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Methane Control on Longwalls With Cross-Measure Boreholes (Lower Kittanning Coalbed)

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	kPa	kilopascal
d/wk	day per week	L/min	liter per minute
ft	foot	m	meter
ft^3	cubic foot	m^3	cubic meter
ft/d	foot per day	m/d	meter per day
ft^3/min	cubic foot per minute	m^3/s	cubic meter per second
ft/s	foot per second	mt/d	metric ton per day
ft/s^2	foot per second per second	pct	percent
gal/min	gallon per minute	rad	radian
h	hour	ton	short ton
in	inch	ton/d	short ton per day
in H_2O	inch of water (pressure)	vol pct	volume percent
in Hg	inch of mercury (pressure)		

METHANE CONTROL ON LONGWALLS WITH CROSS-MEASURE BOREHOLES (LOWER KITTANNING COALBED)

By F. Garcia[1] and J. Cervik[2]

ABSTRACT

The cross-measure borehole technique has been shown by the Bureau of Mines to be an effective method of controlling methane liberated by fracturing the roof strata in longwall gobs where overburden is less than 750 ft (229 m). Boreholes are drilled into roof strata before mining operations affect the roof strata. Longwall mining fractures the roof strata and releases methane from source beds. Surface exhausters or vacuum pumps are used to draw the gas to the surface through an underground pipeline and vertical exhaust hole. The captured methane is thus prevented from entering the mine's ventilation system. About 71 pct of the methane produced by longwall mining in the Lower Kittanning Coalbed was captured by the cross-measure boreholes.

Borehole spacing is an important factor affecting the performance of the technique. Interference tests and measurements of methane flows in return air indicate borehole spacing in the Lower Kittanning Coalbed should be limited to about 200 ft (61 m) except on the first 600 ft (183 m) of the longwall, where spacing should be reduced to about 100 ft (30 m) to capture the large quantities of methane released when the first large roof fall occurs.

Comparisons between measured and calculated gas pressure differentials on boreholes indicate borehole length can be reduced from 280 to 140 ft (85 to 43 m), which reduces drilling costs significantly. Additional experimentation is necessary to verify the calculations.

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INTRODUCTION

Gob gas drainage through surface gob holes in the United States is an effective means of assisting a mine's ventilation system in controlling methane produced by longwall operations. Surface gob holes cannot always be drilled because of severe topography, surface right-of-way problems, and populated areas. An alternative method of controlling gob gas is necessary that is independent of these factors.

In Europe, gob gas is controlled by drilling small-diameter holes into roof strata from underground locations (cross-measure boreholes) and drawing the gas to the surface by vacuum pumps (1).[3] This technique eliminates the factors affecting the drilling of surface gob holes. A test conducted by the Bureau and BethEnergy Mines Inc. in the Upper Kittanning Coalbed showed that approximately 50 pct of the methane produced by the longwall operation was captured by the cross-measure borehole system (2). The performance of the cross-measure system is affected by a number of design parameters, including location of methane-bearing strata in the roof, borehole length and angles with respect to the longwall panel (vertical and horizontal), pipeline diameter, borehole diameter and spacing, and operating characteristics of the surface pumping facility.

In Europe, mathematical models have been developed for determining optimum design parameters. Unfortunately in the United States, "trial and error" is the only method currently available. This report describes further joint efforts by the Bureau and BethEnergy Mines Inc. to establish optimum design parameters that are necessary for controlling methane during retreat longwall mining in the Lower Kittanning Coalbed using the cross-measure borehole technique.

ACKNOWLEDGMENTS

The authors thank the following personnel of BethEnergy Mines Inc., Cambria Division, for their cooperation and assistance in the study at the Cambria 33 Mine, Ebensburg, PA: E. J. Korber, Manager; R. F. Dodson, General Superintendent; D. Weaver, Geological Engineer; N. Carpinello, Mine Foreman; and G. W. Moyer, General Assistant.

STUDY AREA

The study area was located in Pennsylvanian age strata of the Allegheny Group, specifically the Kittanning Formation (3). The Lower Kittanning Coalbed, locally called the B Seam, averages 36 to 60 in (91 to 152 cm) in thickness in Cambria County. A detailed stratigraphic column was produced from the analysis of the core samples taken from a surface borehole drilled nearby the test longwall (fig. 1). Three coal groups are located about 15, 85, and 125 ft (5, 26, and 38 m) above the roof of the Lower Kittanning Coalbed. A total of 9 ft (2.7 m) of coal lies within the first 130 ft (40 m) above the roof. These coalbeds are known sources of methane.

The test retreating longwall is located between 16 Right and 17 Right off F West in BethEnergy Mines Inc.'s Cambria 33 Mine (fig. 2). A detailed view of the test panel is shown in figure 3. All the cross-measure boreholes were drilled from the center entry and connected to an underground pipeline. A surface borehole was drilled between 16 Right and 17 Right to bring the gas to the surface. The center entry was supported with cribs to protect the underground pipeline and to prevent caving so that access to the pipeline and cross-measure boreholes could be maintained during life of the panel.

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

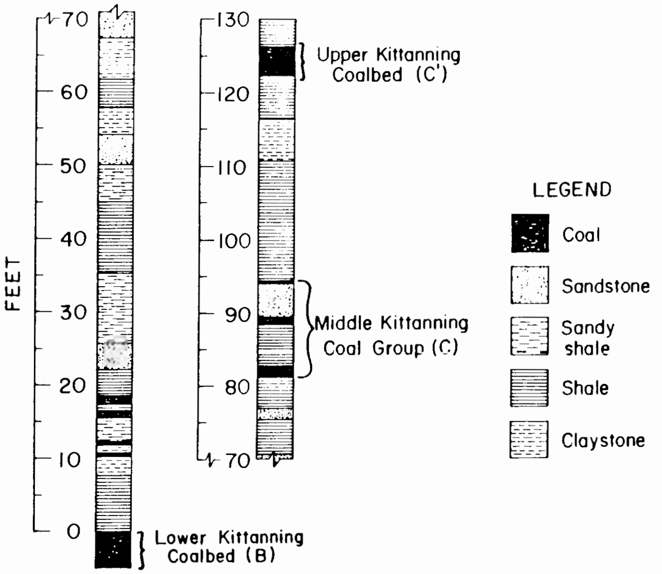

FIGURE 1. - Stratigraphic column above Lower Kittanning Coalbed.

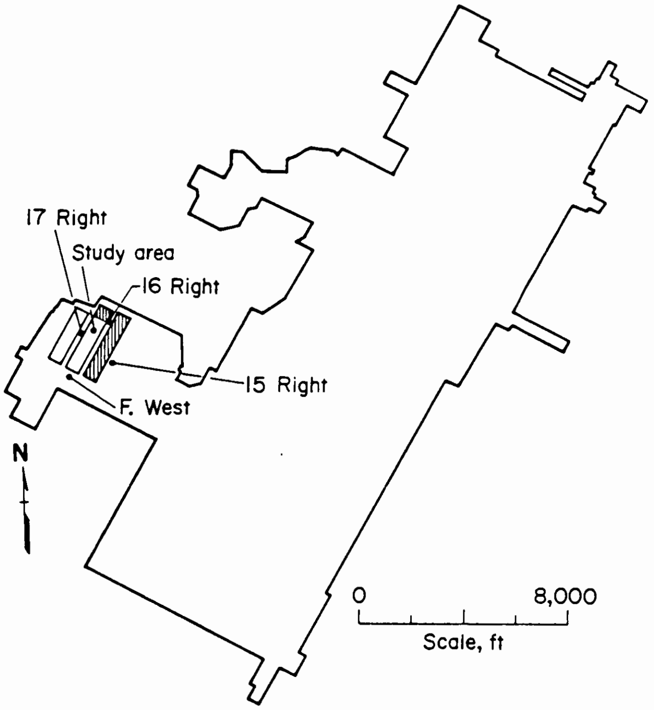

FIGURE 2. - BethEnergy Mines Inc.'s Cambria 33 Mine (Lower Kittanning Coalbed).

