U.S. BUREAU OF MINES
TRAINING WORKSHOP
ON THE
"MFIRE" MINE FIRE AND VENTILATION SIMULATOR

MFIRE USERS MANUAL
VERSION 2.20
AUGUST 1995

U. S. Bureau of Mines
Twin Cities Research Center
Minneapolis, MN

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CONTENTS

1.0 INTRODUCTION

MFIRE is a computer simulation program that performs normal ventilation network planning calculations, and dynamic transient state simulation of ventilation networks under a variety of conditions. The program is useful for the analysis of ventilation networks under thermal and mechanical influence. MFIRE simulates a mine's ventilation system and its response to altered ventilation parameters, external influences such as temperatures, and internal influences such as fires. Extensive output enables detailed quantitative analysis of the effects of the proposed alteration to the ventilation system

Network simulation using digital computers has become widespread throughout the mining industry in recent years. However, as the sophistication of the simulator increases (MFIRE, for example), the complexity of input data requirements and interpretations of results requires more skill and knowledge from the users. Perhaps the most difficult part of using MFIRE is to construct the data set describing the mine's physical layout and its ventilation properties. The initial attempts to get the data set running often reveal unknown or ignored aspects of the mine's ventilation.

MFIRE was written in Fortran 77 and compiled with Microway[1] Fortran for the Intel 80386 based computers with a 80387 math co-processor. The source code is portable and available for users who wish to modify the source code to operate on other computers.

This user manual describes the development of MFIRE, the input format and requirements, the output, common errors, fire parameters, and examples MFIRE application. Valuable reference material is included in the appendices. Knowledgeable users may skip directly to the PROGRAM INSTALLATION AND OPERATION section to begin using MFIRE immediately.

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

2.0 DEVELOPMENT OF MFIRE

Mine ventilation control and mine fire detection and fighting are inseparable. Mine fires produce gases and heat, which the ventilation systems transport through the mines. These gases can be poisonous and/or explosive. The heat can cause ventilation disturbances, which take the gases along unexpected routes or affect the formation of explosive methane mixtures.

The calculation of the airflow distribution in mine ventilation systems as a result of fans, thermal forces, and flow resistances is a formidable mathematical problem. It comprises the solution of twice as many equations as there are airways; half of these equations are quadratic equations. This sort of problem led to the design of special analog computers in the 1950's and 60's and, from the early 1960's on, to the increasing use of electronic digital computers. With the rapidly increasing availability and capacity of digital computers, airflow rate and pressure loss distribution calculations, commonly called ventilation network calculations, have become routine, and a great number of computer programs exist for this purpose. Practically all the programs are capable of performing the required calculations, although differences exist in how the square equations are linearized, the mass conservation law is introduced and observed, the fan characteristics are simulated, and the thermal drafts are considered. All of the programs were based on steady-state conditions.

Of greatest concern in the past were the fire-generated ventilation disturbances. Ventilation engineers developed a large number of methods, by manual calculation, to detect potentially unstable airways with airflow reversals in case of a fire. When the analog and digital computers became available for ventilation planning, they were almost immediately applied to this problem. The expected fire-generated ventilating pressures were manually inserted into the network simulations, with their values usually obtained from experience or from rough calculations. The mutual influence of fire intensities and ventilation conditions were not taken into account. If gas concentrations were calculated at all, they were only calculated for the cases where no recirculation existed. All calculations were, as in conventional network calculations, based on steady-state conditions or based on the assumption that no changes with time occur.

The U.S. Bureau of Mines and Michigan Technological University first solved this problem with steady-state analysis, and the resulting program became known as the MTU/BOM code. Because the mine fire process is dynamic in nature, work on the transient-state modeling problem continued with the resulting program, MFIRE, which accommodates dynamic state modeling of the fire.

MFIRE version 2.20 includes: calculations based on mass flow rates, natural ventilation, spline or least squares fan curve fitting and boundry fixing, air reversal and recirculation calculations. Condensation and evaporation in the mass flow and heat exchange calculations was removed from MFIRE 2.20 but will be incorporated in a later version. The program is useful for the analysis of ventilation networks under the influence of natural ventilation, fans, fires, or any combination of these. MFIRE simulates a mine's ventilation system and its response to altered ventilation parameters such as the development of new mine workings or changes in ventilation control structures, external influences, and internal influences. Extensive output enables detailed, quantitative analysis which the alteration will cause in the ventilation system.

