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CONTINUOUS GAS MONITORING USING TUBE BUNDLES AT THE JOANNE MINE FIRE

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by

L. E. Dalverny,[1] Z. J. Fink,[2] and J. W. Weinheimer[3]

ABSTRACT

This Bureau of Mines report describes the deployment, 5-month operation, and lessons gained from a continuous gas monitoring system using sampling-tube bundles at an underground mine fire in West Virginia. Research information gained indicates the utility of relating certain gas concentration ratios to events during fire development, mine reventilation, and mine recovery. In addition to monitoring the quality of remote fly ash seals, the system provided timely warning of dangerous gas concentrations which developed during surface and underground recovery activities. An evaluation of system components is supplemented by recommendations for improvements.

INTRODUCTION

A fire ignited by electrical arcing began in the Joanne mine of Eastern Associated Coal Corp. (EACC) in Rachel, W. Va., at approximately 12:50 a.m., January 14, 1974. Eight days later, a decision by EACC, the Federal Bureau of Mines, the Mining Enforcement and Safety Administration, the State of West Virginia, and the United Mine Workers of America was made to sample gases in the fire area through boreholes. Shortly thereafter a continuous gas monitoring system using sampling-tube bundles was moved to the Joanne mine.

Subsequent continuous gas monitoring of carbon monoxide, oxygen, carbon dioxide, and methane using the tube bundle system fulfilled three primary objectives:

1. As a key tool in the first successful effort at remote fly ash sealing and reventilation prior to recovery in the United States, the system proved invaluable in assuring a safe, speedy mine recovery. Of particular importance was the immediate monitoring of gas concentrations during potentially hazardous activities such as--

A. Sonar and television probing through boreholes to assure proper location and adequacy of the fly ash seals. During these operations, methane

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[1] Physicist.

[2] Chemical engineer.

[3] Physical science technician.

and oxygen concentrations were monitored to avoid potentially explosive mixtures both at the surface (to be maintained at less than 2% methane) and at the probe location down the borehole. A hazardous situation was detected rapidly when the gage pressure of the borehole being probed changed from negative to positive, and methane-air mixtures at the surface reached the explosive range. Probing was halted until a large blower fan could be moved about the borehole area and then placed to disperse any future methane release and thereby maintain concentrations below the 2% level.

B. Pumping of inert nitrogen diluted with air into the fire zone during sealing operations. Through the progress of these operations, the oxygen concentration was to be maintained at a level below 10% because the fire zone contained over 30% methane. When the oxygen concentration did increase to nearly 10%, the operations were temporarily halted until the oxygen underground could disperse to a low concentration level everywhere.[4]

2. The utility of the Bureau of Mines tube bundle system was demonstrated in this rugged field operation. Results of problems encountered in this field test yield insight into future monitoring where pragmatic constraints must be applied. In this paper, recommendations are made for improving borehole sampling, analyzer reliability, data processing, and the gas sampling system itself.

3. Used as a research tool, the system enabled ratios of $\Delta CO/\Delta O_2$ (the CO index) and of $\Delta CO/\Delta CO_2$ to be followed throughout the fire development and mine reventilation periods. The utility of these ratios in tracking events in a mine fire is clearly demonstrated in this report.

ACKNOWLEDGMENTS

The authors acknowledge the assistance and cooperation of R. Ice, J. Ice, C. Hoffman, S. Yearsovich, and L. Owens, all of Eastern Associated Coal Corp., for the manual recording of data and the care of the analytical equipment. EACC management, safety, and engineering personnel contributed both direction and physical assistance toward success of the project. D. Mitchell coordinated Bureau activities with all other aspects of the endeavor.

EQUIPMENT DEPLOYMENT

The 19-point monitoring system using tube bundles is described elsewhere.[5] The analysis center was housed in a freight trailer adequately equipped for machine maintenance and personnel comfort.

The main equipment cabinet of the analysis center houses the paramagnetic oxygen and the infrared carbon monoxide analyzer-recorder pairs, an exhaust pump, a sampling pump, and an automatic timing-switching device. The exhaust pump continuously pulled sample gases through multicore bundles of 1/4-in-ID

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[4] Foster-Miller Assoc. Joanne Mine Remote Sealing Operation. Contract H0144044, Technical Report, 1975.

