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# REMOVING METHANE (DEGASIFICATION) FROM THE PITTSBURGH COALBED IN NORTHERN WEST VIRGINIA

By W. M. Merritts, W. N. Poundstone, and B. A. Light

UNITED STATES DEPARTMENT OF THE INTERIOR

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# PREFACE

Explosions caused by ignitions of methane accumulations in coal mines have resulted in loss of life and property. In gaseous mines, methane accumulations can be anticipated by periodically checking the ventilating air. Possibly, many explosions may have been prevented by stopping mining operations whenever large methane emissions have been encountered and by allowing the ventilating air to dilute the gas. Stopping operations, however, results in loss of time and increased production costs.

As the more accessible high-quality coalbeds become depleted, and coal must be obtained from the deeper and usually more gaseous coalbeds, the methane hazard encountered during mining probably will increase. Also, the mining industry undoubtedly will expand the use of continuous-mining equipment to recover these coals. Since most gaseous coals emit more methane when they are reduced in size, the equipment and mining methods used are expected to contribute further to methane emission problems. Therefore, to continue capacity production, techniques must be developed to degasify these coalbeds before and during mining operations.

In the United States, several techniques have been used to remove methane from coalbeds, such as drainage by free flow and by vacuum pumping through vertical drillholes from the surface; free-flow drainage from horizontal holes in the coalbed; and free flow from holes drilled into the mine roof and mine floor.

The Bureau of Mines, reviewing the methane problem with coal-mining officials, learned that faces and ribs of entries advancing into virgin coal emit more gas than those of other mine workings. Further, ribs of the outside entries emit more gas than inside entries intersected by crosscuts, and continue to give off gas as the faces advance.

Based upon earlier tests that were conducted to allay coal dust, it appeared possible that methane could be removed from coalbeds by infusing water into holes drilled in the advancing faces. If the process proves successful, hazards created by methane accumulations may be reduced, and a reduction in dust at the working face may also be expected.

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# REMOVING METHANE (DEGASIFICATION) FROM THE PITTSBURGH COALBED IN NORTHERN WEST VIRGINIA[1]

by

W. M. Merritts,[2] W. N. Poundstone,[3] and B. A. Light[4]

## SUMMARY AND INTRODUCTION

A joint investigation by the Bureau of Mines and the Christopher Coal Co. at the Humphrey No. 7 mine, operating in the Pittsburgh coalbed in northern West Virginia, was undertaken to gain more insight concerning the hazardous emission of methane gas in mining. This report describes the equipment, procedure, and results.

Horizontal bleeder holes drilled in the faces drained large quantities of methane, eliminating downtime of mining equipment. Also, larger quantities of methane were removed by forcing 14 to 25 g.p.m. water at 25 to 200 p.s.i.[5] pressure into the bleeder holes. In one infusion test a fluorescein dye was added to the infusion water; in later mining operations, the infusion water was traced for a distance of 1,500 feet. With vacuum pump applied to the horizontal hole the gas-flow rate increased, and the methane content decreased.

Tests indicated that methane and water infused in bleeder holes traveled along the bedding planes of the Pittsburgh coalbed at a faster rate than across the planes.

Methane associated with coalbeds is produced by the slow decomposition of carbonaceous material in the absence of air and the presence of water. It is lighter than air and, depending on its concentration, forms an inflammable or explosive mixture with air. It is believed that methane is entrapped in and around the pores of the coal and adjacent strata--often under great pressure. In many cases where the strata have been disturbed by geologic movements the

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[1] Work on manuscript completed September 1961.

[2] Mining methods research engineer, Coal Mining Research Center, Bureau of Mines, Pittsburgh, Pa.

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[4] Project engineer, Humphrey No. 7 mine, Christopher Coal Co., Osage, W. Va.

[5] All pressures given throughout this report are gage pressures.

gas has escaped from the coalbeds and is confined in pockets and void spaces in the overlying strata--usually under high pressures.

Gas emission during mining is neither regular nor continuous but varies with the rate of coal extraction and conditions existing within the strata. In general, more methane is liberated during rapid extraction of coal, possibly by opening new gas feeders into the working faces. In localities where methane existed under considerable pressure in crevices and voids in the strata, dangerous falls of roof and coal have occurred accompanied by large gas outbursts.

Methane emission into mine workings and subsequent ignition have caused many coal-mine explosions, resulting in loss of life and destruction of property. To minimize this hazard, elaborate ventilating systems are being employed to dilute the methane at the working faces and remove the harmless mixture from the mine. In addition, permissible explosives and explosion-proof mining equipment are being used to reduce further the possibility of igniting gas accumulations.

Before the advent of continuous mining, few American mines had gas emission problems that could not be solved by increasing the volume of ventilating air. In exceptionally gaseous mines, large coal areas were developed and allowed to drain for long periods before mining. The widespread use of continuous-mining machines has resulted in a more rapid rate of coal extraction from fewer working places, which, in turn, has resulted in an increased rate of methane liberation. Often, it is not possible to increase the volume and velocity of the ventilating air necessary to dilute the gas without creating another safety hazard--that of suspending dangerous concentrations of coal dust. In the severest cases, mining is stopped periodically so that the ventilating air can dilute the methane concentration. Thus, the inability to maintain a safe mine atmosphere can place a severe limitation on the highly productive machines.

A safe mine atmosphere could be maintained, however, by approaching the problem in another manner. Instead of allowing the methane to drain into the mine atmosphere during mining, it could be removed before mining, thus avoiding the necessity of large volumes of ventilating air.

Degasification, the extraction of methane from coal-bearing formations before and during mining, has been well received in the United Kingdom, Europe, and other major coal-producing countries. A survey of foreign literature shows that the techniques of draining methane from coal-bearing formations has been thoroughly investigated and has proven to be both practical and economical. In a recent report,[6] it was stated that 135 collieries removed more than 17 billion cubic feet of methane in 1958 for use as town gas, for automotive and gas-turbine fuel, and for steam generation. The various degasification techniques may be classified generally as:

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[6] Boyd, W. T., and Perry, Harry, Degasification of Coalbeds in Advance of Mining: Pres. 47th Nat. Safety Cong. and Exposition, Chicago, Ill., Oct. 20, 1959, Trans. Nat. Safety Cong., vol. 7, 1959, pp. 21-34.

1. Cross-measure borehole method: Boreholes are drilled through overlying beds or into the floor strata from the working areas.

2. The Hirschbach method: Superjacent entries are developed over the working areas.

3. Packed-cavity method: Drainage of methane is controlled as mining progresses.

4. Surface and underground borehole drainage.

5. Drainage from virgin coalbeds by collecting gas from pockets.

The cross-measure borehole method is the most widely used for removing methane from the coal formations. In this method, the gas is collected by free flow and vacuum pumping from boreholes and is piped to the surface.

Analysis of the literature indicates that European degasification techniques would not be adaptable to existing natural conditions or mining methods used by the U. S. coal industry. Longwall mining is practiced extensively in Europe, while room-and-pillar mining predominates in the United States. In longwall mining the roof subsides as mining progresses, resulting abutment pressures at and ahead of the longwall face breaking and cracking the overlying strata. In room-and-pillar mining, the roof is supported and generally remains undisturbed until the pillars are removed during retreat mining. The effect of the longwall-mining method on methane liberation is that when the pressure on the longwall face is relieved, much of the gas in the coalbed is liberated and is trapped in the overlying strata. In room-and-pillar mining the overburden pressure is not relieved and the gas enters the mine workings or remains in the coal pillars and immediate adjacent strata. Other differences in mining conditions and practices such as the number beds worked simultaneously, interval between workable coalbeds, attitude of the beds, and the character of the adjacent strata have a marked effect on the success of degasification techniques.

Increased use of continuous-mining equipment and the encouraging results obtained by the degasification techniques being used in foreign countries prompted the Bureau of Mines to initiate laboratory and field studies to determine the feasibility of degasifying coalbeds before and during mining and to develop techniques applicable to U. S. mining conditions and practices.

The laboratory phase of the work was to determine the sorption characteristics of coal, while the field investigations were to study migration of methane in the coalbed, use of surface boreholes and long underground horizontal drill holes in advance of mining, and water-infusion technique for degasification.

## ACKNOWLEDGMENTS

The cooperation and assistance of the late G. R. Spindler, director, and G. W. Campbell, oil and gas research engineer, School of Mines, West Virginia University, is gratefully acknowledged.

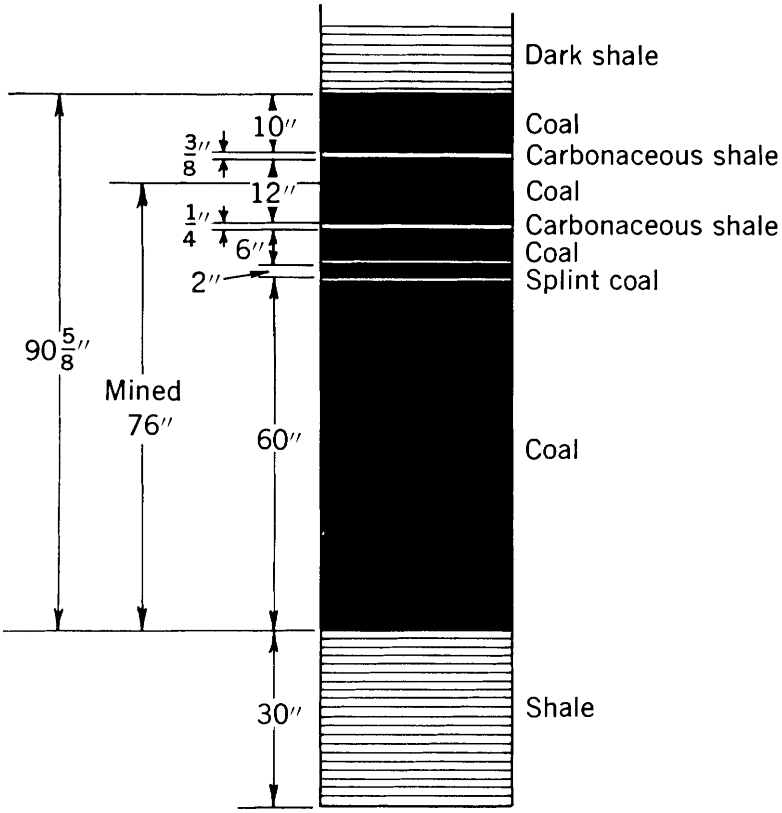

FIGURE 1. - Section of Pittsburgh Coalbed of Humphrey No. 7 Mine.

## TEST SITE

### Location

The degasification experiments were conducted at the Humphrey No. 7 mine, Christopher Coal Co., near Osage, Monongalia County, W. Va., operating in the Pittsburgh coalbed.

### Coalbed

The Pittsburgh coalbed is the basal stratum of the Monongahela series of the Pennsylvanian period. This series is composed chiefly of limestones, interstratified sandstones, shales, and coal; of these the Pittsburgh coalbed is of greatest economic importance. Figure 1 shows a columnar section of the immediate roof, the coalbed, and the bottom. The coalbed outcrops along the Monongahela River and dips gradually N. 75° W. The westward extension of the bed from the area contiguous to the Monongahela River has been mined extensively and constitutes the principal reserves which are below drainage--depth of cover increasing away from the river.

The coalbed in this area averages 90 inches in thickness and has a blocky structure, resulting from well-defined butt and face cleats at approximately right angles to each other. About 5 feet from the bottom, 2 inches of splinty coal occurs, and two shale partings just above the splinty coal are known locally as the 6-foot and 7-foot binders. The coalbed is intersected by numerous clay veins of various thickness, which may extend over large areas.

Immediately overlying the coalbed is a foot or more of shale that disintegrates readily upon exposure to the mine atmosphere. To protect this immediate roof 1 foot or more of top coal is left during mining.

A typical analysis of coal at this mine on the as-received basis is as follows:

| | | |
|---|---|---|
| Moisture | percent | 3.2 |
| Volatile matter | do. | 37.0 |
| Fixed carbon | do. | 53.2 |
| Ash | do. | 6.6 |
| Sulfur | do. | 1.45 |
| Calorific value, B.t.u. per pound | | 14,000 |

## Mine Development

The coalbed was entered through two drifts and four shafts--the latter ranging from 325 to 568 feet in depth. A multiple-entry block system was used to develop the coalbed. The main entries were developed in sets of nine or more and the panel entries in sets of seven or more; all were driven 14 to 17 feet in width on 50- or 70-foot centers. Crosscuts were driven on approximately 80-foot centers. Pillars were recovered on retreat by the pocket-and-fender method. Figure 2 shows the plan of developing the main and 4 and 5 South entry groups; contour lines show the elevation of the bed.

One ripper-type continuous-mining machine was used in each set of entries, and the coal was first discharged onto the mine floor and then loaded into shuttle cars by a conventional loading machine. The shuttle cars discharged the coal onto an extensible-belt intermediate-haulage system, which, in turn, discharged it into mine cars for haulage to the surface.

Roof bolting was the predominant roof support method, but in areas of dangerous roof conditions the roof bolts were supplemented with crossbars and posts. Yielding steel arch supports were used along main haulage roads that had heavy or squeezing roof.

The mine was classed as gassy by the West Virginia Department of Mines and was liberating about 8 million cubic feet of methane per day. About 915,000 cubic feet of air per minute was circulated through the mine by three exhaust fans. A split system of ventilation, using noncombustible permanent stoppings, overcasts, and regulators, coursed the air to the active sections of the mine. Intake air in each set of developing entries was coursed through the center entries, split near the active faces, and returned through the outside entries.

Air currents were directed to the working faces by means of brattice cloth faced with a thin sheet of plastic on the higher pressure side of the cloth to minimize leakage. By installing the line brattice on the return side of a working place, mining equipment could travel to and from the working face without passing under a line brattice or check curtain. Figure 3 shows the ventilating system and the general arrangement of equipment used in development. Figure 4 shows the sequence of advancing a set of seven entries. By following this sequence of mining it was possible to advance all working places under positive ventilation.

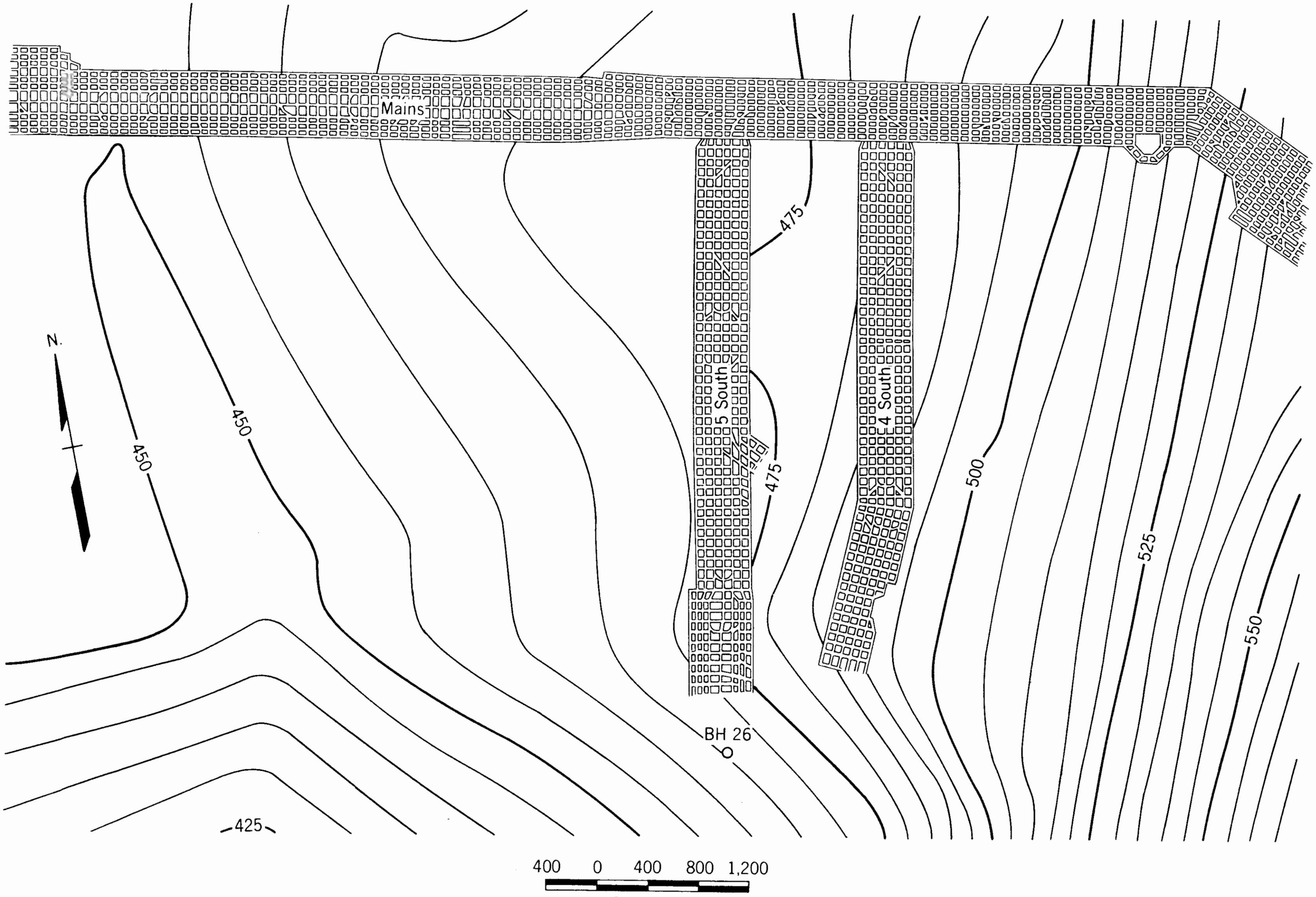

FIGURE 2. - Plan of Developing Entries in Mine and Contours of Coalbed.

