

RI 9399

RI 9399

REPORT OF INVESTIGATIONS/1992

PLEASE DO NOT REMOVE FROM LIBRARY

U.S. Bureau of Mines
Spokane Research Center
E. 315 Montgomery Ave.
Spokane, WA 99207
LIBRARY

Jet Fan Ventilation in Very Deep Cuts—A Preliminary Analysis

**By Gerrit V. R. Goodman, Charles D. Taylor,
and Edward D. Thimons**

LIBRARY
SPOKANE RESEARCH CENTER
RECEIVED

FEB 6 1992

US BUREAU OF MINES
E. 315 MONTGOMERY AVE.
SPOKANE, WA 99207

UNITED STATES DEPARTMENT OF THE INTERIOR



BUREAU OF MINES

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting 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.

Report of Investigations 9399

Jet Fan Ventilation in Very Deep Cuts—A Preliminary Analysis

**By Gerrit V. R. Goodman, Charles D. Taylor,
and Edward D. Thimons**

**UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary**

**BUREAU OF MINES
T S Ary, Director**

Library of Congress Cataloging in Publication Data:

Goodman, Gerrit V. R.

Jet fan ventilation in very deep cuts—a preliminary analysis / by Gerrit V.R. Goodman, Charles D. Taylor, and Edward D. Timons.

p. cm. — (Report of investigations; 9399)

Supt. of Docs. no.: I 28.23:9399.

Includes bibliographical references (p. 12).

1. Mine ventilation—Equipment and supplies—Testing. 2. Fans (Machinery)—Testing. I. Taylor, Charles D. (Charles Darrell), 1946- . II. Timons, Edward D. III. Title. IV. Series: Report of investigations (United States. Bureau of Mines); 9399.

TN23.U43 [TN303] 622 s—dc20 [622'.42] 91-34688 CIP

CONTENTS

	<i>Page</i>
Abstract	1
Introduction	2
Jet fan testing	3
Analysis of jet fan plus flow extender	7
Anemometer surveys	7
Tracer gas surveys	9
Discussion and conclusion	12
References	12

ILLUSTRATIONS

1. Idealized jet flow in entry showing inflow and outflow	2
2. Jet fan gallery showing test setup	3
3. Fan configurations used during testing	4
4. Velocity readings using fan alone	5
5. Velocity readings using fan plus nozzle	5
6. Velocity readings using fan plus injector	6
7. Velocity readings using fan plus extender	7
8. Balanced ventilation network using fan plus extender	8
9. Balanced ventilation network using fan plus extender and check curtain	8
10. Decay curve of initial tracer gas test	9
11. Tracer gas test results	11

TABLE

1. Results of constant flow tracer gas test	10
---	----

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute	L/min	liter per minute
cm ³	cubic centimeter	min	minute
ft	foot	mL	milliliter
ft ³	cubic foot	pct	percent
hp	horsepower	ppm	part per million
in	inch	s	second

JET FAN VENTILATION IN VERY DEEP CUTS—A PRELIMINARY ANALYSIS

By Gerrit V. R. Goodman,¹ Charles D. Taylor,² and Edward D. Thimons³

ABSTRACT

Future coal mining systems will be able to cut from crosscut to crosscut where advances could exceed 100 ft. However, limitations arise when ventilating such mining systems. In deep advance mining, there would be no workers at the face to advance ventilation tubing or curtain manually. Traditional methods also provide no means for maintaining face ventilation after the miner backs away from the face. U.S. Bureau of Mines research is studying means to provide effective ventilation at cut depths beyond the current limit of 40 ft.

Several innovative ventilation schemes are currently being considered. One such method is the use of a jet fan to ventilate a deep cut. A jet fan is simply a freestanding fan using little or no ducting to direct the ventilation flow.

Jet fan testing in a 90-ft entry revealed that higher exit velocities and greater penetration depth occurred when various configurations were used to confine and direct the air flow. Additional testing also indicated that 2,200 cfm of fresh air was delivered to the face 90 ft distant when a check curtain was used to limit entrainment around the fan. Without this curtain, this quantity dropped to only 1,000 cfm.

This testing indicated that a jet fan was capable of providing ventilation to a distant face area. It also highlighted potential problems, such as recirculation at the fan and reentrainment in the jet flow. Despite these potential problems, jet fans may be adequate for ventilating cuts exceeding 40 ft.

¹Mining engineer.

²Industrial hygienist.

³Supervisory physical scientist.

Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

A number of factors have been responsible, in part, for the increasing productivity of continuous mining sections over the past decade (1).⁴ One of these is the increasing use of extended cutting. In extended cutting, the continuous miner advances from 20 to 40 ft, rather than the usual 10 to 20 ft. Distances beyond 40 ft are rare because of limitations of ventilation systems, roof control methods, shuttle car haulage, and operator visibility. Extended cutting results in more time spent in actual mining and less time spent in tramping the miner between entries. However, many questions concerning the safety of extended cutting remain unanswered.

Several ventilation techniques have been used in conjunction with extended cutting systems. These techniques include machine-mounted scrubbers, sprayfan systems, improved sprayfan systems, and extensible line curtains. To date, face ventilation systems for extended cuts have been adaptations of conventional practices, in which tubing or brattice is maintained within 40 ft of the working face.

It is quite likely that the advantages of extended cutting can be enhanced by cutting from crosscut to crosscut where cut depths could exceed 100 ft. Cut depths of this magnitude would require ventilation techniques quite different from existing designs with the ability to supply sufficient quantities of air to remote face areas.

One possible method is to use a jet fan to ventilate very deep cuts. A jet fan is simply a freestanding fan that uses little or no ducting to direct the ventilation flow to the face. In very deep cutting situations, this is a distinct advantage. With any ducted ventilation system, tubing or curtain would have to be handled remotely because there would be no workers near the face area (2).

The jet fan is usually placed on the upstream corner of the last open crosscut. The fan projects a high-velocity jet of air that expands by entraining the surrounding air into its stream. The jet expands until, ideally, the fresh air is flowing to the face in half the crosscut and returning as contaminated air through the other half (fig. 1). Through entrainment of the surrounding air, a jet fan can deliver a volume much greater than its rated capacity. This increased volume improves mixing of the contaminated air. A recent study found that entrainment ratios averaged 4:1; that is, entrained volumes were four times as large as the fan output (3). The total volumetric flow moving to the face was then five times the fan's output.

Jet fans have been used traditionally to ventilate faces in metal-nonmetal operations with large cross-sectional entries. In one instance, a large jet fan (55 in, 100,000 cfm) adequately ventilated a face 300 ft distant (4). In another

instance, a smaller fan (29 in, 20,000 cfm) adequately ventilated a 150-ft heading in a large copper operation (5).

Despite the apparent appeal of jet fans for ventilating faces, a number of questions remain regarding their effectiveness in coal mining operations (2). One concern in jet fan use is the recirculation of contaminated air, which arises when contaminated return air finds its way into the fan inlet. Dust and gas concentrations at the face may not decrease, but may actually increase because the intake air is contaminated (6). Although recirculation of contaminated air is a potentially serious problem, it can be easily controlled by mounting a length of rigid ducting on the fan inlet and pointing this ductwork into the fresh air. Recirculation can also be controlled by extending a check curtain from the jet fan side of the entry to a point midway across the entry and draping it on top of the fan. Either measure ensures that contaminated air is unable to find its way into the fan inlet.

