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Control of Longwall Gob Gas With Cross-Measure Boreholes (Upper Kittanning Coalbed)

By A. A. Campoli, J. Cervik, and S. J. Schatzel

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	kW	kilowatt
deg	degree	L	liter
ft	foot	L/min	liter per minute
ft^3/min	cubic foot per minute	m	meter
gal	gallon	mm	millimeter
gal/min	gallon per minute	m^3/s	cubic meter per second
h	hour	pct	percent
hp	horsepower	rad	radian
in	inch	VAC	volt alternating current
kPa	kilopascal		

CONTROL OF LONGWALL GOB GAS WITH CROSS-MEASURE BOREHOLES (UPPER KITTANNING COALBED)

By A. A. Campoli,[1] J. Cervik,[2] and S. J. Schatzel[3]

ABSTRACT

The cross-measure borehole technique is being studied by the Bureau of Mines as an alternative to the use of surface gob boreholes as a means of controlling methane in gobs during longwall mining. Small-diameter holes are drilled from underground locations into strata overlying the mined coalbed. When the roof strata are fractured by the mining operation, a partial vacuum applied to the boreholes draws the methane out of the fractured strata and prevents it from entering the mine ventilation system.

Tests in the Upper Kittanning Coalbed showed that 50 pct of the methane produced by the longwall mining operation was captured by the cross-measure boreholes. Borehole inclination and penetration into the gob are two important borehole parameters that affect the performance of the cross-measure borehole system.

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[1] Mining engineer.
[2] Supervisory geophysicist.
[3] Geologist.
Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Methane produced by longwall operations in the United States is controlled by dilution with ventilation air and by surface gob boreholes. Surface gob boreholes cannot always be drilled because mining may be under populated areas, topography may be too severe, or access to private property may be denied. Consequently, an alternative method of controlling gob gas is needed that is independent of the mine ventilation system and surface right-of-way problems.

The single-entry longwall is the predominant mining system in Europe where both retreating and advancing longwalls are used. However, the proportion of faces utilizing advancing techniques dominates, with 82 pct in Great Britain (2)[4] and 75 pct in West Germany (3). Post-World War II mechanization and mining of deeper and gassier coalbeds forced the application of gob drainage systems on European longwalls. The most commonly used method of controlling gob gas during mining in Europe is the cross-measure borehole technique (1). It is independent of the mine ventilation system and surface right-of-way problems. This report describes joint efforts by the

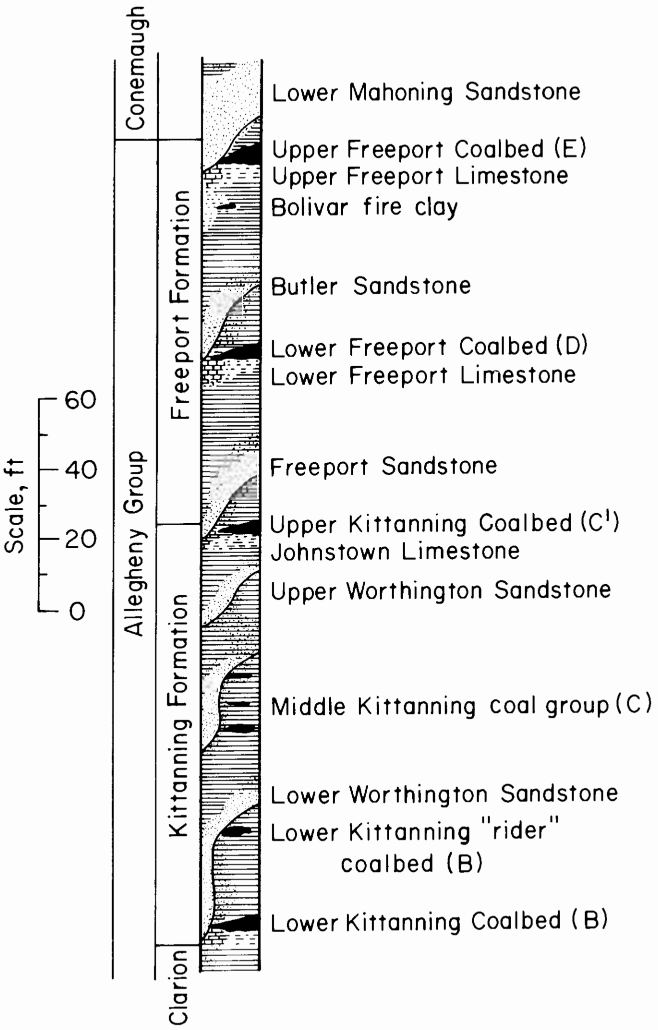

FIGURE 1. - Generalized stratigraphic column of Pennsylvanian system. Letters in parentheses are local seam designations.

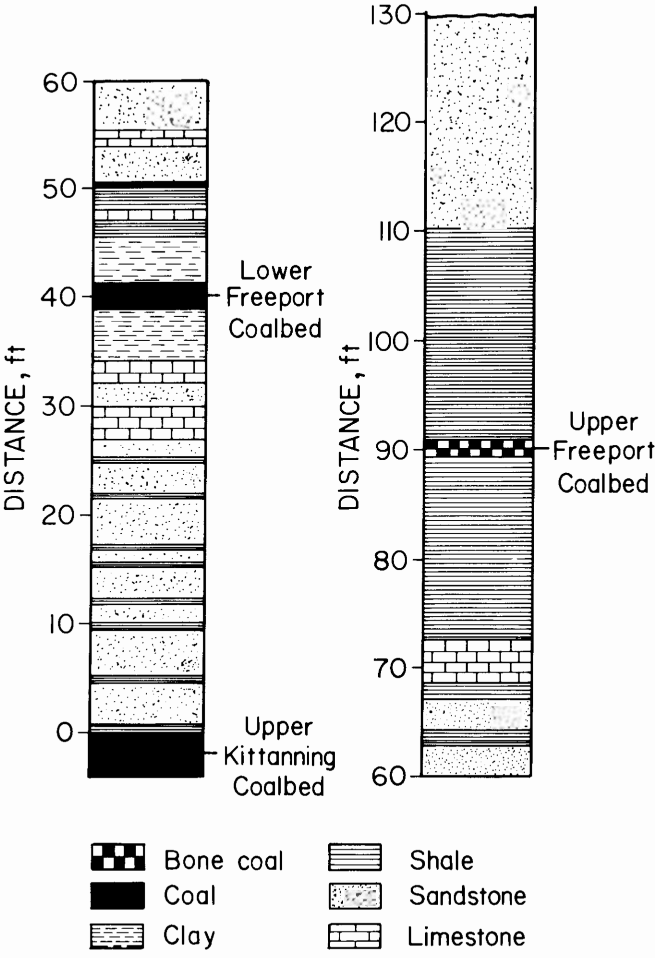

FIGURE 2. - Stratigraphic column above Upper Kittanning Coalbed.

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

Bureau and Bethlehem Mines Corp. to adapt the cross-measure borehole technique of gob gas control to multiple-entry retreating longwalls in the Upper Kittanning Coalbed.

