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BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

hp	horsepower	m/s	meter per second
kg	kilogram	m^2/s	square meter per second
kg/m^3	kilogram per cubic meter	m^3/s	cubic meter per second
kg/mt	kilogram per metric ton	mt	metric ton
kg/s	kilogram per second	pct	percent
m	meter	pct/s	percent per second
m^2	square meter	ppt	part per trillion
min	minute	s	second
m^3/mt	cubic meter per metric ton		

COMPUTER SIMULATION OF FACE VENTILATION TO DILUTE HIGH METHANE CONCENTRATIONS DEVELOPED BY BLASTING OIL SHALE

By C. E. Brechtel[1] and E. D. Thimons[2]

ABSTRACT

Cooperative research efforts by the Bureau of Mines and Agapito & Associates, Inc., Grand Junction, CO, used a one-dimensional, finite-element computer model to simulate turbulent mass transfer in face ventilation of oil shale mines. The objective was to study the dilution of methane released by rubbled oil shale during blasting. A methane release rate function was developed from the back-analysis of field measurements, and the finite-element model was calibrated using tracer gas characterization data from tests of full-scale face ventilation systems.

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INTRODUCTION

Experimental measurements of the methane saturation of the kerogen in Green River Formation oil shales of the Western United States have been reported by Matta (*1*)[3] and Sapko (*2-3*). The methane saturation level impacts face ventilation design because blasting at the face has the potential to release large quantities of methane gas in dead-end headings. The rate of methane release is high and, in conjunction with the large tonnages of oil shale excavated by each blast, has the potential to produce dangerously high concentrations of methane soon after the blast.

Ventilation in the face after blasting must be capable of safely diluting the methane as it is released from the muckpile to keep it below the explosive range. Data produced in a Bureau of Mines research contract with J.F.T. Agapito & Associates, Inc., that tested large-capacity face ventilation equipment in an oil shale mine, suggested that the use of freestanding jet fans would be an effective method of diluting blast-released methane. The fan could be left on during the blast, thereby preventing the buildup of methane in still air.

Since the Bureau has as part of its mission improved safety in mines, it was decided to enter into a joint project with J.F.T. Agapito & Associates, Inc., to use the data produced during the earlier contract by incorporating it into a finite-element computer model, which would simulate the dilution of methane by ventilation in large opening oil shale faces. Analysis of this problem required a technique that allowed the coupling of the effects of turbulent mass transfer with the time rate of production of methane after the blast. An existing computer code, BASFEH, was adapted for the simulation of turbulent mass transfer and was back-calibrated using tracer gas measurements of face ventilation systems in an oil shale mine. A methane generator function for simulating the time rate of methane production was developed using field measurements of methane emitted in oil shale mining operations.

The objective of this work was to study the effect of two parameters, time lag between blasting the face and activating the fan and face ventilation quantity, on methane dilution. The results would provide a design tool to specify ventilation flowrate and fan activation time for a range of gas saturations. This paper discusses preliminary results of the application of the BASFEH Code.

THE BASFEH COMPUTER CODE

BASFEH is a two-dimensional, finite-element model developed to analyze conductive heat transfer by Nelson (*4*) and modified to include convective heat transfer by Hardy (*5*). The program incorporates one-dimensional elements that solve a conduction-convection equation identical in form to mass transfer models presented by Thakur (*6*) for use in mine ventilation and shown as equation 1:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left[E_x \frac{\partial c}{\partial x}\right] - u(x) \frac{\partial c}{\partial x} + f(x,t), \qquad (1)$$

where c = concentration, kg/m^3,

x = distance from point source, m,

t = time, s,

E_x = turbulent dispersion coefficient, (m/s),

$u(x)$ = airflow velocity in the x direction, (m/s),

and $f(x,t)$ = a source term, kg/s.

BASFEH solves equation 1 explicitly in time and is, therefore, well suited for application using microcomputers because storage requirements are small and execution is very fast. These analyses were performed using a PC-AT[4] computer.

This work was oriented toward application of the modeling technique to mine ventilation problems; therefore, discussion of the mathematics and implementation of the programming is not presented. Other work in this area, presented by Bandopadhyay *(7)*, discusses mathematical formulations for solution by finite difference schemes and may be of interest to the reader.

