RECENT EXPERIENCE WITH THE SPRAY FAN

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ABSTRACT

Work done by Foster-Miller Associates under a Bureau of Mines research contract has developed methods to increase significantly the amount of fresh air that reaches the front of a continuous-mining machine. The emphasis was on removing methane buildups that occur at the cutterhead. Using a full-scale plywood mockup of a coal mine working face area, the study showed that in many instances only about 20 pct of the fresh air heading towards an exhaust brattice or tubing actually gets to within 1 ft (0.3m) of the face. The key to providing more air at the face is to enhance and move forward the natural airflow pattern.

This change in the natural airflow pattern can be accomplished by taking advantage of the air-moving abilities of the conventional water spray. It was discovered that if all the water sprays on the machine were realigned, then ventilation efficiencies of 70 pct or more were achieved regularly. This meant that if 9.000 cfm (4.2 m^3/s) was entering the brattice, at least 6,300 cfm (3.0 m^3/s) of this was reaching to within 1 ft (0.3m) of the face.

This water spray realignment consists of placing a few nozzles on the side of the machine opposite the curtain and also tilting the front sprays slightly towards the curtain side.

Recently, two underground tests and two additional independent laboratory tests of the water "Spray Fan" have been completed. In general, they have confirmed the performance of the Spray Fan system, but they also have provided useful information as to its difficulties and limitations.

INTRODUCTION

The mining engineer, given some fans and vent tubing and assigned the task of improving the ventilation of a working place, would follow certain guidelines to insure that -

1. The intake was in fresh air,

2. The vent tube used was as large a diameter as possible, and

3. If the fans were to be placed in series, they were working together, not against each other.

These familiar ventilation principles are central to the design of the Spray Fan, a modified water spray system which increases the amount of air forced to the front of a continuous-mining machine. It has been recognized for some time that a water spray will move air like a small fan does, and that the laws governing the airflow are similar. The Spray Fan concept is a simple application of these laws to ventilation of a continuous miner. The early laboratory work (1) that resulted in the Spray Fan was completed in 1976 and will only be briefly reviewed. More recently, two completed underground tests and two independent laboratory tests have generally confirmed the performance of the Spray Fan system, as well as providing useful information on its problems and limitations.

EARLY LABORATORY WORK

The Spray Fan was developed under a Bureau research contract originally designed to improve the diffuser fan.*/ The work, started in 1973, was conducted by Foster-Miller Associates, in Waltham, Mass. Some of the main findings of the diffuser fan study, later used in the design of the Spray Fan system, follow:

1. For a given diffuser fan quantity, an asymmetric configuration at the face that augmented the natural airflow provided better ventilation. Systems that delivered air at both the left and right sides of the face simultaneously were not as effective.

2. The source of air entrained by the diffuser fan discharge flow is critical. A jet of high-velocity air will entrain about three times its volume of surrounding air. Thus, positioning the discharge outlet in fresh air was extremely important. For example, a single 1,000-cfm (.47 m^3/sec) discharge outlet close to the front of the machine would entrain and carry forward about 3,000 cfm (1.4 m^3/sec) of contaminated air, whereas the same 1,000-cfm outlet located at the rear would entrain and carry forward about 3,000 cfm of fresh air.

The Spray Fan, based on these diffuser fan principles and the three guidelines cited earlier, is shown in Figure 1. The sprays at (1) and (2) entrain incoming fresh air at the tail of the machine and move it up the intake side, which is opposite the curtain, The sprays at (3) and (4) are in conventional locations, but angled to the right to provide air movement from left to right across the face as well as forward. An additional group at (5) was useful in high coal to prevent turbulent dusty air at the face from rolling back over the operator.

