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Water Infusion for Coal Mine Dust Control: Three Case Studies

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASUREMENT ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	mm	millimeter
ft	foot	pct	percent
ft^3	cubic foot	psi	pound per square inch
ft/min	foot per minute	psig	pound per square inch, gage
gal	gallon	rpm	revolution per minute
gal/min	gallon per minute	s	second
h	hour	st	short ton
hp	horsepower	vol pct	volume percent
lb	pound	wk	week
mg/m^3	milligram per cubic meter	yr	year

WATER INFUSION FOR COAL MINE DUST CONTROL: THREE CASE STUDIES

By John J. McClelland,[1] John A. Organiscak,[1]
Robert A. Jankowski,[2] and B. Rao Pothini[3]

ABSTRACT

This Bureau of Mines report discusses recent applications of water infusion technology to control dust in U.S coal mines and presents recommended guidelines for determining coal seam infusibility. The techniques required to use water infusion are presented in detail. A Bureau case study indicated that water infusion reduced dust levels by 68 pct along a longwall plow face, bringing this section into compliance with the 2.0-mg/m^3 Federal dust standard. Similar studies conducted by Occidental Research Corp. under a Bureau contract show water infusion at two longwall double-drum shearer operations produced dust reductions ranging from 38 to 50 pct. Water infusion was found to be cost effective, averaging 5 cents per ton.

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INTRODUCTION

Water infusion is the process of injecting water under pressure into the coal seam ahead of the face. The liquid infuses into the seam along fractures and cracks and, under pressure, penetrates a considerable distance from the hole radially, wetting the coal well (1).[4]

Longwall water infusion techniques have been recognized and widely practiced for many years in European mining as an effective means of dust control (appendix A). Belgium has utilized water infusion techniques for over 20 yr, and in the northern coalfields of France it is the basic dust control technique for 89 pct of the coal produced (2-3). Mining regulations in the Federal Republic of Germany require water infusion where possible, and over 50 pct of their longwalls are infused (4).

Longwall mining in the United States has only a recent history (a little more than 20 yr), and only during the past decade has there been a dramatic growth in its use. In the early to middle 1970's more than half the longwalls were out of compliance with the mandatory 2.0-mg/m^3 Federal dust standard. Since then the Bureau has done considerable work adapting and modifying European water infusion technology to meet U.S. longwall operator's needs (appendix A).

This paper presents three underground case studies and final guidelines for implementation to conclude Bureau of Mines research on infusion. A Bureau survey of water infusion applications was conducted at a large southern West Virginia coal mine operating a longwall plow face in the Pocahontas No. 3 Seam. Similar surveys were conducted by Occidental Research Corp. under a Bureau contract at two longwall double-drum shearer operations mining the Pocahontas No. 3 and Upper Freeport Seams. The objective of all three surveys was to quantify the potential dust reduction benefits from water infusion and to identify new and/or improved methods for infusing longwalls.

CASE STUDY 1: INFUSION OF A PLOW FACE IN THE POCAHONTAS SEAM

Water infusion was successfully applied on a longwall plow face to supplement the standard dust control methods for achieving compliance with the 2.0-mg/m^3 dust standard. Prior to infusion, the most recent Mine Safety and Health Administration (MSHA) compliance sampling had indicated that the exposure levels of four shield setters and a tailgate plow operator exceeded this standard. Despite the mine's numerous attempts to effectively control and/or suppress the generation of respirable dust, it was unable to maintain compliance consistently. Based on discussions between representatives from the mine, MSHA, and the Bureau of Mines, it was decided to implement water infusion as an alternative dust control technique. At the invitation of the mine, the Bureau designed and initiated a dust sampling program to evaluate the effects of water infusion on dust levels along the longwall plow face (appendix B).

IMPLEMENTATION

The mine used the Bureau infusion method as modified under an Occidental Research Corp.-Bureau of Mines cost-sharing contract (5).

Five 3-in-diam holes, on 270-ft centers, were drilled, packed, and infused along the rib side of the 530-ft-wide coal block. Located roughly 18 in below the roof and above a midseam parting, infusion holes were drilled to a depth of 270 ft, using Acker Big John and Little John portable electric-hydraulic rotary drills.[5] An extruded bag packer was used for grouting and packing infusion holes (fig. 1). As each hole was completed, a premixed batch of grout was pumped in and packed to a depth of 220 ft at pressures

[4]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

[5]Reference to specific equipment does not imply endorsement by the Bureau.

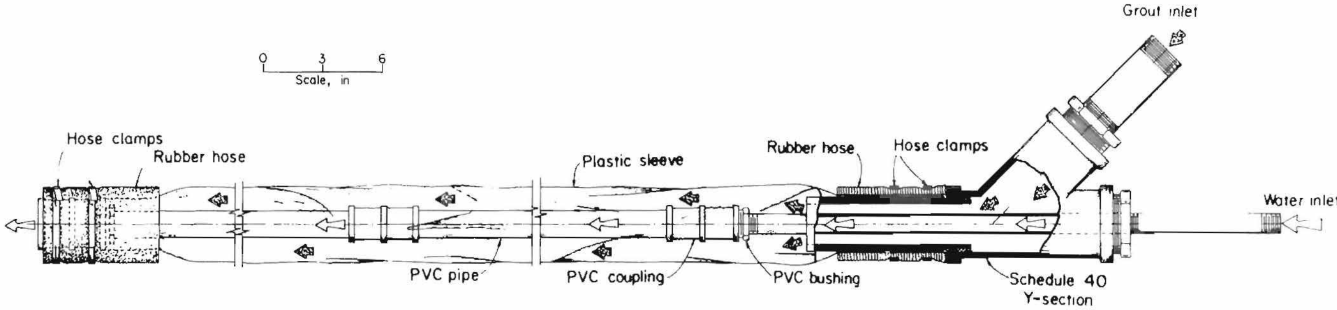

FIGURE 1.—Bureau extruded bag packer.

of 125 to 150 psi. Grout composition consisted of water, Calseal, cement, salt, and CFR2 (a grout fluidizing agent). As experience and success with the infusion procedure increase, the mine will investigate the possibility of maintaining compliance while increasing infusion hole spacing to equal the panel width.