BASFEH was tested against a one-dimensional analytical solution for concentrations produced by an instantaneous stationary point source shown in equation 2 *(6)*:

$$c(x,t) = \frac{M}{2A(\pi E_x t)^{0.5}} \exp\left[-\frac{(x-ut)^2}{4E_x t}\right], \qquad (2)$$

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

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

where c = concentration, kg/m^3,

M = mass introduced instantaneously, kg

E_x = turbulent dispersion coefficient, m^2/s,

u = air velocity, m/s,

A = tunnel area, m^2,

x = distance from methane point source, m,

and t = time, s.

The results are compared in figure 1 and confirmed that the formulation in BASFEH could successfully simulate turbulent mass transfer. The figure shows the concentrations at 8 and 48 m from the source for an air velocity of 0.5 m/s (symbols) compared with the BASFEH output (lines) at the same locations.

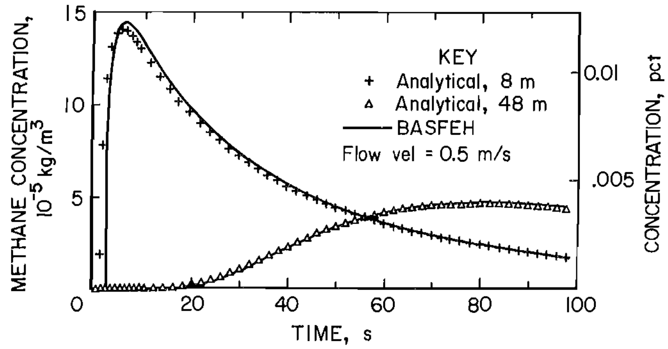

Figure 1.—Comparison of BASFEH results with analytical solutions in equation 2.

METHANE PRODUCTION MODEL

The methane production model was developed from field measurements of methane liberated during mining operations at the Horse Draw experimental mine in the Piceance Creek Basin of Colorado, and at the White River Shale Oil Mine in the Uinta Basin of Utah. Experimental data presented by Sapko *(2-3)* indicated that methane release began immediately when the shale was rubbled and reached peak rates within 5 min of the blast. The rate of production then began to fall, with the shape of the curve very similar to a log-normal statistical distribution.

A log-normal curve was chosen as the basis of the methane production model using equation 3

$$f(t) = \frac{1}{A\ t\ \sqrt{2\pi}} \exp\ \{-1/2A^2\ (\log\ t\ -\ B)^2\},(3)$$

where $f(t)$ = normalized rate of production (rate-peak rate),

A, B = shape factors, no units,

and t = normalized time, s.

The log-normal curve in equation 3 is normalized in general statistical application so that integration of the curve over a normalized x-axis interval from 0 to t produces an area of 1.0. Conversion of equation 3 for use in BASFEH was performed by scaling the area under the curve to equal the total quantity of methane liberated as shown in equation 4,

$$q(t) = Mt \int_{t_1}^{t_2} f(t) \quad (4)$$

and

$$t = \frac{T}{T_f} \quad (5)$$

where $q(t)$ = quantity of methane liberated in a time increment t_2 - t_1, kg,

M_t = total quantity of methane liberated by a blast, kg,

T = time, s,

and T_f = time scaling factor with no units.

This process is illustrated in figure 2, where the normalized production rate (percent of peak production rate) and cumulative production (percent of total methane quantity liberated) are plotted versus time. In this case, the actual time is plotted to illustrate the scaling of the pulse time to fit the field results. Integration of the production rate curve produces a cumulative production curve, which is very similar to laboratory desorbtion behavior for methane in finely ground oil shale *(1)*. This indicates that the use of the log-normal curve is consistent with the physical process of gas desorbing from the solid kerogen in the oil shale.