Exact location of individual sprays is not critical, except that the sprays at (1) should be as far back as possible. Nozzles should be aimed so that the water moves the air, rather than wetting down the sides of the machine. The total water flow is 20 to 25 gpm (1.3×10^{-3}-$1.6 \times 10^{-3} m^3/s$), about the same as in a conventional water spray system. When the spray fan is installed, the conventional system is removed. Hollow-cone sprays are more effective air movers. When the nozzle sprays into a confined space, as at

*/ The diffuser fan is the term applied in the United States to a machine-mounted fan that ejects air towards the coal face.

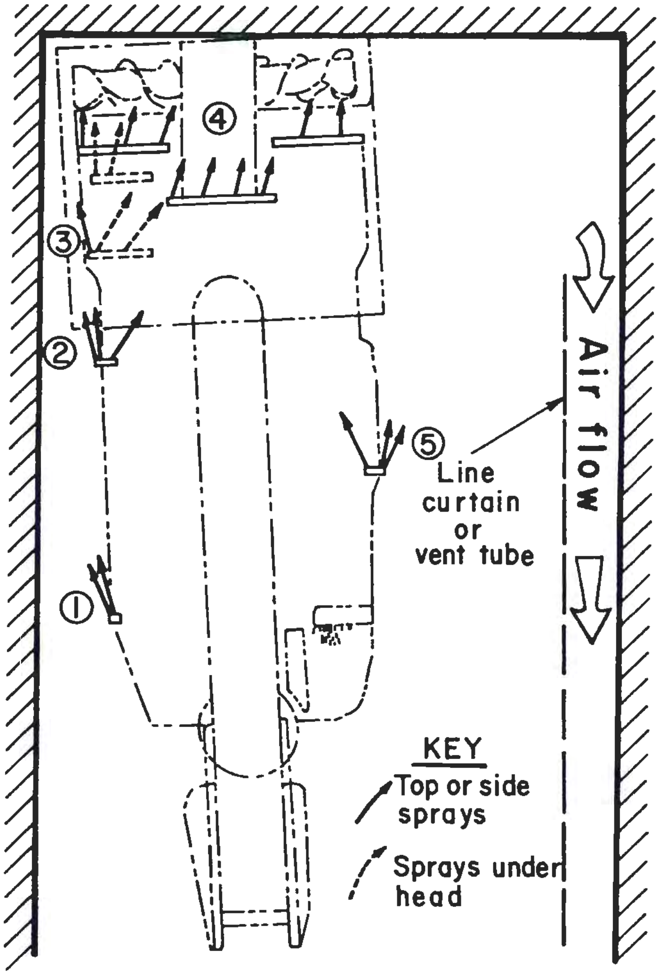

FIGURE 1. The Spray Fan system mounted on a continuous-mining machine.

(1) narrow-angle cones are more effective. Venturi-type sprays offer no advantage since in this application a conventional nozzle with the same water flow rate and pressure moves just as much air.

Figure 1 shows the nozzle configuration used when the line curtain or vent tube is on the right. When the curtain or tube is on the left, a mirror-image system must be provided. The miner is equipped with both a left- and a right-hand system, and selection of one or the other is controlled by a three-way water valve.

Clogging of individual nozzles reduces ventilation effectiveness very little. Testing showed that a surprisingly large fraction of clogged nozzles (say 1/4) at the face would reduce system effectiveness only about 10 pct. Malfunction of the sprays at (1) was more serious.

How well did the Spray Fan work? Tests conducted under a variety of conditions up to 9,000 cfm (4.2 m^3/s) of primary air at the curtain showed a Face Ventilation Effectiveness (FVE) of about 80 pct. FVE was defined as follows:

$$FVE = \frac{\text{methane concentration in return}}{\text{average methane concentration at mine face locations 1 ft (0.3m) outby}}$$

FVE can also be interpreted as the fraction of the entering air that reaches to within 1 ft (0.3m) of the face. The degree to which this 80 pct represents an improvement over any conventional, or baseline, system depends largely on how effective the baseline system was.

