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Impact of Using Auxiliary Fans on Coal Mine Ventilation Efficiency and Cost

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

\$/yr	dollar per year	m^2	square meter
h	hour	m^3/s	cubic meter per second
h/d	hour per day	Ns^2/m^8	Newton second^2 per meter^8
kg/m^3	kilogram per cubic meter	Pa	Pascal
kW	kilowatt	pct	percent
m	meter		

IMPACT OF USING AUXILIARY FANS ON COAL MINE VENTILATION EFFICIENCY AND COST

By Keith G. Wallace, Jr.,[1] Malcolm J. McPherson,[2] Dan J. Brunner,[3] and Fred N. Kissell[4]

ABSTRACT

Coal mine ventilation systems are often subject to high leakage rates. As a result, changes in airflow resistance will strongly affect the efficiency with which air is delivered to the working place. One major source of airflow resistance is the line brattice used to direct air from the last open crosscut to the working face. Because it is a great distance from the fan, the resistance of the line brattice can result in more overall leakage than an equivalent resistance closer to the fan.

Substituting auxiliary fans for brattice eliminates this source of resistance, with improvements in system efficiency and cost. Also, in some mines, the leakage that leads to spontaneous combustion can be reduced. The benefits obtained by several different brattice and fan substitutions have been studied by Mine Ventilation Services, Inc., Lafayette, CA, under contract to the U.S. Bureau of Mines. Changes in main fan duty were compared with additional costs associated with auxiliary fans. Results indicate that in some circumstances, considerable leakage reductions and cost savings are possible.

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INTRODUCTION

The mine ventilation engineer usually thinks of airflow resistance as occurring somewhere between the surface and the working place. However, in coal mines line brattices also create resistance, which can affect overall system efficiency in a manner similar to that of any other system resistance. Line brattice resistance can be removed by substituting auxiliary fans, but little research has been done to determine whether such a substitution is beneficial from an overall system cost and efficiency standpoint, especially considering the extra costs associated with purchasing and operating auxiliary fans.

This U.S. Bureau of Mines funded study was conducted in two phases: (1) a preliminary underground test in a longwall development during which line brattice was alternately tightened and loosened to gauge the effect on section airflow, and (2) a computer simulation of an entire mine in which various auxiliary fan configurations were substituted for brattice lines and the resulting impact on system efficiency and cost calculated.

PRELIMINARY UNDERGROUND TEST

The test site (fig. 1) was a longwall development panel consisting of two parallel airways approximately 820 m long. Average cross-sectional area was 13.7 m^2. The only obstruction in either airway was a conveyor belt in the return. Twenty-five crosscuts connected the intake and return. Of these, the 2 closest to the face had check curtains, and the remaining 23 were sealed with woodblock or masonry stoppings. All appeared to be in good condition.

Pressure drops and air quantities were measured throughout the panel for three situations. In the first situation, very well constructed brattice lines were placed in the development ends and last open crosscut. In the second situation, the brattice was in the last open crosscut loosened to a leaky condition, representing a practical situation that would exist with a shuttle car traveling in the crosscut. In the third situation, the brattice in the last open crosscut was removed for a very short period of time to allow a direct short circuit of air. This simulated an auxiliary fan and duct system since the pressure to move air to the face would then be supplied by the auxiliary fan.

Equipment for the surveys consisted of a calibrated medium speed Davis[5] anemometer, calibrated Dwyer magnehelic gages, and flexible tubing. Airflows were measured by anemometer traverse.