Water containing a 0.2-pct concentration of Wendon Dustally Plus was pumped into each hole at flow rates averaging 6 to 10 gal/min under 600 psig. Standard procedures for infusing coal do not require the addition of surfactants to the water supply. However, since surfactants were injected into the main water line, no attempt was made to run a fresh split of water. Simultaneous infusion of several holes was possible using a Myer D50 pump with a rated maximum capacity of 50 gal/min at 2,000 psi, connected to a 50-hp motor. As past research had indicated, the Pocahontas No. 3 Seam proved to be an excellent seam for water infusion. The first infused hole encountered by the retreating longwall face received 79,054 gal of water, the computed theoretical volume. The mine elected to infuse the remaining four holes beyond their calculated theoretical volume to ensure that the coal block was completely saturated. Water was pumped into each hole until (1) accumulations of water on the floor interfered with mining, (2) short circuiting of water occurred, or (3) the face reached the hole. Hole 2 had received only 2,300 gal of water when the packer failed, resulting in short circuiting of water. Holes 3, 4, and 5 accepted 175,306, 120,140, and 107,049 gal, respectively.

For infusion to work, water must completely saturate the coal block. For this to occur in the Pocahontas Seam, it was necessary for water to penetrate a midseam parting. Observations along both the panel intake and return side ribs revealed runoff of water above and below the parting, up to 270 ft on each side of the hole. Pools of water were common along the base of the rib where water had run out of the bottom. Observations also revealed that water had migrated across a 6- to 8-in top drawrock and into an overlying 1-1/2-in coal parting. Based on these observations, it was concluded that the coal block had been successfully saturated.

Four weeks following the initial (pre-infused) underground dust survey, the active face had advanced 1,080 ft and encountered the first of five infused holes. A follow-up (infused) survey was then initiated to evaluate the effects of water infusion on dust levels along the longwall plow face. Dust sampling commenced 55 ft outby the infusion hole axis, still well within the infused zone.

RESULTS OF GRAVIMETRIC SAMPLING

Table 1 lists the results of gravimetric sampling for pre-infused and infused dust surveys. Concentrations reflect the average over three shifts for each of the six sampling stations. Note that no 8-h, full-shift sampling, similar to compliance sampling, was performed. Dust

TABLE 1. - Pre-infused versus infused gravimetric sampling data

Sampling station	Dust concentration,[1] mg/m³		Dust reduction, pct
	Pre-infused	Infused	
Section intake.....	0.2	0.1	50
Beltway............	.2	.1	50
Support 2..........	1.1	.5	55
Support 15.........	2.1	1.2	43
Midface............	3.9	1.3	67
Support 97.........	3.1	1.0	68

[1]Concentrations are not calculated MRE equivalents.

TABLE 2. - Average face air velocities and tonnage per shift

	Face air vel, ft/min	Output per shift, st
Pre-infused..	567	1,417
Infused......	562	1,605

TABLE 3. - MSHA compliance data

Occupation		Concentration, mg/m³	
Code	Operator	Pre-infused	Infused
044.....	Headgate.	2.0	0.6
041-1[1]..	Support..	5.0	1.1
041-2...	...do....	5.5	1.8
041-3...	...do....	4.1	1.5
041-4...	...do....	4.5	1.6
052.....	Tailgate.	2.3	1.3
Average..........		3.9	1.3

[1]The 041 occupations are numbered starting at the head side with number 1 and ending at the tail with number 4.

reduction values have been computed and represent the percent difference in dust levels at each sampling station resulting from the implementation of water infusion.

No attempt has been made to normalize gravimetric data for production or face air velocity. As shown in table 2, conditions were almost identical during both surveys. Any attempt to normalize the data would actually increase computed dust reduction values.

Through a comparison of baseline, pre-infused, and infused dust data, it is apparent that a successful application of water infusion was achieved. Dust reductions ranged from 43 to 68 pct along the face, with the most significant reductions measured at midface and support 97. Samples have shown the moisture content of the coal increased by more than 1.0 vol pct, resulting in significant dust reductions at several face sources. (Although primary intake and beltway air had little impact on dust levels, the data were included to indicate the possible association between water infusion and intake sources of dust.)

Listed in table 3 are the results of MSHA compliance sampling conducted at or near the time of both Bureau dust surveys. A direct correlation exists between the Bureau survey and MSHA compliance sampling, indicating that water infusion resulted in substantial reductions in respirable dust exposure levels. Results from MSHA compliance sampling, taken while mining in the infused zone, found the plow section to be in compliance with the 2.0-mg/m³ Federal dust standard. Based on Bureau and MSHA findings, the mine has made water infusion a part of its dust control plan.

RESULTS OF INSTANTANEOUS SAMPLING

Stationary instantaneous sampling was conducted at support 26 to help determine the degree of impact water infusion had on several face dust sources, namely plow- and support-generated dust. Results from pre-infused and infused surveys are summarized in table 4.

Results support earlier conclusions stating that water infusion directly affected the quantity of dust generated by several sources along the face. Initial survey results indicate that support-generated dust contributed most

TABLE 4. - Results of instantaneous sampling, pre-infused versus infused

Sources of dust	Concentration, RAM units		Dust reduction, pct
	Pre-infused	Infused	
Plow..............	0.1	0.1	0
Headgate sources[1].	.8	.4	50
Supports..........	2.0	1.5	25

[1]Headgate sources: stageloader, crusher, coal transport, section intake.

of the respirable dust responsible for face workers' exposure. Best estimates are that water infusion reduced this dust source by 25 pct. Since gravimetric results show dust reductions of 67 and 68 pct at midface and support 97, respectively, it is assumed that support dust reductions were greater in the vicinity of these supports.

The effects of water infusion on plow-generated dust were negligible. During a typical cut, plow-generated dust is reflected in the computed difference between intake and return air side dust levels with respect to the plow. Results from both surveys indicate plow-generated dust averaged less than 0.2 RAM unit.

RESULTS OF CONTRACT RESEARCH

Similar studies were conducted under a Bureau of Mines contract by Occidental Research Corp., which has access to Island Creek Corp's. longwalls. (Both are wholly owned subsidiaries of Occidental Petroleum Corp.) Island Creek Corp. operates longwalls in several different coal seams. Some of these longwalls were having compliance problems and were ideal as test sites. The following two case studies highlight the Occidental evaluation of water infusion technology. Specific details can be found in the contract final report (5).

CASE STUDY 2: INFUSION OF A SHEARER FACE IN THE POCAHONTAS SEAM

IMPLEMENTATION

Water infusion was tested on a double-drum shearer longwall in the Pocahontas No. 3 Seam. The 60-in-thick Pocahontas No. 3 Seam had an average overburden depth of 1,800 ft and an average moisture content of 0.5 pct. Twenty-four holes were drilled in a 600-ft-wide panel with an average spacing of 300 ft. Hole depths ranged from 42 to 300 ft. The shallower holes were due to the lack of reserve power from an air-powered drill needed to overcome high abutment pressures. An electric-hydraulic post-mounted drill produced more consistent and deeper holes.