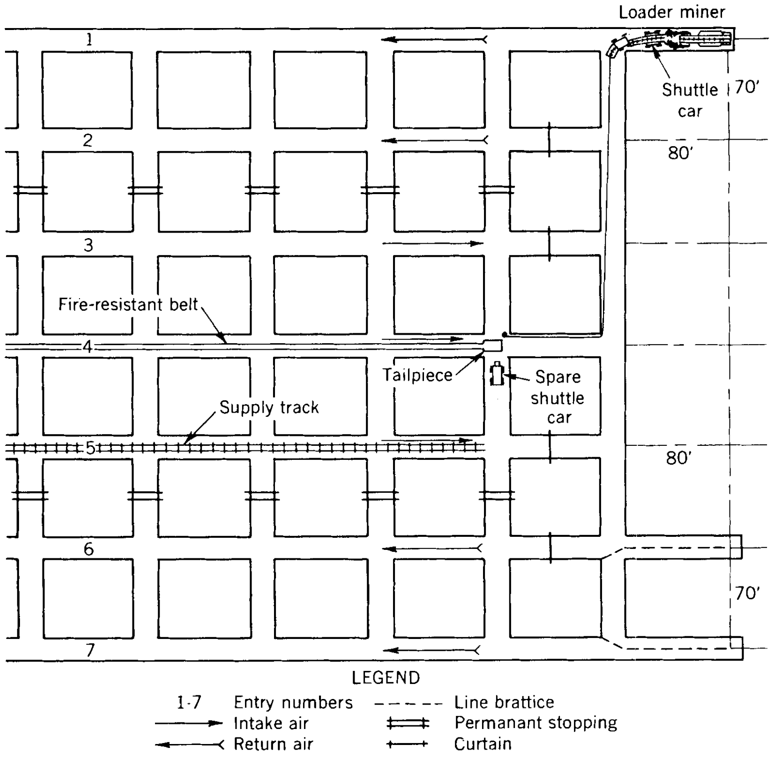

FIGURE 3. - Face Ventilation System and General Arrangement of Mining Equipment.

## PREVIOUS DEGASIFICATION EXPERIMENTS

As early as 1952, the School of Mines and the Engineering Experiment Station of West Virginia University and the Christopher Coal Co. started experimental degasification work at an adjoining mine. The purpose was to investigate the characteristics of the Pittsburgh coalbed with respect to the liberation of methane and to study various techniques for degasifying the coalbed in advance of and during mining. This early work centered mainly around the use of vertical boreholes for methane drainage. The findings were that this method had only limited application, unless the drainage zone could be extended by hydraulic fracturing.[7]

## RECENT DEGASIFICATION EXPERIMENTS

### Horizontal Drill Holes

Following these early experiments, the company began a study using horizontal drill holes in advance of the working faces for controlling methane drainage. General test procedures followed, and some early results have been published.[8] [9] As the drilling methods for horizontal free-flow holes and those used for water-infusion purposes are similar, only a brief description of horizontal-drill-hole procedure and results will be included in this report.

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[7] Spindler, G. R., Degasification of Coal Seams: Coal Mine Modernization, Am. Min. Cong., 1953, pp. 206-220; West Virginia Eng. Exp. Sta. Tech. Paper 46, 1953, 15 pp.

[8] Spindler, G. R., and Poundstone, W. N., Experimental Work in the Degasification of the Pittsburgh Coal Seam by Horizontal and Vertical Drilling: Preprint 60-F106 of paper pres. Ann. Meeting AIME, New York, February 1960, 28 pp.

[9] Light, B. A., Recent Experiments in Degasification of the Pittsburgh Coal Seam in Northern West Virginia: Paper pre. 50th Conv. Mine Inspectors' Inst. of Am., Louisville, Ky., June 13-15, 1961, 16 pp.

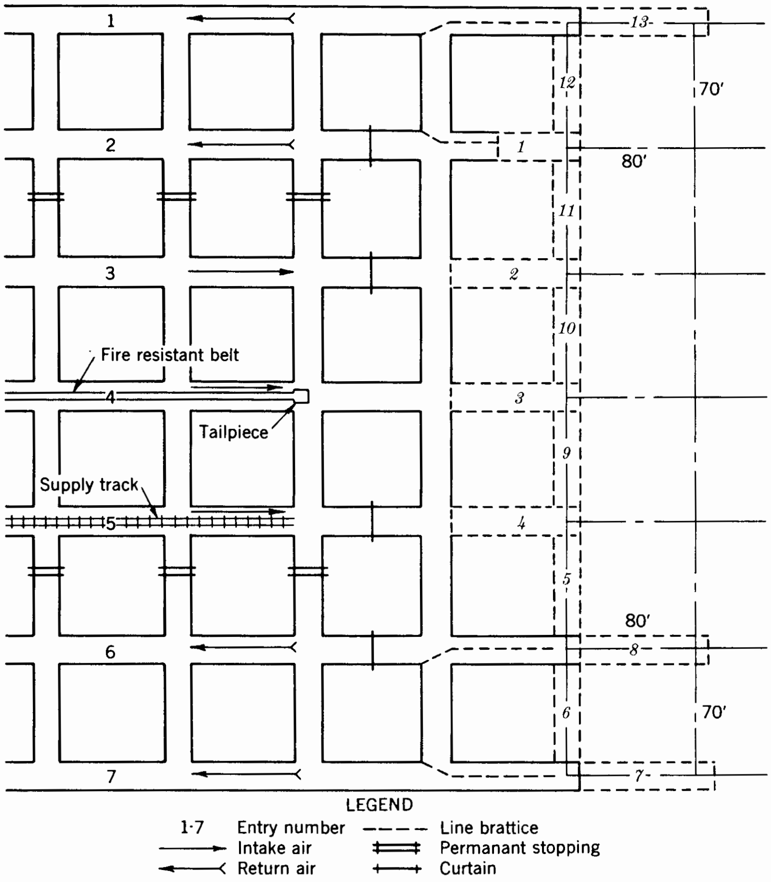

FIGURE 4. - Sequence of Cuts to Advance a Set of Seven Entries.

## Equipment

The principal equipment for this work was a handheld electric drill capable of drilling long holes. The drill stem was a fluted auger having a 2-inch-diameter double-prong bit and was followed by hollow 10-foot sections through which water flowed to flush cuttings from the holes.

## Procedure

In developing groups of entries in virgin coal, company engineers determined that solid ribs of the outside entries liberated more methane than ribs of the other entries--the greatest emission was from the faces of the two outside entries. The gas concentration occasionally was so high that mining had to be interrupted until the gas was diluted to a safe level by the ventilating air. It also was proven that these solid ribs continued to bleed gas much longer than the pillar ribs of the outside entries.

Figure 5 illustrates the plan of spacing the bleeder holes. Most of the holes were 100 to 150 feet deep, although a few were 230 feet deep. They were so collared that when the connecting crosscuts between entries were completed and line brattices placed in the outside entries, gas would be liberated directly into the return air. As each entry adjacent to the virgin coal was advanced far enough for the succeeding crosscut, another bleeder hole was drilled in each outside entry. The holes were 2 inches in diameter although some holes up to 4 inches in diameter were tested. Horizontal holes at various angles to the entry were drilled as well as several in the roof and bottom.

Drilling was done on the intake air through a prepared opening in the line brattice, and therefore all gas emitted during drilling was released into the return-air current. As a precaution, the amount of air passing the drill hole was increased during drilling to keep the concentration low in the event of a sudden outburst of gas. Gas pressures, flows, and methane concentrations were measured repeatedly to record the production of gas from the holes.

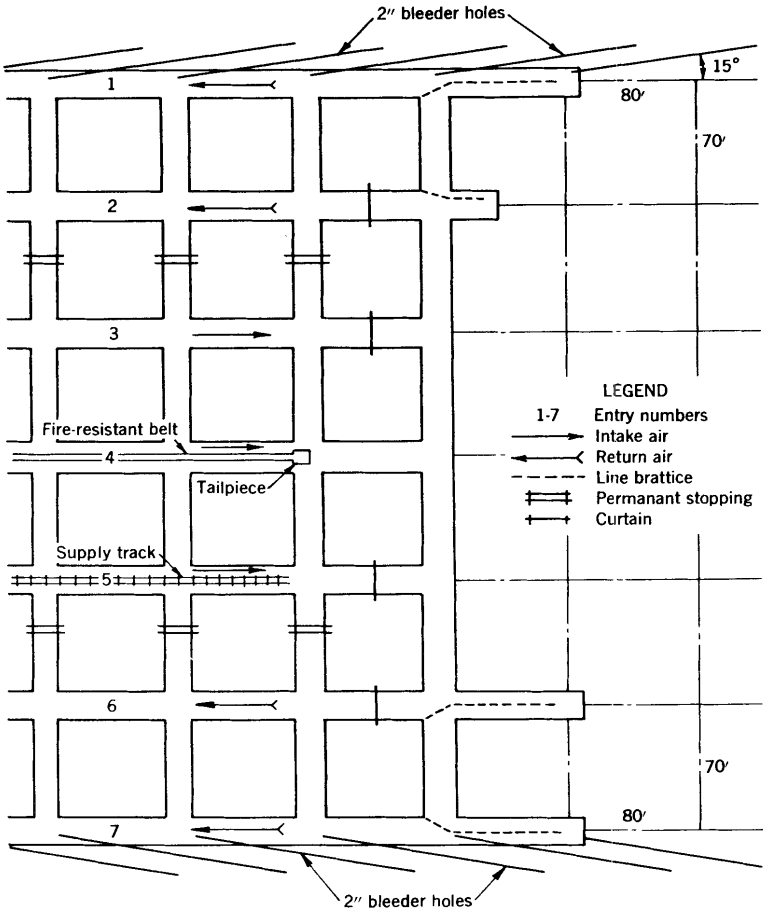

FIGURE 5. - Spacing of 2-Inch Bleeder Holes in Solid Ribs.

## Results of Degasification With Horizontal Boreholes

Before January 1960, 240 horizontal boreholes were drilled in developing 14,000 feet of main- and cross-entry sets. Observations made during and after drilling indicated that the holes could be spaced further apart and still obtain satisfactory results. As a result, from January to September 1960, only 24 rib-line holes were drilled to develop 8,000 feet of entry.

As might have been expected, there were variations in: (1) Drilling time; (2) methane emission from the holes; (3) shut-in pressures; and (4) total time holes emitted gas.

During the first 5 feet of drilling little gas was encountered, but the emission increased generally with hole depth. Table 1 summarizes the actual drilling time and the amount of methane released during drilling of a hole in No. 1, Main. The face area was 98 square feet, and from the velocities of the ventilation current measured at intervals, the air volumes were computed. While air velocities were being measured, readings were being taken with a Riken gas indicator to determine the percent of methane in the ventilating air from which the cubic feet of methane was computed. In these calculations it was assumed that increases in methane emission were entirely the result of drilling and that the volume of intake air, percent methane, and volume of methane remained substantially constant between measurements.

Practically all holes emitted gas during drilling and continued to do so for lengths of time varying up to several months. Shortly after a hole was completed, the velocity and volume of gas issuing from it was measured, and the methane concentration was determined from bottle samples and checked by Riken readings. Shut-in pressure also was determined.

TABLE 1. - Cumulative actual drilling time and methane released during drilling of a bleeder hole at face of No. 1 Main entry

| Cumulative drilling time, minutes | Cumulative advance, feet | Intake air, c.f.m. | Return air, methane: Percent | Return air, methane: C.f.m. | Remarks |
|---|---|---|---|---|---|
| - | - | 39,200 | 0.20 | 78 | Before drilling started. |
| 3 | 10 | - | - | - | Add 2d stem. |
| 5 | - | 39,200 | .22 | 86 | Drilling. |
| 8 | 20 | - | - | - | Add 3d stem. |
| 9 | - | - | - | - | Drilling. |
| 10 | 30 | - | - | - | Add 4th stem. |
| 13 | - | - | - | - | Drilling. |
| 16 | 40 | 42,200 | .22 | 93 | Add 5th stem. |
| 17 | - | - | - | - | Drilling. |
| 19 | 50 | - | - | - | Add 6th stem. |
| 21 | - | - | - | - | Drilling. |
| 22 | 60 | - | - | - | Add 7th stem. |
| 23 | - | - | - | - | Drilling. |
| 25 | 70 | 49,000 | .21 | 103 | Add 8th stem. |
| 26 | - | - | - | - | Drilling. |
| 28 | 80 | - | - | - | Add 9th stem. |
| 29 | - | - | - | - | Drilling. |
| 32 | 90 | - | - | - | Add 10th stem. |
| 34 | - | - | - | - | Drilling. |
| 36 | 100 | - | - | - | Add 11th stem. |
| 39 | 110 | - | - | - | Finish drilling. |
| 46 | 110 | 50,000 | .23 | 115 | 7 minutes after completion. |

Table 2 summarizes free-flow drainage data from horizontal bleeder holes. Unless otherwise shown, all holes were drilled 15° from the direction of entry advance. On completion of the 70-foot bleeder hole in No. 1 entry, 5 South, the velocity of the gas was 8,900 f.p.m. The hole emitted 193 cubic feet of methane per minute with a shut-in pressure of 60 p.s.i., despite a considerable leakage through cracks in the coal at the collar of the hole.

Although the volume of methane produced from bleeder holes was not uniform, the volumes usually were greater after penetrating clay veins.

When a long hole was sealed, and provided no mining was done in the immediate area, the time required for the gas to reach maximum shut-in pressure ranged from several minutes to several weeks. After maximum pressure was reached it was possible to open the seal, bleed off the gas, reseal the hole, and regain the previous shut-in pressure. A pressure gage connected to the seal in the hole fluctuated continuously until the maximum pressure was reached; these fluctuations were greater with deeper seals.

