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# Water Infusion of Coalbeds for Methane and Dust Control

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 8241

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# WATER INFUSION OF COALBEDS FOR METHANE AND DUST CONTROL

by

Joseph Cervik,[1] Albert Sainato,[2] and Maurice Deul[3]

ABSTRACT

This Bureau of Mines report deals with water infusion of coalbeds, which can control methane emission at face areas during developmental mining and which may sometimes suppress dust.

Studies show that water infused into the coalbed flows through the fracture system and displaces the methane in the fractures and prevents migration from the solid coal. Displaced gas migrates away from the face area that has been water infused and enters the return ventilation airways. A gradual decrease in methane emission is observed from the start of infusion until the infused zone is mined through. Depending on the permeability of the coalbed, infusion pressures ranged from 300 to 2,200 lb/in$^2$.

Face emissions in the Upper Kittanning coalbed were reduced by 89 pct; reductions of 38 to 79 pct were measured in the Pittsburgh coalbed depending on the relationship between the face cleat direction and mining direction. Respirable dust levels were reduced by about 75 pct on a longwall section in the Pocahontas No. 3 coalbed and by about 50 pct on a development section in the Upper Kittanning coalbed, but no statistically reliable reduction was found in the respirable dust levels in the Pittsburgh coalbed.

## INTRODUCTION

Water infusion of coalbeds is a method of controlling methane flows at active face areas and, in some cases, of suppressing dust during mining. Water infusion is practiced widely in Europe and is reported to be the best means of combating dust (15).[4]

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

In Germany, experience has shown that infusion must provide a minimum of 1.6 gal of water per ton of coal to suppress dust (2). German regulations require infusion of coalbeds where possible and over 50 pct of their longwalls are infused (16). In France, water infusion is the basic dust prevention technique (8). Water infusion is widely practiced and covers 89 pct of the coal produced in the northern coalfields. In Belgium (14), a quantity of infused water equivalent to about 2.4 gal/ton of coal suppresses 95 pct of the particles between 0.5 and 5 microns produced at the face.

Water infusion is not practiced as widely in the United Kingdom as on the Continent (9). In the Welsh coalfield, "short hole" infusion is carried out at the face but with doubtful effectiveness, and in the Stadfordshire coalfield, no significant improvements in dust conditions were noted during an infusion test. In the Durham and Lancashire coalfields, infusion is practiced effectively on retreat mining; dust reduction of 50 pct is reported on three Durham faces and somewhat lower on the Lancashire coal faces.

In the United States, a study on a retreating longwall in the Pocahontas No. 3 coalbed showed that both total and respirable dust levels were reduced 40 to 79 pct by infusion (6). Morton (12) found water infusion of longwall faces in the Eagle coalbed at Carbon Fuel Co. No. 20 Mine to be an effective and economical means of controlling airborne dust created by the mining operation.

This report attempts to present the mechanics of water infusion in a simple manner so that coal producers unfamiliar with fluid dynamics will understand the process. It is intended as a guide for diagnosing and solving problems associated with the application of water infusion by mine personnel and describes equipment and procedures for accomplishing drilling and infusion through short horizontal holes.

## EUROPEAN DRILLING AND INFUSION PROCEDURES

The predominant mining system in the United Kingdom and Europe is the advancing longwall. In the United Kingdom (9), for example, only 7 pct of the 840 major longwall faces are worked on retreat. The integration of a drilling and infusion phase is more difficult on an advancing longwall than on a retreating one. Figure 1 shows three European procedures for infusing advancing longwalls (2):

1. Horizontal holes are drilled into the face to a depth of approximately the daily advance of the panel (shallow infusion). The distance between holes is about twice the length of the holes. Thus, if the daily advance rate is 10 ft, hole length is 10 ft and the distance between holes is 20 ft. If the panel is 400 ft wide, about 20 holes are necessary to infuse the panel. In some instances, holes are drilled to depths of about 40 ft (deep infusion). The spacing between holes is 80 ft and on a 400-ft face, about five holes are required.

2. The second procedure is known as remote infusion, or infusion from outside of the mined coalbed. If there is a roadway above the panel being

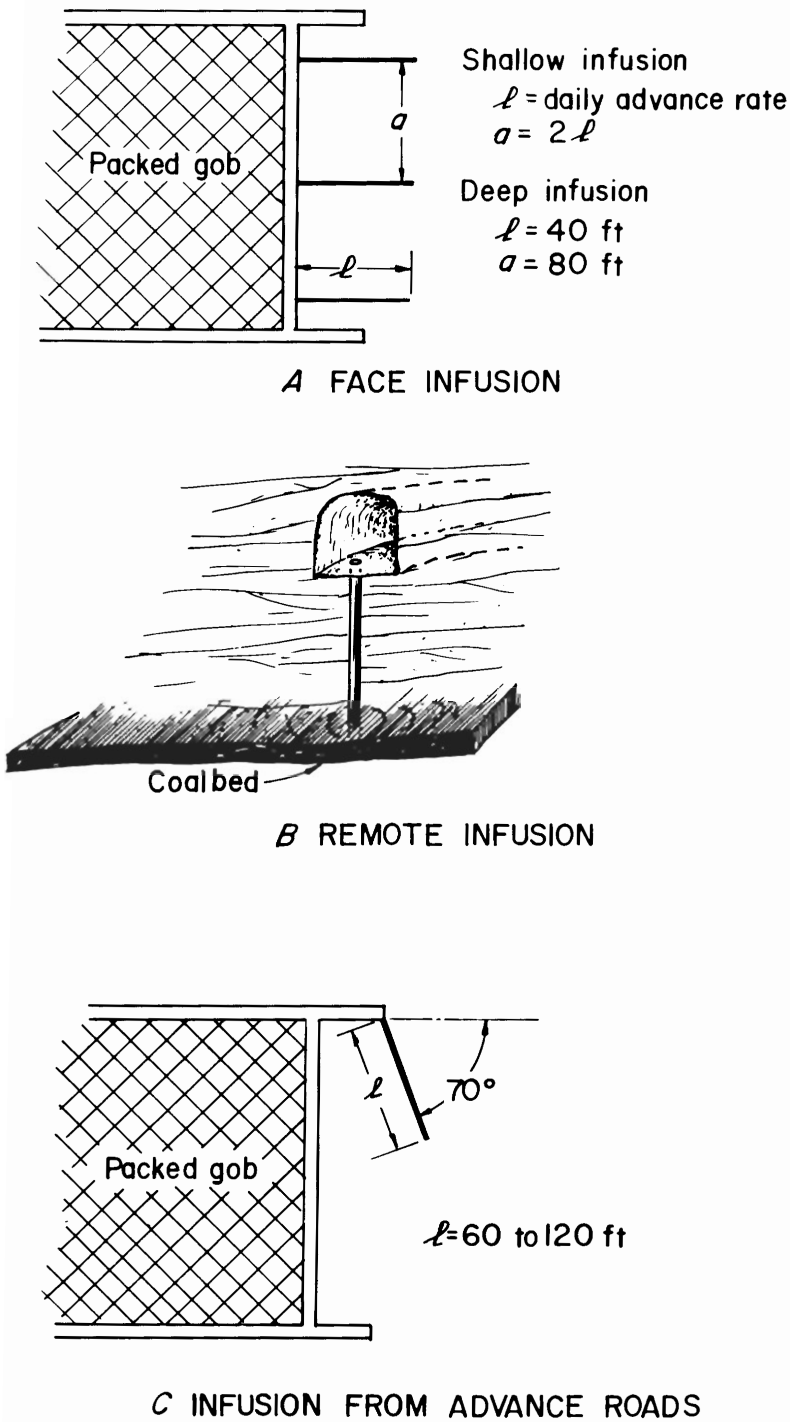


FIGURE 1. - European infusion methods.

mined, holes are drilled downward from this roadway into the panel and infused continuously.

3. A third procedure is infusion from advanced gate roads in which holes are drilled at an angle of 70° relative to the axis of the roadway. Hole depth ranges from about 60 to 120 ft. Infusion hose is grouted into the hole for distances of 45 to 60 ft.

Each of these methods has serious limitations. Shallow infusion in the face of the panel, where large numbers of holes are drilled and infused daily, can delay production. This method works well where manpower and equipment are available to complete the drilling and infusion phases in one shift. Although deep infusion requires fewer holes, more time is needed to infuse a larger volume of coal. In France, continuous face infusion is practiced in certain special situations on plow faces (2). Infusion holes are drilled in the upper part of the coalbed and infusion is performed during mining. A plow mines the lower portion of the coalbed and the top coal with the holes falls. Continuous infusion can be carried out only on plow faces that advance slowly. In some cases, the infusion hoses are damaged when the top coal falls.

With remote infusion or infusion from outside the coalbed, harder or more abrasive rocks make drilling more expensive and require special drills. This method is not used widely.

Drilling of holes in the advance gate roads does show promise, providing certain operational problems can be solved. At present, advance headings on high output faces in Germany (2) are ahead of the face only about 75 to 89 ft, even though these headings are manned 24 hours. Therefore, holes are drilled on weekends only. If problems develop during the drilling or sealing of the hole, infusion must be postponed until the following weekend. In France (8), longwalls are infused from the advance gate roads and complemented by infusion into the face of the longwall.

In spite of the operational difficulties of incorporating drilling and infusion cycles on an advancing longwall and not withstanding production delays, water infusion for dust suppression is a widespread practice in Europe.

## COALBED CHARACTERISTICS

Coalbeds are naturally fractured and can be characterized as being made of fractures and matrix (solid coal) (3). Generally, there are at least two sets of vertical fractures that intersect at right angles to form an interconnected network throughout the coalbed (11). These two fracture systems are known as face and butt cleats.

The matrix (solid coal) plays no part in the infusion process. Although it contains an interconnected pore system, these openings, which are about 5 A° (2 by $10^{-5}$ inches) in diameter (1), are too small to permit water to pass. Therefore, infusion of water into coalbeds is confined to the fracture systems only.

Fracture density of coalbeds, that is the number of fractures per inch, varies. Blocky coals, such as the Pittsburgh and Beckley, are characterized by a fracture spacing of 1 to 6 inches. Friable coals, such as parts of the Freeport, Kittanning, and Pocahontas No. 3 coalbeds, are characterized by a fracture spacing of about one-fourth of an inch. The ability of a coalbed to transmit fluids, such as water and methane, is determined by its fracture systems and is called the fracture permeability. Generally, blocky coalbeds are more permeable than friable coalbeds.

## INFUSION PROCEDURES

Although the migration of water through a coalbed during infusion cannot be observed, associated problems can be diagnosed and solved if the mechanics of infusion are understood. Definite relationships exist among parameters such as hole length, spacing between holes, quantity of infused water, and panel or section width.