For example, for a baseline system in which the primary air is 3,000 cfm (1.4 m^3/s) and the curtain is maintained at 10 ft (3.0m) from the face, the FVE is about 40 pct. Here a Spray Fan at 80 pct would represent a factor of 2 improvement, or twice the entering air brought to the face. However, if the primary air is 9,000 cfm (4.2 m^3/s) and/or the curtain is maintained at 20 ft (6.1m) the baseline FVE drops to about 20 pct. Here, 80 pct FVE with the Spray Fan would result in a factor of 4 improvement.

Coalbed thickness is also important. Low coal has a higher baseline FVE because the reduced clearance between machine and roof inhibits the short-circuiting of air to the curtain, thus, the Spray Fan improvement is not as great.

A shortcoming of the Spray Fan system is that it requires higher water pressures than are normally found on most mining machines. In many instances, a booster pump on the working section is required. A nozzle pressure of 150 psi (1030 kPa) provided effective Spray Fan operation; 200 psi (1380 kPa) was better. Below 100 psi (690 kPa) at the nozzles, the system rapidly lost effectiveness.

For example, independent laboratory testing of the Spray Fan was conducted using a nozzle pressure of 80 psi. Low coal was simulated, the airflow was 5,000 cfm (2.4 m^3/s), and the curtain was maintained at 8 and 15 ft (2.4 and 4.6m). Baseline ventilation effectiveness was good, and improvement by the Spray Fan was at best a marginal factor of 1.2. Since FVE can be increased by raising the nozzle pressure (and flow), the Bureau recommends a nozzle pressure of at least 125 psi (862 kPa), and 150 psi (1030 kPa) in a gassy mine.

UNDERGROUND TESTING IN PENNSYLVANIA

Following the laboratory work (1), Foster-Miller and the Bureau conducted an underground test in a coal mine in southwestern Pennsylvania. The mining machine, a Joy 10 CM, was equipped with both conventional sprays and a partial Spray Fan system in which the sprays under the head were retained in their conventional positions for reasons of convenience. The mine was in high coal, primary airflow at the inby end of the line curtain averaged 5,000 cfm (2.4 m^3/s), and the curtain was maintained at 10 ft (3.0m) according to standard practice. Water pressure at the nozzles averaged 150 psi (1030 kPa).

During mining, methane levels were recorded with monitor intakes directly behind the cutter picks. Concentration levels were continuously marked by strip chart recorders. In contrast to the laboratory tests where methane was released at a constant rate, methane emission at the coal face was very irregular, peaking sharply as the continuous miner sumped in and sheared down.

In the tests, the conventional and Spray Fan systems were used alternately; other variables were kept as constant as possible.

The results are shown in Figures 2 and 3.