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

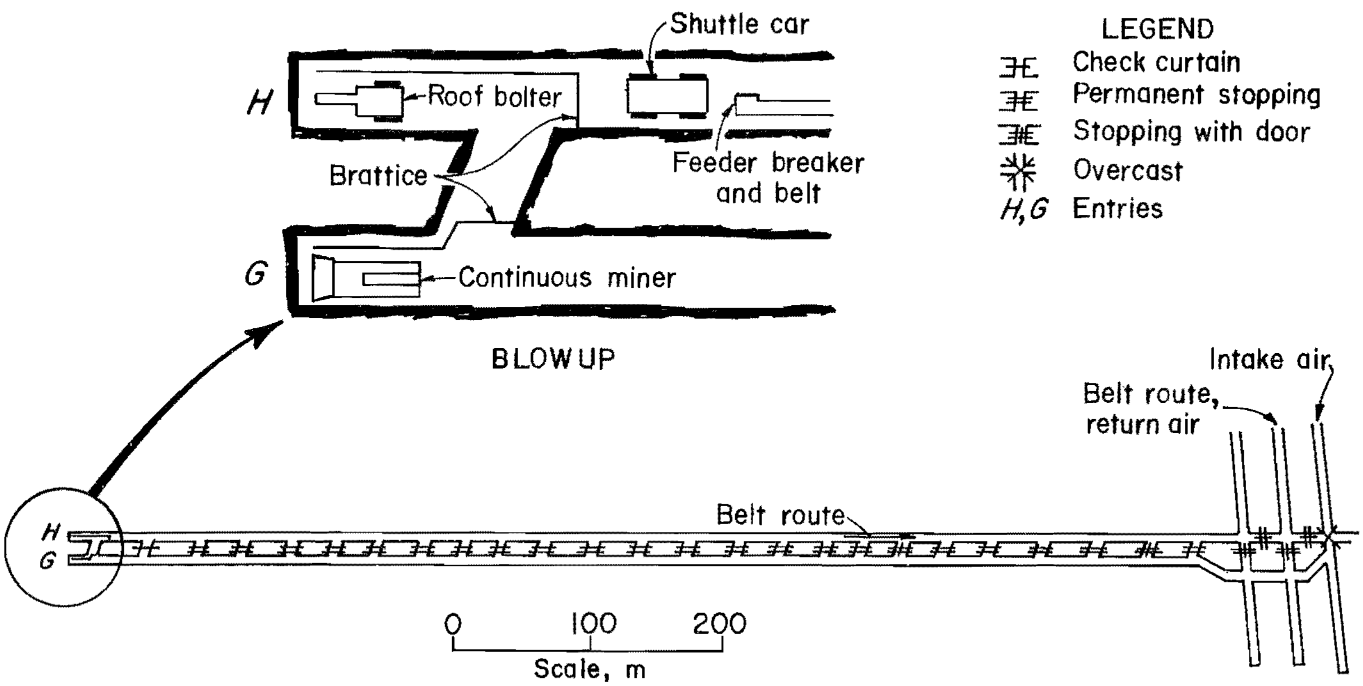

Figure 1.–Development panel.

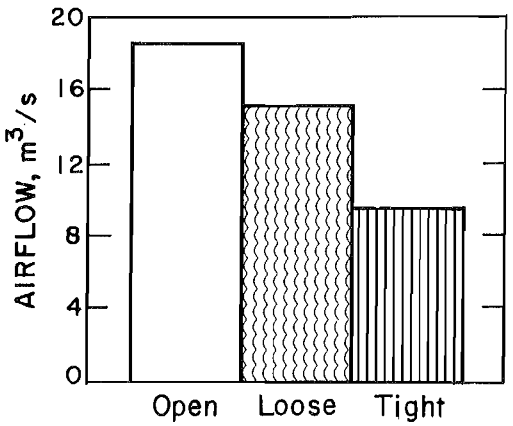

Figure 2.–Airflow reaching last crosscut for each brattice conditions.

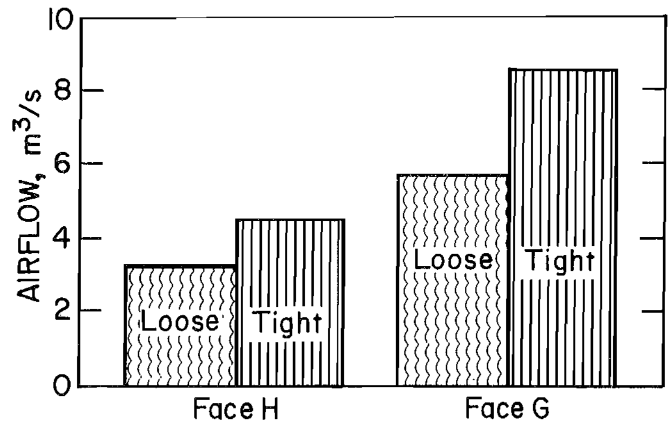

Figure 3.–Airflow reaching faces G and H for loose and tight brattice conditions.