ACKNOWLEDGMENTS

The authors thank the following personnel of Bethlehem Mines Corp.'s Cambria Division for their cooperation and assistance in the study at the Cambria 33 Mine, Ebensburg, PA: E. J. Korber, manager; F. A. Burns, general superintendent; D. Weaver, mining engineer; Bill Radebaugh, mine foreman; and Paul Rusnak, general assistant. The cooperation of the Central Mining Institute, Katowice, Poland, in designing the cross-measure borehole system is greatly appreciated.

STUDY AREA

The study area was located in Pennsylvanian age strata of the Allegheny Group, specifically the Kittanning and Freeport Formations (fig. 1) (4, p. 6). The Upper Kittanning Coalbed, locally called the C-prime (C') seam, varies from 29 to 45 in (74 to 114 cm) in height over the study area (6, pp. 5-7). A detailed stratigraphic column was produced by analyzing drill cuttings from cross-measure boreholes (fig. 2). It shows three coalbeds which are known sources for methane. These coalbeds are located 40, 50, and 90 ft (12, 15, and 27 m) above the roof of the Upper Kittanning Coalbed.

The test was conducted on a retreating longwall in Bethlehem Mines Corp.'s Cambria 33 Mine (fig. 3). An enlarged view of the test panel is shown in figure 4. The underground pipeline is located in the center entry of the three-entry return air gateroad. All cross-measure boreholes were drilled from the center entry, which was supported by a line of cribs and remained open and passable after the panels on both sides were removed.

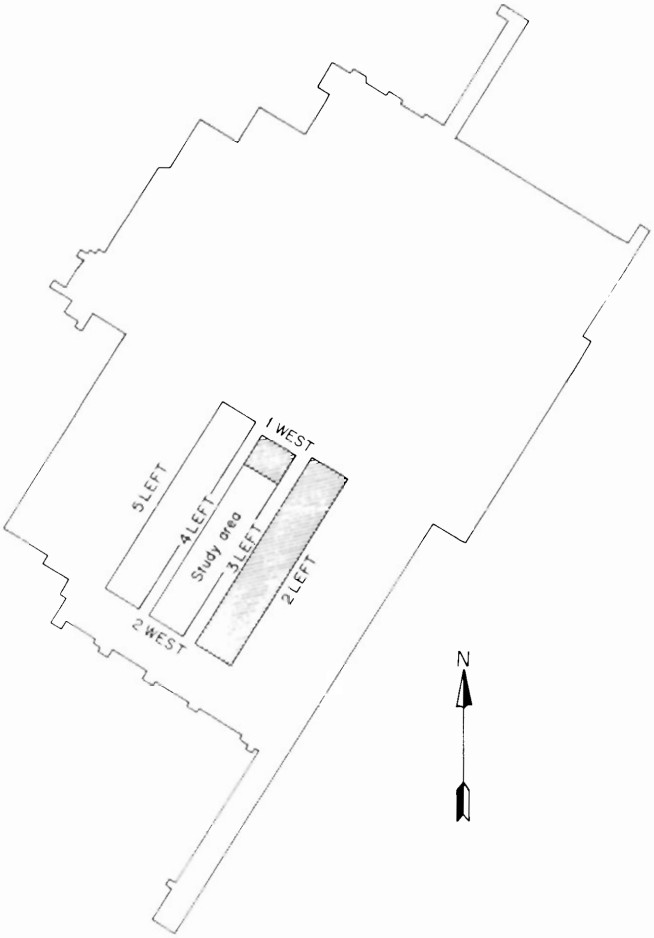

FIGURE 3. - Bethlehem Mines Corp.'s Cambria 33 Mine (Upper Kittanning Coalbed).

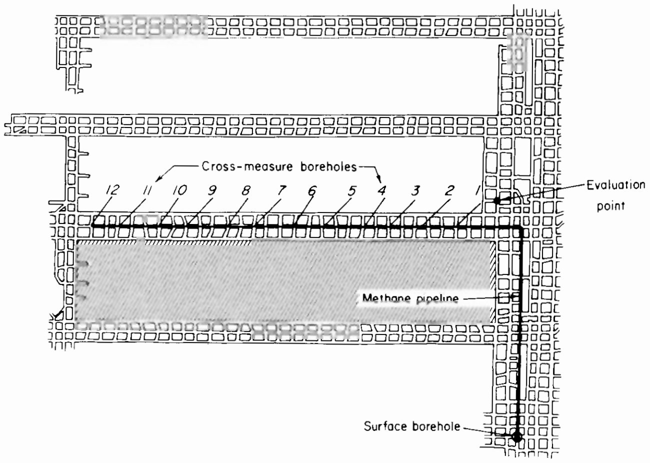

FIGURE 4. - Longwall test panel.

CROSS-MEASURE BOREHOLE SYSTEM DESIGN

The design of the cross-measure boreholes was based on European information and knowledge gained in a prior Bureau of Mines study (7, pp. 2, 4, 13). Figure 5 shows the final borehole parameters, which were determined through in-hole surveys.

The endpoints of the cross-measure boreholes were spaced 250 ft (76 m) apart. All boreholes were drilled over a support pillar to protect the borehole when the longwall face passed the collar. Borehole length, inclination, and horizontal direction were chosen to accomplish the following:

1. Maintain the height of the borehole over the far end of the support pillar at least eight times the coalbed thickness (fig. 5, E). Estimates of the height of the rubblized zone in the gob range from 4 to 8 times coalbed thickness.

*	A	B	C	D	E	F	G	H
1	23	48	248	97	46	90	153	27
2	28	42	288	135	64	90	189	261
3	26	53	288	126	49	127	156	544
4	31	56	258	133	58	103	124	776
5	25	56	288	122	45	136	146	1044
6	31	64	258	133	53	119	97	1303
7	25	48	288	122	50	114	175	1525
8	21	58	258	92	36	124	128	1762
9	24	47	288	117	49	112	179	2031
10	33	54	258	141	64	95	127	2273
11	26	53	288	126	49	127	156	2554
12	28	54	258	121	53	104	134	2776

* Cross-measure borehole number
A - Inclination, degrees
B - Horizontal angle, degrees
C - Hole length, feet
D - Terminal height of hole, feet
E - Height of hole at end of supported length, feet
F - Penetration over longwall panel, feet
G - Distance from endpoint to origin of hole, feet
H - Distance from start of panel to endpoint of hole, feet