The holes were sealed using an extruded bag packer. Packer lengths varied but were usually 250 ft with a maximum length of 270 ft. The shorter holes (under 65 ft) were usually not packed because infusibility was determined from previous trial holes and the benefits realized did not seem to justify the labor expended on infusing these holes. Packer grouting pressures ranged from 100 to 200 psi. A day was the minimum time allotted for the grout to cure before infusion.

The infusibility of the Pocahontas No. 3 Seam was fairly good, but moderately high water pressures were required due to high overburden thickness and fairly high gas pressures. The infusion procedure used to achieve good saturation of the coal seam was based on experience gained on previous holes. Since good water pressure (650 psi) was available from gravity-fed lines, this water pressure and supply were used continually until water flow fell significantly below 10 gal/min. A pump was then used to increase the water pressure and flow to approximately 1,000 psi and 10 gal/min, respectively. At this flow rate and pressure, good seam saturation was achieved. In one hole a maximum quantity of 128,342 gal was infused, which was higher than the estimated volume.

RESULTS

After the panel was infused, dust concentrations were monitored along the face with instantaneous and gravimetric samplers inside and outside the infused zones. Multiple gravimetric samplers were placed at the headgate, midface, and tailgate. Gravimetric and instantaneous samples were also taken at the midpoint of the shearer. Respirable dust reductions were usually greater than 50 pct along the face in the infused zones, and the dust levels were well below the compliance level near the axis of the infusion hole (5). Infusion in the Pocahontas No. 3 Seam was reasonably cost effective at 5 cents per ton. In consequence, this mine has made water infusion part of its dust control plan.

CASE STUDY 3: INFUSION OF A SHEARER FACE IN THE UPPER FREEPORT SEAM

IMPLEMENTATION

Water infusion was also tested on a double-drum shearer longwall in the Upper Freeport Seam. This 90-in-thick seam had an average overburden depth of 350 ft and an average moisture content of 3.2 pct. Four holes were drilled in a 550-ft-wide longwall panel in this seam. Holes were placed approximately on 300-ft centers to depths ranging from 160 to 280 ft. As the seam had a fairly thick rock binder (12 in), three holes were placed below the rock binder and one hole above. The 3-in-diam holes were drilled with a compressed-air-operated wet-head drill. A portable track-mounted dc-driven compressor supplied air to the drill. Since the drill was a pure rotary type, an air hoist was used to provide drilling thrust. This procedure worked well, particularly in this thick seam where a 300-ft-deep hole can be maintained within the seam without entering the floor. Lower abutment pressures associated with a shallow overburden depth permitted the drill to have adequate power to drill 300-ft holes. Lower equipment cost and low weight are the principal advantages of this setup.

The holes were grouted and packed, as in the Pocahontas No. 3 Seam, and the packer depths ranged from 110 to 190 ft. After allowing for grout curing in the holes, water from the mine supply was infused at low pressures (180 to 225 psi). These low pressures yielded good flow rates, usually a little less than 10 gal/min. Volumes of water accepted in this seam were much lower than in the Pocahontas No. 3 Seam. The largest volume of water infused in the Upper Freeport Seam was 24,486 gal, versus 128,342 gal in the Pocahontas No. 3 Seam. This was attributed to several coal seam characteristics, but the significance of each could not be determined. One characteristic was the widely spaced cleat system, which may allow only a limited amount of coal wetting. Another was the more pronounced face cleat parallel to the mining face, which would allow water to flow easily across the panel from rib to rib. Thus, the water infused into the coal seam would take on an elliptical shape (in plan view) with the longest axis parallel to the face. Other factors that may be responsible for the high permeability (high flows at low pressures) are low gas pressures and large cleat openings.

RESULTS

Dust sampling was conducted at this panel inside and outside the infusion zone, as was done in the Pocahontas No. 3 Seam. Respirable dust reductions up to 38 pct were achieved (5). However, dust reduction along the face was usually lower than 38 pct. Closer hole spacing (less than 300 ft) and slower infusion rates (under 1.5 gal/min) might improve the effectiveness of infusion in this seam. However, with the cost of water infusion directly proportional to the number of holes drilled and the time it takes to infuse each hole, it was decided that water infusion was not a cost-effective dust control technique in the Upper Freeport Seam.

The infusion work conducted by Occidental Research Corp. has shown that current water infusion practices can be a viable longwall dust control technique, but the success and the cost effectiveness of this technique depend primarily on coal seam conditions. Factors contributing to the variation between coal seams are fracture porosity, moisture content in fracture pores prior to infusion, cleat system and its orientation relative to the axis or the longwall panels, and depth of cover. At shallow depths, the fractures may be too wide owing to lack of confining pressure, and therefore water leaks out through the ribs prematurely. At great depths, confining pressure may result in lower fracture pore volume, and therefore less water is taken. For water infusion to be effective, experience indicates that the quantities of water would have to approach 0.5 to 1 pct of coal volume. Hole spacing would have to be adjusted for seam conditions to assure such levels. In some instances, the hole spacing may be too close for infusion to be cost effective compared to alternative dust controls.

Water infusion is a preventive dust control measure that reduces the amount of dust generated. This may be a beneficial supplement to the conventional suppression and avoidance control methods used on many longwall sections throughout various coal seams. Therefore, it may be worthwhile to ascertain whether water infusion would be a viable and cost-effective dust control method.

RECOMMENDATIONS FOR DETERMINING COAL SEAM INFUSIBILITY

The effectiveness of water infusion is a function of the amount of water the coal seam accepts (its infusibility), which depends on the cleat density (cleat spacing) and cleat size (crack diameter). The cost of infusion is directly proportional to the number of infusion holes needed. In general, cost-effective infusion can be achieved by increasing the coal's moisture content by more than 0.5 vol pct for a hole spacing no closer than one-fourth the face length.

To identify cost-effective infusibility, ideally four 3-in-diam trial holes should be drilled parallel to, and remote from, the active longwall face outside the influence of abutment pressures. The length of abutment zone from the face varies with depth, but 1,000 ft between the face and the first hole at the time of drilling would provide sufficient time for infusion.

The holes should be drilled from the headgate entry to the center of the panel block, or 300 ft deep in a typical 600-ft face. With shorter trial holes, fractures may be more pronounced near the ribs, and defects in shorter seals (packers) can tend to allow water to leak more rapidly toward the rib along the packer. Holes should be spaced at a quarter of the face length, or 150 ft for a 600-ft-wide face. Each hole should be sealed by pumping a grout mixture between a 3.5-in polyurethane tubing and a 1-in polyvinyl chloride (PVC) pipe inserted to within 25 to 50 ft of the inby hole end. See appendix C for a discussion of equipment and material selection. All holes should cure for 24 h before infusion.

