MEASUREMENTS AND SIMULATIONS OF FACE VENTILATION EFFECTIVENESS FOR LARGE DIESEL EQUIPMENT

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ABSTRACT

Providing adequate airflow to effectively dilute and remove diesel pollutants in large mine working headings is a little researched area. A simulated diesel mucking operation was carried out in the Exxon Colony Pilot Mine in Colorado to establish expected levels of diesel pollutants in dead-ended working headings. This heading was nominally 50 ft wide by 30 ft high. Two face ventilation systems were tested using sulfur hexafluoride tracer gas to represent the diesel pollutants. The results of these tests showed that conventional face ventilation systems operating at high flow rates could adequately ventilate diesel equipment in the 600- to 700-hp range, even in a 300-ft-long dead heading.

INTRODUCTION

Ventilation of diesel exhaust at the face of a room-and-pillar oil shale mine was expected to be a difficult problem because of the large room dimensions and because the very high horsepower engines required to power the equipment produce large amounts of air pollutants. Conventional air moving equipment was capable of supplying the quantities of fresh air necessary to dilute the exhaust; however, at the projected flow rates, little was known about the effects of room size or large-scale turbulence on mixing efficiency and ventilation effectiveness. Studies of ventilation flow in large underground excavations by Bossard[3] had shown the existence of flow and temperature stratification, both of which had the potential to reduce ventilation effectiveness.

A project was initiated to develop large-capacity face ventilation systems and to characterize their ventilation performance in full-scale tests at an oil shale mine. Studies of pollutant mixing and dilutions were performed at Exxon's Colony Pilot Mine using existing face ventilation equipment and a 600- to 700-hp loader and haul truck to provide a full-scale simulation of mucking in a dead-end face heading. The data provided information on the degree of temperature and pollutant stratification that would occur, and were used for design guidelines. The performance of two candidate face ventilation systems was later characterized using sulfur hexafluoride tracer gas released to simulate various types of mine pollutant production.

FULL-SCALE SIMULATION AND MONITORING OF THE MUCKING OPERATION

The full-scale mucking simulation was performed using old diesel equipment not well suited for underground operations because of the equipment's high emission rates. The Huff-400C loader and Wabco 35-st-capacity truck were powered by direct injected Cummins VT-1710 engines. The pollutant levels measured were not representative of operations using prechamber engines designed and configured for underground use. The data are therefore normalized to peak concentrations in the presentation to show relative effects rather than actual levels of pollutants. Care was taken during the tests to avoid exposing personnel to time-weighted-average limits for the various pollutants.

The objective of the simulation was to provide data in the following areas:

Distribution of pollutant concentrations throughout the dead-end heading to indicate mixing uniformity.

Evaluation of the degree of pollutant stratification.

Evaluation of the degree of temperature stratification.

Confirmation of the expected fresh air capacity required for the particular engines operating.

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[3] Bossard, F.C., and J. LeFever. Designing an Oilshale Mine Ventilation System (Pres. at Soc. Min. Eng. AIME Fall Meeting and Exhibit, Salt Lake City, UT, Oct. 19-21, 1983). Soc. Min. Eng. AIME preprint 83-367, 1983, 23 pp.

A dead-end heading in the Colony Pilot Mine was set up for the mucking simulation, as shown in figure 1. The test room was nominally 50 ft wide by 30 ft high, and contained a pile of stored oil shale that previously had been mined and stacked to a height of roughly 10 ft. Ventilation air was carried to the face area in a 60-in-diameter, collapsible ventilation tube hung along the roof, at a nominal flow rate of 72,000 ft^3/min.

The truck and loader were positioned at the face of the stored muck, as indicated by the test room layout, and the loader worked to move muck from side to side in a manner that would simulate both loader movement and engine load in an actual operation. The loaded truck was cycled in and out of the test room to simulate the arrival and loading of a fleet of trucks, with an average cycle time of 7.9 min.

The concentration of gaseous pollutants was measured using process instrumentation at sections 90, 140, and 190, as shown in figure 1, with samples drawn at heights of 5, 15, and 25 ft above the floor. Samples were drawn through a 1/4-in plastic tube, whose inlet was moved from station to station and elevated above the floor using a tripod-mounted surveyor's rod. Particulates were sampled at stations D3 and D4 using cascade impactors mounted 5 and 12 ft above the floor.