TABLE 2. - Summary of free-flow drainage data from horizontal bleeder holes

| Location of drill hole | Depth, feet | Location of face, inby drill hole, feet | Time interval after drilling, days | Velocity of gas, f.p.m. | Shut-in pressure, p.s.i. | Methane | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Volume, c.f.m. | Purity, percent | |
| No. 1, 3 West | 180 | - | - | 6,000 | 40 | 130 | 98 | Penetrated a 2-inch clay vein. |
| | | 150 | 14 | 3,000 | 18 | 65 | 98 | |
| | | 350 | 30 | 1,100 | 14 | 24 | 98 | |
| | | 500 | 38 | 650 | 8 | 14 | 98 | |
| | | 650 | 43 | 500 | 5 | 11 | 98 | |
| No. 6, 3 West | 91 | - | - | 4,000 | 31 | 87 | 98 | Penetrated three 2-inch clay veins. |
| | | 100 | 10 | 1,500 | 16 | 33 | 98 | |
| | | 180 | 16 | 950 | 12 | 21 | 98 | |
| | | 250 | 23 | 450 | 4 | 10 | 98 | |
| No. 1, 5 South | [1]70 | - | - | 8,900 | 60 | 193 | 96 | Drilled into 12-foot-thick clay vein; considerable leakage around collar of hole. |
| | | - | 4 | 6,000 | 60 | 131 | 92 | |
| | | 39 | 39 | 3,000 | 16 | 65 | 92 | |
| | | 140 | 76 | 200 | 6 | 4 | 97 | |
| | | 1,340 | 256 | 200 | 2 | 4 | 92 | |
| Do....... | [2]120 | - | - | 1,500 | 4 | 33 | 85 | Hole drilled 39 feet inby 12-foot-thick-clay vein. |
| | | - | 39 | 150 | 2 | 3 | 97 | |
| No. 1, Mains.. | 110 | - | - | 2,400 | 6 | 52 | 70 | - |
| | | - | .6 | 500 | 2 | 11 | 86 | |
| No. 9, Mains.. | 100 | - | - | 950 | 15 | 15 | 69 | - |
| | | - | .5 | 400 | 2 | 9 | 83 | |
| Do....... | 30 | - | - | 1,900 | 4 | 41 | 63 | Inby end of hole against roof to drain water from top of bed. |
| | | - | .5 | 200 | 1 | 4 | 72 | |

[1] Drilled at an angle of 45° to direction of entry.
[2] Drilled at an angle of 5° to direction of entry.

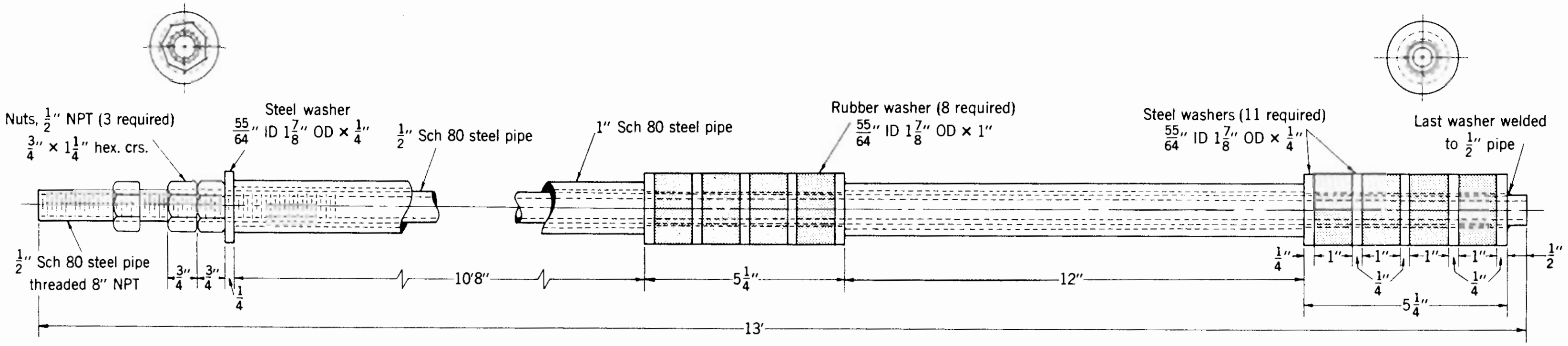

FIGURE 6. - Water-Infusion Seal.

## Water Infusion of Horizontal Drill Holes

During some earlier experimental work by the Bureau in water infusion to allay dust, it was indicated that the infusion contributed to partial degasification of coal pillars.[9] Because of these results, it was decided to determine the effect of water infusion on the release of gas from solid coal.

### Equipment Used

#### Pump

The pump was a triplex-plunger type, capable of producing a maximum of 600 p.s.i. and delivering as much as 15 g.p.m. of water.

Figure 6 gives details of the water-infusion seal. When it is inserted in a drill hole and the inby nut is tightened, the 1-inch pipe is moved toward the collar of the hole. This compresses the rubber washers, causes them to expand outward and grip the wall of the hole firmly, and makes a watertight seal. The outby nuts act as jamnuts to keep the 1/2-inch pipe from turning when the inby nut is turned to release the rubber washers and to remove the seal.

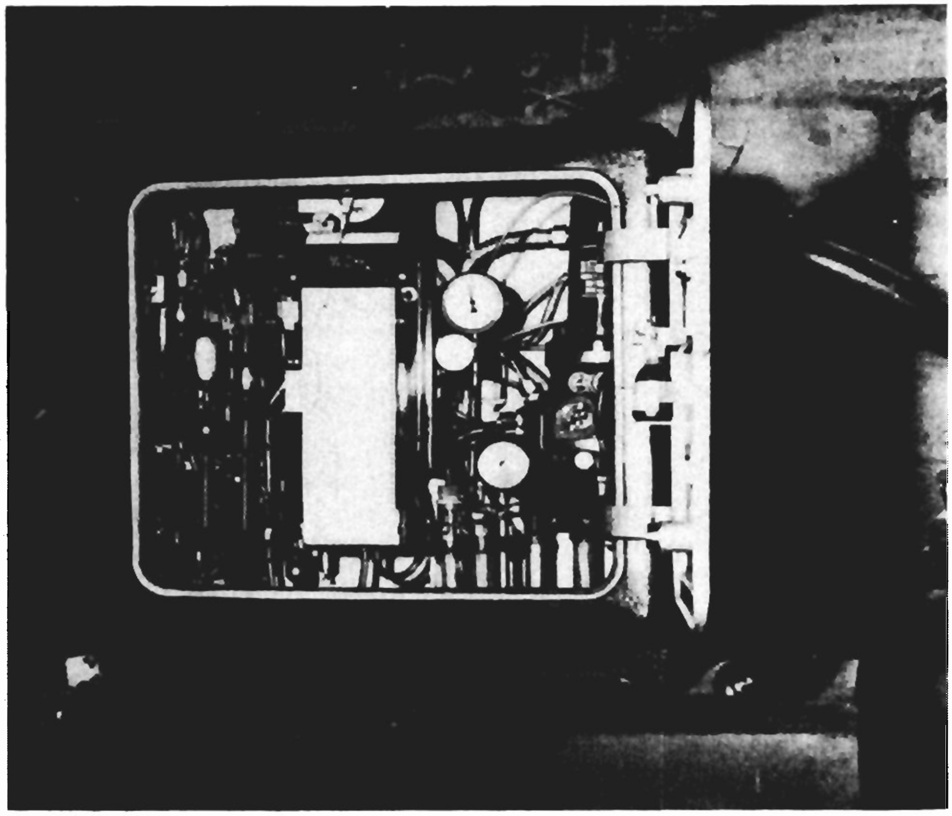

FIGURE 7. - Maihok Mono-Methane Analyzer and Recorder.

#### Continuous Methane Recorders

The company had a German Maihak Mono-Methane unit that required compressed air for operation. (See fig. 7.) This recorder was used almost exclusively in the water-infusion experiments. By checking the record periodically

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[9] Jackson, E. O., and Merritts, W. M., Water Infusion of Coal Pillars Before Mining, Kenilworth Mine, Independent Coal & Coke Co., Kenilworth, Utah: Bureau of Mines Rept. of Investigations 4836, 1951, 25 pp.

with analyses of bottle samples of gas taken simultaneously with samples analyzed by the instrument, the accuracy was found to be satisfactory. Technically this unit is not a continuous recorder because sampling, analyzing, and recording a single sample requires a minimum of 3 minutes, and thus, any changes in gas emission during the interval cannot be recorded. During most of the study no other portable continuous methane recorder was available either in the United States or in foreign countries. However, through a joint effort by the Combustion Section, Pittsburgh Coal Research Center, and the Electrical-Mechanical Testing Section, Health and Safety Research Center, Pittsburgh, Pa., a continuous methane analyzer and recorder was designed and built. (See fig. 8.)

The unit is battery operated and obtains air samples through a flexible tube leading from the analyzer to the sampling area. Samples are pulled through the tubing by a vacuum aspirator operated by controlled release of Freon gas from a storage tank. When the aspirator is operating, analyzing and recording are continuous except during the time needed for the first sample to reach the analyzer.

After the unit was completed it was tested, taken underground, and put in service. With a few modifications to eliminate the effect of mine-air moisture on its accuracy, the unit was proven reliable by comparing with frequent bottle samples.

### Miscellaneous

In addition, equipment such as high-pressure water hose, plastic tubing, gages, gas and water flowmeters, a wetting agent proportioner, methane indicators and testers, oxygen and carbon dioxide analyzers, permissible flame safety lamps, barometers, thermometers, pitot tubes, psychrometers, and an ultraviolet lamp--remodeled and approved for use in a gassy mine--were used.

## Procedure

While the details of infusion procedure had to be varied to suit conditions, the general approach was as follows:

The pump was placed in an intake-air course and connected to waterlines, and 3/4-inch heavy-duty hose connected the pump discharge with the infusion equipment at the infused face. A typical arrangement of equipment is shown in figure 9 with the watermeter in the hose line leading from the infusion pump. The hose with an intervening valve and pressure gage was connected to the infusion seal. The orifice meter in the inclined pipe was sealed in a hole near the top of the coalbed to measure the flow of gas from that part of the bed during the infusion, and the flow measurements were continuously recorded. Figure 10 is a closeup of the face showing the water trap in the orifice-meter pipe, the infusion seal, and, in the upper left corner of the face, a pressure gage and pipe sealed in another hole to indicate pressure developed at that part of the coalbed by gas, water, or both during infusion of the face bleeder hole.

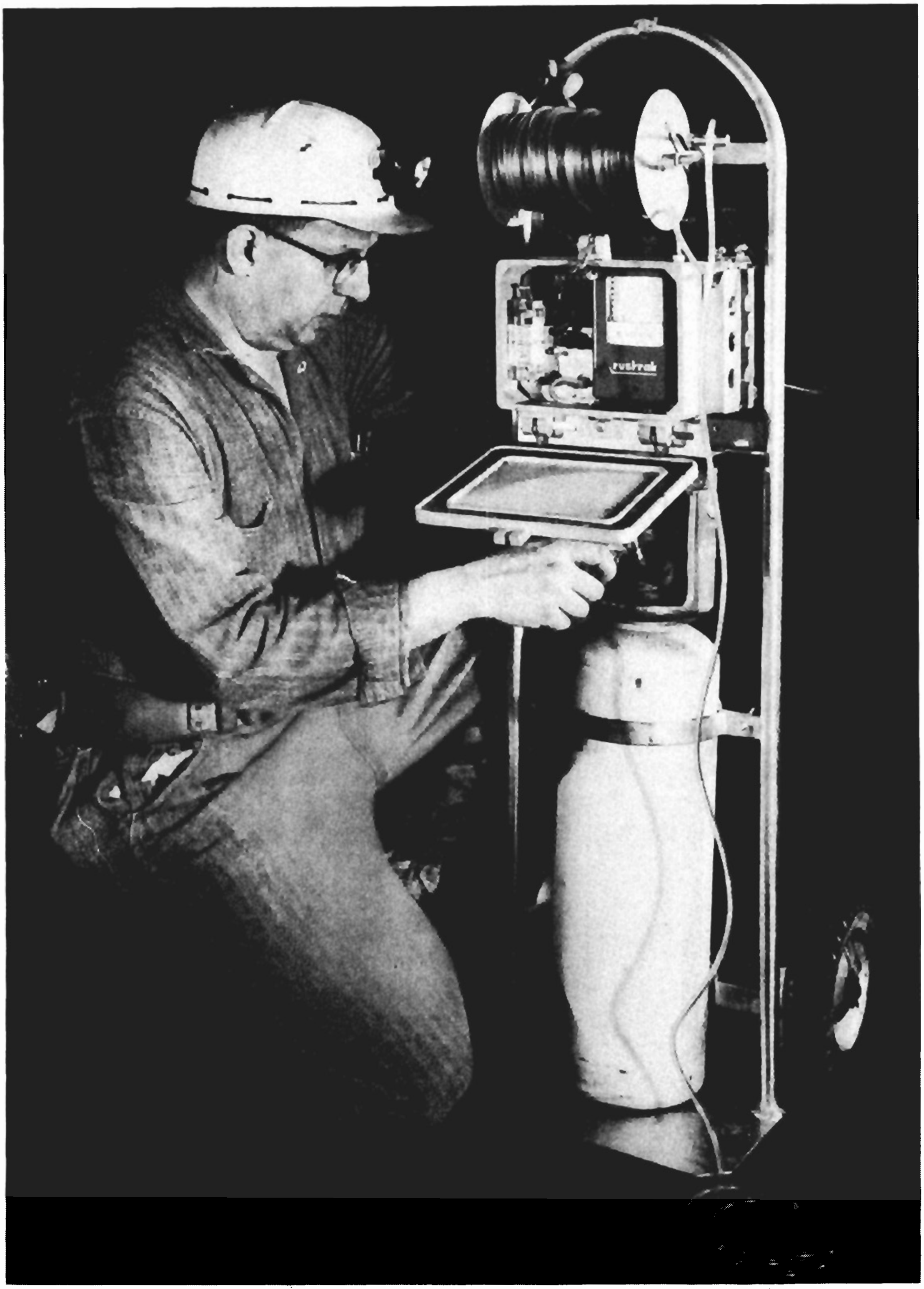


FIGURE 8. - Bureau of Mines Continuous Methane Analyzer and Recorder.

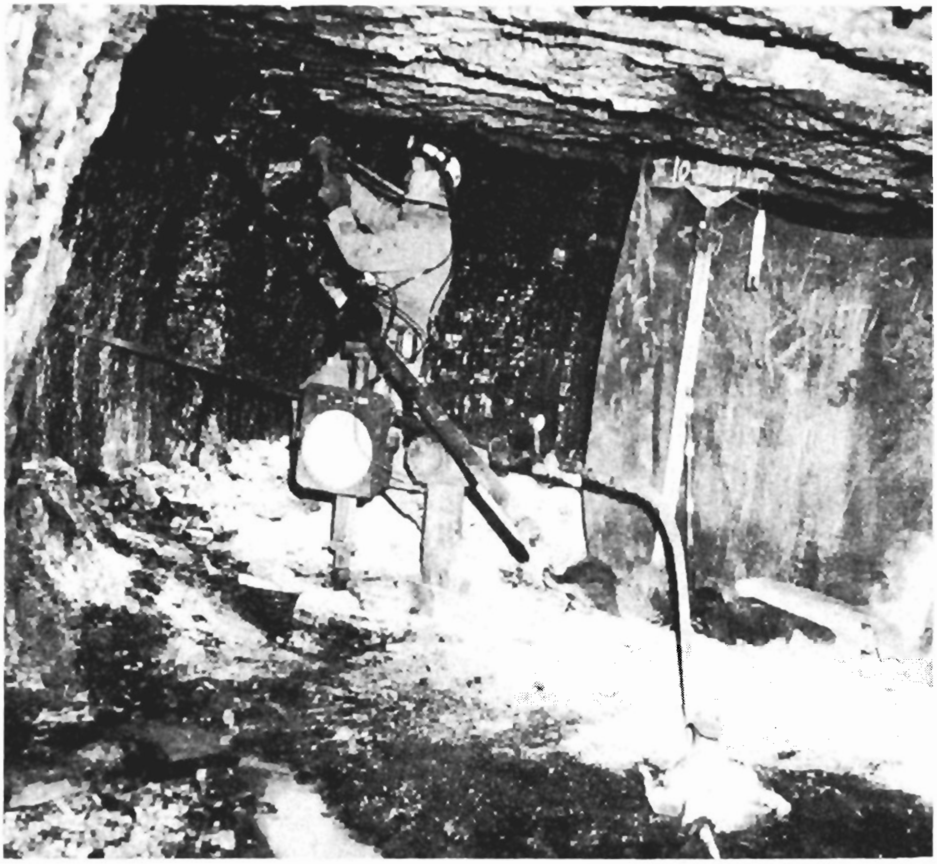


FIGURE 9. - Typical Arrangement of Infusion Equipment at Face; Sampling Air at Face-Sampling Point.

The Maihak Mono-Methane analyzer and recorder was placed in the intake outby the face with the sampling tubes to each return-air course. Riken readings or bottle samples were taken before infusions at other points in the face area to determine the normal amount of gas being emitted.