### Infusion of a Development Section

Figure 2 shows water being pumped down a well bore and forced under pressure into a coalbed. The water flow rate will be governed by the water pressure in the well bore and the fracture premeability of the coalbed. Figure 3 is a plan view of the migration of water through the coalbed. The fracture

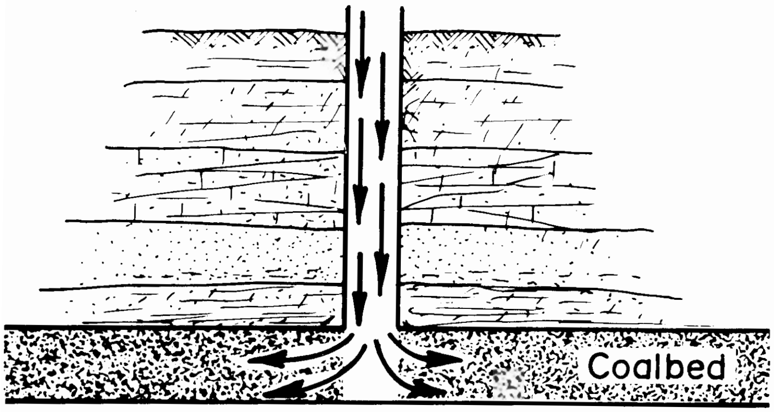


FIGURE 2. - Flow into coalbed through vertical borehole.

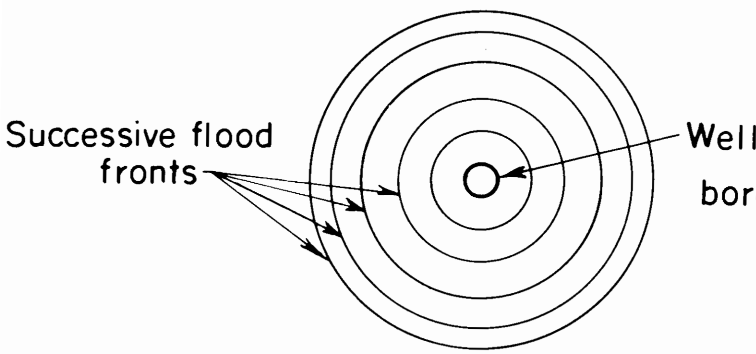


FIGURE 3. - Migration of waterfront through coalbed.

permeability of the coalbed has been assumed to be constant and the same in all directions. This condition is met by friable coalbeds, such as the Freeport, Kittanning, and Pocahontas No. 3. Under this assumption, the water moves away from the well bore uniformly in all directions and the circles in figure 3 show the successive positions of the waterfront.

Figure 4 shows a coalbed being infused by two wells separated by a distance, d. The waterfronts from each well will eventually merge and continue as one oval front. If three or more wells are used, the resulting infused zone will become oval shaped.

In the case of horizontal holes drilled underground into coalbeds, water should enter the coalbed from a small segment (10 to 15 ft) at the rear of the hole. This condition can be met by filling the horizontal hole with inflatable packers (fig. 5). Good results are obtained when 5-ft packers are connected with 5-ft lengths of pipe (5). If too few packers are used, the water at the rear of the hole tends to short circuit along the hole instead of penetrating the coalbed. As an alternate procedure, 3/4- or 1-inch plastic pipe can be grouted into the horizontal hole (6).

## Methane Flows During Infusion

Figure 6 shows the start of infusion in a 4-ft thick coalbed. Water flows into the coalbed from the rear of a 125-ft horizontal hole. As the waterfront, which has the shape of a right circular cylinder, moves outward, water which is being pumped into the coalbed at a rate of 15 gal/min, for example, moves outward through the sides of this imaginary cylinder at the same rate, because water is incompressible. When the cylinder is 50 ft in radius, the lateral surface area of the cylinder is about 1,256 $ft^2$. Therefore, water is flowing through each square foot of lateral surface area of the cylinder at a rate of 0.012 $gal/min/ft^2$. Methane is being displaced by the water at the same rate or 0.0016 $ft^3/min/ft^2$.

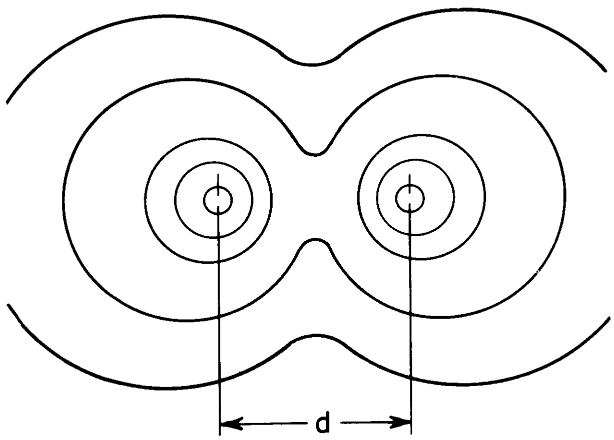


FIGURE 4. - Waterfront of two wells.

Just before the waterfront reaches the mine opening, the radius of the circular cylinder is about 125 ft. Water flow rate through the cylinder side is 0.005 gal/min/$ft^2$ and methane is being displaced into the mine opening at the same rate or 0.0007 $ft^3$/min/$ft^2$. If the average gas pressure in the coalbed is 300 lb/$in^2$, the methane flow rate will, in first approximation, be 20 times greater or 0.14 $ft^3$/min/$ft^2$. Assuming a face area of 80 $ft^2$ (20 by 4 ft), the total methane flow rate through the face due to infusion is 1.1 $ft^3$/min. This is barely detectable, even if only 3,000 $ft^3$/min of air is sweeping the face.

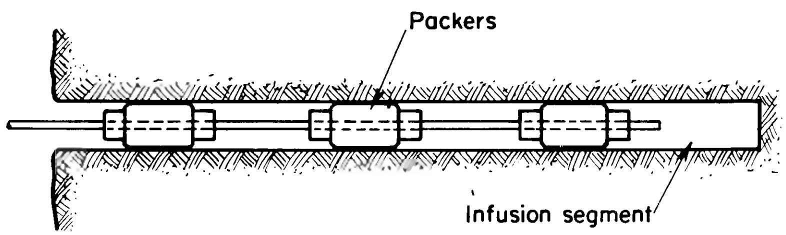


FIGURE 5. - Packed hole for water infusion.

Generally, during water infusion operations, two events work against each other. As the infused zone expands, it blocks gas flowing toward the face from virgin coal and consequently the flow through the face of the entry tends to decrease. However, as the waterfront moves toward the face, methane is pushed ahead of it, which would tend to increase gas flow through the face. However, observations during water infusion operations show no increase in methane flow at the face, Instead, a gradual decrease is observed from the start of infusion until the waterfront breaks through at the face. Thus, blocking action of infused water dominates its action.

As water reaches the face of the entry near the hole, it spreads until the face is covered. The calculations based on the example above show that the water flow rate from the face is about 0.005 gal/min/$ft^2$. Water appears on the face as droplets of water. When the face area (80 $ft^2$) is completely covered with droplets, the flow rate into the entry is 0.4 gal/min. Infusion is continued until droplets of water are observed for a short distance along the rib. If the floor is deteriorated by water, infusion should be terminated when water droplets cover the face.

## Location and Length of Horizontal Holes

A typical section advancing into virgin coal may be about 500 ft wide. To reduce methane flows through the section faces, a continuous waterbank must be emplaced to form a barrier across the width of the section. This prevents methane from flowing toward the faces and routes it around the water infused zone, allowing it to enter the mine opening through the ribs outby the face areas of the section.

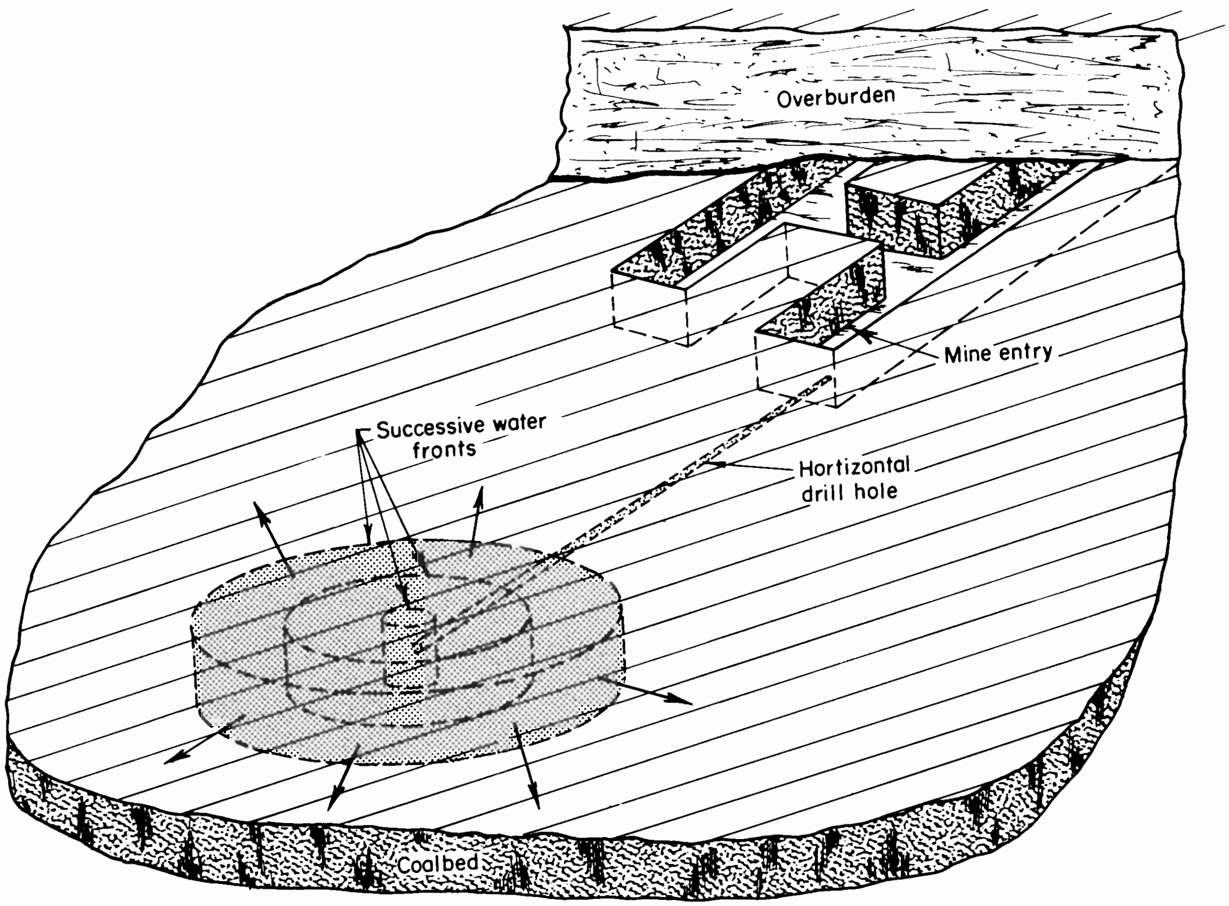


FIGURE 6. - Water infusion of coalbed through a horizontal hole.