Concentrations of gaseous pollutants (CO, CO_2, NO_x, and NO) increased rapidly at the beginning of each test, and then settled to relatively constant values throughout the remainder of the tests. Figures 2 through 5 show time versus concentration data (normalized to the peak value measured) for separate tests with the truck engine shut down during loading and idling during loading. Individual data points are grouped by height above the floor, but are the results of measurements throughout the plan area of the test room. There was no correlation between concentration and plan location in the test room. Data points represent the average concentration for roughly 1-min intervals after allowing the instruments to stabilize at the new level of concentration, and indicate uniform mixing throughout the room.

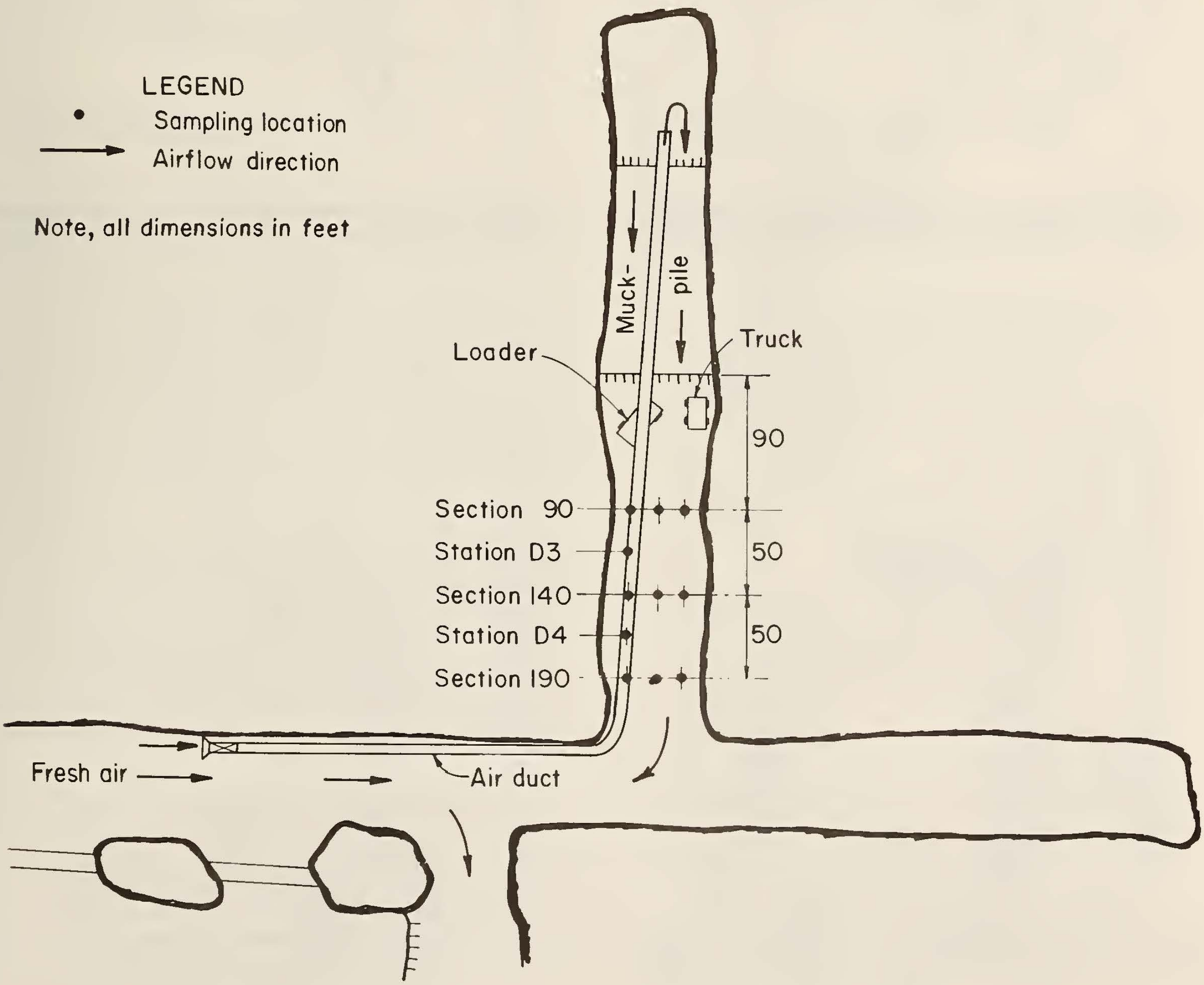

Figure 1.—Schematic of crosscut showing the location of the truck and loader with respect to sampling sections 90, 140, and 190 ft from the muckpile.

