## For Reference

Not: to be taken from this room

LIERARY
SPOKANE RESEARCH CENTEA RECEIVED


UNITED STATES DEPARTMENT OF THE INTERIOR


## U.S. Department of the Interior Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. This Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Cover: Site in mine beltway for injecting dust-suppression reagents into mainstream water line. This water line leads to the spray system that controls aimome coal dust during the longwall mining operation. Testing has shown that some suffactant-polymer dust-suppression reagents provide improved respirable dust control compared to water sprays without injected reagents.

# Suppression of Longwall Respirable Dust Using Conventional Water Sprays Inoculated With Surfactants and Polymers 

By H. W. Kilau, O. L. Lantto, K. S. Olson, T. A. Myren, and J. I. Voltz

UNITED STATES DEPARTMENT OF THE INTERIOR Bruce Babbitt, Secretary

BUREAU OF MINES
Rhea Lydia Graham, Director

## CONTENTS

## Page

Abstract ..... 1
Introduction ..... 2
Preliminary laboratory testing ..... 2
Materials ..... 2
Laboratory experimental procedures ..... 3
Laboratory experimental results ..... 4
In-mine longwall testing ..... 4
Reagent injection ..... 4
Longwall water and dust sampling ..... 4
Longwall test results for mine A ..... 5
Longwall characteristics of mine A ..... 5
Reagent concentrations and other water spray data for mine A ..... 5
Intake dust distributions on longwall of mine A ..... 15
Intake filter samples at mine A ..... 15
Ventilation distribution at mine A ..... 15
Computation of intake dust flow patterns at mine A ..... 15
Coal production data for mine A ..... 16
Computation of respirable dust reductions at stationary sampling locations for mine A ..... 16
Computation of respirable dust reductions for mobile sampling at mine A ..... 16
Longwall test results for mine B ..... 17
Longwall characteristics of mine B ..... 17
Reagent concentrations and other water spray data for mine B ..... 28
Intake dust distributions on longwall of mine B ..... 28
Intake filter samples at mine B ..... 28
Ventilation distribution at mine B ..... 28
Computation of intake dust flow patterns at mine B ..... 29
Coal production data for mine B ..... 29
Computation of respirable dust reductions at stationary sampling locations for mine B ..... 29
Computation of respirable dust reductions for mobile sampling at mine B ..... 29
Discussion ..... 30
Stationary sampling at mine A ..... 30
Mobile sampling at mine A ..... 31
Stationary sampling at mine B ..... 31
Headgate dust bias at mine B ..... 31
Correction of headgate dust bias at mine B ..... 32
Coal production bias at mine B ..... 32
Mobile sampling at mine B ..... 32
Dust reduction in beltway of mine B ..... 32
Reagent costs ..... 33
Influence of reagent concentrations ..... 33
Conclusions ..... 33
Acknowledgments ..... 34
References ..... 34
Appendix A.-Ventilation distribution calculations ..... 35
Appendix B.-Intake dust flow calculations ..... 36
Appendix C.-Coal production calculations ..... 37
Appendix D.-Calculation of corrected and normalized dust values ..... 38
Appendix E.-Mobile sampling calculations ..... 39
Appendix F.-Headgate dust correction ..... 40

## ILLUSTRATIONS

Page

1. Particle volume distributions of ground coal samples used in laboratory wettability testing ..... 41
2. Particle surface area distributions of ground coal samples used in laboratory wettability testing ..... 42
3. Drop penetration test results for aqueous solutions of SD2ES surfactant with and without polymers and SAES surfactant with polymer ..... 43
4. Drop penetration test results for aqueous solutions containing SD2ES + SAES surfactant with polymers ..... 44
5. Schematic diagram of bypass system for injecting reagents into longwall water spray system ..... 45
6. Reagent bypass injection system set up at minesite ..... 46
7. Schematic diagram of stationary dust-sampling locations, ventilation pattern, and intake dust flows for reagent experiment 1a on mine A longwall ..... 47
8. Schematic diagram of stationary dust-sampling locations, ventilation pattern, and intake dust flows for reagent experiment 1 b on mine B longwall ..... 48
9. Dust-suppression results for stationary gravimetric samplers located at shields 10,85 , and 152 on mine A longwall ..... 49
10. Dust-suppression results for mobile gravimetric sampling on mine A longwall ..... 50
11. Schematic diagram of headgate dust flows and ventilation patterns for reagent experiment 7 b on mine B longwall ..... 51
12. Comparison of dust suppression at mines $\mathbf{A}$ and $\mathbf{B}$ as determined from mobile sampling ..... 52
13. Comparison of dust reduction and costs for reagent combinations at mines $\mathbf{A}$ and $\mathbf{B}$ as determined from mobile sampling. ..... 53
TABLES
14. Chemical analyses of as-received coal and water samples ..... 3
15. Reagent concentrations, surface tensions, and injection data for water sprays during longwall testing at mine $A$ ..... 6
16. Filter data for stationary gravimetric dust sampling in intake crosscut at mine $A$ ..... 7
17. Filter data for stationary gravimetric dust sampling in beltway at mine A ..... 7
18. Ventilation distribution at shield 10 of mine $A$ ..... 7
19. Ventilation distribution at shield 85 of mine A ..... 8
20. Ventilation distribution at shield 152 of mine $A$ ..... 8
21. Intake dust flow distribution at shield 10 of mine A ..... 8
22. Intake dust flow distribution at shield 85 of mine $A$ ..... 9
23. Intake dust flow distribution at shield 152 of mine A ..... 9
24. Coal production during longwall testing of dust-suppression reagents at mine $A$ ..... 9
25. Filter data for stationary gravimetric dust sampling at shield 10 of mine A ..... 10
26. Filter data for stationary gravimetric dust sampling at shield 85 of mine A ..... 10
27. Filter data for stationary gravimetric dust sampling at shield 152 of mine A ..... 10
28. Computation of respirable dust reduction at shield 10 of mine A ..... 11
29. Computation of respirable dust reduction at shield 85 of mine $\mathbf{A}$ ..... 12
30. Computation of respirable dust reduction at shield 152 of mine A ..... 13
31. Filter data for mobile gravimetric dust sampling at mine A ..... 14
32. Computation of respirable dust reduction for mobile gravimetric dust sampling at mine A ..... 14
33. Water spray reagent concentrations and surface tensions during longwall testing at mine $\mathbf{B}$ ..... 17
34. Water spray flows and pressures during longwall testing at mine $\mathbf{B}$ ..... 17
35. Filter data for stationary gravimetric dust sampling in intake crosscut of mine $B$ ..... 18
36. Filter data for stationary gravimetric dust sampling in beltway of mine B ..... 18
37. Ventilation distribution at shield 13 of mine $\mathbf{B}$ ..... 18
38. Ventilation distribution at shield 54 of mine B ..... 19
39. Ventilation distribution at shicld 109 of mine B ..... 19

## TABLES-Continued

## Page

27. Intake dust flow distribution at shield 13 of mine $B$ ..... 19
28. Intake dust flow distribution at shield 54 of mine $B$ ..... 20
29. Intake dust flow distribution at shield 109 of mine B ..... 20
30. Coal production during longwall testing of dust-suppression reagents at mine $\mathbf{B}$ ..... 20
31. Filter data for stationary gravimetric dust sampling at shield 13 of mine $\mathbf{B}$ ..... 21
32. Filter data for stationary gravimetric dust sampling at shield 54 of mine $\mathbf{B}$ ..... 21
33. Filter data for stationary gravimetric dust sampling at shield 109 of mine $\mathbf{B}$ ..... 21
34. Computation of respirable dust reduction at shield 13 of mine $B$ ..... 22
35. Computation of respirable dust reduction at shield 54 of mine $B$ ..... 23
36. Computation of respirable dust reduction at shield 109 of mine $B$ ..... 24
37. Computation of respirable dust reduction in beltway of mine $\mathbf{B}$ ..... 25
38. Filter data for mobile gravimetric dust sampling at mine $\mathbf{B}$ ..... 25
39. Computation of respirable dust reduction for mobile gravimetric dust sampling at mine $B$ ..... 26
40. Computation of respirable dust reduction corrected for headgate dust at shield 54 of mine $\mathbf{B}$ ..... 26
41. Computation of respirable dust reduction corrected for headgate dust at shield 109 of mine $\mathbf{B}$ ..... 27
42. Computation of respirable dust reduction corrected for headgate dust for mobile dust sampling at mine B ..... 27

## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| Metric Units |  |  |  |
| :---: | :---: | :---: | :---: |
| cm | centimeter | $\mathrm{mg} / \mathrm{min}$ | milligram per minute |
| dyn/cm | dyne per centimeter | $\mathrm{mg} / \mathrm{t}$ | milligram per metric ton |
| $g$ | gram | min | minute |
| h | hour | mm | millimeter |
| kg | kilogram | ppm | part per million |
| $\mathrm{kg} / \mathrm{cm}^{2}$ | kilogram per square centimeter | $s$ | second |
| L/min | liter per minute | t | metric ton |
| m | meter | wt \% | weight percent |
| $\mathrm{m}^{3}$ | cubic meter | $\mu \mathrm{L}$ | microliter |
| $\mathrm{m}^{3} / \mathrm{min}$ | cubic meter per minute | $\mu \mathrm{m}$ | micrometer |
| mg | milligram | $\varphi / \mathrm{t}$ | cent per metric ton |
| $\mathrm{mg} / \mathrm{m}^{3}$ | milligram per cubic meter |  |  |
| U.S. Customary Units |  |  |  |
| $f t$ | foot | in | inch |
| $\mathrm{ft}^{3}$ | cubic foot | lb | pound |
| $\mathrm{gal} / \mathrm{min}$ | gallon per minute | psig | pound per square inch gauge |

Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

# SUPPRESSION OF LONGWALL RESPIRABLE DUST USING CONVENTIONAL WATER SPRAYS INOCULATED WITH SURFACTANTS AND POLYMERS 

By H. W. Kilau, ${ }^{1}$ O. L. Lantto, ${ }^{2}$ K. S. Olson, ${ }^{3}$ T. A. Myren, ${ }^{4}$ and J. I. Voltz ${ }^{5}$


#### Abstract

The U.S. Bureau of Mines is evaluating water spray additives for the purpose of improving respirable dust control during coal mining operations, with particular emphasis on the longwall shearer. Recent field tests of surfactant-polymer reagents at two production longwall operations have shown favorable respirable dust reductions compared with water sprays containing no additive. Gravimetric dust samples obtained by a technician downwind of the shearer while following or preceding the machine showed dust reductions in the range of about $40 \%$ to $60 \%$ for some of the reagent formulations compared with using water alone. Three polymers were tested: two polyethylene oxide compounds of different molecular weight and hydroxypropyl methylcellulose (HPMC). All were effective for dust reduction, and two were cost effective when used in combination with sodium di(2-ethylhexyl) sulfosuccinate surfactant. However, the use of these reagents requires the longwall operator to be more aware of headgate dust control. Experimental evidence indicates that dust captured by reagent-treated sprays at the shearer can be reemitted in the headgate area if stageloader-crusher sprays and other dust controls are inadequate.


[^0]
## INTRODUCTION

The control of airborne respirable coal dust during mining operations and its health-related implications for the miner is a continuing concern of the U.S. Bureau of Mines (USBM). There are health hazards associated with inhaled coal dust that continue to be a problem in underground coal mining. The increased production achieved by modern mining machines leads to higher respirable airborne dust concentrations. Especially troublesome is the longwall shearer since the layout of a longwall and the duties of the operating personnel make it difficult to protect the workers from excessive exposure to dust. The ventilation methods that are very effective in a continuous miner section are not applicable to the longwall situation. Consequently, the use of water sprays to suppress airborne dust during the shearing operation is of primary importance in longwall dust control.

The ultimate dust-control effectiveness of water sprays may be limited because coal particle surfaces are normally hydrophobic and therefore resistant to wetting and maximum capture agglomeration by water spray droplets. Surfactant wetting agents are sold commercially to improve the coal wetting characteristics of water sprays and their ability to suppress dust during mining operations. The efficacy of these commercial products is controversial among mine operators. There have been few scientific in-mine studies in which surfactant wetting agents have been objectively evaluated for their dust-suppression properties. Meets and Neethling (1) ${ }^{6}$ published some results of their
longwall and continuous miner application of surfactants. They claimed a $40 \%$ respirable dust-reduction improvement over water only, but the identity of the surfactants used was not given. Kost and others (2) conducted tests on a spray-equipped auger miner and determined an average airborne respirable dust reduction of $27 \%$ when using four surfactants selected on the basis of previous laboratory testing. The performance of each surfactant in the mine testing was similar, so no ranking of the surfactants was attempted.

There are theoretical reasons supporting the use of an additive combination composed of surfactant plus longchain, water-soluble polymer for dust suppression in place of just surfactant alone (3). The results of laboratory studies have further encouraged this current effort to test the surfactant-polymer combinations in underground longwall operations (4).

The surfactant serves to wet the coal surfaces to aid dust capture and acts as a medium for attaching polymer to the coal surfaces. The polymer serves as a binding agent to foster the attachment of fine particles to large coal fragments and to promote the gathering of respirablesize particles into larger, nonrespirable agglomerates. It is the objective of this current work to evaluate the respirable coal dust-suppression effectiveness of several surfactant-polymer combinations on actual production longwall operations.

## PRELIMINARY LABORATORY TESTING

## MATERIALS

Two anionic surfactants were employed in the longwall dust-control experiments. One was sodium di(2ethylhexyl) sulfosuccinate (SD2ES), which was supplied by the Witco Corp. as a $70 \%$ solution in water and ethanol ( $i \%$ ) under the brand name Emcol 4500. This surfactant has been shown to be especially effective for wetting hydrophobic coals in previous laboratory testing (5).

The second surfactant used was a sodium alcohol ether sulfate (SAES), which was supplied by Witco as a $38.4 \%$ solution in water under the brand name Witcolate 7093. This reagent is a foaming agent. Although no attempt was made in this work to inject air to make foam during the longwall trials, it was believed that foaming from entrained

[^1]air would be helpful in suppressing dust, particularly during transport of the cut coal in the face conveyor. In addition, laboratory testing showed that this surfactant improved the solubility of SD2ES and polymer in the concentrate blend and decreased the viscosity for improved pumping action.

Three polymers were used in the longwall experiments to improve dust capture and agglomerate stability. Two are nonionic polyethylene oxide (PEO) compounds, but of different molecular weights. The polymers were obtained from Union Carbide Corp. as minus 10 -mesh powders, and the purities were specified as being greater than $98.5 \%$ by the manufacturer. Polyox WSR 205 (PEO-205) has a molecular weight of 600,000 and, when combined with an anionic surfactant, can greatly improve the wettability of coal. Polyox WSR-N-10 (PEO-10) has a lower molecular weight of 100,000 . Its less viscous solutions are easier to pump, but its coal wetting and agglomerating
capabilities are less than those of PEO-205. The third polymer tested is a modified cellulose compound obtained from Dow Chemical Co. under the brand name Methocel K4M. The powdered product is a hydroxypropyl methylcellulose (HPMC) of $90 \%$ purity, having a molecular weight of about 370,000 , according to the manufacturer.

The coal and water samples used in the preliminary laboratory testing were from the mines in which subsequent longwall trials of the foregoing dust-suppression reagents were conducted. One set of samples was from the JWR No. 5 Mine of Jim Walter Resources, Inc., located near Tuscaloosa, AL. This metallurgical-grade coal is mined at a depth of $640 \mathrm{~m}(2,100 \mathrm{ft})$ from the Blue Creek Seam. This mine will be designated as "mine A" in this report. The second set of samples was from the Skyline No. 3 Mine of Utah Fuel Co., located in the Wasatch mountain range near Helper, UT. This coal is mined at a depth of 366 to $671 \mathrm{~m}(1,200$ to $2,200 \mathrm{ft})$ from the lower O'Connor Seam and used for electric power generation. This mine will be designated as "mine $B$ " in this report.

The analyses of the coal and water samples from mine A and mine B are provided in table 1. Both coal samples were ground to minus 200 mesh for the laboratory testing. The ground coal samples were dispersed in water using a small amount of Triton X100 scintillation-grade surfactant (Union Carbide) and their size distributions measured with an HIAC-ROYCO Optisizer with HRLD-600-JS laser sensor (Pacific Scientific Corp.). This instrument employs laser light extinction principles to measure particle distributions in the range 2 to $500 \mu \mathrm{~m}$. Essentially, the instrument measures particle diameters and sorts them into various size intervals. The volume of particles in an interval is determined by computing the volume of each particle (based on spherical geometry), followed by summation of the calculated particle volumes within an interval. The volume of particles in each size interval are divided by the total volume from all size intervals to obtain the differential volume percent distribution plot of figure 1.

It is evident from figure 1 that the particle volume distributions of the two hand-ground coals are quite similar. As far as the laboratory wetting test is concerned, a more important parameter is the surface area distributions of the ground coal samples. Assuming the particulates are spherical in shape, a surface area distribution can be calculated from the data of figure 1. The results, displayed in figure 2 , again show similar characteristics between the two coals from mine A and mine B. Therefore, any differences in wetting response between the two coals in the laboratory testing are not likely caused by the physical characteristics of the coal samples, but rather by differences in surface chemistry.

Table 1.-Chemical analyses of as-recelved coal and water samples

| Constituent | Mine A | Mine B |
| :---: | :---: | :---: |
| Coal ${ }^{1}$ analysis, wt \%: |  |  |
| Moisture | 0.3 | 2.3 |
| Volatile matter | 21.72 | 44.2 |
| Total carbon | 78.9 | 74.2 |
| Fixed carbon ${ }^{2}$ | 67.3 | 47.6 |
| Ash | 10.7 | 5.9 |
| Sulfur | 0.7 | 0.4 |
| Oxygen ${ }^{3}$ | 3.4 | 10.4 |
| Hydrogen | 4.5 | 5.2 |
| Nitrogen | 1.4 | 1.5 |
| Water analysis, ppm: |  |  |
| Calcium | 50 | 30 |
| Magnesium | 36 | 71 |
| Sulfate | 271 | 513 |
| Chloride | 9 | 7 |
| Sodium | 41 | 200 |
| Potassium | 3 | 16 |
| Water pH . . . . . . . . . . . | 7.8 | 8.0 |

${ }^{1}$ Mine A coal is medium volatile bituminous; mine $B$ coal is high volatile bituminous. Rank is determined from ASTM D388-84 standard classification of coal (6).
${ }^{2}$ By subtraction [100-(\% moisture + ash + volatile matter)].
${ }^{3}$ By subtraction [100-(\% carbon + hydrogen + sulfur + nitrogen + ash + moisture)].

## LABORATORY EXPERIMENTAL PROCEDURES

The drop penetration test (3) was used to test the ground coals in the laboratory prior to field trials. In the test, a dilute wetting solution is prepared containing the surfactant or surfactant-polymer to be evaluated. The water used in the solution preparation contains added salts to simulate the actual mine waters corresponding to the chemical analysis given in table 1. A $2.5-\mu \mathrm{L}$ droplet of the wetting solution to be evaluated is deposited on a planar bed of minus 200 mesh-coal particles. The droplet is observed with a microscope, and the time required for the droplet to fill with particles is recorded with a stopwatch. The shorter this time, the better the performance of the wetting agent. Furthermore, when comparing surfactantonly solutions with those containing both surfactant and polymer, an improvement in wetting time should be noted for the surfactant-polymer solution if proper interaction is occurring between the two additives. An explanation of how the drop penetration test relates to the capture of coal dust particles by water sprays has been described in detail in another report (3).