[5] Fink, Z. J., and D. T. Adler. Continuous Monitoring System for Mine Gas Concentrations Using Tube Bundles. BuMines RI 8060, 1975.

polyethylene tubing from the surface ends of 1/4-in-ID copper tubes lowered through vertical boreholes into the mine. The smaller sampling pump feeding the analyzers pulls gas from 1 of the 19 sampling point tubes terminating at the trailer. The switching device can be automatically sequenced through the 19 points, or can be manually operated to observe chosen points as required. Additional infrared analyzers for carbon dioxide and methane were connected permanently in parallel to the original oxygen and carbon monoxide analyzers. An electrochemical CO analyzer was used intermittently when the infrared CO analyzer required repair. The monitoring instrument volume concentration ranges available were--

O_2 (paramagnetic).............	0-25%
CO (infrared)..................	0-100, 0-300, and 0-1,000 ppm
CO (electrochemical)...........	0-100 and 0-1,000 ppm, or 0-250 and 0-2,000 ppm (2 units used)
CO_2 (infrared)................	0-10%
CH_4 (infrared)................	0-25%

EACC personnel performed supplemental analyses for the same gases; initially, they used an Orsat apparatus, but later a small gas partitioner[6] was moved into the gas sampling trailer and used. Occasional gas chromatographic analyses requested from the Bureau's Analytical Research Group (Pittsburgh Mining and Safety Research Center), Bruceton, Pa., provided additional data.

Although the CO (IR) analyzer automatically calibrates itself approximately every 12 hours, it and the other analyzers are calibrated manually when necessary, using cylinders of known gas mixtures kept in the trailer. Sample flow rates are adjusted for all sampling points, with needle valves, to approximately 2 scfh to be independent of tube lengths, which range from approximately 6 to 4,000 feet. Analysis time for each point is approximately 5 minutes, limited by the amount of time necessary for the oxygen analyzer to indicate a meaningful concentration. The analyzer has a time constant of 45 seconds to indicate 63% of full scale.

An underground map of the fire area is shown in figure 1. The gas sampling trailer was located approximately 450 feet above the mine and to one side of a hill that peaks over the fire origin.

Multicore plastic tubing sufficient to sample up to seven points was extended over to the far side of the hill. Up to nine sampling tubes could be connected on the near side; two sampling points were located at an air shaft (East Run intake and return, not shown in figure 1) away from the fire area. As a safety precaution and a calibration check, the 19th tube sampled the air in the trailer itself. Outside air could be sampled simply by allowing one or more tubes to be opened and positioned above ground level to prevent blockage by water or soil. The ends of unused tubes were sealed with black, plastic electrical tape. A water trap and two dust filters installed

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[6] The word "partitioner" differentiates this portable instrument from the bulky, usually higher precision, laboratory chromatograph.