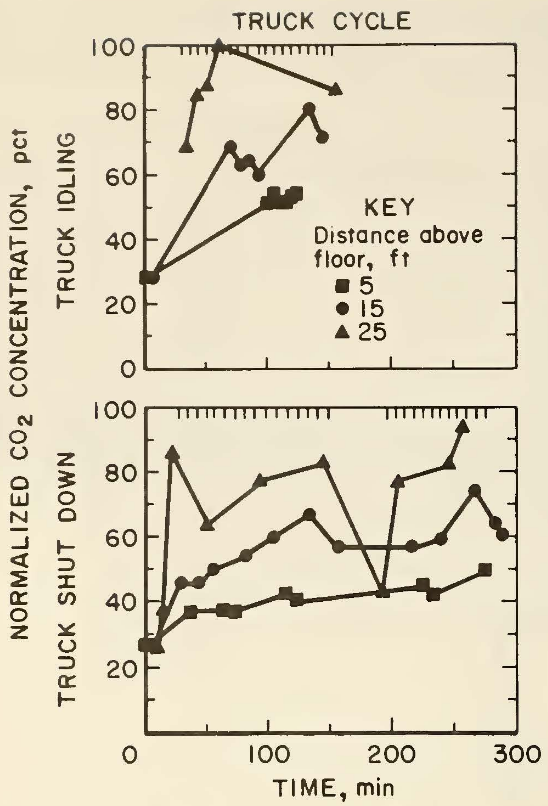

Figure 2.—Concentrations of CO_2 normalized to peak measured value versus time during simulated mucking operations.

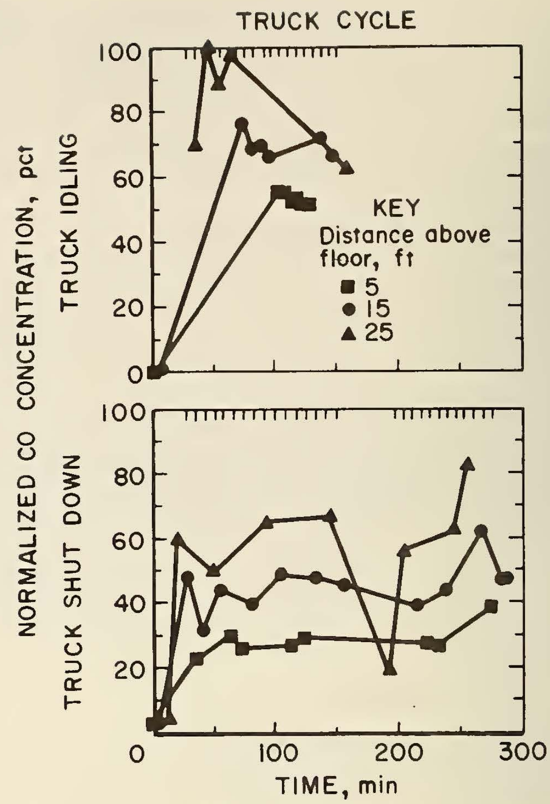

Figure 3.—Concentrations of CO normalized to peak measured value versus time during simulated mucking operations.