## LABORATORY EXPERIMENTAL RESULTS

The results of measuring the drop penetration times for some surfactant-polymer solutions are provided in figures 3 and 4. The error bars in the figures represent the $90 \%$ confidence lcvel. It is clear from figure 3 that the SD2ES surfactant alone is more effective when applied to mine $\mathbf{B}$ coal (shorter drop penetration time) compared with mine A coal. The improved coal wetting gained from adding HPMC polymer to the SD2ES surfactant solution is also greater for mine B coal ( $46 \%$ improvement) compared with mine A coal ( $33 \%$ ). The PEO-205 polymer, because of its longer chain molecule, is the most effective polymer additive, being nearly equivalent to HPMC and PEO-10 at
about a third of the concentration. Unfortunately, it is also the most difficult to prepare and inject in the mine environment because of the high viscosity of its concentrated solutions. By itself, SAES surfactant is so weakly surface active toward coal that its lengthy drop penetration time cannot be measured in a reasonable time; and therefore, it is not presented in figure 3. When combined with polymer, its activity increases remarkably, a result that encouraged its use in the mine testing. In figure 4, SAES is shown combined with SD2ES and polymer to further improve the wettability of coal. The decreased wetting time in the range 100 to 150 s after the addition of polymer is comparable to that obtained with SD2ES surfactant alone in figure 3.

## IN-MINE LONGWALL TESTING

The dust generated during a work shift was sampled at several fixed locations on the longwall and downwind of the moving shearer. The dust sampling experiments were carried out during most of a working shift. The shifts at mine A were 8 h long, while mine $B$ had $10-\mathrm{h}$ shifts. One shift would be sampled when reagent was injected into the sprays, and the other shift would be sampled when no reagent was injected for comparison. The improvement in dust suppression when using reagent compared with no reagent injection was calculated whenever possible on this basis of consecutive shifts with and without reagent each day.

To help avoid bias due to differences in shearer operation, the shift in which reagent was injected was changed the second week at mine $B$ to obtain a different longwall operating crew.

## REAGENT INJECTION

Reagent metering pumps and injection ports were installed along the longwall water supply line several hundred feet from the face. The location was in the track entry at mine $A$ and in the beltway at mine $B$. The location must be downstream from any water used in the emulsions for the hydraulic roof supports since the reagents most likely would harm the emulsion. Concentrated aqueous solutions of the surfactant or surfactantpolymer reagents were prepared at the injection site and metered into the longwall water spray supply line. The preparation of the aqueous surfactant-polymer concentrates required the use of a mixing device (Penberthy flocculant disperser 62D by Houdaille Industries, Inc.) to dissolve the solid polymers without forming insoluble clumps of polymer in the solutions. [wo duplex diaphragm pumps (Hydroflo Inc., model CRIT 0614-04028)
were used to inject the reagent concentrates into the water spray supply line. The maximum rated flow capacity of each pump was $3.03 \mathrm{~L} / \mathrm{min}(0.8 \mathrm{gal} / \mathrm{min})$, and the reagent amount metered was automatically adjusted in response to supply line flow rate fluctuations by a proportional controller (adjustable frequency controller, model GPD 502, by Magnetek Drives and Systems Co., with Signet Metalex flow sensor, model MK525, by Signet Scientific Co.). This system was designed to maintain constant reagent concentrations in the supply line independent of the supply flow rate. The injected concentrate was subjected to dilution and mixing in the turbulence of the supply line leading to the longwall shearer's spray nozzles.

The injection ports, pressure gauge, and flow sensor were mounted in a bypass system depicted schematically in figure 5. This design with its three major supply line valves permitted isolation of the injection system from the longwall water supply in the event of injection equipment failure. The system is shown installed at a minesite in figure 6.

## LONGWALL WATER AND DUST SAMPLING

Water spray samples were collected at the longwall face during the test runs for determination of surface tension and surfactant concentration. The surface tensions of the water samples were measured using a du Nouy ring-type instrument (tensiometer NR 1792 by A. Kruss, OptischMechanische Werkstatten, Hamburg, Germany). The concentration of SD2ES surfactant in the water samples was measured potentiometrically with a surfactant ion selective electrode and reference electrode (surfactant electrode, model 93-42; double-junction reference electrode, model 90-02; microprocessor ionalyzer, model 901, all by Orion Research Inc., Boston, MA). The method
was not applicable for SAES or mixtures of SAES + SD2ES. The concentration of SAES and total SAES + SD2ES in the water spray samples was measured using a two-phase titration method (confidential method, courtesy of Witco). The polymers were not directly analyzed. They were determined by calculation from the surfactant analysis using the known ratio of the polymer concentration to the surfactant in the injected mixtures of reagent concentrates.

Average airborne respirable dust concentrations were determined using two methods, stationary sampling and mobile sampling. In the stationary sampling method, three gravimetric samplers were placed at each of five locations, including three positions along the longwall face (headgate, midface, and tailgate), one position in the intake crosscut, and a position in the beltway a short distance upwind of the crusher (figure 7 for mine A and figure 8 for mine B). The face samplers were suspended from the roof supports approximately $1.2 \mathrm{~m}(4 \mathrm{ft})$ over the walkway railing. The dust-sampling equipment (Mine Safety and Appliance Corp. (MSA), part 56241) used was the standard type used for compliance sampling in underground coal mines in the United States. The samplers use $10-\mathrm{mm}$ nylon cyclones to separate the respirable-size dust fraction, the respirable dust being collected on $37-\mathrm{mm}$, polyvinyl chloride filters
(MSA part 457193) of $5-\mu \mathrm{m}$ pore size. The dust-laden air was sampled at the rate of $2.0 \mathrm{~L} / \mathrm{min}$. Vane anemometers (Davis Instrument Co., model A/2, 4-in diameter, ballbearing) were used to measure ventilation velocities at each of the five sampling positions. The cross-sectional area at each position was estimated to enable calculation of ventilation volume flow.

The purpose of the mobile sampling method was to measure airborne respirable dust generated primarily by the longwall shearer. This was accomplished by sampling the air at a constant distance downwind of the shearer on the production cuts. A technician, wearing three sampler units on a vest, moved with the shearer, maintaining a constant downwind distance of about 10 shields, or 15.2 m ( 50 ft ), from the shearer. At mine A, the shearer was followed by the technician in the walkway next to the railing. At mine $B$, the roof support system offered a choice of two walkways. Because of severe spalling of the face, the mine operator requested that the mobile sampling be done in the outer (gob-side) walkway for safety. In this case, since the production cut was head to tail, the sampling technician preceded the shearer by 10 shields. The sampler units were of the same gravimetric type employed in the stationary sampling.

## LONGWALL TEST RESULTS FOR MINE A

## LONGWALL CHARACTERISTICS OF MINE A

Mine A had a $259-\mathrm{m}$ ( $850-\mathrm{ft}$ ) longwall with a $165-$ to $229-\mathrm{cm}$ ( $65-\mathrm{to} 90-\mathrm{in}$ ) cutting height. The shearer depth of cut was 76 cm ( 30 in ). The face received ventilation from both the intake crosscut and beltway. Ventilation went from headgate to tailgate.

The shearing was unidirectional, the production cut proceeding from tailgate to headgate and the cleanup cut in the opposite direction. The data and calculated results for mine A are displayed in tables 2 to 19 . The data and results given pertain to respirable dust only. Total dust was not measured in this work.

## REAGENT CONCENTRATIONS AND OTHER WATER SPRAY DATA FOR MINE A

Table 2 lists some data related to the water sprays and the reagent concentrations employed. The shearer drums were equipped with 42 sprays per drum. In addition to the drum sprays, the shearer had four fog jet sprays mounted on the shearer. Two were directed toward the headgate drum, another at the tailgate drum, and the last toward the shields when the shearer is in a production-cut
direction (tailgate to headgate). The stageloader-crusher area employed 11 sprays for dust control. One spray was located at the inlet to the crusher, five were located inside the crusher, two were directed at the tunnel area, and three V-shaped sprays were mounted at the point where the face discharges onto the stageloader conveyor.

Mine A also employed a face conveyor water spray system, which positioned three V-shaped sprays on the panline to spray the coal on the face conveyor when the shearer was cutting toward the headgate. Each of the 3 sprays was located 20 shields apart on the headgate end of the face.

Table 2 reveals that the reagent concentrations for those injections containing polymer (reagent experiments 1a, 2a, 3a, and 4a), as determined by chemical analysis of water samples collected at the minesite, were considerably less than the intended concentrations. This is believed because of the inefficiency of the injection pumps when the viscous surfactant-polymer concentrate was injected. The pumps required constant attention to relieve plugging due to pockets of coagulated polymer. To cure this problem in the future, better reagent mixing methods will be introduced and the current diaphragm-type pumps replaced with pumps better able to handle viscous fluids.
Table 2.-Reagent concentrations, surface tensions, and injection data for water sprays during longwall testing at mine A

| Experiment | Day | Date | Shift | Surfactant, ppm |  |  |  | Polymer, ppm |  |  |  |  |  | Surface tension, dyn/cm | Waterflow to longwall face, $\mathrm{L} / \mathrm{min}(\mathrm{gal} / \mathrm{min})$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | SD2ES |  | SAES |  | PEO-205 |  | PEO-10 |  | HPMC |  |  |  |  |
|  |  |  |  | Actual | Target | Actual | Target | Actual | Target | Actual | Target | Actual | Target |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Mon. | 3/1 | 1 | 59 | 180 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 70 | 32.3 | 416-530 | (110-140) |
| 2 a | Tues. | 3/2 | 1 | 126 | 180 | 251 | 360 | 0 | 0 | 0 | 0 | 49 | 70 | 27.0 | 492-852 | (130-225) |
| 3 a | Wed. | 3/3 | 1 | 99 | 225 | 99 | 225 | 37 | 85 | 110 | 250 | 0 | 0 | 29.1 | 492-530 | (130-140) |
| 4 a | Thurs. | 3/4 | 1 | 136 | 225 | 136 | 225 | 51 | 85 | 151 | 250 | 0 | 0 | 27.2 | 568 | (150) |
| 5a | Fri. | 3/5 | 1 | 0 | 0 | 400 | 450 | 0 | 0 | 0 | 0 | 0 | 0 | 31.5 | 398-568 | (105-150) |
| 6 a | Fri. | 3/5 | 2 | 232 | 225 | 232 | 225 | 0 | 0 | 0 | 0 | 0 | 0 | 27.0 | 416-549 | (110-145) |
| Water: |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 a | Mon. | 3/1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.7 |  | NA |
| 2 a | Tues. | 3/2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.8 |  | NA |
| 3 a | Wed. | 3/3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.8 |  | NA |
| 4a | Thurs. | 3/4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.8 |  | NA |

Table 3.-Filter data for stationary gravimetric dust sampling In Intake crosscut at mine A

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 12 | HPMC | 0.08 | 0.06 | 0.04 | 0.06 | 315 | 0.630 | 0.10 |
| 2 a | HPMC | 0.04 | 0.10 | 0.08 | 0.07 | 333 | 0.666 | 0.11 |
| 3 a | PEO | 0.00 | 0.01 | 0.01 | 0.01 | 304 | 0.608 | 0.01 |
| 4 a | PEO | 0.01 | 0.03 | 0.00 | 0.01 | 318 | 0.636 | 0.02 |
| 5 a | None | 0.03 | 0.00 | 0.00 | 0.01 | 303 | 0.606 | 0.02 |
| 6a | None | 0.00 | 0.03 | 0.00 | 0.01 | 313 | 0.626 | 0.02 |
| Water: |  |  |  |  |  |  |  |  |
| 1 a | NAp | 0.05 | 0.02 | 0.08 | 0.05 | 310 | 0.620 | 0.08 |
| 2a | NAp | 0.03 | 0.05 | 0.06 | 0.05 | 322 | 0.644 | 0.07 |
| 3 a | NAp | 0.01 | 0.04 | 0.03 | 0.03 | 308 | 0.616 | 0.04 |
| 4 a | NAp | 0.00 | 0.00 | 0.00 | 0.00 | 84 | 0.168 | 0.00 |

NAp Not applicable.

Table 4.-Filter data for stationary gravimetric dust sampling in beltway (upwind of crusher) at mine A

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 12 | HPMC | 0.32 | 0.29 | 0.33 | 0.31 | 314 | 0.628 | 0.50 |
| 2 a | HPMC | NA | 0.27 | 0.27 | 0.27 | 325 | 0.650 | 0.42 |
| 3 a | PEO | 0.11 | 0.15 | 0.13 | 0.13 | 299 | 0.598 | 0.22 |
| 4 a | PEO | 0.35 | 0.22 | 0.25 | 0.27 | 309 | 0.618 | 0.44 |
| 5 a | None | 0.19 | 0.21 | 0.21 | 0.20 | 300 | 0.600 | 0.34 |
| 6a | None | 0.38 | 0.38 | 0.39 | 0.38 | 317 | 0.634 | 0.60 |
| Water: |  |  |  |  |  |  |  |  |
| 1 a | NAp | 0.30 | 0.26 | 0.26 | 0.27 | 306 | 0.612 | 0.45 |
| 2 a | NAp | 0.31 | 0.26 | 0.29 | 0.29 | 313 | 0.626 | 0.46 |
| 3 a | NAp | 0.22 | 0.20 | 0.17 | 0.20 | 308 | 0.616 | 0.32 |
| 4 a | NAp | 0.08 | 0.05 | 0.07 | 0.07 | 82 | 0.164 | 0.41 |
| NA Not available. <br> NAp Not applicable |  |  |  |  |  |  |  |  |

Table 5.-Ventilation distribution at shield 10 of mine A

| Experiment | Polymer | Measured ventilation in intake, $\mathrm{m}^{3} / \mathrm{min}$ |  |  | Ventilation at shield 10, $\mathrm{m}^{3} / \mathrm{min}$ |  | Fraction of intake ventilation at shield 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Crosscut | Beltway | Total ${ }^{1}$ | Measured at face | Calculated for gob |  |
| Reagent: |  |  |  |  |  |  |  |
| 1a | HPMC | 2,615 | 2,217 | 4,832 | 1,765 | 3,067 | 0.365 |
| 2 a | HPMC | 434 | 2,513 | 2,947 | 1,484 | 1,463 | 0.504 |
| 3 a | PEO | 3,198 | 2,827 | 6,025 | 1,832 | 4,193 | 0.304 |
| 4a | PEO | 2,996 | 2,949 | 5,945 | 2,199 | 3,746 | 0.370 |
| 5a | None | 1,624 | 2,045 | 3,668 | 2,011 | 1,658 | 0.548 |
| 6a | None | 3,157 | 2,765 | 5,922 | 1,673 | 4,248 | 0.283 |
| Water: |  |  |  |  |  |  |  |
| 1 a | NAp | 2,939 | 2,712 | 5,650 | 1,935 | 3,715 | 0.342 |
| 2 a | NAp | 2,723 | 1,992 | 4,715 | 2,432 | 2,284 | 0.516 |
| 3 a | NAp | 3,874 | 2,406 | 6,280 | 2,550 | 3,729 | 0.406 |
| 4a | NAp | NA | 2,131 | ${ }^{2} 5,109$ | 1,727 | 3,382 | 0.338 |
| NA Not available. |  |  |  |  |  |  |  |
| NAp Not applicable. |  |  |  |  |  |  |  |
| ${ }^{1}$ Sum of intake crosscut and beltway. |  |  |  |  |  |  |  |
| ${ }^{2}$ Not measured | culated as | verage of $v$ | tilation m | ured in | other nine experim |  |  |

Table 6.-Ventilation distribution at shield 85 of mine A

| Experiment | Polymer | Ventilation at shield $85, \mathrm{~m}^{3} / \mathrm{min}$ |  |  |  | Fraction at shield 85 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Measured at face | $\begin{gathered} \text { Lost } \\ \text { to gob } \end{gathered}$ | Gained from gob | Calculated for gob | Shield 10 face ventilation | $\begin{gathered} \text { Shield } 10 \\ \text { gob ventilation } \end{gathered}$ |
| Reagent: |  |  |  |  |  |  |  |
| 12 | HPMC | 1,457 | 308 | NAp | 3,375 | 0.826 | NAp |
| 2 a | HPMC | 1,421 | 63 | NAp | 1,526 | 0.958 | NAp |
| 32 | PEO | 1,480 | 352 | NAp | 4,545 | 0.808 | NAp |
| 4 a | PEO | 1,471 | 728 | NAp | 4,474 | 0.669 | NAp |
| 5 a | None | 1,597 | 414 | NAp | 2,071 | 0.794 | NAp |
| 6 a | None | 1,871 | NAp | 198 | 4,050 | NAp | 0.953 |
| Water: ${ }^{\text {a }}$ |  |  |  |  |  |  |  |
| 12 | NAp | 1,873 | 62 | NAp | 3,777 | 0.968 | NAp |
| 2a | NAp | 1,618 | 813 | NAp | 3,097 | 0.666 | NAp |
| 3 a | NAp | 2,457 | 93 | NAp | 3,823 | 0.963 | NAp |
| 4a . . . . . | NAp | 2,168 | NAp | 441 | 2,941 | NAp | 0.870 |

NAp Not applicable.
Table 7.-Ventilation distribution at shield 152 of mine A

| Experiment | Polymer | Ventilation at shield $152, \mathrm{~m}^{3} / \mathrm{min}$ |  |  |  | Fraction at shield 152 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Measured at face | $\begin{aligned} & \text { Lost } \\ & \text { to } \mathrm{gob} \end{aligned}$ | Gained from gob | Calculated for gob | Shield 85 face ventilation | Shield 85 gob ventilation |
| Reagent: |  |  |  |  |  |  |  |
| 12 | HPMC | 1,534 | NAp | 77 | 3,298 | NAp | 0.977 |
| 2 a | HPMC | 1,492 | NAp | 71 | 1,455 | NAp | 0.953 |
| 3 a | PEO | 1,530 | NAp | 50 | 4,498 | NAp | 0.990 |
| 4 a | PEO | ${ }^{1} 1,513$ | NAp | 42 | 4,432 | NAp | 0.991 |
| 5a | None | 1,534 | 63 | NAp | 2,134 | 0.961 | NAp |
| 6 a | None | 1,475 | 396 | NAp | 4,447 | 0.788 | NAp |
| Water: |  |  |  |  |  |  |  |
| 12 | NAp | 1,780 | 93 | NAp | 3,871 | 0.950 | NAp |
| 2a | NAp | 1,310 | 309 | NAp | 3,406 | 0.809 | NAp |
| 3 a | NAp | 2,114 | 343 | NAp | 4,166 | 0.860 | NAp |
| 4a ......... | NAp | 2,437 | NAp | 270 | 2,672 | NAp | 0.909 |

NAp Not applicable.
${ }^{1}$ Not measured; calculated as average of ventilation measured in the other five reagent experiments.
Table 8.-Intake dust flow distribution at shield 10 of mine $A$

| Experiment | Polymer | Dust flow in intake, mg/min |  |  | Intake dust flow at shield 10, mg/min |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Crosscut | Beltway | Total ${ }^{1}$ | Measured at face | Calculated for gob |
| Reagent: |  |  |  |  |  |  |
| 1a | HPMC | 248.83 | 1,105.60 | 1,354.43 | 494.80 | 859.63 |
| 2a | HPMC | 47.77 | 1,043.01 | 1,090.78 | 549.17 | 541.61 |
| 3a | PEO | 35.07 | 614.13 | 649.20 | 197.31 | 451.89 |
| 4 a | PEO | 62.77 | 1,303.49 | 1,366.26 | 505.34 | 860.92 |
| 5 a | None | 26.77 | 692.37 | 719.14 | 394.18 | 324.96 |
| 6 a | None | 50.39 | 1,670.57 | 1,720.96 | 486.26 | 1,234.70 |
| Water: |  |  |  |  |  |  |
| 1 a | NAp | 236.82 | 1,210.18 | 1,447.00 | 495.61 | 951.39 |
| 2a | NAp | 197.19 | 911.64 | 1,108.83 | 571.84 | 536.99 |
| 3a | NAp | 167.58 | 767.61 | 935.19 | 379.82 | 555.37 |
| 4a | NAp | ${ }^{2} 200.53$ | 865.56 | 1,066.09 | 360.31 | 705.78 |

${ }^{1}$ Sum of intake crosscut and beltway.
${ }^{2}$ Not measured; calculated as average of the other three water experiments.