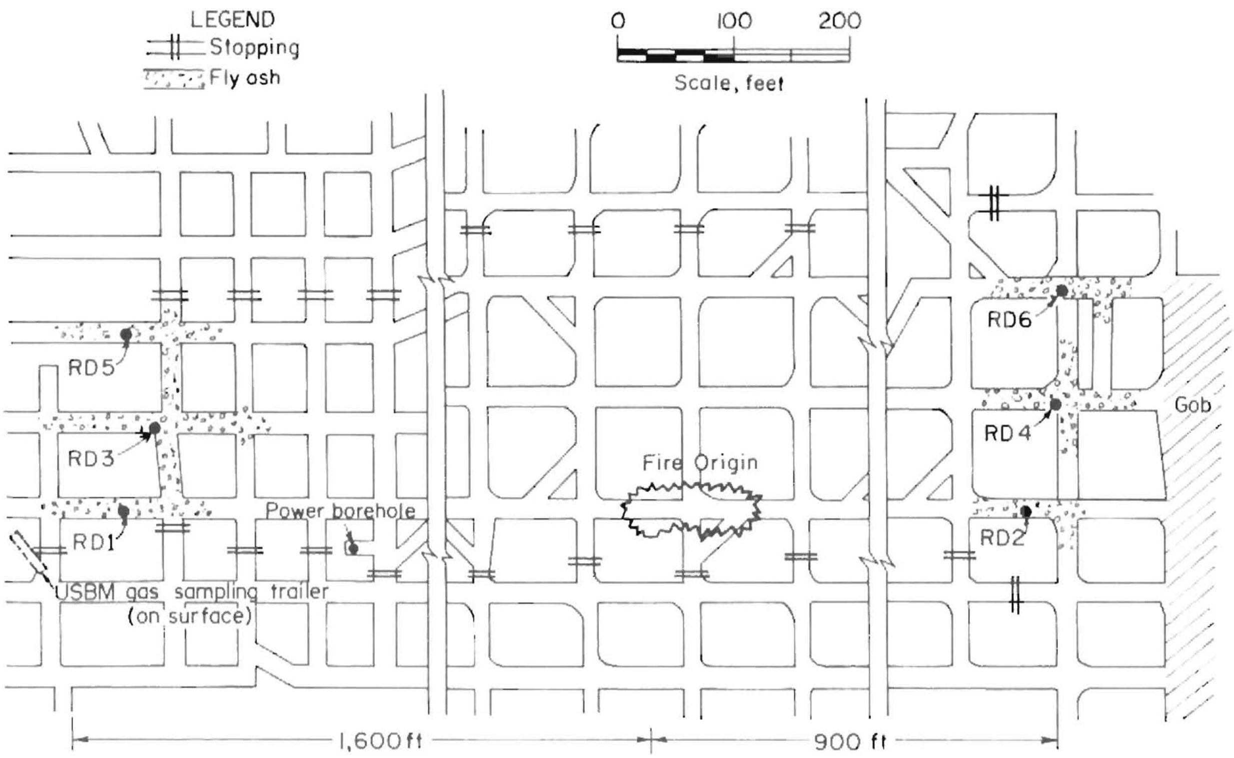

FIGURE 1. - Underground map of fire area.

between the sampling pump and analyzers removed moisture and dust in the sampled gases. Occasional checks of the filters and the trap did not show perceptible residues from the gases sampled during the project. Exhaust gases from the analyzers and from bypassed samples were vented to the atmosphere through tubing extended to a high position outside the trailer.

At the outlet of the sampling pump, the sampled gases were at a pressure slightly higher than atmospheric. A ball valve inserted between the pump and the analyzers was used for extracting bottle and syringe samples for gas chromatographic analysis.

Each analyzer had a front-panel meter showing numbers proportional to the concentrations of currently analyzed gases. Multipoint continuous strip chart recorders were employed to store the analysis information. The recorder for each of the O_2 and CO (IR) analyzers stamped on its chart, after each analysis, the number of the sampling tube (1 through 19) alongside a dot corresponding to the indicated concentration. The outputs of the CO_2 and CH_4 analyzers were recorded continuously on one dual-pen (100 increments full scale) recorder. Therefore, the number of the tube being sampled was written periodically on this chart for reference. Dates and times were also noted on all the charts. Special data sheets were initiated when the O_2 and CO (IR) recorders were inoperative because of an electrical malfunction, and continued in use after repairs were completed. The data so recorded included date and time of analysis, meter readings from each analyzer for all sampling points, and equivalent percentages and/or parts per million as obtained from calibration charts. In addition, the output of the electrochemical CO analyzer was recorded by hand on these data sheets. Periodically, the charts and data sheets were returned to the Bureau's Bruceton facility for computerized computations (CO and CO/CO_2 indices) and plotting of the data.

Figure 1 indicates the location of the fire origin relative to seven of the boreholes used for sampling mine gases. The six RD boreholes also were used to insert fly ash into the mine entries during remote-sealing operations. Two additional boreholes located approximately 30 feet on either side of each of the six numbered holes shown in figure 1 were used to check the remote seals. (These six pairs, not shown, were suffixed, with A being designated as inby and B as outby the fire origin.) The fire area that eventually was sealed was surrounded by the RD boreholes into the entries and by stoppings in the ribs, as shown in figure 1. The power borehole was in continuous use as a sampling point from the first day of the fire; EACC safety personnel had installed a 1/4-in-OD copper tube plus a thermocouple probe, which were later supplemented with tubing attached to the Bureau analyzers.

RESULTS

Constraints on the maximal gas concentration values must be noted. The oxygen analyzer was calibrated for 0% to 25% with 100 increments full scale, and was so used during the project. The carbon monoxide infrared analyzer was used on the particular range required (usually 0-100 ppm), also with 100 increments full scale. A second infrared analyzer for CO in the 0% to 5% (50,000 ppm) range was tried but was found to be defective; the concentration fell below 1,000 ppm (available high range) before another unit could be found.