Another concern is the limit of effective ventilation or penetration distance of the jet flow. At this point, the flow ceases to move toward the face and begins to move away from this area. This depth limit depends upon the velocity and integrity of the air jet, that is, the coherence of the jet downwind of the fan outlet. It also depends on the characteristics of the entry, such as its size and roughness. A very rough surface could detach the jet from the rib, thus reducing effective penetration.

Penetration distance of a jet in a large opening increases, however, if the fan is placed against one rib (7). In this configuration, the rib permits the formation of only a half-jet so that the total jet energy acts on only half the jet. Experimental results indicated that the penetration distance was effectively doubled by restricting jet expansion in this manner (8).

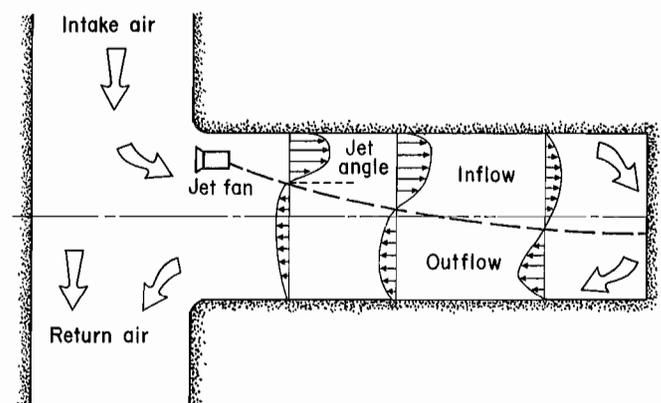


Figure 1.—Idealized jet flow in entry showing inflow and outflow.

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

Previous work has shown that jet fans are well suited for ventilating large entries in metal-nonmetal operations. However, the feasibility of jet fan ventilation in smaller coal mine entries has never been fully investigated. Therefore, the U.S. Bureau of Mines conducted testing to determine if a jet fan could provide adequate ventilation for

very deep cuts in coal mine operations. This testing was seen as the first step toward the development of ventilation schemes compatible with future crosscut-to-crosscut mining systems. This research was performed in support of the Bureau's mission to ensure the continued health and safety of miners.

JET FAN TESTING

Jet fan testing was done in an L-shaped gallery. A 40-hp Joy Series 1000⁵ vane axial fan (23.25 in diameter, 13,500 cfm) was used to pull air into the gallery through two access doors in one end of the building (fig. 2). A curtain was erected to draw this air across the entrance to a 90-ft wing of the building. This wing was 16 ft wide and 7 ft high, and it was used to simulate a blind coal mine heading. Air passing by this heading simulated airflow in a last open crosscut. With the main fan operating, roughly 13,500 cfm flowed into the gallery and then behind the return curtain.

An 18-in-diameter vane axial fan rated at 6,800 cfm was used as the jet fan. Airflow was regulated using an inlet vane controller mounted on the intake of the fan. During testing, the fan was positioned against the left rib in the upstream corner of the last open crosscut to blow into the 90-ft heading. The centerline of the fan outlet was 2 ft off the floor. Various fan and nozzle configurations were

tested to evaluate their effectiveness in ventilating a face 90 ft distant.

Point velocity readings were made during fan testing. These measurements were made at specific locations within the gallery: 10, 30, 50, and 70 ft from the fan outlet and at 2-ft intervals across the width of the gallery. At these locations, readings were taken 2 ft and 6 ft off the floor. The number and location of these readings were necessary to define the complex nature of the jet flow in this 90-ft heading. Digital vane-type anemometers (model AN-8600) manufactured by Material Control, Inc., were used to determine the velocity readings at each point.

The penetration depth and expansion angle of the jet flow were also examined and recorded during testing using smoke tubes. The depth of penetration was the location at which the smoke ceased to move toward the face. The expansion or jet angle was the angle at which the airstream expanded after leaving the fan. It was along this line that considerable mixing occurred between the high-velocity and low-velocity airstreams. Near the fan, outflowing air was entrained into the higher velocity inflowing airstream. At greater distances from the fan, the inflow was entrained into the outflow airstream.

During testing, several different fan configurations were investigated (fig. 3). The first configuration was simply the fan by itself with no tubing or nozzles used. The second was the fan plus a conical nozzle. This nozzle was 16.5 in long with an outlet diameter that was reduced from 18 to 14.5 in. In the third configuration, the fan was positioned to blow into a 10-ft length of 24-in-diameter rigid tubing. The tubing was positioned 12 in downstream from the fan outlet to allow additional air entrainment at the fan outlet. Analysis of this "injector" arrangement using an equal-area pitot tube traverse revealed that the total fan output was increased to 9,300 cfm. This represents nearly a 40-pct increase in volume flow due to entrainment of air into the 24-in-diameter tube.

The final fan configuration was an 18-in-diameter, 48-in-long "flow extender" mounted on the fan outlet. This extender had a set of helical fins welded on the inside to impart a slight spinning action to the airflow.

Flow velocity measurements were made for each of these different fan configurations. In general, flows near

⁵Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

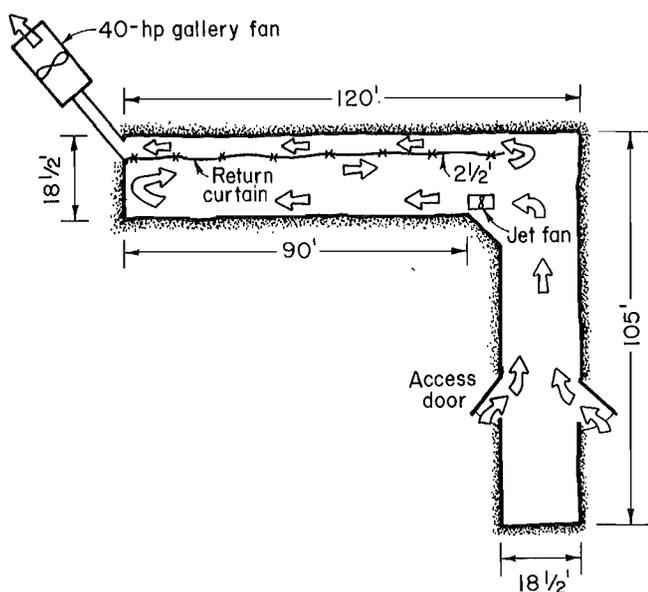


Figure 2.—Jet fan gallery showing test setup.

