the gate roads from G3 in a shorter time than the observed 30 days. Therefore, when G2 went off production, tracer gas flow from the vicinity of G3 was eventually influenced by the pressure sink of the ventilation system. As the pressure sink in the gob diminished in the vicinity of G2, some of the remaining tracer gas at the completion end of G panel was able to migrate to the ventilation system and was eventually detected at BF2. No other occurrence of tracer gas was observed at any location outside the longwall panel.

One important caution must be noted at this point relative to the observations of gas flow paths discussed above. At the time that the borehole injection experiment was conducted, G panel had been completed for 3.6 months, and considerable gob gas had already been removed from the panel via the three gob gas ventholes. It does not necessarily follow that similar results, i.e., minimal gas flow into the ventilation system from the gob would be observed when the longwall was active. During active mining on the panel, some (but at this point unknown) portion of the gob gas probably reaches the ventilation system, especially if the exhausters on the gob gas ventholes are undersized. It is also possible that gob gas may enter the ventilation system on the headgate side of the panel during longwall mining, because the gob gas ventholes are placed on the tailgate side. Gas may also reach the mine's ventilation system via mining-induced fractures that extend into the gas bearing overburden strata beyond the footprint of the mined-out longwall panels. These additional pathways for gas flow are important unknowns that will be addressed in subsequent investigations.

All three gob gas ventholes on G Panel were shown to be in communication with each other, as indicated by the detection of the tracer gas injected into G3 at both of the inby ventholes. A second line of evidence that supports communication between the three gob gas ventholes on the study panel is that variations in gas production at G1 and G2 influenced the shut-in pressure at G3, and in some instances, production from each other. As can be seen in Figure 10, at the start of the borehole injection experiment when G3 was shut in, both G1 and G2 were producing gob gas. The shut-in pressure at G3 was decreasing, as would be expected with the extraction of gas from the gob with the aid of an exhausters via holes G1 and G2. However, at 0.9 days of the experiment, G1 went off production. Concurrently, the shut-in pressure at G3 began to rise. G1 was off production for approximately 8 days, during which time the shut-in pressure at G3 stabilized at about -0.1866 kPa (-7.5-in H₂O), and gas production from G2 rose slightly. On day 9, production was restored on G1 for about 4 days, before going off production again for 2 days. The shut-in pressure at G3 declined again because of the extraction of gob gas from G1 during the 4 days of production, and gob gas production from G2 declined. During the short time (2 days) that G1 was off production again, the shut-in pressure at G3 increased, as did the production from G2. When G1 came back on production on day 15, the shut-in pressure at G3 and gas production from G2 once again decreased.

The SF₆ migration time (first arrival) from the injection point in G3 to the next gob gas venthole in by the release point was relatively quick (1.1 days) considering that it had been approximately 5 months and 6 months since G3

and G2, respectively, had been undermined. With this amount of time for compaction to have taken place in the gob between G3 and G2, and the obstruction at 42 m (137 ft) in the injection borehole, it is somewhat surprising that a velocity (first arrival) of 0.012 m/s (2.40 ft/min) was observed between these two gob gas ventholes. The maximum migration path length [1,185 m (3,888 ft)] includes the 158 m (518 ft) from the injection point in G3 to the top of the coalbed at that location, the horizontal distance between G3 and G2 [762 m (2,500 ft)], and the 265 m (870 ft) from the bottom of G2 to the surface monitoring location.

As mentioned previously, gob gas venthole G1 was off production for approximately 8 days, beginning at 0.9 days after the tracer gas release. The calculated velocity (first arrival) for the 15.3 days of total elapsed travel time for the tracer gas from the injection point in G3 to the surface monitoring location at G1 is 0.002 m/s (0.36 ft/min). However, if the time G1 was off production (and the velocity presumably reduced), is subtracted from the total test time before the first arrival of SF₆ at G1, then a velocity of 0.004 m/s (0.77 ft/min) is calculated as an estimate for gas flow to gob gas venthole G1, if it had remained on production early in the experiment. The maximum migration path length [2,449 m (8,036 ft)] includes the 158 m (518 ft) from the injection point in G3 to the top of the coalbed at that location, the horizontal distance between G3 and G1 [2,073 m (6,800 ft)], and the 219 m (718 ft) from the bottom of G1 to the surface monitoring location.