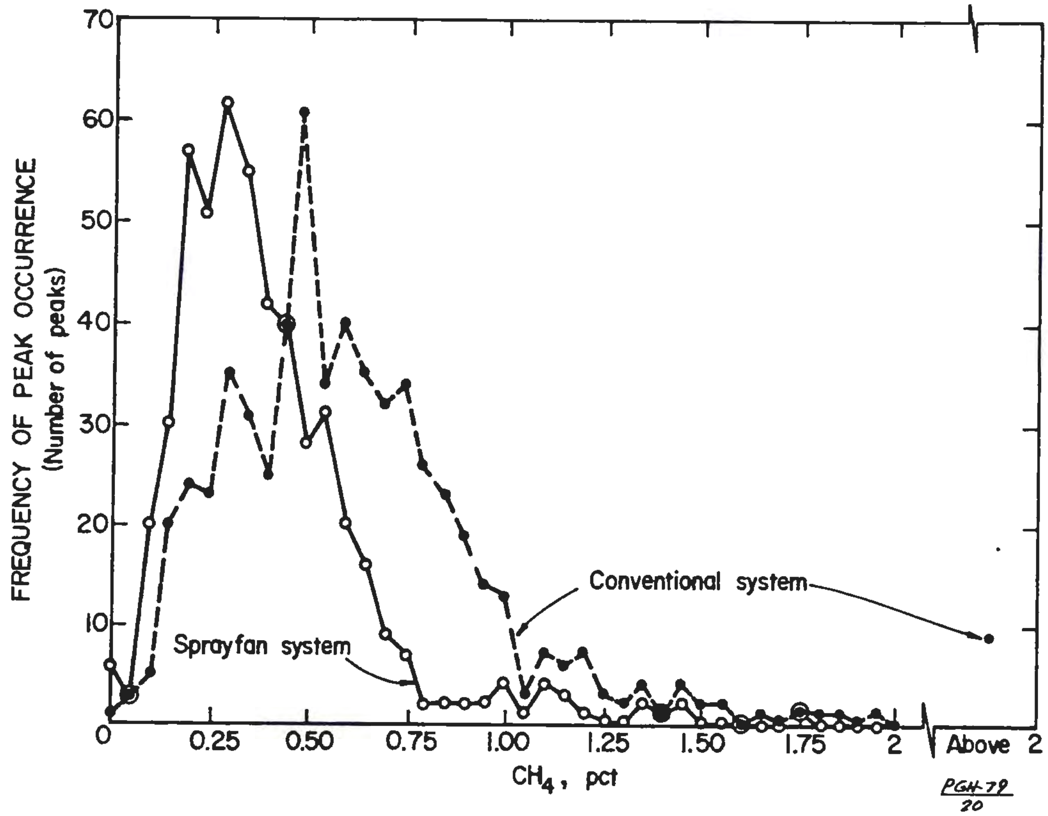

FIGURE 2. Histogram of methane concentration peaks from an underground test of the Spray Fan.

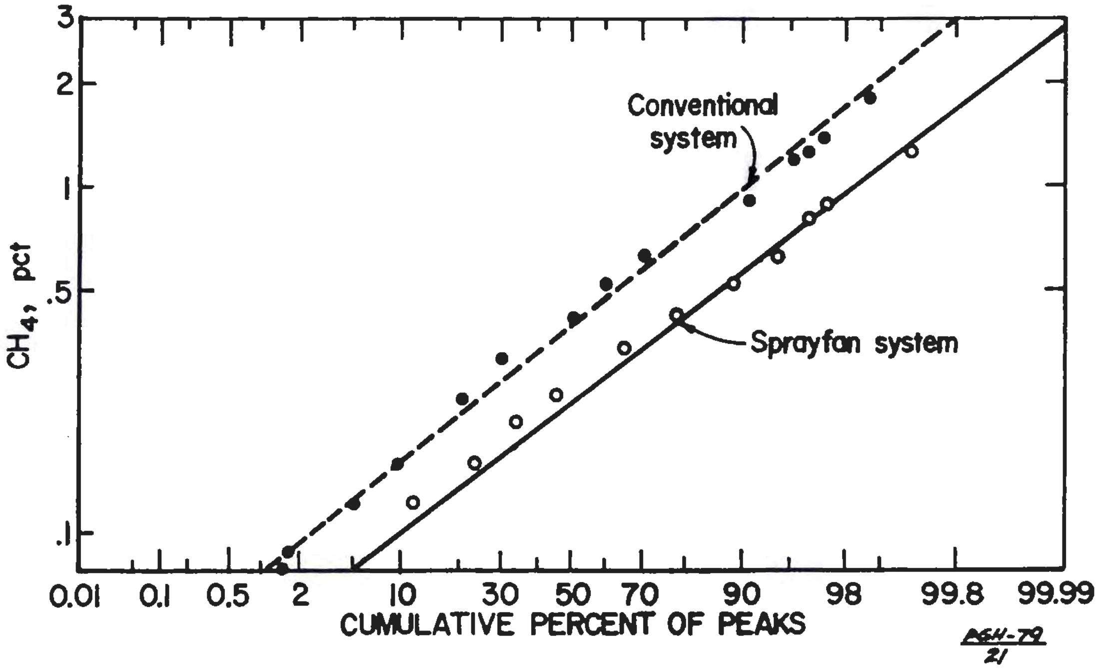

FIGURE 3. Methane peaks from Spray Fan and conventional systems plotted as a cumulative frequency distribution.