The CO_2 analyzer was set for a 0% to 10% range. Initially, the CH_4 unit was set for a 0% to 50% range full scale. About a month after monitoring began, a decision was made to change to a 0% to 25% range to obtain more precise values when methane volume concentrations decreased into the explosive range during sealing and/or reventilation activities. Subsequently, occasional gas chromatographic analyses were performed to ascertain the methane concentrations greater than 25%. (IR analyzer data >25% are marked as 30% on figures 2 and 3.) Analyses of oxygen content by the gas partitioner were not corrected for the 0.8% concentration of argon present in air. Therefore, the results appear slightly higher than those obtained with the paramagnetic oxygen analyzer.

Gas concentration data from two borehole tubes sampling for many weeks from near the two ends of the fire area are graphed in figures 2 and 3. Fluctuations in all four gas concentrations during the first 15 days probably resulted from incomplete sealing of the mine's surface openings. Carbon monoxide and oxygen levels decreased at rates of ~-0.02% CO per day and ~-0.3% O_2 per day, leveling out at approximately 0.006% CO and 1% O_2 some 60 days after the fire began. The methane concentration increased steadily at a rate of ~0.25% per day to a maximum of 30% to 35% CH_4. At rates of 0.06% CO_2 per day, the carbon dioxide concentration first decreased to approximately 1.8%, then increased to a maximum of approximately 4.1% by the time remote sealing operations began.