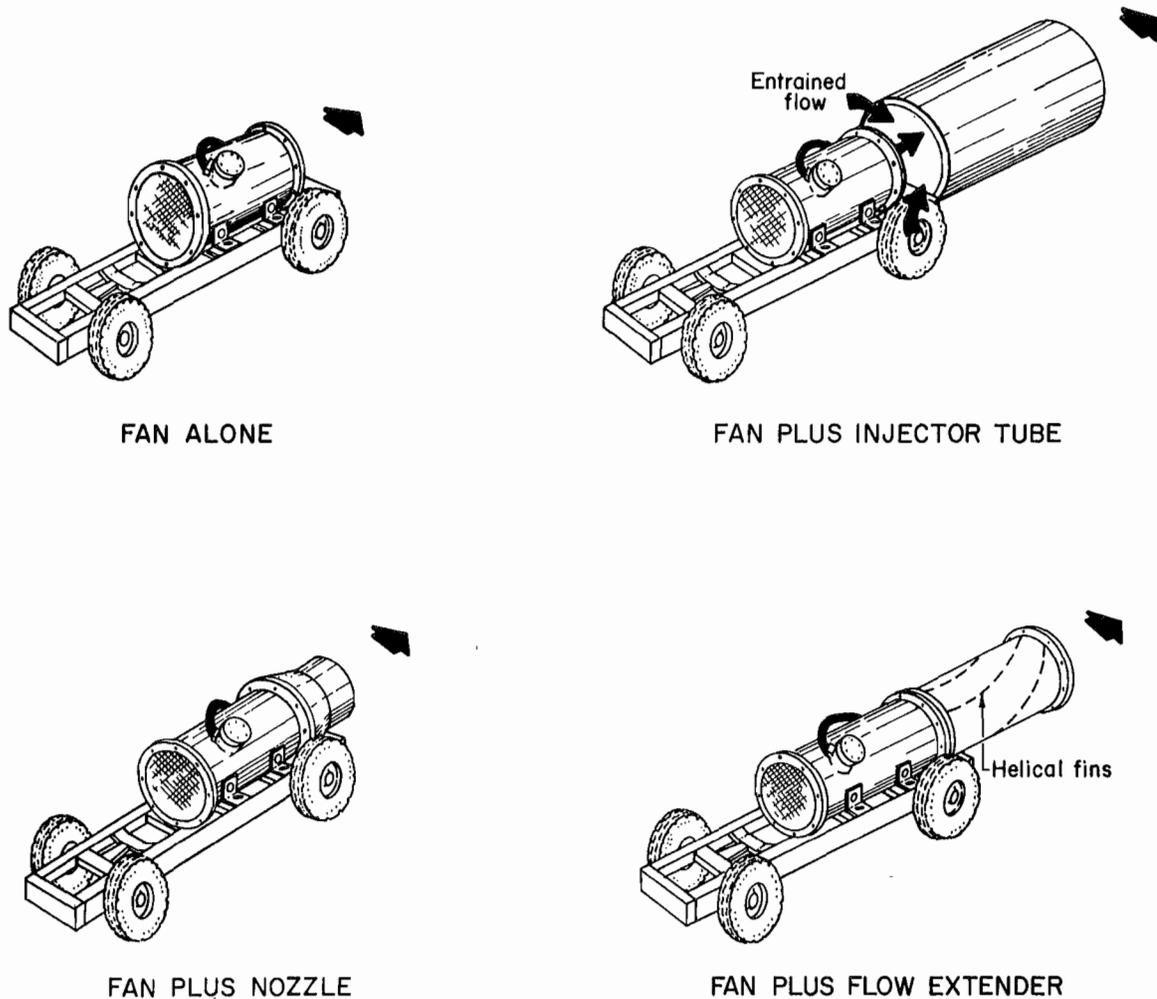


Figure 3.—Fan configurations used during testing.

the fan were much more predictable, with well-defined boundaries between the inflow and outflow airstreams. Beyond a distance of 50 ft from the fan, however, the flow in the heading was extremely erratic, characterized by numerous eddies and airflow reversals.

The data in figure 4 show the velocity readings in the heading when ventilating with the fan alone. The jet angles at various distances from the fan also were also determined from these data. The velocity readings taken near the floor, as opposed to those near the roof, were used to determine jet angle, because the fan was blowing closer to the floor than the roof.

At a distance of 10 ft, the airflow direction changed from inflow to outflow (positive to negative) roughly 5 ft from the rib when using the fan alone. This corresponded to an expansion of 26°. At a distance of 30 ft from the fan, the jet expanded to a width of 14 ft. This corresponded to a jet angle of 25°. At a distance of 50 ft, the jet flow became nonuniform and, hence, very unstable. As

evidenced by the data in figure 4, the jet detached from the rib and began to move into the center of the heading. A "fishtail" flow pattern developed, with return flow forming along the left and right ribs. This resulted in a loss of jet integrity and, hence, a smaller penetration of the heading. Smoke tubes revealed a maximum penetration to approximately 60 ft from the fan.

Flow along the roof of the heading was directed toward the face to a distance of 10 ft. At distances of 30 and 50 ft, the flow at the roof began to move away from the face. The flow at 70 ft was almost nonexistent.

A similar test was conducted using the jet fan plus conical nozzle to ventilate the heading. The results in figure 5 indicate several major differences. The first was the increased coherence of the jet flow as evidenced by the jet angles. At distances of 30 and 50 ft from the fan, the jet angle ranged from 10° to 15°. The smaller jet angle resulted in increased jet velocities at these distances compared with velocities from the fan used alone. At a distance of

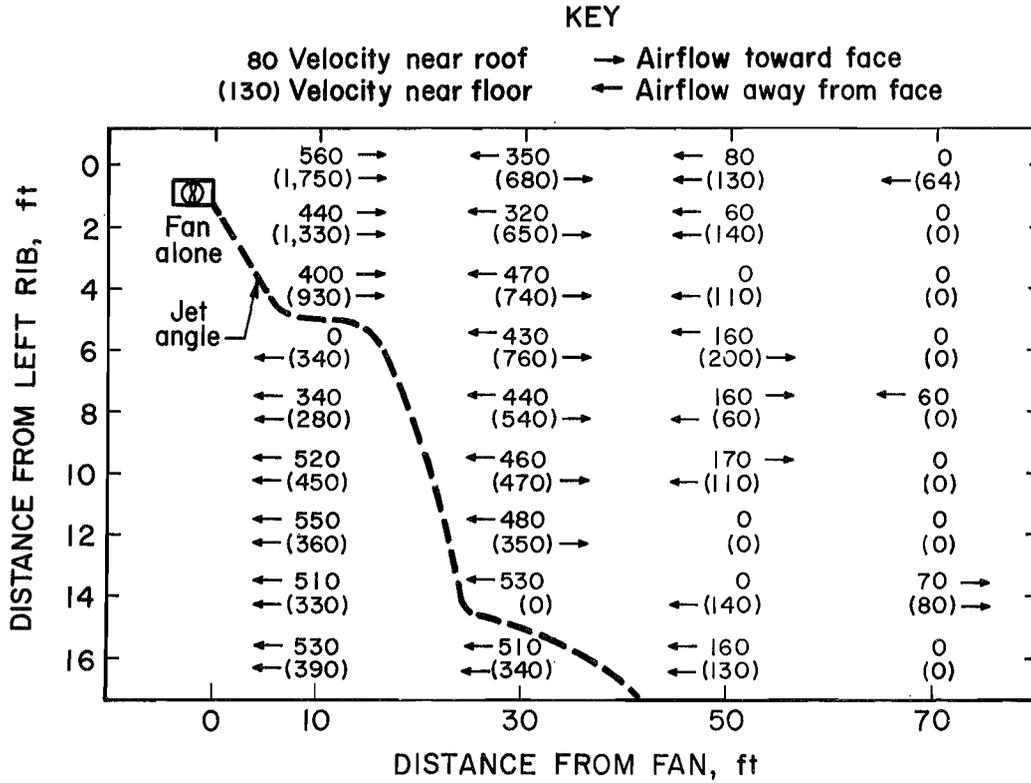


Figure 4.—Velocity readings (feet per minute) using fan alone.