The emplacement of a waterbank across the section requires two or more horizontal holes, depending on the length of the holes. Generally, horizontal holes 125 to 150 ft in length can be drilled with handheld drill equipment used underground. In some mines, entries are advanced in about 100-ft increments. Integrating a drilling and infusion phase into a mining cycle presents no special problems when 125- to 150-ft long holes are drilled.

Figure 7 is a schematic of the infusion of a coalbed through a packed horizontal hole (125 ft). When the waterfront first reaches the mine opening, the diameter of the infused zone is about 250 ft. The second hole should be drilled 140 to 170 ft from the hole shown in figure 7. When breakthrough occurs, the infused zones of each hole will merge like those in figure 4. This procedure is repeated with two additional holes to produce a continuous waterbank across the section (fig. 8).

There is no preferred sequence of infusing horizontal holes. They may be infused simultaneously or in sequence as they are drilled. The important thing is to leave no partially infused zones where methane can funnel through to the mine opening.

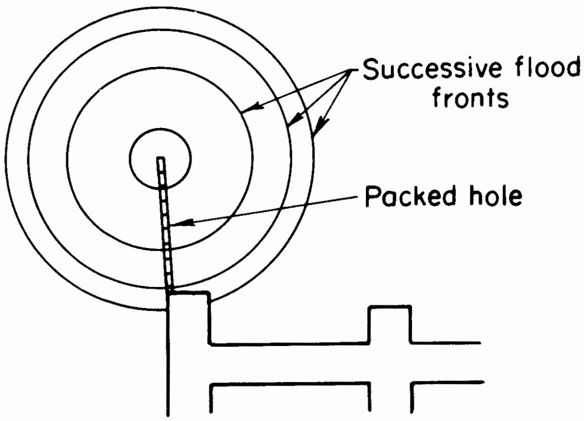


FIGURE 7. - Completed infusion of one hole.

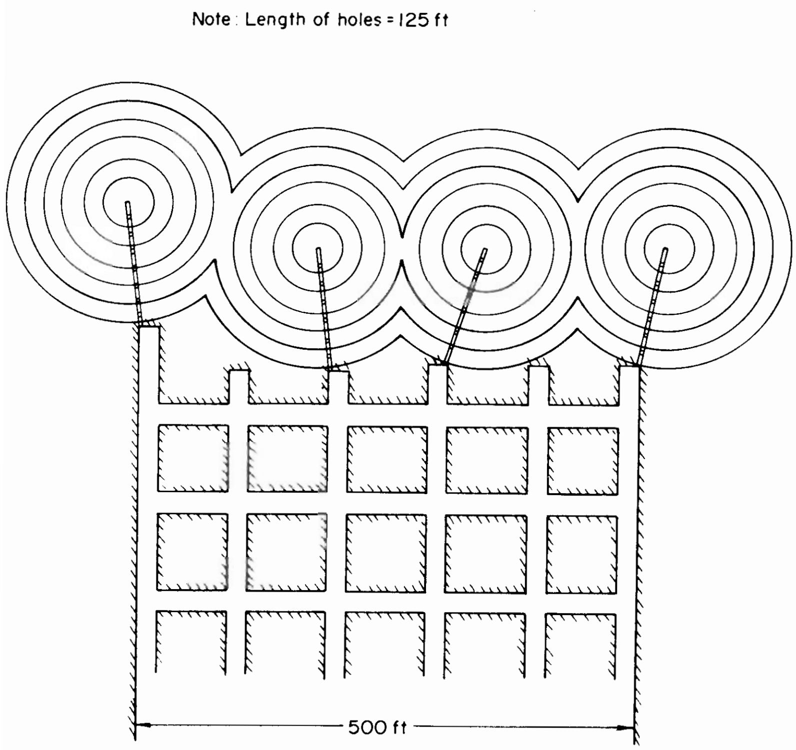


FIGURE 8. - Water-infused section.

## Directional Permeabilities

When the permeability of the butt cleat is appreciably different from that of the face cleat, the successive stages of the waterfront are distorted into an elliptical shape instead of being circular (fig. 8). In the Pittsburgh and Beckley coalbeds, which exhibit strong directional permeability, water migrates faster along the face cleat than along the butt cleat.

In figure 9, the more permeable face cleat is perpendicular to the direction of advance of the section. This is an ideal situation because the water tends to run across the section. Four equally spaced holes across a 500-ft section will emplace a waterbank free of uninfused or partially infused regions.

In figure 10, the face cleat is in the direction of advance of the section. At breakthrough, the distance of migration of the waterfront across the section is much less than in the direction of advance of the section. Drilling and infusing four holes across a 500-ft section can result in an infused zone where coal between holes may not have been swept by water (fig. 11). Such zones permit methane to bleed through to the faces of the section, thereby making the blocking action of water less effective. Six horizontal holes may be necessary to emplace a water bank across the section.

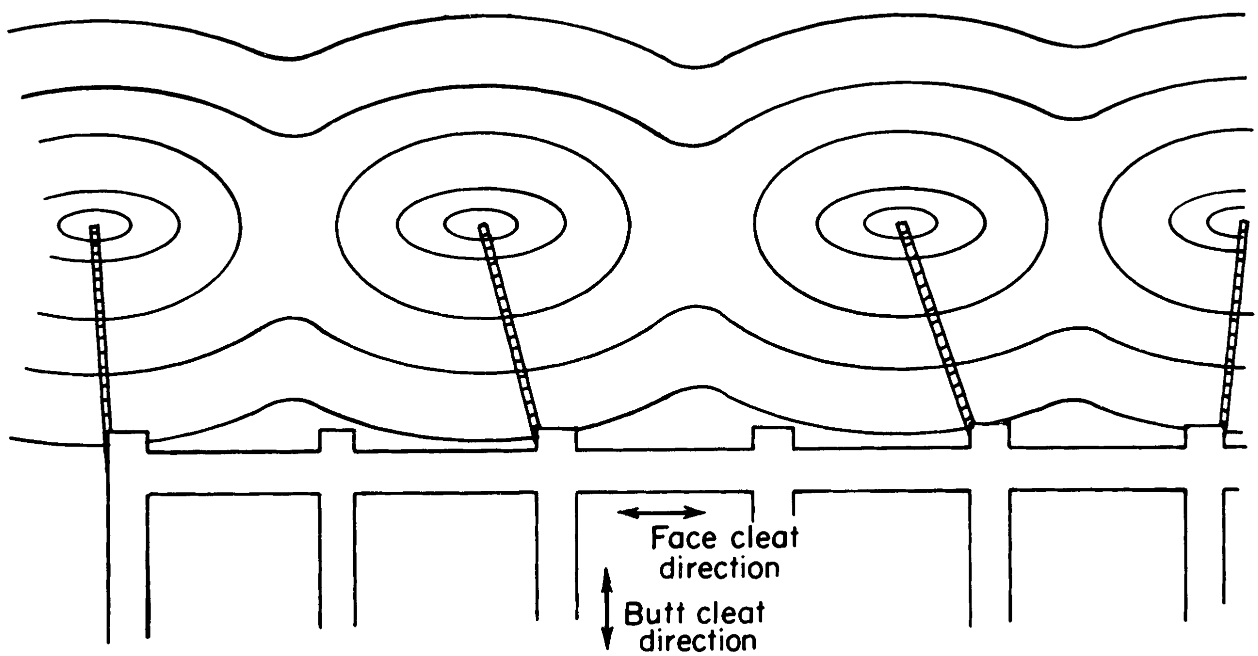


FIGURE 9. - Elliptical waterfronts for face cleat perpendicular to section advance direction.

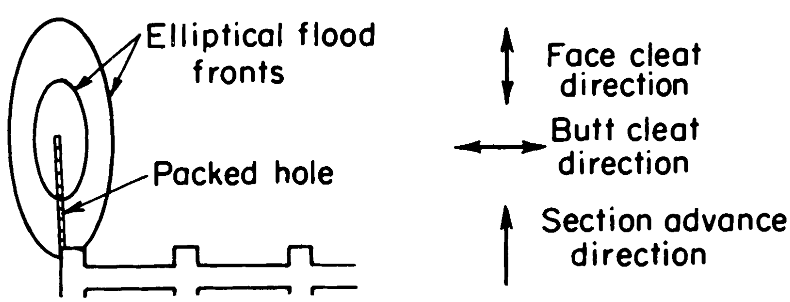


FIGURE 10. - Elliptical waterfronts for face cleat parallel to section advance direction.

## Effect of Mine Opening

The proximity of the infusion segment of the horizontal hole to the mine opening affects the shape of the waterfront, although the effect is not as critical in figures 8 and 9 as it is in figure 11. As the waterfront migrates toward the opening, the elliptical shape is distorted. This distortion is called cusping (12). Figure 12 shows the cusping of successive stages of the waterfront as it travels toward the mine opening. Cusping causes premature breakthrough of the waterfront with a corresponding decrease in lateral migration.

## Effect of Gas Pressure in Coalbed

Gas pressure increases with distance into the coalbed from the mine opening. Therefore, during water infusion, the waterfront farthest from the mine opening encounters a greater resistance than one closer to the mine opening. Because of the low gas pressure in the Pittsburgh coalbed at a depth of 100 ft (less than 30 $lb/in^2g$), distortion of the waterfront due to gas pressure should not be as pronounced as the effects of the mine opening or directional

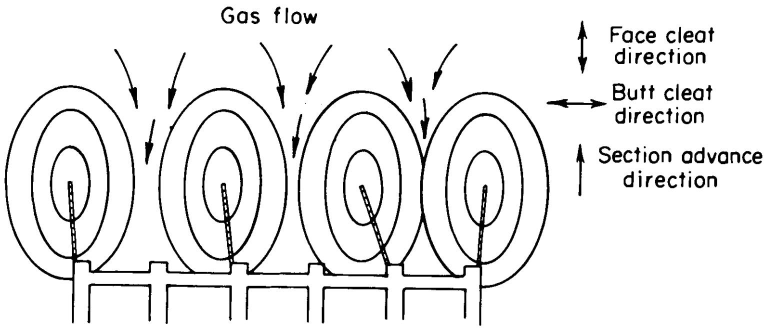


FIGURE 11. - Water-infused section for face cleat parallel to section advance direction.

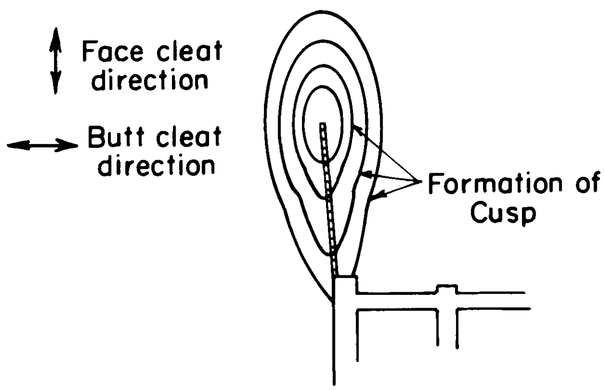


FIGURE 12. - Cusping of waterfront.

permeabilities. However, in coalbeds such as the Pocahontas No. 3 (10), where the gas pressure is about 600 lb/in$^2$g at a depth of 100 ft into coal, its effect could be as important as that of the mine opening or the directional permeabilities.