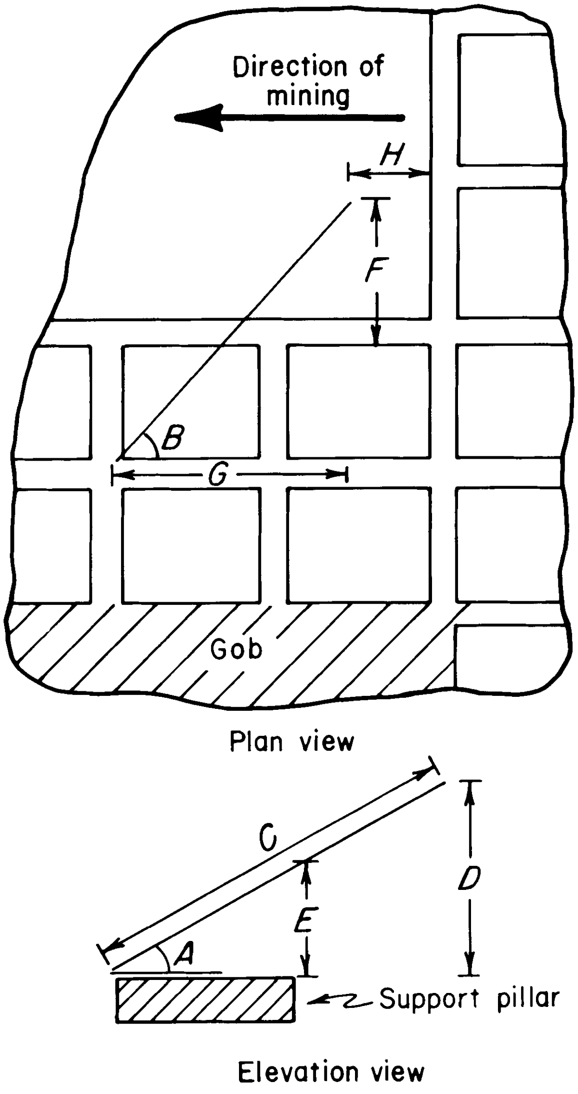

FIGURE 5. - Schematic of cross-measure borehole design parameters.

2. Terminate the borehole about 100 ft (30.5 m) into the gob (fig. 5, F). Polish studies show higher methane concentrations in the gob on the return side than the intake side because of the pressure differentials of the mine's ventilation system (5).

3. Intercept all coalbeds at least 100 ft (30.5 m) above the mined coalbed (fig. 5, D).

4. Angle the borehole at least 45° (0.79 rad) to the axis of the longwall (fig. 5, B).

Generally, gas production begins when the face is 75 to 100 ft (22.9 to 30.5 m) beyond the end of the borehole but before it passes the collar.

DRILLING EQUIPMENT AND PROCEDURES

An electrohydraulic drill mounted on 3 hydraulic jacks was used to drill the 12 cross-measure boreholes (fig. 6). Bit thrust and rotational speed were adjusted at the central unit, which was located 10 to 15 ft (3.0 to 4.6 m) from the drill unit (fig. 7). The skid-mounted powerpack was located in a fresh air entry during drilling. It consists of a 20-hp (14.9-kW), 460-VAC, three-phase electric motor, a hydraulic pump, and a 35-gal (132-L) hydraulic reservoir. The

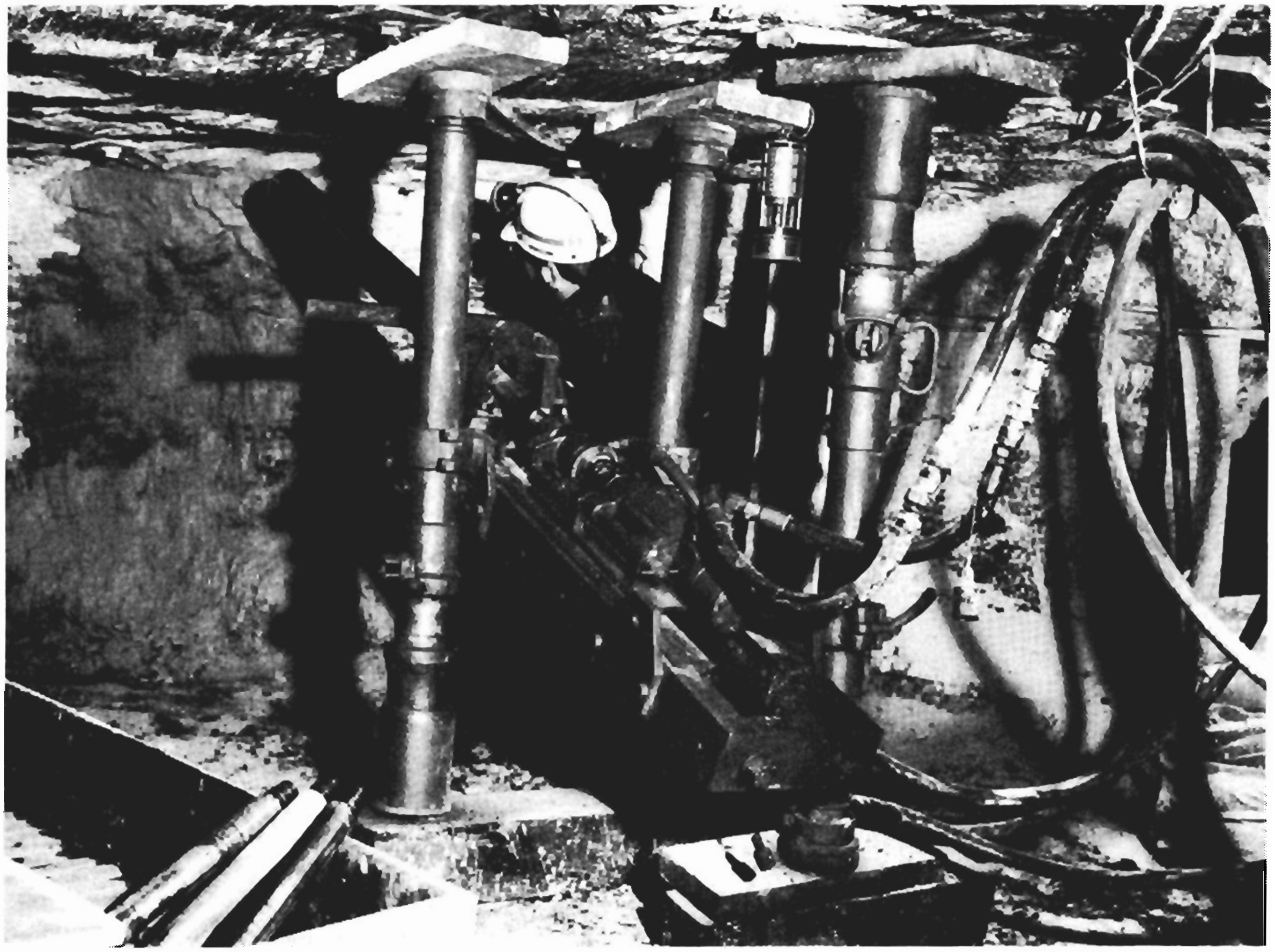

FIGURE 6. - Electrohydraulic drilling unit.

FIGURE 7. - Hydraulic drill control unit.

hydraulic fluid is a fire-resistant 60/40 water emulsion fluid.