G2 was off production for approximately 2 days starting on day 20 of the experiment, at which time the shut-in pressure at G3 rose by about 0.1742 kPa (7.0-in H₂O) (Fig. 10). This is a significantly greater influence on the shut-in pressure at G3 compared to the pressure increases observed when G1 was not producing. This is due to G2 being 1,311 m (4,300 ft) closer to G3 than is G1. Finally, by day 26, G2 was off production for the rest of the experiment, causing a permanent rise in shut-in pressure at G3 to an average of about -0.0995 kPa (-4.0-in H₂O). There was also a slight rise in average gas production from G1 after G2 was off production.

EVALUATION OF GOB GAS VENTHOLE PERFORMANCE

Because the ultimate goal of the gob gas characterization studies is to optimize methane control strategies for longwall gobs, it was necessary to document the baseline performance of the current gob gas ventholes at the study mine. These baseline data would then be one benchmark against which the success of any suggested optimization strategies could be judged. The gob gas venthole production data necessary for this part of the study were supplied by the mine operator. The time interval between data points for gob gas venthole production volumes was widely spaced, typically reported every 2 weeks. These widely spaced data made it difficult to correlate the gob gas production to specific mining events or coal production rates.

Inspection of the methane production curves for individual gob gas ventholes in the study area suggests that ventholes on the start-up ends of the panels generally performed the best, especially on the later panels (D through G, Fig. 11). To quantify this observation, the average gob gas venthole cumulative methane production by location on the panel (start-up end, center, and completion end) was plotted (Fig. 12). It is quite evident that the average cumulative methane production from gob gas ventholes on the start-up end of the panels is by far the highest of the three general hole locations. The average cumulative methane production of approximately 4.13×10^6 m³ (146 MMcf) for the holes on the start-up end of the panels is nearly 3.5 times the production from the holes located near the center of the panels and more than six times the production from the holes located at the completion end of the panels.

A combination of factors probably contributes to the high level of methane production from holes on the start-up end of the panels. Holes on the start-up end of the panels are the first holes to come on production; therefore, they have a time advantage for longer term production, which generally results in higher cumulative gas production. Also, a general flow direction for gas in the gob and ventilation airflow towards the start-up end of the panels is established early by the presence of the first gob gas venthole on this end of the panels as well as the bleeder fan shafts located at the back end of the panels.

In contrast to the gob gas production trends established at this study site, studies by the former U.S. Bureau of Mines at the Cambria 33 Mine operating in the Lower Kittanning Coalbed, Cambria County, PA, showed that gob gas ventholes on both ends of the panels produced at the highest rates [2]. The Cambria 33 Mine study demonstrated that given enough time, cumulative gob gas production from the holes on the completion end of the panels eventually caught up to that of holes on the start-up end of the panels. The primary difference between these two mine sites is that the Cambria 33 Mine did not use bleeder fan shafts on the back ends of the panels, but relied on the main mine fans for bleeder ventilation.

Gob gas ventholes in the Pittsburgh Coalbed study area produced 3.94×10^6 m³/qtr (139.0 MMcf/qtr) of methane during 1996. By comparison, methane production from the two bleeder fan shafts average 7.6×10^6 m³/qtr (268.5

MMcf/qtr), or nearly double that of the gob gas ventholes during the same time period (sufficient bleeder fan shaft data were not available to extend this comparison into 1997). There is some evidence to suggest that methane production from one of the methane control systems influenced the other, i.e., when there was an increase or decrease in methane production from the gob gas ventholes, there was a corresponding decrease or increase in methane production from the bleeder fan shafts.

Based on the evaluation of gob gas venthole performance, it would appear that optimizing the performance of gob gas ventholes outby those on the start-up end of the panels would probably have the greatest impact, potentially reducing the number of ventholes to two per panel from the current three per panel. Additional data on gob gas flow characteristics during active mining would be helpful for research efforts relative to improving gob gas venthole performance.

SUMMARY

Tracer gas studies can be a valuable tool to study ventilation airflows associated with longwall gobs, bleeders, and gob gas ventholes. The primary findings resulting from the analysis of the data obtained from the tracer gas experiments and ancillary investigations at the study mine are as follows:

Underground Tracer Gas Releases

1. Tracer gas released into the ventilation airflow generally stayed in the bleeder system. A maximum of only 0.7% of the tracer gas released from an underground location reached a gob gas venthole.
2. Flow paths for tracer gas released at the completion ends of the panels were inby, i.e., towards the bleeder fan shafts at the back (start-up) end of the panels.