Table 9.-Intake dust flow distribution at shield 85 of mine $\mathbf{A}$

| Experiment | Polymer | Measured at face, $\mathrm{mg} /$ min | Lost to gob, $\mathrm{mg} / \mathrm{min}$ | Gained from gob, $\mathrm{mg} / \mathrm{min}$ | Calculated for gob, $\mathrm{mg} /$ min |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Reagent: |  |  |  |  |  |
| 1 a | HPMC | 408.47 | 86.33 | NAp | 945.96 |
| 2 a | HPMC | 525.94 | 23.23 | NAp | 564.84 |
| 3 a | PEO | 159.41 | 37.90 | NAp | 489.79 |
| 4 a | PEO | 338.03 | 167.31 | NAp | 1,028.23 |
| 5 a | None | 313.04 | 81.14 | NAp | 406.10 |
| 6 a | None | 543.83 | NAp | 57.57 | 1,177.13 |
| Water: |  |  |  |  |  |
| 1 a | NAp | 479.71 | 15.90 | NAp | 967.29 |
| 2 a | NAp | 380.57 | 191.27 | NAp | 728.26 |
| 3 a | NAp | 365.89 | 13.92 | NAp | 569.30 |
| 4a | NAp | 452.24 | NAp | 91.93 | 613.85 |

NAp Not applicable.

Table 10.-Intake dust flow distribution at shield 152 of mine A

| Experiment | Polymer | Measured at face, $\mathrm{mg} / \mathrm{min}$ | Lost to gob, $\mathrm{mg} / \mathrm{min}$ | Gained from gob, $\mathrm{mg} / \mathrm{min}$ | Calculated for gob, $\mathrm{mg} / \mathrm{min}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Reagent: |  |  |  |  |  |
| 1 a | HPMC | 429.96 | NAp | 21.50 | 924.47 |
| 2a | HPMC | 552.13 | NAp | 26.19 | 538.65 |
| 3 a | PEO | 164.80 | NAp | 5.38 | 484.40 |
| 4 a | PEO | 347.68 | NAp | 9.66 | 1,018.58 |
| 5a | None | 300.79 | 12.25 | NAp | 418.35 |
| 6 a | None | 428.64 | 115.19 | NAp | 1,292.32 |
| Water: |  |  |  |  |  |
| 1 a | NAp | 455.77 | 23.93 | NAP | 991.23 |
| 2 a | NAp | 307.94 | 72.62 | NAp | 800.89 |
| 3a | NAp | 314.84 | 51.05 | NAp | 620.35 |
| 4a ...... | NAp | 508.51 | NAp | 56.27 | 557.57 |

NAp Not applicable.

Table 11.-Coal production during longwall testing of dust-suppression reagents at mine $A$

| Experiment | Polymer | Coal produced during shift, t |  | Estimated total production time, min |
| :---: | :---: | :---: | :---: | :---: |
|  |  | Clean | Paw |  |
| Reagent: |  |  |  |  |
| 1a | HPMC | 1,559 | 2,078 | 265 |
| 2a | HPMC | 2,109 | 2,812 | 397 |
| 3 a | PEO | 2,614 | 3,484 | 463 |
| 4 a | PEO | 2,763 | 3,684 | 463 |
| 5 a | None | 2,268 | 3,024 | 437 |
| 6 a | None | 2,199 | 2,932 | 424 |
| Water: |  |  |  |  |
| 1a | NAp | 1,714 | 2,285 | 291 |
| 2a | NAp | 2,321 | 3,094 | 437 |
| 3 a | NAp | 2,614 | 3,484 | 463 |
| 4a | NAP | 474 | 631 | 79 |

NAp Not applicable

Table 12.-Filter data for stationary gravimetric dust sampling at shield 10 of mine $A$

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling <br> time, min | Volume of air <br> sampled, $\mathrm{m}^{3}$ | Average dust <br> conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |  |

Table 13. Filter data for stationary gravimetric dust sampling at shield $\mathbf{8 5}$ of mine $\mathbf{A}$

| Experiment | Polymer | Weight of dust collected, mg |  |  |  |  | Sampling <br> time, min | Volume of air <br> sampled, $\mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |  |
| conc, $\mathrm{mg} / \mathrm{m}^{3}$ |  |  |  |  |  |  |  |  |

Table 14.-Filter data for stationary gravimetric dust sampling at shield 152 of mine A

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 12 | HPMC | 0.87 | 0.91 | 0.85 | 0.88 | 273 | 0.546 | 1.61 |
| 2 a | HPMC | 1.30 | 1.15 | 1.04 | 1.16 | 305 | 0.610 | 1.91 |
| 3 a | PEO | 0.81 | 0.62 | 0.65 | 0.69 | 282 | 0.564 | 1.23 |
| 4 a | PEO | 1.05 | 0.89 | 0.92 | 0.95 | 298 | 0.596 | 1.60 |
| 5a | None | 0.71 | 0.64 | 0.65 | 0.67 | 306 | 0.612 | 1.09 |
| 6a | None | 1.24 | 1.00 | 1.09 | 1.11 | 289 | 0.578 | 1.92 |
| Water: |  |  |  |  |  |  |  |  |
| 12 | NAp | 0.79 | 1.59 | 0.81 | 1.06 | 291 | 0.582 | 1.83 |
| 2a | NAP | 1.26 | 2.15 | 1.34 | 1.58 | 286 | 0.572 | 2.77 |
| 3 a | NAP | 1.43 | 1.33 | 1.29 | 1.35 | 294 | 0.588 | 2.30 |
| 4a | NAP | 0.33 | 0.38 | 0.30 | 0.34 | 72 | 0.144 | 2.34 |

NAp Not applicable.
Table 15.-Computation of respirable dust reduction at shield 10 of mine $A$

| Experiment | Polymer | Shearer operating time, ${ }^{1}$ min | Rate of airborne dust formation, ${ }^{2}$ $\mathrm{mg} / \mathrm{min}$ | Airborne dust, g |  |  | Total airborne dust, $\mathrm{mg} / \mathrm{t}$ of coal mined ${ }^{6}$ | Dust reduction, ${ }^{7}$ \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Formed during shift ${ }^{3}$ | Intake contribution ${ }^{4}$ | Formed during shift, corrected ${ }^{5}$ |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1a | HPMC | 259 | 2,111.65 | 559.08 | 131.02 | 428.06 | 186.87 | 842.41 |
| 2 a | HPMC | 268 | 2,185.17 | 867.95 | 218.13 | 649.82 | 209.62 | 956.02 |
| 3 a | PEO | 243 | 652.91 | 302.56 | 91.43 | 211.13 | 54.96 | ${ }^{10} 89.54$ |
| 4a | PEO | 276 | 2,346.51 | 1,087.37 | 234.18 | 853.19 | 210.09 | ${ }^{11} 52.44$ |
| 5a | None | 274 | 2,224.32 | 971.85 | 172.23 | 799.62 | 239.89 | ${ }^{12} 45.75$ |
| 6 a | None | 255 | 5,070.51 | 2,148.27 | 206.02 | 1,942.25 | 600.95 | ${ }^{13}-35.89$ |
| Water: |  |  |  |  |  |  |  |  |
| 1 a | NAp | 165 | 3,301.30 | 961.60 | 144.36 | 817.24 | 324.47 |  |
| 2a.... | NAP | 267 | 4,292.73 | 1,875.58 | 249.85 | 1,625.73 | 476.66 | NAP |
| 3a.... | NAp | 287 | 4,736.13 | 2,194.72 | 176.01 | 2,018.71 | 525.53 | NAP |
| 4a.... | NAp | 76 | 3,027.62 | 240.51 | 28.62 | 211.89 | 304.44 | NAP |

NAp Not applicable.
${ }^{2}$ Upwind of sampling position during dust-sampling period and normalized for shearer operating time.
${ }^{3}$ Upwind of sampling position during shift production time, uncorrected for intake contribution.
cala
${ }_{6}$ F
Calculated using equation 1 .
${ }^{9}$ Based on the results of reagent experiment 2 a compared to water experiment 2 a .
${ }^{10}$ Based on the results of reagent experiment 3 a compared to water experiment 3 a .
${ }^{11}$ Based on the results of reagent experiment 4 a compared to the average of the results for water experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3 a . If the questionable results for ${ }^{12}$ based on the results of reagent experiment 5 a compared to the average of the results for water experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3 a . If the question atypical water experiment 4 a are used to calculate the dust reduction, a value of $21.20 \%$ is obtained.
${ }^{13}$ Based on the results of reagent experiment 6 a compared to the average of the results for water experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3 a . If the quate atypical water experiment $4 a$ are used to calculate the dust reduction, a value of $-97.40 \%$ is obtained.
Table 16.-Computation of respirable dust reduction at shield 85 of mine A

| Experiment | Polymer | Shearer operating time, ${ }^{1}$ min | Rate of airborne dust formation, ${ }^{2}$ $\mathrm{mg} / \mathrm{min}$ | Airborne dust, g |  |  | Total airborne dust, mg/t of coal mined ${ }^{6}$ | Dust reduction, ${ }^{7}$ \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Formed during shift ${ }^{3}$ | Intake contribution ${ }^{4}$ | Formed during shift, corrected ${ }^{5}$ |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1a.. | HPMC | 245 | 2,288.31 | 605.16 | 108.16 | 497.78 | 217.31 | 847.23 |
| 2a | HPMC | 262 | 2,860.69 | 739.06 | 208.90 | 530.16 | 171.02 | 957.31 |
| 3 a | PEO | 242 | 1,283.49 | 594.77 | 73.87 | 520.90 | 135.60 | ${ }^{1075.70}$ |
| 4 a | PEO | 276 | 1,693.27 | 784.66 | 156.64 | 628.02 | 154.63 | ${ }^{11} 66.16$ |
| 5 L | None | 278 | 1,587.97 | 693.81 | 136.77 | 577.04 | 167.11 | ${ }^{12} 63.43$ |
| 6 a | None | 261 | 3,701.66 | 1,568.32 | 230.41 | 1,337.91 | 413.96 | ${ }^{13} 9.40$ |
| Water: |  |  |  |  |  |  |  |  |
| 1 a | NAP | 105 | 4,040.82 | 1,177.01 | 139.73 | 1,037.28 | 411.84 | NAp |
| 2a | NAp | 242 | 3,508.38 | 1,532.88 | 166.28 | 1,366.60 | 400.69 | NAp |
| 3 a | NAp | 277 | 4,993.16 | 2,313.83 | 169.56 | 2,144.27 | 558.21 | NAp |
| 4 a | NAp | 67 | 3,448.40 | 273.94 | 35.93 | 238.01 | 341.97 | NAp |

[^2]Table 17.-Computation of respirable dust reduction at shield 152 of mine A

| Experiment | Polymer | Shearer operating time, ${ }^{1}$ min | Rate of airborne dust formation, ${ }^{2}$ $\mathrm{mg} / \mathrm{min}$ | Airborne dust, 9 |  |  | Total airborne dust, mg/t of coal mined ${ }^{6}$ | Dust reduction, ${ }^{7}$ \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Formed during shift ${ }^{3}$ | Intake contribution ${ }^{4}$ | Formed during shift, corrected ${ }^{5}$ |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 12 | HPMC | 230 | 2,921.30 | 773.56 | 113.85 | 659.71 | 288.00 | ${ }^{8} 45.55$ |
| 2 a | HPMC | 257 | 3,373.64 | 1,340.01 | 219.30 | 1,120.71 | 361.52 | ${ }^{9} 27.70$ |
| 3 a | PEO | 234 | 2,265.20 | 1,049.69 | 76.37 | 973.32 | 253.38 | ${ }^{10} 54.03$ |
| 4a | PEO | 272 | 2,649.51 | 1,227.78 | 161.12 | 1,066.66 | 262.64 | ${ }^{11} 50.14$ |
| 5a | None | 282 | 1,812.24 | 791.80 | 131.42 | 660.38 | 198.11 | ${ }^{12} 62.39$ |
| 6 a | None | 260 | 3,146.09 | 1,332.94 | 181.60 | 1,151.34 | 356.23 | ${ }^{13} 32.37$ |
| Water: |  |  |  |  |  |  |  |  |
| 12 | NAp | 188 | 5,029.50 | 1,464.99 | 132.76 | 1,332.23 | 528.94 | NAp |
| 2 a | NAp | 246 | 4,211.26 | 1,839.98 | 134.55 | 1,705.43 | 500.03 | NAp |
| 3 a | NAP | 292 | 4,883.70 | 2,263.11 | 145.90 | 2,117.21 | 551.17 | NAp |
| 4 a | NAp | 68 | 6,029.19 | 478.96 | 40.40 | 438.56 | 630.12 | NAp |

${ }^{11}$ Based on the results of reagent experiment 4 a compared to the average of the results for water experiments $1 a, 2 a$, and $3 a$. If the questionable results for ${ }^{9}$ Based on the results of reagent experiment 2 a compared to water experiment 2 a .
${ }^{10}$ Based on the results of reagent experiment 3 a compared to water experiment 3 a . ${ }^{3}$ Upwind of sampling position during shift production time, uncorrected for intake contribution.
on
5 calculated
${ }^{6}$ Formed upwind of sampling position, normalized for coal production, and corrected for intake dust.
${ }^{7}$ Calculated using equation 1.
${ }^{8}$ Based on the results of reagent experiment 1a compared to water experiment 1 a .
atypical water experiment $4 a$ are used to calculate the dust reduction, a value of $58.32 \%$ is obtained.
${ }^{12}$ Based on the results of reagent experiment 5 a compared to the average of the results for water experiments $1 \mathrm{a}, \mathbf{2 a}$, and 3 a . If the questionable results for
atypical water experiment 4 a are used to calculate the dust reduction, a value of $68.56 \%$ is obtained. ${ }^{13}$ Based on the results of reagent experiment 6a compared to the average of the results for water atypical water experiment 4 a are used to calculate the dust reduction, a value of $43.47 \%$ is obtained

Table 18.-Fiter data for mobile gravimetric dust sampling at mine $A$

| Experiment | Polymer | Weight of dust collected, mg |  |  |  |  | Sampling <br> time, min | Volume of air <br> sampled, $\mathrm{m}^{3}$ |
| :---: | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |  |
| conc, $\mathrm{mg} / \mathrm{m}^{3}$ |  |  |  |  |  |  |  |  |

NA Not available.
NAp Not applicable.

Table 19.-Computation of respirable dust reduction for mobile gravimetric dust sampling at mine $A$

| Experiment | Polymer | Av intake dust flow, $\mathrm{mg} / \mathrm{min}$ | Av ventilation, $\mathrm{m}^{3} / \mathrm{min}$ | Av dust conc from intake, $\mathrm{mg} / \mathrm{m}^{3}$ | Weight of dust, mg |  | Corrected ${ }^{1}$ av dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ | Dust reduction, ${ }^{2}$ \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | Intake contribution | Corrected for intake |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
|  | HPMC | 444.41 | 1,585 | 0.28 | 0.06 | 0.32 | 1.44 | ${ }^{3} 61.58$ |
| 2 a | HPMC | 542.41 | 1,465 | 0.37 | 0.09 | 0.46 | 2.02 | ${ }^{4} 2.88$ |
| 3 a | PEO | 173.84 | 1,614 | 0.11 | 0.02 | 0.17 | 1.23 | $5_{51.19}$ |
| 4 a | PEO | 397.02 | 1,728 | 0.23 | 0.05 | 0.31 | 1.50 | ${ }^{6} 46.24$ |
| 5a | None | 336.00 | 1,714 | 0.20 | 0.05 | 0.37 | 1.57 | ${ }^{7} 43.73$ |
| 6a | None | 486.24 | 1,673 | 0.29 | 0.07 | 0.54 | 2.50 | ${ }^{8} 10.39$ |
| Water: |  |  |  |  |  |  |  |  |
| 1 a | NAp | 477.03 | 1,863 | 0.26 | 0.02 | 0.34 | 3.78 | NAp |
| 2a | NAp | 420.12 | 1,787 | 0.24 | 0.06 | 0.50 | 2.08 | NAp |
| 3 a | NAp | 353.52 | 2,374 | 0.15 | 0.03 | 0.56 | 2.52 | NAp |
| 4a | NAp | 440.45 | 2,111 | 0.21 | 0.01 | 0.08 | 1.29 | NAp |
| NAp Not applicable. <br> ${ }^{1}$ Corrected for intake dust contribution. <br> ${ }^{2}$ Calculated using equation 1. |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{3}$ Based on the results of reagent experiment 1a compared to water experiment 1a. |  |  |  |  |  |  |  |  |
| ${ }^{4}$ Based on the results of reagent experiment 2 a compared to water experiment 2 a . |  |  |  |  |  |  |  |  |
| ${ }^{5}$ Based on the results of reagent experiment 3 a compared to water experiment 3a. |  |  |  |  |  |  |  |  |
| ${ }^{6}$ Based on the results of reagent experiment 4a compared to the average of the results for water experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3 a . If the |  |  |  |  |  |  |  |  |
| questionable results for atypical water experiment 4 a are used to calculate the dust reduction, a value of $-16.28 \%$ is obtained. |  |  |  |  |  |  |  |  |
| ${ }^{8}$ Based on the results of reagent experiment $6 a$ compared to the average of the results for water experiments $1 \mathrm{a}, 2 \mathrm{a}, \mathrm{and} 3 \mathrm{a}$. If the questionable results for atypical water experiment 4 a are used to calculate the dust reduction, a value of $-93.80 \%$ is obtained. |  |  |  |  |  |  |  |  |

All the measured surface tensions (column 15 of table 2) of the water samples containing reagent were comfortably below the critical surface tension of $45 \mathrm{dyn} / \mathrm{cm}$, the value required for spreading wetting of coal (7). All the surface tensions of water samples collected when reagent was not injected were at values to be expected for pure water. This result indicates that no carryover of reagent was occurring between the reagent and water-only tests.

The waterflow to the longwall face (last column of table 2) was typical for longwall operations. The water pressure at the injection ports was measured as 35 to 42 $\mathrm{kg} / \mathrm{cm}^{2}$ ( 500 to 600 psig ) at the beginning of the testing. The pressure gauge ceased to function soon afterwards and no further pressure measurements were available for the rest of the testing program.