For each infusion, the pump operating time, volume of water metered, pressures developed, temperature, barometric pressure, amount of ventilating-air flow, and the methane content of air at the sampling points were measured and recorded. Bottle gas samples were taken frequently to check these readings. Water with and without a wetting agent was used in infusions. Fluorescein dye stabilized with an alkali also was added to the water, and by means of an approved ultraviolet light it was possible to identify and trace the progress of the infusion water.

During infusions, the path and distribution of the water could be traced by sweating of the coal. Small gas-water bubbles would appear on the coal surface at the face being infused and spread gradually to other adjacent faces and ribs. (See fig. 11.) Usually the seal was set 3 feet in the hole from the collar, but if the infusion water oozed too rapidly at the face being infused, the seal was reset deeper in the hole.

## Infusions in 4 South Entries

This set of entries, driven on the face cleats, had been idle 3 months before infusions were started. Methane bleeder holes already had been drilled in the solid coal at the faces of the outside entries, and these bleeder holes were used for the infusions.

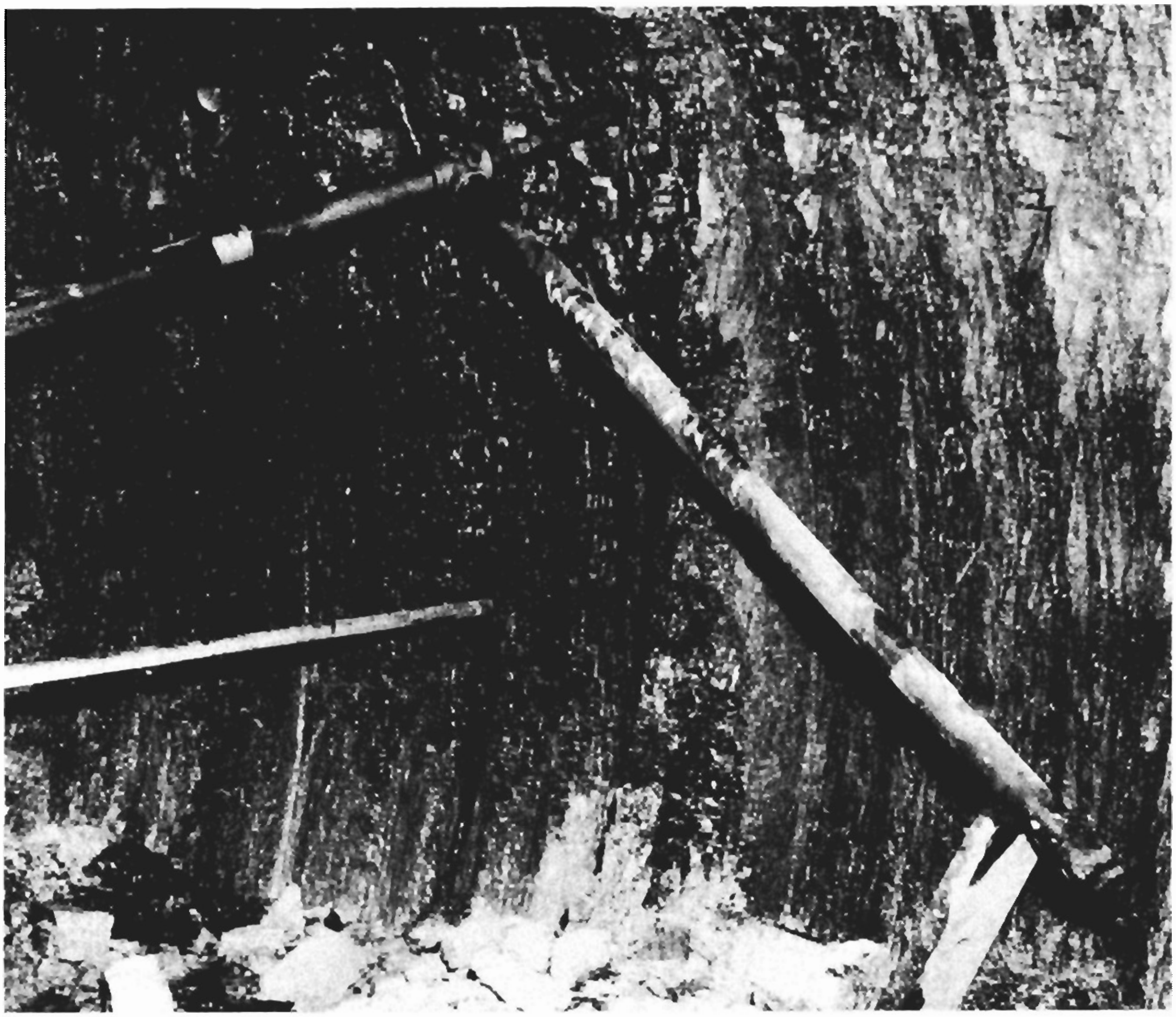


FIGURE 10. - Closeup of Orifice-Meter Piping at Face.

No. 7 Entry

Figure 12 shows the locations of the face bleeder holes, two rib bleeder holes, and three roof-bolt holes inby the last open crosscut in entry 7.

Water under pressure of 60 p.s.i. and at a rate of 15 g.p.m. was injected into hole L for several hours; within 1 hour, water seepage on the coal surface was noted. As infusion continued, the seepage extended across the entire section and along the outside ribs of entries 1 and 7. After 8 hours of water injection, the amount of methane in the immediate right return-air course decreased 28 c.f.m., but there was an increase of 84 c.f.m. in the immediate left return--a net increased release of 56 c.f.m.

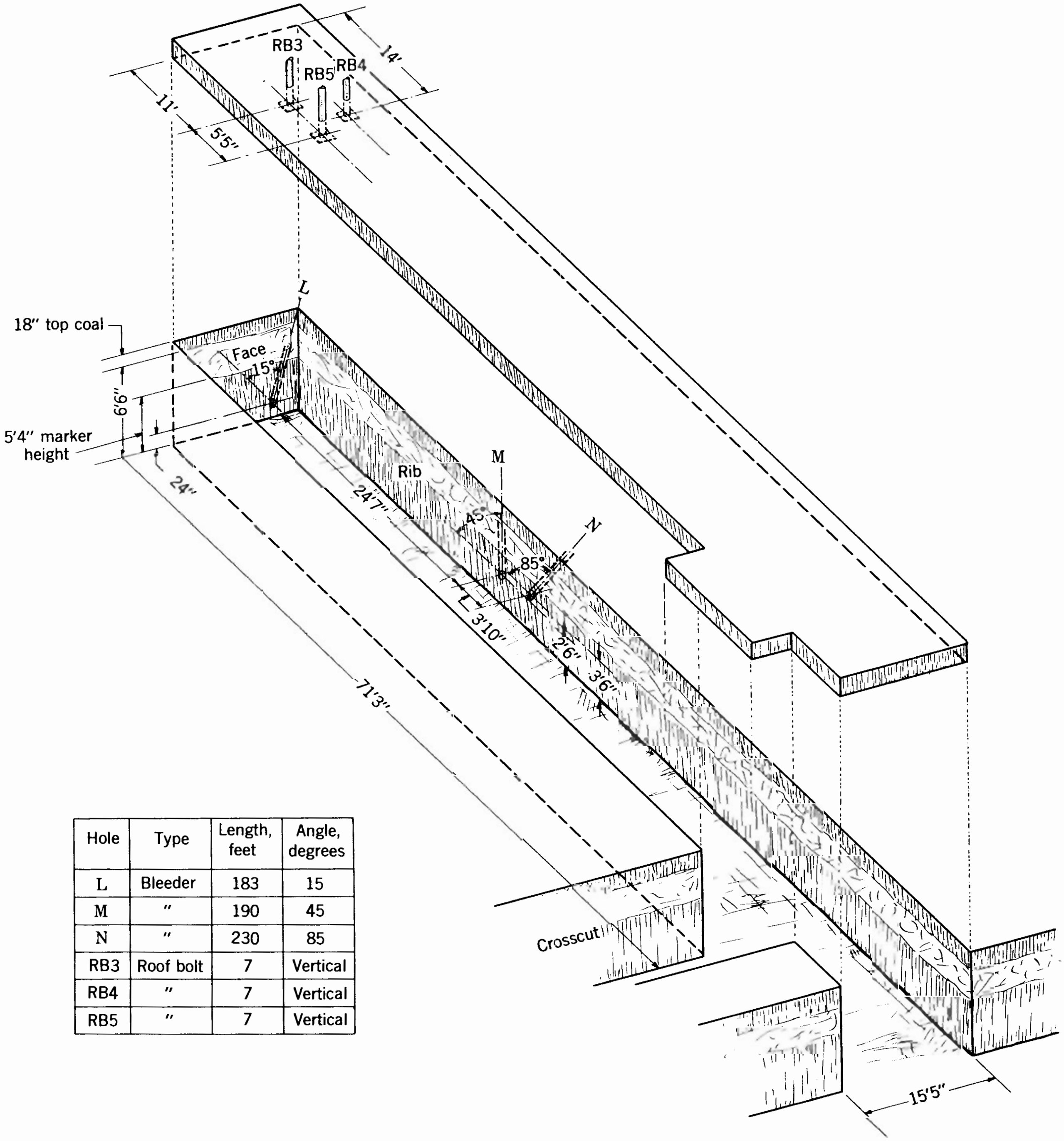
It had not been realized then that the changes in methane content of the air at the return regulators would differ from changes at the immediate

FIGURE 11. - Dark Streaks Are Water and Gas Oozing From Coal Face During Infusion.

returns. The immediate return samples accounted only for changes in methane content at the immediate face; samples taken at the return regulators included, in addition, the gas forced from the ribs outby the immediate returns. Had the methane content at the return regulators been taken during these initial infusions, they probably would have shown an increase at each return regulator.

Six additional infusions of hole L were made. The total injection time for the seven infusions was 44 hours--the longest single infusion period being 18 hours. Figure 13 shows the relationship between water pressures and hours during infusions. The maximum water pressure was 125 p.s.i., and a total of 36,400 gallons of water was injected.

During one of these infusions, water mixed with fluorescein dye traveled along the coal bedding planes 64 f.p.h. (feet per hour) and moved vertically across the bedding planes at a rate of 0.5 f.p.h.



| Hole | Type | Length, feet | Angle, degrees |
|---|---|---|---|
| L | Bleeder | 183 | 15 |
| M | " | 190 | 45 |
| N | " | 230 | 85 |
| RB3 | Roof bolt | 7 | Vertical |
| RB4 | " | 7 | Vertical |
| RB5 | " | 7 | Vertical |

FIGURE 12. - Face Area of No. 7 Entry, 4 South, During Water Infusions.

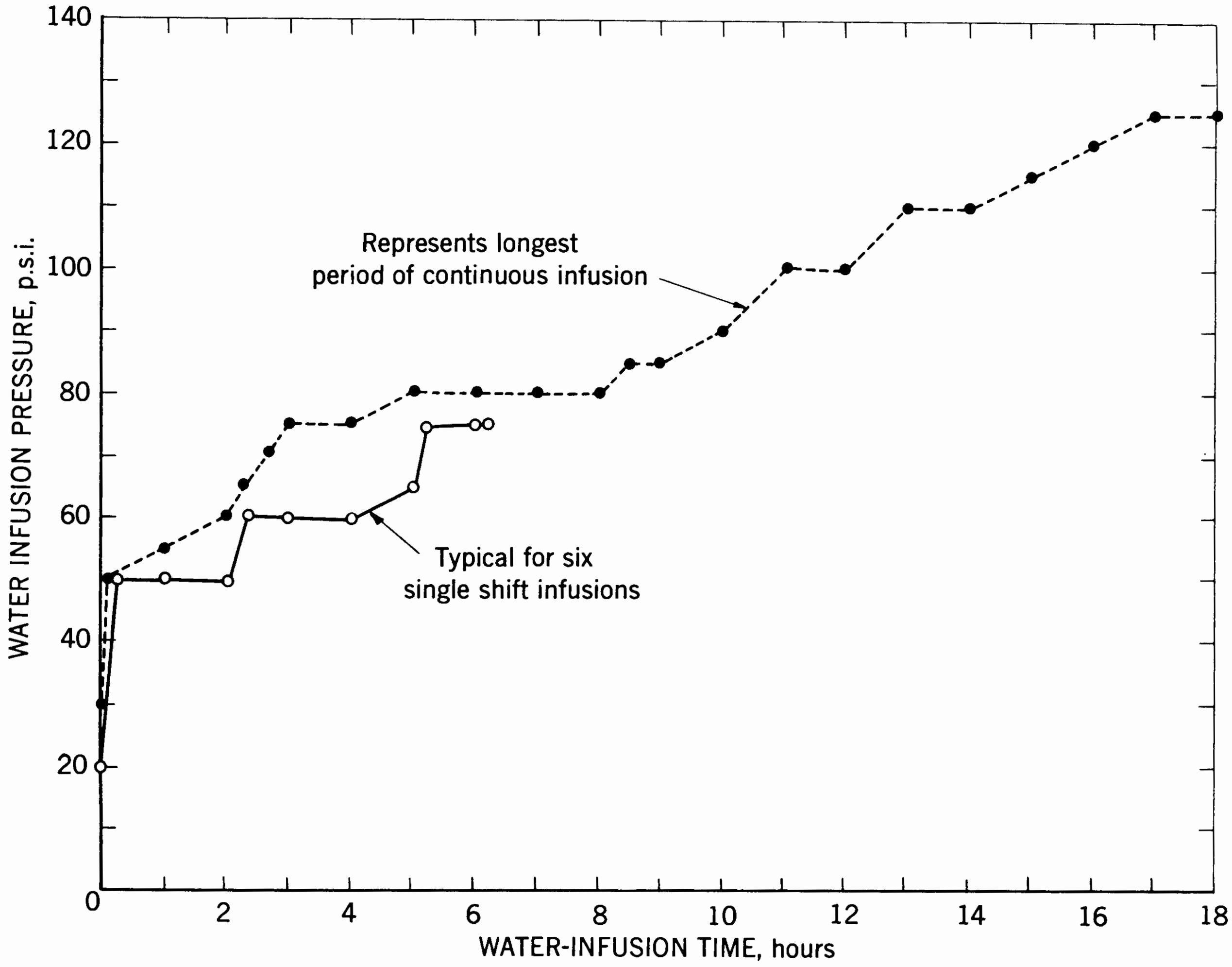


FIGURE 13. - Graph of Water-Infusion Pressure Versus Time, No. 7 Entry, 4 South.

Air measurements were made at 23 locations in the 4 South entries, as shown in figure 14. The methane content of the air was measured at each location before, during, and after infusions to determine the amount of methane released in the section. The percentage of methane in the air at locations 1 and 20 was read from the recorder charts; methane content at the other locations was taken by Riken readings or from analyses of bottle samples. Table 3 summarizes the available data regarding methane released in 4 South before, during, and after infusion into hole L in entry 7.

No. 1 Entry

Figure 15 is a sketch of the face area of No. 1 entry 4 South. Borehole C was infused six times, during which 29,880 gallons of water with dye added were injected at maximum pressure of 50 p.s.i. The longest infusion period was 11 hours. (See fig. 16.)