Borehole Tracer Gas Injection

1. Tracer gas released into the gob generally stayed in the gob, as long as the associated gob gas ventholes were operating. The flow of tracer gas (4.5% recovery) to BF2 is probably associated with gob gas venthole G2 going off production 5 days prior to the SF₆ arrival at BF2.
2. The arrival of tracer gas at both G2 and G1 from the injection into G3 indicates that all three gob gas ventholes on G panel are in communication.
3. Production variations at gob gas ventholes G2 and G1 influenced the shut-in pressure at injection hole G3, which further confirmed that all three boreholes on G panel were in communication during the borehole injection experiment.
4. The relatively quick arrival of tracer gas at G2 [1.1 days, 0.012 m/s (2.40 ft/min) velocity] indicates a relatively high permeability flow path between these two points in the gob, even 5 and 6 months after G3 and G2, respectively, were mined through.

Gob Gas Venthole Performance Evaluation

1. Gob gas ventholes located at the start-up end of the panels produced methane at higher rates for a longer time than holes located in the central or completion end of the panels.
2. The bleeder fan shafts generally produced more gas than the active gob gas ventholes during the same time intervals.

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Table 1. - Recovery percentage of SF₆ tracer gas at monitored locations

| Test No. | Bleeder fan | | Gob gas venthole | | | | | | | Underground | | | | | | | Total |
|------------------|----------------|-----|-----------------------------------|----|----|----|----|----|----|---------------------|----|----|----|----|----|----|-------------------|
| | BF2 | BF3 | A+1 | D1 | E1 | F1 | G1 | G2 | G3 | CBR | E1 | E2 | F1 | F5 | FR | GR | |
| 2-0 ¹ | D ² | D | ND ² D D | | | | | | | | | | | | | | NA ² |
| 2-1 | 66.0 | ND | ND | | | | | | | | | | | | | | 66.0 |
| 2-2 | 89.1 | ND | ND | | | | | | | | | | | | | | 89.1 |
| 2-3 | 57.4 | ND | Trace | | | | | | | | | | | | | | 57.4 |
| 2-4 | 85.2 | ND | ND ND ND | | | | | | | 0.7 | | | | | | | 85.9 |
| 2-5 | 56.2 | 1.1 | ND ND 0.7 ND | | | | | | | ND 1.1 ³ | | | | | | | 59.1 ³ |
| 2-6 | 68.8 | ND | ND ND ND | | | | | | | ND ND | | | | | | | 68.8 |
| 3-1 | 4.5 | ND | ND 3.2 75.3 ⁴ Injected | | | | | | | ND ND | | | | | | | 83.0 |

¹Insufficient monitoring data for this test to calculate recovery percentages.

²ND = Not detected, D = Detected, NA = Not applicable.

³Underground sampling ended prematurely, therefore, recovery percentage is underestimated.

⁴Venthole taken off production while SF₆ concentration still high.

Table 2. - SF₆ gas recovery data

| Test No. | Recovery location | First arrival | Peak concentration | | Last detected | Duration | Recovery |
|---------------------------|-------------------------------|---------------|--------------------|------------|---------------|-----------|------------|
| | | Test time | Test time | Conc., ppb | Test time | Test time | Percentage |
| Test No. 2-0 ¹ | | | | | | | |
| Test No. 2-1 | BF2 | 0.75 h | 1.0 h | 485.25 | 14.5h | 13.75 h | 66.0 |
| | | | 2.7 h | 594.98 | | | |
| Test No. 2-2 | BF2 | 5.6 h | 10.2 h | 31.41 | 3.0 d | 2.8 d | 89.1 |
| Test No. 2-3 | BF2 | 1.2 h | 4.5 h | 56.56 | 4.1 d | 4.1 d | 57.4 |
| | A+#1 | 6.9 h | 6.9 h | 0.90 | 7.2 h | 0.3 h | trace |
| Test No. 2-4 | CBR (underground) | 37 min | 42 min | 149.20 | 77 min | 40 min | 0.7 |
| | BF2 | 7.0 h | 1.4 d | 10.36 | 8.1 d | 7.8 d | 85.2 |
| Test No. 2-5 | F5 (underground) ² | 1.1 h | 1.4 h | 94.98 | 2.1 h | 1.0 h | 1.1 |
| | BF3 | 9.6 h | 12.5 h | 1.35 | 28.0 h | 18.4 h | 1.1 |
| | BF2 | 14.2 h | 24.5 h | 9.54 | 6.1 d | 5.5 d | 56.2 |
| | G2 | 15.5 h | 31.8 h | 18.37 | 23.1 d | 22.4 d | 0.7 |
| Test No. 2-6 | BF2 | 8.1 h | 28.5 h | 18.95 | 6.9 d | 6.5 d | 68.8 |
| Test No. 3-1 | G2 ³ | 1.1 d | 7.1 d | 1,308.59 | 25.0 d | 23.9d | 75.3 |
| | G1 | 15.3 d | 25.1 d | 43.65 | 303.1 d | 287.8 d | 3.2 |
| | BF2 | 30.0 d | 35.0 d | 0.25 | 39.2 d | 9.2 d | 4.5 |