The first 26 ft (7.9 m) of each borehole was drilled with a 4-in (102-mm) diamond core bit, and the cores were removed in 30-in (76.2-cm) sections. The remainder of the hole was drilled with a 1.9-in (48-mm) bit. Because abnormal methane flows could be encountered during drilling of the 1.9-in (48-mm) hole, all drilling was conducted through a stuffing box attached to a 4-in (102-mm) expandable mechanical packer (fig. 8). Return water and drill cuttings were transported to a well-ventilated area 30 ft (9.1 m) downstream from the drill site through a hose connected to the mechanical packer (fig. 9). The packer, stuffing box, and valve at the end of the drainage hose

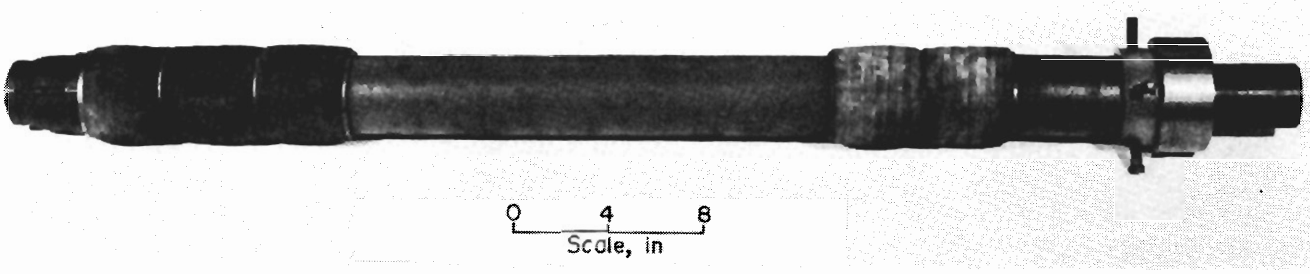

FIGURE 8. - Expandable mechanical packer.

FIGURE 9. - Stuffing box.

provided the means to shut-in the borehole if abnormal methane flows were encountered during drilling. However, no abnormal flows occurred during the drilling of any of the holes on the test panel.

A synthetic diamond wafer bit [1.9 in (48 mm)] was used to drill the cross-measure boreholes (fig. 10). Penetration rate through the sandstones and shales averaged 70 ft (21.3 m) per shift, and bit life was exceptional. Only one bit

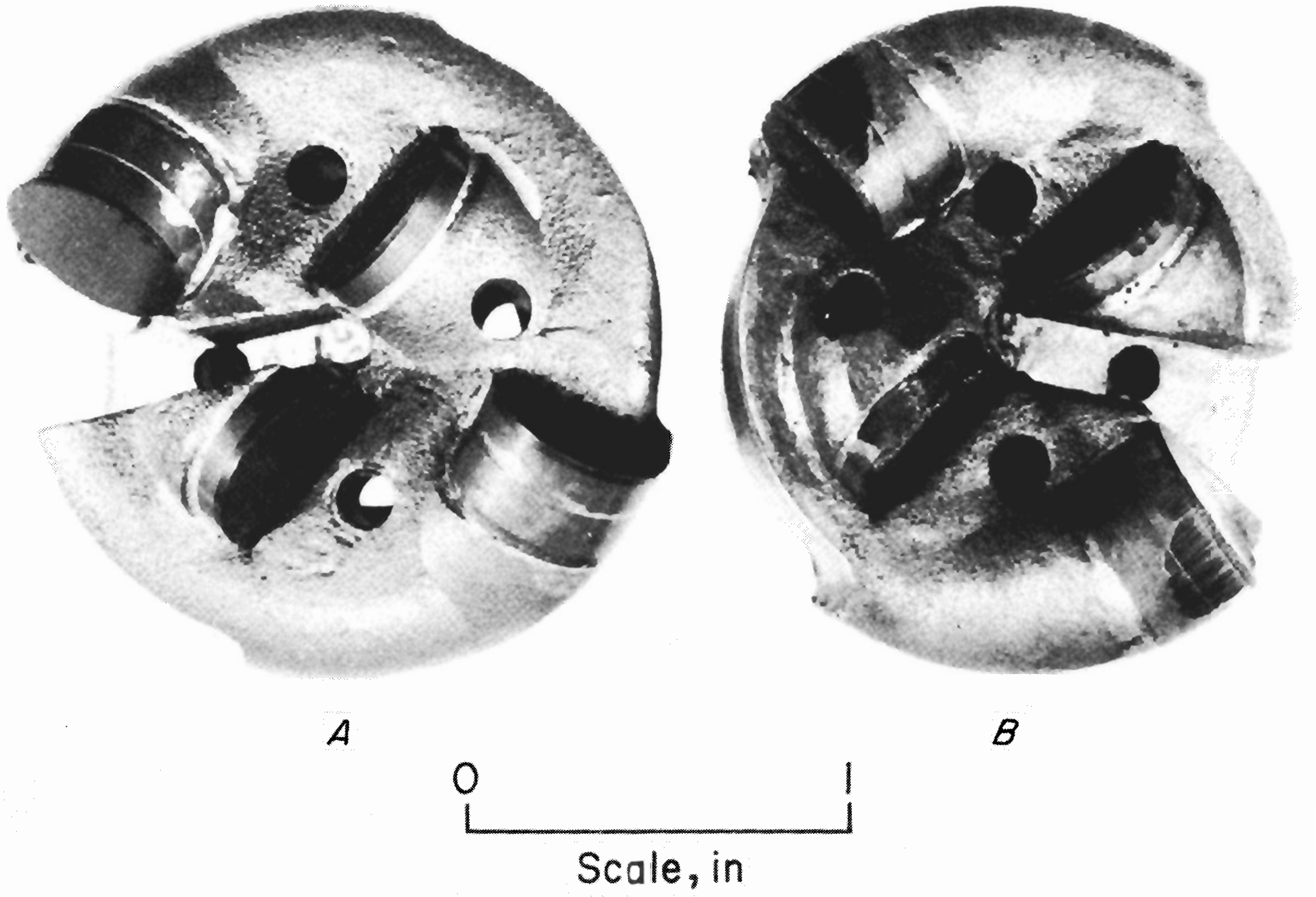

FIGURE 10. - Synthetic diamond wafer bits. *A*, New; *B*, worn.

was used to drill all cross-measure boreholes on the test panel. Figure 10 compares a new bit (A) to one that had drilled over 3,100 ft (945 m) of rock (B). The diamond wafers are chipped and worn to the point where the matrix had been rubbing on the rock surface during drilling. The worn bit (B) can be salvaged by removing the diamond wafers and rotating them about 180° (3.1 rad). The cost to salvage the bit is about half the cost of a new bit.

The drill unit was limited to a length of about 54 in (137 cm) (fig. 6) because coalbed height is about 45 in (114 cm) and holes were inclined upward 23° to 33° (0.40 to 0.58 rad). Drill rods are 1.6 in (41 mm) in diameter and 15 in (381 mm) long (fig. 11), which required frequent interruptions in drilling to insert drill rods. The rods were screwed into one another with a special coarse taper thread (ETA) for rapid connection and dismantling. No centralizers were used during drilling because of the small difference in diameter between the drill rods and bit. Downhole surveys showed little variation in borehole trajectory.