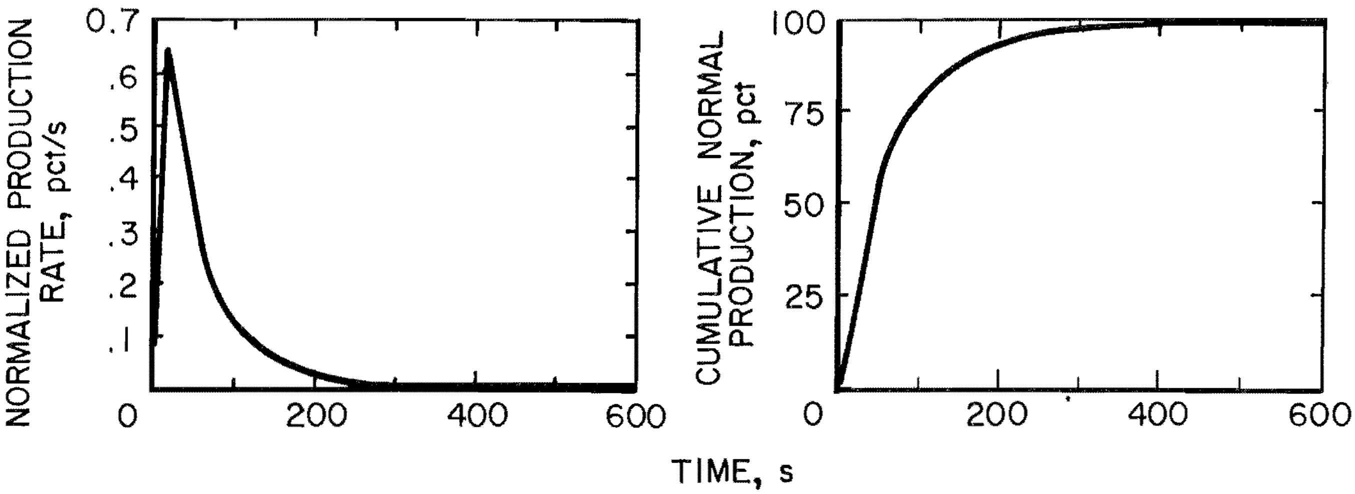

Figure 2.—Normalized production rate and cumulative production curves showing the methane production model.

BACK-ANALYSIS OF METHANE PRODUCTION DATA

BASFEH was used to model experimental measurements from the Horse Draw Mine data developed by Sapko *(2)* in order to back-analyze the correct shape parameters for the log-normal curve. Figure 3 shows the underground configuration in the mine and the finite-element mesh used to simulate the field measurements. The blast modeled was in a face heading being ventilated by 3.25 m^3/s of fresh air and liberated 137.7 kg of methane (assuming an air density of 1.189 kg/m^3). A total of 69.5 mt of oil shale was rubbled for an estimated methane saturation of 1.98 kg/mt. The drift was assumed to be 3.7 by 3.7 m. The log-normal curve was scaled to a 10-min duration pulse with a total quantity of 137.7 kg, based upon the shape of the experimental data. A coefficient of turbulent dispersion of 20.0 was used in the simulation. The results of the BASFEH simulations are shown in figure 4, which presents the time-concentration curve at the experimental sample point and compares the BASFEH output with experimental measurements. A very good fit was obtained with both of the log-normal shape factors equal to 1.

BACK-ANALYSIS OF TRACER GAS EXPERIMENTS

A model of the face heading configuration utilized in room-and-pillar oil shale mining was developed using the results of large-scale face ventilation experiments reported by Brechtel *(8)*. Those tests measured the efficiency of a 1.4-m-diam freestanding, jet fan in ventilating a dead-end heading 91 m long, with a cross section of 16.8 by 9.1 m. The face ventilation experiments were conducted in the Exxon Colony Shale Oil Mine, Parachute, CO, at expected full-scale conditions. The dilution of sulfur hexafluoride (SF_6) tracer gas was used to measure efficiency of the face ventilation system and the combined effects of full-scale turbulence and recirculation.

The experimental configuration used in the face ventilation tests is compared with the finite-element mesh used for the simulation in figure 5. Air leaves the fan as a turbulent jet of high-velocity air directed toward the face area. The jet expands and loses velocity as it approaches the face, because of frictional entrainment of slower velocity air at the perimeter of the jet. The entrainment action produces great turbulence throughout the test room and very effective mixing of any pollutants. The rate of pollutant dilution is controlled by the net flow of fresh air in and out of the room.