## Infusion of a Retreating Longwall

Unlike a room-and-pillar section, a retreating longwall can be infused with one or at most two holes drilled from the rib sides of the panel (fig. 13). Thereafter, the water spreads through the panel in much the same way as in room-and-pillar infusion. To infuse a 500-ft panel with one hole drilled from the rib side, the hole is drilled to a depth of about 275 ft which is about 25 ft beyond the centerline of the panel. Plastic pipe is grouted into the hole to approximately 255 ft, leaving about 50 ft of open hole for infusion of the panel. When completely infused, water will have traveled about 225 ft to the left and right of the hole and to both ribs of the panel. The total quantity of infused water will be about 15,000 gal/ft of coalbed height. Fracture porosity of the coalbed is assumed to be 1 pct. For the two adjacent infused zones to merge, the adjacent hole should be spaced approximately 400 ft or less from the infused hole.

An alternate procedure is to drill and infuse from both sides of the panel. Two holes are drilled to a depth of 150 ft and plastic pipe is grouted to a depth of 135 ft. When both holes are infused, the infused zones from each hole will merge and water will have spread about 135 ft to the left and right of the holes. The adjacent pair of holes should be located about 200 ft outby the infused holes.

The use of short holes drilled and infused from both sides of the panel is recommended. Long holes are difficult to drill because they may terminate prematurely in the roof or floor rock. They are also more difficult to grout since the grout may set prematurely because of the greater length. Possible disadvantages of drilling from both sides of the panel are that power may not be available on both sides of the panel and that drilling space is limited because of the conveyor belt. However, both these disadvantages can be avoided by drilling the holes during the development of the panel.

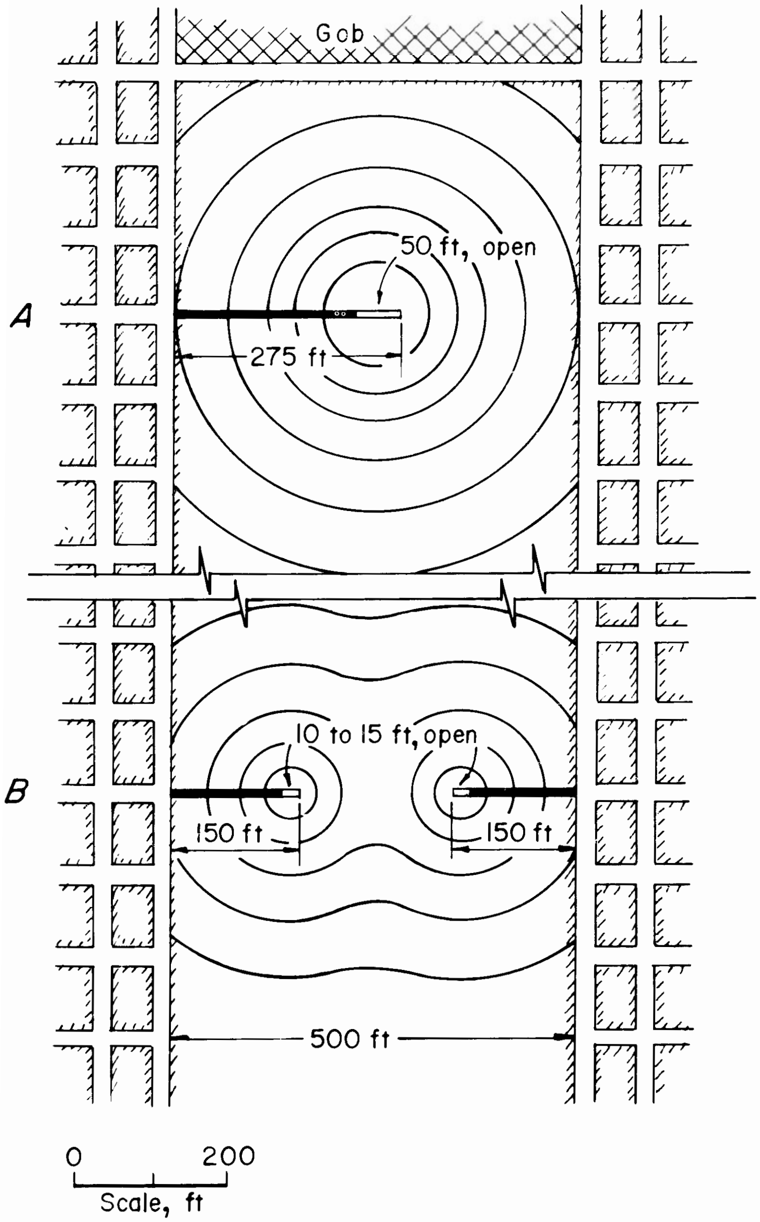


FIGURE 13. - Infusion of longwall with one or two holes.

## CASE STUDIES

### Methane

Several water infusion studies in friable and blocky coalbeds can serve to illustrate procedures, problems, and solutions. Figure 14 is a schematic of a 500-ft wide developmental section. The number of entries may range from six to nine, and generally, a split system of ventilation is employed. Four horizontal holes were spaced across the section; one in each outside return, and the two others spaced across the inside entries. Each hole was angled a few degrees off the projected development of the entry and infused with water.

Methane recording instruments were set up in the immediate returns. The sum of the readings of the inby instruments gives the total methane flow rate from the faces of the section. Two other sets of instruments were set up in the returns about 600 ft outby the faces of the section. The sum of the two outby instrument readings gives the total methane flow rate from the faces of the section and the two outside ribs. The difference between outby and inby methane flow rates is the flow rate of methane through the two outside ribs of the section.

A first study was conducted in the Pittsburgh coalbed in a section where the more permeable face cleat was at right angles to the direction of section advance (5). Referring to figure 9, this is an ideal condition because water tends to run across the section faster than toward the mine opening. A continuous waterbank is emplaced across the section, leaving no zones where methane can funnel through. Figure 15 shows the effect of the waterbank on methane flows in the face areas during mining.

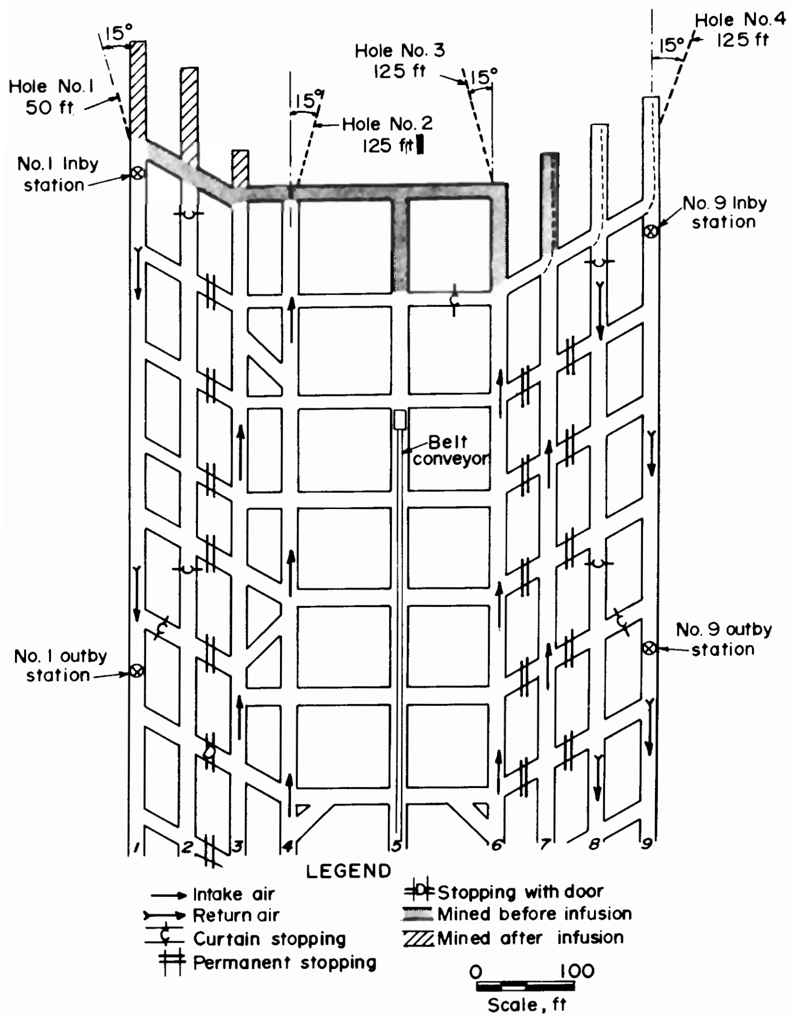


FIGURE 14. - Test section showing location of horizontal holes, methane monitoring stations, and ventilation plan.

The methane flow rate from the faces of the section (inby curve) averaged 132 ft$^3$/min before infusion and 28 ft$^3$/min after infusion. The average flow rate was thus reduced approximately 79 pct. The average methane flow rate at the outby stations decreased from 243 before infusion to 166 ft$^3$/min after infusion, a decrease of about 32 pct. As already noted, the difference between the inby and outby flow rates represents the quantity of methane entering the mine opening through the two outside ribs--111 ft$^3$/min before infusion and 138 ft$^3$/min after infusion. This 24-pct increase shows that the emplaced water is diverting methane from the face areas to the outside ribs.

A second study was conducted in a section (Pittsburgh coalbed) advancing parallel to the more permeable face cleat. Referring to figure 11, the infused water tends to run in the direction of section advance faster than across the section. Consequently, zones which have not been filled with water may exist between holes and may permit methane to funnel through to the faces of the section.

In figure 16, the average methane flow rate from the immediate face areas of the section (inby curve) is 265 ft$^3$/min before infusion and 165 ft$^3$/min after infusion, that is, a 38-pct reduction in methane flow rate. At the outby stations, the methane flow rate has dropped from 306 ft$^3$/min before infusion to 208 ft$^3$/min after infusion and represents a 32-pct reduction. The difference in flow rate between outby and inby curves is 41 ft$^3$/min before infusion and 43 ft$^3$/min after infusion.

These differences, which are not significant, indicate that no large volumes of methane are being diverted from the face areas to the outside ribs.