The hole closest to the face should be infused first and the adjacent holes used as control holes to observe water flow through the seam. Any continuous-duty pump capable of delivering in excess of 10 gal/min at pressures exceeding 1,200 psi is adequate. (See also appendix C). During infusion, water pressure, water flow, and water quantity must be monitored. Water should be infused at a rate of 3 to 10 gal/min with pressures up to 2,000 psi. Initially, lower pressures should be tried in the first few trial holes (usually less than 500 psi) to observe the flow of water into the coal at these pressures. At higher pressures water tends to create and flow through larger fractures, rather than filling existing ones, leading to premature leakage through the rib and reducing the water accepted by the coal seam.

While infusing the first hole, each subsequent control hole should be temporarily closed with a valve after water appears. Infusion of the first hole should continue until seepage is detected around it or near the floor. Then the next hole is infused, and the adjacent holes serve as control holes. When water flows from the adjacent holes, they should be temporarily sealed. Water should also flow from a previously infused hole during infusion of the adjacent hole.

After all four holes are infused, the infusibility of the coal seam can be evaluated. If high pressures (>2,000 psi) achieve flow rates less than 3 gal/min, the coal seam is generally not suitable for water infusion. If intermediate to low water pressures (<2,000 psi) result in flow rates of 3 to 10 gal/min, infusion may be cost effective.

Hole spacing depends mainly on the regularity, size, and direction of the face and butt cleats. If the difference between the face and butt cleat is marginal, water tends to migrate uniformly in all directions from the center of the panel, and infusion is circular in plan view. Hole spacing should generally equal hole length (fig. 2*A*). When the face cleat is significantly more prominent, water migrates faster along the face cleat and the infusion zone tends to be elliptical. Hole spacing will depend on the direction of the face cleat relative to the mining face. If the face cleat is perpendicular to the face, hole spacing can be greater than hole depth

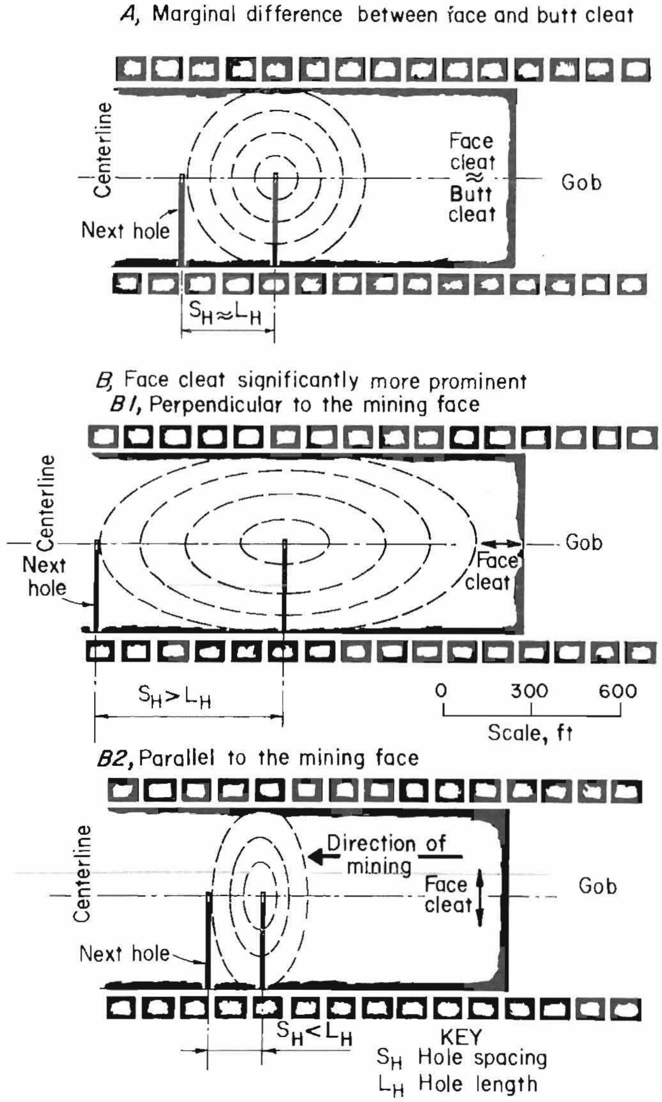

FIGURE 2.—Relationship between cleat systems and infusion zones.

(fig. 2*B1*). If the face cleat is parallel to the face, hole spacing should be less than hole depth (fig. 2*B2*).

As experience and success with the infusion procedure increase (low rate of hole failures), hole spacing may be increased to reduce overlap of the infusion zones. Maximum hole spacing should be slightly less (20 to 50 ft) than twice the estimated distance between the previous hole and its outer bounds of infusion. However, there is a tradeoff between dust control and cost.

Although the infusion cost decreases as hole spacing approaches the maximum limit and the overlap of the two infusion zones decreases, the amount of uninfused coal at the interface of the two zones increases (fig. 3). If a hole fails, there will be more uninfused coal than with closer spacing.

Cost-effective infusibility depends mainly on the percent moisture added to the coal seam and the hole spacing required for good areal coverage. An increase in moisture content can be determined by estimating the volume of coal infused, based on control hole data, and the volume of water infused. This estimate can be verified by determining the inherent moisture content of an uninfused versus an infused coal sample.

Following infusion, dust sampling is done as the longwall advances toward and beyond the infused area. With an additional 0.5 pct moisture added to the coal seam and good areal coverage from water infusion, 35- to 70-pct dust reduction should be expected.

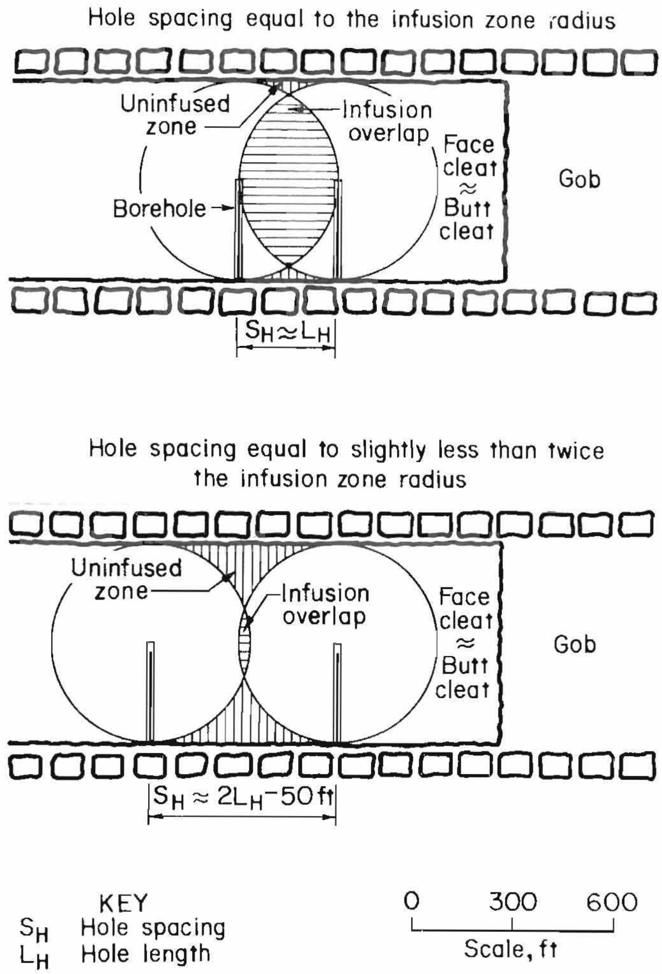

FIGURE 3.—Relationship between hole spacing and infusion zone overlap.