## INTAKE DUST DISTRIBUTIONS ON LONGWALL OF MINE A

A first consideration in comparing the effectiveness of the reagent applications is to determine and correct for the contributions from dust sources that are not affected by the reagent. For mine A, these sources include dust from roof support movement, dust entering the face from the gob, dust from the main entry leading to the intake crosscut, and dust from the beltway that is ventilated at mine A. The dust contributions from the intake crosscut and beltway were measured. The methods used to correct dust totals along the face for these intake contributions will be discussed in the following section. Roof support dust was not measured or considered in the dust total corrections in this work. Dust generated in the gob and flowing to the face was also not considered. Fortunately, for the mincs tested in this work, ventilation reentry to the face from the gob was relatively low for most of the tests conducted.

## Intake Filter Samples at Mine A

The gravimetric results for filter samplers located in the intake crosscut are given in table 3. The average dust concentrations from this dust source are small. The dust concentrations measured in the beltway (table 4), however, were much larger, greater than tenfold in some cases. There is some question whether beltway dust should be treated as a dust source independent of reagent application since the higher dust concentration in this entry is likely due to entrainment from coal on the belt. The entrainment effect could be changed by the presence on the surface of lingering traces of reagent sprayed earlicr downwind on the face. The comparability of the average dust concentrations between the reagent ind water tests of table 4 indicates that changes in entrainment are not
occurring at mine A to any great degree with the possible exception of reagent experiment 3 a .

## Ventilation Distribution at Mine A

Because the total intake dust (intake crosscut plus beltway) is subject to proportioning that corresponds to ventilation losses and gains along the face, it cannot be strictly deducted directly from measured dust levels on the face. For each experiment, the ventilation distribution must be determined along the face and the corresponding dust flow pattern derived if intake corrections are to be done appropriately. The ventilation distribution at shield 10 [or about $15.2 \mathrm{~m}(50 \mathrm{ft})$ downwind of the headgate] is given in table 5. The value for the gob ventilation at shield 10 in column 7 is simply the sum of the intake ventilations minus the face ventilation measured at shield 10 . It is assumed that there are no other sources of ventilation feeding the longwall than the intake crosscut and beltway. It can be seen in the last column of the table that intake ventilation losses to the gob exceed $50 \%$ in most experiments. After this initially large ventilation loss, the losses are mainly less than $30 \%$ at the two sampler locations downwind at midface and tailgate (shield 85 in table 6 and shield 152 in table 7 , respectively). In some cases, face ventilation gains occur when gob ventilation reenters the face toward the tailgate. Some details concerning the calculation of the ventilation distributions in tables 5, 6, and 7 are provided in appendix A. An example of the ventilation distribution along the entire longwall for reagent experiment 1a is diagrammed in figure 7.

## Computation of Intake Dust Flow Patterns at Mine A

When the ventilation pattern is established in the longwall section, the flow pattern for dust originating from the intake can be estimated. The intake dust will split between face and gob under the influence of the ventilation pattern as it flows from the headgate to the tailgate of the longwall. These splits must be determined if correct dust intake corrections are to be made at each of the three sampling positions and for the mobile dust sampling. Any settling of the airborne respirable dust was not considered in the flow analysis. Table 8 gives the dust flows emanating from the intake crosscut and beltway and their distribution between the face and gob by the time they reach the shield 10 dust sampler location. The intake dust flow will be split again as it proceeds from shield 10 to shield 85 (table 9), and again as it proceeds from shield 85 to shicld 152 (table 10 ). The procedures used to derive tables 8,9 , and 10 are provided in appendix B. An example of mine A's longwall intake dust flow pattern for reagent
experiment 1a is also presented as a schematic diagram in figure 7.

## COAL PRODUCTION DATA FOR MINE A

A second consideration for normalizing the dust data to facilitate comparison of dust-reduction efficiency between tests is to incorporate the coal production and the time for that production into the computations for each test. The clean coal production for each shift or experiment in column 3 of table 11 was obtained from the daily production $\log$ of mine A. At the time of the testing, $25 \%$ of the raw coal was being removed as gangue in the mine's flotation beneficiation process. There was initial concern by the mine operator that the presence of the dust-suppression reagents would disturb this beneficiation process. The subsequent testing showed no adverse effects of this nature from the injected reagents. Most importantly, the production of raw coal was quite consistent from shift to shift, with the one exception of water experiment 4 a , when the shearer was down most of the shift. The procedures for determining coal production and production times in table 11 are given in appendix C.

## COMPUTATION OF RESPIRABLE DUST REDUCTIONS AT STATIONARY SAMPLING locations for mine a

The dust-sampling filter results for the three sampling locations along the face (shields 10,85 , and 152 ) are given in tables 12, 13, and 14 , respectively. The results from these tables were used in conjunction with the ventilation results from tables 5,6 , and 7 , the production-time results from table 11, and the dust flow results from tables 8,9 , and 10 to calculate the corrected and normalized dust values listed in column 8 of tables 15,16 , and 17. A demonstration of the calculation procedures is available in appendix D.

The corrected and normalized dust values (column 8 of tables 15,16 , and 17) are employed to calculate the percentage improvement in dust reduction at each shield location for injected water sprays compared with sprays containing no reagent. The percentage dust-reduction improvements for reagent experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3 a (listed in the last column of tables 15,16 , and 17) were calculated from the formula-

$$
\begin{equation*}
\text { Percentage dust reduction }=100 \cdot\left(\mathrm{D}_{\mathrm{W}}-\mathrm{D}_{\mathrm{R}}\right) / \mathrm{D}_{\mathrm{W}}, \tag{1}
\end{equation*}
$$

where $\quad D_{W}=$ corrected and normalized dust collected during water-only run (lower part of column 8 of tables 15, 16, and 17)
and

$$
\begin{aligned}
\mathrm{D}_{\mathrm{R}}= & \text { corrected and normalized dust collected } \\
& \text { during reagent test run on same day } \\
& \text { as water-only test (upper part of } \\
& \text { column } 8 \text { of tables } 15,16 \text {, and } 17) .
\end{aligned}
$$

It is best to compute the percentage dust suppression on the basis of consecutive shifts on the same day, as expressed earlier. However, in the case of water experiment 4a, the production of coal was far from typical because of shearer breakdown (see table 11). For this reason, this experiment is not considered suitable for computing dust suppression. Also, in the case of reagent experiments 5 a and 6a, no water-only runs were made the day of these experiments. Therefore, the percentage dust reductions for reagent experiments $4 \mathrm{a}, 5 \mathrm{a}$, and 6 a were computed using equation 1 , but on the basis of comparisons with the average of the water tests in water experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3a. For comparison, the computations based on the doubtful test of water experiment 4 a are given in footnotes 11,12 , and 13 of tables 15,16 , and 17.

## COMPUTATION OF RESPIRABLE DUST REDUCTIONS FOR MOBILE SAMPLING AT MINE A

The dust-sampling filter results for the mobile sampling are provided in table 18. It is appropriate to correct these results for background intake dust as was done for the stationary sampling. However, the correction is more complicated as the shearer and mobile sampling technician pass through regions of varying intake dust concentration and ventilation during the cutting pass along the face. To approximately correct the mobile gravimetric samples for background intake dust, average values for the ventilation along the face and intake dust flows were calculated. The average values were used to calculate the intake dust contributions and corrections of columns 6 and 7 of table 19 (see appendix E). The percentage dust reductions for the experiments in the last column of table 19 were calculated from equation 1 using the corrected average dust concentrations of column 8 in place of the coal production normalized values used in the stationary sampling calculations of tables 15,16 , and 17. This procedure, uncorrected for coal production, is appropriate for the mobile sampling since the mobile samplers were only running while coal was being produced. This is in contrast to the stationary samplers, which were continuously sampling during shearer down times as well as when coal was being produced. The same water-run selection procedures were employed that were used and discussed in the stationary sampling calculations.

## LONGWALL TEST RESULTS FOR MINE B

## LONGWALL CHARACTERISTICS OF MINE B

Mine B longwall had a $219.5-\mathrm{m}$ ( $720-\mathrm{ft}$ ) panel width with a $457-\mathrm{cm}(180-\mathrm{in})$ cutting height. The shearer depth of cut was $76 \mathrm{~cm}(30 \mathrm{in})$. The face received ventilation only from the intake crosscut; the beltway was not
ventilated. Ventilation was in the direction headgate to tailgate. The shearing was unidirectional, the production cut proceeding from headgate to tailgate, and the cleanup was in the opposite direction. The data and calculated results for mine $B$ are displayed in tables 20 to 42 .

Table 20.-Water spray reagent concentrations and surface tensions during longwall testing at mine $B$

| Experiment | Day | Date | Shift | Surfactant, ppm |  |  |  | Polymer, ppm |  |  |  | Surface tension, dyn/cm |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | SD2ES |  | SAES |  | PEO-10 |  | HPMC |  |  |
|  |  |  |  | Actual | Target | Actual | Target | Actual | Target | Actual | Target |  |
| Reagent: |  |  |  |  |  |  |  |  |  |  |  |  |
| 1b | Mon. | 4/19 | 3 | 21 | 267 | 0 | 0 | 16 | 140 | 0 | 0 | 38.0 |
| 2b | Tues. | 4/20 | 3 | 65 | 180 | 0 | 0 | 51 | 140 | 0 | 0 | 32.0 |
| 3b | Wed. | 4/21 | 3 | NA | 180 | 0 | 0 | 0 | 0 | NA | 33 | NA |
| 4b | Thurs. | 4/22 | 3 | 109 | 180 | 0 | 0 | 0 | 0 | 20 | 33 | 28.8 |
| 5b | Mon. | 4/26 | 2 | 0 | 0 | 40 | 360 | 22 | 200 | 0 | 0 | 39.8 |
| $6 b^{1}$ | Tues. | 4/27 | 2 | NAp | NAp | NAp | NAp | NAp | NAp | NAp | NAp | NAp |
| 7 b | Wed. | 4/28 | 2 | 157 | 180 | 0 | 0 | 122 | 140 | 0 | 0 | 27.8 |
| Water: |  |  |  |  |  |  |  |  |  |  |  |  |
| 1b | Mon. | 4/19 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 72.0 |
| $2 b^{1}$ | Tues. | 4/20 | 1 | NAp | NAp | NAP | NAp | NAp | NAP | NAp | NAP | NAp |
| 3 b | Wed. | 4/21 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NA |
| 4b | Thurs. | 4/22 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NA |
| 5b | Mon. | 4/26 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.6 |
| 6b | Tues. | 4/27 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NA |
| $7 b^{1}$ | Wed. | 4/28 | 1 | NAP | NAp | NAp | NAp | NAp | NAp | NAP | NAp | NAp |
| 8b | Thurs. | 4/29 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NA |
| NA Not available. |  |  |  |  |  |  |  |  |  |  |  |  |
| NAp Not applicable. ${ }^{1}$ Shearer down, no testing. |  |  |  |  |  |  |  |  |  |  |  |  |

Table 21.-Water spray flows and pressures during longwall testing at mine $B$

| Experiment | Polymer | Waterflow to longwall face |  | Water pressure at injection point |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | L/min | $\mathrm{gal} / \mathrm{min}$ | $\mathrm{kg} / \mathrm{cm}^{2}$ | psig |
| Reagent: |  |  |  |  |  |
| 1 b | PEO | 700-833 | 185-220 | 49-56 | 700-800 |
| 2 b | PEO | 757-1,136 | 200-300 | 63 | 900 |
| 3b | HPMC | 795-1,022 | 210-270 | 49-53 | 700-760 |
| 4b | HPMC | 511. 946 | 135-250 | 32-39 | 450-550 |
| 5b | PEO | 379-1,136 | 100-300 | 62-63 | 890-900 |
| 7b | PEO | 606-719 | 160-190 | 36-65 | 510-925 |
| Water: |  |  |  |  |  |
| 1 b | NAp | NA | NA | NA | NA |
| 3b | NAp | NA | NA | NA | NA |
| 4b | NAp | NA | NA | NA | NA |
| 5b | NAp | NA | NA | NA | NA |
| 6b | NAp | 946-1,136 | 250-300 | NA | NA |
| 8b | NAp | NA | NA | NA | NA |
| NA Not available. |  |  |  |  |  |
| NAp Not app |  |  |  |  |  |

Table 22.-Filter data for stationary gravimetric dust sampling in intake crosscut of mine B

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1b | PEO | 0.44 | 0.53 | 0.45 | 0.47 | 466 | 0.932 | 0.51 |
| 2 b | PEO | 0.47 | 0.57 | 0.53 | 0.52 | 403 | 0.810 | 0.65 |
| 3b | HPMC | 0.36 | 0.45 | 0.30 | 0.37 | 224 | 0.448 | 0.83 |
| 4b | HPMC | 0.32 | 0.33 | 0.38 | 0.34 | 413 | 0.826 | 0.42 |
| 5 b | PEO | 0.05 | 0.13 | 0.18 | 0.12 | 425 | 0.850 | 0.14 |
| 7b | PEO | 0.30 | 0.34 | 0.32 | 0.32 | 248 | 0.496 | 0.65 |
| Water: |  |  |  |  |  |  |  |  |
| 1b | NAp | 0.25 | 0.32 | 0.19 | 0.25 | 415 | 0.830 | 0.31 |
| 3b | NAp | 0.14 | 0.20 | 0.68 | 0.34 | 437 | 0.874 | 0.39 |
| 4b | NAp | 0.16 | 0.15 | 0.13 | 0.15 | 386 | 0.772 | 0.19 |
| 5 b | NAp | 0.26 | 0.17 | 0.33 | 0.25 | 303 | 0.606 | 0.42 |
| 6 b | NAp | 0.21 | 0.14 | 0.21 | 0.19 | 458 | 0.916 | 0.20 |
| 8 b | NAp | 0.29 | 0.21 | 0.23 | 0.24 | 342 | 0.684 | 0.36 |

NAp Not applicable.
Table 23.-Filter data for stationary gravimetric dust sampling in beltway of mine B

| Experiment | Polymer | Weight of dust coilected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1b | PEO | 0.71 | 0.67 | 0.13 | 0.50 | 462 | 0.924 | 0.54 |
| 2 b | PEO | 0.77 | 0.66 | 0.73 | 0.72 | 401 | 0.802 | 0.90 |
| 3b | HPMC | 1.32 | 1.03 | 1.09 | 1.15 | 220 | 0.440 | 2.61 |
| 4b | HPMC | 5.65 | 5.75 | 5.69 | 5.70 | 410 | 0.820 | 6.95 |
| 5b | PEO | 0.37 | 0.40 | 0.36 | 0.38 | 425 | 0.850 | 0.44 |
| 7b. | PEO | 4.86 | 2.77 | 4.90 | 4.18 | 247 | 0.494 | 8.45 |
| Water: |  |  |  |  |  |  |  |  |
| 1b. | NAp | 1.69 | 1.61 | 0.79 | 1.36 | 425 | 0.850 | 1.60 |
| 3b | NAp | 1.58 | 2.85 | 1.94 | 2.12 | $43{ }^{\circ}$ | 0.860 | 2.47 |
| 4b | NAp | 6.34 | 6.11 | 5.97 | 6.14 | 40c | 0.804 | 7.64 |
| 5 b | NAp | 3.38 | 3.68 | 3.84 | 3.63 | 378 | 0.756 | 4.81 |
| 6b | NAp | 1.13 | 1.07 | 1.00 | 1.07 | 451 | 0.902 | 1.18 |
| 8b . . | NAp | 3.14 | 3.06 | 4.34 | 3.51 | 327 | 0.654 | 5.37 |

NAp Not applicable.
Table 24.-Ventilation distribution at shield 13 of mine B

| Experiment | Poiymer | Measured ventilation in intake crosscut, $\mathrm{m}^{3} /$ min | Ventilation at shield $13, \mathrm{~m}^{3} / \mathrm{min}$ |  | Fraction of intake ventilation at shield 13 |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Measured at face | Calculated for gob |  |
| Reagent: |  |  |  |  |  |
| 1b | PEO | 1,024 | 1,246 | 0 | ${ }^{1} 1.000$ |
| 2b | PEO | 1,572 | 823 | 749 | 0.524 |
| 3b | HPMC | 1,346 | 1,472 | 0 | ${ }^{1} 1.000$ |
| 4b | HPMC | 2,296 | 1,081 | 1,215 | 0.471 |
| 5b | PEO | 1,277 | 1,378 | 0 | 11.000 |
| 7b | PEO | 1,746 | 1,582 | 164 | 0.906 |
| Water: |  |  |  |  |  |
| 1b | NAp | 1,479 | 1,783 | 0 | 11.000 |
| 3b | $N A p$ | 21,891 | 1,624 | 268 | 0.858 |
| 4b | NAp | 2,571 | 1,974 | 597 | 0.768 |
| 5b | NAp | 1,941 | 932 | 1,010 | 0.480 |
| 6 b | NAp | 1,607 | 1,019 | 588 | 0.634 |
| 8b | NAp | 1,858 | 1,365 | 493 | 0.735 |

NAp Not applicable.
${ }^{1}$ Arbitrarily set to 1 . Actual value slightly greater.
${ }^{2}$ Not measured; calculated as average of ventilation measured in the other five water experiments.

Table 25.-Ventilation distribution at shield 54 of mine B

| Experiment | Polymer | Ventilation at shield $54, \mathrm{~m}^{3} / \mathrm{min}$ |  |  |  | Fraction at shield 54 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Measured at face | $\begin{aligned} & \text { Lost } \\ & \text { to } \mathrm{gob} \end{aligned}$ | Gained from gob | Calculated for gob | Face ventilation | Gob ventilation |
| Reagent: |  |  |  |  |  |  |  |
| 1b.. | PEO | 1,179 | 67 | NAp | 67 | 0.946 | NAp |
| 2 b | PEO | 1,177 | NAp | 354 | 395 | NAp | 0.527 |
| 3b | HPMC | 1,198 | 273 | NAp | 273 | 0.814 | NAp |
| 4b | HPMC | 1,817 | NAp | 736 | 479 | NAp | 0.394 |
| 5b | PEO | 1,192 | 186 | NAp | 186 | 0.865 | NAp |
| 7b | PEO | 1,260 | 322 | NAP | 486 | 0.797 | NAp |
| Water: |  |  |  |  |  |  |  |
| 1b | NAp | 1,632 | 150 | NAp | 150 | 0.916 | NAp |
| 3b | NAp | 846 | 778 | NAp | 1,045 | 0.521 | NAp |
| 4b | NAp | 1,210 | 764 | NAp | 1,360 | 0.613 | NAp |
| 5b | NAp | 437 | 494 | NAp | 1,504 | 0.470 | NAp |
| 6 b | NAp | 711 | 308 | NAp | 896 | 0.698 | NAp |
| 8b . . . . | NAp | 989 | 376 | NAP | 869 | 0.724 | NAp |

NAp Not applicable.
Table 26.-Yentilation distribution at shield 109 of mine B

| Experiment | Polymer | Ventilation at shield $109, \mathrm{~m}^{3} / \mathrm{min}$ |  |  |  | Fraction at shield 109 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Measured at face | $\begin{aligned} & \text { Lost } \\ & \text { to gob } \end{aligned}$ | Gained from gob | Calculated for gob | Face ventilation | Gob ventilation |
| Reagent: |  |  |  |  |  |  |  |
| 1b | PEO | 1,168 | 11 | NAp | 78 | 0.990 | NAP |
| 2 b | PEO | 1,218 | NAp | 41 | 354 | NAp | 0.897 |
| 3b | HPMC | 1,345 | NAp | 146 | 127 | NAp | 0.464 |
| 4b | HPMC | 1,270 | 547 | NAp | 1,026 | 0.699 | NAp |
| 5b | PEO | 1,023 | 169 | NAp | 355 | 0.858 | NAp |
| 7b | PEO | 1,286 | NAp | 26 | 460 | NAp | 0.947 |
| Water: |  |  |  |  |  |  |  |
| 1b | NAp | 1,618 | 15 | NAp | 165 | 0.991 | NAp |
| 3 b | NAp | 507 | 338 | NAP | 1,384 | 0.600 | NAp |
| 4b | NAp | 973 | 238 | NAp | 1,598 | 0.804 | NAp |
| 5b | NAp | 601 | NAp | 164 | 1,340 | NAp | 0.891 |
| 6b | NAp | ${ }^{1} 943$ | NAp | 232 | 664 | NAp | 0.741 |
| 8b | NAp | 1.014 | NAP | 26 | 844 | NAp | 0.971 |

NAp Not applicable.
${ }^{1}$ Not measured; calculated as average of ventilation measured in the other five water experiments.