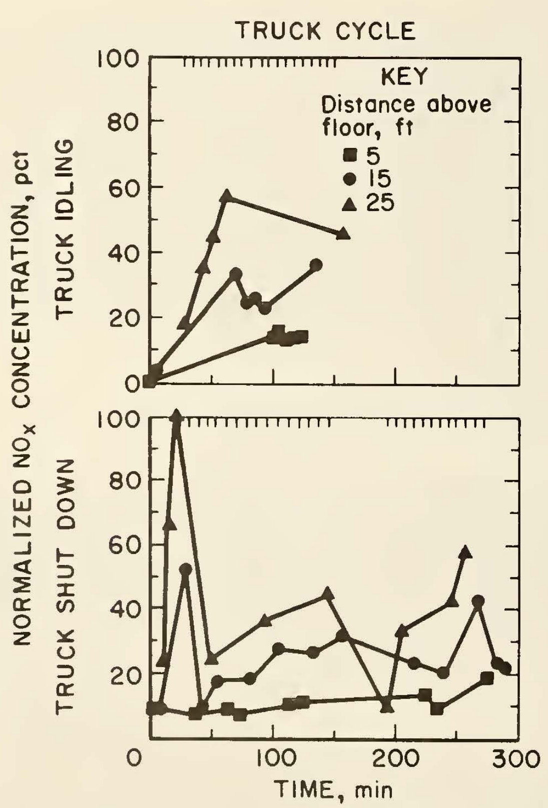

Figure 4.—Concentrations of NO_x normalized to peak measured value versus time during simulated mucking operations.

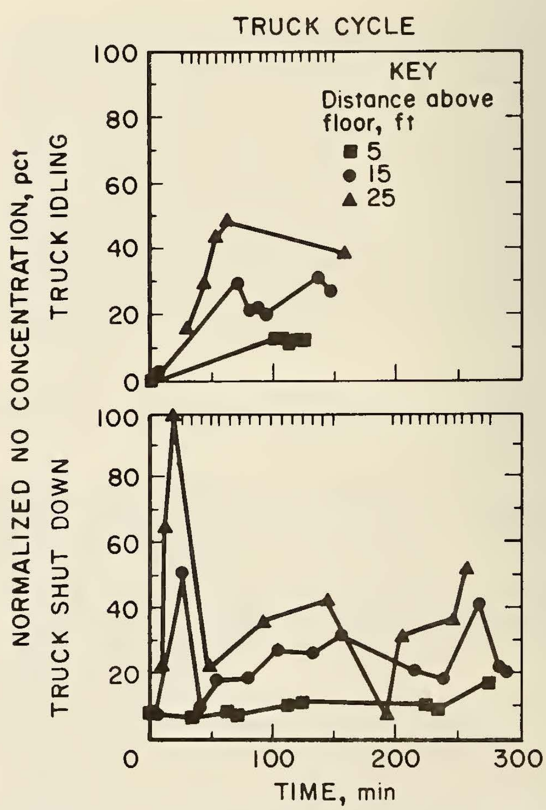

Figure 5.—Concentrations of NO normalized to peak measured value versus time during simulated mucking operations.

Vertical stratification of the pollutants because of the density difference between ventilation air and the hot exhaust was clearly shown by the data in figures 2 through 5. Table 1 lists the time-weighted-average (TWA) concentrations, normalized to the highest TWA value for each pollutant to provide a relative measure of the stratification. Concentrations at 5 ft above the floor varied between 28 and 64 pct of the concentrations measured at 25 ft above the floor. The normalized TWA values indicated that leaving the truck idling during loading increased the pollutant levels.

Table 1. — Relative difference in TWA concentration at various heights

Height above floor, ft	Normalized conc × 100,[1] pct	
	Truck shut down	Truck idling
CO_2:		
25	72	100
15	48	64
5	22	42
CO:		
25	68	100
15	55	84
5	36	64
NO_x:		
25	75	100
15	52	57
5	23	28
NO:		
25	82	100
15	56	58
5	24	28

[1]Normalized to peak TWA value.

Stratification of diesel particulates because of the buoyancy of the hot exhaust was also observed. The concentration of diesel particulates (aerodynamic particle diameters less than 0.69 μm) at 5 ft above the floor were 66 pct of the concentration measured at 12 ft above the floor.

The air temperature was also measured throughout the room to establish the degree of temperature stratification. The data are presented in figure 6, using a format similar to the concentration data. Time-weighted-average temperature for the steady-state portions of the data are listed in table 2 for sections 90, 140, and 190, and indicate that temperatures at 28 ft above the floor averaged 3.9° F higher than at 10 ft above the floor, because of stratification of the hot exhaust.