SUMMARY

Water infusion, as a longwall dust control technique, is widely recognized and practiced in Europe. Despite its popularity overseas, acceptance in the United States has been slow. Research has shown that water infusion can be a cost-effective viable alternative for controlling dust along some longwall faces.

A recent application of water infusion successfully brought a longwall plow operation mining the Pocahontas No. 3 Seam into compliance with Federal dust standards. Prior to infusion the mine had been consistently out of compliance despite numerous attempts to control dust generation. A Bureau survey found dust reductions between 43 and 68 pct were achieved with water infusion. Based on these results, the mine has since incorporated water infusion into the dust control plan.

In 1978, over two-thirds of all U.S. double-drum shearer longwalls were out of compliance with the 2.0-mg/m^3 Federal dust standard (6). Under a cooperative cost-sharing contract with Occidental Research Corp., the Bureau set out to evaluate water infusion as a dust control technique in several coal seams. A method for infusing retreating longwall faces was developed by the Bureau and modified by Occidental. Water infusion was applied at two longwalls operating double-drum shearers in the Pocahontas No. 3 and Upper Freeport Seams. In the Pocahontas No. 3 Seam, dust reductions of 50 pct were obtained. Results show that infusion was a cost-effective ($0.05/st) viable dust control technique. Based on these results, the mine elected to make water infusion part of the dust control plan. Although the high permeability of the Upper Freeport Seam allowed for good low-pressure flow rates, the largest volume of water infused in one hole was 24,486 gal versus 128,342 gal in the Pocahontas No. 3 Seam. Dust sampling results indicated a maximum dust reduction of 38 pct was achieved.

Although water infusion is a wothwhile alternative dust control technique, it may not work for all longwall operations. Infusibility depends upon both physical and chemical properties of a seam, which may vary even within the same seam. Infusibility can be determined by drilling a series of 3-in-diam holes (approximately one-half the face length deep) in the rib side of the proposed panel and infusing the hole by the Bureau method. If seam characteristics prevent water infusion at reasonable pressures and flow rates, other dust control techniques may be more effective.

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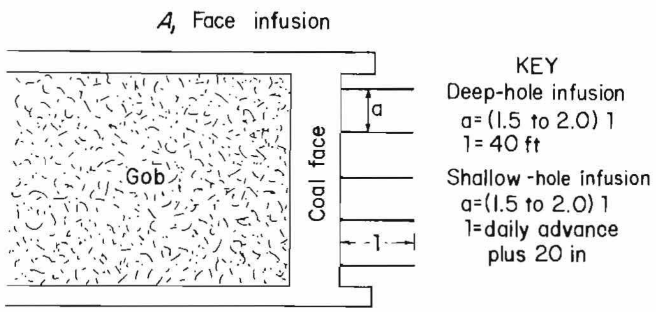
APPENDIX A.--AN OVERVIEW OF INFUSION TECHNOLOGY

EUROPEAN TECHNOLOGY

The predominant coal mining method in Europe is the advancing longwall system. In the Federal Republic of Germany, 75 pct of the faces are advancing longwalls (7).[1] The two water infusion methods practiced on advancing longwall panels are face infusion (fig. A-1*A*) and infusion from advanced gate roads (fig. A-1*B*). For face infusion, shallow or deep holes are drilled using an air-operated drill. Shallow holes are drilled approximately 20 in past the daily face advance and are spaced along the face 1.5 to 2.0 times the depth of the hole. Deep holes are drilled to a depth of approximately 40 ft, for several days of mining, and are spaced along the face 1.5 to 2.0 times the depth of the hole. Spacing of holes depends largely on geologic conditions. When using shallow holes for face infusion, more holes are needed along the face but less time is required to infuse the hole. Either method adversely affects production.

[1]Underlined numbers in parentheses refer to items in the list of references preceding this appendix.



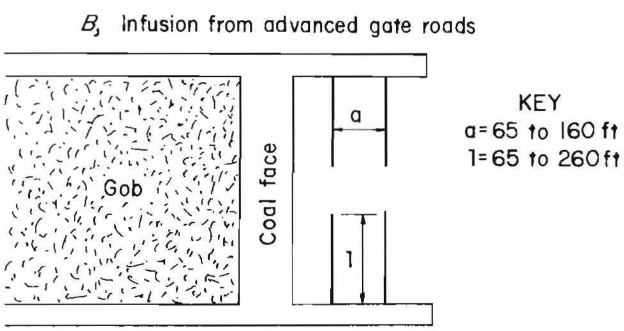


FIGURE A-1.—Water infusion methods practiced on advancing longwalls.

Several types of reusable infusion sealing devices are available to seal the hole while water is pumped into the coal seam. One assembly is a mechanical device consisting of internal tubing for water passages and external tubing with rubber washers that expand by levers or threads to seal the hole and prevent water leakage around the periphery. Another method uses the infusion water pressure to hydraulically expand a rubber boot (sheath) along the length of the hole. Higher water infusion pressures yield a better seal.

Water consumption and pressure and the duration of the infusion process per hole depend on the physical properties of coal seam structure and may vary significantly. To successfully face-infuse the coal, 15 to 80 gal of water must be pumped into each hole. The entire conditioning operation is restricted to a single shift. These water quantities can normally be achieved at pressures not exceeding 200 psig; only in the case of hard and dense coal are pressures greater than 600 psig needed. Either electric or compressed-air-driven water pumps are used to infuse the face. Dust reductions are usually more than 50 pct and seldom exceed 70 pct (8).