Plastic standpipes were cemented into each cross-measure borehole after the completion of the drilling phase. The cementing phase is important because if not completed properly, mine air could short-circuit into the cross-measure borehole, reducing its ability to draw methane from the gob.

FIGURE 11. - ETA drill rod being added to drill string.

Two grouting procedures were tested to determine the best method of grouting the standpipes. In holes 1 through 7, 9, and 10, 5-ft (1.5-m) lengths of 2.25-in (57-mm) diameter plastic pipe were joined with sockets. Total length of standpipe was about 20 ft (6.1 m) (fig. 12). Short 15-in (38-cm) plugs of cement were emplaced every 30 in (76 cm) along the plastic pipe. If roof movements during mining cause a misalignment of the hole, the plastic pipe bends at the socket joints and because the cement is emplaced in short plugs, cracking would be minimal. In holes 8, 11, and 12, 1.25-in (32-mm), 2.5-in (64-mm), and 2-in (51-mm) diameter plastic pipes, respectively, were grouted 18 ft (5.5 m) into the holes. Drilling the hole and grouting the plastic standpipe required about five 8-h shifts by a three-person crew.

PIPING SYSTEM AND FLOW MEASUREMENT PROCEDURES

Access to the surface was provided by a 688-ft (210-m) long, 12-in (30.5-cm) diameter surface borehole (fig. 4). The borehole was cased with 8-in (20.3-cm) steel pipe and cemented the entire length. A 6-in (15.2-cm) crushproof plastic pipeline [4,750 ft (1,448 m)] connected the surface borehole to the cross-measure boreholes.

Movement of a gas through a plastic pipeline can cause a static charge build-up on the pipeline. A static charge can ignite explosive methane-air mixtures. To dissipate the static charge, the entire pipeline was wrapped with bare copper wire, which was attached to copper grounding rods. These rods were placed in 10-ft (3-m) holes drilled into the bottom and packed with charcoal. The grounding rods were spaced 500 ft (152 m) along the pipeline.

The pipeline entry adjacent to the test panel (fig. 4) sloped about 1 pct downward from hole 12 to 1; at the right-angle bend, the slope increased to 3 pct downward toward the vertical borehole. Water flow from the cross-measure boreholes was discharged directly into the main pipeline; at the right-angle bend, the water was collected in a 2-in (51-mm) metal pipeline installed directly below the main pipeline. Water was drained from the metal pipeline periodically.

Gas flow (methane plus air) from each cross-measure borehole was calculated from gas pressure drop measurements with

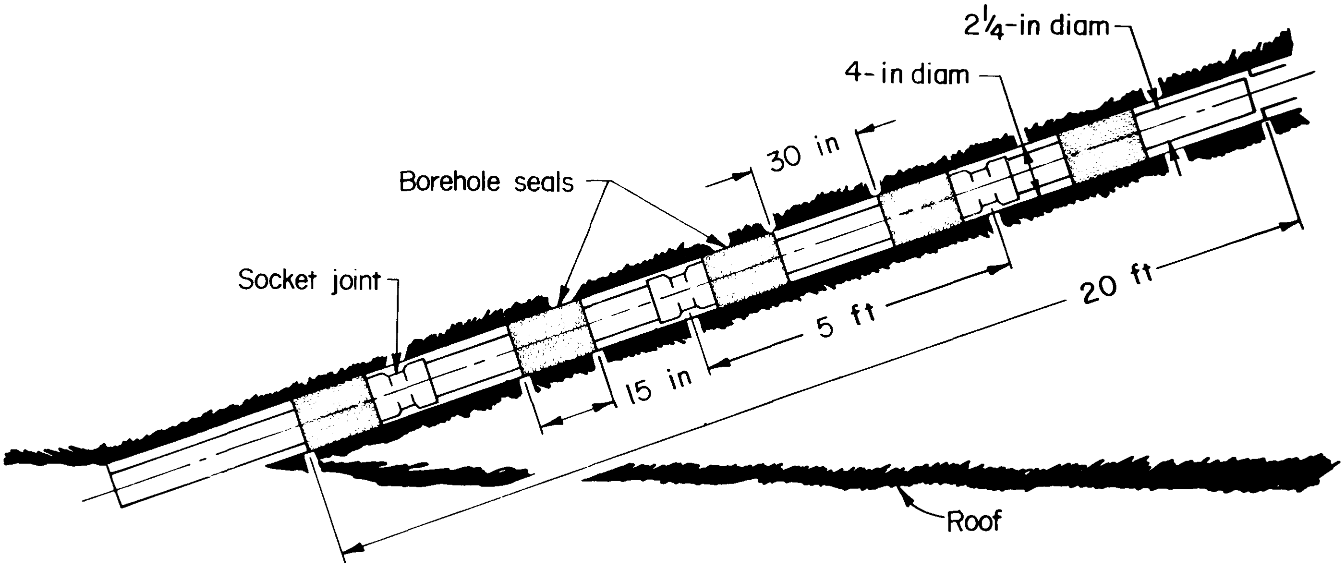

FIGURE 12. - Plastic standpipe with sockets.