The data indicated that thermally induced stratification of the pollutants acted to enhance face ventilation effectiveness. Pollutants tended to be transported at higher concentrations near the roof, thereby reducing the concentration at lower heights where personnel were exposed. Mixing was uniform throughout the plan area of the room, indicating that ventilation flow rates sufficient to dilute the diesel fumes would also provide sufficient turbulence in full-size operations.

Table 2. — TWA temperatures during loading, degrees Fahrenheit

Height above floor, ft	Section 90	Section 140	Section 190
10	52.7	52.0	52.0
20	54.7	56.0	55.0
25	56.3	57.5	57.1
28	55.6	56.0	56.7

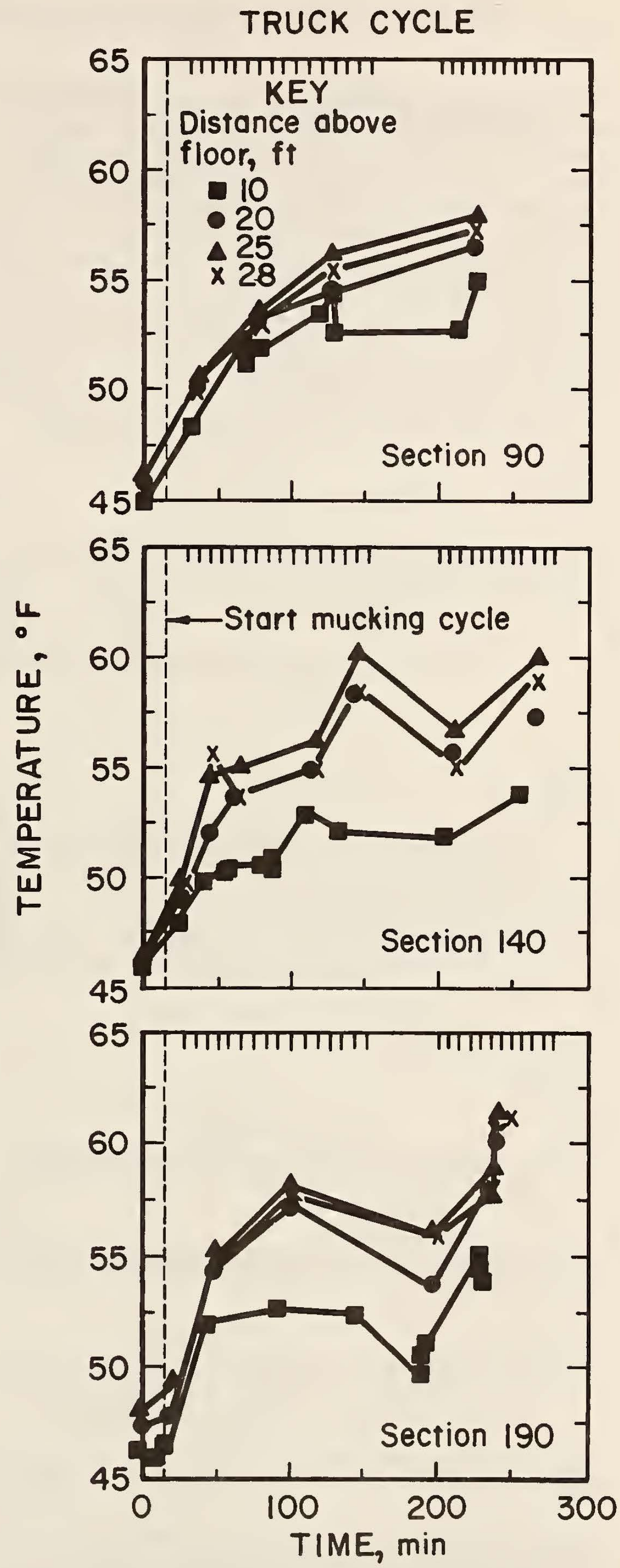

Figure 6.—Temperature versus time during the mucking simulation.