DRILLING EQUIPMENT AND PROCEDURES

Except for minor alterations, drilling equipment and procedures were similar to those developed in a prior study conducted in the Upper Kittanning Coalbed at the Cambria 33 Mine, Ebensburg, PA (2). The first 30 ft (9 m) of the cross-measure borehole was drilled with a 4-in (10 cm) diamond core bit, and the cores were removed in 30-in (76 cm) sections. The remainder of the hole was drilled using a 1.9-in (5 cm) "stratapac" bit. The 1.6-in (4 cm) diameter drill rods were 15 in (38 cm) long, and no centralizers were used during drilling. After completion of the boreholes, a 2.5-in (6 cm) diameter, 20-ft (6.1 m) plastic pipe was then grouted 18 ft (5.5 m) into the hole using a cement-flyash slurry containing 50 vol pct flyash. An experienced two-person drill crew could set up the drill, drill the hole, and install and grout the plastic pipe in about ten 8-h shifts.

METHANE REMOVAL SYSTEM

Extraction of a coalbed by longwall mining fractures and breaks up the overlying strata and releases methane into the mine workings. By capturing and transporting methane through the cross-measure borehole system, methane flows entering the mine's ventilation system can be reduced.

Twelve cross-measure boreholes were drilled along the panel, and all holes were connected to a 6-in (15 cm) diameter polyethylene pipeline. The gas (air plus methane) was brought to the surface through a steel-cased, 8-in (20 cm) diameter borehole and discharged into the atmosphere.

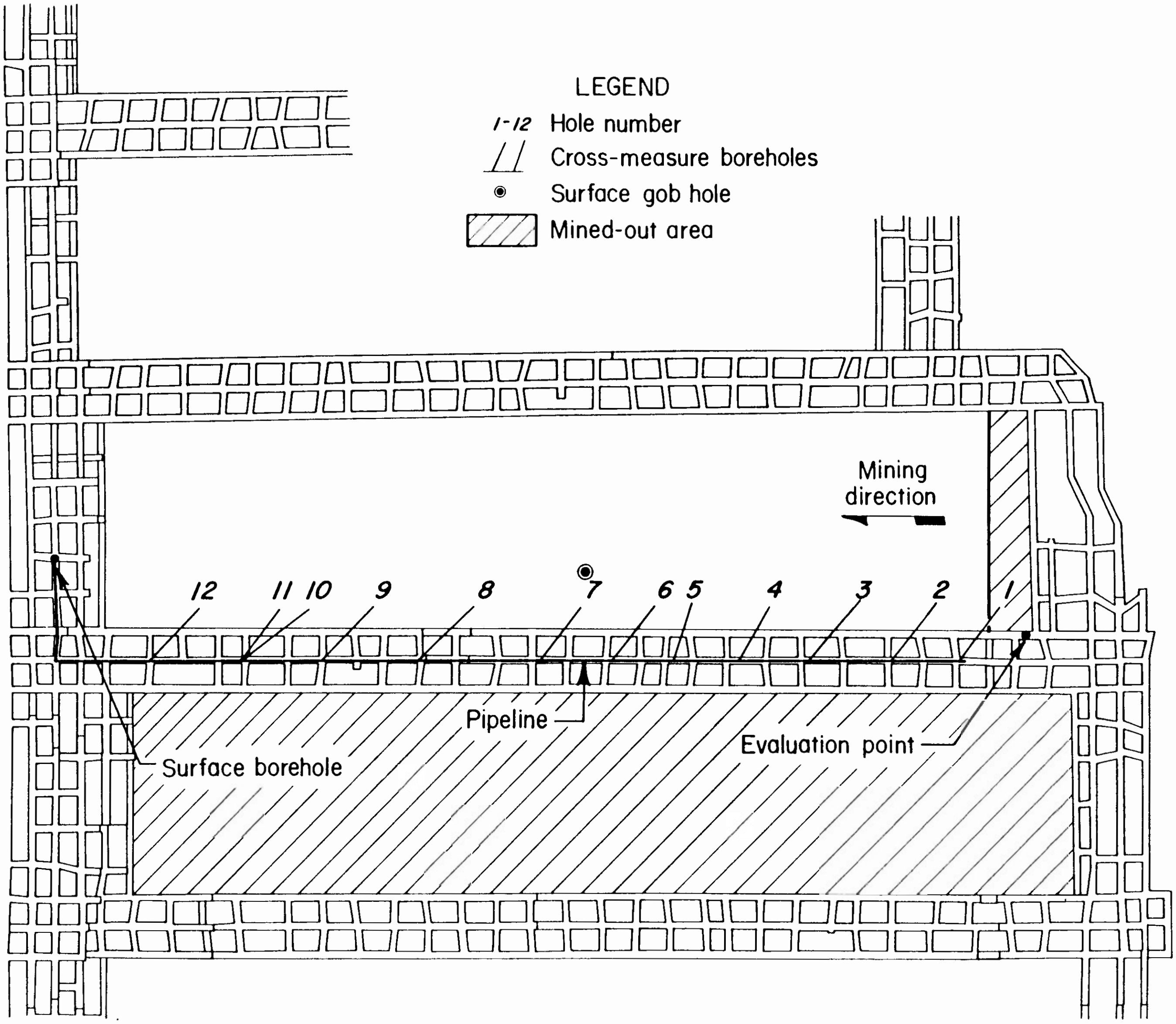

FIGURE 3. - Longwall test panel.

Gas flow occurs from a cross-measure borehole only after partial undermining of each hole and application of a partial vacuum by an exhauster or vacuum pump. In this study, two exhausters were used (fig. 4). The capacity of the smaller exhauster ranged to 450 ft^3/min (0.212 m^3/s) at a partial vacuum of 8.65 in Hg (29 kPa). The larger exhauster requires a minimum flow of 350 ft^3/min (0.165 m^3/s), and maximum capacity is 1,300 ft^3/min (0.614 m^3/s) at a partial vacuum of 12.6 in Hg (42 kPa). The smaller exhauster was used initially until the gas flow from the undermined cross-measure boreholes reached about 400 ft^3/min (0.189 m^3/s), and thereafter the larger capacity exhauster was used.

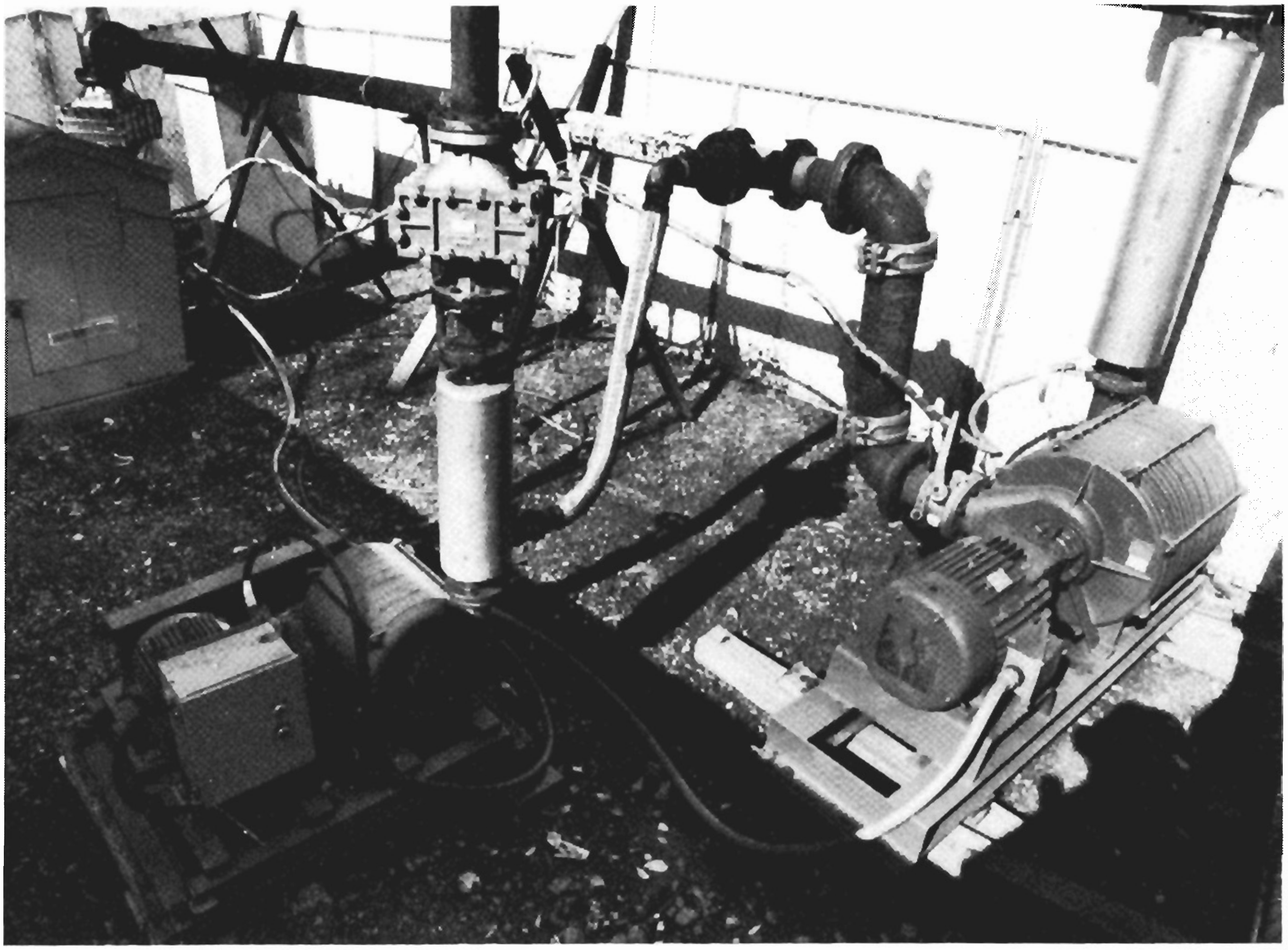

FIGURE 4. - Surface exhausters.