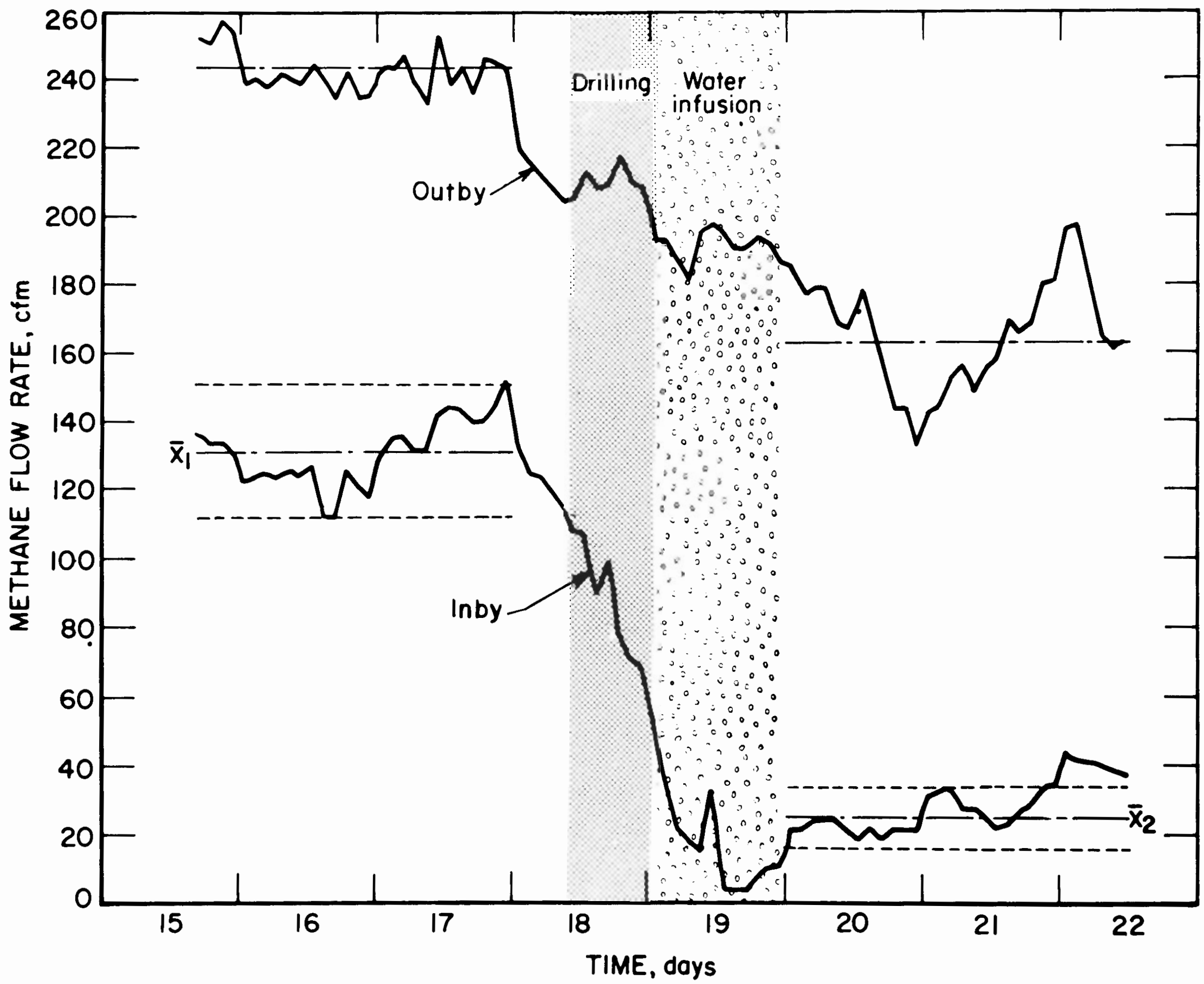


FIGURE 15. - Total methane flow rates from study area where face cleat is perpendicular to section advance direction.

To improve the effectiveness of water infusion, two alternatives are available. The first is to increase the hole depth to about 200 ft. The infused water will then tend to migrate further across the section before breakthrough occurs. The second alternative is to leave hole depth the same, but to increase to six the number of holes drilled across the section. Each of these procedures tends to produce a continuous waterbank across the section.

The third study was conducted in a friable coalbed (Upper Kittanning) where fracture permeability tends to be constant and the same in all directions, allowing infused water to spread uniformly outward from the hole (fig. 8). In this case, methane flow rate from the faces of the section averaged 90 $ft^3$/min before infusion and 10 $ft^3$/min after infusion (fig. 17). This represents an 89-pct reduction in methane at the faces during mining.

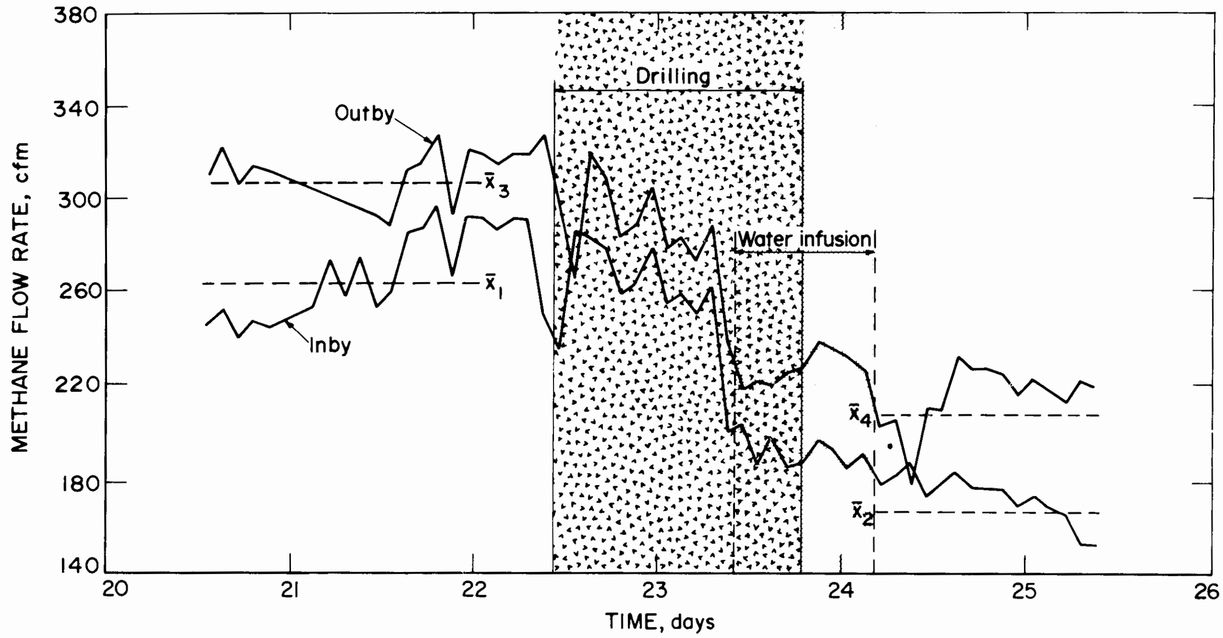


FIGURE 16. - Total methane flow rates from study area where face cleat is parallel to section advance direction.

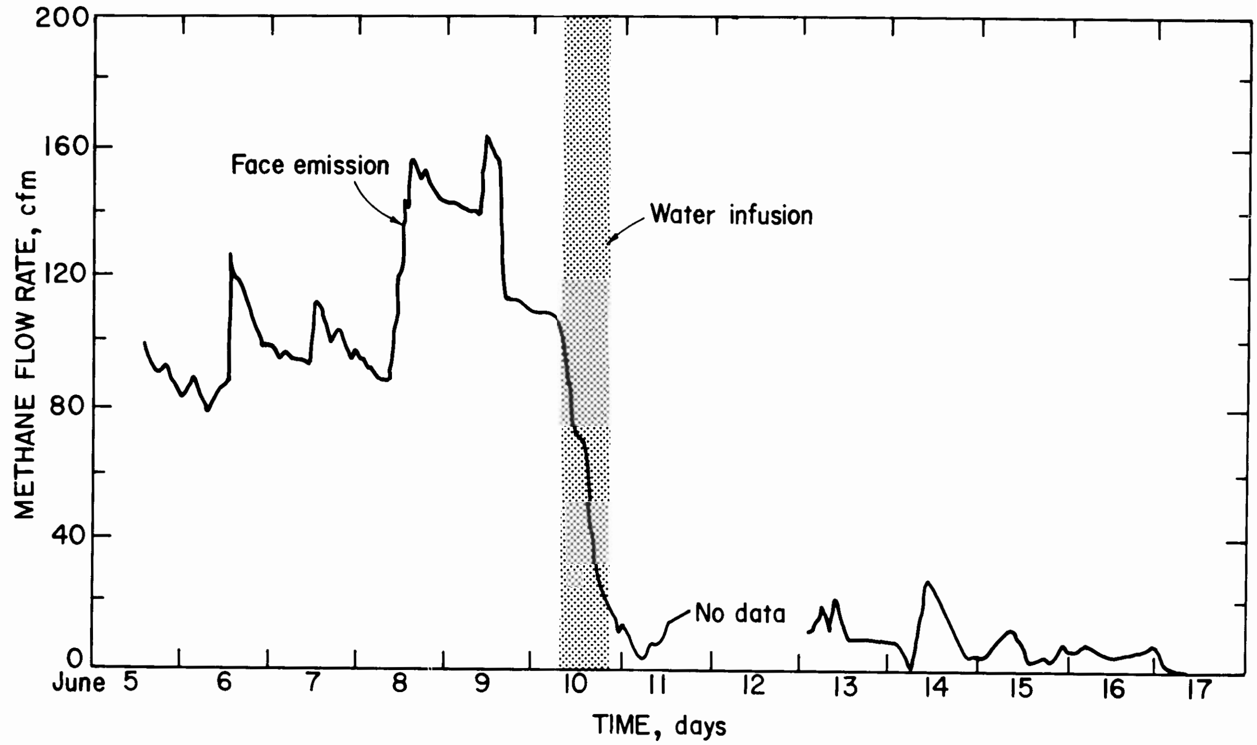


FIGURE 17. - Methane flow rates from faces of section in Upper Kittanning coalbed.