This chapter reviews the evolution of the MFIRE program from its infancy as a simple digital network simulator that replaced analog computers to the present version. Landmark features and modeling improvements are discussed.

2.1 HISTORY OF MINE VENTILATION MODELING

Ventilation network calculations have been performed for several centuries. Due to mathematical difficulties caused by diagonal airways, the preferred method of practitioners was a trial and error approach in which junction and mesh equations were made compatible. Since the beginning of this century, airflow and pressure loss distributions in a large number of more frequently occurring subnetworks were analytically and graphically determined. These were the subjects of numerous publications and were of considerable help to practitioners.

Trial and error methods, which can be surprisingly efficient in one case, can become frustratingly inefficient in another. A large number of methods of successive approximation were consequently developed. Atkinson's solution in 1854 for a single diagonal airway and Cross's method because of its general applicability and simplicity became the widest known examples. Some of these methods were based on the linearization of the quadratic resistance equation and used in electric analog computers. Practically all of the methods were tested for their utility with digital computers when these became available.

The forerunners of analog computers were fluid flow models. They were used in several countries but never found wide application. The similarity between node and mesh equations in ventilation networks with Kirchoff's laws of electrical networks made the electrical models persuasive. The first patent for an electric analog computer for water and gas networks was awarded in 1941 in Germany. This computer used filament bulb resistance to model the second power resistance function in the network calculations.

The idea was taken up or independently discovered in several countries, but the limited working range of commercially-available filament bulbs made them inflexible and the number installed remained small. Development of a specially- constructed low voltage lamp in the United States overcame this obstacle and in 1954 a "network analyzer" was installed at the U.S. Bureau of Mines, after six earlier installations had shown their usefulness with waterworks (McElroy, 1954).

In 1951-52, the University of Nottingham (UK) pioneered the idea to combine an electrical network simulation of the nodes and mesh equations of ventilation networks with a manual approximation method for the resistance equation. This led to the design of the commercially available "National Coal Board Network Analyzer", which found a wide distribution. Home-built models and modifications, using different approximation methods for the resistance equation, were used in almost all mining countries. At some places ancillaries for adjustment steps without calculations were introduced.

An electromechanical analog computer, in which the approximation of the resistance equation was automatically performed, was first developed in 1950 at a German coal mine. It became commercially available in 1952. Thirteen of these computers were installed in German coal mines and a larger number were installed abroad and for gas and water companies. In 1959, electronic function generators for the simulation of the resistance equation were introduced in Japan; in 1960 the German manufacturer adopted this principle, also. In 1964, a British model became commercially available and may be the only one still on the market. In 1962, the French coal mines built an electronic model which has been used for several decades.

Fully-automatic analog computers for ventilation network calculations are excellent planning tools. Their handicap is that they are single purpose machines. All-purpose digital computers became commercially available in the late 1950's and predictably replaced the majority of the analog computers.

The literature reports that the first network calculations with digital computers were performed for waterworks in the United States in 1957. The first digital ventilation network calculations were reported in Belgium in 1958 and in Germany in 1959. Following the lead of gas and water companies, efforts to replace the expensive analog computers with digital computers began in Germany in 1958. The replacement progressed quite rapidly since many of the analog computer users were cooperating with this effort. The literature reports that the same coal company which had pioneered the use of electromechanical analog computers performed almost all of their network calculations on digital computers by the end of 1959.

By the end of 1969 the majority of analog computer users, representing 80 pct of the German coal production, had switched to digital computers.

Since the first attempts with the Cross method of balancing pressure losses gave poor convergence most other known approximation methods were initially attempted. These were dropped when it was found that assembling meshes in such a way that airways with high resistance factors or, even better, with high products of airflow rates and resistance factors, occurred in as few meshes as possible overcame the convergence problem. The mesh assembly was done in a systematic way by arranging a tree in a sequence from tree tip to root, which allows the computer to elect correct movements when assembling the meshes.

From 1961 on, it became customary to include natural ventilation obtained from information on temperatures and elevations in every mesh. Fixed quantity airways had always been a feature of analog computers and were included in the earliest applications of digital computers. Fan characteristics were treated in different ways as storage allowed. A FORTRAN version of a type of standard program became a part of the IBM program library in 1966; in 1967 it was adopted by the British National Coal Board for ventilation planning purposes at its divisional computer centers. It has been used for instructional purposes at Michigan Technological University (MTU) since 1967. Although many enhancements and attempts at improvements were made, it is basically still in its original form and is the core of the MFIRE program.