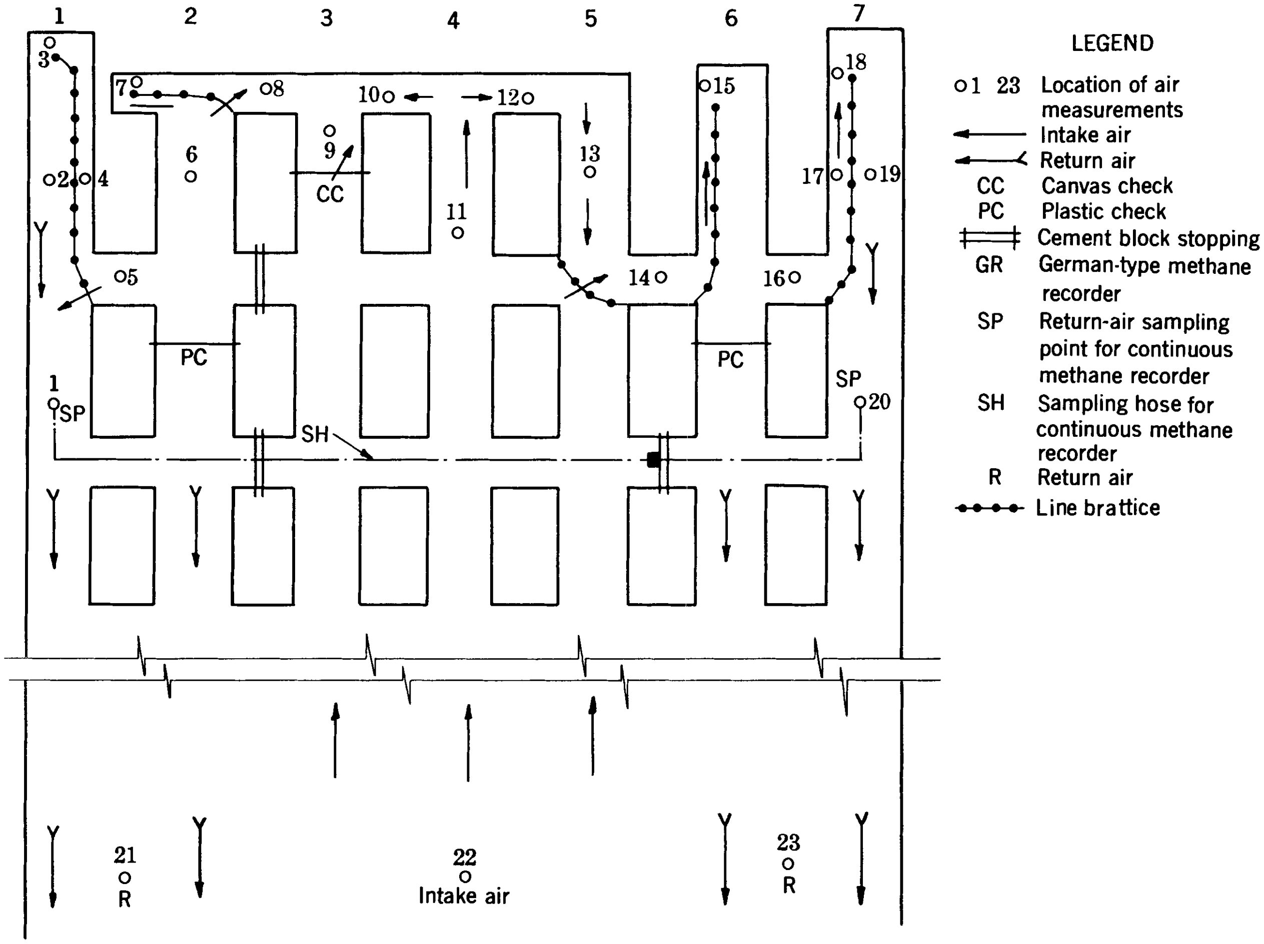


FIGURE 14. - Locations Where Air Measurements Were Taken in 4 South.

## Discussion of Infusion Results, 4 South Entries

While the results of the infusion in 4 South varied, the effects were more widespread than had been anticipated, being noted not only in the 4 South entries but also in the parallel 5 South.

Soon after water infusion was started in No. 1 entry, 4 South, the section foreman of the 5 South section reported abnormal changes in the methane emission. After this report additional readings were taken in 5 South to determine methane liberations before, during, and after succeeding water infusions of 4 South. Table 4 summarizes these results and shows that methane concentration in 5 South increased during each infusion and decreased afterward.

The quantity of methane removed from the 5 South section before and after infusions in 4 South is given in table 5.

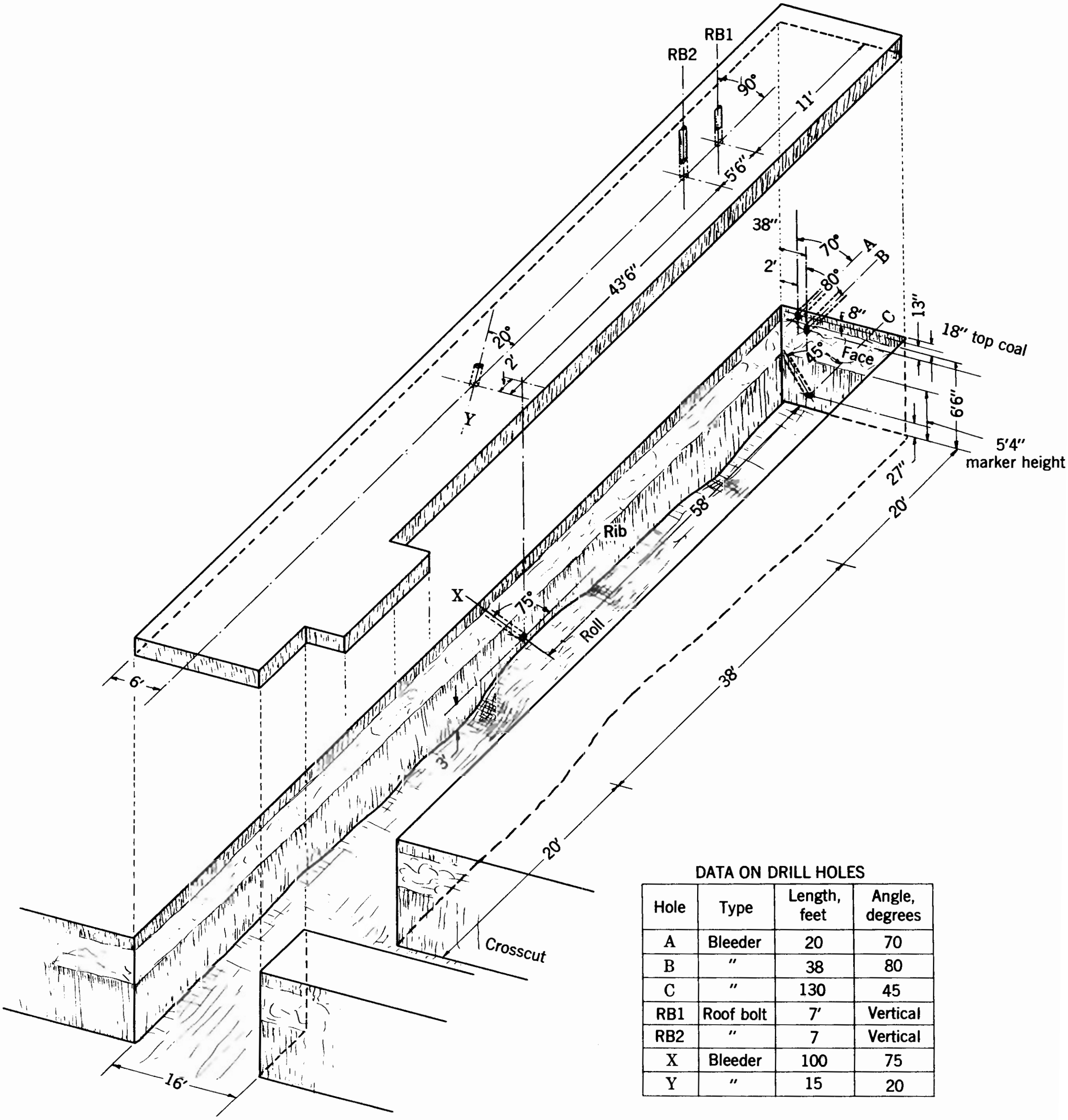
TABLE 3. - Methane released in 4 South before, during, and after infusion of hole L in entry 7

| Locations[1] | Air, c.f.m. | Methane | | | | | |
|---|---|---|---|---|---|---|---|
| | | Before infusion | | During infusion | | After infusion | |
| | | Percent | C.f.m. | Percent | C.f.m. | Percent | C.f.m. |
| 1 | 49,200 | 0.32 | 157 | 0.42 | 207 | 0.12 | 59 |
| 2 | 11,500 | .20 | 23 | .25 | 29 | .03 | 3 |
| 3 | 11,100 | .35 | 39 | .50 | 55 | .08 | 9 |
| 4 | 11,500 | .20 | 23 | .25 | 29 | .03 | 3 |
| 5 | 48,900 | .05 | 24 | .21 | 103 | .02 | 10 |
| 6 | 50,800 | .06 | 30 | .15 | 76 | .01 | 5 |
| 7 | 13,900 | .18 | 25 | .40 | 56 | .03 | 4 |
| 8 | 51,700 | .03 | 15 | .06 | 31 | - | - |
| 9 | 3,500 | - | - | - | - | - | - |
| 10 | 49,400 | .02 | 10 | .05 | 25 | - | - |
| 11 | 88,000 | - | - | - | - | - | - |
| 12 | 37,700 | - | - | .01 | 4 | - | - |
| 13 | 38,100 | - | - | .01 | 4 | - | - |
| 14 | 43,700 | - | - | .01 | 4 | - | - |
| 15 | 13,400 | .02 | 3 | .05 | 7 | - | - |
| 16 | 41,200 | .03 | 12 | .04 | 16 | - | - |
| 17 | 12,700 | - | - | - | - | - | - |
| 18 | 11,900 | .11 | 13 | .15 | 18 | .01 | 1 |
| 19 | 12,500 | - | - | - | - | - | - |
| 20 | 40,800 | .16 | 65 | .15 | 61 | .05 | 20 |
| 21 | 60,100 | .42 | 252.4 | .56 | 337 | .30 | 180 |
| 22 | 107,200 | - | - | - | - | - | - |
| 23 | 46,200 | .24 | 111 | .28 | 129 | .17 | 79 |

[1] See figure 14.

TABLE 4. - Methane content of air at 5 South regulators before, during, and after water-infusion tests in No. 1 entry, 4 South

| Date, 1959 | Right regulator | | Left regulator | | Remarks |
|---|---|---|---|---|---|
| | Air, c.f.m. | Methane, percent | Air, c.f.m. | Methane, percent | |
| September: | | | | | |
| 23 | 38,000 | 0.05 | 58,000 | 0.05 | Before infusing. |
| 25 | 37,400 | .06 | 57,600 | .05 | Do. |
| October: | | | | | |
| 3 | 38,000 | - | 57,500 | .08 | Do. |
| 5 | 37,900 | .15 | 59,000 | .30 | Infusing. |
| 6 | 38,400 | .06 | 58,600 | .05 | After infusing. |
| 8 | 39,000 | .23 | 59,400 | .20 | Infusing. |
| 9 | 39,000 | .05 | 57,400 | .15 | After infusing. |
| 14 | 39,000 | - | 58,200 | - | Do. |
| 19 | 39,800 | .10 | 58,200 | .18 | Infusing. |
| 21 | 39,400 | .21 | 58,200 | .23 | Do. |
| 31 | 39,600 | - | 58,000 | - | After infusing. |
| November 1 | 39,000 | - | 57,900 | - | Do. |



DATA ON DRILL HOLES

| Hole | Type | Length, feet | Angle, degrees |
|---|---|---|---|
| A | Bleeder | 20 | 70 |
| B | " | 38 | 80 |
| C | " | 130 | 45 |
| RB1 | Roof bolt | 7′ | Vertical |
| RB2 | " | 7 | Vertical |
| X | Bleeder | 100 | 75 |
| Y | " | 15 | 20 |

FIGURE 15. - Face Area No. 1 Entry, 4 South, During Water Infusions.

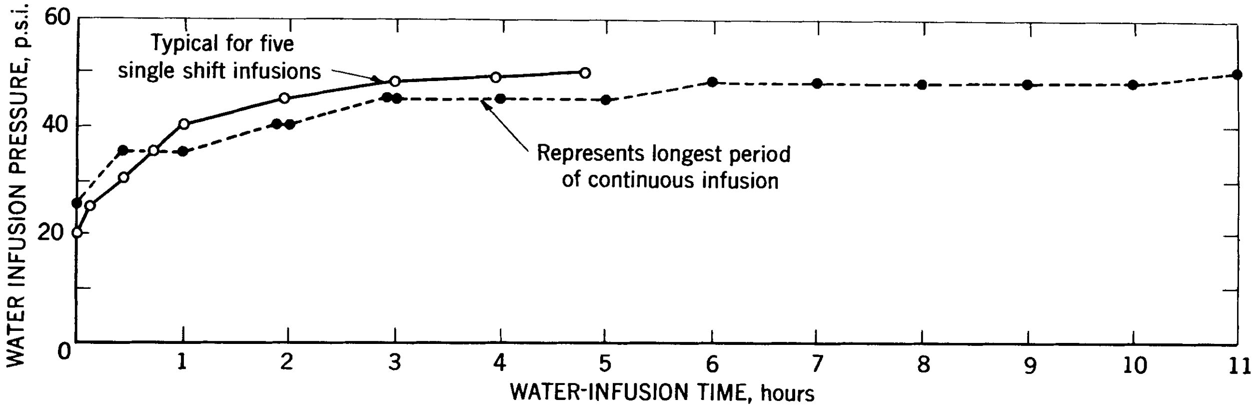


FIGURE 16. - Graph of Water-Infusion Pressure Versus Time, No. 1 Entry, 4 South.

TABLE 5. - Methane released from 5 South before and after infusions in 4 South

| Location of infusion hole | Methane, c.f.m. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Left regulator | | | Right regulator | | | Total section | | |
| | Before | After | Increase | Before | After | Increase | Before | After | Increase |
| No. 7 entry | 46 | 172 | 126 | 0 | 57 | 57 | 46 | 229 | 183 |
| Do. | 29 | 119 | 90 | 23 | 90 | 67 | 52 | 209 | 157 |
| Do. | 0 | 105 | 105 | 0 | 40 | 40 | 0 | 145 | 145 |
| Do. | 0 | 134 | 134 | 0 | 83 | 83 | 0 | 217 | 217 |
| No. 1 entry | 0 | 180 | 180 | 0 | 76 | 76 | 0 | 256 | 256 |
| Do. | 0 | 116 | 116 | 0 | 79 | 79 | 0 | 195 | 195 |

During some infusions in 4 South a dye mixed with the infusion water traveled through 1,500 feet of solid coal to and across the faces of 5 South. Also, when mining was resumed in 4 South, the dye was detected by the use of an ultraviolet light for 1,500 feet ahead of the infusion point.

The quality of gas draining from the horizontal drill holes changed materially during water infusions. Table 6 shows the composition of gas from boreholes in 4 South before water infusions were started; table 7 shows the composition of gas from borehole N during an infusion of borehole L. During this infusion the gas emission increased from 15 to 20 c.f.m. Repeated infusions of borehole L produced similar results in gas emission rates and quality from borehole N. The temperature of water seeping from hole N during infusions was 57° to 58° F., and that of the infusion water was 1° to 2° F. higher.

During infusion of borehole L in No. 7 entry, 4 South, the gas velocity from holes in No. 1 entry, 4 South, increased as follows: Zero to 250 f.p.m. from A; 600 to 800 f.p.m. from B; 400 to 500 f.p.m. from C; and 50 to 200 f.p.m. from Y. Borehole X was sealed. The flow of gas from roof-bolt holes RB1 and RB2 also increased considerably. The rib of borehole X exuded water freely and was covered with gas-water bubbles during these infusions. Several hours after infusions were completed, the gas being liberated from this rib created a loud hissing sound. These results were obtained after each infusion.

TABLE 6. - Mass spectrometer analysis of gas from horizontal boreholes, 4 South entries

| Hole sampled | Percent | | | | | | |
|---|---|---|---|---|---|---|---|
| | $CH_4$ | $N_2$ | $CO_2$ | Ar | $O_2$ | $C_2H_6$ | $C_3H_8$ |
| L[1] | 90.00 | 1.60 | 8.00 | 0.02 | 0.30 | 0.01 | 0.03 |
| N[1] | 92.40 | 1.20 | 6.10 | .02 | .20 | .01 | .03 |
| B[2] | 94.00 | 2.30 | 3.10 | .04 | .50 | .02 | .03 |
| C[2] | 90.50 | 4.20 | 4.20 | .01 | .90 | .02 | .03 |

[1] See figure 12.

[2] See figure 15.