Table 1.–Ventilation data from preliminary underground test

	Brattice condition		
	Open	Loose	Tight
Airflow entering panel at outby end .... m^3/s ..	25.5	24.8	21.0
Airflow reaching last open crosscut .... m^3/s ..	19.0	15.0	9.5
Total leakage through all stoppings .... m^3/s ..	6.5	9.8	11.5
Pressure drop across outby end of panel .... Pa ..	55	70	90
Pressure drop across last open crosscut .... Pa ..	2	25	60
Airflow volumetric efficiency of the panel[1] .... pct ..	75	63	44

[1]Air at last open crosscut divided by air entering panel.

Survey results for the three situations are shown in figures 2 and 3, and in table 1. Changing brattice resistance by loosening it or temporarily removing it substantially increased the amount of air reaching the last open crosscut. Part of this increase came from more air entering the panel, the other part was from reduced leakage stopping within the panel (table 1). Not surprisingly, these same changes (loosening the brattice) reduced the amount of air reaching the face (fig. 3). Other changes in volumetric efficiency, airflow, and resistance are shown in table 1.

These results, particularly the large increase in airflow at the last open crosscut, indicated that continued investigation was worthwhile. In the second phase, a computer network model was used to simulate the ventilation system of the entire mine.

VENTILATION NETWORK MODEL

Network modeling was performed by using a modified schematic of an existing mine that provided for eight room-and-pillar panels in various stages of advance. Six face ventilation schemes were applied to all eight panels of the network and analyzed using the computer program VNET ventilation network analysis program developed by Mine Ventilation Services, Inc. The results from each analysis provided the airflow distribution, the required operating pressures, the ventilating efficiency, and the main fan operating costs.

For a complete cost estimate, the amount of line brattice and/or auxiliary fans and ducting was also determined for each ventilation scheme. Current prices and average lifetimes were then used to construct a capital cash-flow for each alternative over 12 years. After accounting for the depreciation of the auxiliary fans, the operating costs were added to produce a net cash-flow for each alternative. These cash-flows were analyzed on the basis of net present value to obtain an overall cost comparison. For all fans, the cost of power was assumed to be 4.0 cents per kilowatt hour, and the overall efficiency of the main fan was assumed to be 70 pct. Auxiliary fans were assumed to be 7.5 kW each and operate 16 h/d.

SYSTEM EVALUATION

Three basic systems and three alternative systems were evaluated by network modeling. (For the alternative systems, see the appendix.)

Basic System 1 - six headings, all with tight, well-constructed brattice and minimum leakage; brattice-to-rib distance of 0.56 m.
Basic System 2 - six headings, five with loose leaky brattice and one with tight, well-constructed brattice; 0.56 m to rib.
Basic System 3 - six headings, five with loose leaky brattice and one with an auxiliary fan; 0.56 m to rib.

Figure 4 shows a typical panel. Entries were taken as 7.62 m wide by 2.13 m high. The pillars were assumed square at 7.62 by 7.62 m. Each six heading panel confined intake air to two entries by stoppings constructed in the crosscuts. Each panel was represented in network form and incorporated into the basic mine network. For all of the analyses, the airways were assigned a friction factor of 0.0121 kg/m^3; masonry stoppings and check curtains were assigned resistances of 400 and 4.0 Ns^2/m^8, respectively. These are typical values for coal mines.