Infusion from gate roads is not used extensively in Europe. However, successful experiments have been conducted by infusing water at pressures up to 600 psig into deep holes (65 to 260 ft) for 10 h or longer. European mines use either hydraulic packers or high-pressure grout packers for long-hole infusion. The hydraulic packers are retrievable and reusable, but installation is labor intensive. The cost to effectively seal 250 ft of hole by European methods can be significantly higher than that of grouting methods (9). If the hold deforms during the infusion process, the packers are locked in place and lost. With European high-pressure grout packers, inflatable packers are placed at both ends of the water pipe and grout is injected at high pressure (up to 1,400 psi) (5). Unless high pressure is used, cavities and gas bubbles develop in the grout and permit water to creep along the hole at a rate higher than occurs during the infusion process. Thus water will short-circuit at the rib side of the packer before the infusion area is completely saturated. European operators initially used specially formulated polyurethane grout and later used specially developed cement-type grouts, which required only several hours of setting time if injected at the higher pressures. In seams with a high degree of permeability, dust reductions are usually between 35 to 50 pct; in some cases up to 60-pct dust reduction is achieved (8).

BUREAU OF MINES TECHNOLOGY

In retreat longwall systems, by far the prevalent form in the United States, infusion from the existing gate entries is more desirable than face infusion, which limits production (fig. A-2). The Bureau of Mines has developed an alternative infusion hole sealing method (packer) for long holes (65 to 260 ft), which is less costly and labor intensive and more reliable (9). The packer can be assembled in any mine machine shop from commercially available materials. This packer consists of 10-mil polyurethane plastic sheathing with the edges glued together so as to form a tube 1/2 in larger in diameter than the infusion hole around a

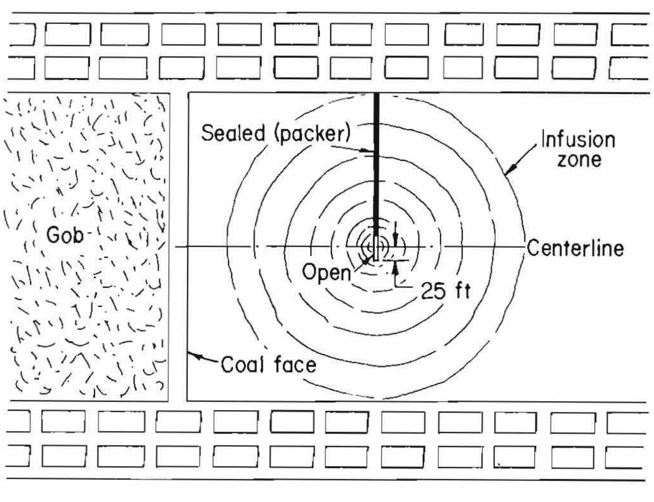


FIGURE A-2.—Water infusion on a retreat longwall.

1-in PVC pipe (fig. 1). The tube is protected and sealed at both ends by an approximately 1-ft (30.5-cm) long rubber hose banded over the pipe. This tube is filled with a grout mixture of cement, Calseal, and salt at a pressure up to 250 psi and is allowed to set for about 24 h. Pressurizing the grout in the packer does not produce any stresses in the polyurethane tube because it is wider than the hole. The material cost to construct this packer for a 250-ft-long hole is $250.

Infusion holes require a drilling capability for 3-in-diam holes extending approximately 25 ft beyond the centerline of the panel width. Hole spacing may vary owing to physical properties of the coal seam, but holes are usually spaced at distances equal to the radius of the infusion zone (one-half the panel width). Several commercial portable electric-hydraulic drills are suitable for this task. An air-powered drill may be suitable under certain circumstances (if coal is friable enough and there is no deformation of the hole at the rib). The hole is then packed approximately 50 ft from the inby end.

After the infusion hole is properly drilled and packed, a water pump is used to maximize the amount of water infused into the coal. There are several commercially available water pumps that meet water infusion needs. Optimum water flow and pressure during infusion will vary from mine to mine and seam to seam. However, the pump should be able to operate continuously for many days at pressures up to 2,500 psi to assure optimum flow rates of 10 gal/min or more under most seam conditions.

Water infusion is usually confined to the coal seam because the host strata are typically impermeable rock (siltstone, shale, sandstone, etc.). The amount of water infused through a hole and the shape and size of the infusion zone will depend highly upon cleat size, density, and direction. To estimate the amount of water the coal around the hole will absorb, a 1.0-pct uniform fracture porosity for the coalbed and a cylindrical infusion zone are assumed (9). The estimated water quantity for infusion on one hole can be calculated as follows:

Volume of coal infused:

$$V = \pi r^2 h, \text{ ft}^3$$

where r = half the panel width, ft,

and h = coal seam thickness, ft.

Quantity of water infused:

$$Q = 0.01 V (7.48 \text{ gal/ft}^3)$$

(best estimate)

where V = volume of coal infused, ft^3,

and 0.01 = 1.0 pct of coal volume fracture void space.

To achieve the maximum quantity of water to be infused in a hole (approach or surpass the estimate), an optimum pressure and flow rate must be established. It is usually recommended that trial holes first be tried to determine whether the coal seam is suitable for infusion; see "Recommendations for Determining Coal Seam Infusibility" (pp. 7-9). Rates are then established from trial or test infusion holes. Generally, hard coals with virtually no fracture systems are unsuitable for infusion because they are impermeable. Infusion of blocky coals with widely spaced cleat systems may not produce satisfactory results because a significant amount of the coal will be unwetted. Friable coals with greater fracture densities (closely spaced cleats) are generally most suitable for water infusion.

Completion of the infusion process of a hole is determined by regular inspections of water seepage on both sides of the panel. However, seepage may be difficult to find at the ribs because mining-induced fractures parallel to the rib will prevent water from migrating to the entry. Water may be observed at all places along the ribs and seeping from the panel near the floor.

Another sign that the infusion process may be complete is a drop in infusion pressure, accompanied by an increase in flow rate, which usually indicates that the water has reached the rib or is short-circuiting along the path of least resistance.

APPENDIX B.--SAMPLING PROCEDURE FOR EVALUATING THE EFFECTIVENESS OF WATER INFUSION ALONG A PLOW FACE

Two surveys were conducted to evaluate water infusion as a means to reduce dust on the longwall plow face. The objective of an initial and follow-up survey is to collect dust data representative of conditions prior to infusion for comparison against dust levels measured while mining in the infused zone. Using instantaneous and gravimetric sampling, attempts are made to identify, isolate, and quantify potential sources of respirable dust (10). To provide the most appropriate A-B comparison (noninfused versus infused conditions), it is essential that the sampling procedure remains unchanged throughout both surveys. Three shifts of sampling were completed for each survey with 4 wk separating the initial (preinfused) and follow-up (infused) surveys.

GRAVIMETRIC SAMPLING

Six gravimetric sampling stations were identified along the headgate and face. Each station was monitored by a package of two gravimetric samplers. Face-side gravimetrics were suspended, respectively, from roof support canopies, over the walkway, at shields 2 (No. 1 shieldsetter location), 15, 50 (midface operator's position), and 97 (fig. B-1). These gravimetrics were used to determine the impact of water infusion on several sources of dust along the face. Two additional packages were suspended from the roof in the section intake (last open crosscut) and beltway entry to measure and determine the potential benefits from water infusion on intake dust sources. It was assumed that the increased moisture content of the coal would reduce dust generated at outby belt transfer points, thus reducing intake dust levels.