CROSS-MEASURE BOREHOLE DESIGN

The design of the cross-measure borehole system was similar to the design used in the Upper Kittanning Coalbed studies (2, 4):

Vertical inclination angle	- 28° (0.49 rad)
Hole length	- 280 ft (85 m)
Terminal height	- 132 ft (40 m)
Horizontal angle	- 45° (0.79 rad)
Spacing	- 200 ft (61 m) on first half of panel and 300 ft (91 m) on second half of panel.

All holes were surveyed after completion of drilling to determine the actual path of the bit through the roof strata. In general, the surveys show that the holes turned upward more steeply and to the right because of clockwise rotation of the bit.

Generally, holes will turn upward because of difference in diameters of bit and drill rods. For the equipment used in this study, a 1.9-in (4.8 cm) diameter bit and 1.6-in (4.1 cm) diameter rods were used. Consequently when drilling, the first 5 ft (1.5 m) of drill string tends to be cocked upwards in the hole, and hole trajectory turns upward more steeply. Applying excessive thrust also tends to turn the hole upward more steeply. The use of centralizers, one behind the bit and a second about 5 ft (1.5 m) from the bit, would tend to prevent hole trajectory from turning upward more steeply. However, even with centralizers, excessive thrust on a bit will turn hole trajectory upward more steeply. To prevent the retreating face of the adjacent panel from passing the drilling site, holes were drilled as rapidly as possible, which caused the holes to turn upwards more steeply than planned.

Hole locations were changed in many cases to provide more drilling time before the face of the adjacent panel reached the drill site and because of poor roof conditions. Consequently, hole spacing was varied from 170 to 210 ft (52 to 64 m) on the first half of the panel and from 220 to 350 ft (67 to 107 m) on the second half.

Figure 5 shows the design characteristics of the cross-measure boreholes. The initial inclination (column A) varied from 28° to 33° (0.49 to 0.58 rad) except for holes 11 and 12, which were purposely drilled lower in the projected gob. Horizontal angle (column B) is greater than the 45° (0.79 rad) design criterion and varied from 50° to 65° (0.87 to 1.13 rad). Except for the initial inclinations and horizontal angles, holes 3 and 6 could not be surveyed completely because of debris in the holes.

*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
1	31	64	280	134	42	120	160	75
2	32	52	268	101	49	75	200	230
3	33	54	280	ND	ND	ND	ND	ND
4	32	59	280	169	47	130	110	760
5	30	65	280	171	41	150	85	980
6	33	57	280	ND	49	ND	ND	ND
7	28	56	280	154	45	100	145	1,305
8	33	54	280	141	43	90	185	1,605
9	30	54	280	145	38	85	170	1,725
10	33	50	280	167	46	110	160	2,130
11	25	54	220	91	30	100	130	2,160
12	21	50	220	120	30	70	80	2,440

LEGEND

*	Cross-measure borehole number
A	Initial inclination, degrees
B	Horizontal angle, degrees
C	Hole length, ft
D	Terminal height of hole, ft
E	Height of hole at end of supported length, ft
F	Penetration over longwall panel, ft
G	Distance from endpoint to origin of hole, ft
H	Distance from start of panel to endpoint of hole, ft
ND	Not determined

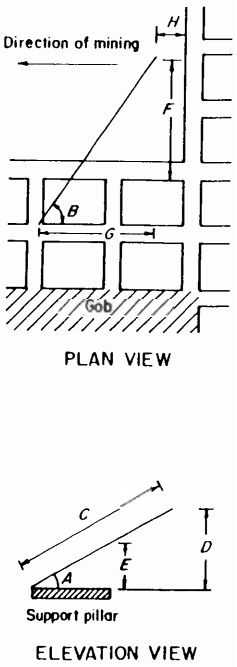

FIGURE 5. - Cross-measure design characteristics.

SURFACE GOB HOLES

Surface gob holes have been used at this mine since 1968 to assist in controlling methane in gobs. Figure 6 shows a typical borehole layout on longwall panels. Shorter than normal longwall panels usually employ only two surface holes. Generally, a low-pressure exhauster is mounted on the surface gob holes to draw the methane from the gob.

The cross-measure borehole study was conducted on a test panel where only one surface gob hole could be drilled about 1,300 ft (396 m) from the start of the test panel because of a populated area on the surface. Even this borehole was displaced about 75 ft (23 m) from the center line towards the return side of the longwall to avoid surface buildings.

UNDERGROUND AND SURFACE INSTRUMENTATION

Figure 7 shows the underground measurement instrumentation used in connecting a cross-measure borehole to the underground pipeline. Gas flow rates (air plus methane) were calculated from differential pressure measurements with a U-tube manometer across the pressure taps of a venturi. A handheld, 0- to 100-pct methanometer was used for determining the concentration of methane in the gas flows, and the partial vacuum at each borehole was measured with a manometer at the venturi.

The total gas flow from the cross-measure system was determined by summing the flows from the individual boreholes and by measuring the flow at the surface through an orifice plate installed in the surface piping (fig. 8). The differential pressure across the orifice plate

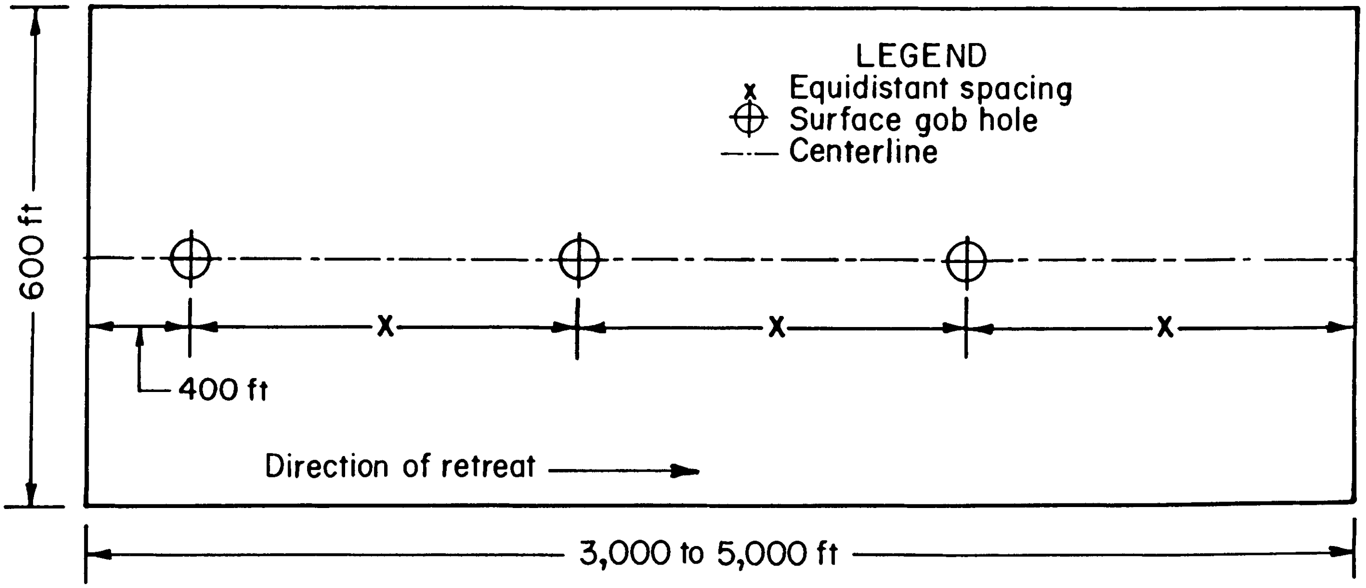

FIGURE 6. - Surface gob hole locations for longwall panel.