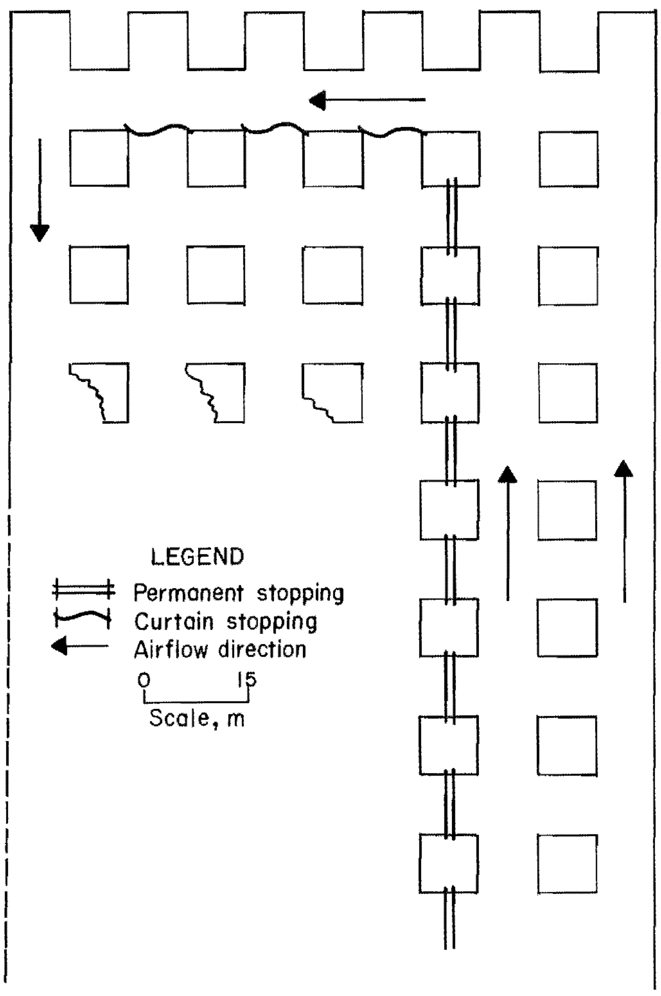

Figure 4.-Scale diagram of one room-and-pillar panel added to network.

SYSTEM 1-ALL TIGHT BRATTICES

The representative room-and-pillar panel, with the brattice lines and stoppings, is shown in figure 5. This panel was represented in the model by the network representation on the right in figure 5. For modeling purposes, three of the entries were represented by a single branch C, D, and E. In addition, the flow path around the brattice line in each heading was modeled in parallel with a leakage flow path through that brattice line. The paths were represented by branches that appear as a last open crosscut in the network representation.

Figure 5 also indicates the airflow criterion used as an indicator of acceptable ventilation. The value indicated (4.3 m^3/s) is the minimum allowable airflow along the last open crosscut. This criterion remained the same for each system analyzed. Thus, differences in systems resulted from differences in resistance values.

In system 1, the value for the brattice line resistance was 0.336 Ns^2/m^8. This was the average resistance of tight, well-constructed brattice lines as determined in the preliminary underground test. It is a combined resistance of the leakage flow path in parallel with the path leading the air around the brattice. The latter corresponds to a brattice to rib distance of 0.56 m.

Results from the VNET analysis are shown in figure 6 and table 2.

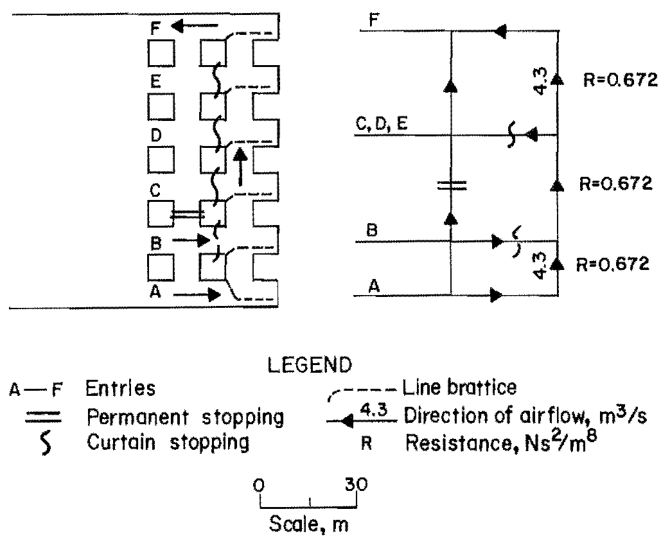

Figure 5.-Scale drawing and network respresentation of line brattice, system 1.