TABLE 7. - Composition of gas from borehole N during water infusion of borehole L

| Elapsed time, minutes | Percent | | | |
|---|---|---|---|---|
| | $CH_4$ | $N_2$ | $CO_2$ | $O_2$ |
| 0 | 92.50 | 1.20 | 6.10 | 0.20 |
| 177 | 72.20 | 16.60 | 7.10 | 4.10 |
| 225 | 68.70 | 19.10 | 7.20 | 5.00 |
| 268 | 22.30 | 53.80 | 7.10 | 16.80 |
| 333 | 9.50 | 62.60 | 7.10 | 20.80 |

During the infusion of borehole C in No. 1 entry, the gas emission rates from borehole A increased from nearly zero to 400 f.p.m.; borehole B increased from 600 to 800 f.p.m.; and borehole Y increased from 50 to 300 f.p.m. A considerable volume of gas was suddenly emitted from roof-bolt holes RB1 and RB2, and the left rib at borehole X again exuded water, freely covering the rib with gas-water bubbles. After each infusion the liberating gas from the rib created a loud hissing sound. Also, the gas emission rate from borehole L was increased from nearly zero to 700 f.p.m. As the gas emission rates increased, the methane content decreased.

## Infusions in Main Entries

### No. 9 Entry

The Mains were developed in a group of nine entries on the butt cleats. Figure 17 is a plan of the Main entries during two water infusions showing locations of methane drainage holes.

Hole No. 1 was infused for 9 hours, and 10 minutes at water pressures ranging from 30 to 118 p.s.i., using two pumps in parallel capable of delivering 25 g.p.m. A total of 13,650 gallons of water was infused. During the last 30 minutes a wetting agent was added to the water, and within a few minutes after the infusion hole No. 2 was discharging water colored by the wetting agent.

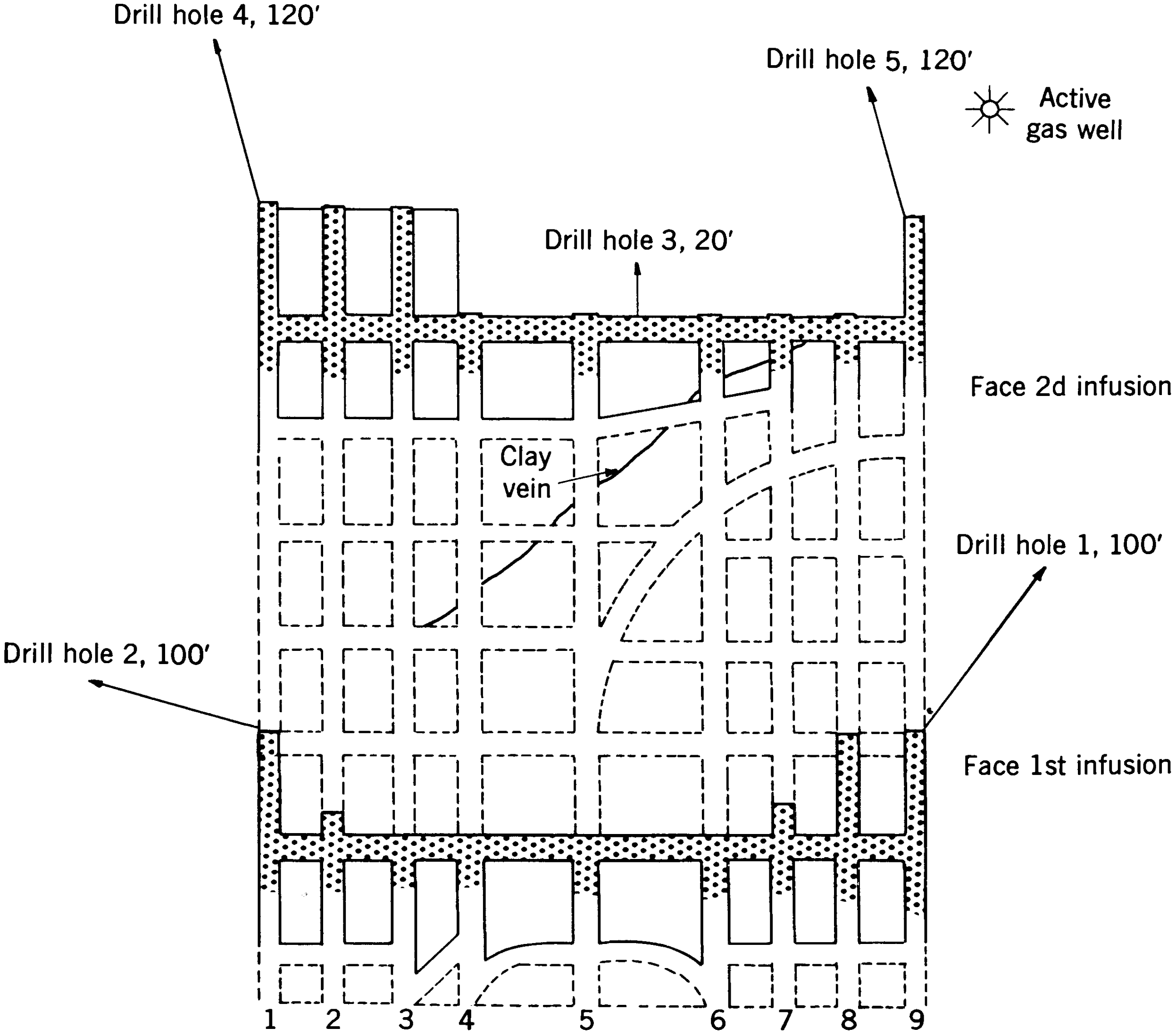


FIGURE 17. - Plan of Main Entry Faces During Two Infusions.

Less dust became airborne during mining operations in the section infused with a wetting agent solution than in those sections where water alone was used.

Air measurements before and during this infusion at the right and left return regulators were 54,400 and 63,000 c.f.m., respectively. The methane content of the air after infusion increased 0.28 percentage point at the left regulator and 0.17 percentage point at the right regulator. Thus, the total methane liberation from the Mains as a result of infusion was 268 c.f.m.

## Crosscut Between the 5 and 6 Entries

Figure 17 shows horizontal borehole No. 3 drilled in the pillar between projected 5 and 6 entries, the face of Mains when the hole was drilled, and the bleeder holes 4 and 5. Hole No. 3 was infused at the same time the continuous-mining machine was being operated in No. 3 entry. Pressure of infusion water ranged from 100 to 150 p.s.i. at the beginning of the infusion; later it was reduced to 50 p.s.i. and then to 25 p.s.i. to prevent the release of an excessive amount of methane.

Air measurements at the right and left return regulators before and during this infusion were 55,600 and 44,200 c.f.m., respectively. The methane content of the air after the infusion increased 0.14 percentage point at the left regulator and 0.13 percentage point at the right regulator. Thus, the total methane liberation from the Mains as a result of infusion was 134 c.f.m.

## Infusions in 5 South Entries

### Crosscut Outby Clay Vein

Entries 1 through 4 had been driven through a clay vein that was exposed at the face of entry 5. (See fig. 18.) Holes 2 and 3 terminated in the clay vein. Hole No. 3 was infused for 21 hours and 10 minutes. During the first 7 hours, water at pressures ranging from 50 to 110 p.s.i. was injected. During the last 14 hours and 10 minutes of the infusion, water at 100 p.s.i. was supplied from a pipeline at a static pressure of 225 p.s.i. Water, totalling 14,560 gallons, and wetting agent solution were used at the rate of 11.5 g.p.m.

Air measurements before and during the infusions at the right and left return regulators were 80,100 and 65,900 c.f.m., respectively. Methane content of the air after infusion increased 0.9 percentage point at the right regulator and 0.6 percentage point at the left. Thus, the total methane liberation from 5 South as a result of the first infusion was 1,116 c.f.m.

After 5 hours, hole No. 3 again was infused for 1 hour and 15 minutes with water at pump pressures ranging from 70 to 140 p.s.i. The flow rate was 14 g.p.m. The flow of air at the left and right return regulators was 58,500 and 83,300 c.f.m., respectively. There was no increase in methane content at the left regulator, but there was an increase of 0.2 percentage point at the right regulator. Thus, total methane liberation from 5 South as a result of the second infusion was 167 c.f.m.

During subsequent mining in the 5 South entries, the mine officials and workmen reported that there was a substantial decrease in airborne dust.

### Crosscut Inby Clay Vein

After the entries had been mined four crosscuts past the clay vein, bleeder holes 5, 6, and 7 were drilled. (See fig. 18.) Hole 6 was infused for 13.5 hours. Water at pump pressure of 250 p.s.i. and a rate of 15 g.p.m. was injected into the hole for 12 hours and 10 minutes. Water at a pressure of 200 p.s.i. was supplied from a static pipeline for 1 hour and 10 minutes at the rate of 11.5 g.p.m.

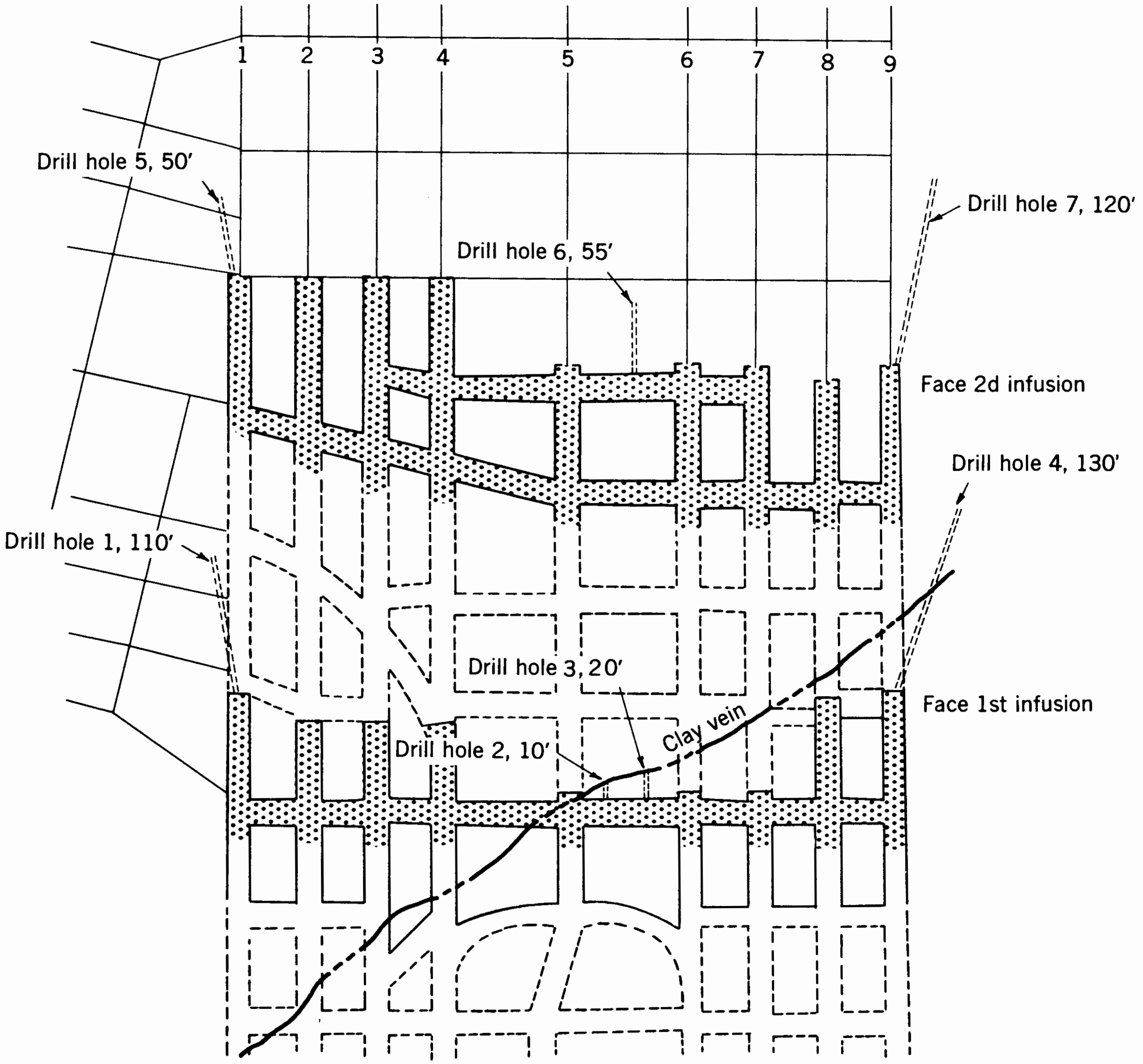


FIGURE 18. - Clay Vein and Face Areas During Two Infusions, 5 South.

Air measurements before and during the infusion at the right and left return regulators were 64,300 and 63,100 c.f.m., respectively. The methane content of the air after infusion increased 0.65 percentage point at the right regulator and 0.3 percentage point at the left. Thus, the total methane liberated from 5 South as a result of the infusion was 607 c.f.m.

When the faces had advanced another crosscut, hole 7 was drilled in the pillar between 5 and 6 entries. It was fitted with a water-infusion seal, a pressure gage, and a shutoff valve. When the valve was closed for 1 minute, the shut-in pressure was 0.5 p.s.i., and after 4 hours the pressure was 5 p.s.i.

### Discussion of Infusion Results, Main and 5 South Entries

The results of infusion in the Mains and the 5 South entries were similar to those in the 4 South. The Mains were driven on butt cleats, and although higher pressures were needed to force the water into the boreholes, there is no conclusive proof that the cleats were wholly responsible for pressure differences.

As in 4 South, there was no indication of damage to the floor or roof as a result of water infusion.

## DEGASIFICATION THROUGH VERTICAL BOREHOLE

### Free Flow of Methane

A power-drop borehole, BH26 (fig. 1), was drilled from the surface to the top of the coalbed ahead of the 5 South entries. Before completing the drilling through the coalbed, the hole was cased with 6-5/8-inch standard casing and grouted to the surface. The total depth of the hole was 455 feet. Both gas and water entered the hole, but the gas flow stopped when water reached a static level of 365 feet.

A bottom-hole pump (fig. 19) was installed, and when water was removed, 24,000 cubic feet per day of gas was emitted. The hole developed a shut-in pressure of 28 p.s.i.

### Flow by Vacuum

Two months after the pump was installed the free flow of gas from the hole, when dewatered, decreased to 17,000 cubic feet per day. A rotary vacuum pump with a capacity of 53 c.f.m. was connected to the casing, and the flow of gas was increased to 29,200 cubic feet per day. The installation of a vacuum pump with a capacity of 115 c.f.m. at a vacuum of 13.5 inches of mercury increased the gas flow further to 82,200 cubic feet per day.

Samples of gas were taken from the borehole during free flow and while the vacuum pump was being operated. After the larger vacuum pump was connected, the gas samples showed an increase of air content. Although the 5 South entries were 800 feet from the borehole, the increased air content probably was coming from the mine ventilating currents.

Table 8 summarizes drainage data and gas analyses of samples taken from BH26. Gas samples were taken periodically from the hole at free flow by stopping the vacuum pump. After each sample, orifice readings showed that the gas quantity decreased; likewise the methane content decreased.

To determine if mine ventilating air was passing through the 800 feet of coal between the 5 South entries and the borehole, a Veeco Ms-9A helium-leak detector was installed on the surface. (See fig. 20.) Helium emission readings were taken for several days before helium was released in 5 South. The accuracy of the leak detector permits measurement of 1 part helium in 10 million parts of gas.