TRACER GAS CHARACTERIZATION OF FACE VENTILATION SYSTEMS

Two candidate ventilation systems were fabricated and then tested in the test room to compare operating characteristics. Sulfur hexafluoride (SF_6) gas was used to compare ventilation effectiveness in identical test conditions. These tests are reported in detail by Brechtel.[4]

The candidate ventilation systems were—

A free-standing jet fan consisting of a 52-in-diameter fan with a two-speed, 75-kW motor,

A reversible fan with rigid duct consisting of a 52-in-diameter, two-stage fan with two 93-kW motors connected to a 54-in-diameter round steel duct.

Both systems were designed to deliver 100,000 ft³/min in dead-end heading ventilation illustrated by figure 7.

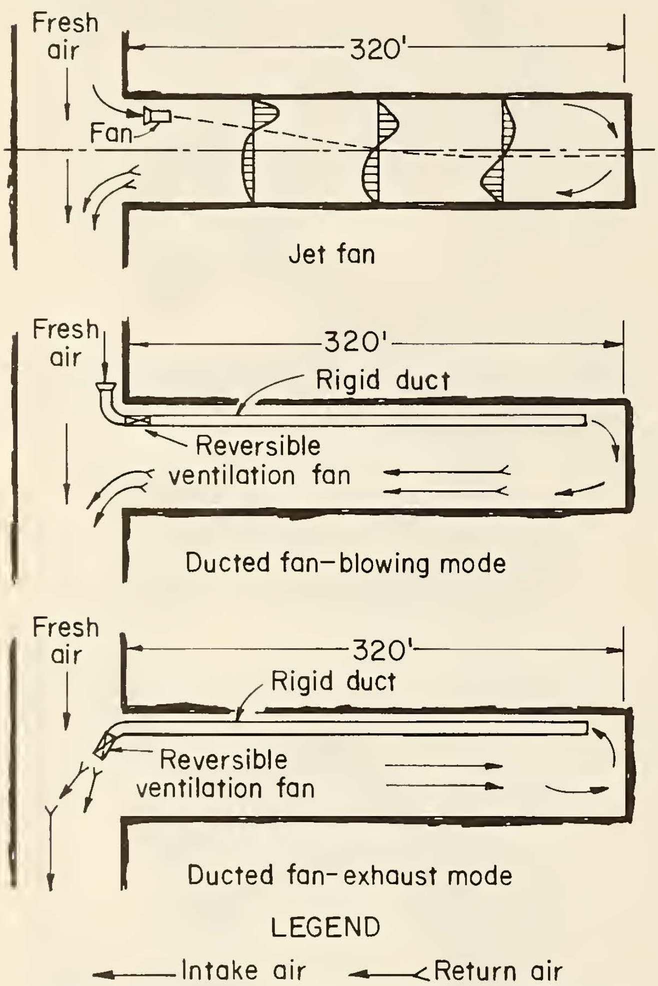

Figure 7.—Schematic of jet fan and ducted fan systems in a dead-end heading.

The configuration of the tracer gas simulation of diesel exhaust production is illustrated in figure 8. A mixture of SF_6 in air was released at a constant flow rate (5.44 L/min) into the exhaust stream of a 50-kW space heater located in the face area. The heated air was intended to simulate the buoyancy of hot diesel exhaust released from a vertical stack at 15 ft above the floor. Air samples were collected using programmable automatic samplers hung at 5, 15, and 25 ft from the roof, and located at the points indicated in figure 8.

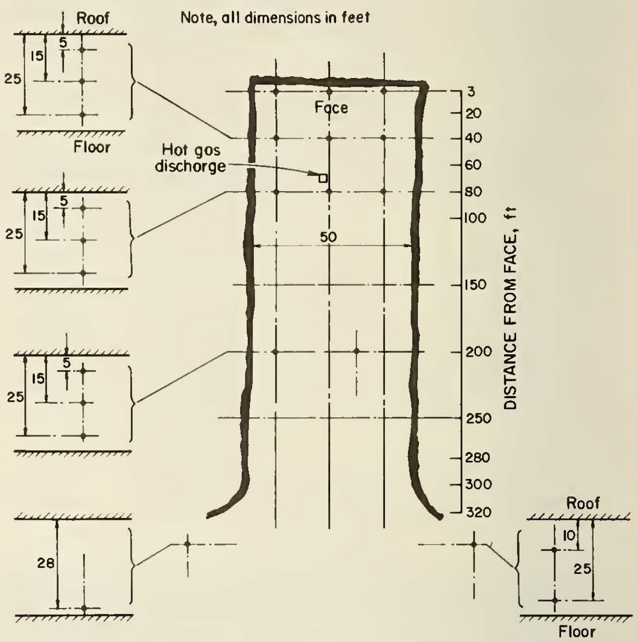

Figure 8.—Schematic of tracer gas release points and sampling locations (plan view).