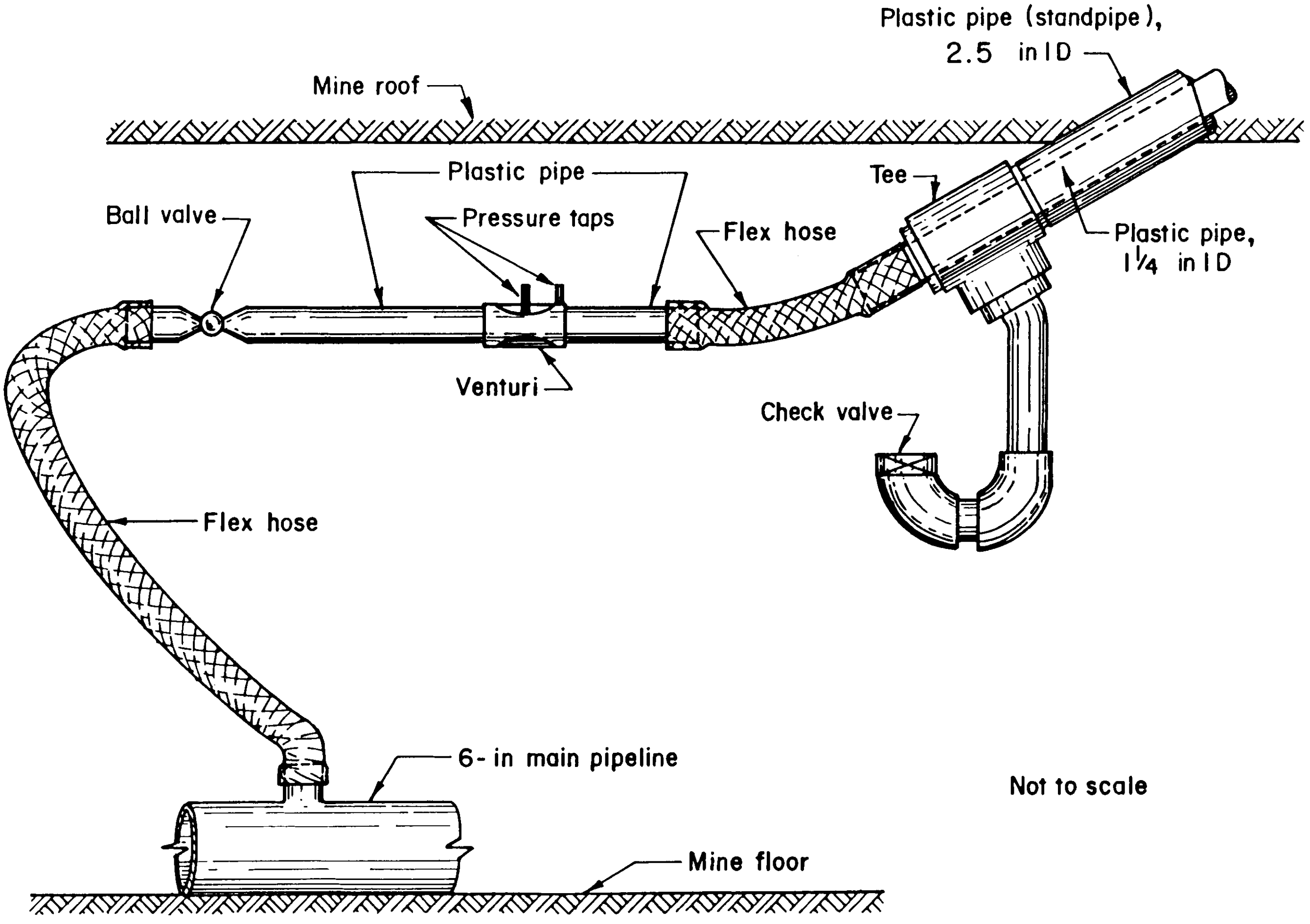

FIGURE 7. - Underground measurement instrumentation.

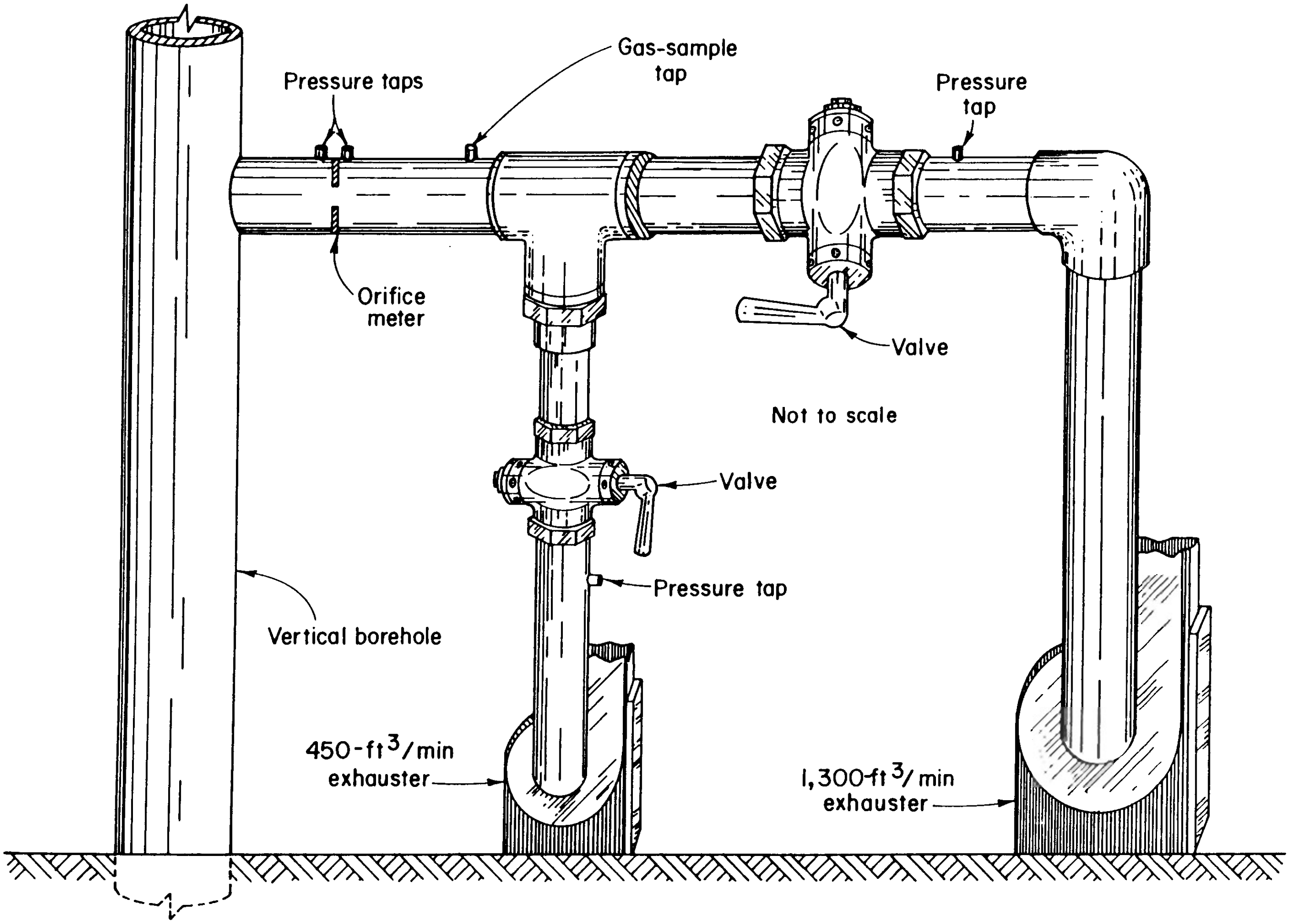

FIGURE 8. - Dual exhauster arrangement.

was continuously recorded, and the gas flow was calculated from the differential pressure measurements. All gas flow measurements were corrected to mine atmospheric conditions so that comparisons could be made between underground and surface measured flows. The concentration of methane in the gas flow was measured continuously by drawing a small quantity of gas through a recording infrared gas analyzer. A pressure tap was used to measure the partial vacuum at the inlet to each exhauster.