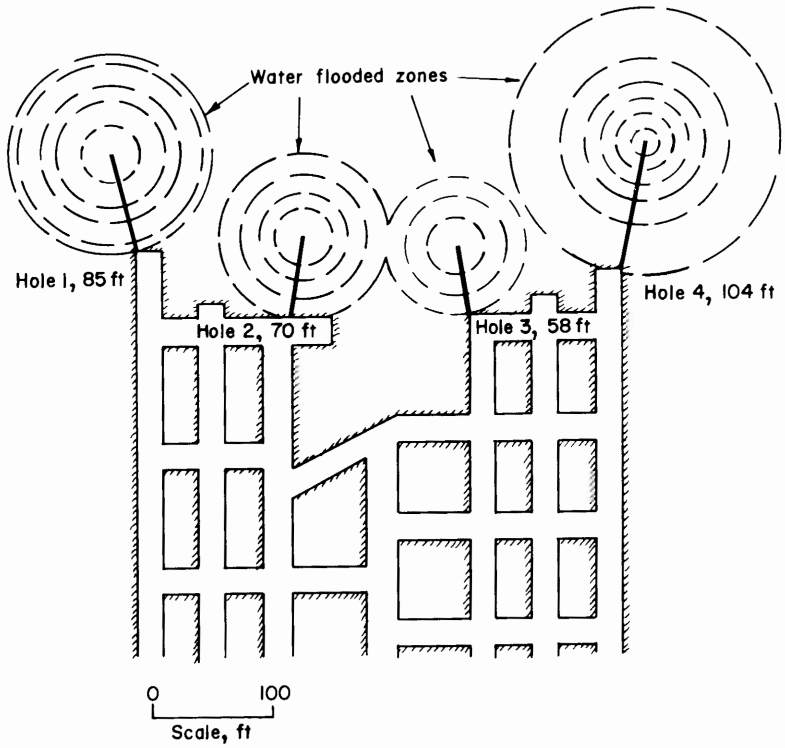


FIGURE 18. - Test section in Upper Freeport coalbed.

The fourth and final study was conducted in the Upper Freeport coalbed. The length of infusion holes ranged from 58 to 104 ft. Methane monitoring showed no significant reduction in methane flow from the faces of the section, although each hole was infused until water droplets appeared along the face, because uninfused zones allowed methane to migrate into the mine opening through the faces (fig. 18). This example illustrates the importance of the relationship of hole depth to spacing of holes across the section. If the holes are too short, uninfused regions occur through which methane funnels to the mine opening. As a general rule, the distance between the holes should be less than twice the length of the holes and all holes should be approximately the same length.

## Dust

Several water infusion studies for dust control have been conducted but not all have been successful. In two cases, water was channeled through large fractures and short circuited to the mine opening. In other cases in the Pittsburgh and Upper Freeport coalbeds, valid conclusions could not be drawn because of large variations in dust measurements. However, several tests have been conducted successfully and their results are summarized below.

Table 1 shows the results of an infusion test in a development section in the Upper Kittanning coalbed. Dust levels were reduced by 25 pct in spite of a 63-pct increase in production. If the data are corrected for the increase in production and air velocity during postinfusion sampling, the dust reduction due to water infusion is about 50 pct.

TABLE 1. - Infusion of development section

| | Average dust concentration (MRE mg/m$^3$) | Average production (tons/shift) | Average air velocity (ft/min) | Percent reduction (normalized) |
|---|---|---|---|---|
| Preinfusion..... | 2.4 | 67 | 332 | NAp |
| Postinfusion.... | 1.8 | 109 | 397 | 50 |

NAp--Not applicable.

In two trials on a longwall in the Pocahontas No. 3 coalbed, an 81-pct dust reduction was achieved in the infused zone (table 2). If the data are corrected for lower tonnage during postinfusion sampling, the dust reduction is 79 and 69 pct for tests 1 and 2, respectively (6).

TABLE 2. - Infusion of longwall

| | Dust concentration (MRE mg/m$^3$) | Production (tons/shift) | Average air velocity (ft/min) | Percent reduction (normalized) |
|---|---|---|---|---|
| Preinfusion.............. | 9.6 | 2,104 | 450 | NAp |
| Postinfusion (test 1).... | 1.8 | 1,900 | 450 | 79 |
| Postinfusion (test 2).... | 1.8 | 1,260 | 450 | 69 |

NAp--not applicable.

Dust measurements are made with MSA Monitare Model G personal dust samplers. Reproducible results are obtained when cyclones are separated from the dust pumps. In a development section, four cyclones are hung in the immediate return from the section to measure the effects of water infusion on dust generation during mining and reproducibility. On a longwall, cyclones are mounted near the tailgate (100 ft upstream) of the panel.

## MINING THROUGH AN INFUSED ZONE

When a section is water infused through holes drilled to 125 ft, the infused zone is about 250 ft deep and spans the width of the section. Starting on the left side of the section, two entries are advanced in increments alternately to 100 ft and the crosscut between these entries is also driven in increments (fig. 19). The continuous miner continues this cycling across the section until the section has been advanced one break, or about 100 ft. The miner then moves to the left side of the section and begins to advance the section on the second 100-ft increment, still within the infused zone. As the miner completes driving entries and crosscuts on the left side of the section, the hole drilling and infusion phases should be repeated. When the miner completes the advance on the right side of the section and moves back to the left side, the left side has been reinfused and the hole drilling and infusion phases are completed on the right side. Initially, the section should be infused over a weekend to avoid possible methane problems. Thereafter, drilling and infusion phases are incorporated into the mining cycle. Integrating the drilling and infusion phases into the mining cycle creates no serious problems and does not delay production.

The quantity of water infused on a development section (500 ft) ranges from 15,000 to 25,000 gallons for coalbeds from 4 to 6 ft in thickness. This amounts to 1 or 2 gal per ton of mined coal, as compared with an average water consumption of 6 gal/ton on a shearer and an average of 7.5 gal/ton on a continuous miner.

If the section is not infused after the second 100-ft increment has been mined, the flow of methane into each entry will begin to increase slowly. At this time, the infused zone is thin. Methane tends to drive the water in the

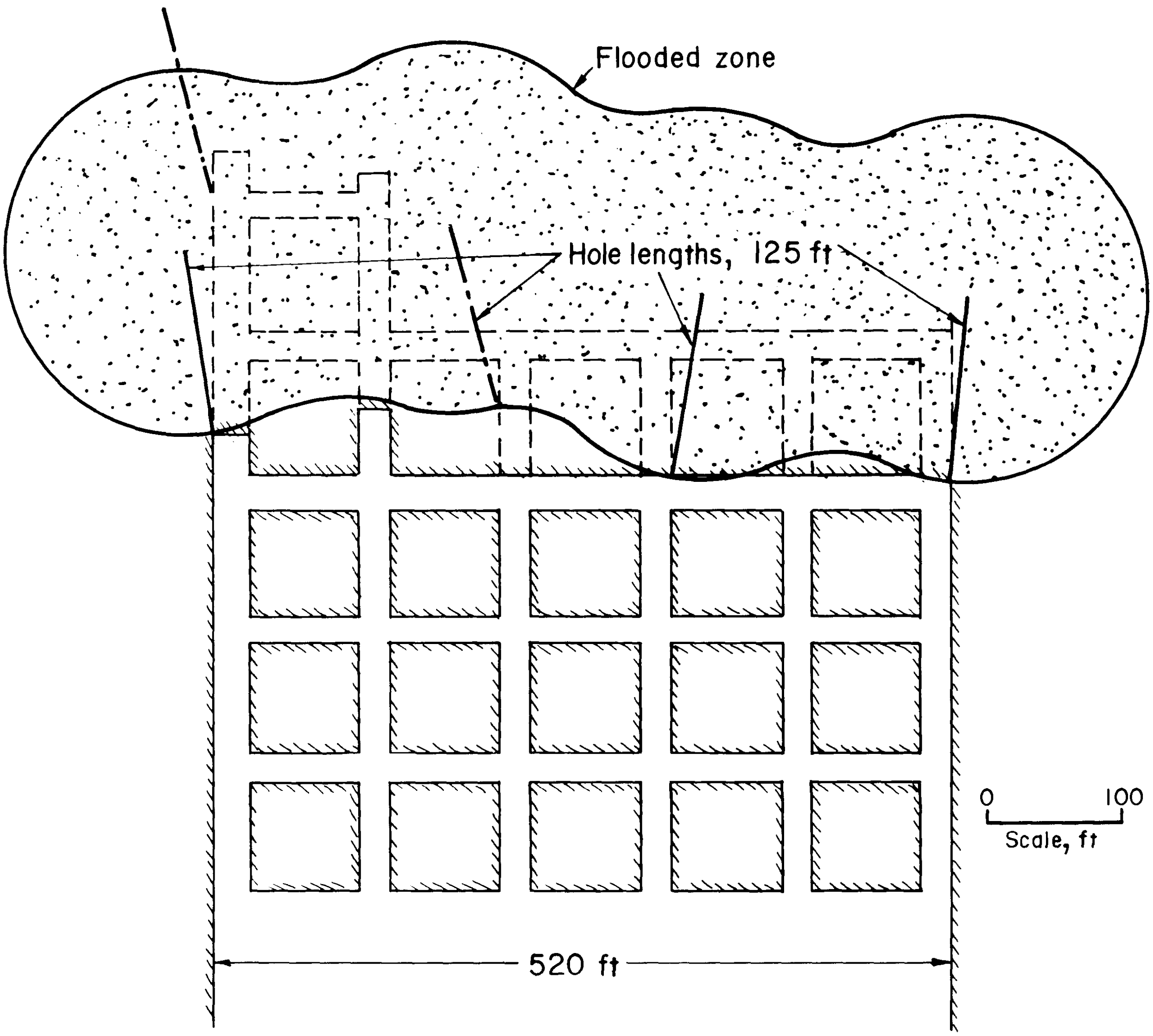


FIGURE 19. - Mining through infused zone.

coalbed aside and gradually methane flow through the faces increases. No abrupt surges of methane have been observed. Therefore, mining through an infused zone presents no special safety hazards. As always, sufficient air must be available to dilute methane to permissible levels.

Intercepting a water infusion hole during crosscut operations does not create an unsafe condition because flow from the hole is water. Mining parallel and into a water infusion hole, although not expected to create unsafe conditions, can be avoided by drilling all holes a few degrees off the direction of projected development of the entry.

## EFFECT OF WATER ON ROOF AND FLOOR STRATA

Like methane, water is normally associated with coal. Most coalbeds contain inherent water which is stored in the fracture system. In the Pittsburgh coalbed, horizontal holes drilled 400 to 500 ft in advance of mining produce water at persistent rates of 700 to 900 gal/day, even in sections that are considered "dry." In coalbeds throughout the United States, vertical boreholes drilled into virgin coal must have water pumps installed to clear the well bores of water in order to maintain gas production (7).

Because water does not readily wet coal and because of gravity, water is assumed to be in the bottom part of the coalbed. Observations show that the bottom 1 foot of coal along an outside entry is wet and the remainder of the coal is generally dry. If the bottom is in contact with inherent water, infusing water into a coalbed will not create conditions that have not already existed for ages. Thus, it appears doubtful that water infusion would affect even a soft bottom adversely.

The exposure of roof rock to water during infusion is not expected to contribute to roof failures. The roof is in contact with the infused water only where fractures in the coalbed terminate at the roof. Since fracture widths in coalbeds range from perhaps one-sixteenth of an inch to hairline cracks, the area of water contact with the roof is small in comparison to the area of the infused zone.

In actual practice, no roof or floor problems have been observed due to water infusion. One infused area was thoroughly investigated several months after the section advanced through the area. There were no indications in the roof or floor that the area had been infused. In one area, haulage was affected by accumulated drill water and breakthrough water which had been absorbed in the bottom. Such situations can be avoided by channeling water or installing pumps.