The variation of tracer gas concentration observed in the tests is illustrated by the time versus SF_6 concentration plots shown in figure 9, and suggests minor stratification due to the buoyancy difference.

Table 3 lists the concentration data for the various sampling points. Vertical variations of concentration were much less than measured during the mucking tests, with a maximum difference of 9 pct as compared to the 60 to 70 pct measured in the mucking simulation. Horizontal variations of the SF_6 concentration throughout the room were very small, indicating that both fans were effective at dispersing the tracer gas.

The overall effectiveness of the two systems is compared in figure 10, and indicates that both systems had relatively high efficiency. The figure shows average dilution efficiency as a function of time, where dilution efficiency is the concentration of tracer gas measured divided by the ideal concentration that would have been obtained if the full flow of the fan were perfectly mixed with the flow of the tracer gas. The efficiencies include the effects of inlet recirculation, which was measured to be 24 and 28 pct for the jet fan and reversible fan, respectively. The inlet recirculation significantly affects dilution efficiency, but was considered typical for these fan installations.

Buoyancy effects typical of full-scale mucking operations were not well simulated by these tests because the quantity of heated airflow in the tracer tests was much less than the diesel exhaust flow during actual operations. This is indicated by the relatively small vertical variation of tracer gas concentrations. Buoyancy effects of the hot exhaust gas

[4] Brechtel, C.E., M.E. Adam, J.F.T. Agapito, and E.D. Thimons. Characterization of the Performance of Large Capacity Face Ventilation Systems for Oil Shale Mining. Paper in the Proceedings of the 2d U.S. Mine Ventilation Symposium, ed. by P. Mousset-Jones. A.A. Balkema, 1985, pp. 517-529.