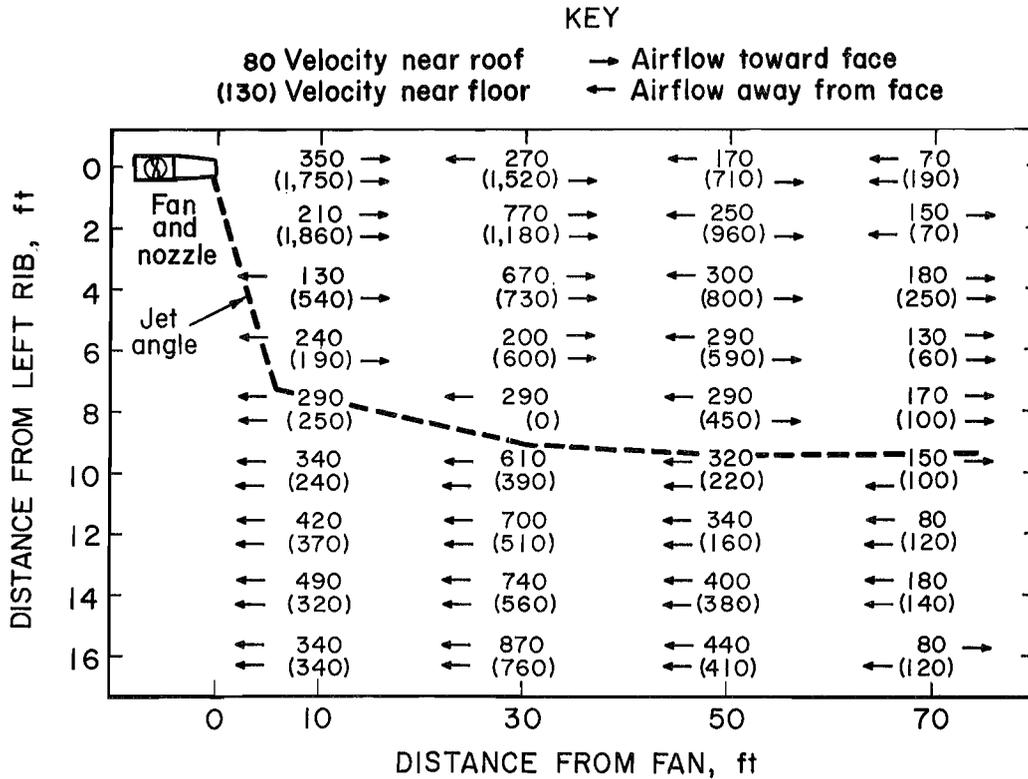


Figure 5.—Velocity readings (feet per minute) using fan plus nozzle.

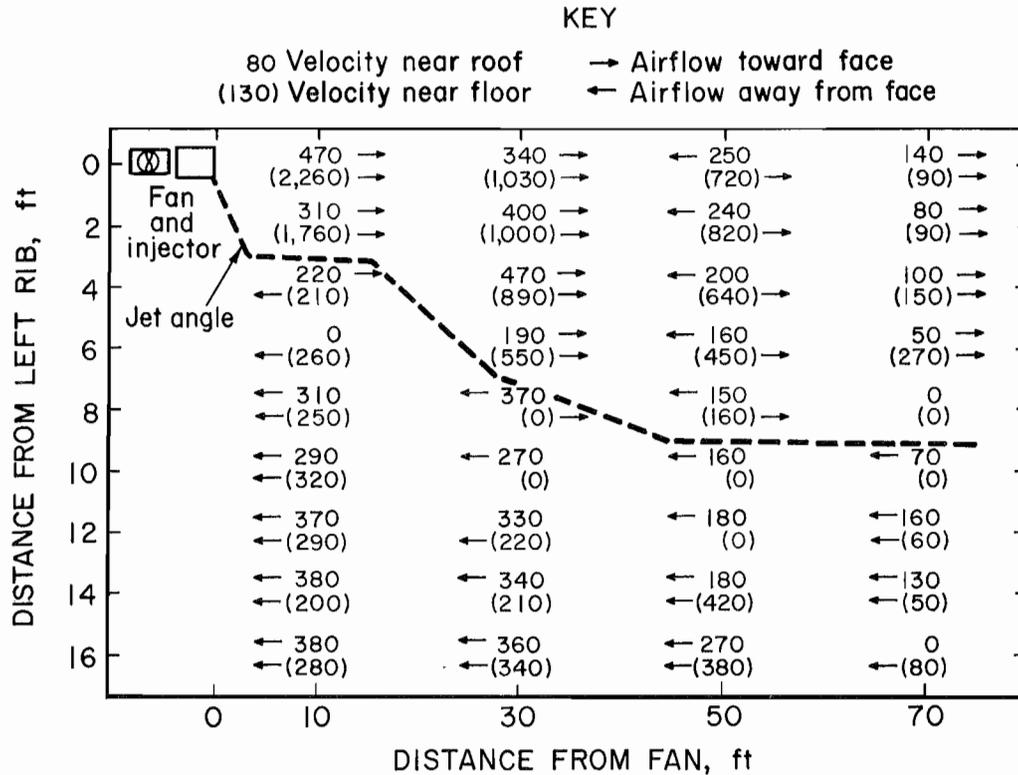


Figure 6.—Velocity readings (feet per minute) using fan plus injector.

70 ft from the fan, the jet flow detached from the rib with the inflow situated in the region 4 to 8 ft from the rib. Outflow was present in the other areas. For this fan combination, penetration was approximately 70 ft from the fan.

For the fan plus conical nozzle, flow along the roof of the gallery extended to 70 ft from the fan. At a distance of 50 ft, the flow reversed and began moving away from the face. At 70 ft, inflow was present at the roof near the center of the heading, with return flow present at the ribs.

Velocity readings were also taken for the jet fan plus injector (fig. 6) and for the fan plus flow extender (fig. 7). The results for both configurations were quite similar and indicated a very well established jet flow, even to depths exceeding 50 ft. Definition of the jet stream led to very high velocities throughout most of the flow regime. The jet angles averaged roughly 13° at depths of 50 ft. Effective penetrations in both cases averaged roughly 50 ft, although a small positive flow was still present at a distance of 70 ft when using the fan plus injector. Using an average penetration distance of 50 ft, this left a 40-ft eddy zone located between the limit of jet penetration and the face area.

The presence of eddy zones in face ventilation has been discussed in detail by Kissell and Bielicki (9). These zones were found to be poorly ventilated, compared with the rest

of the face area, and as such were often characterized by nonuniform airflow.

In the current study, the important factors were limited to jet velocity, jet flow coherence, and penetration depth. Of all the fan configurations investigated, the jet fan without any nozzle exhibited the lowest jet velocities, poorest jet flow coherence, and the smallest penetration. The relatively large jet angle of 23° to 26° led to a rapid extinguishment of the jet flow at distances beyond 50 ft from the fan.