GAS-WATER SEPARATOR SYSTEM

The strata overlying a coalbed may contain several water-bearing formations that are penetrated by cross-measure boreholes. Some boreholes produce water when initially drilled; others produce water when the strata are fractured by the longwall mining operation; and some boreholes do not produce water at any time. Consequently, boreholes need to be fitted with gas-water separators to prevent the water, if any, from entering and blocking the underground pipeline. If the underground pipeline can be sloped so that water runs freely to one end of the pipeline, then individual gas-water separators are not necessary. The water can be discharged directly into the main pipeline and subsequently removed through a gas-water separator at a convenient location.

Most commercial gas-water separators are designed to operate in a positive pressure environment. When pressure is negative, the separators malfunction.

Consequently, special gas-water separators must be designed and built to operate in an environment where partial vacuum conditions exist (5). These separators require expensive machined parts, delicate adjustments, and maintenance. The Bureau has developed a separator that operates in a partial vacuum environment, contains only one moving part, and can be constructed of plastic pipe that is readily available (fig. 9) (6). This device requires only minimal maintenance.

After a cross-measure borehole has been drilled, a 20-ft (6.1 m), 2.5-in (6.4 cm) diameter plastic pipe is grouted 18 ft (5.5 m) into the hole. About 2 ft (0.6 m) of the pipe protrudes into the mine entry. A 2.5-in (6.4 cm) plastic "T" is fitted on the end of the pipe; this "T" provides support for a 1.25-in (3.2 cm) concentric gas pipe. Water flowing down the hole enters the annulus between the two concentric pipes and is discharged through a one-way check valve mounted on a pipe extension from the "T." Gas is drawn from the hole through the inner plastic pipe, which is fitted with an end cap and is slotted a short distance on its top surface only. The end cap prevents cascading water from entering the concentric pipe and accumulating in the underground pipeline.

Typically, cross-measure boreholes are inclined about 30° (0.52 rad). Consequently, the vertical height from the roof to the end of the 2.5-in (6.4 cm) plastic pipe is about 9 ft (2.7 m). About 2 ft (0.6 m) is added for the extension pipe, which makes a total vertical height of 11 ft (3.4 m). When a

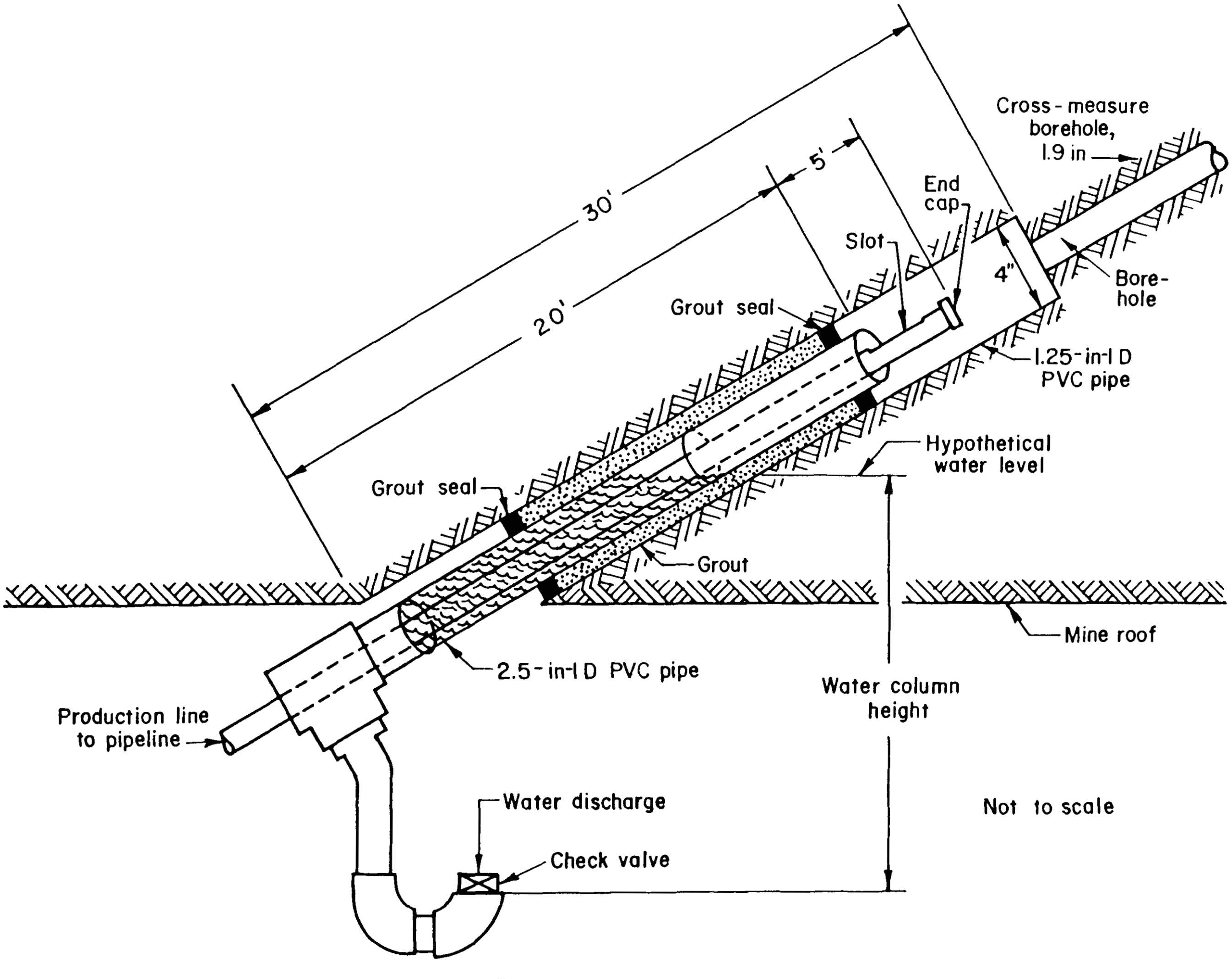

FIGURE 9. - Gas-water separator.

partial vacuum is applied to the hole, water accumulates in the annulus until the vertical height of the water column is balanced by the applied vacuum. Any further accumulation of water is discharged through the one-way check valve.

For example, suppose the applied vacuum is 8 in Hg (27.2 kPa); then the vertical height of the water column is about 9.1 ft (2.8 m). The water column extends about 14.2 ft (4.3 m) along the hole in the annulus above the roof line. The maximum partial vacuum that can be applied to the hole is about 9.7 in Hg (33 kPa). In this case, the water column may reach the slot in the concentric gas drainage pipe, and consequently water will discharge directly into the underground pipeline instead of through the one-way check valve. In the event the cross-measure borehole does not produce water, then the one-way check valve remains closed and prevents mine air from entering the gas drainage line.

Small particles of roof rock may be washed down the hole and accumulate at the pipe extension just before the one-way check valve. Eventually, the pipe extension becomes blocked and water is prevented from discharging through the one-way check valve. The water will accumulate in the annulus until the slot in the gas drainage pipe is reached and then discharge into the underground pipeline. Consequently, the underground pipeline should be fitted on the bottom side with one-way check valves located in low spots along the pipeline. When the surface exhausters are shut off periodically, the one-way check valves open automatically and discharge the accumulated water in the pipeline. All cross-measure boreholes should be inspected to ensure that rock particles are not accumulating in the pipe extension near the one-way check valve.

DATA ANALYSES

LONGWALL PRODUCTION

The test longwall is 585 ft (178 m) wide and 2,750 ft (838 m) long. The panel was worked 3 shifts per day but in a predominantly 3-d/wk schedule because of the low demand for coal (fig. 10). On working days, the panel was retreated an average of 40 ft/d (12 m/d). Average coal production was 3,800 ton/d (3,447 mt/d), which is above average coal production in a 4-ft (1.2 m) coalbed (7). The longwall panel was completely mined in 69 working days, which were spread over a 240-day interval and included three idle periods of about 73, 32, and 10 days (fig. 10).

CROSS-MEASURE BOREHOLE GAS PRODUCTION

Table 1 shows all boreholes produced gas except hole 7. Other holes (holes 1, 3, 4, 6, and 8) were shut in for short periods totaling 6 to 120 nonconsecutive days during the life of the panel because of excessive water flow, low methane concentration, or blockage.

Table 2 summarizes the average gas and methane flow rates from the boreholes. Flow rates are much greater where partial vacuum is low (holes 4, 9, and 12), indicating a highly permeable gob compared with those cases were partial vacuums are high (holes 3, 8, and 10) and flows lower. Approximately 71 pct of the methane produced by the longwall mining operation was captured by the cross-measure borehole system.