Table 27.-Intake dust flow distribution at shield 13 of mine $B$

| Experiment | Polymer | Dust flow in intake crosscut, $\mathrm{mg} / \mathrm{min}$ | Intake dust flow at shield 13, mg/min |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | Measured at face | Calculated for gob |
| Reagent: |  |  |  |  |
| 1b | PEO | 521.64 | 521.64 | 0.00 |
| 2b | PEO | 1,021.09 | 534.72 | 486.37 |
| 3b | HPMC | 1,116.03 | 1,116.03 | 0.00 |
| 4b | HPMC | 963.57 | 453.66 | 509.92 |
| 5b | PEO | 178.65 | 178.65 | 0.00 |
| 7b | PEO | 1,133.89 | 1,027.41 | 106.48 |
| Water: |  |  |  |  |
| 1b | NAp | 458.28 | 458.28 | 0.00 |
| 3b | NAp | 737.04 | 632.75 | 104.29 |
| 4b | NAp | 488.07 | 374.80 | 113.27 |
| 5b | NAP | 814.76 | 390.96 | 423.80 |
| 6b | NAp | 321.15 | 203.65 | 117.50 |
| 8b | NAP | 668.35 | 490.92 | 177.43 |

Table 28.-Intake dust flow distribution at shield 54 of mine B

| Experiment | Polymer | Measured at face, $\mathrm{mg} / \mathrm{min}$ | Lost to gob, $\mathrm{mg} / \mathrm{min}$ | Gained from gob, mg/min | Calculated for gob, $\mathrm{mg} / \mathrm{min}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Reagent: |  |  |  |  |  |
| 1 b | PEO | 493.55 | 28.09 | NAp | 28.09 |
| 2 b | PEO | 764.72 | NAP | 230.00 | 256.37 |
| 3b | HPMC | 908.84 | 207.19 | NAp | 207.19 |
| 4b | HPMC | 762.55 | NAp | 308.89 | 201.02 |
| 5b | PEO | 154.58 | 24.07 | NAp | 24.07 |
| 7b | PEO | 818.43 | 208.98 | NAp | 315.45 |
| Water: |  |  |  |  |  |
| 1b | NAp | 419.67 | 38.61 | NAp | 38.61 |
| 3 b | NAp | 329.62 | 303.13 | NAp | 407.42 |
| 4 b | NAp | 229.81 | 144.99 | NAp | 258.26 |
| $5 b$ | NAp | 182.57 | 207.39 | NAP | 631.19 |
| 6 b | NAp | 142.11 | 61.53 | NAp | 179.04 |
| 8 b | NAp | 355.62 | 135.30 | NAP | 312.73 |

NAp Not applicable.
Table 29.-Intake dust flow distribution at shield 109 of mine B

| Experiment | Polymer | Measured at face, $\mathrm{mg} / \mathrm{min}$ | Lost to gob, $\mathrm{mg} / \mathrm{min}$ | Gained from gob, mg/min | Calculated for gob, mg/min |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Reagent: |  |  |  |  |  |
| 1b | PEO | 488.86 | 4.69 | NAp | 32.78 |
| 2b | PEO | 791.09 | NAp | 26.37 | 230.00 |
| 3b | HPMC | 1,019.80 | NAp | 110.96 | 96.23 |
| 4b | HPMC | 533.16 | 229.39 | NAp | 430.41 |
| 5b | PEO | 132.61 | 21.97 | NAp | 46.04 |
| 7b | PEO | 835.04 | NAp | 16.61 | 298.85 |
| Water: |  |  |  |  |  |
| 1b | NAp | 415.93 | 3.74 | NAp | 42.34 |
| 3b | NAp | 197.77 | 131.85 | NAp | 539.27 |
| 4b | NAp | 184.67 | 45.14 | NAp | 303.40 |
| 5 b | NAp | 252.44 | NAp | 68.86 | 562.33 |
| 6 b | NAp | 188.41 | NAp | 46.30 | 132.74 |
| 8b | NAp | 364.82 | NAp | 9.20 | 303.54 |

NAp Not applicable.
Table 30.-Coal production during longwall testing of dust-suppression reagents at mine B

| Experiments | Polymer | Raw coal produced during shift, $\mathbf{t}$ | Estimated total production time, min |
| :---: | :---: | :---: | :---: |
| Reagent: |  |  |  |
| 1b | PEO | 4,781 | 239 |
| 2b | PEO | 5,320 | 266 |
| 3b | HPMC | 4,306 | 215 |
| $4 b$ | HPMC | 5,820 | 291 |
| 5b | PEO | 6,311 | 316 |
| 7 b | PEO | 3,902 | 195 |
| Water: |  |  |  |
| 1b | NAp | 3,042 | 152 |
| 3b | NAp | 7,497 | 375 |
| 4b | NAp | 7,020 | 351 |
| 5b | NAp | 10,250 | 513 |
| 6 b | NAp | 7,900 | 395 |
| 8b | NAp | 6,300 | 315 |

NAp Not applicable.

Table 31.-Filter data for stationary gravimetric dust sampling at shleid 13 of mine $\mathbf{B}$

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1 b | PEO | 1.09 | 0.50 | 1.23 | 0.94 | 436 | 0.872 | 1.08 |
| 2 b | PEO | 0.80 | 0.78 | 0.85 | 0.81 | 412 | 0.824 | 0.98 |
| 3b | HPMC | 0.45 | 0.53 | 0.57 | 0.52 | 208 | 0.416 | 1.25 |
| 4 b | HPMC | 0.65 | 0.66 | 0.61 | 0.64 | 370 | 0.740 | 0.86 |
| 5b | PEO | 1.52 | 0.95 | 1.04 | 1.17 | 417 | 0.834 | 1.40 |
| 7b | PEO | NA | 0.74 | 0.79 | 0.77 | 261 | 0.522 | 1.48 |
| Water: |  |  |  |  |  |  |  |  |
| 1b | NAp | 0.18 | 0.34 | 0.61 | 0.38 | 363 | 0.726 | 0.52 |
| 3b | NAp | 0.47 | 0.63 | 0.71 | 0.60 | 375 | 0.750 | 0.80 |
| 4b | NAp | 0.47 | 0.41 | 0.36 | 0.41 | 371 | 0.742 | 0.55 |
| 5b | NAp | 0.74 | 0.61 | 0.66 | 0.67 | 384 | 0.768 | 0.87 |
| 6 b | NAp | 0.79 | 1.03 | 1.01 | 0.94 | 421 | 0.842 | 1.12 |
| 8b | NAp | 0.70 | 0.61 | 0.62 | 0.64 | 340 | 0.680 | 0.95 |
| NA Not availa NAp Not applic |  |  |  |  |  |  |  |  |

Table 32.-Filter data for stationary gravimetric dust sampling at shield 54 of mine $B$

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1b | PEO | 1.46 | 1.50 | 1.39 | 1.45 | 418 | 0.836 | 1.73 |
| 2 b | PEO | 1.17 | 1.23 | 1.24 | 1.21 | 402 | 0.804 | 1.50 |
| 3b | HPMC | 0.81 | 0.82 | 0.73 | 0.79 | 207 | 0.414 | 1.91 |
| 4b | HPMC | 1.72 | 1.10 | NA | 1.41 | 387 | 0.774 | 1.82 |
| 5b | PEO | 1.50 | 1.62 | 1.54 | 1.55 | 413 | 0.826 | 1.88 |
| 7 b | PEO | 1.25 | 1.35 | 1.39 | 1.33 | 269 | 0.538 | 2.47 |
| Water: |  |  |  |  |  |  |  |  |
| 1b | NAp | 1.06 | 1.00 | 1.20 | 1.09 | 360 | 0.720 | 1.51 |
| 3 b | NAP | 0.93 | 1.10 | 1.08 | 1.04 | 371 | 0.742 | 1.40 |
| 4b | NAP | 1.19 | 1.32 | 1.14 | 1.22 | 387 | 0.774 | 1.58 |
| 5 b | NAp | 1.11 | 1.65 | 1.97 | 1.58 | 384 | 0.768 | 2.06 |
| 6 b | NAp | 1.75 | 1.90 | 1.46 | 1.70 | 422 | 0.844 | 2.01 |
| 8b | NAp | 1.73 | 1.37 | 1.15 | 1.42 | 333 | 0.666 | 2.13 |
| NA Not availab <br> NAp Not applic |  |  |  |  |  |  |  |  |

Table 33.-Filter data for stationary gravimetric dust sampling at shield 109 of mine B

| Experiment | Polymer | Weight of dust coilected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1 b | PEO | 2.75 | 2.91 | NA | 2.83 | 408 | 0.816 | 3.47 |
| 2 b | PEO | 1.54 | 1.70 | 1.86 | 1.70 | 391 | 0.782 | 2.17 |
| 3b | HPMC | 1.49 | 1.49 | 1.15 | 1.83 | 213 | 0.426 | 3.23 |
| 4 b | HPMC | 3.20 | 3.38 | 3.52 | 3.37 | 367 | 0.734 | 4.59 |
| 5 b | PEO | 2.39 | 2.17 | 3.20 | 2.59 | 414 | 0.828 | 3.12 |
| 7 b | PEO | 2.33 | 2.10 | 2.28 | 2.24 | 263 | 0.526 | 4.25 |
| Water: |  |  |  |  |  |  |  |  |
| 1b | NAp | 2.17 | 1.77 | 1.93 | 1.96 | 363 | 0.726 | 2.70 |
| 36 | NAp | 2.02 | 2.30 | 1.94 | 2.09 | 363 | 0.726 | 2.87 |
| 4b | NAp | 2.80 | 2.62 | 3.28 | 2.90 | 317 | 0.634 | 4.57 |
| 5 b | NAp | 5.29 | 2.55 | 1.08 | 2.97 | 383 | 0.766 | 3.88 |
| 6b | NAp | 2.60 | 2.02 | 1.82 | 2.15 | 417 | 0.834 | 2.57 |
| 8b | NAp | 1.40 | 2.06 | 2.27 | 1.91 | 325 | 0.650 | 2.94 |
| $\begin{array}{ll}\text { NA } & \text { Not availa } \\ \text { NAp } & \text { Not applic }\end{array}$ |  |  |  |  |  |  |  |  |

Table 34.-Computation of respirable dust reduction at shield 13 of mine $B$

| Experiment | Polymer | Shearer operating time, ${ }^{1}$ min | Rate of airborne dust formation, ${ }^{2}$ $\mathrm{mg} / \mathrm{min}$ | Airborne dust, g |  |  | Total airborne dust, mg/t of coal mined ${ }^{6}$ | Dust reduction, \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Formed during shiff $^{3}$ | $\begin{gathered} \text { Intake } \\ \text { contribution } \end{gathered}$ | Formed during shift, corrected ${ }^{5}$ |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1 b | PEO | 217 | 2,697.05 | 644.73 | 124.70 | 520.03 | 108.77 | 7.24 .25 |
| 2b | PEO | 192 | 1,735.27 | 461.58 | 142.24 | 319.35 | 60.03 | $\begin{array}{r}81.02 \\ \hline 8\end{array}$ |
| 3b | HPMC | 121 | 3,141.83 | 676.44 | 240.28 | 436.15 | 101.29 | 9-93.94 |
| 4b | HPMC | 284 | 1,217.06 | 354.16 | 132.01 | 222.15 | 38.17 | ${ }^{9} 26.92$ |
| 5b | PEO | 215 | 3,745.97 | 1,182.04 | 56.37 | 1,125.67 | 178.37 | ${ }^{10}-584.91$ |
| 7b | PEO | 195 | 3,100.46 | 604.90 | 200.45 | 404.45 | 103.65 | ${ }^{11}-43.93$ |
| Water: ${ }^{\text {a }}$ |  |  |  |  |  |  |  |  |
| 1b | NAp | 152 | 2,209.10 | 336.00 | 69.70 | 266.30 | 87.54 |  |
| 3b | NAp | 367 | 1,332.88 | 499.63 | 237.19 | 262.44 | 35.01 |  |
| 4 b | NAp | 287 | 1,419.35 | 498.19 | 131.56 | 366.63 | 52.23 | NAP |
| 5b | NAp | 342 | 911.81 | 467.30 | 200.37 | 266.93 | 26.04 | NAp |
| 6 b | NAp | 318 | 1,509.74 | 596.35 | 80.44 | 515.91 | 65.30 | NAP |
| 8b . . . | NAp | 315 | 1,391.81 | 438.42 | 154.64 | 283.78 | 45.04 | NAp |

[^3]Table 35.-Computation of respirable dust reduction at shieid 54 of mine $B$

| Experiment | Polymer | Shearer operating time, ${ }^{1}$ min | Rate of airborne dust formation, ${ }^{2}$ $\mathrm{mg} / \mathrm{min}$ | Airborne dust, g |  |  | Total airborne dust, mg/t of coal mined ${ }^{6}$ | Dust reduction, \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Formed during shift $^{3}$ | Intake contribution ${ }^{4}$ | Formed during shift, corrected ${ }^{5}$ |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1 b | PEO | 206 | 4,145.43 | 990.97 | 117.98 | 872.98 | 182.59 | ${ }^{7} 32.50$ |
| 2 b | PEO | 192 | 3,717.08 | 988.74 | 203.42 | 785.33 | 147.62 | ${ }^{8} 2.95$ |
| 3b | HPMC | 121 | 3,892.76 | 838.11 | 195.67 | 642.44 | 149.20 | 9.27 .84 |
| 4b | HPMC | 284 | 4,507.77 | 1,311.76 | 221.90 | 1,089.86 | 187.26 | $9-60.46$ |
| 5b | PEO | 215 | 4,304.28 | 1,358.22 | 48.78 | 1,309.44 | 207.48 | ${ }^{10}-403.64$ |
| 7 b | PEO | 195 | 4,293.73 | 837.71 | 159.68 | 678.03 | 173.77 | ${ }^{11} .45 .04$ |
| Water: |  |  |  |  |  |  |  |  |
| 1 b | NAp | 152 | 5,830.08 | 886.76 | 63.83 | 822.92 | 270.52 | NAp |
| 3 b | NAP | 367 | 1,193.58 | 447.41 | 123.56 | 323.86 | 43.20 | NAp |
| 4 b | NAp | 287 | 2,563.93 | 899.94 | 80.66 | 819.27 | 116.71 | NAp |
| 5b | NAp | 342 | 1,007.52 | 516.35 | 94.08 | 422.27 | 41.20 | NAp |
| 6 b | NAp | 313 | 1,933.27 | 763.64 | 56.13 | 707.51 | 89.56 | NAp |
| 8b | NAp | 315 | 2,221.19 | 699.68 | 112.02 | 587.65 | 93.28 | NAp |

[^4]Table 36.-Computation of respirable dust reduction at shield 109 of mine $B$

| Experiment | Polymer | Shearer operating time, ${ }^{1}$ min | Rate of airborne dust formation, ${ }^{2}$ $\mathrm{mg} / \mathrm{min}$ | Airborne dust, g |  |  | Total airborne dust, $\mathrm{mg} / \mathrm{t}$ of coal mined ${ }^{6}$ | Dust reduction, \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Formed during shift ${ }^{3}$ | $\begin{gathered} \text { Intake } \\ \text { contribution } \end{gathered}$ | Formed during shift, corrected ${ }^{5}$ |  |  |
|  |  |  |  |  |  |  |  |  |
| 1 b | PEO | 202 | 8,179.04 | 1,955.20 | 116.86 | 1,828.34 | 384.51 | ${ }^{7} 23.17$ |
| 2 b | PEO | 192 | 5,378.32 | 1,430.63 | 210.43 | 1,220.20 | 229.36 | ${ }^{8} 9.53$ |
| 3b | HPMC | 131 | 7,057.67 | 1,519.50 | 219.65 | 1,299.94 | 301.89 | ${ }^{9}-27.88$ |
| 4 b | HPMC | 284 | 7,529.58 | 2,191.11 | 155.15 | 2,035.96 | 349.82 | ${ }^{9}-48.18$ |
| 5b | PEO | 215 | 6,139.38 | 1,937.28 | 41.84 | 1,895.44 | 300.34 | ${ }^{10}-154.61$ |
| 7 b | PEO | 195 | 7,363.81 | 1,436.68 | 162.92 | 1,273.76 | 326.44 | ${ }^{11}$-62.59 |
| Water: |  |  |  |  |  |  |  |  |
| 1 b | NAp | 152 | 10,424.86 | 1,585.62 | 63.26 | 1,522.36 | 500.45 | NAp |
| 3b | NAp | 347 | 1,522.51 | 570.71 | 74.13 | 496.58 | 66.24 | NAp |
| 4 b | NAp | 287 | 4,906.14 | 1,722.06 | 64.82 | 1,657.24 | 236.07 | NAp |
| 5b | NAp | 342 | 2,611.60 | 1,338.44 | 129.37 | 1,209.07 | 117.96 | NAp |
| 6 b | NAp | 308 | 3,277.87 | 1,294.76 | 74.42 | 1,220.34 | 154.47 | NAp |
| 8b . . . | NAP | 315 | 3,073.93 | 968.29 | 114.92 | 853.37 | 135.46 | NAp |

[^5]Table 37.-Computation of respirable dust reduction in beltway of mine B

| Experiment | Polymer | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ | Sampling time, min | Corrected ${ }^{1}$ average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ | Dust reduction, \% |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Reagent: |  |  |  |  |  |
| 1b | PEO | 0.54 | 462 | 1.16 | ${ }^{2} 74.14$ |
| 2 b | PEO | 0.90 | 401 | 1.88 | ${ }^{3} 49.17$ |
| 3b | HPMC | 2.61 | 220 | 4.74 | ${ }^{4} 55.70$ |
| 4b | HPMC | 6.95 | 410 | 10.03 | ${ }^{4} 6.24$ |
| 5b | PEO | 0.44 | 425 | 0.88 | ${ }^{5} 8.51$ |
| 7 b | PEO | 8.45 | 247 | 10.71 | ${ }^{6}$-195.27 |
| Water: |  |  |  |  |  |
| 1b | NAp | 1.60 | 425 | 4.48 | NAp |
| 3 b | NAp | 2.47 | 430 | 2.89 | NAp |
| 4b | NAp | 7.64 | 402 | 10.70 | NAp |
| 5b | NAp | 4.81 | 378 | 5.31 | NAp |
| 6 b | NAp | 1.18 | 451 | 1.68 | NAp |
| 8b | NAp | 5.37 | 327 | 5.58 | NAp |

NAp Not applicable.
${ }^{1}$ Normalized for shearer operating time during sampling period.
${ }^{2}$ Compared with water experiment 1b
${ }^{3}$ Compared with average of water experiments 1 b and 3 b .
${ }^{4}$ Compared with water experiment 4b.
${ }^{5}$ Compared with water experiment 5 b.
${ }^{6}$ Compared with average of water experiments 6 b and 8 b .