Ventilating the heading with the fan plus conical nozzle produced better results. The improvements most likely arose from the constriction of the airflow at the nozzle. Similar results have been noted by Krause (8), who found that a simple conical nozzle reduced the angle of expansion of the jet stream. Krause also concluded that a jet with a small expansion angle would have a greater penetration than one with a large expansion angle (8). Although these comments were only applied to air jets in very large openings, a similar effect can be seen in these results. When the flow was confined by a nozzle, injector, or flow extender, the penetration depth was increased.

Only small differences in penetration were seen among the nozzle, injector, and flow extender fan configurations despite the increased flow volume from the injector tube.

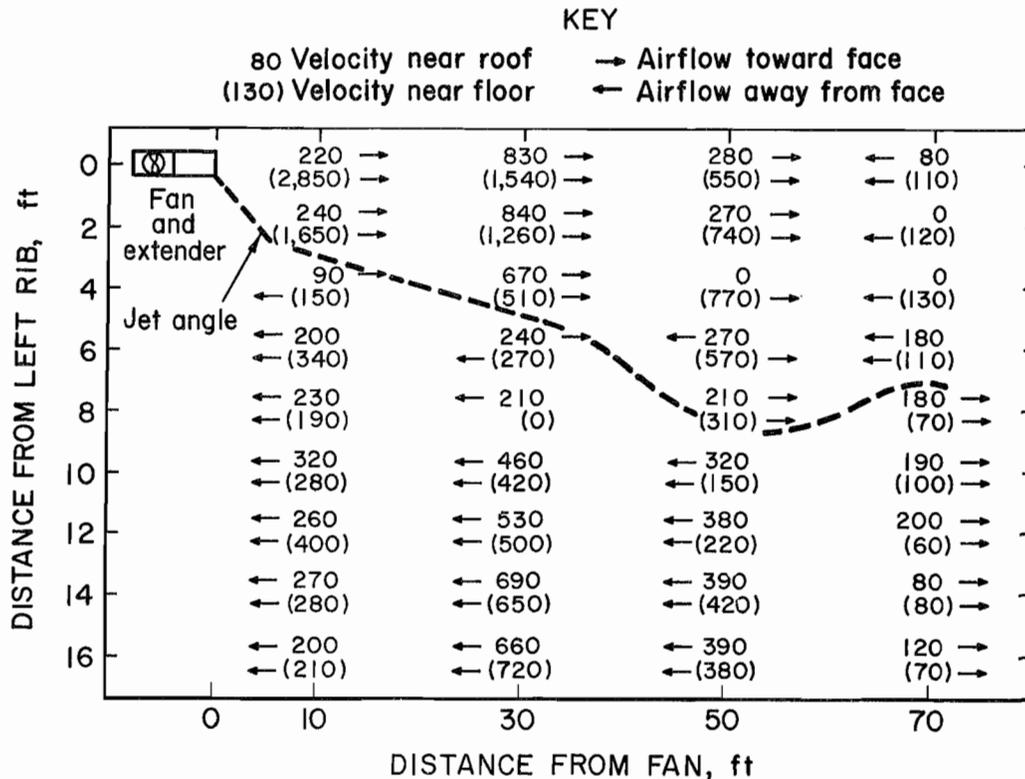


Figure 7.—Velocity readings (feet per minute) using fan plus extender.

A reasonable explanation is that the increased flow from the injector (9,300 cfm) simply increased turbulence in the heading. This turbulence resulted in increased eddying, which decreased penetration depth. This hypothesis was verified by reducing the output volume using the inlet vane controller. While using the fan plus injector and setting the controller to 9,300 cfm, the penetration depth remained about 50 ft. As the flow was reduced to 8,900 cfm and then to 5,600 cfm, the penetration depth did not change appreciably.

To better define the flow patterns in the heading, several additional analyses were conducted. To avoid

repetition, only one fan configuration was selected for these additional tests. The flow extender fan configuration was selected because of its cohesive jet flow. Although the injector configuration performed similarly, this setup was considered to be too cumbersome to use in actual practice.

In the previous series of tests, there were insufficient data to conclude that the helical fins in the flow extender led to cohesive jet flow. It is likely that the characteristics of the jet flow were influenced by both the presence of the helical fins and the confining action of the extender tube.

ANALYSIS OF JET FAN PLUS FLOW EXTENDER

ANEMOMETER SURVEYS

Anemometer traverses were conducted to determine the quantity of air flowing to the face at various distances from the fan. By using smoke tubes, the jet angle could be easily approximated. Traverses were then conducted in both the inflow and outflow jet streams at distances of 10, 30, 50, and 70 ft from the fan. The flow beyond 70 ft was difficult to detect with the instruments. To quantify the amount of recirculation into the fan inlet, readings were

also taken near the inlet. All readings were taken using a standard vane-type anemometer mounted on a slender rod.

Using these anemometer readings, a ventilation circuit was constructed that indicated the average flow at various distances from the fan outlet. The flows in the inflow and outflow jet streams were balanced by introducing entrainment quantities. However, entrainment in the heading was not a point-type phenomenon, but rather a continuous flow of air between the inflow and outflow airstreams.

The balanced network is shown in figure 8A for the flow extender fan configuration. The network indicated that 2,400 cfm reached a distance of 70 ft from the fan. These data also showed that a flow of 20,200 cfm was present at a distance of 10 ft. With the fan rated at 6,800 cfm, this meant that 13,400 cfm came from other sources, namely entrainment of fresh air from the last open crosscut (3,400 cfm) and reentrainment of the flow passing down the return side of the entry (10,000 cfm) as shown in figure 8B. A flow of 3,400 cfm was also recirculated into the fan inlet. At 10 ft from the fan, 10,000 cfm of the 20,200 cfm, or roughly 50 pct, was reentrained

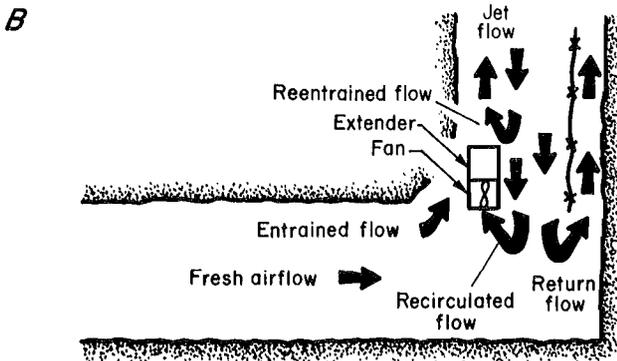
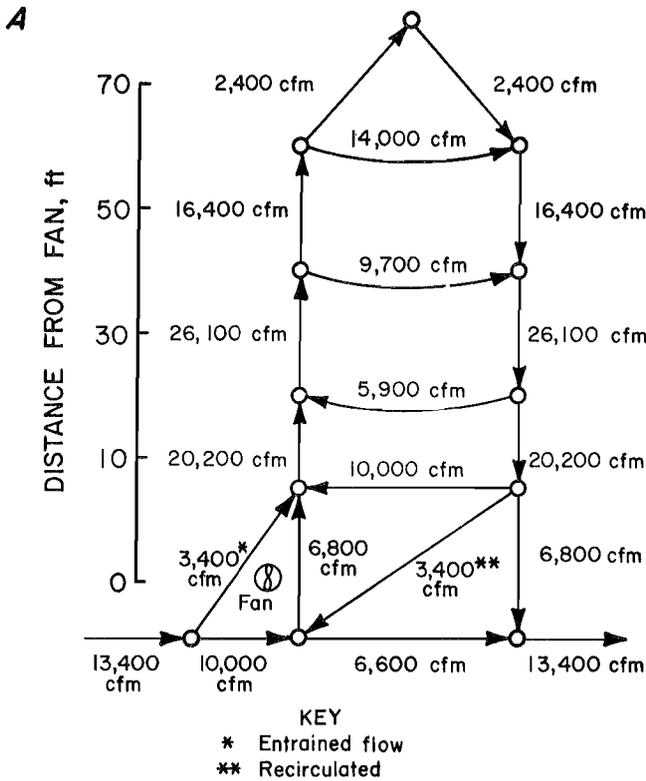