¹Insufficient data for characterization.

²Underground sampling ended prematurely; therefore, recovery percentage is underestimated.

³Venthole taken off production while SF₆ concentration still high.

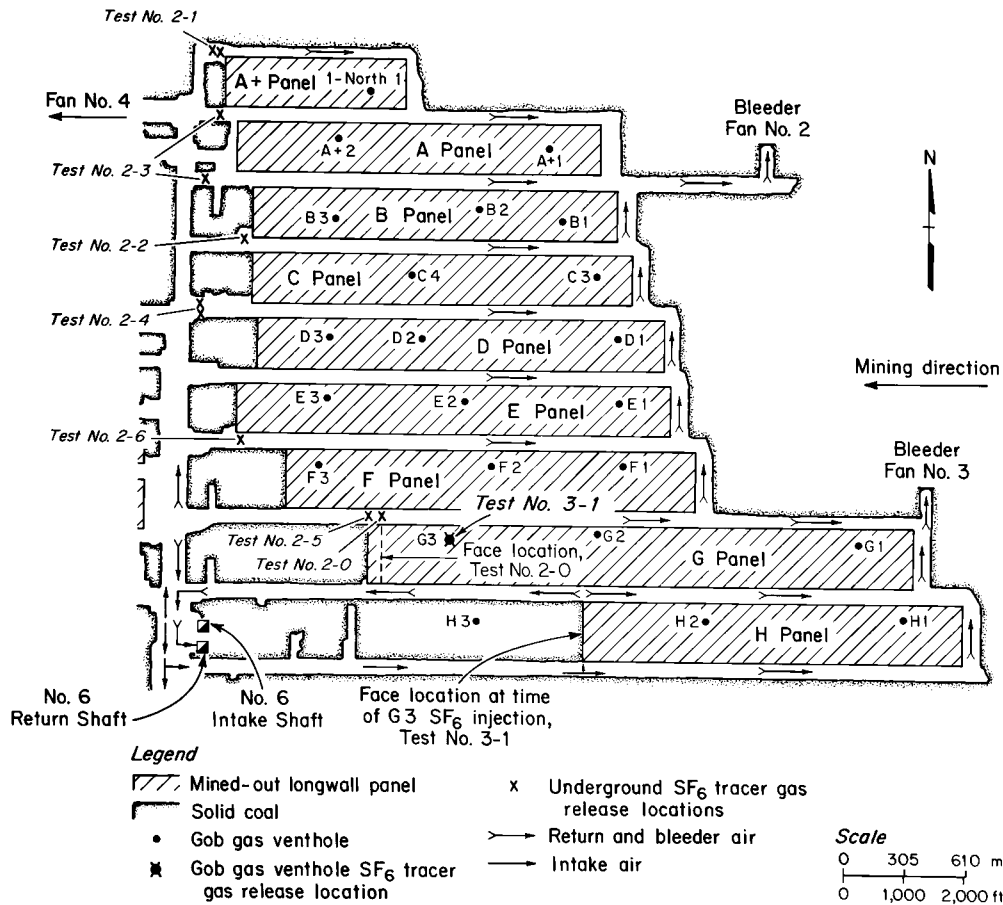


Figure 1.-Map of study area.