Table 38.-Filter data for mobile gravimetric dust sampling at mine B

| Experiment | Polymer | Weight of dust collected, mg |  |  |  | Sampling time, min | Volume of air sampled, $\mathrm{m}^{3}$ | Average dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Filter 1 | Filter 2 | Filter 3 | Average |  |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1b | PEO | 1.7. | 1.87 | 1.61 | 1.73 | 107 | 0.214 | 8.08 |
| 2b | PEO | 0.57 | 1.20 | 1.31 | 1.36 | 96 | 0.192 | 7.08 |
| 3b | HPMC | 0.94 | 0.83 | 0.95 | 0.91 | 88 | 0.176 | 5.17 |
| 4b | HPMC | 1.90 | 1.82 | 2.18 | 1.97 | 110 | 0.220 | 8.95 |
| 5b | PEO | 1.81 | 1.90 | 1.86 | 1.86 | 153 | 0.306 | 6.08 |
| 7 b | PEO | 1.98 | 1.95 | 1.99 | 1.97 | 134 | 0.268 | 7.35 |
| Water: |  |  |  |  |  |  |  |  |
| 1b | NAp | 2.18 | 1.84 | 1.79 | 1.94 | 74 | 0.148 | 13.11 |
| 3b | NAp | 1.80 | 1.61 | NA | 1.71 | 149 | 0.298 | 5.74 |
| 4b | NAp | 2.20 | NA | 2.31 | 2.26 | 126 | 0.252 | 8.97 |
| 5b | NAp | 2.66 | 1.96 | 2.00 | 2.21 | 149 | 0.298 | 7.42 |
| 6 b | NAp | 2.21 | 2.15 | 3.86 | 2.74 | 164 | 0.328 | 8.35 |
| 8b | NAp | 1.35 | 1.27 | 1.42 | 1.35 | 116 | 0.232 | 5.82 |

NA Not available.
NAp Not applicable.

Table 39.-Computation of respirable dust reduction for mobile gravimetric dust sampling at mine B

| Experiment | Polymer | Av intake dust flow, $\mathrm{mg} / \mathrm{min}$ | Av ventilation, $\mathrm{m}^{3} / \mathrm{min}$ | Av dust conc from intake, $\mathrm{mg} / \mathrm{m}^{3}$ | Weight of dust, mg |  | Corrected ${ }^{1}$ av dust conc, $\mathrm{mg} / \mathrm{m}^{3}$ | Dust reduction \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | Intake contribution | Corrected for intake |  |  |
| Reagent: |  |  |  |  |  |  |  |  |
| 1b | PEO | 501.35 | 1,198 | 0.42 | 0.09 | 1.64 | 7.66 | ${ }^{2} 40.34$ |
| 2 b | PEO | 696.84 | 1,073 | 0.65 | 0.12 | 1.24 | 6.46 | ${ }^{3} 28.93$ |
| 3b | HPMC | 1,014.89 | 1,338 | 0.76 | 0.13 | 0.78 | 4.43 | ${ }^{4} 49.49$ |
| 4 b | HPMC | 583.12 | 1,389 | 0.42 | 0.09 | 1.88 | 8.55 | ${ }^{4} 2.51$ |
| 5b | PEO | 155.28 | 1,197 | 0.13 | 0.04 | 1.82 | 5.95 | ${ }^{5} 14.76$ |
| 7b | PEO | 893.63 | 1,376 | 0.65 | 0.17 | 1.80 | 6.72 | ${ }^{6} 1.25$ |
| Water: |  |  |  |  |  |  |  |  |
| 1b | NAp | 431.29 | 1,678 | 0.26 | 0.04 | 1.90 | 12.84 | NAp |
| 3b | NAp | 386.71 | 992 | 0.39 | 0.12 | 1.59 | 5.34 | NAp |
| 4b | NAp | 263.10 | 1,386 | 0.19 | 0.05 | 2.21 | 8.77 | NAp |
| 5b | NAp | 275.66 | 657 | 0.42 | 0.13 | 2.08 | 6.98 | NAp |
| 6 b | NAp | 178.06 | 891 | 0.20 | 0.07 | 2.67 | 8.14 | NAp |
| 8b .... | NAp | 403.79 | 1,122 | 0.36 | 0.08 | 1.27 | 5.47 | NAp |

NAp Not applicable.
${ }^{1}$ Corrected for intake dust contribution.
${ }^{2}$ Compared with water experiment 1 b .
${ }^{3}$ Compared with average of water experiments 1 b and 3 b .
${ }^{4}$ Compared with water experiment 4 b .
${ }^{5}$ Compared with water experiment $5 b$.
${ }^{6}$ Compared with average of water experiments 6 b and 8 b .

Table 40.-Computation of respirable dust reduction corrected for headgate dust at shield 54 of mine B

| Experiment | Polymer | Dust formed at headgate, ${ }^{1}$ g | Headgate dust flow, $\mathrm{mg} / \mathrm{min}$ |  | Total airborne dust at shield 54 |  | $\begin{gathered} \text { Dust } \\ \text { reduction, }{ }^{6} \\ \% \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | From headgate ${ }^{2}$ | Passing shield $54^{3}$ | Corrected for intake and headgate, ${ }^{4} \mathrm{~g}$ | Normalized for coal production, ${ }^{5} \mathrm{mg} / \mathrm{t}$ |  |
| Reagent: |  |  |  |  |  |  |  |
| 1b | PEO | 520.03 | 2,175.42 | 2,058.27 | 380.95 | 79.68 | ${ }^{7} 58.14$ |
| 2 b | PEO | 319.35 | 1,200.55 | 1,200.55 | 465.98 | 87.59 | ${ }^{8} 9.32$ |
| 3b | HPMC | 436.15 | 2,025.80 | 1,649.71 | 287.25 | 66.71 | ${ }^{9} 21.22$ |
| 4 b | HPMC | 222.15 | 763.40 | 763.40 | 867.71 | 149.09 | ${ }^{9}$-76.06 |
| 5b | PEO | 1,125.67 | 3,567.32 | 3,086.71 | 335.43 | 53.15 | ${ }^{10}$-83.47 |
| 7 b | PEO | 404.45 | 2,073.05 | 1,651.39 | 355.85 | 91.20 | ${ }^{11}$-37.16 |
| Water: |  |  |  |  |  |  |  |
| 1b | NAp | 266.30 | 1,750.83 | 1,603.33 | 579.06 | 190.35 | NAp |
| 3b | NAp | 262.44 | 700.12 | 364.73 | 187.14 | 24.96 | NAp |
| 4b | NAp | 366.63 | 1,044.54 | 640.47 | 594.47 | 84.68 | NAp |
| 5 b | NAp | 266.73 | 520.84 | 244.56 | 296.94 | 28.79 | NAp |
| 6 b | NAp | 515.91 | 1,306.06 | 911.45 | 347.49 | 43.99 | NAp |
| 8b | NAp | 283.78 | 900.89 | 652.60 | 382.09 | 60.65 | NAp |

[^6]Table 41.-Computation of respirable dust reduction corrected for headgate dust at shield 109 of mine $\mathbf{B}$

| Experiment | Polymer | Headgate dust flow, $\mathrm{mg} / \mathrm{min}$ |  |  | Total airborne dust at shield 109 |  | Dust reduction, \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | At shield 109 , corrected for gob loss ${ }^{1}$ | $\begin{aligned} & \text { In gob } \\ & \text { area }^{2} \end{aligned}$ | At shield 109, corrected for gob influx ${ }^{3}$ | Corrected for intake and headgate, ${ }^{4} \mathrm{~g}$ | Normalized for coal production, ${ }^{5}$ mg/t |  |
| Reagent: |  |  |  |  |  |  |  |
|  | PEO | 2,038.71 | NAp | NAp | 1,350.99 | 282.57 | ${ }^{7} 32.88$ |
| 2 b | PEO | NAp | NAp | 1,200.55 | 900.86 | 169.33 | ${ }^{8} 14.45$ |
| 3 b | HPMC | NAp | 376.09 | 1,851.12 | 901.39 | 209.33 | ${ }^{9} 0.48$ |
| 4 b | HPMC | 533.37 | NAp | NAp | 1,880.63 | 323.13 | ${ }^{9}-53.62$ |
| 5b | PEO | 2,647.91 | NAp | NAp | 1,059.89 | 167.94 | ${ }^{10}$-61.14 |
| 76 | PEO | NAp | 421.66 | 1,673.59 | 947.25 | 242.76 | ${ }^{11}$-135.39 |
| Water: |  |  |  |  |  |  |  |
| 1b | NAp | 1,589.05 | NAp | NAp | 1,280.66 | 420.99 | NAp |
| 3b | NAp | 218.83 | NAp | NAp | 414.55 | 55.30 | NAp |
| 4 b | NAp | 514.66 | NAp | NAp | 1,476.59 | 210.34 | NAp |
| 5b | NAp | NAp | 276.28 | 274.70 | 1,068.29 | 104.22 | NAp |
| 6b . . . . | NAp | NAp | 394.65 | 1,013.50 | 820.00 | 103.80 | NAp |
| 8b . . . . | NAp | NAp | 248.29 | 659.90 | 645.50 | 102.46 | NAp |

NAp Not applicable.
${ }^{1}$ Corrected for ventilation losses to gob.
${ }^{2}$ Coming from shield 54 because of ventilation loss to gob.
${ }^{3}$ Corrected for gain from gob because of ventilation loss at shield 54 and reentry at shield 109.
${ }^{4}$ Dust at shield 109 during shift production time, after deducting both intake and headgate dust.
${ }^{5}$ Dust at shield 109 during shift production time, after deducting intake and headgate dust and dividing by coal production.
${ }^{6}$ Normalized for coal production, and corrected for intake and headgate dust.
${ }^{7}$ Compared with water experiment 1 b .
${ }^{8}$ Compared with average of water experiments 1 b and 3 b .
${ }^{9}$ Compared with water experiment 4 b .
${ }^{10}$ Compared with water experiment 5 b .
${ }^{11}$ Compared with average of water experiments 6 b and 8 b .
Table 42.-Computation iff respirable dust reduction corrected for headgate dust for mobile dust sampling at mine $\mathbf{B}$

| Experiment | Polymer | Av headgate dust flow along longwall, ${ }^{1}$ $\mathrm{mg} / \mathrm{min}$ | Av headgate dust conc along longwall, ${ }^{2}$ $\mathrm{mg} / \mathrm{m}^{3}$ | Weight of dust, mg |  | Corrected ${ }^{3}$ av total dust cone, $\mathrm{mg} / \mathrm{m}^{3}$ | Dust reduction, \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Headgate contribution | Total after deducting headgate |  |  |
| Reagent: |  |  |  |  |  |  |  |
| 1b . . | PEO | 2,090.80 | 1.75 | 0.37 | 1.27 | 5.93 | ${ }^{4} 51.23$ |
| 2b | PEO | 1,200.55 | 1.12 | 0.22 | 1.02 | 5.31 | ${ }^{5} 38.00$ |
| 3b | HPMC | 1,842.21 | 1.38 | 0.24 | 0.54 | 3.07 | ${ }^{6} 63.32$ |
| 4b | HPMC | 686.85 | 0.49 | 0.11 | 1.77 | 8.05 | ${ }^{6} 3.82$ |
| 5 b | PEO | 3,100.64 | 2.59 | 0.79 | 1.03 | 3.37 | ${ }^{7} 48.78$ |
| 7b | PEO | 1,799.34 | 1.31 | 0.35 | 1.45 | 5.41 | ${ }^{8} 12.18$ |
| Water: |  |  |  |  |  |  |  |
| 1b | NAp | 1,118.05 | 0.67 | 0.10 | 1.80 | 12.16 | NAp |
| 3b | NAp | 354.95 | 0.36 | 0.11 | 1.48 | 4.97 | NAp |
| 4 b | NAp | 561.67 | 0.41 | 0.10 | 2.11 | 8.37 | NAp |
| 5b . . . . | NAp | 255.13 | 0.39 | 0.12 | 1.96 | 6.58 | NAp |
| 6 b | NAp | 739.18 | 0.83 | 0.27 | 2.40 | 7.32 | NAp |
| 8b .... | NAP | 517.83 | 0.46 | 0.11 | 1.16 | 5.00 | NAp |

[^7]
## REAGENT CONCENTRATIONS AND OTHER WATER SPRAY DATA FOR MINE B

Tables 20 and 21 list data related to the water sprays. The shearer drums were equipped with 44 water sprays per drum. In addition to the drum sprays, the shearer had eight fan jet sprays mounted on the shearer body and nine on a shearer spray boom. The stageloader-crusher area used three sprays for dust control. Mine B did not employ panline sprays to wet the coal on the face conveyor.

Table 20 reveals that the injected reagent concentrations in the water sprays were less than intended for reagent experiments $1 \mathrm{~b}, 2 \mathrm{~b}, 3 \mathrm{~b}, 4 \mathrm{~b}, 5 \mathrm{~b}$, and 7 b (all of which contained polymer as well as surfactant). This result is similar to that obtained for mine $A$. As with mine $A$, this low, off-target injection is likely due to the viscous nature of the surfactant-polymer solution concentrates that are injected. The generally high viscosity of the concentrates and the presence of lumpy masses of poorly mixed polymer again interfered with the efficient operation of the diaphragm-type injection pumps.

Surface tension measurements were made on all water samples from the reagent tests (except for reagent experiment 3 b ) and on two water runs (table 20, last column). The results were similar to mine A-all the reagent tests meeting the criteria for spreading wetting and no indications of reagent carryover between shifts.

The waterflow to the longwall face for mine $B$ (table 21) was about twice that used at mine A. The water pressures ware also much higher for mine $B$, reflecting the higher waterflow rates. The large variation in the rate of water application was of major concern regarding the accurate measurement of dust-suppression effectiveness at mine B. Changes in water application rates affect airborne dust levels, which make it difficult to assess the effect of added dust-suppression reagents. The variation in waterflow at mine $B$, i.e., the difference between maximum and minimum waterflow rates, could be as much as $757 \mathrm{~L} / \mathrm{min}$ ( $200 \mathrm{gal} / \mathrm{min}$ ) during a shift (reagent experiment 5 b , table 21) and averaged $318 \mathrm{~L} / \mathrm{min}(84 \mathrm{gal} / \mathrm{min}$ ) during a shift for the flows recorded in table 21 . In contrast, the maximum variation observed at mine A was $360 \mathrm{~L} / \mathrm{min}$ ( $95 \mathrm{gal} / \mathrm{min}$ ) (table 2 , reagent experiment 2 a ), with an average variation of $163 \mathrm{~L} / \mathrm{min}(43 \mathrm{gal} / \mathrm{min})$ during a shift.

## INTAKE DUST DISTRIBUTIONS ON LONGWALL OF MINE B

The procedures for determining dust flow patterns on the longwall of mine $B$ were similar to that employed for mine $A$. One difference between the two mines is that the beltway was not ventilated at mine B. A second departure
is that intake ventilation was not only split between the face and gob, but likely to some degree between the two walkways along the face (figure 8).

## Intake Filter Samples at Mine B

The results for gravimetric samplers located in the intake crosscut are provided in table 22. The beltway was also sampled despite the lack of ventilation (table 23). In the latter case, the gravimetric samplers measured the dust emanating from the stageloader at the point of coal discharge to the belt near the tailpiece. Because of the lack of ventilation, the effectiveness of the sprays at this location, with and without reagent, could be uniquely evaluated without the interference of upwind dust sources, as was the case with the ventilated beltway at mine $A$.

## Ventilation Distribution at Mine B

The ventilation patterns for the various experiments on the longwall at mine $B$ were determined similar to that for mine $A$. The patterns differed from those for mine $A$ in respect to the unventilated beltway and the possible ventilation split in the two walkways. However, an estimate of the walkway split is not available, since ventilation measurements were only made in the face-side walkway by the samplers. The two walkways were separated by the front pillars of the roof shields. An example of the ventilation distribution at mine $B$ for reagent experiment $1 b$ is given as a schematic diagram in figure 8. The ventilation distributions at each of the three face sampling positions (shields 13,54 , and 109) are given in tables 24,25 , and 26, respectively. On two occasions, ventilation measurements were accidently omitted and an average from the other shifts substituted, as indicated in tables 24 and 26.

It also evident in table 24 that in some experiments (reagent experiments $1 \mathrm{~b}, 3 \mathrm{~b}$, and 5 b , and water experiment 1b) the measured ventilation at shield 13 was a little larger than that measured in the intake. This is an impossibility unless other unknown intake sources were present. The beltway ventilation was measured a few times and usually found to be nil, although one time a ventilation reading measured about $6 \%$ of that measured in the intake crosscut. Other than leakage from unknown sources, the ventilation discrepancy inight be due to error in estimating cross-sectional areas at the sampler positions, especially along the face where tape-measuring opportunities were limited. The area estimation was particularly complicated at mine $B$ by the line of front roof support pillars extending down the face (figure 8). For those experiments where the fraction of intake ventilation at shield 13 exceeded that at the intake crosscut, the fraction of intake
ventilation at shield 13 was arbitrarily limited to a maximum value of 1 .

## Computation of Intake Dust Flow Patterns at Mine B

The intake dust flow patterns along the longwall for mine $B$ were determined in the same manner as those for mine $A$, except that only ventilation from the intake crosscut needed to be considered in the flow configuration. The intake dust flow distributions at each sampler location are provided in tables 27,28 , and 29. An example of the intake dust flow pattern for reagent experiment $1 b$ is shown in figure 8.

## COAL PRODUCTION DATA FOR MINE B

Mine $B$ coal did not require beneficiation, so only raw coal production is provided in table 30 (column 3). Most importantly, unlike mine $A$, there was a shift bias at mine $B$ in regard to coal production. Except for reagent experiment 1 b and its corresponding water-only test (water experiment 1 b ), the shifts during which reagent was injected (reagent experiments $2 \mathrm{~b}, 3 \mathrm{~b}, 4 \mathrm{~b}, 5 \mathrm{~b}$, and 7 b ) were consistently much lower in coal production than the corresponding water shifts (water experiments $1 \mathrm{~b}, 3 \mathrm{~b}, 4 \mathrm{~b}, 5 \mathrm{~b}$, $6 b$, and $8 b$ ) in which no reagent was added. The coal production during these water shifts ranged from 21 to as much as $74 \%$ greater than the reagent shifts.

The estimated total production time in column 4 of table 30 was calculated from the raw coal production furnished by the mine operator. Each pass of the shearer (head to tail and return) was estimated to cut $1,000 \mathrm{t}$ of coal, according to the operator. It was observed by USBM technicians that each pass of the shearer required an average of 50 min to complete. This figure takes into account any shearer stoppages or down times that occurred during the shearer's passage along the longwall. The total production time given in table 30 is simply the raw coal production of column 3 divided by 1,000 to obtain the number of passes, which was then multiplied by 50 . The USBM sampling crews could not be on site the entire shift to measure the total production time directly. This was due to reasons involving equipment setup and removal and transportation into and out of the mine.