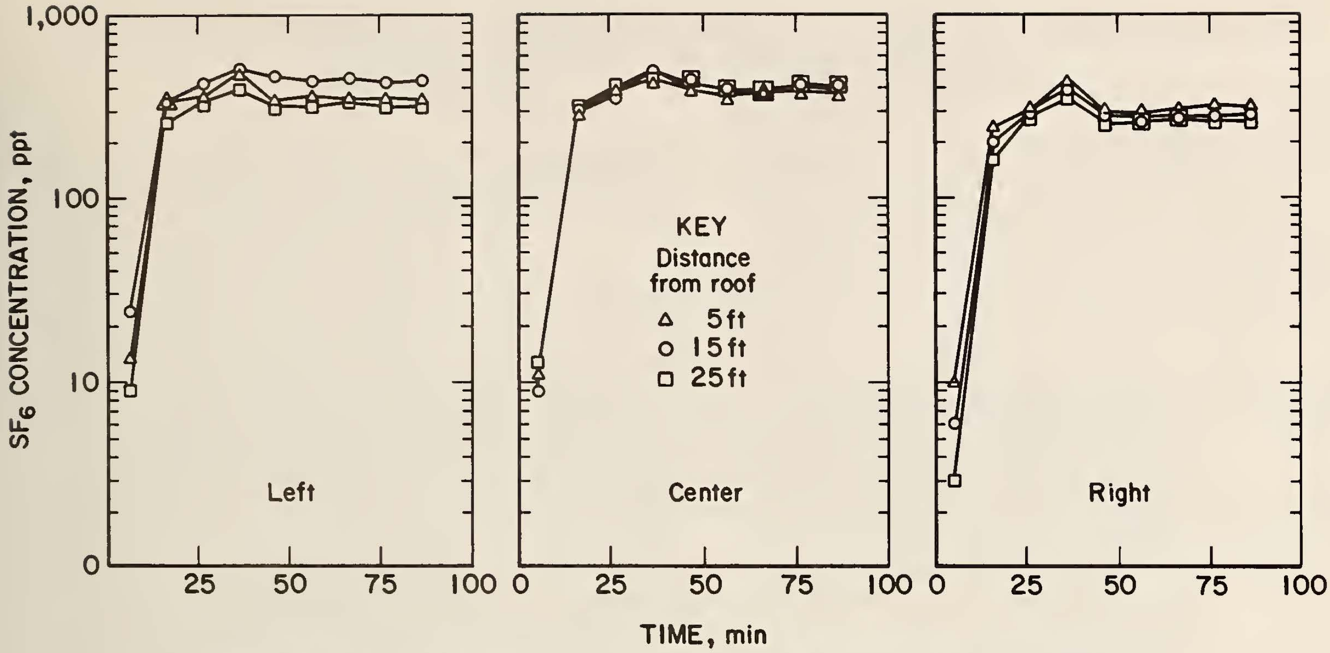

Figure 9.—Vertical and horizontal variations of tracer gas concentrations versus time.

Table 3.—Comparison of TWA SF_6 concentration for diesel exhaust simulation, average SF_6 concentration, parts per trillion

Distance from roof, ft	Jet fan, 88,400 ft³/min	Ducted fan-blowing, 90,700 ft³/min
30 ft from face: 6	289±41	227±11
40 ft from face:		
5	320±40	346±32
15	315±46	375±71
25	310±31	328±52
Mean	315±39	350±56
80 ft from face:		
5	287±52	295± 9
15	265±58	292±18
25	265±48	285±11
Mean	272±52	290±14
200 ft from face:		
5	268± 3	259± 9
15	266±15	252±10
25	236±29	244±11
Mean	256±25	245±18
Overall mean	282	288

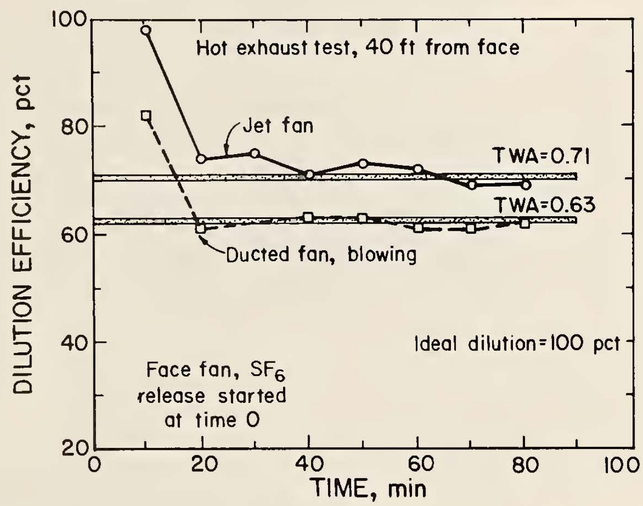

Figure 10.—Comparison of the performance of the jet fan and ducted fan for the hot exhaust test at 40 ft from the face.

could be fully simulated using tracer gas if the heated airstream flow rate was similar to the output of the large engine.

The tracer gas results indicated that both fan systems delivered uniform mixing at high efficiency. This result is similar to results of the mucking simulation, except that vertical stratification of the magnitude observed in the mucking simulation served to enhance ventiliation effectiveness by reducing pollutant concentration at floor level where personnel are exposed.

CONCLUSIONS

These tests indicated that conventional face ventilation systems operating at the high flow rates necessary to ventilate diesel equipment in the 600- to-700-hp range could provide effective mixing as far as 300 ft from the fan in large rooms. The mixing of pollutants was very uniform in the horizontal plane, and vertical stratification of air flow due to the large room size was not observed. Vertical stratification of pollutants due to thermally induced buoyancy of the exhaust fumes was observed, but tended to improve air quality at room heights where personnel would be working.

SF_6 tracer gas was effective in characterizing the mixing uniformity in the test rooms, but did not simulate the thermal stratification because of the low flow rate of the heated air. The tracer gas tests provided an effective method to compare the performance of the different fans and to measure their capacity to ventilate steady-state pollutant production similar to diesel exhaust.

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