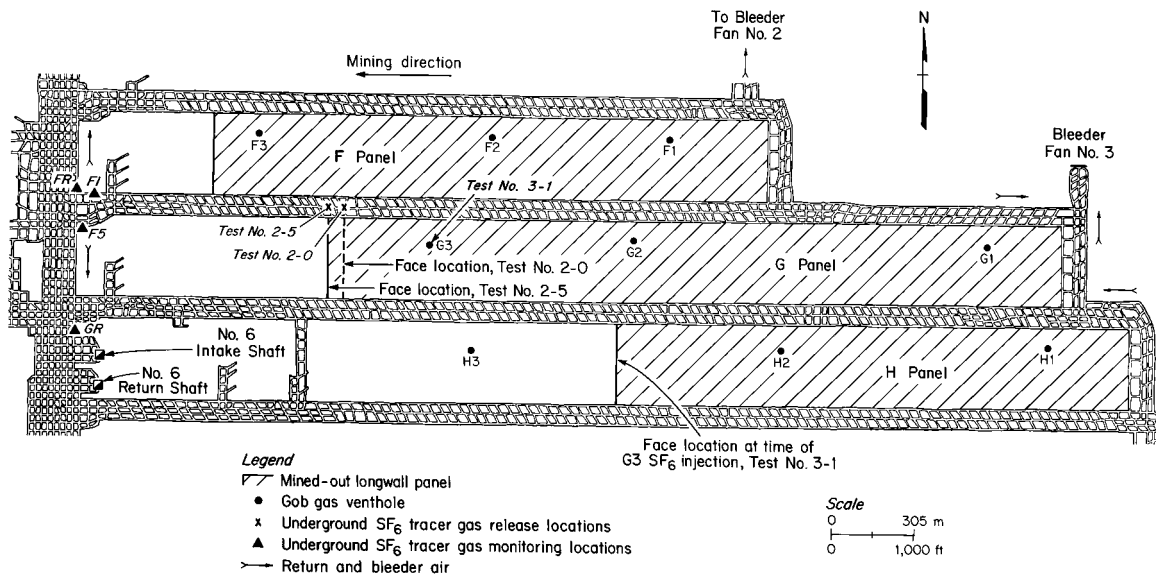


Figure 2.-Detailed map of F, G, and H longwall panel area at time of borehole injection experiment, Test 3-1.

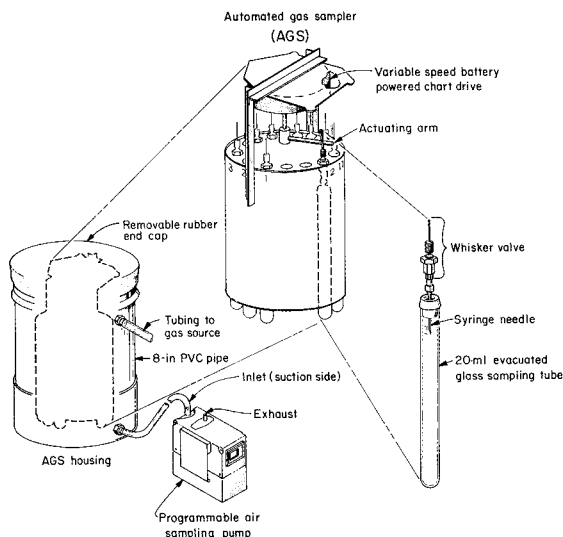


Figure 3.-Schematic drawing of AGS system.

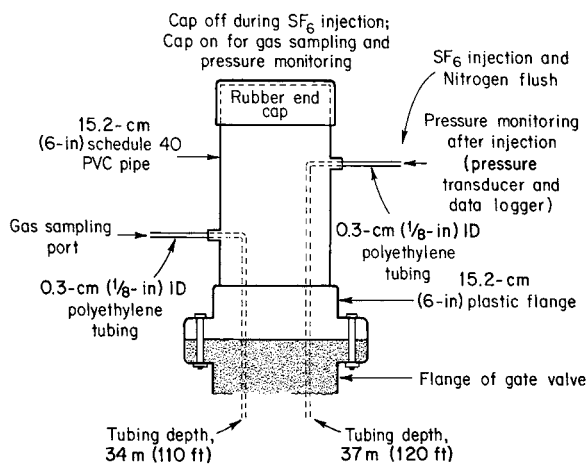


Figure 4.-Schematic of G3 wellhead configuration for tracer gas injection and shut-in pressure monitoring.