Evaluation of the tracer gas data indicated that mixing throughout the test room was very uniform because of the great turbulence. For a steady-state release of SF_6, the standard deviation of all measurements throughout plan and vertical area of the room averaged 12 pct of the mean

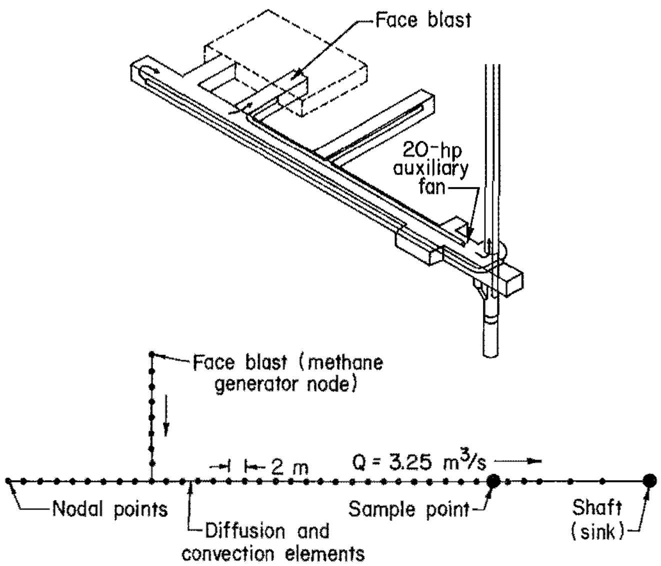

Figure 3.—Schematic Horse Draw Mine configuration and finite-element mesh used for simulation.

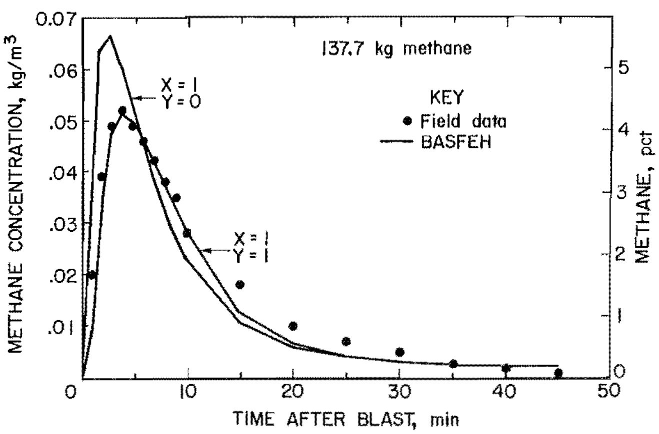

Figure 4.—Time-concentration predicted by BASFEH versus experimental data.

value. This suggested that use of the one-dimensional approximation, which assumes that turbulent dispersion is the same in all directions, would produce acceptable results.

The finite-element mesh was made up of one-dimensional diffusion-convection elements forming the average path of airflow past the room in the last open crosscut and within the room. Nodal points were cross connected by diffusion elements to simulate the large turbulence created by entrainment along the jet.

Figure 6 compares the experimental data with the results predicted by the BASFEH model at three distances

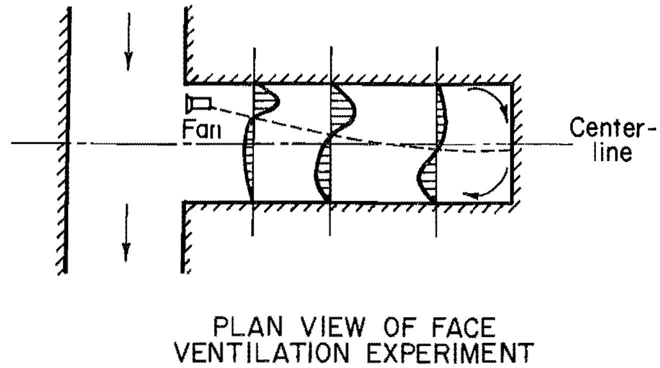

Figure 5.—Schematic jet fan experimental configuration and finite-element mesh used for simulation.