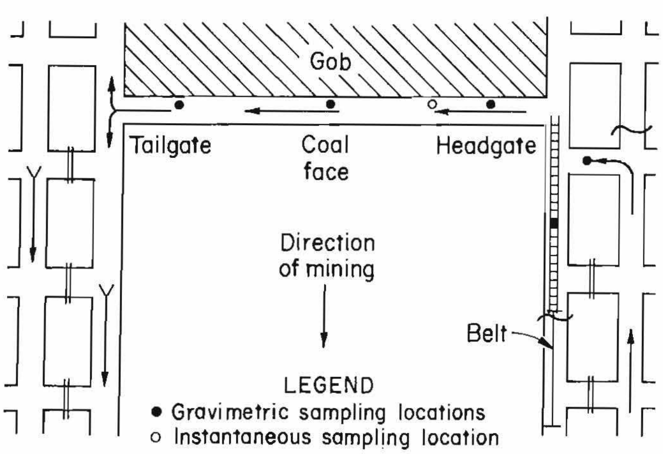


FIGURE B-1.—Gravimetric and instantaneous sampling locations

Gravimetric sampling was scheduled as part of each day's sampling program, but no 8-h, full-shift sampling, similar to compliance sampling, was performed.

INSTANTANEOUS SAMPLING

The GCA RAM-1 instantaneous dust monitor was used to measure dust concentrations generated by plow and roof support movements. Stationary instantaneous sampling was conducted at support 26 to monitor dust levels in the vicinity of the plow. The sampling location represents the approximate midpoint of the upper (head-to-midface) half of the face. As the plow approached the instantaneous sampling station, an engineer commenced recording dust concentrations every 2 s, beginning 30 s prior to the plow's arrival. At an average tramming speed of 132 ft/min, this would put the plow approximately 66 ft upwind or downwind (depending upon cut direction) of the sampling station. After the plow passed the sampling location, dust levels were recorded for an additional 30 s. Results provide a 1-min time history respirable dust profile that reflects concentrations measured on the intake and return air side of the plow.

Unlike shearer-operated longwalls, plow operations require support operators stationed at various intervals along the face. Each individual, except for tail and headgate support operators, is responsible for approximately 15 to 20 supports. Because shieldsetters must remain in the vicinity of their supports, contamination from upwind dust sources is a major concern. For example, as the plow cuts along the lower half of the face (midface-to-tail), support operators stationed in this area are exposed to several potentially significant sources of respirable dust generated by the plow, upwind support movement activity (head-to-midface), and headgate sources. Attemps were made to approximate the quantity of respirable dust generated during support movement. To accomplish this, additional stationary instantaneous sampling was conducted at support 26 during a time when the plow cut downwind, between midface and tail. This eliminated contamination of measured support dust concentrations by plow-generated dust. Typically, shieldsetters advanced supports from a position located adjacent to, and upwind of, the target support. A set of 15 to 20 supports was advanced, in order, beginning with support 25, followed by each subsequent head side support. Instantaneous dust levels were measured and recorded every 10 s as the No. 2 shieldsetter advanced supports upwind of the sampler location. Data collection began with movement of support 25 and continued until upwind support movement had been completed.

APPENDIX C.--EQUIPMENT AND MATERIALS SELECTION

The method of infusion used by Occidental Research Corp. was essentially the Bureau method, with a few modifications to the grouting or packing phase of the operation. Three-inch-diameter holes were drilled from the headgate, usually 25 ft past the centerline of the panel. Drilling was done by a portable electric-hydraulic rotary drill manufactured by Victors Products Ltd. (fig. C-1). This drill had ample power for drilling 300-ft-long holes in tough seam conditions (hard coal, rock inclusions, etc.). The drill was powered by a remote power pack consisting of a 10-hp motor (either ac or dc), driving a hydraulic pump. A handheld compressed-air-operated wet-head Thor drill was used on a limited basis for drilling holes. This drill was identified as a low-cost alternative, but it lacks reserve power to drill through hard coal, rock inclusions in the seam, or squeezing caused by abutment pressures.

Grouting and packing of the hole were similar to those in the Bureau method, but both the components and packer installation were improved. Instead of gluing polyurethane plastic sheathing to form a tube around a pipe, extruded tubing was obtained from Spiratex (Dearborn, MI). This tubing offered a more consistent quality and reduced the time needed to make the sheath. To improve underground assembly, a threaded schedule 80 PVC pipe was substituted for the smooth-ended schedule 40 PVC pipe. Finally, a 15-ft steel section was used instead of a 5-ft section in the rib area to prevent shearing of the pipe due to settling of the rib.