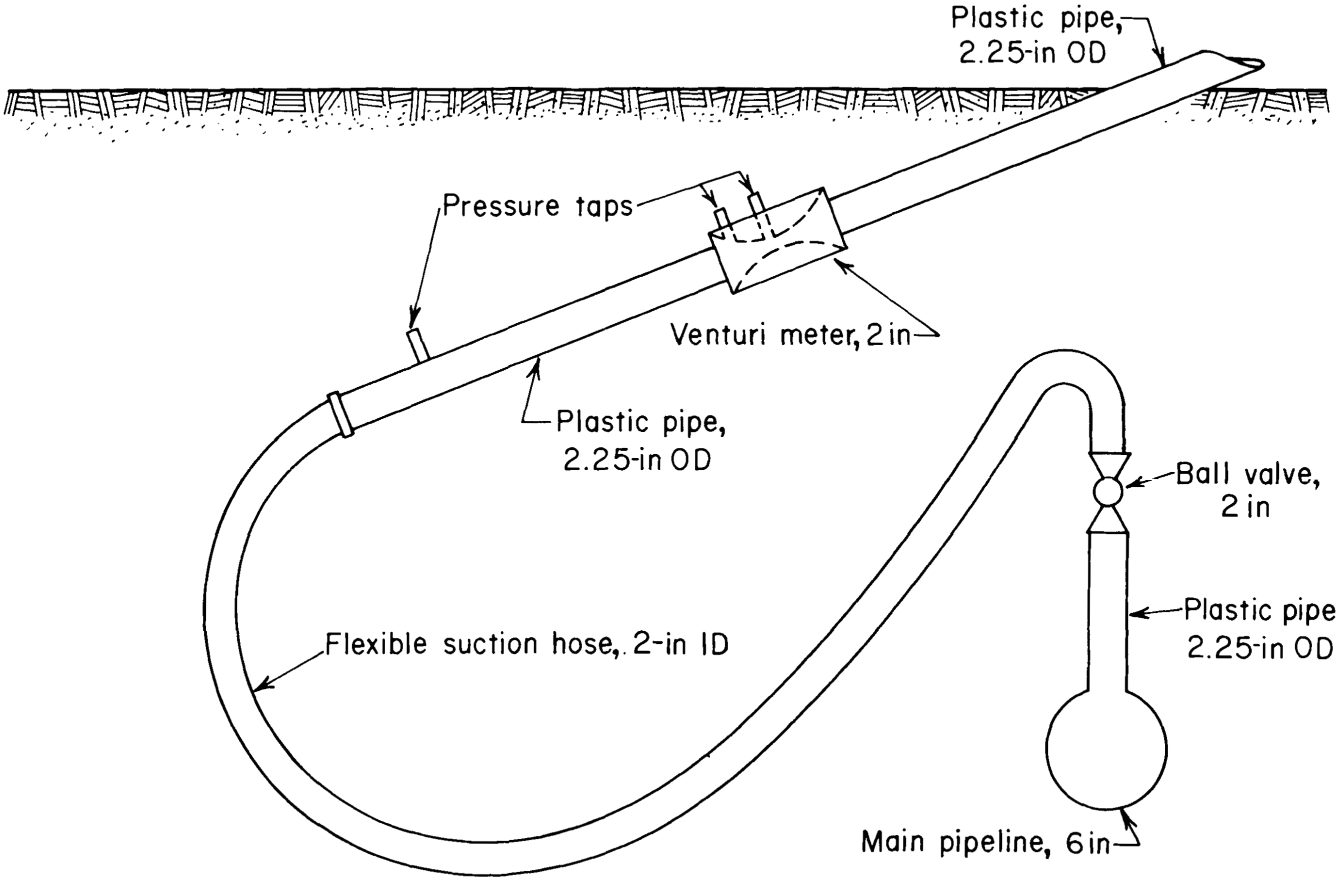

FIGURE 13. - Cross-measure borehole equipment.

a mercury manometer across a venturi, and the concentration of methane in the gas flow was measured with a 0- to 100-pct methanometer (fig. 13). The partial vacuum at each hole was measured with a mercury manometer at a pressure tap.

Return air from the longwall mining operation was channeled through a single entry before it entered the main returns (fig. 4--evaluation point). Periodically, the volume of air was measured with an anemometer at the evaluation point. Gas bottle samples were also taken simultaneously and analyzed with a gas chromatograph to determine methane concentration in the return air. Thus the total methane flow from the longwall mining operation is the sum of the flows from the cross-measure boreholes and in the return air from the longwall (fig. 4--evaluation point).

SURFACE VENTING FACILITY

The surface venting facility (fig. 14) was protected by a flame arrestor, lightning arrestor, and check damper to prevent backflow into the pipeline. An ignition-proof exhauster, capable of producing flows up to 200 ft^3/min (0.09 m^3/s) and a partial vacuum up to 3.5 in of mercury (11.8 kPa), removed the gob gas. The exhauster was driven by a 5-hp (3.7-kW) 440-VAC motor.

FIGURE 14. - Surface venting facility.

The total flow of gob gas (methane plus air) at the surface was calculated from individual cross-measure borehole gas flows. The methane concentration in the gas flow at the surface was measured and recorded continuously with an infrared gas analyzer. The instrument was set to sound an alarm in the mine office when methane concentration dropped below 25 pct. The partial vacuum at the intake to the exhauster was also measured periodically.

PRODUCTION DATA

GOB GAS PRODUCTION

Gob gas was extracted from 11 of the 12 cross-measure boreholes. Hole 1, the only borehole that failed to produce gob gas, was drilled with its endpoint only 27 ft (8.2 m) from the starting point of the panel (fig. 5, H). Apparently the strata in this area did not fracture; thus no flow paths were created to permit gob gas movement toward the hole.

No free flow of methane occurred from any cross-measure borehole. Even with an applied partial vacuum, flow did not occur until the face passed 75 to 100 ft (23 to 30 m) beyond the end of the hole; it did occur before the face passed the collar of the hole, however.

Figures 15 and 16 show methane and gob gas (methane plus air) flow rates, respectively, for each cross-measure borehole. Generally, the flow rate curves for each cross-measure borehole follow the same pattern except for holes 4 and 8. For these two holes, the methane flow rates declined to zero but the air flow from each hole increased, which indicated direct communication with the mine ventilation air. For holes 2, 3, 5, 6, 7, and 9, when gob gas flow declined, the methane flow also declined. Eventually the holes were shut-in because the methane concentration in the gob gas flow dropped below 25 pct. Subsequently, the gob gas flow declined to a negligible quantity, indicating gob compaction and fracture system closure. A complete production