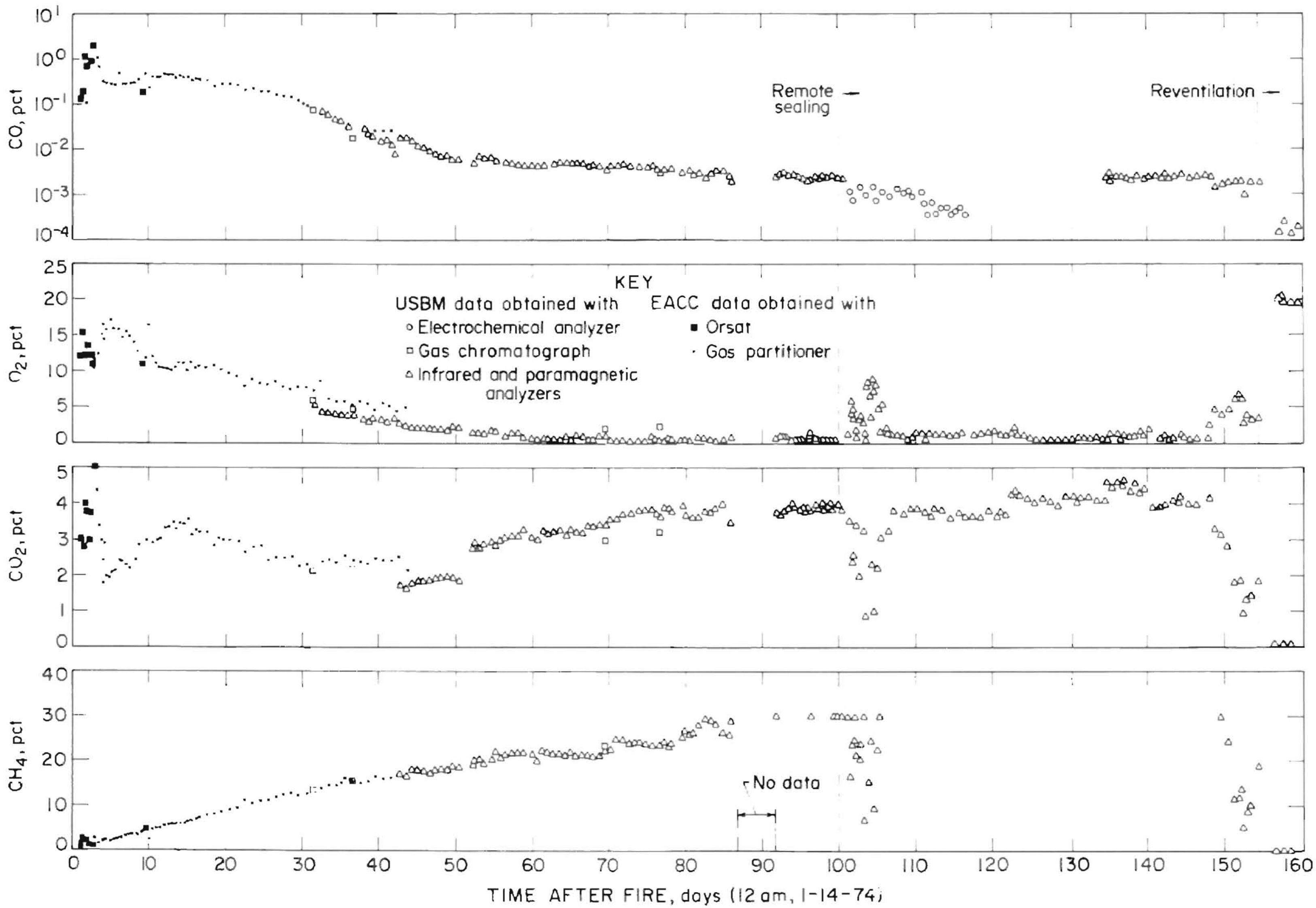

FIGURE 2. - Carbon monoxide, oxygen, carbon dioxide, and methane gas analyses versus time after fire—power borehole sampling point.