## DRILLING PROCEDURES AND EQUIPMENT

Coal is a soft brittle material and presents no special drilling problems. Water infusion holes are drilled with two types of 3-inch bits, One is a three-blade drag bit (fig. 20) and the other is a three-cone roller bit (fig. 21). The drag bit costs less and only the blades are replaced when worn. Under comparable conditions, the drag bit penetrates coal three to four times faster than the three-cone roller bit (4), which is used only when rock is encountered. The penetration rate of the drag bit in rock is nil. Flush joint drill casing is used in horizontal drilling work conducted by the Bureau of Mines. For holes drilled to 500 ft, EW flush joint casing is used which is 1-13/16-inch ID and weighs 28 lb per 10 ft. The drill casing is in 10-ft lengths for ease in handling underground. Shorter lengths of casing require more frequent interruptions in drilling.

FIGURE 20. - Three-blade drag bit.

Maintaining a bit on a horizontal trajectory or an incline to follow the dip of the coalbed is difficult even for short holes (200 ft). If the drill string in the hole consists of a bit and EW casing only, the trajectory of the hole is unpredictable. With low thrust levels and high rotational speed, the bit tends to wear the bottom side of the hole and consequently follows a trajectory into the floor. As thrust is increased, the bit may arc upward or downward.

A 10-ft stabilizer (fig. 22) is used to drill infusion holes rapidly and to minimize the effects of thrust and rotational speed on the path of the bit. An end view (fig. 23) shows the construction of the stabilizer, which is 2-15/16-inch OD and is used with a 3-inch bit. The outer tube is centered on EW drill casing. Water and drill cuttings pass through the annulus.

Starting or collaring a hole is very important. If the hole deviates by 2° from a given trajectory, the roof or floor will be intercepted in 100 ft in a 7-ft coalbed and in about 50 ft in a 4-ft coalbed if started in the center of the coalbed. Therefore, hole angle at the start of drilling must be within 1° of bedding planes. The 10-ft stabilizer cannot be turned or redirected because of the close fit between the wall of the hole and the outside diameter of the stabilizer.

After the hole has been collared, it is drilled as rapidly as possible. Generally, 125- to 150-ft holes can be drilled in 1.5 to 2 hours. However, if the hole must be redirected, more time will be required to complete the hole.

If the hole must be redirected, the 10-ft stabilizer is removed from the drill string. Procedures for redirecting a hole depend on the trajectory of the hole. If the trajectory is toward the top, the drill string consists of a drag bit and EW casing. This drill string is rotated at high speed and low thrust. This tends to wear the bottom side of the hole, causing it to drop. In some cases, after every 10 ft of advance, several slow reaming passes are made to increase the wear on the bottom side of the hole, causing it to drop faster.

FIGURE 21. - Three-cone roller bit.

If the hole trajectory is toward the bottom, the drill string consists of a short centralizer (fig. 24) placed directly behind the bit and followed by EW casing. The casing, which lies on the bottom of the hole, tends to tilt the centralizer and bit slightly upward, causing the hole trajectory to turn upward.

Generally, these procedures are sufficient for drilling holes to depths of at least 200 ft. If the hole has been collared initially at the proper angle, there will be no need to redirect it at a later state.

Horizontal holes can be drilled with equipment normally present on an operating section. A 56-lb handheld air drill (fig. 25) develops enough power to drill horizontal holes 500 ft (15). It can be placed on a frame and pushed manually. An alternate method is to pull the drill with a 1-ton "come-along." This drill unit can be moved from one site to another and set up rapidly in comparison to an electrohydraulic drill unit.

Power for the electrohydraulic drill (fig. 26) is supplied by a 15- to 20-hp electric motor which drives two hydraulic pumps in tandem. One pump drives an hydraulic motor which rotates the drill string; the other pump powers dual cylinders which provide the thrust on the drill string. A fire-resistant fluid is used in the hydraulic system.

FIGURE 22. - Ten-foot stabilizer.

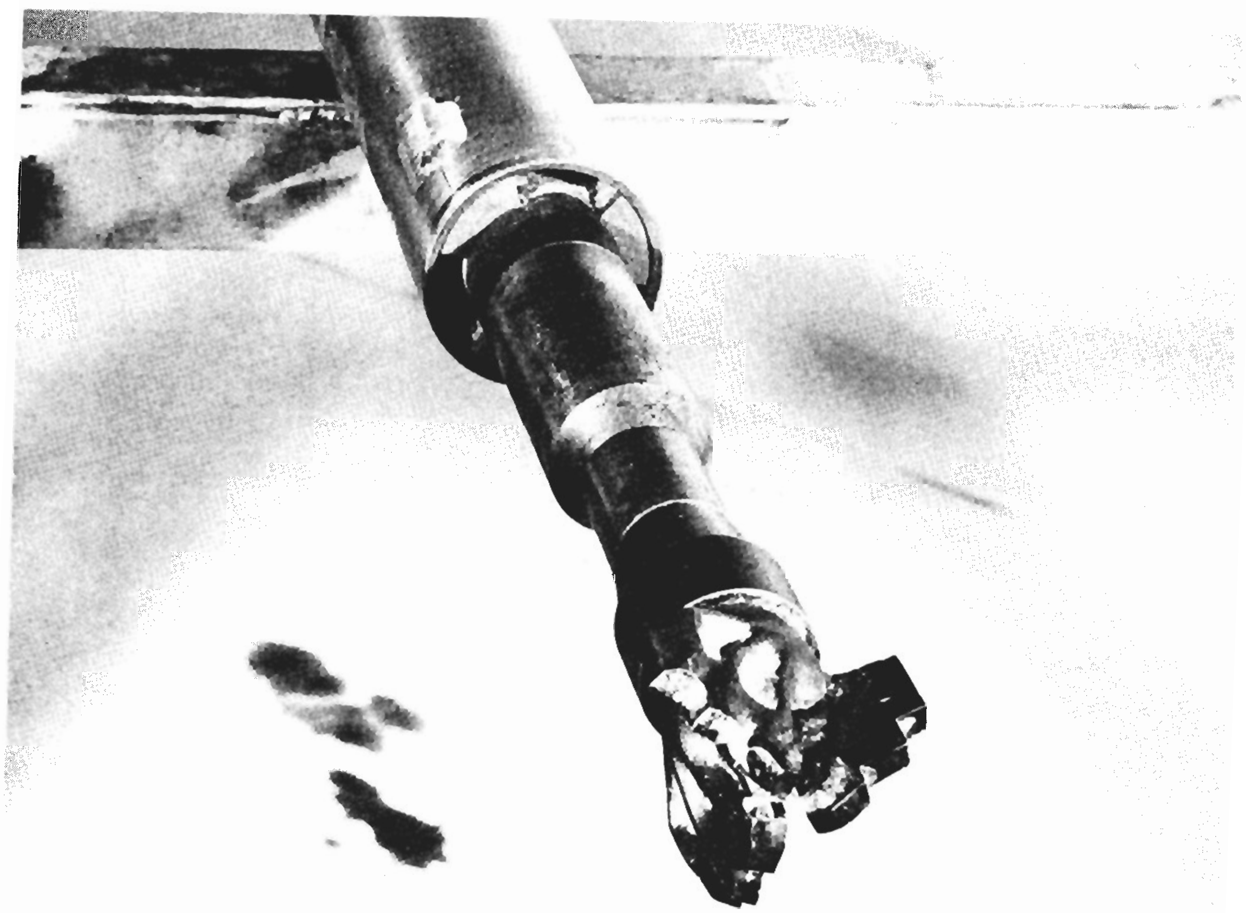

FIGURE 23. - End view of 10-foot stabilizer.

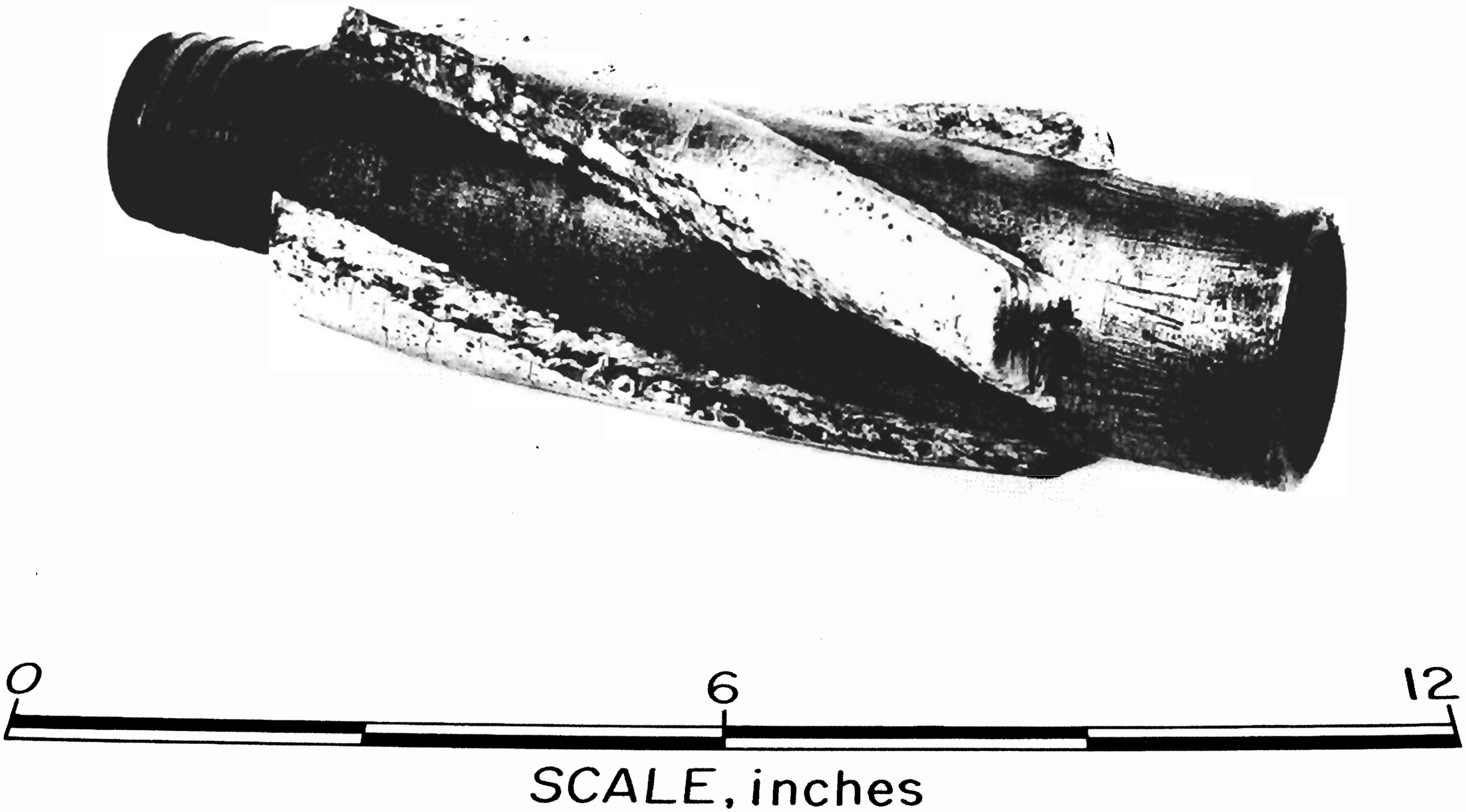


FIGURE 24. - Short centralizer (2-15/16-inch-diameter).