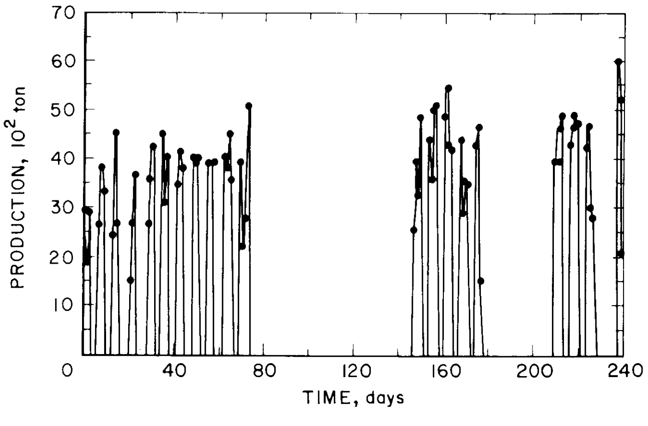

FIGURE 10. - Daily longwall coal production.

TABLE 1. - Production history of boreholes

Hole	Production day		Shutdown periods, days	Comments
	Startup	Termination		
1	8	240	120	Water problems and low methane concentration.
2	17	240	0	None.
3	36	149	91	Blocked by debris.
4	58	240	6	Water problems.
5	65	240	0	None.
6	77	240	39	Water problems.
7	(1)	(1)	(1)	No gas production.
8	183	240	7	Water problems.
9	183	240	0	None.
10	232	240	0	None.
11	219	240	0	None.
12	233	240	0	None.

[1] No productive life.

TABLE 2. - Average methane and gas flows from boreholes

Hole	Partial vacuum, in Hg	Methane conc, pct	Av. flow rate, ft^3/min	
			Gas	Methane
1	3.1	73	138	100
2	3.7	62	112	70
3	5.5	61	50	30
4	1.9	61	118	72
5	3.4	78	116	91
6	3.1	86	84	72
7	(1)	(1)	(1)	(1)
8	4.1	73	58	42
9	1.6	80	121	97
10	5.8	100	39	39
11	3.9	86	136	118
12	2.6	97	124	120

[2] No productive life.

Most boreholes did not produce gas until a partial vacuum was applied and the longwall face passed 75 to 100 ft (23 to 30 m) beyond the end of the borehole but before the face reached its collar. Holes 5 and 10 were exceptions. A free flow of methane [60 ft^3/min (0.028 m^3/s)] was measured from hole 5 before the face reached its collar. After the face passed beyond the collar, the free flow stopped and a partial vacuum was required to maintain flow. Gas production occurred from hole 10 only after the face passed well beyond its collar.

Holes 10 and 11 were drilled from the same location; they terminated 167 and 91 ft (51 and 28 m), respectively, above the mined coalbed (fig. 5, column D). Table 2 shows that the average gas and methane flows from hole 11 were about 3 times larger than flows from hole 10, suggesting that boreholes drilled lower in the gob are more productive. However, the production life of these boreholes was short because mining of the panel was completed and the study terminated shortly after the boreholes were undermined. If the boreholes had been drilled further from the end of the panel, long-term production history may have shown that the concentration of methane in the gas flow from hole 11 dropped significantly because of its low position in the gob. gob. More tests are needed to evaluate the effects of terminal height of boreholes on methane concentrations in the gas flow.

The gas flow from the cross-measure system and the number of boreholes producing gas are shown in figure 11. Figure 12 shows the methane concentrations in the gas flow. During idle periods, the flow of gas from the cross-measure system remains relatively constant (fig. 11) but the methane concentration in the gas flow drops abruptly (fig. 12). When mining resumed, the increase in methane concentration was as abrupt as the decline. The corresponding methane flows are shown in figure 13. Also shown are the times when each borehole started methane production, which is greatest when it first goes on production and is generally represented by a small peak in the graph. The dependency of methane flow rates on mining is clearly demonstrated by the prolonged idle periods. The first idle period (73 days) shows that methane flow declined from about 400 to 100 ft^3/min (0.189 to 0.047 m^3/s) and when mining resumed, the flow increased again to about 400 ft^3/min (0.189 m^3/s). These data indicate that about 75 pct of the methane in the gob comes from newly fractured roof strata near the face.

The variations in methane concentrations in the gas flows from individual cross-measure boreholes were very similar to methane concentration variations at the surface exhauster (fig. 12). Flow from hole 2 is typical of methane concentration variations in gas flow from individual cross-measure holes (fig. 14).

The partial vacuum at the inlet to the surface exhauster averaged about 8.5 in Hg (28.8 kPa) during mining and rose to above 11 in Hg (37.3 kPa) during idle periods (fig. 15). The decline in methane flows during idle periods (fig. 13) is compensated by increased flow of air (fig. 11), which must be drawn from the mine upward into the gob and finally into the cross-measure system. This causes the exhauster to work harder to maintain a constant flow. Because methane is more readily available when mining resumes, the partial vacuum at the exhauster declines and air flow into the cross-measure system is reduced.

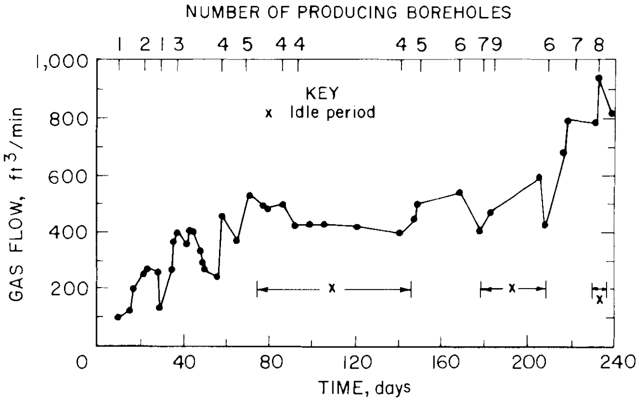

FIGURE 11. - Total gas flow from cross-measure system.

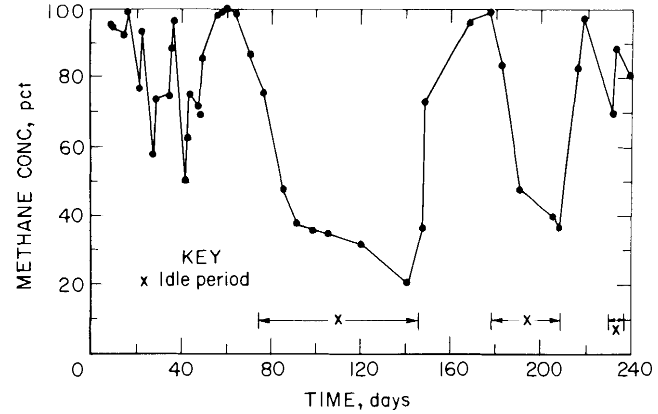

FIGURE 12. - Surface methane concentrations in gas flow.

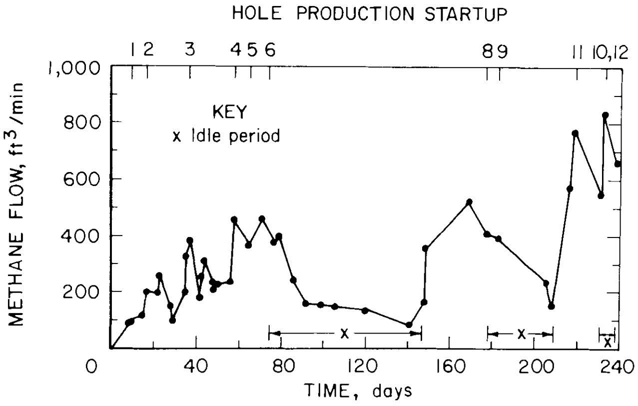

FIGURE 13. - Methane flow from cross-measure system.

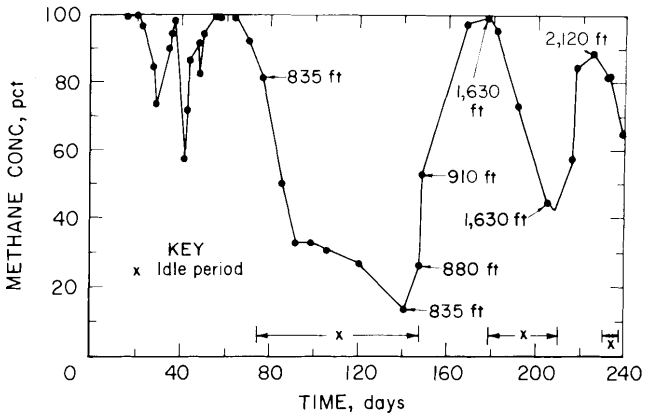

FIGURE 14. - Methane concentrations in gas flow from hole 2.