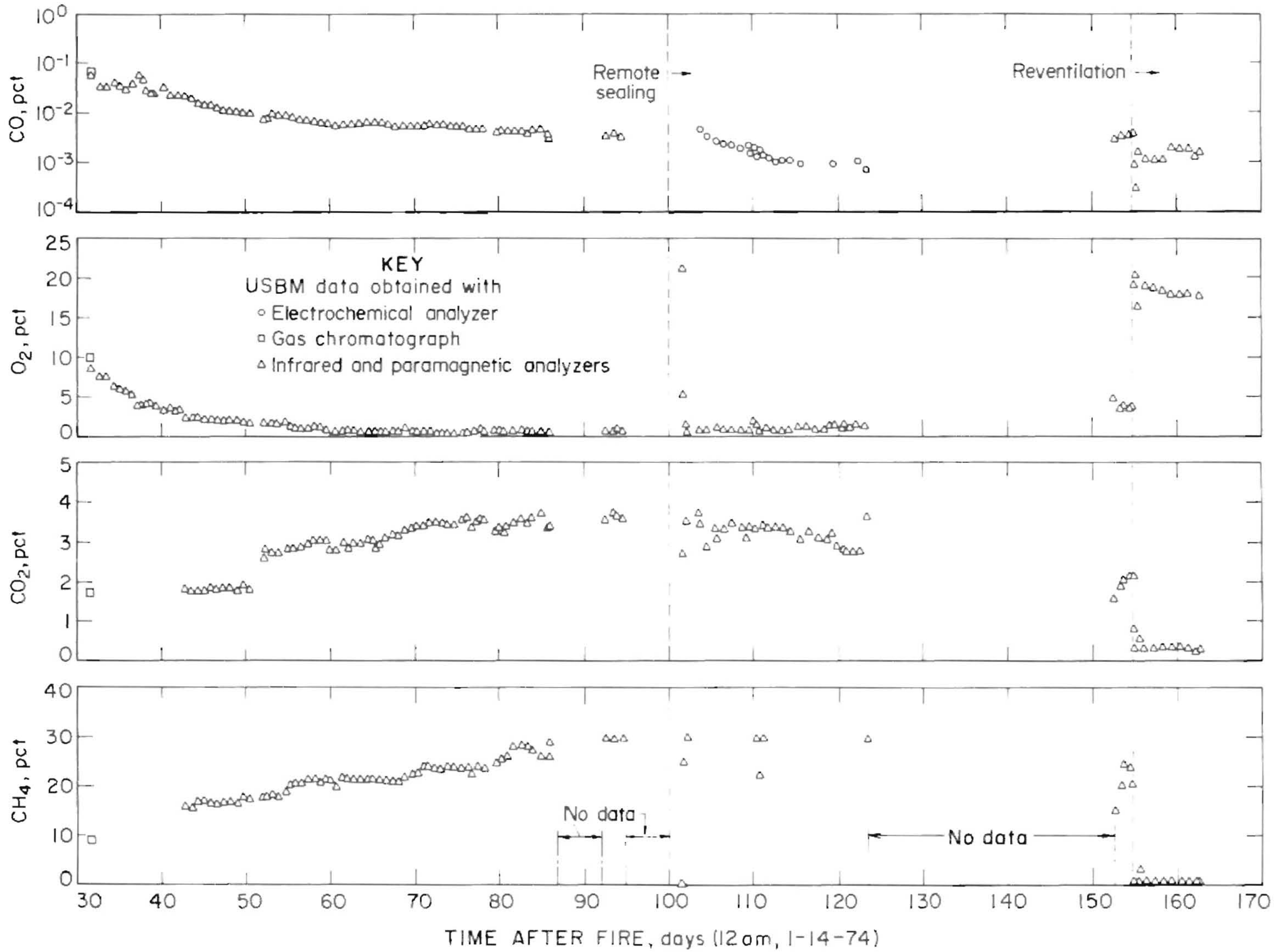

FIGURE 3. - Carbon monoxide, oxygen, carbon dioxide, and methane gas analyses versus time after fire–RD4B borehole sampling point.

The final concentrations of the four gases when remote sealing began were approximately the same on both sides of the fire (figs. 2 and 3); these concentrations may be typical of a sealed area of the Joanne mine. In figure 2, the initial concentrations of the two carbon oxides (to about 1% CO and 5% CO_2) clearly reflect a fire in the mine. The indices in figure 4 show corresponding high values (to about 1,400 CO index and 5,000 CO/CO_2 index).

Trends of the CO index (Δppm CO/Δ%O_2) or the CO/CO_2 index (Δppm CO/Δ% CO_2) may be used as indicators of fire activity if ventilation patterns are sufficiently known. For a working mine, gradual increases from an established base line index for a particular mine area indicate incipient heating from slow oxidation of the coal.

Figure 4 shows these indices versus time after the fire began. The graph data were calculated for a sample point underground (power borehole) referenced to outside air. Some of the CO index results in the figure were calculated using a partial air composition of 20.63% O_2, 1.6 ppm CO, and 0.2% CO_2; this was determined to be the average outside air from data by various analyzers. Conservative minimum limits on the relative concentration differences of Δ%O_2 = 0.2%, Δppm CO = 1 ppm, and Δ% CO_2=0.05% were set but not required until after reventilation. With the atmosphere in the mine returning to normal, the concentration differences dropped to less than the minima. As shown in figure 4, the CO/CO_2 and CO indices calculated using outside air form smooth curves from about the 10th day after the fire (when most of the surface openings of the mine had been sealed) to the beginning of the remote sealing operation. During the initial remote sealing work, various quantities of air were injected intermittently to the underground volume and are reflected by temporary interruptions in the smooth curves.

EQUIPMENT EVALUATION AND RECOMMENDATIONS FOR IMPROVEMENT

This section considers two major components of the Bureau of Mines continuous gas monitoring system--the analysis center and the tube bundles and borehole tubing.

Analysis Center

Overall, the performances of the pumping system and the automatic timing-switching device were excellent.

A power failure occurring prior to the remote sealing effort temporarily shut down the analysis center. (The resulting lack of data before remote sealing is apparent in figures 2 and 3.) It is recommended that the analysis center be better protected in the future with a transformer-regulator capable of dampening the effects of power transients, sometimes worse in effect than power failures.

Data plotted in figures 2 to 4 (for the 30th to 85th day after the fire began) were processed using the computer scheme described by Fink and Adler.[7]

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[7]Work cited in footnote 5.