Figure 8.—Balanced ventilation network using fan plus extender. A, Network diagram; B, airflow directions through gallery.

from the return side. At a distance of 30 ft, an additional 5,900 cfm was reentrained. The total reentrained flow of 15,900 cfm represented over 60 pct of the total flow of 26,100 cfm.

As previously explained, a potentially serious problem can arise if recirculation causes contaminated air to enter the fan inlet. To reduce this recirculation, a check curtain was hung from the left rib to a point 8 ft across the heading. It was also draped across the fan housing. The presence of this curtain resulted in dramatic changes in the jet flow (fig. 9A). Although the check curtain eliminated recirculation, it also reduced the quantity of fresh air entrained around the fan and into the jet flow (fig. 9B). It is conceivable that the reduced jet flow simply reduced the eddying in the gallery and, hence, increased the efficiency of the fan to ventilate the face. Figures 8A and 9A show that flow traveled from the outflow side to the inflow side in the first 30 ft. In this region, the lower velocity outflow was entrained by the higher velocity inflow. As the inflow quantity increased, its velocity decreased relative to the

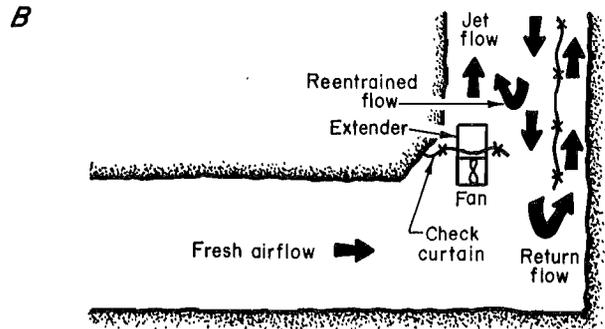
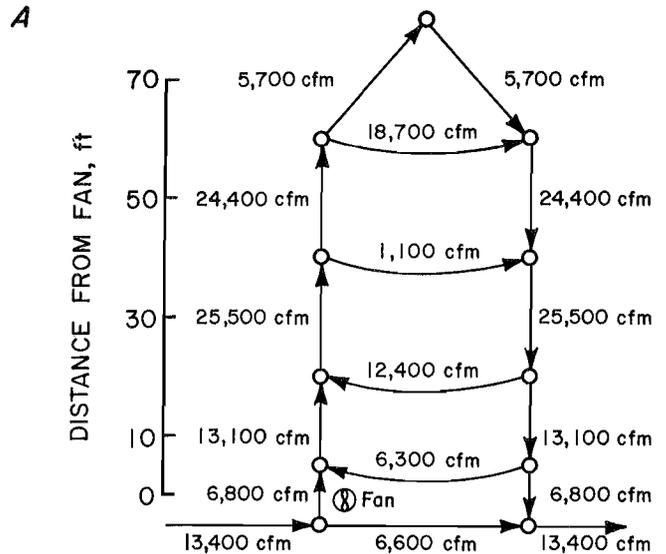


Figure 9.—Balanced ventilation network using fan plus extender and check curtain. A, Network diagram; B, airflow directions through gallery.

outflow side. At depths exceeding 30 ft, the inflow was entrained by the higher velocity outflow, which then proceeded toward the last open crosscut.

Also, the largest quantity of inflow air to the return sides occurred at a distance of 50 ft from the fan. This distance agreed with the initial assessment by researchers regarding the position of the eddy zone. Therefore, it appeared that strong inflow existed to a point roughly 50 ft from the fan outlet. At greater distances, the jet stream was greatly diminished and most likely characterized by weaker, nondirected flow.

These anemometer surveys provided some insight into the flow patterns in the heading. However, because of low and erratic air velocities near the face, tracer gas surveys were conducted to obtain more accurate estimates of these flow quantities.

TRACER GAS SURVEYS

The tracer gas used in this study was sulfur hexafluoride (SF_6). This gas is safe, odorless, not found naturally, and detectable at low concentrations (10^{-3} ppm). To find the effectiveness of a jet in ventilating a known volume, V , SF_6 is released uniformly throughout the volume. It has been shown (10) that the SF_6 concentration, C , at any time, t , decays exponentially as

$$C = C_0 e^{-(Q/V)t}, \quad (1)$$

where Q is the amount of fresh air entering the volume, V , and C_0 is the initial concentration of SF_6 . A plot of concentration versus time on semilog paper gives a straight line with a slope equal to $-Q/V$. The slope is written as the following relationship, where C_1 and C_2 are concentrations along the slope line at t_1 and t_2 .

$$-Q/V = \ln(C_1/C_2)/(t_1 - t_2). \quad (2)$$

Knowing the slope of the best fit line and the volume of the heading, the quantity of fresh air, Q , can be calculated. More complete descriptions of tracer gas studies are found in Thimons and Kissell (10).

For this test, a single sampling line was hung at the face area; the line was positioned in the middle of the heading, 1 ft from the face and 1 ft from the top. To begin the test, 10 cm^3 of SF_6 was released throughout the heading. Uniform mixing was achieved by pulsing the jet fan on and off. Samples were then collected every minute for 3 min from this face location to establish a baseline reading. With the check curtain in place, the jet fan was turned on. Samples were then drawn from this location every 30 s for 5 min. The check curtain was then quickly removed and samples were again drawn every 30 s for 5 min.

Assuming the volume of the gallery to be $10,080 \text{ ft}^3$ (16 by 7 by 90 ft), a uniform release of 10 cm^3 of SF_6 would lead to an initial concentration at the face of 0.035 ppm . This figure closely agrees with the initial values shown in figure 10. These results also reveal that without jet fan operation the decay curve is essentially flat, indicating that very little air reached the face area. When the fan was turned on, the SF_6 concentration decreased, indicating that fresh air was reaching the face area.

The amount of fresh air reaching the face was calculated from equation 2 by multiplying the slope of the semilog plot by the value of $(-V)$. In this case, the volume, V , was the volume of the eddy zone situated between the limit of jet penetration and the face area. The eddy zone was 40 ft deep, 16 ft wide, and 7 ft high, or $4,500 \text{ ft}^3$. Using a slope equal to -0.482 yielded a fresh air quantity, Q , of $2,200 \text{ cfm}$ (fig. 10). This value represented the amount of fresh air moving at this location and not the total airflow. The total flow would undoubtedly be greater because of entrainment.