In Figure 2, all methane concentration peaks are plotted as a histogram, indicating the frequency of occurrence of peaks of a given methane concentration. Comparison of the two systems shows that with the Spray Fan the most probable peak concentration is 0.25 pct methane, versus 0.50 pct methane with the conventional system.

The probability of occurrence of higher concentrations is of more interest. For this purpose, the data in Figure 2 were replotted in Figure 3 as a cumulative frequency distribution on log-normal probability paper. This type of plot gives the probability of obtaining a methane peak at or below the stated concentration (2). For example, the plotted data for the conventional system shows that methane peaks are 2 pct or less 98.5% of the time. Peaks in excess of 2 pct methane would be expected in 1.5% of the measurements. For the Spray Fan, methane peaks of 2 pct or less are expected 99.9% of the time; 2-pct methane peaks would be exceeded 0.1% of the time. Therefore, a peak over 2 pct methane was 15 times less probable with the Spray Fan. During the underground testing in which over 1,000 peaks were measured, methane concentrations exceeded 2 pct a total of 9 times with conventional sprays but never exceeded 1.75 pct with the Spray Fan system.

While the predicted Spray Fan improvement factor is 15 at 2 pct methane, a close look at Figure 3 shows that the improvement factor varies with the concentration; the higher the concentration, the greater the improvement factor. Thus, the underground testing revealed one aspect of the Spray Fan not observed in the laboratory. Besides reducing the average methane concentration, it has some peak chopping effect. We do not completely understand why this is so, but there is no doubt that it is the case. Future laboratory work should involve the pulse-release of methane and statistical evaluation of data to more closely simulate the release of methane underground.

For extrapolations that estimate the probability of explosive methane concentrations, the normal distribution should be replaced by an "extreme value" distribution, such as is commonly used to estimate the probability of rare events, like 100-year flood levels (2). The data in Figure 3 were replotted on extreme-value probability paper, with similar results; that is, the Spray Fan offers a very large factor of improvement, which is better at higher methane concentrations.

Some dust measurements were also made to see if the Spray Fan was affecting the level of respirable dust at the operator position. These measurements were made with the SRI meter, an instantaneous dust level monitor developed under a Bureau research contract to the Stanford Research Institute. In a brief test sequence, no difference in dust levels at the operator position could be detected.

UNDERGROUND TESTING BY MSHA IN WEST VIRGINIA

Another underground test of the Spray Fan was recently conducted by the Mine Safety and Health Administration (MSHA) in low coal in southern West Virginia. An operator working the gassy Pocahontas No. 3 coalbed had requested permission to remove the diffuser fans on the Jeffrey 120L and Joy 11CM machines and replace them with Spray Fans. The diffuser fans had originally been required by MSHA because of a face ignition problem at the mine, but they were difficult to maintain and face ignitions continued to occur. Both electric and hydraulic diffuser fans were being used. Approximately 2,000 cfm (0.94 m^3/s) of air was coursed through metal ducting to dual outlets at the ripper heads.

For testing, the Spray Fan system was installed on one machine without removing the diffuser fan; it used in excess of 30 gpm ($1.9 \times 10^{-3} m^3/s$) of water at a pressure of 200 psi (1380 kPa). During testing, the line curtain was maintained within 10 ft (3.0m) of the face. The primary air quantity at the inby end of the curtain ranged from 5,400 to 13,000 cfm (2.5 to 6.1 m^3/s) and averaged 9,100 cfm (4.3 m^3/s). All methane samples were collected near the continuous miner ripperhead using continuous methane detectors and tubing.