The grout equipment was a custom-made Moyno pump model 314 and a 3.5-ft^3 grout

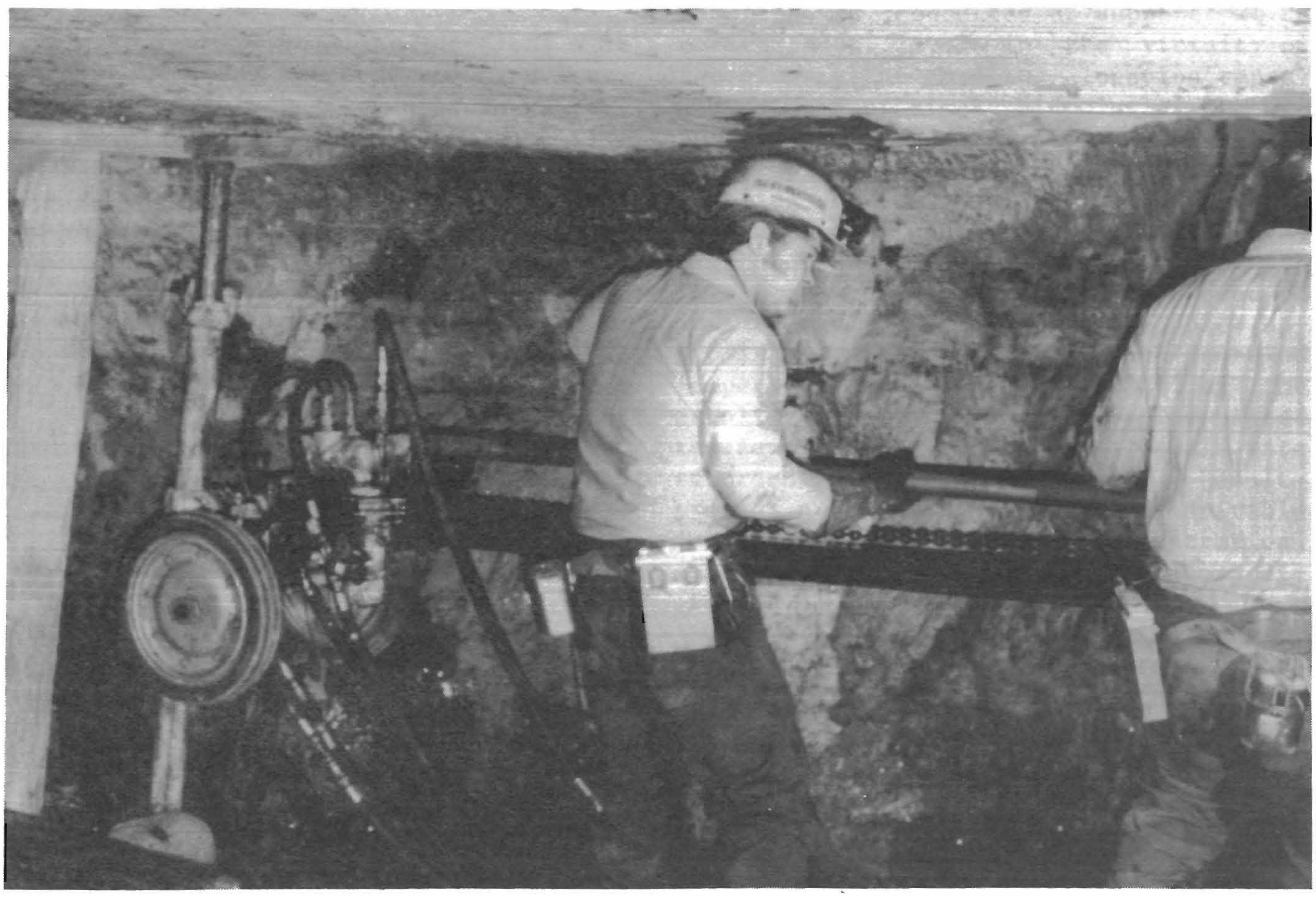


FIGURE C-1.—Portable electric hydraulic rotary drill.

mixer; both are powered by compressed air and were supplied by Masonry Equipment Co. (Brecksville, OH) (Fig. C-2). The grout mixer bucket capacity of 3.5 ft^3 corresponds to the volume required for one batch consisting of 10 gal water, 15 lb salt, 2 lb CFR2 (a grout-fluidizing agent), 94 lb (1 bag) of cement, and 100 lb (1 bag) of Calseal. The Moyno pump is utilized to inject grout mixture from the mixer into the hole at pressures typically between 100 and 200 psi. One day is allowed for the grout mixture to set before infusion is started.

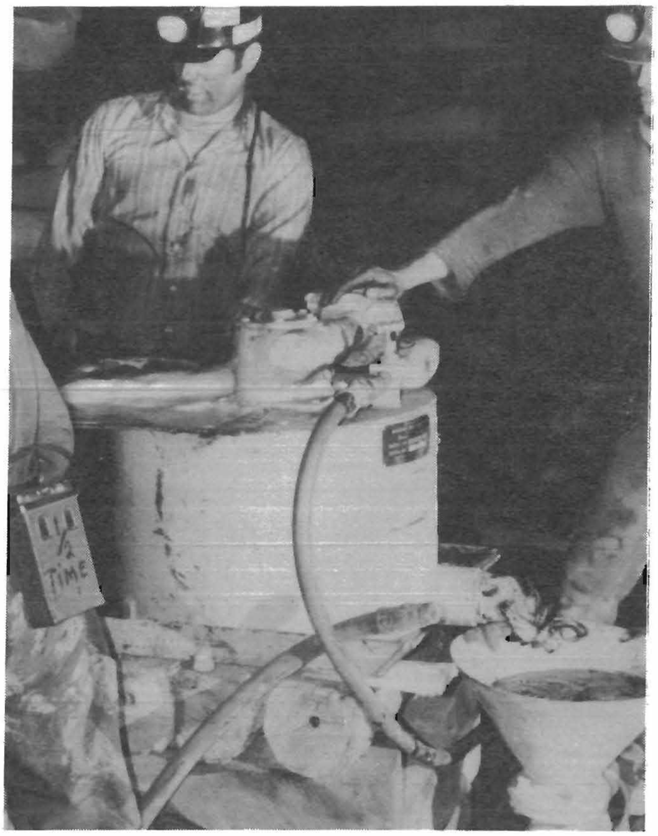


FIGURE C-2.—Grout mixer and injection pipe.

The WOMA model 752 pump has been identified as an ideal water infusion pump. It has a maximum flow rate of 35.5 gal/min at 2,800 psi when connected to a 75-hp motor operating at 1,800 rpm. Its high capacity would allow for simultaneous infusion of several holes. Although the WOMA unit is ideal from a performance standpoint, an alternative pump was used for infusion in these experiments. The alternative pump was a John Bean Triplex Plunger Pump, model M0610, capable of 13.6 gal/min at 1,800 psi constant pressure (fig. C-3). It is much lower in cost and horsepower requirements so that dc power from the trolley wire could be tapped. It is less bulky and lighter, making it easier to transport between infusion holes. However, it may require more preventive maintenance in the long run.

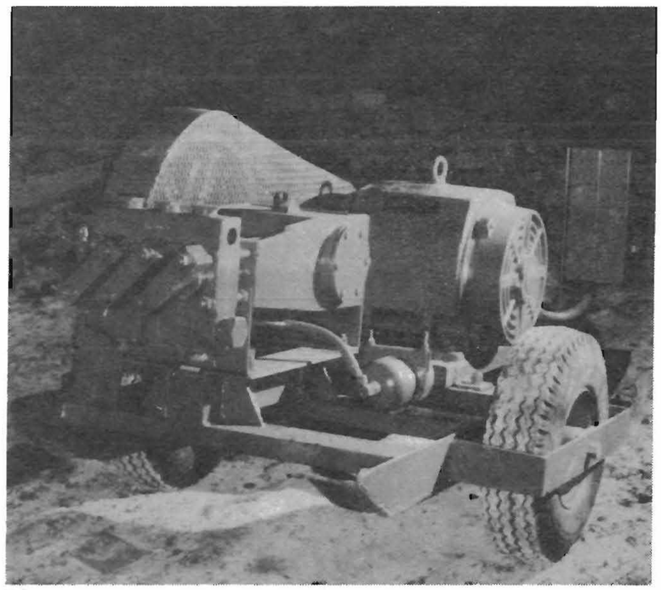


FIGURE C-3.—Plunger pump for water infusion.

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