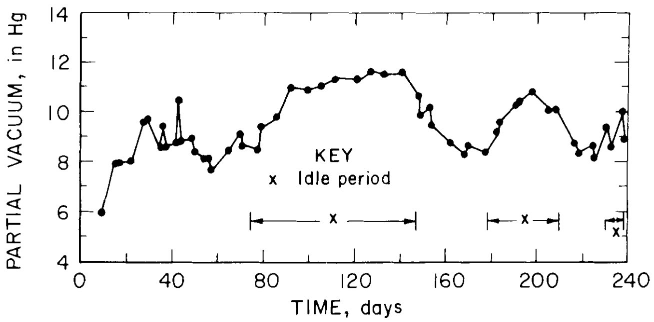

FIGURE 15. - Partial vacuum measured at surface exhauster.

METHANE MIGRATION THROUGH GOBS

The numbers shown in figure 14 represent the distances between hole 2 and the moving face. During the first idle period, the concentration of methane in the gas flow from the hole declined from about 90 to 30 pct in 20 days. When mining resumed on day 140, the methane concentration in the gas flow began to increase and reached 100 pct on day 178, when the face of the panel was 1,630 ft (497 m) from hole 2. During the second idle period (day 180 to 210), the methane concentration again declined and then increased and reached 90 pct after mining resumed. At this time the distance between face and hole 2 was 2,120 ft (646 m). These data clearly indicate that methane migrates through the gob for distances of at least 2,120 ft (646 m). A Bureau study in the Pittsburgh Coalbed showed that an increase in gas flow from a vertical gob hole was attributable to an increase in mining rate at the face, which was 2,800 ft (853 m) from the gob hole.

BOREHOLE SPACING

Application of a partial vacuum to a cross-measure borehole creates a low-pressure zone around the borehole in the gob. If boreholes are properly spaced, these low-pressure zones overlap and create a continuous low-pressure zone within the gob. Methane migrating downward and some mine air and methane from lower levels in the gob will be drawn upward toward the low-pressure zone and captured by the cross-measure system. If the low-pressure zones around each hole do not overlap, which indicates boreholes are spaced too far apart, then methane from higher levels in the gob will migrate into the mine opening between boreholes.

Borehole spacing depends upon gob permeability and operating characteristics of the surface pump or exhauster. Because little is known about gob permeability, borehole spacing is best determined from underground interference tests. During this test, all boreholes are shut-in and the gas pressure in the gob is allowed to stabilize. The boreholes are then opened to flow, except for one borehole (test borehole) which is monitored for changes in gas pressure. If no pressure change occurs, adjacent boreholes are spaced too far apart. If a slight pressure change occurs, spacing is adequate.

Interference tests were conducted on hole 1 near the start of the panel, on hole 5 near the center of the panel, and on hole 11 near the end of the panel. All test results were similar to the interference test on hole 11 (fig. 16). When all holes were shut-in, the negative gas pressure in the gob around hole 11 quickly dissipated, and in 5 min, gas pressure in the gob reached a positive 0.28 in H_2O (0.07 kPa) with respect to the mine environment. Then holes downstream from hole 11 (hole 2, 4, 5, 6, and 9) were open to flow, and within a few moments, gas pressure at hole 11 declined and stabilized at a partial vacuum of 0.15 in H_2O (0.04 kPa). Hole 9 is spaced 220 ft (67 m) from hole 11; the test indicated that the spacing is adequate. When hole 12 (located 280 ft (85 m) upstream from hole 11) was opened to flow, the partial vacuum at hole 11 increased further to 0.5 in H_2O (0.12 kPa). These data appear to indicate that a borehole spacing of 220 to 280 ft (67 to 85 m) is reasonable for the fractured strata above the Lower Kittanning Coalbed.

METHANE FLOW IN THE RETURN AIR

Figure 17 shows the flow of methane in the return air from the longwall and the times each cross-measure borehole started gob gas production. Measurements taken at the tailgate of the longwall indicate a methane flow due to mining of 30 ft^3/min (0.014 m^3/s) across the face and no measurable flow after mining stops.

The effect of each borehole on methane flow in the return air is clearly demonstrated by the large decrease in flow in the return immediately after each borehole starts gob gas production. These peak flows range from about 200 to 450 ft^3/min (0.142 to 0.212 m^3/s) and suggest that borehole spacing should be reduced.

After mining of the panel was started, the first large roof fall was accompanied by large flows of methane and mining was suspended for short periods because sufficient air was not available to maintain methane concentrations in the returns at permissible levels. Generally only one borehole is on production at this time, and the quantity of gob gas that can be drawn through a 1.9-in (4.8 cm) diameter borehole is small in comparison to the tremendous quantities generated in the gob. Consequently, gob gas begin to spill into and overload the return air system. Additionally, boreholes drilled between holes 1 and 2 and between holes 2 and 3 would prevent large peak flows and would lower the general level of methane flow in the return. Therefore, boreholes should be spaced 100 ft (30 m) apart along the first 600 ft (183 m) of the longwall and thereafter 200 ft (61 m) apart. Although the data presented in figure 16 appear to indicate that a borehole spacing of 220 to 280 ft (67 to 85 m) is possible, the smaller spacing should prevail to prevent or to reduce the severity of peak methane flows (fig. 17). The large peak methane flow around day 180 (fig. 17) was caused by a partially water blocked pipeline and a nonproductive cross-measure borehole (hole 7). Hole 7 was undermined around day 160 (fig. 17).

When the cross-measure system is shut-in, methane gradually refills the gob area and then begins to spill over into the return airways. Methane flows in the return gradually increase and more than double in a 20-h period (fig. 18). When the system is back in operation, methane flows declined to pretest conditions in about 4 h. These tests could only be conducted during nonmining periods or

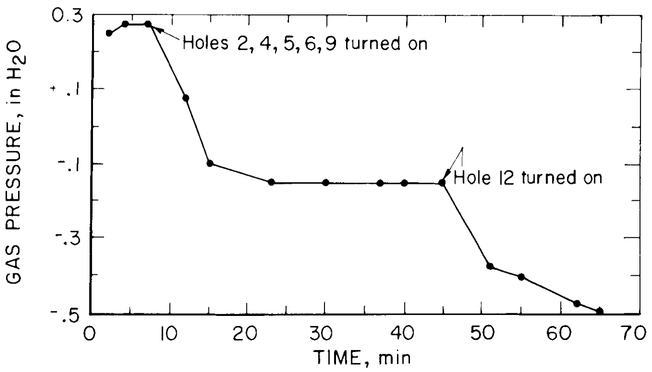

FIGURE 16. - Interference test using hole 11.

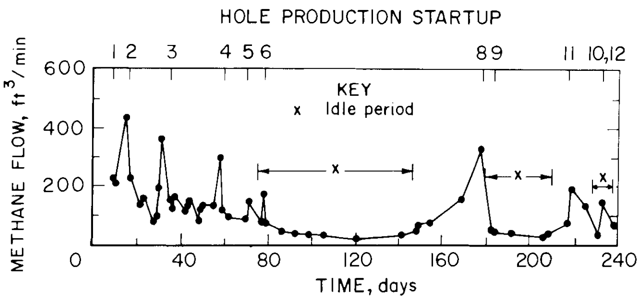

FIGURE 17. - Methane flow in return air.

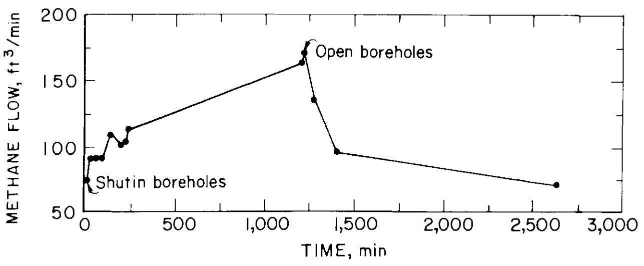

FIGURE 18. - Effects of cross-measure system on methane flow in return air.

over weekends. This test was conducted on day 78 when the first five boreholes had been intercepted and were producing gob gas (fig. 17).