As the availability of digital computers increased, the number of users doing creative work in ventilation planning increased tremendously. Due to personal, societal, or company restraints, much work went unreported. However, by analyzing available published literature, it is clear that continental European ventilation engineers cooperated closely. An advanced program capable of performing high speed calculations for large networks was in use in France in 1961. A storage saving program based on the Cross method of flow rate balancing was introduced in 1967. In Japan network calculations with digital computers started in 1961. Convergence-improving mesh assemblies were reported in 1969. In Russia, first attempts with digital computers were made in 1963. In 1965 and 1967, reports on different approximation methods were published. In Great Britain, the first network calculations with the meshes assembled manually were reported in 1964. A program with automatic mesh assembly was described in 1965. In the United States, the first program to prove the usefulness of digital computers was described in 1963; an improved version allowing the inclusion of fan characteristics was reported in 1964. Both programs still required the manual assembly of meshes.

In 1967, a much more sophisticated program with mesh assembly and assignment of initial airflow rates performed by the computer was reported and in 1970 a new version of the program which accommodated fixed quantity airways was described.

Over the past two decades efforts focussed on: (1) replacing the Cross method with more efficient approximation methods, (2) combining network calculation for optimization purposes with operations research approaches, (3) making the programs more user friendly in particular by using interactive graphics, (4) combining network calculations with temperature and concentration calculations, and (5) extending network calculations to transient state conditions.

The first objective has been a continual goal since the first days of digital computer use. So far, all results seem to confirm that the Cross method for networks of ordinary size and complexity is as good or better than other methods. The second objective is a very valid one since network calculations are only a means to an end. The third objective is probably the most important one.

The non-steady-state behavior of ventilation systems has attracted research in connection with control problems since the 1950's. Studies concentrated upon the effects of explosions, gas outbursts, and other mechanical disturbances. A publication describing the use of digital computers for this purpose originated in Poland in 1972 and another one using analog computers was published in Yugoslavia in 1984.

Efforts to combine ventilation network calculations with the precalculation of temperatures and humidities started in Japan in 1969. An early program which included temperatures, humidity, methane and dust concentrations, plus a transient state methane simulator originated at the University of Pittsburgh in 1972. In 1975, at the First International Mine Ventilation Congress, reports on four programs from the United States and Great Britain for combined network, temperatures and humidity calculations were given. At the Third Congress in 1984, a program for temperature, humidity, and radon concentrations was introduced from Australia.

Litigation connected with the Sunshine mine fire in the mid-1970's showed that existing programs could only partially simulate the interaction of mine fires and ventilation systems. Although manual non-steady-state temperature precalculations had become a common feature and steady-state fume concentrations were easy to add as long as no recirculation occurred, manual insertions of thermal draft, and throttling effects proved to be cumbersome and the handling of recirculation to be impossible.

This led to the development of a new program at MTU in 1975 and 1976. The goals of this program were to determine the equilibrium between fires and ventilation systems in steady- state conditions at any given time. The crucial heat exchange between rock and air were calculated under non-steady-state conditions. The program was based on mass flow rates and considered natural ventilation in all meshes and throttling effects in all airways. Airflow reversal and fume recirculation were also calculated. This program, sometimes referred to as the MTU/BOM code, was the first building block of MFIRE.

2.2 DESIGN OF MFIRE

The potential for ventilation disturbances caused by fires has always been a great concern in fire emergency planning. Where mine workings extend over large elevation differences and where the ventilation is weak, such disturbances have been the cause of large mine disasters. The 1928 mine fire at Roch-la-Moliere (France), which killed 48 miners, is a classic and often-quoted example. The first computer simulator (Greuer, 1977) for the interaction of mine fires and mine ventilation systems focused, therefore, on the assessment of these disturbances.

This MTU/BOM code made use of the existing programs for ventilation network calculations. Steady-state conditions for the ventilation as well as for the fire were assumed. The resulting program featured mass-based flow rates and transient state temperature simulation. The program was useful and became popular because of its simplicity. These features became part of the more advanced transient-state computer model, MFIRE.

The program was written for routine applications by practical ventilation engineers but without violating physical laws or simplifying facts of practical importance. The amount of necessary input data has been kept small and checks are performed for their completeness and for such errors as occur most frequently. Where they do not influence the results significantly, user-stated average values can be used to reduce the input.