Five minutes after the fan was turned on (8 min after test start), the curtain was removed. The effects of this action were quickly apparent. Because of increases in recirculation at the fan, the slope of the decay curve

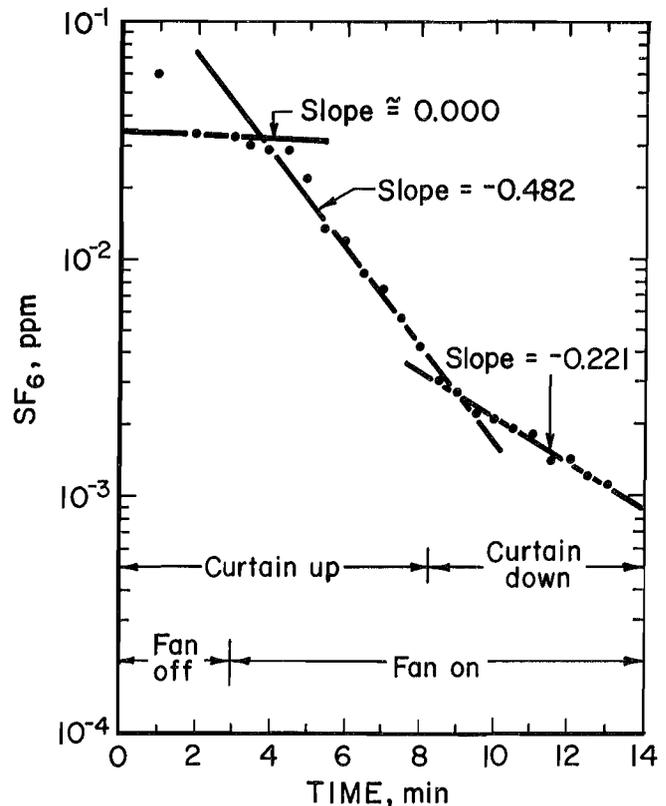


Figure 10.—Decay curve of initial tracer gas test.

decreased to -0.221, showing that less fresh air was reaching the eddy zone at the face. In fact, the amount of fresh air dropped to 1,000 cfm after removing the curtain.

Although this test did provide a preliminary estimate of the airflow reaching the face area, the calculations in equation 2 involved an estimate of the value of the eddy zone volume, V . Because it was not possible to directly measure this volume, further confirmation of its size was necessary.

In this test, SF_6 was released into the gallery at a constant rate while samples were taken at specified time intervals. The concentration, C , measured at any point is equal to the ratio G/Q , where G and Q are the flow rates of SF_6 and fresh air, respectively.

Three sampling lines were hung in the gallery. One line was hung behind the return curtain leading to the main gallery fan. The line was positioned in the middle of the return airstream and 1 ft from the top. The remaining sampling locations were positioned at the face 5 ft from the left rib and 5 ft from the right rib. These lines were hung 1 ft from the face and 1 ft from the roof. Samples were again drawn through these lines at 1.7 L/min and collected in 20-mL evacuated containers.

To begin the test, 1,000 ppm SF_6 was released at the gallery face at a constant flow rate of 0.5 cfm. Samples were taken at the two face locations every 15 min for 60 min with the jet fan off to establish a baseline. With the check curtain in place, the jet fan was then turned on. Samples were taken from all three locations every 15 min for 90 min. The check curtain was then removed with samples again drawn every 15 min for 90 min. The results of the sampling are indicated in figure 11.

To determine the quantity of fresh air reaching the left and right sides of the face area, it was necessary to find the values of G and C at each face location. The value of G was assumed to be constant throughout the test at $(1,000 \times 10^{-6})(0.50 \text{ cfm}) = 500 \times 10^{-6} \text{ cfm}$. The value of C was simply the average concentration at each sample location.

As shown in table 1, the average fresh airflows reaching the face with the curtain up and with the curtain down were 2,000 cfm and 890 cfm, respectively. These average airflows were very close to the values of 2,200 cfm and 1,000 cfm calculated from equation 2. The close agreement of these values affirms that the eddy zone starts about 40 ft from the face. The agreement also suggests that the volume, V , in equation 2 should be the eddy zone volume rather than the total volume of the heading, as reported by Matta, Thimons, and Kissell (5). Using the

total heading volume for the value of V overestimates the amount of fresh air entering that volume.

Table 1.—Results of constant flow tracer gas test
(Gas flow rate, 500×10^{-6} cfm; average return concentration, 0.05 ppm)

Test	Average face concentration, ppm	Fresh air flow rate, cfm	FVE
Curtain up:			
Left side	2.58	200	0.02
Right side13	3,800	.38
Average		2,000	.20
Curtain down:			
Left side	3.00	170	.02
Right side32	1,600	.16
Average		890	.09
FVE	Face ventilation effectiveness.		

During this final testing, several trends became apparent. First, the presence of the check curtain across the fan had a measurable effect on the quantity of fresh air reaching the face area. This finding was consistent with results from the initial tracer gas survey. Second, there was considerable variation in the airflow along the face, where the right (off-fan) side was much better ventilated than the left (fan) side. This variation indicates that the jet flow detached from the left rib and moved to the right side of the face. The fan side of the face received significantly less fresh air than the off-fan side.

Although this testing was conducted without any in-place mining equipment, it is possible that the airflow imbalance would also be present at the face area during cutting. In this case, the left side of the face could experience dangerous gas concentrations. Therefore, sprayfan and scrubber systems must be designed to hold the jet stream along the fan-side rib until it reaches the face. Testing will be necessary to determine the proper capacity and orientation of these sprayfan and scrubber systems.

Jet fan effectiveness can be assessed by measuring the quantity of fresh air reaching the face area. However, a more desirable means is to calculate the face ventilation effectiveness (FVE). FVE is the ratio of the gas concentration in the return to the concentration at the face. From the last tracer gas test, the average return concentration was 0.05 ppm SF_6 (fig. 11). Using the average face concentrations given in table 1, the FVE values were calculated. These values also reveal the imbalance in airflow at the face area, with the right side better ventilated (higher FVE) than the left side (lower FVE).