The resulting values are given for the average peak:

	Curtain side,pct	Off-curtain side,pct
Diffuser Fan	0.78	0.41
Spray Fan	0.28	0.31

The Spray Fan was superior to the diffuser fan by a factor of 2. The magnitude of the improvement is substantial considering that diffuser fans are generally felt to improve face ventilation significantly. The marked improvement with the Spray Fan may be due to the combination of several factors: high pressures and water flow rates on the Spray Fan, and a less-than-optimum diffuser fan design.

Based on these results, MSHA gave the operator permission to use Spray Fans provided that a minimum pressure of 150 psi (1030 kPa) was maintained and that the sprays and mining machine controls were interlocked to ensure that the water was "on" during cutting.

Subsequently, the mine operator sampled respirable dust concentrations at the machine operator position in an extensive testing program. The diffuser fans barely kept dust concentrations in compliance, whereas with the Spray Fan dust levels were reduced by two-thirds. This is not surprising, because the impact of the high-velocity diffuser fan air jets on the coal face created such turbulence that the dust cloud rolled back as far as the machine operator, even with the curtain at 10 ft (3.0m).

Because it reduced dust and produced no noise or impaired visibility, the Spray Fan was readily accepted by the workers at the face. As of January 1979, the operator had installed the Spray Fan on 30 machines.

PARTIAL RETROFITTING WITH SIDE SPRAYS ONLY

Another coal operator in southern West Virginia has equipped his machines with the side sprays (1) and (2) only. The sprays at the front are unchanged and on the average point directly forward. This greatly reduces installation effort, especially since right- and left-handed systems are normally required. Early laboratory tests had indicated that failure to tilt the front sprays cut system effectiveness to about one half, but those tests used 5 gpm ($0.32 \times 10^{-3} m^3/s$) on the sides, whereas this mine operator uses 13.5 gpm ($0.85 \times 10^{-3} m^3/s$). This probably compensates somewhat for failure to tilt the front nozzles; however, side spray water goes on the floor instead of being loaded out with the coal. In many mines, 13.5 gpm of water would cause floor-softening problems.

TESTING AT THE MSHA PITTSBURGH SURFACE TEST FACILITY

MSHA regulations require that the exhaust curtain be kept to within 10 ft (3.0m) of the face. Keeping the curtain at this distance means that a miner must sometimes stand under roof that is not permanently supported. To reduce the roof fall hazard, MSHA is currently investigating ventilation methods that allow placement of the curtain at more than 10 ft but provide the same degree of safety as a 10-ft curtain.

The early laboratory data obtained by Foster-Miller indicated that the Spray Fan would accomplish this. In fact, the Spray Fan FVE with the curtain at 20 ft (6.1m) even exceeded the FVE of blowing ventilation under similar conditions.

To confirm this, MSHA repeated many of the tests in its Pittsburgh Technical Support Center (PTSC) test facility. A coalbed 42 inches (1.1m) thick was simulated. The full-scale simulated mining machine was sumped 16 ft (4.9m) into a box cut. Methane was released at a constant rate, and concentrations were measured at seven locations close to the face. Three airflows and two water pressures were used.

As a measure of how well a coal mine face is being cleared of methane, MSHA uses an index called Dilution Capacity (DC). This is defined as the methane flow at which the highest measured concentration in the face area is 1 pct under the tested conditions, or

$$DC = \frac{\text{methane concentration in return}}{\text{highest measured concentration at the face}} \times \text{airflow in return} \times 0.01$$

The essential difference between the Dilution Capacity, as used by MSHA, and the Face Ventilation Effectiveness, as used by the Bureau and Foster-Miller, is that the former is calculated using the highest measured methane concentration at the face, whereas the latter is calculated using the average methane concentration at the face. Since the highest concentration is generally two or three times the average face concentration, use of Dilution Capacity makes any system tested appear to have one-half to one-third the effectiveness that the comparable FVE would indicate.