TABLE 8. - Methane drainage data for borehole BH26

| Accumulated producing time of hole, days | Temperature, ° F. |  | Water gage, inches | Vacuum, inches Hg | Gas produced cubic feet per day | Water produced, g.p.m. | Analyses of gas, percent |  |  |  |  |  | Capacity of vacuum pump, c.f.m. | Section | Distance from bottom of hole, feet | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Atmosphere | Gas |  |  |  |  | $CH_4$ | $CO_2$ | $O_2$ | $N_2$ | Combustibles | $H_2$ |  |  |  |  |
| 0....... | - | - | - | - | 24,000 | - | 90.5 | 2.8 | 0.6 | 6.1 | - | - | None | 4S<br>5S | 2,400<br>1,410 | Hole finished. |
| 51....... | - | - | - | - | 9,000 | 30 | 94.5 | 2.8 | .2 | 2.5 | - | - | None | 4S<br>5S | 2,400<br>980 | 18,000 cubic feet per day when infusing in 4 South. |
| 111....... | - | - | - | - | 17,000 | (1) | 94.5 | 2.8 | .2 | 2.5 | - | - | None | 4S | 1,900 | Hole dewatered. |
|  | - | - | 1.4 | 2.6 | 29,200 | (1) | 92.1 | 2.5 | 1.0 | 4.4 | - | - | 53 | 5S | 980 | Operated vacuum pump. |
| 145....... | - | - | 1.2 | 2.0 | 27,100 | 10 | 87.7 | 2.8 | 2.0 | 7.5 | - | - | 53 | 5S | 940 | Do. |
| 151....... | - | - | 5.1 | 7.5 | 56,000 | 30 | - | - | - | - | - | - | 115 | 5S | 800 | Changed vacuum pumps. |
| 158....... | 32 | 78 | 6.0 | 8.0 | 60,600 | 5 | 90.5 | 2.8 | .6 | 6.1 | - | - | 115 | 5S | 800 | Vacuum pump operating. |
| 164....... | 30 | 88 | - | - | 17,000 | 5 | 92.1 | 1.5 | 1.0 | 5.4 | - | - | 115 | 5S | 800 | Vacuum pump stopped. |
|  | 38 | 91 | 6.0 | 8.0 | 60,600 | 5 | 83.6 | 1.5 | 2.8 | 12.1 | - | - | 115 | 5S | 800 | Vacuum pump operating. |
| 165....... | 32 | 82 | 6.0 | 8.0 | 60,600 | 5 | 69.6 | 2.8 | 7.2 | 19.0 | 0.5 | 0.9 | 115 | 5S | 800 | Do. |
| 216....... | 30 | 84 | 8.0 | 9.25 | 70,100 | 5 | - | - | - | - | - | - | 115 | 5S | 800 | Do. |
| 244....... | 35 | 82 | 6.3 | 9.0 | 62,200 | 3 | - | - | - | - | - | - | 115 | 5S | 610 | Do. |
| 256....... | 68 | 110 | 6.8 | 9.0 | 64,600 | 3 | - | - | - | - | - | - | 115 | 5S | 450 | Do. |
|  | - | - | - | - | 5,000 | 3 | 87.8 | 4.7 | 1.8 | 5.7 | - | - | - | - | - | Vacuum pump stopped. |
| 258....... | 40 | 80 | 3.6 | 9.0 | 47,000 | 3 | 51.8 | 2.7 | 8.3 | 37.2 | - | - | 115 | 5S | 400 | Vacuum pump operating. |
| 264....... | 46 | 86 | 3.6 | 9.0 | 47,000 | 3 | 36.0 | 2.0 | 12.1 | 48.4 | .6 | .9 | 115 | 5S | 400 | Do. |
| 266....... | 46 | 89 | 3.6 | 9.75 | 47,000 | 1 | 36.0 | 2.0 | 12.1 | 48.4 | .6 | .9 | 115 | 5S | 370 | Do. |
| 267....... | 26 | 102 | 3.6 | 10.0 | 47,000 | 1 | 30.1 | 1.9 | 14.3 | 53.7 | - | - | 115 | 5S | 370 | Do. |
| 271....... | 56 | 61 | - | - | 2,900 | 1 | 93.0 | 4.0 | - | 3.0 | - | - | 115 | 5S | 290 | Vacuum pump stopped. |
|  | 64 | 84 | 3.6 | 12.0 | 47,000 | 1 | 25.0 | 1.5 | 8.0 | 65.5 | - | - | 115 | 5S | 290 | Vacuum pump operating. |
| 275....... | 49 | 80 | 5.0 | 13.0 | 55,500 | 1 | 40.0 | 2.5 | 10.0 | 47.5 | - | - | 115 | 5S | 180 | Do. |
| 284....... | 50 | 51 | - | - | 2,900 | 1 | 90.2 | 7.0 | .5 | 2.3 | - | - | - | 5S | 100 | Vacuum pump stopped. |
|  | 52 | 70 | 11.0 | 13.5 | 82,200 | 1 | 23.4 | 1.9 | 15.7 | 59.0 | - | - | 115 | 5S | 100 | Vacuum pump operating. |
| 290....... | 40 | 65 | 1.0 | 11.5 | 24,800 | - | 19.1 | 1.7 | 16.6 | 62.6 | - | - | 115 | 5S | 72 | Do. |
| 293....... | - | - | - | - | - | - | - | - | - | - | - | - | - | 5S | 0 | 5 South section cut through to hole. |

[1] Hole dry.

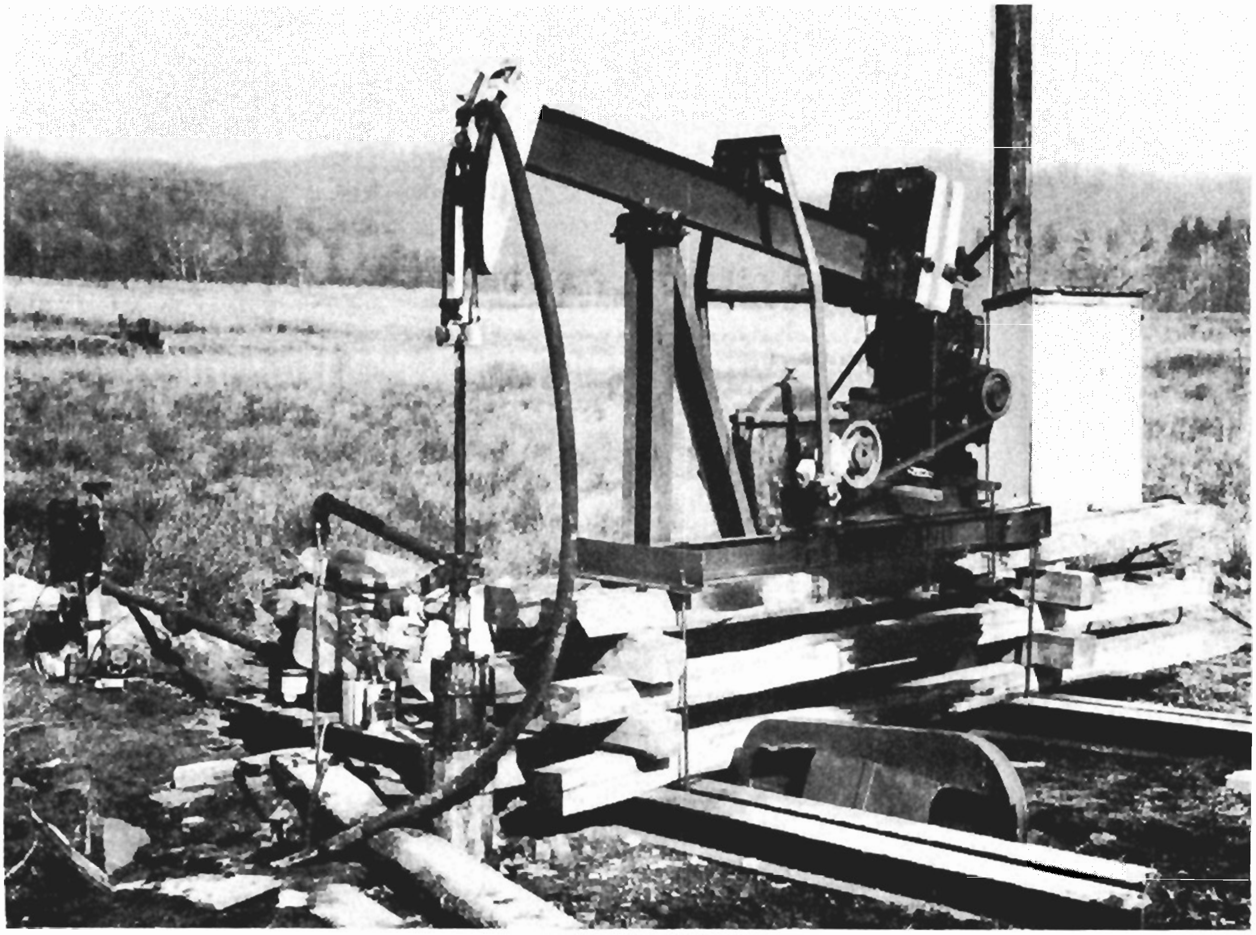


FIGURE 19. - Bottom-Hole Pump Installation at BH26. Belt guard removed for photographic purposes.

Helium was released from a cylinder under pressure of 350 p.s.i. into the mine atmosphere at the face of No. 1 entry, 5 South. A substantial increase in helium was detected at the borehole 3 hours and 20 minutes after release. The following day, helium under pressure of 50 p.s.i. was released through an infusion seal into a bleeder hole in the No. 1 entry. One hour after the release it was detected on the surface. Three more releases, on successive days, were made: (1) At the face of No. 1 entry, 5 South; (2) at the face of No. 4 entry, 5 South; and (3) in the intake air of No. 4 entry, 5 South. Two hours after each release a substantial increase in helium was detected on the surface.

Table 9 summarizes data for the five helium releases in the mine.

TABLE 9. - Summary of data on helium releases, 5 South

| Days operating helium leak detector | Time of readings | Top of BH26, ° F. | Meter reading of leak detector[1] | Released | Location | Condition |
|---|---|---|---|---|---|---|
| 1st day.... | 3:30 p.m. | 40 | [2]1.80 | - | - | - |
| 2d day..... | 8:30 a.m. | 14 | [2]1.10 | - | - | - |
| | 9:30 a.m. | 20 | [2]1.50 | - | - | - |
| | 10:00 a.m. | 25 | [2]1.90 | - | - | - |
| | 2:00 p.m. | 35 | [2]1.50 | - | - | - |
| | 2:15 p.m. | 35 | 2.20 | 2:15 to 2:30 p.m. | Face of No. 1 entry | From cylinder into mine atmosphere. |
| | 3:00 p.m. | 35 | 2.30 | - | - | - |
| | 5:00 p.m. | 30 | 2.25 | - | - | - |
| | 5:50 p.m. | 25 | 3.20 | - | - | - |
| | 6:15 p.m. | 22 | 3.90 | - | - | - |
| | 6:35 p.m. | 22 | 3.00 | - | - | - |
| | 9:50 p.m. | 18 | 4.00 | - | - | - |
| | 10:03 p.m. | 18 | 5.20 | - | - | - |
| | 10:21 p.m. | 17 | 3.70 | - | - | - |
| | 10:30 p.m. | 17 | 2.35 | - | - | - |
| | 12:00 a.m. | 17 | 2.00 | - | - | - |
| 3d day..... | 8:00 a.m. | 17 | 1.95 | - | - | - |
| | 10:00 a.m. | 18 | 2.10 | 9:50 to 9:55 a.m. | In 100-foot bleeder hole of face of No. 1 entry. | From cylinder into hole at 50 p.s.i. |
| | 10:30 a.m. | 20 | 1.90 | - | - | - |
| | 11:00 a.m. | 25 | 2.60 | - | - | - |
| | 12:30 p.m. | 32 | 2.60 | - | - | - |
| | 2:00 p.m. | 36 | 2.60 | - | - | - |
| | 2:30 p.m. | 38 | 2.50 | - | - | - |
| | 4:00 p.m. | 45 | 2.30 | - | - | - |
| | 4:30 p.m. | 50 | 2.20 | - | - | - |
| | 7:05 p.m. | 43 | 2.10 | - | - | - |

| | | | | | |
|---|---|---|---|---|---|
| 4th day.... | 12:30 a.m. | 34 | 2.00 | - | - | - |
| | 7:00 p.m. | 45 | 1.90 | - | - | - |
| 5th day.... | 2:00 a.m. | 41 | 1.80 | - | - | - |
| | 7:30 a.m. | 42 | 1.60 | - | - | - |
| | 8:00 a.m. | 42 | 1.50 | - | - | - |
| | 9:00 a.m. | 42 | 1.30 | - | - | - |
| | 10:00 a.m. | 44 | 1.45 | 10:00 to 10:15 a.m. | Face of No. 1 entry | From cylinder into mine atmosphere. |
| | 11:00 a.m. | 44 | 1.45 | - | - | - |
| | 12:00 n. | 45 | 2.00 | - | - | - |
| | 1:00 p.m. | 46 | 2.00 | - | - | - |
| | 2:30 p.m. | 47 | 1.90 | - | - | - |
| | 3:00 p.m. | 47 | 1.80 | - | - | - |
| 6th day.... | 8:00 a.m. | 40 | 1.60 | 8:00 to 8:05 a.m. | Face of No. 4 entry | From cylinder into mine atmosphere. |
| | 9:00 a.m. | 41 | 1.60 | - | - | - |
| | 10:00 a.m. | 42 | 1.95 | - | - | - |
| | 12:00 n. | 39 | 2.00 | - | - | - |
| | 1:00 p.m. | 40 | 1.90 | - | - | - |
| | 6:00 p.m. | 37 | 1.80 | - | - | - |
| 7th day.... | 4:00 a.m. | 30 | 1.70 | - | - | - |
| | 5:00 a.m. | 30 | 1.50 | - | - | - |
| | 7:00 a.m. | 30 | 1.40 | - | - | - |
| | 8:00 a.m. | 32 | 1.20 | 8:00 to 8:03 a.m. | Intake of No. 4 entry. | From cylinder into mine atmosphere. |
| | 9:00 a.m. | 33 | 1.30 | - | - | - |
| | 10:00 a.m. | 35 | 2.00 | - | - | - |
| | 12:30 p.m. | 40 | 2.20 | - | - | - |
| | 2:00 p.m. | 41 | 2.05 | - | - | - |
| | 3:00 p.m. | 40 | 1.50 | - | - | - |
| | 12:00 a.m. | 37 | 1.40 | - | - | - |
| 8th day.... | 8:00 a.m. | 35 | 1.20 | - | - | - |
| | 9:30 a.m. | 40 | 1.30 | - | - | - |

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[1] Meter reading times 0.00122 (constant) equals micron cubic feet per hour; for example, first meter reading in table, 1.80, times 0.00122 (constant) equals 0.002196 micron cubic feet of helium per hour.

[2] Readings taken before helium was released underground to establish normal helium emission for the borehole.

FIGURE 20. - Veeco MS-9A Helium-Leak Detector.

Gas analyses previously given in tables 6 and 7 showed an increase of air during infusions in the 4 South. At that time the reason for the increase was not explainable. There was evidence that the infusion water traveled through solid coal as much as 1,500 feet and moved gas ahead of it. The helium releases proved that mine air could be evacuated if the vacuum pump was operating. It is very probable that the infusion water intersected the path of airflow from the coal face to BH26, and that in doing so the water displaced air and methane ahead of it from this path. This would account for the dilution of gas emitted from bleeder holes outby the hole infused.

## Flow by Vacuum Through Horizontal Drill Hole in Face

When BH26 was exposed underground, a horizontal hole was drilled in the face between projected Nos. 4 and 5 entries, 5 South. The horizontal borehole was connected to BH26 as shown in figure 21. After the connection was made, the free flow of gas to surface was at the rate of 2,800 cubic feet per day.

Under vacuum the flow of gas from the coal increased to 82,000 cubic feet a day. After several days' intermittent operation of the pump, methane was not detected in the right return and only 0.08 percent in the left return. The section was advanced 400 feet in 5 weeks without any appreciable increase in methane in the returns.