## COMPUTATION OF RESPIRABLE DUST REDUCTIONS AT STATIONARY SAMPLING LOCATIONS FOR MINE B

The dust-sampling filter results for the three sampling locations along the face (shields 13,54 , and 109) are given
in tables 31, 32, and 33, respectively. The results from these tables combined with the ventilation distribution tables ( 24,25 , and 26), the dust flow tables (27, 28, 29), and the coal production time of table 30 were used to calculate the percentage dust reductions at each sampler location along the longwall face. The computation methods were identical to those employed for mine A, except for some variations in using equation 1 to compute the final dust reductions. The results of the calculations for each of the three sampler face locations are provided in tables 34, 35 , and 36. As was the case with mine A, consecutive reagent and water shifts were calculated using equation 1 to derive the percentage dust reduction. When the shearer was down on an adjacent shift, an average of the two water shifts flanking the down shift was employed (reagent experiments 2 b and 7 b compared with the average of water experiments 1 b to 3 b , and 6 b to 8 b , respectively). Alternatively, the nearest water shift to the reagent test of interest was used to calculate the dust reduction (reagent experiments 1 b and 4 b compared with water experiments $1 b$ and $3 b$, respectively).

The samplers located in the unventilated beltway required a different calculation approach. These samplers are not subject to intake dust corrections, but the measured dust concentrations need to be adjusted for the time when coal is actually being discharged to the belt during the period when the samplers are collecting airborne dust. This adjustment was made by multiplying the measured average dust concentration (table 37, column 3) by the ratio of the sampling time (table 37, column 4) to the shearer operating time within the sampling period (table 34, column 3). The result is presented in column 5 of table 37. The percentage dust reductions recorded in column 6 of table 37 were calculated on the same basis of adjacent, consecutive reagent and water shifts as was done for the stationary sampling positions along the face.

## COMPUTATION OF RESPIRABLE DUST REDUCTIONS FOR MOBILE SAMPLING AT MINE B

Airborne respirable dust was collected on the mine $B$ longwall with gravimetric samplers carried at a constant $15.2-\mathrm{m}$ ( $50-\mathrm{ft}$ ) distance downwind of the shearer. This mobile sampling was conducted in the same manner as in mine A. The dust-sampling filter results are provided in table 38. It is not entirely appropriate to correct these results for background intake dust as was done for mine A. This is because mobile sampling was done in the gobside walkway while the ventilation was only measured in the face-side walkway. It is not known how much error this discrepancy might introduce. Nevertheless, in the
interest of obtaining at least an approximation, the background intake dust corrections were made based on the face-side walkway ventilation and dust flow measurements, as if the mobile sampling was conducted in this
walkway. The correction procedure using average ventilation rates and dust flows in the longwall section was the same as that employed for mine A. The corrected results are provided in table 39.

## DISCUSSION

## STATIONARY SAMPLING AT MINE A

The dust-suppression results for the stationary samplers located along the longwall face at mine A (from tables 15, 16, and 17) are plotted in figure 9. Except for the test with SD2ES + SAES surfactant only (curve F of figure 9), the dust-suppression results were consistent and generally greater than $40 \%$ reduction. For the midface position (shield 85 ), which is less likely to be affected by headgatecrusher dust or gob dust, the results fall in the range $47 \%$ to $76 \%$ respirable dust suppression. The average midface dust reduction for all the polymer tests (curves A, B, D, and E of figure 9 ) was $62 \pm 14 \%$ ( $90 \%$ confidence).

There was a tendency to have somewhat decreased dust suppression at the sampler locations near the headgate and tailgate. These tendencies may be due to dust sources unrelated to shearer-generated dust. At the headgate, dust emanating from the crusher-stageloader can add to the dust along the longwall, particularly at the headgate sampler position (shield 10). This effect might account for the anomalous negative dust-suppression result near the headgate obtained for the surfactant-only test of curve F in figure 9 and the high dust concentration measured at shield 10 (reagent experiment 6a, table 12, last column). The phenomenon is particularly likely in the presence of surfactant and the absence of polymer. The presence of surfactant improves coal wettability to help dust capture, but reduces the surface tension of the water spray. The reduced surface tension tends to lower the stability of agglomerated particles and particle-to-fragment attachments formed in water sprays during coal shearing. The agglomerates and particles, after attachment and transport on large coal fragments in the face conveyor, are then disintegrated and detached in the crusher.

Evidence of particle attachment to large coal fragments during various mining operations, including longwalls, has been reported by Cheng and Zukovich (8). They determined that the number of respirable particles adhering to run-of-face coal under conventional conditions (no reagents in water sprays) ranged from $10^{11}$ to $10^{12}$ particles per pound of coal. These results indicate that about $7^{1 / 4} \mathrm{~kg}$ ( 16 lb ) of broken coal with attached particles could contaminate $28,300 \mathrm{~m}^{3}$ ( 1 million $\mathrm{f}^{3}$ ) of air to the $2-\mathrm{mg} / \mathrm{m}^{3}$ level if all the particles detached. Also of interest was

Cheng and Zukovich's observation that airborne respirable dust emanating from handling operations after shearing should be attributed to old particle detachment rather than from the production of new particles from secondary breakage.

In the present work, it is postulated that respirable dust is captured at the shearer and adheres to larger coal fragments (3). This attached dust is reemitted into the air at the crusher to again be carried by the ventilation past the stationary sampling positions along the face. If reagenttreated coal has more attached particles than untreated coal with possible accompanying weaker attachment forces for the particles, a resulting increase in dust levels will occur for reagent experiments and negative dust-reduction values will be observed. Paradoxically, the more efficient the capture of particles by the reagent employed, the more potential for reemission of particles. In the absence of reagents to wet and agglomerate the coal particles, there will be fewer particles captured by the water spray droplets and many of those that are captured will simply be washed to the floor from the nonwetted coal fragments, which results in fewer particles being transported to the crusher for subsequent reemission. The susceptibility to this reemission phenomenon may be reduced somewhat by the presence of water-soluble polymers to restore binding action that is lost from surfactant addition. But more importantly, the proper application and location of water sprays appear to be decisive for controlling this effect. Water spray control of reemission will be discussed later for mine B results, where the reemission effect was unusually serious.

Reagent experiment 5 a appears to be inconsistent with respect to the desirability of polymer addition. In this experiment, SAES foam surfactant was used alone at high concentration with a successful result (figure 9, curve C). It is suspected that this success is due to foaming action caused by entrained air. Foam inhibits dust release by blanketing the dust with a foam cover, but this dust-control mechanism requires high concentrations to be effective. Supporting this view is the mediocre result of curve $F$ when the concentration of SAES was approximately halved and combined with an equal amount of low-foaming SD2ES surfactant.

The dropoff of dust suppression near the tailgate for curves A, B, and D in figure 9 is believed caused by the entrance of gob dust onto the face as ventilation reenters near the tailgate. This explanation is largely supported by an examination of the ventilation distribution at shield 152 (table 7). Dust-suppression performance tended to decline near the tailgate, when there was entry of ventilation to the face from the gob (table 7, column 5, reagent experiments $2 \mathrm{a}, 3 \mathrm{a}$, and 4 a , which correspond with curves $\mathrm{D}, \mathrm{A}$, and B , respectively, of figure 9). Conversely, dustsuppression performance tended to be little affected near the tailgate when there was no observed entry of gob ventilation to the face (table 7, column 5, reagent experiments 5 a and 6 a , which correspond with curves C and F , respectively, of figure 9). The one exception to the hypothesis is curve E, which showed only a small decline in dust reduction toward the tailgate, but had significant ventilation entry from the gob (reagent experiment 1 a , table 7). All the water experiments used in calculating the dust reductions in figure 9 (water experiments 1a, 2a, and 3a) did not have ventilation entry from the gob and therefore are not a factor in estimating the tailgate dustreduction declines. It is concluded that sampling near the tailgate is less than ideal for determining the effectiveness of dust-control water spray additives.

## mOBILE SAMPLING AT MINE A

The test results of table 19, obtained at mine A when a technician sampled airborne dust while following downwind of the shearer, are plotted in figure 10 (reagent experiment 2a omitted). The results resemble those obtained for the stationary samplers. Except for reagent experiment 2 a , the pattern of $>40 \%$ dust reductions for the surfactant-polymer combinations and for the SAES foam agent (at high concentration) was duplicated. The poor performance of a lower concentration of SAES combined with the low-foaming SD2ES was also duplicated.

HPMC polymer was the top performer when combined with SD2ES surfactant. But when combined with both SD2ES and SAES in reagent experiment 2a, HPMC was unaccountably measured as ineffective in the mobile sampling. The stationary sampling results for this experiment had a reduction value comparable to the other polymer-added experiments. Furthermore, since the other stationary and mobile results corresponded well with each other, it is suspected that the mobile results for reagent experiment 2a are in error and should be disregarded. Consequently, reagent experiment 2 a is not plotted in figure 10.

## STATIONARY SAMPLING AT MINE B

The generally poor, even negative dust-suppression results calculated for the stationary samplers located along the longwall face at mine B (tables 34, 35, and 36) do not agree with the results at mine A or with the mobile and beltway results of mine B. There is no indication in the preliminary laboratory testing that the nature of the coal or mine water could cause this result. On the contrary, mine $B$ coal responded to the reagents better than mine A coal in laboratory testing (figure 3). It is apparent that certain conditions at mine B are skewing the dust results to yield improbably large negative values at the stationary sampler positions and some weaker reduction results for the mobile sampling. It is believed that two adverse conditions biased the results at mine B. The conditions are (1) the presence of a headgate dust bias between reagent and water tests and (2) a coal production bias between reagent and water tests.

## Headgate Dust Bias at Mine B

Since the shearer spends most of its time downwind of shield 13, the dust collected at this position is mostly from the crusher-stageloader in the headgate arca. Excessive dust can occur in this area during reagent experiments because of the disintegration and detachment of dust agglomerates and particles carried by the face conveyor from the shearer, as discussed earlier. This apparent reemission effect occurred to an even greater degree during a previous longwall test of dust-control reagents in another mine (3). An examination of table 31 reveals that the average dust concentrations at the headgate stationary samplers (shield 13) of mine B were generally higher for reagent experiments compared with those for water experiments. The average ratio of dust concentrations for the reagent experiments over the water experiments was 1.7 for mine B. In contrast, a ratio of 0.8 was calculated for mine A (table 12, shield 10). The excess headgate dust present at mine $\mathbf{B}$ during reagent tests and its absence at mine A may be due to the lack of panline sprays at mine B. The additional wetting of the coal on the conveyor by panline sprays at mine A may improve the adhesion of attached agglomerates and particles and prevent the release of dry particles within an agglomerate of wetted exterior particles when the agglomerate is subjected to the high energy forces in the crusher. Furthermore, mine B had three water sprays in the headgate-crusher area to control dust, whereas mine A had a total of 11 sprays. It is instructive to try to correct the stationary sampling data
to determine what the dust levels might be at mine B if panline and additional crusher-stageloader sprays were installed to eliminate the headgate dust bias.

## Correction of Headgate Dust Bias at Mine B

If it is assumed that all of the intake-corrected dust measured at shield 13 is the result of emission from the crusher-stageloader, corrections can be made at the sampler locations downwind, taking into account the ventilation patterns for each experiment similar to the treatment used for the intake dust corrections. It was also assumed that conservation of ventilation rates was approximately maintained along the longwall, i.e., the input intake ventilation to the longwall section was approximately equal to the sum of face and gob outputs at the tailgate, with no losses or gains in between. The ventilation patterns influence the headgate dust flows down the longwall and decide the amount of headgate dust that can be deducted for the downwind sampling positions located at shields 54 and 109. The correction can be a direct subtraction of dust flow at each position if the pattern is simple with no dust lost to the gob, or the pattern can be complex, as presented in the example of figure 11 for reagent experiment 7 b , where the dust flow leaves the face and then reenters from the gob. The method used for correcting the headgate dust bias is described in appendix $F$.

The percentage dust reductions computed for stationary sampling in column 8 of tables 40 and 41 after correction for headgate and intake dust are improved over those in tables 35 and 36, although some negative anomalies remain for reagent experiments $4 b, 5 b$, and $7 b$. Further corrections beyond the headgate dust bias are evidently needed.

## Coal Production Bias at Mine B

Comparison of the coal production figures for mine A and mine $\mathbf{B}$ in table 11 and table 30, respectively, reveals that the two mines differed significantly in the raw coal production between shifts in which reagent was and was not injected into the longwall water sprays. Mine A showed essentially no difference in coal production between reagent and water-only experiments, except for the abnormal test of water experiment 4 a . The ratio of the average raw coal production in the reagent experiments over the average of the water experiments (excluding atypical water experiment 4 a ) is 1.0 for mine A . In contrast, the ratio is calculated to be 1.4 for mine $B$. This ratio increases to 1.6 if the average of the four highest production shifts during water experiments $3 b, 4 b, 5 b$, and 6 b are used to calculate the ratio. It is clear that the
operation of the longwall at mine $B$ often differed considerably between reagent and water shifts, with the higher production water shifts generating less airborne dust. This difference tended to bias the dust results in favor of the water shifts, thereby contributing to the observed anomalous negative dust reductions. Attempts at normalizing the data by dividing the collected dust by the coal production are insufficient in this case (column 8 in tables 34,35 , and 36). It is not known why dust generation was so much greater for the low-production shifts. A possible explanation may be shallow cutting by the shearer bits during the low-production shifts. It has been reported that shallow bit penetration generates more respirable dust than deep penetration ( 9 ).

## MOBILE SAMPLING AT MINE B

The mobile sampling results of table 39 (last column) are more comparable with those for mine A. The biases that skewed the dust-suppression results so severely for the stationary sampling along the mine $B$ face appear not to be so influential in the mobile mode of sampling. Table 42 presents adjusted results for mobile sampling after correction for both intake dust and headgate bias. The headgate bias corrections in the table are based on average dust flows and ventilation rates along the face as described in appendix F . The headgate correction improves the dust reductions still more, making them approximately equivalent to mine A mobile results.

A plot of mobile dust-reduction results from intake-headgate-corrected experiments $1 b, 2 b$, and $3 b$ of mine $B$ compared with the intake-corrected mobile experiments $1 \mathrm{a}, 3 \mathrm{a}$, and 4 a of mine A are provided in figure 12. The corrected mobile results for these selected experiments compare well between the two mines. The average dust reduction for the three mine A experiments is $53 \%$ compared with $51 \%$ for the three mine $\mathbf{B}$ experiments in figure 12. The difference in dust reduction between the two similar HPMC polymer experiments conducted at each mine was less than 2 percentage points (bottom two bars in figure 12) and almost identical for one pair of PEO experiments (middle bars).

## DUST REDUCTION IN BELTWAY OF MINE B

Dust results obtained from the samplers in the beltway (table 37) are free of the complications of intake dust, headgate bias, and coal production bias found at the other stationary locations. The dust reductions are very high, except for reagent experiments 4 b and 7 b . In the latter experiment, the highly negative anomalous result is likely an experimental error, perhaps caused by exposure of the

7 b dust sampler to diluting crosscut intake ventilation during the water experiment. It is significant that the pattern of dust suppressions in the last column of table 37 tends to resemble that in table 42 (last column), and less so in table 39 where mobile dust has not been corrected for headgate bias. This tendency for the beltway dustsuppression pattern to be replicated in the headgatecorrected mobile sampling suggests that the correction procedures are, at least qualitatively, an appropriate approach. Furthermore, the high dust reductions measured for experiments $1 \mathrm{~b}, 2 \mathrm{~b}, 3 \mathrm{~b}$, and 5 b in the beltway suggests that if the bias conditions are eliminated at mine B, the dust-suppression results along the face could be comparable to those obtained at mine A.

## REAGENT COSTS

At the time of writing this report, the cost per pound of bulk quantities of SD2ES, SAES, HPMC, PEO-205, and PEO-10 was $\$ 1.36, \$ 1.48, \$ 2.71, \$ 4.50$, and $\$ 5.14$, respectively. The cost per clean ton of coal mined was computed for reagent experiments $1 \mathrm{a}, 3 \mathrm{a}$, and 5 a at mine A and 1 b and 2 b at mine B . The production times and clean coal production for these experiments were used in the calculations. A constant waterflow of $568 \mathrm{~L} / \mathrm{min}(150 \mathrm{gal} / \mathrm{min})$ to the longwall was assumed at mine A. At mine B, 795 and $946 \mathrm{~L} / \mathrm{min}$ ( 210 and $250 \mathrm{gal} / \mathrm{min}$ ) were used in the calculations for reagent experiments 1 b and 2 b , respectively. The results are shown in the upper part of figure 13,
together with the mobile dust reductions for these experiments in the lower part of the figure. The results for this set of experiments indicate that the combination reagents of SD2ES + HPMC and SD2ES + PEO-10 are the most cost effective, providing better reduction at an affordable expense. The SAES foam agent and SD2ES + SAES + PEO-10 + PEO-205 combination in figure 13 , while providing satisfactory dust reduction, are too costly at the concentrations tested for practical application on longwall operations.

## influence of reagent concentrations

Interpreting individual results from these few tests must be done with caution, since the errors were large, particularly at mine $\mathbf{B}$ where the results were influenced by headgate and coal production biases. But some of the results from both mine A and mine B suggest that increasing reagent concentrations was not necessarily beneficial, despite the low concentrations present in the sprays. Figure 12 shows that increasing the concentrations of the SD2ES + SAES + PEO-10 + PEO-205 reagent combination decreased the dust suppression at mine A. Similarly, at mine B, increasing the concentrations of the SD2ES + PEO-10 reagent combination apparently decreased the dust suppression. The SD2ES + HPMC combination could not be evaluated for this effect, since the data were insufficient. These counterintuitive results need to be investigated further.

## CONCLUSIONS

Data obtained at two longwall coal mining operations were used to evaluate the effectiveness of dust-suppression reagents injected into conventional water sprays. The results obtained using gravimetric samplers for respirable dust measurement were relatively straightforward at one mine, but were skewed by headgate dust and coal production biases at the second mine. There is a tendency under certain conditions for excess dust to be reemitted at the crusher after capture at the shearer when using dustcontrol reagents. This headgate dust bias can greatly harm the effectiveness of the reagents and cause inaccurate evaluations. There is a good chance that this phenomenon has contributed to the confusion concerning the effectiveness of dust-control reagents in the past. It is possible that the excess headgate dust can be remedied by the addition of panline sprays.

It is recommended that a midface location be selected for stationary gravimetric samplers when sampling a longwall to determine shearer dust. Mostly crusherstageloader emissions will be sampled at locations near the headgatc. The tailgate location, which is often selected for
shearer dust measurement, is apt to be contaminated with the influx of gob dust.

The best way to sample shearer dust is to use the mobile sampling method in which samplers are worn by a technician maintaining a constant distance downwind of the shearer. This method is less affected by changing conditions on the longwall, such as fluctuating headgate dust generation and gob dust influx.

It is concluded that the injection of appropriate surfactant-polymer reagents into longwall water spray supply lines can improve dust suppression in the range of approximately $40 \%$ to $60 \%$. The most cost-effective reagent combinations are SD $2 \mathrm{ES}+$ HPMC and SD2ES + PEO -10 , which were calculated to cost less than $4 \Phi / t$ of clean coal. A foam agent at high concentration was effective in suppressing dust with entrained air and without polymer, but it was not cost effective.

Further work is required to overcome some engineering problems concerning the mixing and injection equipment. More work is also needed to determine the reagent concentrations and longwall conditions for obtaining optimum dust suppression.

## ACKNOWLEDGMENTS

The authors are grateful to Skyline No. 3 Mine of Utah Fuel Co., Helper, UT, and JWR No. 5 Mine of Jim

Walter Resources, Inc., Brookwood, AL, for their help and cooperation in planning and carrying out the test program.