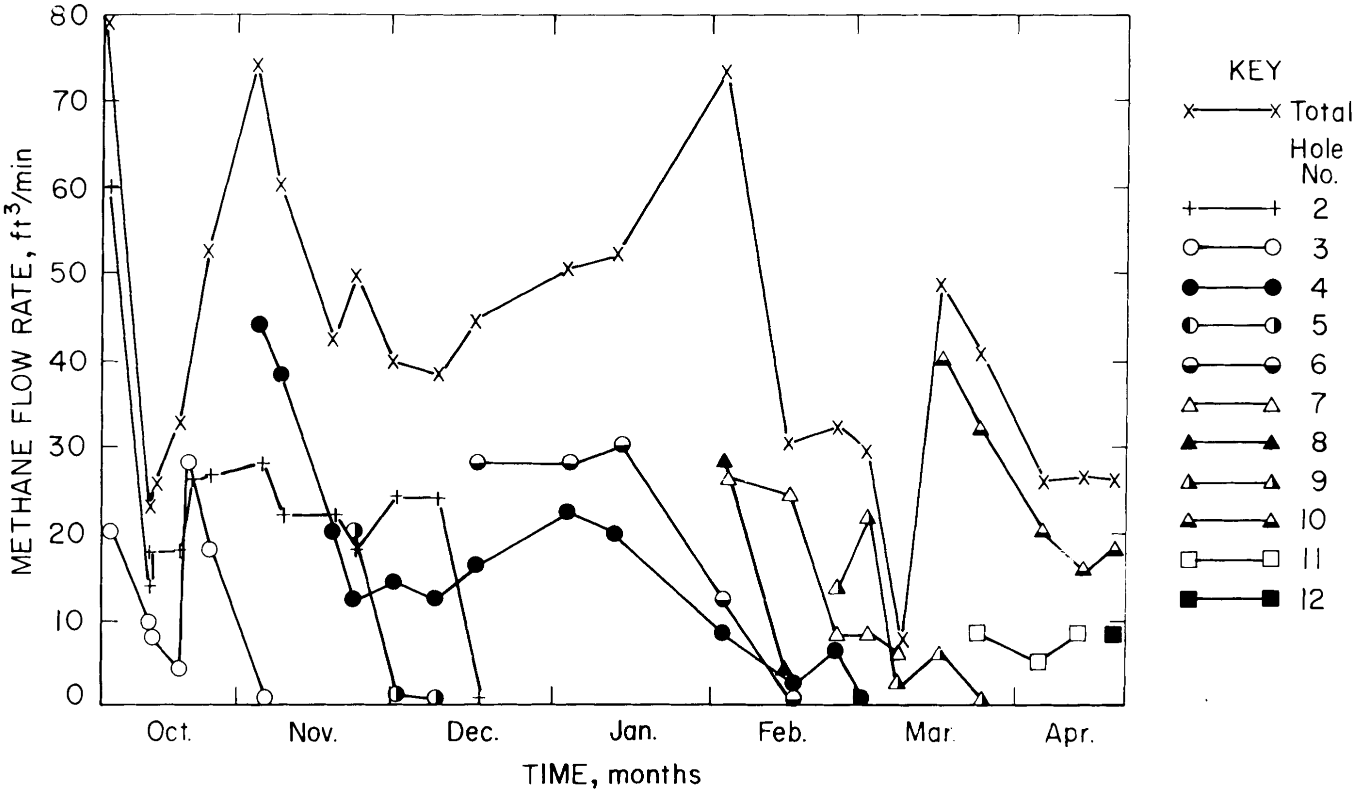

FIGURE 15. - Methane flow rates.

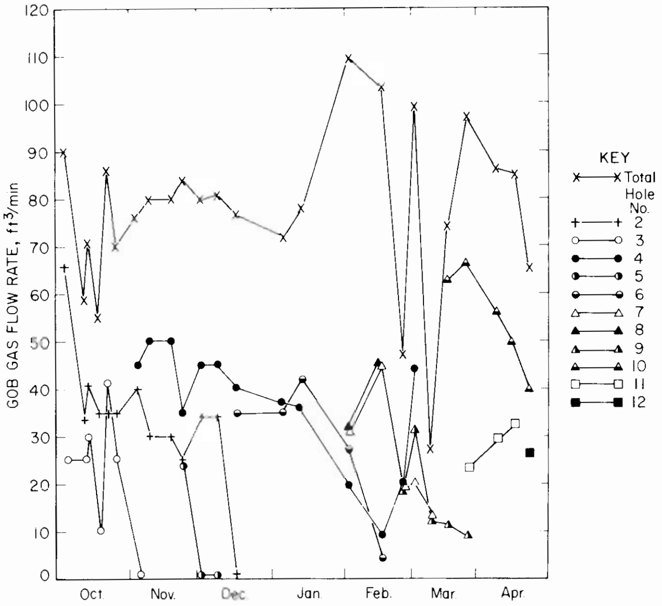

FIGURE 16. - Gob gas flow rates.

history was not obtained for holes 10, 11, and 12 because the holes were shut-in and the study was terminated when mining of the panel was completed.

The gob gas production life of the cross-measure boreholes ranged from 14 to 149 days (table 1). Borehole inclination (fig. 5, F) and penetration into the gob (fig. 5, F) were two important parameters that appear to affect gas production life of boreholes. Figure 17 shows borehole life is greater for inclinations ranging from 26° to 31° (0.45 to 54 rad) than for inclinations of 21° to 25° (0.37 to 0.44-rad). Boreholes with higher inclination angles also tended to produce higher average methane flow rates than lower inclination boreholes.

Borehole penetration into the gob (fig. 5, F) ranged from 90 to 136 ft (27 to 41 m), which is only 16 to 25 pct, respectively, of the width of the longwall panel. Figure 18 shows boreholes that penetrate too far into the gob produce gas for shorter periods than those that are drilled a short distance into the gob. Optimum borehole inclination and penetration into the gob appear to be at least 31° (0.54 rad) and 100 ft (30 m), respectively.

No conclusions could be drawn regarding the procedures used to grout the plastic standpipes into the cross-measure boreholes. Both procedures worked equally well. Drilling the boreholes over a pillar prevented the roof from fracturing around the collars of the boreholes and drawing mine air into the boreholes. Grouting of the standpipe 18 ft (5.5 m) or more into a hole is recommended over the use of socket joints and plugs of cement because the cost is less and the procedures are simpler.

TABLE 1. - Production history of cross-measure boreholes

Hole	Gas production life, days	Reason gas production was terminated
1	0	Hole never produced gob gas.
2	73	Gob compacted and flow declined to zero.
3	32	Do.
4	149	Methane concentration fell below 25 pct with dramatic increase in gas flow rate.
5	16	Gob compacted and flow declined to zero.
6	71	Do.
7	56	Do.
8	14	Methane concentration fell below 25 pct with dramatic increase in gas flow rate.
9	37	Gob compacted and flow declined to zero.
10	45	Complete production history not obtained. Study was terminated when mining of panel was completed.
11	20	Do.
12	8	Do.

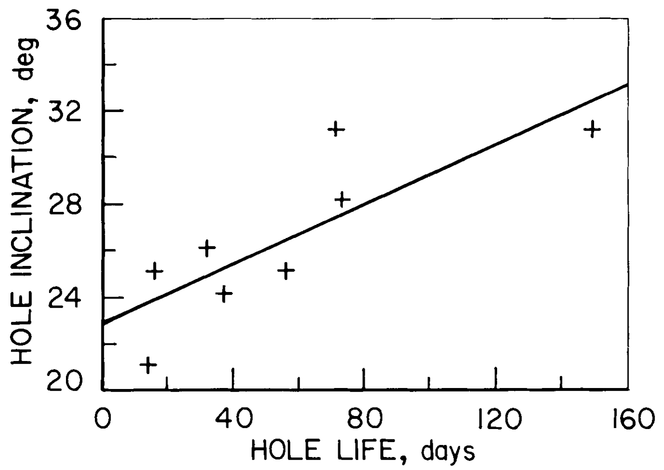

FIGURE 17. - Hole life versus inclination angle.

WATER PRODUCTION

Only cross-measure boreholes 3 and 8 produced water when initially drilled. Water production was 1.5 and 10 gal/min (5.7 and 37.9 L/min), respectively. When undermined, water flow from hole 3 increased to 6 gal/min (22.7 L/min) and flow from hole 8 decreased to 1 gal/min (3.8 L/min). Holes 2, 4, 6, 7, and 11 started to produce water after undermining; flow ranged from 1 to 8 gal/min (3.8 to 30.3 L/min). Holes 1, 5, 9, 10, and 12 did not produce water at any time. No correlation appears to exist between water production and terminal height of the boreholes (figs. 4 and 5, D).