The output provides a listing of airflow rates and pressure losses in airways, methane and contaminant concentrations, and temperatures at airway ends. Concentrations and temperatures are also listed for junctions. Recirculation paths and airways with airflow reversals, as well as airways and junctions with critical conditions, are additionally listed to alert the user to potential danger zones.

2.3 MASS BASED FLOW RATES

Performing network calculations based on actual volume flow rates makes difficult the consideration of the law of conservation of mass. Thus, to minimize computational effort, most computer programs simplify the problem by assuming a "law of volume conservation" instead. Although this assumption normally does not lead to gross inaccuracies, serious errors are introduced when larger density changes occur, such as in a mine fire.

The user is allowed to specify a reference air density and corresponding temperature. These serve as a scale against which other densities, expressed by their temperatures, are measured. All input and output are converted to the reference state defined by the reference density and temperature. In order to avoid output conversion and to obtain values which come close to the actual, density dependent, pressure losses, fan pressures, and volume flow rates, a reference density which is close to the prevailing actual density should be used.

2.4 TRANSIENT STATE CONCENTRATION SIMULATION

The assumption of steady-state conditions may be good enough for the determination of airflow rate and temperature distributions, because airflow rate changes are caused by temperature changes, and temperature changes are observed in the immediate vicinity of the fire only. Investigations showed that ventilation disturbances caused by thermal forces create negligible inertia forces. The airflow assumes steady-state conditions in a very short time as pressure differences propagate at the speed of sound. Changed airflow rate and temperature distributions are, therefore, reached almost instantaneously and time is a minor factor.

Time is definitely an important factor with concentration distributions. Gases travel with the ventilation currents, which normally means speeds of less than 3 to 4 km/h. Many airways downwind of a fire can, for a considerable time after the start of the fire, remain clear of gases. In many cases, the increase of airway gas concentration happens only gradually before steady-state conditions are reached. Assuming steady-state concentration distributions in fire emergency planning frequently means needlessly excluding airways as escapeways, although they are perfectly safe for a long time.

The simulation of concentration distributions does not involve physical principles other than the law of mass conservation. Additionally, the assumptions are made that perfect mixing of air currents occurs in nodes, no longitudinal diffusion in airways exists, and flow velocities in planes perpendicular to flow directions are equal.

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In the resulting programs (Bastow, 1979 and Greuer, 1981), mine atmosphere is divided into control volumes of homogeneous concentrations, which advance with the flow through the ventilation system. When control volumes meet at airway junctions, they are combined to form new control volumes. Because many junctions can be reached via different paths with different amounts of dilution having occurred, the number of control volumes can become quite large, depending on the type of ventilation system. When recirculation occurs, the number can virtually become infinite with smaller and smaller concentration differences between the newly-formed control volumes.

The problem of this simulation is not one of mathematics but of sorting. All control volumes that arrive at a junction have to be detected, and the sequence of their arrival has to be determined. The new control volumes, which are generated in the junctions, have to be advanced into the outgoing airways together with checks to see if they affect any other junctions. If they do, part of the computations have to be repeated.

The main difficulty in writing this program was, therefore, not one of mathematics but one of keeping the computing time within tolerable limits. Experience showed that the choice of the time increment in which the control volumes are advanced is of great importance. If the increment is too large, control volumes may have to be passed through more than one junction, which lengthens and complicates calculations. If the increment is too short, a large number of advancements has to be performed. The solution was to let the program select the optimal length of the time interval as a function of the network type.

Variations of the program accommodated the exposure simulation of escaping miners in 1983 (Greuer, 1983), the simulation of escape movements of miners, based on warning times and travel speeds in 1983, (Greuer, 1983), and simulation of mobile contaminant sources in 1984 (Sheng, 1984).

This program is based on the assumption of constant airflow rates. These can be the airflow rates prevailing in the early stages of a fire or the airflow rates resulting from the equilibrium of fire-generated (thermal) and other (fan, airway resistances) ventilating forces. In the first case, very little input data and expertise on the part of the program user are required. The only ventilation information needed is data on the network configuration (airway and node identification numbers), airflow rates, and airway lengths and cross-sectional areas. The program was useful where fire-generated ventilation disturbances had not yet occurred, in particular for the layout of fire detection systems. It would also be helpful for the design of fire escape plans if an early fire warning system allowed for the evacuation of the mine before the fire progressed beyond its initial stage.

In the second case, considering fire disturbances, the determination of the airflow rates has to precede the concentration calculations. This requires detailed information on the ventilation system and some ventilation expertise by the program user.