WATER PRODUCTION

All boreholes were equipped with gas-water separators. No water flows occurred from holes 2, 3, 5, 11, and 12 during mining of the test panel. Initial water production from holes 4 and 7 was 27 and 10 gal/min (102 to 38 L/min), respectively. When undermined, water flow from hole 4 declined to a negligible quantity and that from hole 7 declined to a steady 1.5 gal/min (5.7 L/min). All other boreholes (hole 1, 6, 8, 9 and 12) produced water at rates from 0.25 to 1.5 gal/min (0.95 to 5.7 L/min) after undermining.

SURFACE GOB HOLE PRODUCTION

The surface gob hole produced gob gas for about 6 days and was finally shut-in because of low methane concentrations in the gas flow. The hole vented about 1,200,000 ft^3 (34,000 m^3) of methane during its short productive life. Gas production started on day 156; no indications exist that the gob hole affected methane flows in the return air from the longwall (fig. 17), in spite of the fact that the end of hole 7 (nonproductive) is in the same area as the surface gob hole (fig. 3).

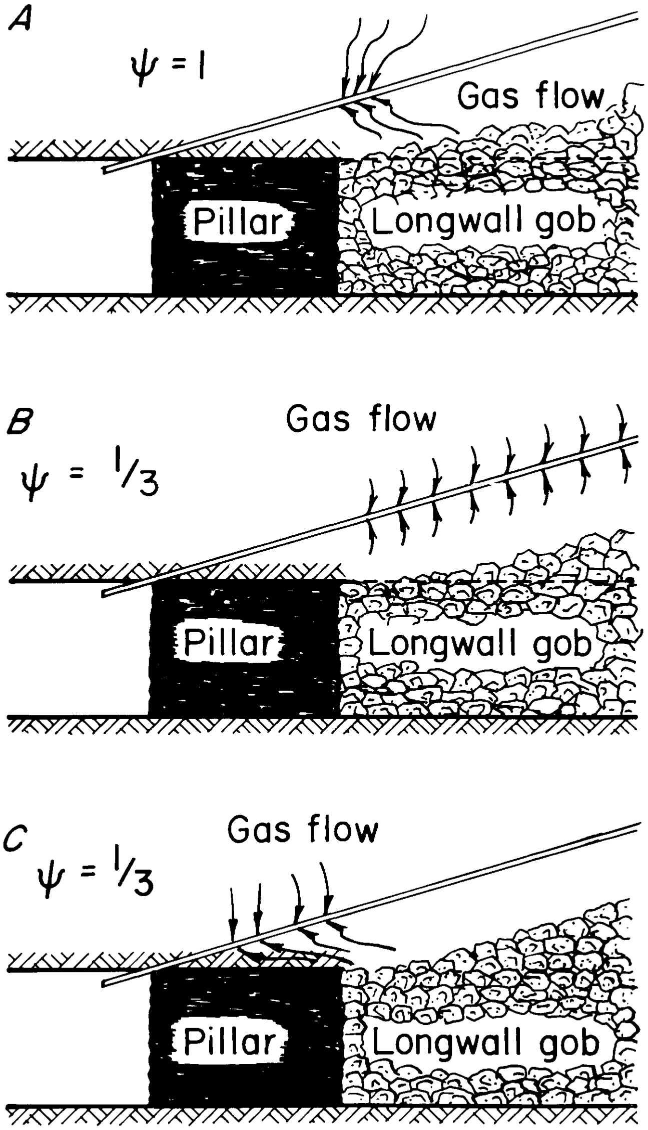

FIGURE 19. - Gas flow into boreholes.

MIGRATION OF GAS INTO A BOREHOLE

Because little is known about the migration behavior of methane in the gobs or the inflow of gas into a borehole, gas pressure differentials associated with flow of gas from boreholes were calculated for two widely separated cases and then compared with the measured values. In the first case, gob gas was assumed to flow into the borehole nearest the pillar line (fig. 19*A*). The remainder of the borehole in the gob is nonproductive. In the second case, gob gas is assumed to flow into the borehole uniformly along the length of borehole in the gob (fig. 19*B*). The following equation was used to compute pressure differentials for the two cases (5):

$$\Delta p = \frac{\psi\lambda}{70.7}\,\frac{L\rho}{2dg}\,\bar{V}^2 ,$$

where Δp = pressure differential (in Hg),

ψ = 1 for case 1 (fig. 19*A*), 1/3 for case 2 (fig. 19*B*),

λ = coefficient of resistance (dimensionless),

L = pipe or hole length (ft),

d = pipe or hole diameter (ft),

ρ = gas density (lb/ft^3),

$\bar{V}$ = average gas velocity (ft/s),

and g = accelerations of gravity (ft/s^2).

Table 3 summarizes the measured and calculated pressure differentials. In most instances, the calculated pressure differentials for case 1 (fig. 19*A*) appeared to match the measured data more closely than case 2 (fig. 19*B*). Holes 4, 9, and 10 were exceptions.

The measured pressure on hole 10 on day 241 (table 3) is much greater than the computed pressure, because the gob around hole 10 at this time is tight and gas does not readily enter the hole. On day 260, the measured and calculated pressures (case 1) agree reasonably well and indicate the gob is more permeable and gas flows easily into the borehole.

For both holes 4 and 9, the measured pressures are much less than the calculated pressures (cases 1 and 2). However, if one assumes that gob gas enters the segment of the borehole over the pillar (fig. 19*C*), then the measured and computed pressures are more nearly in agreement.

The data presented in table 3 appear to indicate that borehole length can be reduced from 280 to 140 ft (85 to 43 m), because gob gas enters the boreholes only near the pillar line. The remainder of the borehole in the gob is nonproductive. Reducing the length of boreholes makes the cross-measure system more cost effective.

An experienced drill crew requires about eight shifts to drill a 280-ft (85 m) cross-measure borehole. If hole length could be reduced significantly without affecting its performance, a considerable savings in labor costs can be effected. For example, if the drilling time is cut to about four shifts per hole, then about 768 person-hours are saved in drilling 12 cross-measure boreholes into rock strata above a retreating longwall. Assuming an hourly rate of $10, about $8,000 can be saved per longwall.

TABLE 3. - Comparison of measured and calculated gas pressure differentials

Hole	Day	Gas flow rate, ft^3/min	Methane conc., pct	Pressure differential, in Hg		
				Measured	Calculated	
					Case 1	Case 2
1	24	142	92	3.8	4.8	8.2
	49	105	45	3.5	3.5	6.1
2	23	133	100	4.8	5.5	8.0
	247	96	52	3.8	3.9	5.6
4	79	109	95	2.7	3.0	5.0
	207	116	43	1.6	5.0	8.3
	220	123	100	1.6	3.9	6.5
5	122	129	50	4.7	5.0	8.5
	220	116	100	3.2	3.1	5.3
6	207	95	48	3.6	3.2	5.1
	220	90	100	3.2	2.1	3.2
9	220	138	100	1.2	4.2	7.8
	260	119	28	1.3	4.9	9.0
10	241	31	100	5.4	.2	.3
	260	113	21	3.9	4.4	7.8
11	220	135	100	3.9	3.7	6.1
	233	119	48	4.3	3.7	6.1
12	234	122	95	2.9	3.2	5.0
	247	101	20	3.0	3.4	5.4

SUMMARY AND CONCLUSIONS

The cross-measure borehole technique is an effective method of controlling methane in gobs in the Lower Kittanning Coalbed. About 71 pct of the methane produced by the longwall mining operation was captured by the cross-measure boreholes.

Interference tests and measurements of methane flows in return air indicate that borehole spacing should be limited to 200 ft (61 m) except on about the first 600 ft (183 m) of the longwall, where spacing should be reduced to 100 ft (30 m). More boreholes are necessary near the start of the longwall to capture the large quantities of methane that are released when the first large roof fall occurs and to prevent it from overloading the return air system.

About 75 pct of the methane in the gob emanates from fractured roof strata near the face. Prolonged idle periods showed that low methane concentrations in the gob located over 2,000 ft (610 m) from the face increase to above 90 pct after mining resumes.

Comparisons between measured and calculated gas pressure differentials in boreholes indicate that gob gas enters the boreholes close to the pillar line, which is about 140 ft (43 m) from the collar of the borehole. The remainder of the borehole is nonproductive. Reducing borehole length from 280 to 140 ft (85 to 43 m) will lower drilling cost per longwall by about $8,000 provided the shorter boreholes are as effective as the longer boreholes. Additional experimentation is necessary to verify these calculations.

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