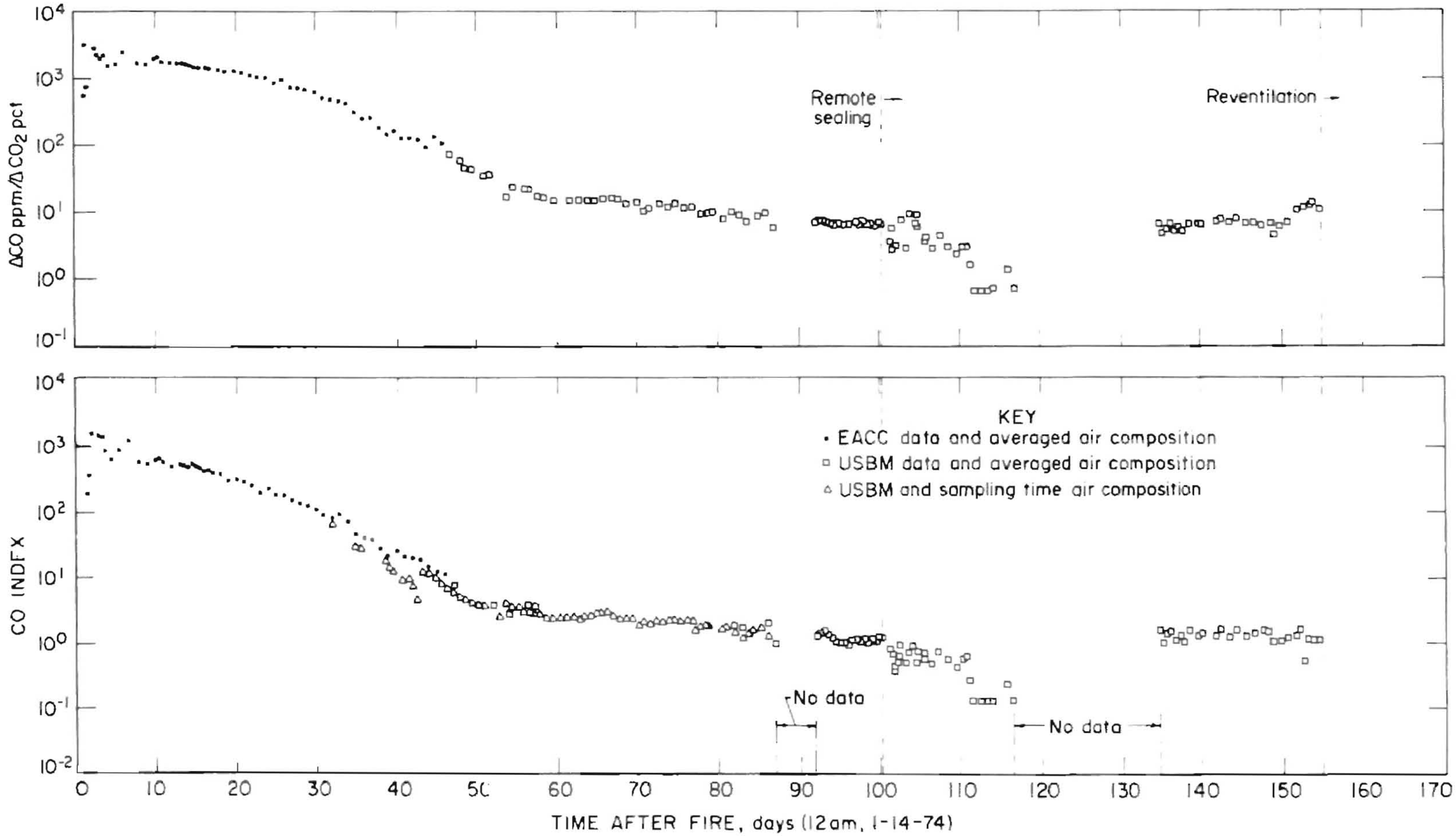

FIGURE 4. - Carbon monoxide/carbon dioxide and CO indices versus time after fire for power borehole gas analyses referenced to air composition.

Processing time for chart data, collected approximately once a week, was 2 to 3 weeks. Because of this large delay in computer processing time, manual plotting was necessary during hazardous remote sealing and reventilation operations occurring after the 85th day. This manual type of processing probably must continue in the immediate future during critical operations.

The infrared CO_2 and CH_4 analyzers and the paramagnetic oxygen analyzer proved to be sufficiently reliable throughout the Joanne mine fire experience when subjected to independent gas chromatography comparison tests. Because the CO (IR) unit initially was intended for analysis of essentially normal mine air, interference by large concentrations of contaminant gases was not corrected for in the optical filtering specifications. Therefore, high concentrations of methane increased the apparent levels of CO being monitored; initially, the error was about +8 ppm CO for +1% CH_4. With a change in detector cell, the error was reduced to about +1 ppm CO for +1% CH_4. Effects by other (low-level concentration) hydrocarbon gases were negligible. CO infrared results in figures 2 and 3 are corrected for methane interference.