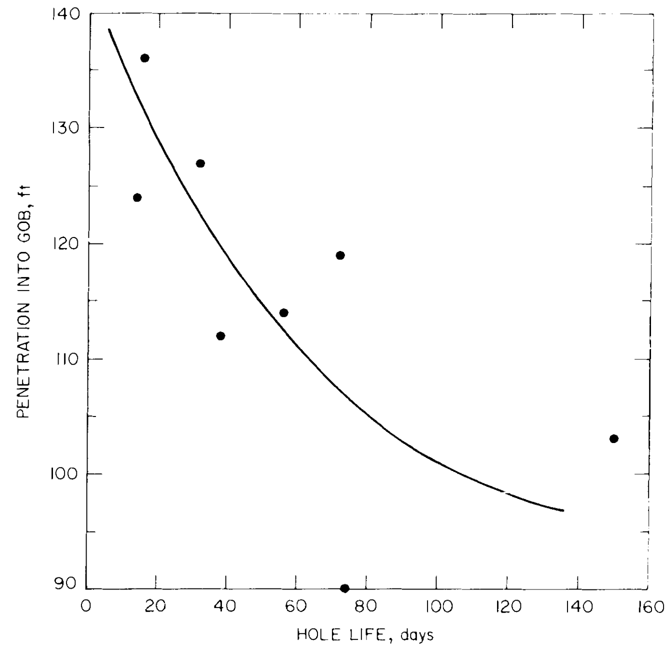

FIGURE 18. - Hole life versus penetration into gob.

PARTIAL VACUUM APPLIED TO CROSS-MEASURE BOREHOLES

The exhauster located on the surface borehole operated at maximum partial vacuum [3.5 in mercury (11.8 kPa)] throughout the study. Because of frictional losses in the pipeline, the partial vacuum at the cross-measure boreholes was always less and will vary among the holes. For example, the maximum partial vacuum measured at a cross-measure borehole was 3.0 in Hg (10.1 kPa) and gob gas flow was 27 ft^3/min (0.013 m^3/s). At another hole, the partial vacuum was 0.9 in Hg (3.0 kPa) and gas flow was 107 ft^3/min (0.050 m^3/s). Gob permeability is the dominant factor affecting flow and partial vacuum at a cross-measure borehole. Flow is high and partial vacuum is low in a loose gob; in a tight gob flow is low and partial vacuum is high.

Pressure measurements with a U-tube water manometer indicated the partial vacuum in the gob at each cross-measure borehole dissipated in less than a minute after the surface exhauster was turned off. Subsequently, all cross-measure boreholes were put on production except one which remained shut-in. Gas pressure in the gob was measured in the shut-in hole over a 24-h period. The partial vacuum in the gob remained zero. These data indicate that no communication exists between adjacent holes and that areas exist in the gob that are not being drained by the cross-measure boreholes. Either the cross-measure boreholes should be spaced closer to one another, or a surface exhauster capable of a larger flow at a greater partial vacuum should be used.

EFFECTS OF THE CROSS-MEASURE SYSTEM

Methane enters mine workings during longwall mining from fractured roof and floor strata and from the mined coalbed. Ventilation and methane surveys conducted at the tailgate of the longwall showed that the flow of methane from the mined coalbed during mining was about 20 ft^3/min (0.01 m^3/s). During nonmining periods, the flow was negligible. The contribution of floor strata to methane in the gob is unknown. Coalbeds in the roof strata are known methane source beds.

Figure 19 shows that the cross-measure borehole system captured about 50 pct of the methane produced by the mining operation. The other half was removed by the mine ventilation system. Methane flows in both systems declined during the life of the panel.

The effect of the cross-measure borehole system on methane in the mine ventilation system was dramatic. Figure 20 shows that the methane flow in the return air from the longwall increased by a factor of over 2 when the cross-measure borehole system was not in operation. These data clearly demonstrate the effectiveness of the boreholes in controlling methane in the gob.

SUMMARY AND CONCLUSIONS

The cross-measure borehole technique is a viable method of controlling methane in gobs of retreating longwalls in the Upper Kittanning Coalbed. About 50 pct of the methane produced by the mining operation was captured by the cross-measure borehole system. Use of an exhauster with a higher flow capacity and partial vacuum would increase the quantity of methane captured by the cross-measure borehole system.

Depth of penetration into the gob and inclination of a cross-measure borehole are two important parameters that affect the quality and quantity of gob gas produced by a borehole. Borehole inclination should be at least 31° (0.54 rad), and larger angles should be tested to determine if performance can be improved further. Borehole penetration into the gob (fig. 5, F) should be limited to about 100 ft (30 m).

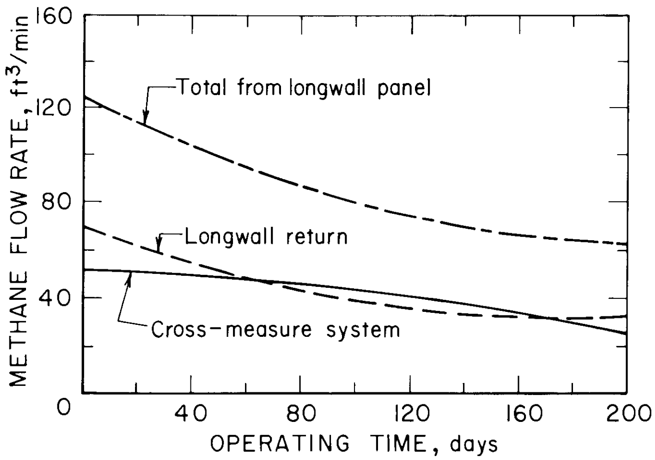

FIGURE 19. - Cross-measure, longwall return, and total methane flow rates.

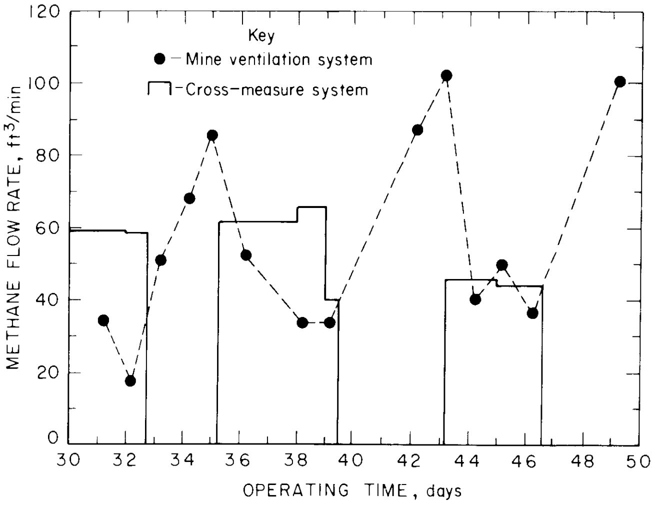

FIGURE 20. - Effect of the cross-measure system on the mine ventilation system.

Seven of the 12 cross-measure boreholes produce water ranging from 1 to 10 gal/-min (3.8 to 37.9 L/min). Gas-water separation devices will be required on each borehole if the main pipeline is not sloped to drain water. No correlation appears to exist between water production and terminal height of boreholes (fig. 5, D).

The cross-measure boreholes were spaced 250 ft (76 m) along the test panel. Communication tests between boreholes indicated the spacing should be reduced or a larger capacity exhauster should be employed to improve the performance of the cross-measure borehole system. The first cross-measure borehole should be drilled so that the end of the borehole is about 100 ft (30 m) from the starting end of the panel. The end of hole 1 was about 27 ft (8 m) from the starting end of the test panel and it produced neither air nor methane. Apparently no fracturing occurred around hole 1.

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