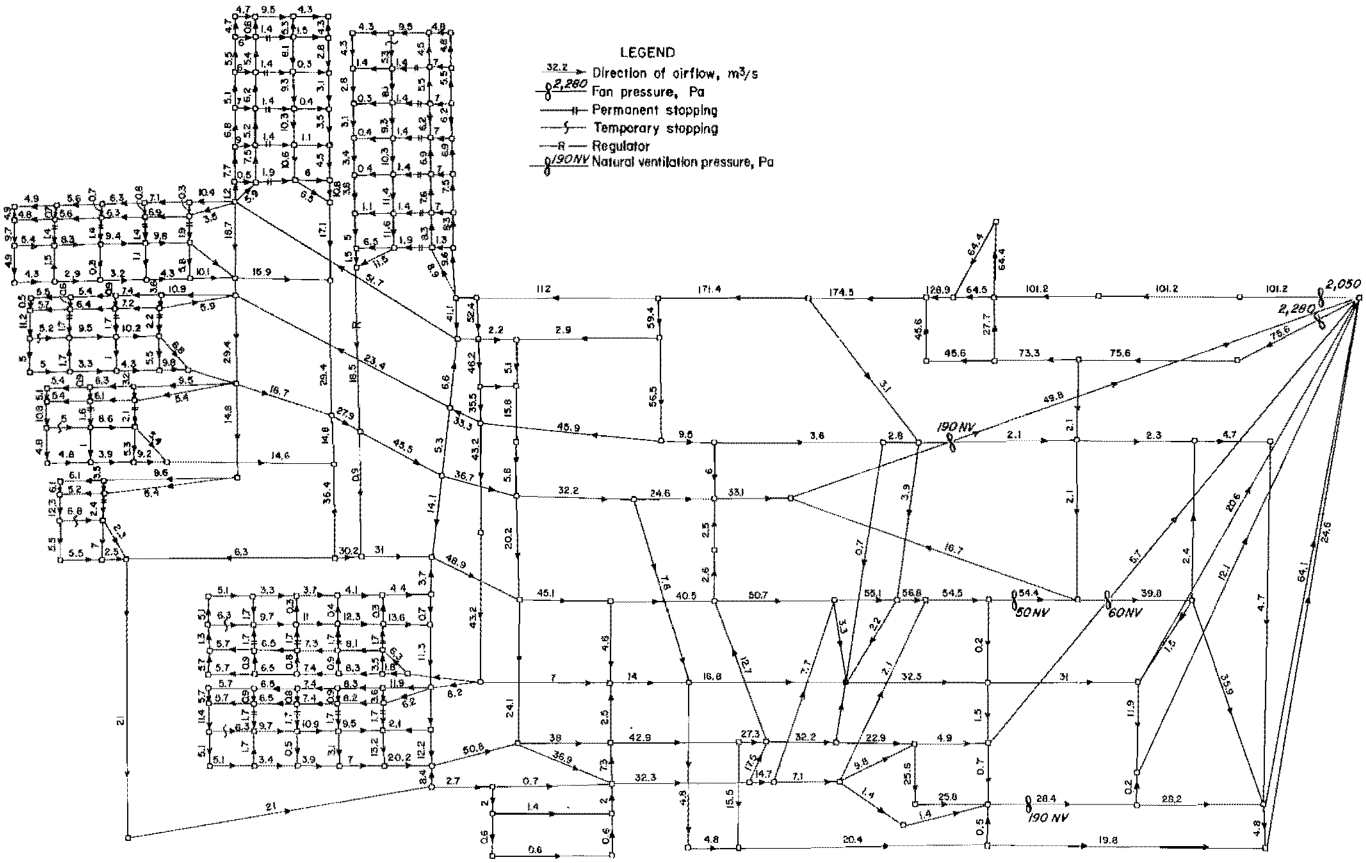

Figure 6.–Detailed network schematic, system 1, airflows in cubic meters per second and fan pressures in pascals.