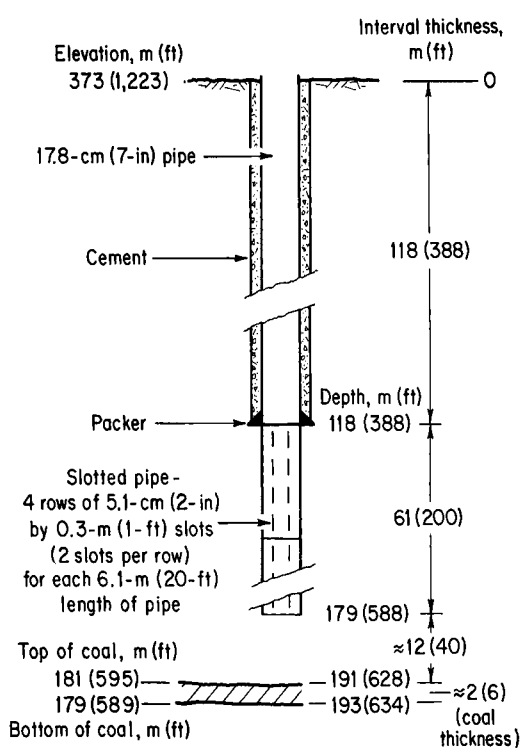


Figure 5.-Schematic of G3 borehole configuration for gob gas production.

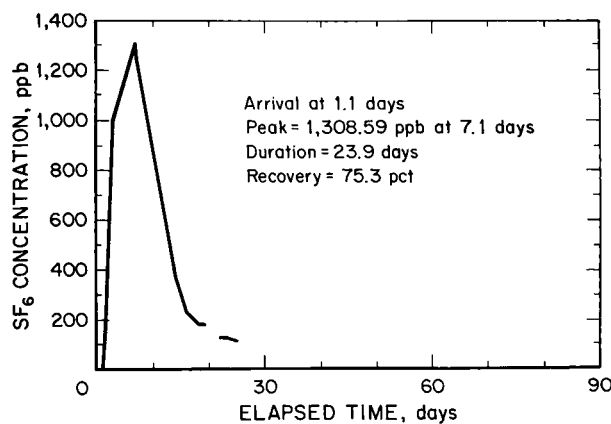


Figure 6.-Graph of SF₆ tracer gas concentrations at G2 during borehole injection experiment.

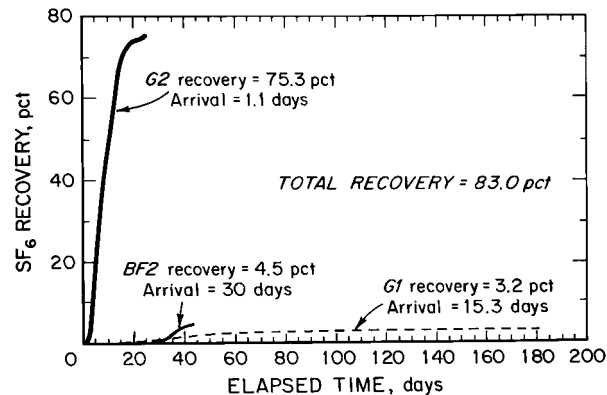


Figure 7.-Graph of SF₆ tracer gas cumulative recoveries for borehole injection experiment.

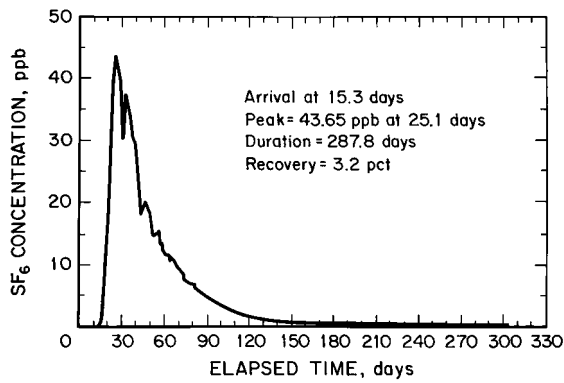


Figure 8.-Graph of SF₆ tracer gas concentrations at G1 during borehole injection experiment.