Results of the testing are shown in Table 1. At 200-psi (1380 kPa) water pressure, the Spray Fan with the curtain at 20 ft (6.1m) is markedly superior to the conventional system with the curtain at 10 ft (3.0m). At 100-psi (690 kPa) water pressure, it is equivalent to the conventional system or better, with one exception at an airflow of 8,700 cfm (4.1 m^3/s), which is within the range of experimental error.

MSHA also tested a 2,700 cfm (1.3 m^3/s) diffuser fan system and found that its performance was roughly equivalent to the Spray Fan at 200-psi (1380 kPa).

In view of these results, MSHA plans to allow some operators who install a Spray Fan to use a curtain distance of more than 10 ft (3.0m).

TABLE 1.

Airflow, cfm (m^3/s)	Dilution Capacity cfm CH_4(m^3/s)
Conventional sprays-curtain at 10 ft (3.0m)	
3,800 (1.8)	11.0 (.0052)
6,000 (2.8)	16.5 (.0078)
9,600 (4.5)	20.0 (.0094)
Spray Fan at 100 psi (690 kPa)-curtain at 20 ft (6.1m)	
3,000 (1.4)	16.5 (.0078)
5,900 (2.8)	17.0 (.0080)
8,700 (4.1)	18.5 (.0087)
Spray Fan at 200 psi(1380 kPa)-curtain at 20 ft (6.1m)	
3,000 (1.4)	21.5 (.010)
5,900 (2.8)	22.5 (.011)
9,000 (4.2	22.5 (.011)

REMAINING PROBLEMS

The perfect ventilation system has yet to be developed, and some potential problems encountered with the Spray Fan should be discussed, in order of importance.

Dust. The Spray Fan was originally designed as a methane control device to be used with a 10 ft (3.0m) curtain. While it has been shown to reduce dust levels when compared with the diffuser fan, comparisons with conventional sprays indicate that dust levels remain about the same. Verbal reports of reduced dust must be regarded with some suspicion, since most people base judgment on visible dust up near the cutterhead, which they can see. The Spray Fan undoubtedly reduces dust at the head, just as it reduces methane, but it does not follow that the dust level at the operator location is reduced.

In particular, we envision dust compliance problems for the operator who uses a Spray Fan and a 20-ft (6.1m) curtain. For this reason, we would suggest that a 15-ft (4.6m) curtain be tried first.

Water pressure is sometimes difficult to maintain. A booster pump is often required. If a 1-inch (0.025m) hose between the supply pipe and mining machine is used, the frictional losses are great; a 1-1/4-inch (0.031m) hose is better. Other pressure losses in the mining machine are great, particularly if all of the water is routed through motor-cooling jackets. Conventional mining machine water filters clog quickly, with more pressure losses. As an alternative, the Bureau has developed an improved filtering system incorporating a hydrocyclone (3). This should be used, and water pressure should be checked periodically.

Ventilation under the head. The original Spray Fan system tested by Foster-Miller had a generous number of water sprays under the head, to ventilate the region under the head as well as above it. In practice, it is difficult to place sprays under the head because they are more vulnerable to damage. Consequently, none of the systems installed underground had underhead sprays closely behind the cutter bits, as the original laboratory-tested system had.

Nevertheless, underhead sprays should be provided to the greatest extent possible. One possibility is to use locations under the head and closer to the hinge point of the machine. Another is to mount sprays near the outby corner of the pan and aim them into the space between the head and the pan. If the number of nozzles is reduced, the flow through each should be increased. For example, if the number of underhead nozzles is halved, the flow through each should be at least tripled to maintain the same air-moving ability.

SUMMARY

The performance of the Spray Fan as a coal mine ventilation device has been confirmed independently in the laboratory and underground, and by several different organizations involved with the mining of coal. Provided that its limitations are recognized, it can undoubtedly serve as a useful tool for a portion of the industry.

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