The two carbon monoxide analyzers using an electrochemical cell were affected by the continuous use. The first unit was later found to require a new temperature-compensating thermistor; the second unit, powered by batteries and operated intermittently, worked fairly well for about a month. It was known that small quantities of acetylene or ethylene (found in mine fire gases) would adversely affect the electrochemical cell. Gas chromatographic analyses of gases sampled on the 32d and the 140th days after the fire began showed that ethylene concentration had decreased from about 20 ppm to about 5 ppm.

Therefore, the need still exists to develop and test a CO analyzer that is free of interference in the 0-100 and 0-1,000 ppm ranges, and is sufficiently durable for extended periods of continuous operation (months).

For emergency situations such as the Joanne mine fire, an in situ independent system of gas analysis is highly advisable. This system would serve both as a cross-check and as a substitute during periods of malfunctioning. A process gas chromatograph, capable of analyzing for CO, O_2, CO_2, CH_4, and other hydrocarbons, is recommended as the independent system. The modern instrument is compact and rugged for field use, and sufficiently portable to be moved from the field facility to the laboratory for routine use.

Tube Bundles and Borehole Tubing

The performance of the polyethylene tubing, both single line and multicore bundles, in delivering representative gas samples to the analysis center was excellent. Over 5 months, the tubing was buried, occasionally run over by heavy surface equipment during remote sealing operations, and subjected to winter and summer temperature extremes; no leaks or material failures occurred.

The copper tubing used for the borehole sections of the sampling lines consisted of 50- to 100-foot lengths connected to total 400 to 650 feet per borehole. There was a possibility of leaks at the tubing unions resulting from frequent manual lowering and raising of the tubing during the remote sealing operations. To resolve this possibility, at the end of the project the copper tubing, pulled out of the boreholes but still attached to the polyethylene tubing, was either pressure-tested for leaks or tested for reliable sampling with CO calibration gas. Results of this testing are listed in table 1. As shown, seven of the eight tubes checked were still capable of giving reliable sampling. Of the borehole sampling locations providing data for figures 2 and 4, only the power borehole could not be checked completely for tubing reliability. The tube remained underground and had been extended by EACC to a stopping near the fire origin after the Bureau's contribution to the recovery project ended. However, the plots from the power borehole sampling (fig. 2) are considered reliable because they show very similar results to these from RD4B (fig. 3). Also, during remote sealing using fly ash fluidized with liquid nitrogen and air, the oxygen content at the power borehole was the highest of any place being sampled. The oxygen concentrations fluctuated in direct correlation to the pumping activity.

TABLE 1. - Final status of sampling lines

(July 22, 1974, 189 days after fire began)

Borehole RD	Pressure or CO test[1]	In-mine status[2]
1A	OK with CO	Copper tube only to 6 inches below roof.
1B	.....do	Copper tube only to breakthrough.
2A	No check	Possible leak in borehole section; had been extended to seal.
2B	OK with CO	-
3A	-	Above fly ash seal; removed when sealing.
3B	-	
4A	No check	-
4B	OK with CO	-
5A	.....do	-
5B	.....do	-
6A	OK with CO; water pushed out on pressure test.	-
6B	Leak in line	-
8	No check	Fell down borehole.
Power	.....do	Extended to stopping.
East run air shaft intake.	.....do	-
East run air shaft return.	.....do	-

[1]On pressure tests, used 4 psi air from cylinder at trailer; on CO checks, used calibration gas.

[2]Information obtained from early recovery team communications and reports.

The major defect of the tube sampling from the boreholes was that the tube ends were not centered in the mine entries. This entry location is critical because large concentration gradients exist at the roof of the entry where the borehole ends. Use of a gas probe designed to sample simultaneously at several heights in the entry, plus use of a movable packer in the borehole at roof level, may resolve questions of representative sampling and reduce concentration gradients.

Certainly, it is necessary to know the correct borehole depth and the mine roof and floor elevations, whatever probe design is used. Ordinary tubing alone requires means to keep the tube straight and to have its in-mine portion rigid and unaffected by gas layering. Basic methods and materials presently available could be applied to preparations for future monitoring during emergency or applied research projects.

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