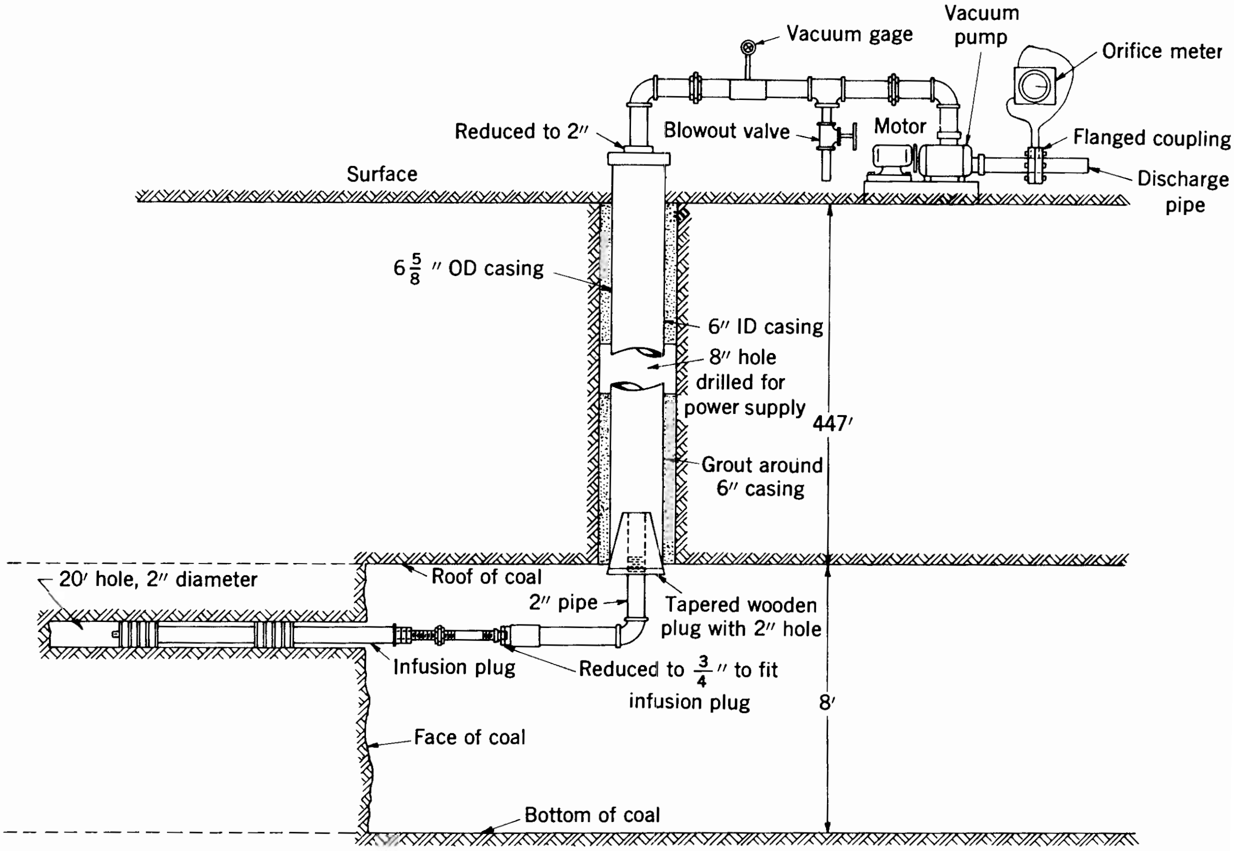

FIGURE 21. - Connection of BH26 With Horizontal Borehole, 5 South.

Table 10 summarizes variations in gas composition emitted under vacuum from the horizontal borehole connected with BH26 as determined from readings and analyses of gas samples taken at intervals during 4 days after the borehole was intersected by underground 5 South workings.

## MIGRATION TESTS, ANHYDROUS AMMONIA

Tests to determine if gas migrated preferentially along or across the coal bedding planes were conducted using anhydrous ammonia as a tracer. Holes were drilled in a freshly exposed working face driven on face cleats as shown in figure 22. A 4-foot length of 1/8-inch-diameter rubber tubing was inserted 6 inches in each hole, except No. 2, and sealed.

TABLE 10. - Gas composition and flow under vacuum through drill hole in face

| Days suction applied | Time | Temperature, ° F. | | Water gage, inches | Vacuum, inches Hg | Analyses of gas, percent | | | | Gas per day, cubic feet |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Atmosphere | Gas | | | $CH_4$ | $CO_2$ | $O_2$ | $N_2$ | |
| 1st.... | [1]2:00 a.m. | - | - | - | - | - | - | - | - | - |
| | 5:30 p.m. | 65 | 60 | 11.0 | 5.0 | - | - | - | - | [2]82,200 |
| | 7:30 p.m. | 65 | 75 | 11.0 | 11.0 | 60.00 | 0.00 | 12.00 | 28.00 | 82,200 |
| | 8:00 p.m. | 65 | 75 | 11.0 | 11.0 | 75.00 | 5.00 | 4.00 | 16.00 | 82,200 |
| | 9:00 p.m. | 64 | 80 | 11.0 | 12.0 | 68.00 | 4.00 | 9.50 | 18.50 | 82,200 |
| | 9:30 p.m. | 64 | 85 | 11.0 | 12.0 | 60.00 | 3.00 | 9.00 | 28.00 | 82,200 |
| | 10:15 p.m. | 62 | 90 | 11.0 | 12.0 | 60.00 | 3.00 | 10.00 | 27.00 | 82,200 |
| | 10:30 p.m. | 62 | 98 | 11.0 | 12.0 | 60.00 | 3.00 | 9.00 | 28.00 | 82,200 |
| | 10:45 p.m. | 60 | 100 | 11.0 | 12.0 | 60.00 | 2.00 | 8.50 | 29.50 | 82,200 |
| 2d..... | 7:00 a.m. | 50 | 60 | - | - | - | - | - | - | - |
| | 7:30 a.m. | 51 | 70 | 11.0 | 11.5 | 50.00 | 2.00 | 9.50 | 38.50 | 82,200 |
| | 8:30 a.m. | 53 | 90 | 11.0 | 12.0 | 35.00 | 3.00 | 12.00 | 50.00 | 82,200 |
| | 9:00 a.m. | 55 | 95 | 11.0 | 12.0 | 30.00 | 3.00 | 14.00 | 53.00 | 82,200 |
| | 9:30 a.m. | 55 | 100 | 11.0 | 12.0 | 24.00 | 2.50 | 15.00 | 58.50 | 82,200 |
| | 7:25 p.m. | 66 | 60 | - | - | .03 | .05 | 20.88 | 79.04 | 82,200 |
| | 7:30 p.m. | 66 | 75 | 11.0 | 5.0 | - | - | - | - | - |
| | 7:35 p.m. | 66 | 75 | 11.0 | 12.0 | 25.80 | 2.00 | 15.10 | 57.10 | 82,200 |
| | 7:37 p.m. | 66 | 75 | 11.0 | 12.0 | 35.40 | 3.00 | 12.90 | 48.70 | 82,200 |
| | 7:39 p.m. | 66 | 75 | 11.0 | 12.0 | 33.30 | 2.90 | 13.30 | 50.50 | 82,200 |
| | 7:41 p.m. | 66 | 75 | 11.0 | 12.0 | 29.10 | 2.60 | 14.30 | 54.00 | 82,200 |
| | 7:44 p.m. | 65 | 80 | - | - | 23.30 | 2.30 | 15.60 | 58.80 | - |
| | 7:47 p.m. | 65 | 80 | 11.0 | 12.0 | 30.70 | 2.80 | 13.90 | 52.60 | 82,200 |
| | 7:50 p.m. | 65 | 80 | 11.0 | 12.0 | 30.10 | 2.80 | 13.90 | 53.20 | 82,200 |
| | 7:52 p.m. | 65 | 86 | 11.0 | 12.0 | 31.60 | 3.00 | 13.60 | 51.80 | 82,200 |
| | 7:57 p.m. | 64 | 91 | 11.0 | 12.0 | 24.10 | 2.30 | 15.30 | 58.30 | 82,200 |
| | 7:59 p.m. | 64 | 100 | 11.0 | 12.0 | 24.30 | 2.10 | 15.40 | 58.20 | 82,200 |
| | 8:00 p.m. | 64 | 105 | 11.0 | 12.0 | 26.10 | 2.30 | 15.00 | 56.60 | 82,200 |

See footnotes at end of table, p. 37.

TABLE 10. - Gas composition and flow under vacuum through drill hole in face (Con.)

| Days suction applied | Time | Temperature, ° F. | | Water gage, inches | Vacuum, inches Hg | Analyses of gas, percent | | | | Gas per day, cubic feet |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Atmosphere | Gas | | | $CH_4$ | $CO_2$ | $O_2$ | $N_2$ | |
| 3d..... | 11:30 a.m. | 44 | 60 | 11.0 | 8.0 | - | - | - | - | 82,200 |
| | 11:42 a.m. | 44 | 60 | 11.0 | 12.0 | 31.40 | 2.70 | 13.70 | 52.20 | 82,200 |
| | 11:43 a.m. | 44 | 60 | 2.3 | 11.5 | 14.40 | 1.50 | 17.60 | 66.50 | 37,600 |
| | 11:54 a.m. | 44 | 62 | 2.6 | 11.5 | 16.50 | 1.60 | 17.20 | 64.70 | 40,000 |
| | 11:55 a.m. | 44 | 62 | 2.8 | 11.5 | 22.10 | 1.90 | 15.80 | 60.20 | 41,500 |
| | 12:27 p.m. | 45 | 66 | 3.8 | 11.0 | 22.70 | 2.20 | 15.70 | 59.40 | 48,300 |
| | 12:40 p.m. | 45 | 90 | 4.4 | 11.7 | 44.50 | 4.10 | 10.80 | 40.60 | 52,100 |
| | 12:46 p.m. | 45 | 96 | 4.5 | 11.7 | 25.10 | 2.40 | 15.20 | 57.30 | 52,600 |
| | 12:48 p.m. | 45 | 100 | 4.5 | 11.7 | 12.20 | 1.00 | 18.20 | 68.60 | 52,600 |
| | 12:50 p.m. | 45 | 108 | 4.5 | 11.7 | - | - | - | - | 52,600 |
| | 6:56 p.m. | 47 | 60 | 11.0 | 8.0 | - | - | - | - | 82,200 |
| | 7:01 p.m. | 47 | 60 | 11.0 | 12.0 | 42.60 | 3.90 | 11.10 | 42.40 | 82,200 |
| | 7:07 p.m. | 47 | 70 | 2.6 | 12.0 | 50.60 | 4.80 | 9.30 | 35.30 | 40,000 |
| | 7:14 p.m. | 47 | 82 | 3.4 | 11.5 | 17.70 | 1.60 | 16.90 | 63.80 | 45,700 |
| | 7:37 p.m. | 47 | 108 | 4.0 | 11.5 | 19.80 | 1.80 | 16.30 | 62.10 | 49,500 |
| | 8:00 p.m. | 47 | 115 | 4.4 | 11.5 | 19.00 | 1.80 | 16.40 | 62.80 | 52,100 |
| | 8:08 p.m. | 47 | 115 | 4.4 | 11.5 | 18.30 | 1.80 | 16.70 | 63.20 | 52,100 |
| | 8:10 p.m. | 47 | 120 | 4.4 | 11.5 | - | - | - | - | 52,100 |
| | 11:10 p.m. | 44 | 60 | 11.0 | 8.0 | - | - | - | - | 82,200 |
| | 11:20 p.m. | 44 | 62 | 11.0 | 12.0 | 30.00 | 3.00 | 14.00 | 53.00 | 82,200 |
| | 11:37 p.m. | 44 | 67 | 4.5 | 11.5 | 25.00 | 2.00 | 15.00 | 58.00 | 52,600 |
| | 11:50 p.m. | 44 | 80 | 4.4 | 11.5 | 15.00 | 1.50 | 18.00 | 65.50 | 52,100 |
| | 12:00 a.m. | 44 | 90 | 4.5 | 11.5 | 20.00 | 2.00 | 17.00 | 61.00 | 52,600 |
| 4th.... | 12:14 a.m. | 43 | 100 | 4.5 | 11.5 | 18.00 | 1.50 | 17.00 | 63.50 | 52,600 |
| | 12:35 a.m. | 43 | 105 | 4.5 | 11.5 | 14.00 | 1.50 | 18.00 | 66.50 | 52,600 |
| | 1:08 a.m. | 43 | 115 | 4.5 | 11.5 | 12.00 | 1.00 | 18.50 | 68.50 | 52,600 |
| | 1:30 a.m. | 45 | 120 | 4.5 | 11.5 | - | - | - | - | 52,600 |

[1] Bottom of No. 26 surface borehole was intersected by 5 South workings.
[2] Capacity of gas vacuum pump was 115 c.f.m.

A piece of litmus paper was attached to the free ends of the tubes, and they were held by one observer together with a piece of cloth soaked in a weak solution of hydrochloric acid. While this observer sniffed the handheld tubes, another released the ammonia from a cylinder through an infusion seal. As the gasified ammonia migrated through the bed, the pungent odor was detected by fuming of the acid-soaked cloth and the change in color of the litmus paper from pink to blue.

It required 21 seconds for ammonia to migrate from hole 2 to hole 1, 27 seconds from hole 2 to hole 3, and 31 seconds from hole 2 to hole 5. No gas

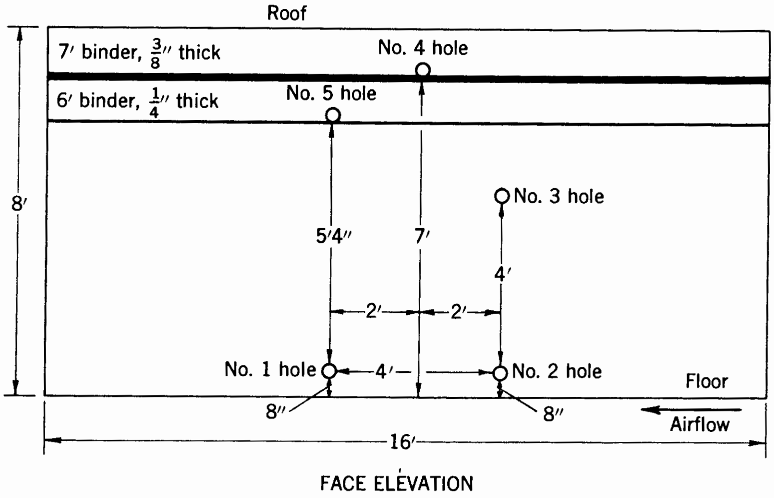

FIGURE 22. - Spacing of Holes in Coal Face for Migration Tests. A. All holes were 5 ft. deep and 2 in. in diameter; B. No. 2 hole was sealed with water-infusion seal for a depth of 2 ft. from collar; and C. A cylinder of anhydrous ammonia was connected to the water-infusion seal; a valve and a pressure gage were provided in the connecting line between the cylinder and the seal.

was detected coming from hole 4. The gas traveled faster along the bedding planes than across the planes and, like the infusion water, did not penetrate the 7-foot binder.

## CONCLUSIONS

From observations made and data collected during these methane drainage experiments, it is concluded that methane can be removed from the Pittsburgh coalbed before and during mining at this mine. However, the tests should be repeated at mines in other mines in the Pittsburgh bed to verify the conclusion.

Gas liberation from horizontal boreholes drilled 100 to 230 feet deep in the coalbed ranged from nearly zero to 135 c.f.m. The flow decreased steadily for several hours; however, many of the holes continued free flow for several months. A hole 70 feet deep terminating in a clay vein emitted 193 c.f.m. for several weeks. Shut-in pressures of the horizontal bleeder holes scaled up to 60 p.s.i.

Methane was liberated from a few roof-bolt holes, and a few holes drilled vertically and at other angles into the roof emitted 50 to 75 cubic feet of gas per minute. Since horizontal holes in the coalbed drained gas longer and at a faster rate than holes in the roof, it appeared that most of the methane was held in the coalbed rather than in the adjacent strata.

Vacuum applied to a drainage hole increased the flow rate of gas. Drainage from a 20-foot horizontal hole in the coal was increased twentyfold by vacuum applied to a surface borehole connected with the horizontal hole.

By controlling the water-infusion rate applied to bleeder holes, release of methane from the coalbed ahead of mining faces can be regulated. During one idle period, as much as 1,600,000 cubic feet of methane was removed; when mining was resumed, the methane content was less than normal.

Infusion water did not penetrate the 7-foot binder of the coalbed and no ill effects of the water were noticed on either the roof or floor of the mine. Water infusion, especially with a wetting agent added to the solution, reduced the amount of dust at the face.

A vertical borehole from the surface to the bottom of the coalbed drained methane from the bed by free flow. With a vacuum pump connected on the surface, the emission rate increased, but the percentage of methane decreased. The total volume of gas removed by free flow and vacuum pumping was 8 million cubic feet. The shut-in pressure ranged from 28 to 100 p.s.i.

Experiments with tracers introduced into the infusion water and the ventilating-air current proved that water, helium, and anhydrous ammonia travel through solid coal. Infusion water mixed with fluorescein dye traveled 1,500 feet through coal.

Helium under vacuum traveled 800 feet through the coalbed and through a 455-foot borehole to surface in 1 to 3 hours.

Anhydrous ammonia under pressure released into horizontal boreholes traveled 4 feet in 21 seconds horizontally, 4 feet in 27 seconds vertically, and 7 feet in 31 seconds diagonally across the bedding planes.