## REFERENCES

1. Meets, B. J., and A. F. Neethling. Some Experiences in the Use of Wetting Agents to Suppress Dust at Sigma Colliery. J. Mine Vent. Soc. S. Afr., v. 40, 1987, pp. 126-133.
2. Kost, J. A., G. A. Shirey, and C. T. Ford. In-Mine Tests for Wetting Agent Effectiveness (contract J0295041, Bitum. Coal Res., Inc.). USBM OFR 30-82, 1980, 190 pp.; NTIS PB 82-183344.
3. Kilau, H. W. The Wettability of Coal and Its Relevance to the Control of Dust During Coal Mining. J. Adhes. Sci. and Technol., v. 7, 1993, pp. 649-667.
4. Kilau, H. W., and J. I. Voltz. Synergistic Wetting of Coal by Aqueous Solutions of Anionic Surfactant and Polyethylene Oxide Polymer. Colloids Surf., v. 57, 1991, pp. 17-39.
5. Kilau, H. W., and J. E. Pahlman. Coal Wetting by Surfactant Solutions and the Effect of Multivalent Anion Additions. Colloids Surf., v. 26, 1987, pp. 217-242.
6. American Society for Testing Materials. Standard Classification of Coals by Rank. Method D388-84 in 1987 Annual Book of ASTM Standards: Section 5, Petroleum Products, Lubricants, and Fossil Fuels; Volume 05.05, Gaseous Fuels, Coal and Coke. 1987, pp. 225-229.
7. Parekh, B. K., and F. F. Aplan. The Critical Surface Tension of Wetting of Coal. Ch. in Recent Developments in Separation Science, ed. by N. N. Li, R. B. Long, S. A. Stern, and P. Somasundaran. CRC Press, 1978, v. 4, pp. 107-112.
8. Cheng, L., and P. P. Zukovich. Respirable Dust Adhering to Run-of-Face Bituminous Coals. USBM RI 7765, 1973, 10 pp .
9. Ludlow, J., and S. Ruggieri. Evaluate Fundamental Approaches to Longwall Dust Control, Subprogram B-Practical Aspects of Deep Cutting (contract J0318097, Foster-Miller, Inc.). USBM OFR 31B-90, 1990, 59 pp.; NTIS DE 90-015508.

## APPENDIX A.-VENTILATION DISTRIBUTION CALCULATIONS

In table 6, for the shield 85 sampler location at mine A, the face ventilation from shield 10 lost to (or gained from) the gob (columns 4 and 5, respectively) is simply the difference between the face ventilations at shields 10 and 85. The calculated gob ventilation of column 6 is the result of
appropriately adding or subtracting the ventilation losses or gains to the calculated gob ventilation at shield 10 in table 5. The data of table 7 for shield 152 were derived similar to that of table 6, except that the ventilation distribution between shields 85 and 152 is used.

## APPENDIX B.-INTAKE DUST FLOW CALCULATIONS

The intake crosscut and beltway dust flows in columns 3 and 4, respectively, of table 8 are basically the product of the measured dust concentrations given in tables 3 and 4 multiplied by the respective measured ventilation rates provided in table 5.

The intake dust flow along the face at shield 10 , given in column 6 of table 8, is calculated by multiplying the total intake dust flow of column 5 by the fraction of intake ventilation appearing at shield 10 , as previously determined in table 5. The remainder of the intake dust flow must then appear in the gob as compiled in the last column of table 8 by subtracting the values in column 6 from those in column 5. The same treatment for estimating intake dust flow is continued in table 9 as one proceeds from shield 10 to shield 85 , the second stationary dust-sampling position. The intake dust flow will be split again as it proceeds from shield 10 to shield 85 , the split being determined by the fraction of shield 10 ventilation appearing at shield 85 (table 6, column 7). The intake dust flow on the face at shield 85 (table 9, column 3) is therefore the product of multiplying this fraction of ventilation by the intake dust flow emanating from shield 10.

The difference between this calculated intake dust flow at shield 85 and the intake dust flow coming from shield 10 is the loss to the gob, listed in column 4 of table 9. When this dust flow is added to the intake dust flowing in
the gob from shield 10 , the result is the gob intake dust flow at shield 85, listed in the last column of table 9.

Two exceptions to this treatment occur for reagent experiment $6 a$ and water experiment $4 a$ where face ventilation is increased through gains from the gob rather than lost. In this case, the intake dust flow on the face at shield 85 can be derived from consideration of gob ventilation and dust flows. The dust flow in the gob at shield 85 (last column of table 9) can be calculated using the fraction of shield 10 gob ventilation that appears at shield 85 (calculated earlier in table 6 , last column). This fractional ventilation multiplied by the shield 10 gob dust flow (last column, table 8) provides the gob intake dust flow at shield 85 . This value subtracted from the gob intake dust emanating from shield 10 is the intake dust flow added to the face from the gob, listed in column 5 of table 9. This added dust flow to the face in column 5 is in turn added to the intake dust flow from shield 10 (column 6, table 8) to achieve reagent experiment 6 a and water experiment 4 a results of column 3 of table 9 for the intake dust flow contribution at shield 85 . Identical procedures are followed for determining intake dust flow contributions at shield 152 in table 10, the procedure used depending on whether face ventilation is lost to or gained from the gob as one proceeds from shield 85 to shield 152 (table 7).

## APPENDIX C.-COAL PRODUCTION CALCULATIONS

The estimate of the raw coal produced per shift in column 4 of table 11 was calculated by dividing the clean coal production by a factor of 0.75 .

The time required to cut the coal each shift (last column of table 11) is based on the longwall advance per shift provided by the mine operator, a $76-\mathrm{cm}$ cutting depth, and the average time to make the complete cutting pass (tailgate to headgate and back). The cutting pass time was
computed from measurements made by a USBM technician following the shearer during the mobile sampling program. Appropriate time deductions were made for any shearer down times en route. The total shift production time of column 5 was computed by dividing the $76-\mathrm{cm}$ cutting depth into the longwall advance to obtain the number of passes, followed by multiplying the average time per pass.

## APPENDIX D.-CALCULATION OF CORRECTED AND NORMALIZED DUST VALUES

The time of shearer operation during the dust-sampling period at shield 10 (column 3 of table 15) was determined by a USBM observer on the face. The rate of airborne dust formed upwind of the sampler position at shield 10 (during the time the samplers were running) in column 4 was calculated according to the formula-

$$
\begin{equation*}
\text { Rate of dust formation }=\mathrm{C} \cdot \mathrm{~V} \cdot\left(\mathrm{~T}_{\mathrm{s}} / \mathrm{T}_{\mathrm{o}}\right) \text {, } \tag{D-1}
\end{equation*}
$$

$$
\begin{aligned}
& \text { where } \quad \begin{aligned}
\mathrm{C}= & \begin{array}{r}
\text { average dust concentration measured at } \\
\text { shield } 10 \text { (table } 12, \text { last column), }
\end{array} \\
\mathrm{V}= & \begin{array}{r}
\text { ventilation measured at shield } 10 \text { (ta- } \\
\\
\text { ble } 5, \text { column } 6),
\end{array} \\
\text { and } \quad \mathrm{T}_{\mathrm{s}}= & \text { sampling time (table } 12, \text { column } 7), \\
\mathrm{T}_{\mathrm{o}}= & \begin{array}{r}
\text { operating time of shearer within sam- } \\
\\
\end{array}
\end{aligned} \begin{aligned}
\text { pling period (table } 15, \text { column } 3) .
\end{aligned}
\end{aligned}
$$

In this formula, the sampling time, $T_{s}$, is normalized by dividing by the shearer operating time, $\mathrm{T}_{\mathrm{o}}$, since airborne dust is formed only when the longwall is operating. If the calculated rate of dust formation in column 4 of table 15 is assumed to be representative of dust formation during the production time of an entire shift, the respirable dust formed during the shift can be calculated by multiplying the rates in column 4 by the shift production times of table 11 , last column. The result, after dividing by 1,000 to convert to grams, is given in column 5 of table 15. During this period, the samplers are also collecting dust from intake sources that are independent of the influence of
dust-suppression reagents. Therefore, this dust needs to be subtracted from the shearer and other longwall dust sources for fair comparison of dust-suppression effectiveness. A measure of this intake dust at shield 10 is achieved by employing the formula-

$$
\begin{equation*}
\text { Intake dust at sample position }=\mathrm{I}_{\mathbf{f}} \cdot \mathrm{T}_{\mathbf{p}} / 1,000 \tag{D-2}
\end{equation*}
$$

where $\quad I_{f}=$ intake dust flow at sampler location (table 8, column 6)
and $\quad T_{p}=$ shift production time (table 11, last column).

The calculated results are provided in column 6 of table 15. Deducting this value from column 5 (the measured airborne dust formed during the shift at shift 10) corrects the column 5 dust quantities for intake dust sources (column 7 of table 15). Since the coal produced during each shift varied, comparison of the shift results requires a further correction to normalize the collected dust for this variable. The coal production normalization was accomplished by dividing the intake-corrected dust of table 15 , column 7 by the raw coal production of table 11, column 4 , and multiplying by 1,000 to obtain the milligrams of dust per metric ton of raw coal mined, shown in column 8 of table 15.

The computations at the other two stationary face sampling positions, shields 85 and 152 , were performed in a similar manner. The results are provided in tables 16 and 17 , respectively.

## APPENDIX E.-MOBILE SAMPLING CALCULATIONS

The ventilation rates measured for a given experiment at shields 10,85 , and 152 (ventilation distribution tables 5 , 6 , and 7 , respectively) were averaged to give an overall value for the ventilation along the longwall listed in column 4 of table 19. Similarly, the intake dust flows along the face at shields 10,85 , and 152 (listed in tables 8,9 , and 10, respectively) were averaged to give the values listed in column 3 of table 19. The average dust concentration from intake sources along the longwall provided in column 5 of table 19 was computed by dividing the average intake dust flow of column 3 by the average ventilation in column 4. This value, in turn, is multiplied by the volume of air
drawn through the filter by the sampling equipment (column 8 of table 18). The result is the weight of dust on the filter contributed by intake dust sources in column 6 of table 19. This value is subtracted from the average weight of dust collected on the filters during the mobile sampling (column 6, table 18) to achieve the corrected weight of dust on the filter listed in column 7 of table 19. This corrected weight is then divided by the volume of air passing through the samplers during the sampling time to obtain the corrected average dust concentrations in column 8 of table 19.

## APPENDIX F.-HEADGATE DUST CORRECTION

An example of the calculation method for correcting headgate dust bias is presented in the following procedure. Referring to reagent experiment 7 b in table 40 and figure 11, the headgate dust flow from shield 13 recorded in column 4 is calculated by dividing the intake-corrected value for the dust formed at the headgate (column 3) by the longwall (shearer) operating time (table 30, column 4). The dust formed at the headgate was determined earlier in table 34, column 7. In flowing toward shield 54, some of this headgate dust flow is attenuated because of ventilation loss to the gob (figure 11). The proportion of dust flow arriving downwind at shield 54 after the ventilation loss (table 40, column 5) is equal to the dust flow from the headgate (column 4) multiplied by the fraction of ventilation appearing at the downwind location (table 25 , column 7), i.e., the ratio of shield 54 ventilation rate to the shield 13 rate. This adjusted headgate dust flow is multiplied by the production time (table 30) and the result is subtracted from the intake-corrected dust measured at shield 54 (column 7 of table 35) to obtain the headgate-corrected (and intake-corrected) value for dust collected at shield 54 (table 40, column 6). After normalizing these values by dividing by the shift coal production (table 40, column 7), the percentage dust reductions (table 40, column 8) were
calculated using the same criteria for selection of wateronly comparison experiments that were used in table 35.

The same procedure is used to compute the headgate dust correction at shield 109 in table 41, except that in this case the calculations must consider a partial restoration of headgate dust flow to the face because of ventilation influx from the gob between shields 54 and 109 (figure 11). The headgate dust flow lost to the gob ( $421 \mathrm{mg} / \mathrm{min}$ ) between shields 13 and 54 is recorded in column 4 of table 41. This is simply the difference between the headgate dust flows at shields 13 and 54 that were calculated earlier. The proportion of this headgate dust flow returning to the face ( $22 \mathrm{mg} / \mathrm{min}$ ) is the difference between the headgate dust flows in the gob at shields 54 and 109. The gob headgate dust flow at shield 109 is computed by multiplying the gob headgate dust flow at shield 54 by the fraction of gob ventilation appearing at shield 109. The fraction is derived after accounting for all the ventilation inputs and losses in the gob and on the face, including the intake ventilation contribution to the gob (figure 11). This accounting assumes that the principle of ventilation conservation is maintained and that no dust created in the gob leaks into the face.

Figure 1


Particle volume distributions of ground coal samples used in laboratory wettability westing.

Figure 2


Particle surface area distributions of ground coal samples used in laboratory wettability testing.

Figure 3


Drop penetration test results for aqueous solutions of SD2ES surfactant with and without polymers and SAES surfactant with polymer. All surfactant concentrations were 600 ppm . (Error bars represent $9 \% \%$ confidence level.)

Figure 4


Drop penetration test results for aqueous solutions cuntaining SD2ES + SAES surfactant with polymers. All tests conducted on mine A coal. (Ermor bars represent $90 \%$ confidence level.)

Figure 5


Schematic diagram of bypass system for injecting reagents into longwall water spray system.

Figure 6


Reagent bypass injection system set up at minesite.

Figure 7


Schematic diagram of stationary dust-sampling locations, ventilation pattern, and intake dust flows for reagent experiment la on mine $A$ longwall.

Figure 8


Schematic diagram of stationary dust-sampling locations, ventilation pattern, and intake dust flows for reagent experiment lb on mine B longwall.

Figure 9


Dust suppression results for stationary gravimetric samplers located at shields 10, 85, and 152 on mine $A$ longwall. Results corrected for intake dust. (Dashed line portion of curve F is an approximation because of negative dust-reduction value near headgate.)

Figure 10


Dust-suppression results for mobile gravimetric sampling on mine A longwall. Results corrected for intake dust.

Figure 11


Schematic diagram of headgate dust flows and ventilation patterns for reagent experiment $7 b$ on mine $B$ longwall.

Figure 13


Comparison of dust reduction and costs for reagent combinations at mines $A$ and $B$ as determined from mobile sampling.


[^0]:    ${ }^{1}$ Research chemist.
    ${ }^{2}$ Mechanical engineer.
    ${ }^{3}$ Program analyst.
    ${ }^{4}$ Mining engincering technician (retired).
    ${ }^{5}$ General engineer.
    Twin Cities Research Center, U.S. Bureau of Mines, Minneapolis, MN.

[^1]:    ${ }^{6}$ Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

[^2]:    NAp Not applicable.
    1 During dust-sampling period
    ${ }^{2}$ Upwind of sampling position during dust-sampling period and normalized for shearer operating time.
    ${ }^{3}$ Upwind of sampling position during shift production time, uncorrected for intake contribution.
    ${ }^{4}$ Calculated contribution to sample position during shift production time.
    Formed upwind of
    ${ }^{8}$ Based on the results of reagent experiment 1a compared to water experiment 1a.
    ${ }^{9}$ Based on the results of reagent experiment 2a compared to water experiment 2 a .
    ${ }^{11}$ Based on the results of reagent experiment 4 compared to the average of the results for water experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3 a . If the questionable results for
    atypical water experiment 4 a are used to calculate the dust reduction, a value of $54.78 \%$ is obtained.
    ${ }^{12}$ Based on the results of reagent experiment 5 a compared to the average of the results for water experiments $1 \mathrm{a}, 2 \mathrm{a}$, and 3 a . If the questionable results for atypical water experiment 4 a are used to calculate the dust reduction, a value of $51.13 \%$ is obtained.
    ${ }^{13}$ Based on the results of reagent experiment 6 a compared to the average of the results tor water experiments $1 \mathbf{a}, 2 \mathbf{a}$, and $\mathbf{3 a}$. If the questionable results for atypical water experiment 4 a are used to calculate the dust reduction, a value of $-21.04 \%$ is obtained.

[^3]:    NAp Not applicable.
    ${ }^{1}$ During dust-sampling period.
    ${ }^{2}$ Upwind of sampling position during dust-sampling period and normalized for shearer operating time. ${ }^{3}$ Upwind of sampling position during shift production time, uncorrected for intake contribution.
    ${ }^{4}$ Caiculated contribution to sample position during shift production time.
    ${ }^{6}$ Formed upwind of sampling position, normalized for coal production, and corrected for intake dust.
    ${ }^{7}$ Compared with water experiment 1b.
    ${ }^{8}$ Compared with average of water experiments 1 b and 3 b .
    ${ }^{9}$ Compared with water experiment 4b.
    ${ }^{11}$ Compared with average of water experiments 6 b and 8 b .

[^4]:    NAp Not applicable.
    During dust-sampling period.
    ${ }^{3}$ Upwind of sampling position during shift production time, uncorrected for intake contribution.
    ${ }^{4}$ Calculated contribution to sample position during shift production time.
    ${ }^{\text {supwind }}$ of sampling position during shift production time after correcting for intake dust.
    ${ }^{6}$ Formed upwind of sampling position, normalized for coal production, and corrected for intake dust.
    ${ }^{7}$ Compared with water experiment 1 b .
    ${ }^{8}$ Compared with average of water experiments 1 b and 3 b .
    ${ }^{9}$ Compared with water experiment 4 b .
    ${ }^{11}$ Compared with average of water experiments 6 b and 8 b .

[^5]:    NAp Not applicable.
    ${ }^{1}$ During dust-sampling period.
    ${ }^{3}$ Upwind of sampling position during shift production time, uncorrected for intake contribution.
    Calculated contribution to sample positon during sither for intake dust.
    Upwind of sampling position during shift production time alotuction, and corrected for intake dust.
    Compared with water experiment 1 b .
    4b.
    ${ }^{9}$ Compared with water experiment 4b.
    ${ }^{11}$ Compared with average of water experiments 6 b and 8 b .

[^6]:    NAp Not applicable.
    ${ }^{1}$ Dust formed upwind of shield 13 during shift production time after deducting intake dust contribution.
    ${ }^{2}$ From upwind of shield 13 , intake dust deducted.
    ${ }^{3}$ Corrected for ventilation losses to gob.
    ${ }^{4}$ Dust at shield 54 during shift production time, atter deducting both intake and headgate dust.
    ${ }^{5}$ Dust at shield 54 during shift production time, after deducting intake and headgate dust and dividing by coal production.
    ${ }^{6}$ Normalized for coal production and corrected for intake and headgate dust.
    ${ }^{7}$ Compared with water experiment 1 b .
    ${ }^{8}$ Compared with average of water experiments 1 b and 3 b .
    ${ }^{9}$ Compared with water experiment 4b.
    ${ }^{10}$ Compared with water experiment 5b.
    ${ }^{11}$ Compared with average of water experim ents 6 b and 8 b .

[^7]:    NAp Not applicable.
    ${ }^{1}$ From tables 40 and 41 , average of values at shields 13,54 , and 109 . Includes intake dust deduction.
    ${ }^{2}$ Calculated by multiplying average headgate dust flow by average of ventilation values at shields 13, 54, and 109.
    ${ }^{3}$ Corrected for headgate and intake dust contributions.
    ${ }^{4}$ Compared with water experiment 1b.
    ${ }^{5}$ Compared with average of water experiments 1 b and 3 b .
    ${ }^{6}$ Compared with water experiment 4b.
    ${ }^{7}$ Compared with water experiment 5b.
    ${ }^{8}$ Compared with average of water experiments 6 b and 8 b .