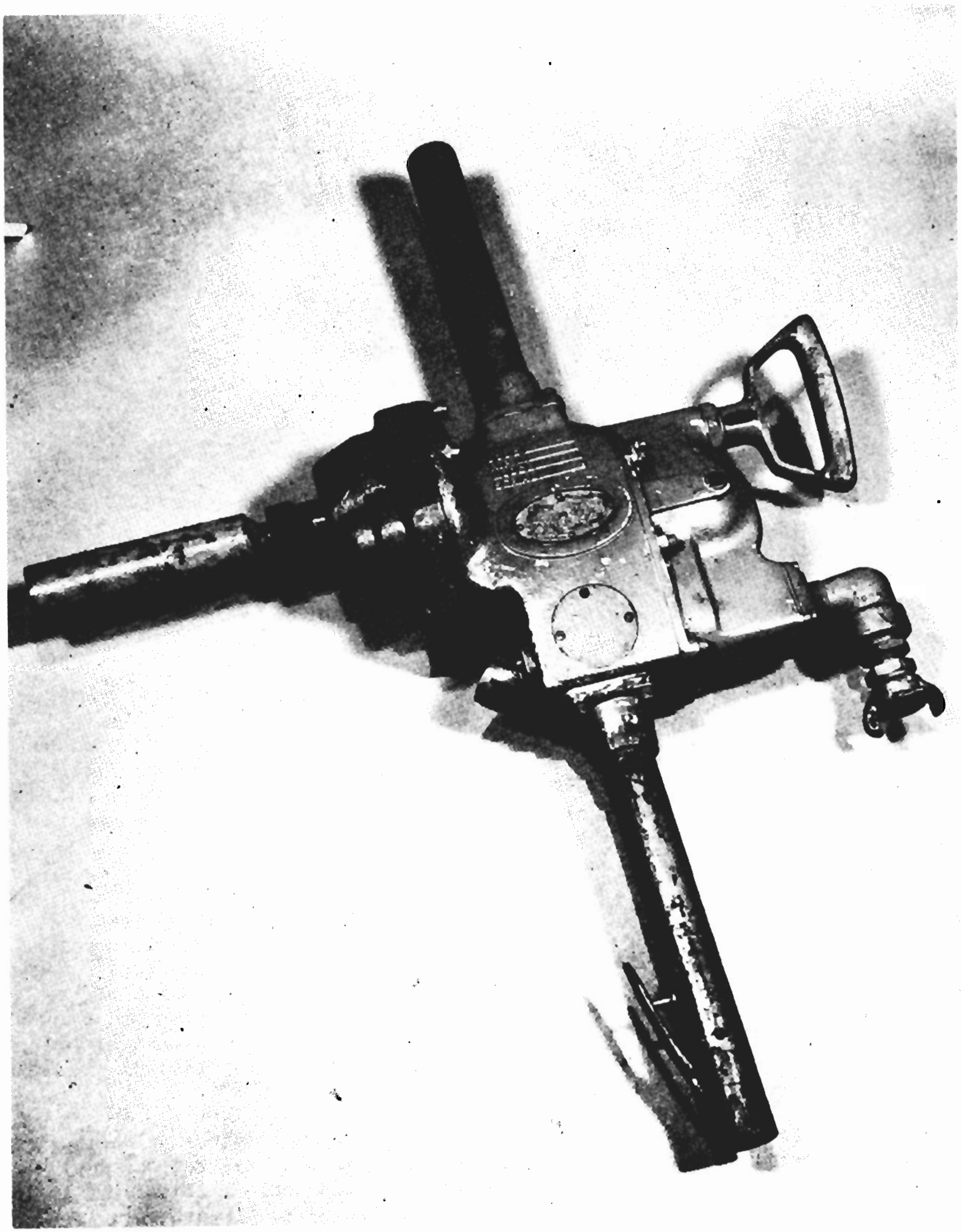

FIGURE 25. - Handheld air drill.

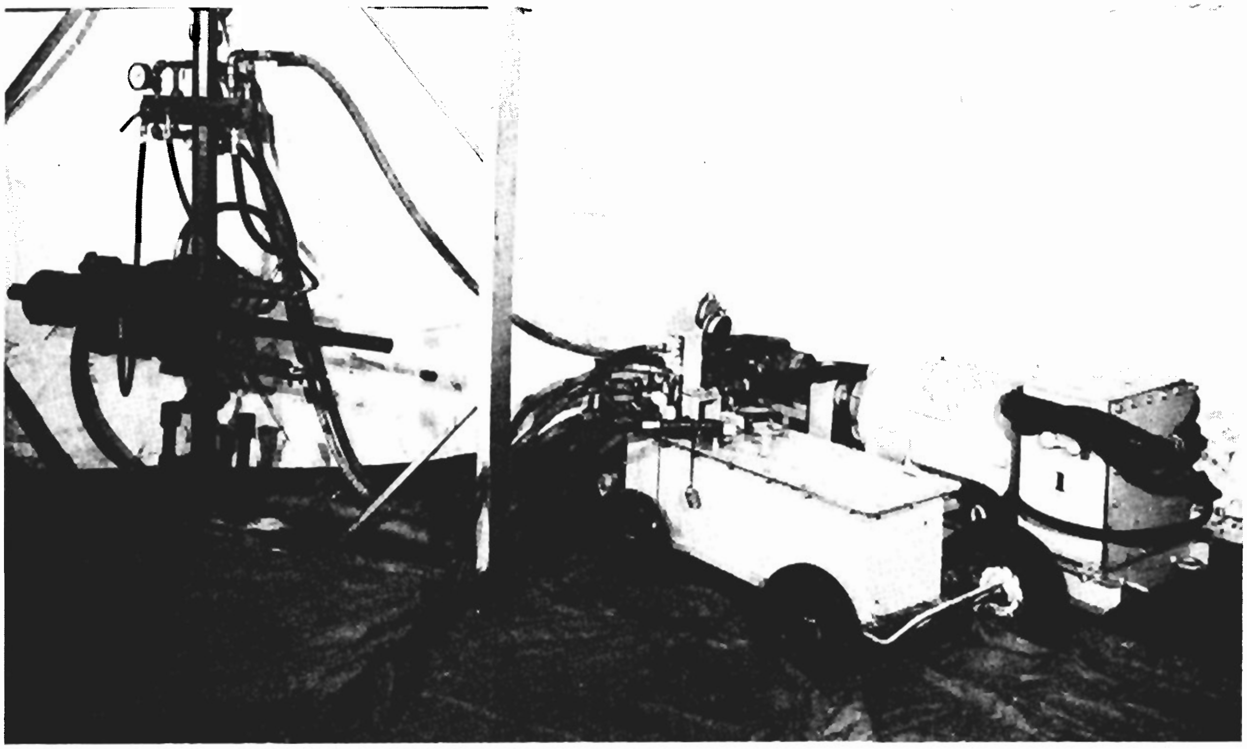

FIGURE 26. - Drill and power units.

## WATER INFUSION PRESSURES AND EQUIPMENT

The pressure required to infuse a coalbed depends on such factors as gas pressure, fracture permeability, and length of open hole through which the coalbed is infused. In many coalbeds, gas pressure is less than 75 $lb/in^2g$ at depths of 100 ft. Thus, gas pressure is not an important factor, except in the Pocahontas No. 3 coalbed, where a pressure of about 600 $lb/in^2g$ increases the infusion pressure significantly.

The length of open hole through which the coalbed is infused affects infusion rate and pressure. Infusion piston pumps are constant volume pumps. Consequently, as the length of open hole increases, infusion flow rate remains constant but the infusion pressure decreases. However, there is a limit to the acceptable open-hole length. In an extreme example, if the length of open hole in a 100-ft hole is 80 ft, the infusion pressure will be extremely low but within minutes the infused water will be short-circuiting through the face of the entry. Open-hole length should not exceed 10 to 15 ft.

Fracture permeability of the coalbed is the dominant factor affecting infusion pressure. Table 3 gives ranges of pressure and flow rates for several coalbeds. Length of open hole through which the coalbed is infused is 10 to 15 ft. In the Pittsburgh coalbed, the mine's water supply pressure is adequate to infuse the coalbed. Except for this coalbed, infusion pumps will generally be required.

TABLE 3. - Infusion pressure and flow rates

| Coalbed | Infusion pressure ($lb/in^2$) | Flow rate (gal/min) |
|---|---|---|
| Pittsburgh........... | 300 to 400 | 8 to 20 |
| Upper Kittanning..... | 700 to 1,150 | 8 to 12 |
| Upper Freeport....... | 1,000 to 1,800 | 7 to 16 |
| Pocahontas No. 3..... | 1,500 to 2,200 | 15 |

In Bureau infusion work, piston pumps are used. Their pressure range can be altered by changing the piston diameter. Table 4 shows pressure ranges of a piston pump and corresponding flow rates.

TABLE 4. - Infusion pump characteristics (three-piston)

| Piston size (inches) | Maximum pressure ($lb/in^2$) | Flow rate (gal/min) |
|---|---|---|
| 2.................... | 870 | 36 |
| 1-3/4................ | 1,140 | 27 |
| 1-1/2................ | 1,550 | 20 |
| 1-1/4................ | 2,200 | 14 |
| 1.................... | 3,500 | 10 |

## SUMMARY

Water infusion is an effective method of controlling methane during mining. In the Pittsburgh coalbed, a 79-pct reduction in methane flow is observed when the face cleat is perpendicular to the section advance direction. When the section advances parallel to the face cleat, only a 38-pct reduction in methane flow is observed. In the Upper Kittanning coalbed, emission rates were reduced 89 pct.

Generally, the spacing of holes across the section should be less than twice the length of the grouted portion of the hole. All holes should be the same length approximately. The coalbed may be infused progressively as each hole is drilled, or all holes may be infused simultaneously.

Infusion pressures range from 300 to 2,200 $lb/in^2g$. In the Pittsburgh coalbed, the mine water supply pressure is sufficient to infuse the coalbed. However, in other coalbeds, infusion pumps are necessary.

Water infusion is effective in reducing respirable dust in the Pocahontas No. 3 and Upper Kittanning coalbeds. Tests in the Upper Freeport and Pittsburgh coalbeds were not conclusive because of large variations in dust measurements.

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