Table 2.–Operating points and costs tabulated with ventilation efficiency for each basic multiple-heading ventilation system

System designation and type	Total airflow in mine, m^3/s	Sum of the 2 main fan pressures, Pa	Operating costs, $/yr Main fans	Aux. fans	Total	Ventilation efficiency, pct
1–Tight brattice, far rib	176.81	4,330	190,139	0	190,139	48.6
2–5 leaky brattice, 1 tight	113.44	1,730	48,670	0	48,670	59.4
3–1 auxiliary, 5 leaky brattice ..	84.15	940	19,962	9,600	29,562	62.4

SYSTEM 2–FIVE LEAKY BRATTICES, ONE TIGHT BRATTICE

This multiple-heading ventilation system assumes that only one active heading requires a tight brattice line, whereas the remaining rooms have loosely hung leaky brattices. In the preliminary underground test, the average resistance of loosely hung brattice was 0.0548 Ns^2/m^8. This value was used for five headings. The tight brattice resistance (0.336 Ns^2/m^8) was used for one heading.

The panel and its network representation is shown as figure 7. Main fan pressures were modified in a series of VNET simulations until the desired airflows in the last open crosscut (4.3 m^3/s) were achieved. With this system, the required face airflow of 1.4 m^3/s is attained in the heading with the tight brattice line. For the other headings containing the loose brattice, data from the preliminary underground study indicated that the percentage of air reaching the face from the last open crosscut ranged from 13 to 20 pct (fig. 3).

Results from the VNET analysis are shown in table 2. Ventilation efficiency is higher and operating costs much lower than system 1.

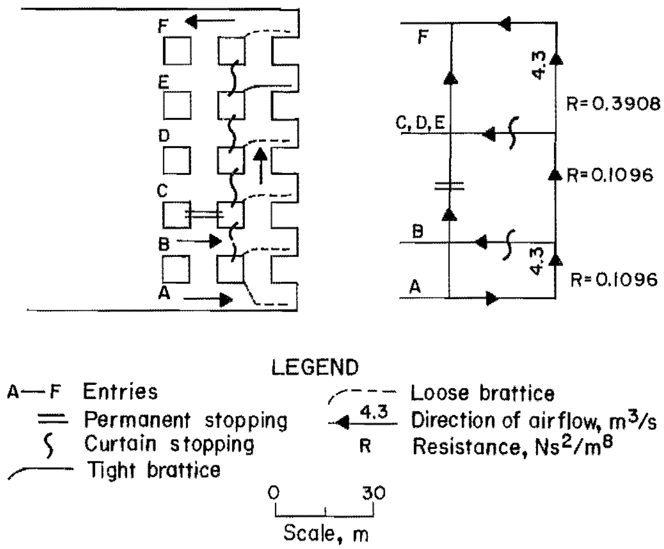

Figure 7.–Scale drawing and network representation of five loose, one tight, brattice line scheme (system 2).

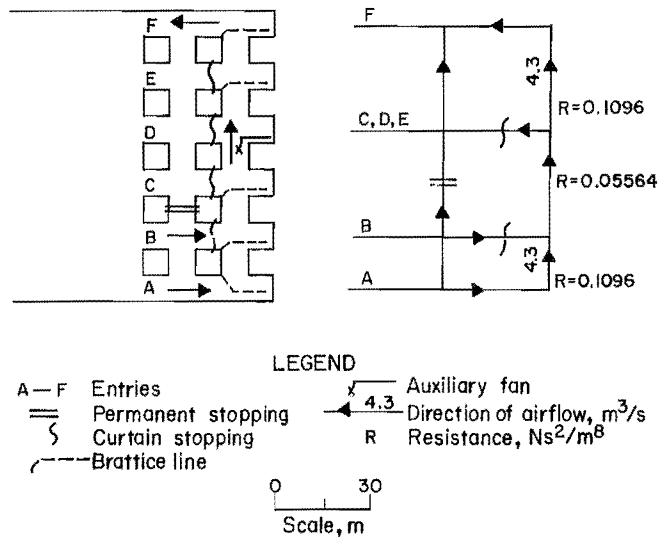

Figure 8.–Scale drawing and network representation of five loose brattice, one auxiliary fan scheme (system 3).