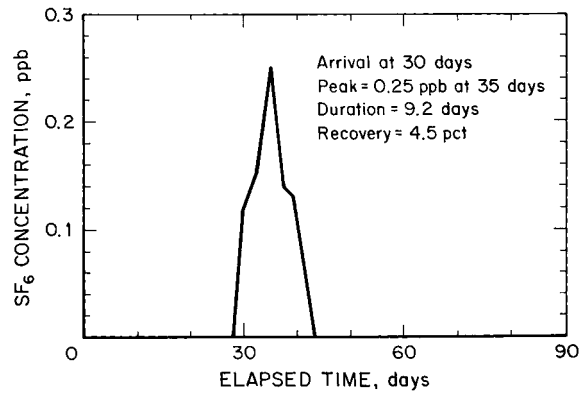


Figure 9.-Graph of SF₆ tracer gas concentrations at BF2 during borehole injection experiment.

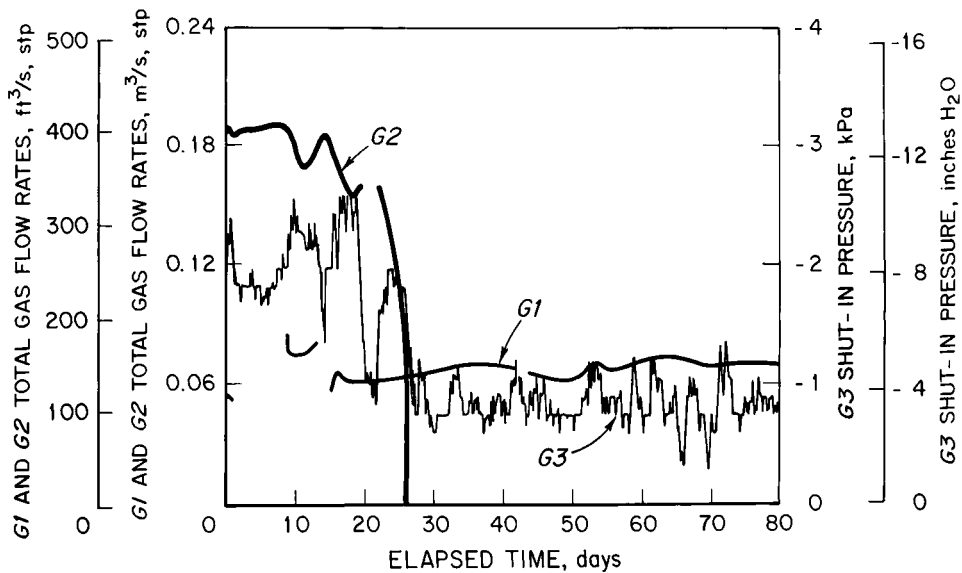


Figure 10.-Graph of influence of gob gas venthole production on G3 shut-in pressure.

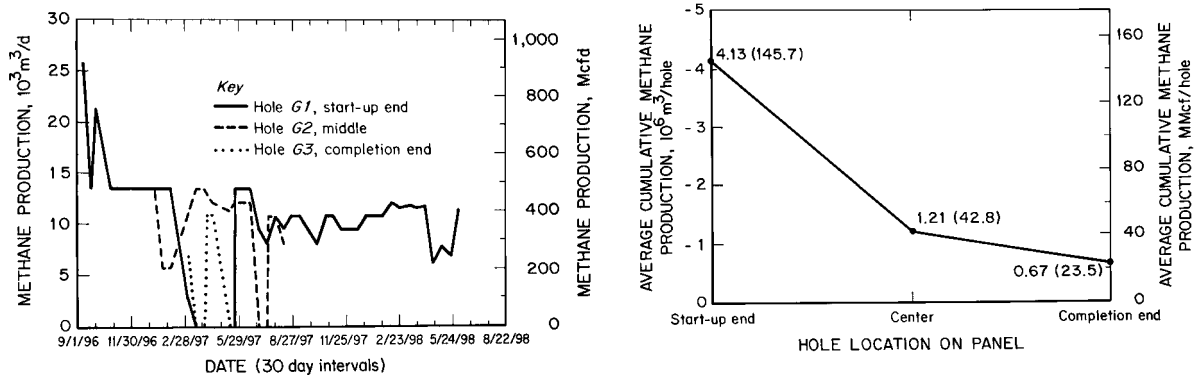


Figure 11.- Graph of methane production from G Panel gob gas ventholes.

Figure 12.-Graph of average cumulative gob gas venthole methane production by location on longwall panel.