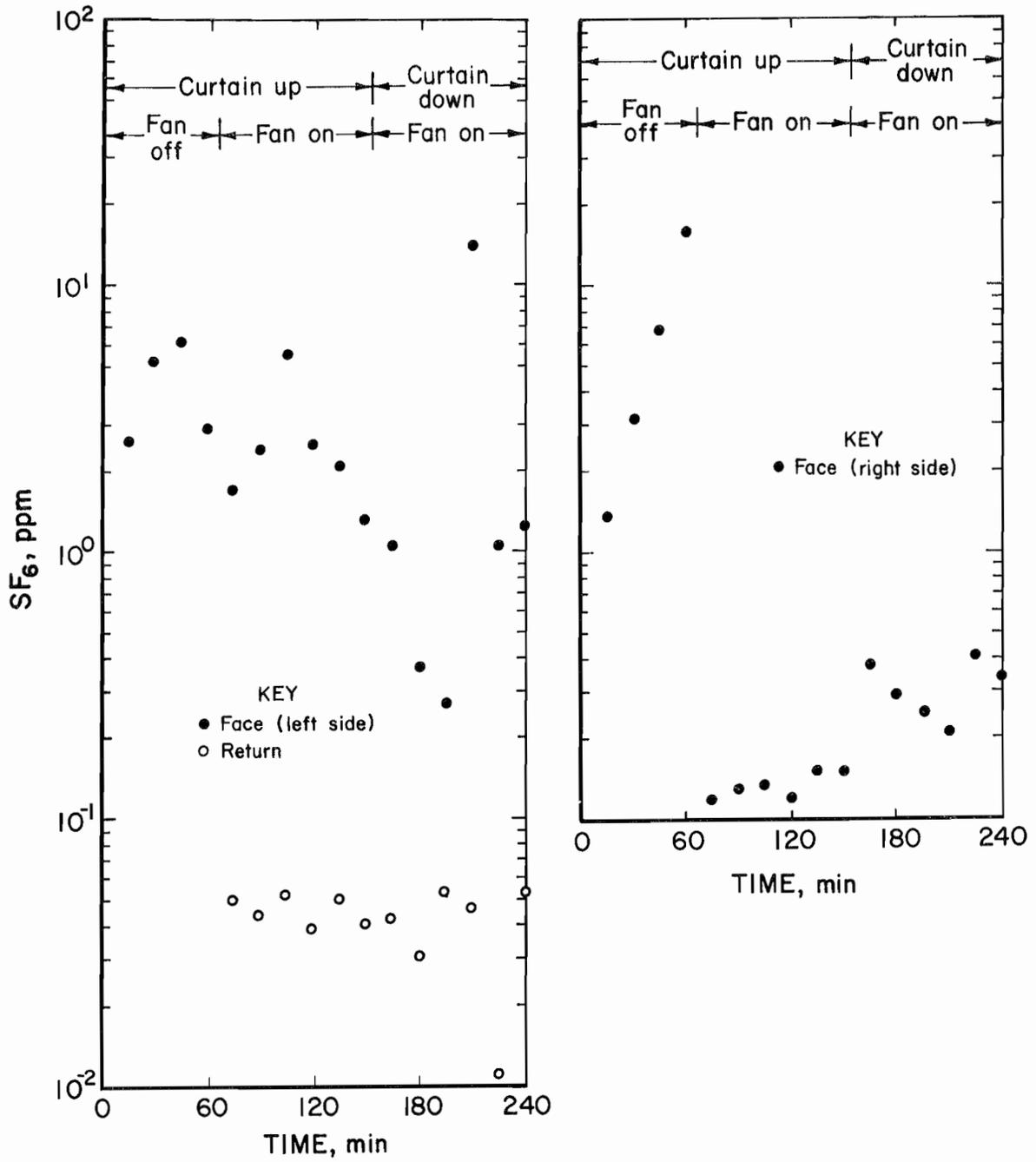


Figure 11.—Tracer gas test results.

DISCUSSION AND CONCLUSION

This report describes research by the Bureau to define and characterize the flow in a 90-ft heading ventilated by a jet fan. Several fan configurations were investigated: a fan without any ductwork, a fan plus conical nozzle, a fan plus 10-ft injector tube, and a fan plus 4-ft flow extender.

First, digital anemometers were used to determine point velocities at various locations throughout the test gallery. The results indicate that the highest jet velocities arose when using the fan plus flow extender. This configuration translated into a more cohesive jet stream and greater penetration depth. Jet angles averaged 13° at a depth of 50 ft from the fan. Measurable penetration was roughly 70 ft. In general, fan configurations using some type of constrictive device on the fan outlet exhibited more confined jet flows, lower jet angles, higher jet velocities, and greater penetrations. In contrast, the jet fan without any ductwork resulted in a jet angle of 25° at 30 ft and a penetration of only 60 ft.

Tracer gas was then used to provide detailed information on the flow characteristics in the jet stream. The fan plus flow extender was selected for this test. To improve flow conditions near the face area, a check curtain was installed over the jet fan. Then, samples were taken of the flows with and without the check curtain. Calculations made using samples taken with the curtain up showed that 2,200 cfm of fresh air was delivered to the face area 90 ft

from the fan. With the curtain removed, the fresh airflow at the face was reduced to 1,000 cfm.

Although this test did provide an indication of the fresh air quantity flowing to the face, the calculations relied upon a volume value that was not independently confirmed. Thus, another SF₆ test was conducted to verify its size. The results of this test confirmed the initial finding that this volume, or eddy zone, began 40 ft from the face. From these data, face ventilation effectiveness values also were calculated. These values revealed that the right side of the face was better ventilated than the left side. This indicated that the jet flow possibly detached from the left rib before hitting the right side of the face.

This testing has revealed that a jet fan may be feasible for ventilating cut depths greater than 40 ft. The results indicated that an average of 2,000 cfm existed at a depth of 90 ft from the fan. Although this is less than the 3,000-cfm minimum required by Federal law, greater quantities were found closer to the fan. This fan configuration, although not presently suitable for 90-ft cuts, would likely be effective in cut depths less than 90 ft.

The feasibility of jet fan ventilation may be improved through the presence of in-place equipment. It is likely that machine-mounted scrubbers or sprayfans would force the jet stream against the fan-side rib, enabling it to sweep the face. Such effects will be studied in future investigations.

REFERENCES

1. Suboleski, S. C., and R. H. King. Estimating Technology's Impact on Underground Coal Productivity. *Min. Eng.* (Littleton, CO), v. 42, 1990, pp. 1159-1164.
2. Goodman, G. V. R., C. D. Taylor, and E. F. Divers. Ventilation Schemes Permit Deep Advance. *Coal Mag.*, v. 95, Oct. 1990, pp. 50-53.
3. Dunn, M. F., F. S. Kendorski, M. O. Rahim, and A. Mukherjee. Testing Jet Fans in Metal/Nonmetal Mines With Large Cross-Sectional Airways (contract J0318015, Engineer's International, Inc.). BuMines OFR 106-84, 1983, 132 pp.; NTIS PB 84-196393.
4. Thimons, E. D., C. E. Brechtel, M. E. Adam, and J. F. T. Agapito. Face Ventilation for Oil Shale Mining. BuMines IC 9118, 1986, 22 pp.
5. Matta, J. E., E. D. Thimons, and F. N. Kissell. Jet Fan Effectiveness as Measured With SF₆ Tracer Gas. BuMines RI 8310, 1978, 14 pp.
6. Campbell, J. A. L. The Recirculation Hoax. Paper in Proceedings of Third U.S. Mine Ventilation Symposium. PA State Univ., University Park, PA, 1987, pp. 24-29.
7. McElroy, G. E. The Role of Air Jets In Mine Ventilation. *Trans. AIME*, v. 163, 1945, pp. 399-414.
8. Krause, D. Free Jets in Auxiliary Ventilation. *Neue Bergbautech.*, v. 2, No. 1, 1972, pp. 44-52.
9. Kissell, F. N., and R. J. Bielicki. Ventilation Eddy Zones at a Model Coal Mine Working Face. BuMines RI 7991, 1974, 14 pp.
10. Thimons, E. D., and F. N. Kissell. Tracer Gas as an Aid in Mine Ventilation Analysis. BuMines RI 7917, 1974, 17 pp.