SYSTEM 3–FIVE LEAKY BRATTICES, ONE AUXILIARY FAN

Of the six headings in system 3, five are inactive and ventilated by loosely hung brattices, while one active heading is ventilated by an auxiliary fan and duct system. The panel and its network representation are shown in figure 8. Airflow requirements were the same. Resistance of each loosely hung brattice was 0.548 Ns^2/m^8 as before. For the heading with the auxiliary fan, the brattice resistance was replaced by the resistance of a short length of airway. VNET analysis results are shown in table 2. Ventilation efficiency is slightly higher than for system 2, and operating costs are lower, despite the extra cost associated with the auxiliary fan.

ANALYSIS AND CONCLUSIONS

Tightening a line brattice will reduce its leakage and improve the proportion of air diverted from the crosscut to the face. However, for the mine simulated, the high resistances produced at the faces caused increased leakage across permanent stoppings, doors, and old workings throughout the mine. This resulted in higher fan airflows and pressures which, when combined with replacement costs of brattice and reduced to net present value, produced high total costs (see system 1). Face resistance may be reduced by loosening brattice as shown in system 2, but it would be impractical for a mine operator to alternately tighten and loosen brattice to keep a high airflow at the face being mined and a low resistance at the others. System 3, on the other hand, is a practical alternative that gives a high face airflow as well as a substantial cost reduction for the mine simulated.

Although these cost savings are substantial for the simulated mine, it is difficult to generalize them for mines as a whole. The mine used was representative of many coal mines, however, since ventilation leakage characteristics vary widely, the degree of cost saving will also vary. Also, in mines with a greater brattice-to-rib distance, the impact of substituting auxiliary fans will be less.

Substituting auxiliary fans for brattice can also boost the amount of air available at the last open crosscut. Although it is not a permanent solution for mines that lack appropriate fan capacity and shafts, it may be a good way to alleviate some short-term problems. If the quantity of air at each last open crosscut is not to be changed, then substituting auxiliary fans for brattice may permit lower ventilating pressures (see table 2), which in turn reduces spontaneous combustion hazards. As with cost, the effectiveness of either will depend on the ventilation characteristics of the specific mine.

If the mine ventilation network has been established on a computer, these questions can be answered. If not, a simple alternative is to conduct a test similar to our preliminary underground test in which brattice was tightened and loosened and the resulting airflow changes measured. If the change in crosscut airflow is similar to that shown between tight and loose in figure 2, then using auxiliary fans probably is beneficial. Removing brattices, even temporarily, to simulate the open condition is not recommended because of the hazard of methane accumulations.

APPENDIX.–ALTERNATIVE SYSTEMS

The three alternative systems are variations on the basic systems. System A-1 is similar to system 1 with only the brattice to rib distance changed. In system A-1, the gap was reduced to 0.43 m causing the resistance to increase from 0.336 to 0.47 Ns^2/m^8.

System A-2 is a variation of the auxiliary fan system 3 and is shown as figure A-1. This auxiliary system is an approach that makes use of independent intake and return crosscuts. Fresh air is drawn from the intake crosscut to each of the six headings via an independent fan and duct system. In the model, duct branches were assigned fixed airflow quantities of 1.4 m^3/s and only the resistances of the intake and return crosscuts were considered. During the VNET runs, main fan pressures were altered until the amount of air flowing past the last fan and duct system in the intake crosscut was 2.8 m^3/s. The cost calculation assumed 48 auxiliary fans (six fans per panel times eight panels).

System A-3 is also a variation of system 3, in which the single fan and five brattices of system 3 are all replaced by six auxiliary fans (fig. A-2). With a fan and duct in each heading, it could be called a series auxiliary system. Like the other systems with auxiliary fans, the heading resistance is negated by the auxiliary fan so that the only resistance used in the VNET simulation is that of the last open crosscut.