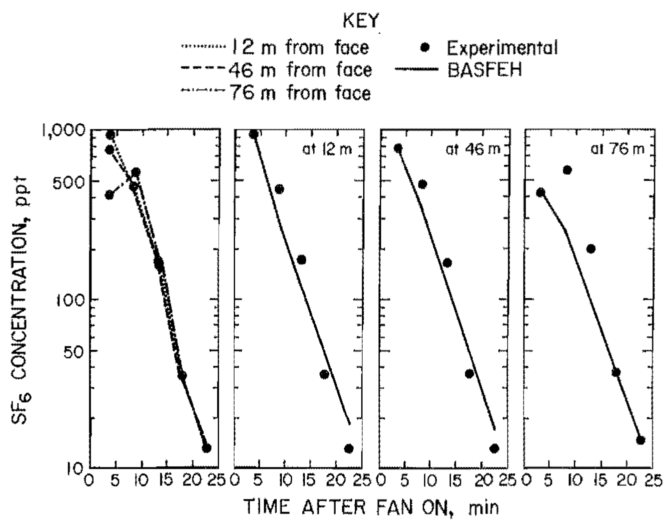

Figure 6.—Comparison of tracer gas data with BASFEH simulation of full-scale face ventilation experiments.

from the face. The tracer gas had been released throughout the room producing a uniform concentration of 920 ppt. The main ventilation system was then actuated and the airflow from the last open crosscut began to remove some SF_6 from the room producing the concentration gradient indicated by the first data points. After the jet fan was actuated, the turbulence produced a uniform concentration throughout the room within 5 min and diluted the SF_6 to levels of minimum resolution within 20 min.

The BASFEH simulation was begun at the same gradient of concentration in an attempt to reproduce the experimental data. The coefficient of turbulent dispersion was raised to 120 m^2/s in an attempt to reproduce the uniform mixing throughout the room.

Simulation of the tracer gas test was not able to reproduce the degree of turbulence observed experimentally; however, the dilution of the tracer gas was duplicated within 20 to 30 pct. Behavior in the simulation was very similar in trend to the experimental data.

SIMULATION OF FULL-SCALE FACE BLASTING

The methane generator function and the jet fan model have been exercised to produce preliminary indications of the application of the work. Sapko *(3)* reported average methane saturations of 0.4 m^3/mt of oil shale from blasting tests at the White River Shale Oil Mine. This value was used for an assumed face blast that rubbled 1,900 mt of oil shale to produce 903 kg of methane. The time normalization for the release was identical to that used in the back-analysis. Air ventilation rates were the same as used in the tracer gas simulation. Figure 7 compares the time-concentration data for a point 12 m from the face for two cases:

- o Face ventilation system OFF.
- o Face ventilation system ON during blast.

Without face ventilation, the methane concentrations reach explosive levels and are diluted very slowly. The operation of the fan during the blast prevents the methane concentrations from reaching the explosive range.

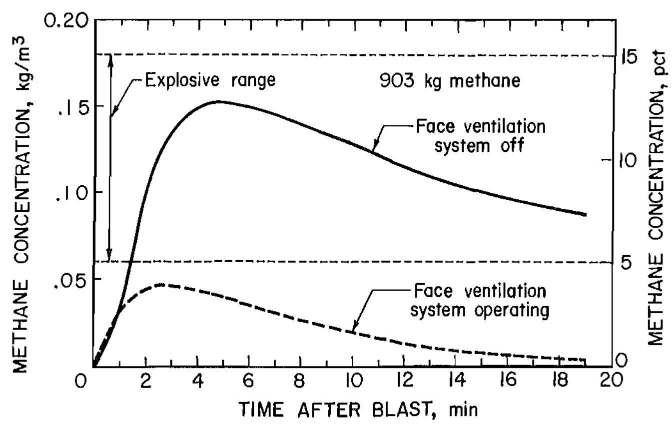

Figure 7.—Methane concentration versus time for simulated full-scale blast with and without ventilation.

CONCLUSIONS

These preliminary results illustrate the utility of a one-dimensional finite computer simulation in the design of face ventilation systems. The approximation is currently unable to simulate the full turbulence of the system; however, it does produce a useful simulation of the time rate of production and dilution of the tracer gas and methane.

The results suggest that jet fans would be effective in preventing the large concentration of methane produced by blasting from reaching dangerous levels.

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