Results for the alternative systems are shown in table A-1. For system A-1, moving the brattice closer to the rib results in a 50 pct increase in operating costs when compared with system 1 in table 1. Such a large cost increase was unexpected. The auxiliary parallel system A-2 gave a ventilation effficiency of 74.4 pct, the highest of any of those investigated; however, operating costs are high. This is due to the need to operate six auxiliary fans plus the need to maintain sufficient air in the intake crosscut to provide 1.4 m^3/s for each fan and also to ensure that at least 2.8 m^3/s flows past the last fan and duct system; all of the foregoing represent a total of 11.2 m^3/s. The series auxiliary system A-3 is slightly less efficient than the parallel system, because system A-3 uses one crosscut instead of two, and therefore has a slightly higher resistance. However, since only 4.3 m^3/s is required at the last open crosscut (a feature of all of the series systems), the operating costs for the main fan were the lowest of any of those investigated. The drawback of system A-3 is that it requires the operation of six auxiliary fans on each section.

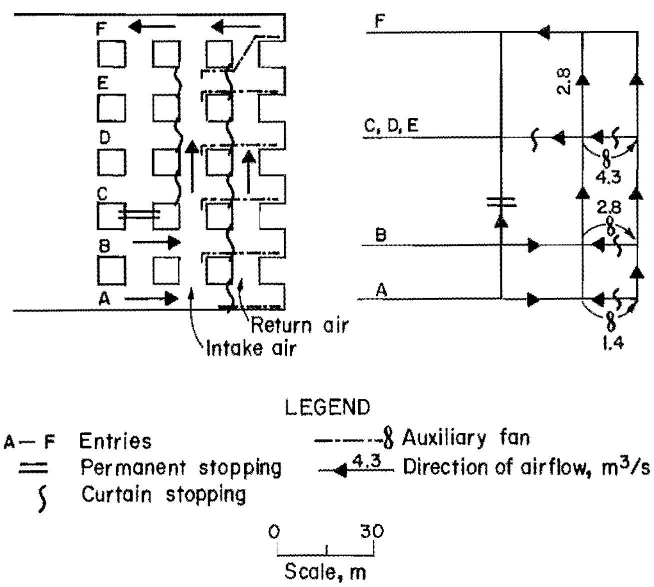

Figure A-1.–Scale drawing and network representation of parallel auxiliary scheme (system A-2).

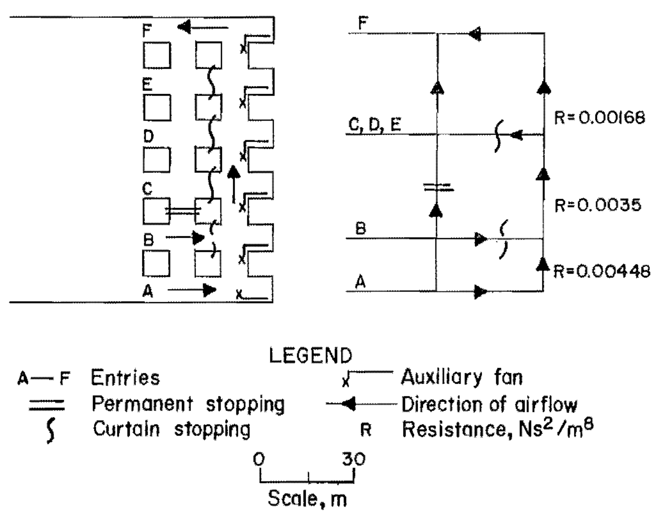

Figure A-2.–Scale drawing and network representation of series auxiliary system (system A-3).

Table A-1.–Operating points and costs tabulated with ventilation efficiency for each alternative multiple-heading ventilation system

System designation and type	Total airflow in mine, m^3/s	Sum of the 2 main fan pressures, Pa	Operating costs, $/yr			Ventilation efficiency, pct
			Main fans	Aux. fans	Total	
A-1–Tight brattice, close rib	207.6	6,045	312,192	0	312,192	45.5
A-2–Auxiliary parallel	119.1	1,870	55,166	57,600	112,766	74.4
A-3–Auxiliary series	55.01	400	6,036	57,600	63,636	72.1

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