2.5 STEADY STATE FIRE DISTURBANCE SIMULATION

If the terminology of ventilation engineers is used, one can say that fires have two effects on ventilation systems: a throttling effect caused by the volume increase of the air passing through the fire zone, and a natural draft effect caused by the conversion of heat into mechanical energy.

The throttling effect is easy to assess. The energy requirement per unit mass to overcome friction losses is proportional to the square of the flow velocity. The latter is in turn proportional to the specific volume or the absolute temperature. The energy requirements to transport air through an airway are, therefore, proportional to the square of the absolute temperature. If a fire causes the temperature increase, the same amount of energy will transport less air.

Natural draft effects, or the conversion of heat into mechanical energy, can occur where the air changes its pressure and its specific volume when it goes through a cyclic process. Every loop of the ventilation system can be considered a cyclic process and can, therefore, develop natural draft effects. The amount of heat converted into mechanical energy is, according to the first law of thermodynamics, equal to the integral of the product of specific volume times pressure change.

The determination of numerical values of this integral is cumbersome because of the continual pressure changes in ventilation systems and owing to the fact that the specific volume cannot be directly measured. A good approximation is possible in most cases by establishing a functional relationship between this integral and an analogous integral of the product of temperature times elevation change, which is easier to determine.

Precalculations of the throttling and natural draft effect require, therefore, the precalculation of temperatures. These are functions of the airflow distribution, which determines the oxygen supply to the fire, the heat transfer to the airway walls, and the mixing of air currents in junctions. The airflow distribution, on the other hand, is a function of the temperature-induced throttling and natural draft effects. It was this interaction between fires and ventilation systems, together with the occurrence of recirculation, which for many years was considered to be too complicated for computer simulations.

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The MTU/BOM code combines conventional network (airflow rate, pressure loss) calculations with concentration and temperature calculations and automatically accounts for the throttling and natural draft effects. It converges to establish the equilibrium at which fire-generated thermal forces (throttling and natural draft) are balanced by the other ventilation forces (fans and resistances).

The beginning of the code is a network calculation for the pre-fire state, to ascertain that the input data are correct. Based on the type of fuel, fuel loading, and air supply, the heat and contaminant production is calculated next. This is followed by a calculation of the temperature and concentration distribution, based on the original airflow rates. The fire-generated thermal forces (throttling and natural draft effects) are then determined and inserted into a new network calculation. This sequence of calculations is repeated until the calculated thermal forces remain constant. This means that equilibrium has been found and, temporarily, steady-state conditions for the airflow rate, pressure loss, and temperature distribution have been established.

This approach can be justified because changes of the temperature distribution are observed only in the vicinity of the fire and short distances downwind from it. Fire-caused thermal forces are, therefore, generated almost instantaneously, and changed airflow rate and temperature distributions also establish themselves almost instantaneously. This does not apply to the concentration distributions, however, and, only in rare cases, to fire intensities. Even if the fire intensity does not change, the temperature distribution will change with time, since the airway walls will be heated and provide less cooling. This is taken into account by considering the transient-state nature of the heat transfer, although with the simplifying assumption that the equilibrium airflow did prevail from the very beginning of the fire.

The MTU/BOM code was divided into two main parts: network and concentration/temperature. To make the program as flexible as possible, network, temperature, and concentration calculations can be performed separately or combined. Methane concentrations are, however, always determined when a change in the airflow distribution takes place, since this is indispensable for coal mines.

The network part basically contains the previous network simulator and performs airflow rate and pressure-loss calculations. The program uses the Hardy Cross method, since studies, which were recently updated by a variety of investigators, showed that for networks of the size of mine ventilation systems, this method still gives the shortest calculating times when accompanied by a convergency promoting method of mesh selection.

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This can be done by letting airways with large products of airway resistances and airflow rates appear in as few meshes as possible. The pertinent mesh assembly process occupies a large portion of the program but its computer execution is superior to most other mesh-assembly programs.

So-called fixed quantity airways or regulators, which maintain a constant airflow rate and which are a valuable planning aid, have to be converted into regular airways if more than a conventional network calculation is demanded. In case of an emergency, there will be no time to pay attention to the adjustment of regulators that keep the airflow rate constant.

Concentration and temperature calculations are performed jointly in the second program part because they have many common features. One can think of heat as being a contaminant, also, and temperature changes caused by heat influx or by mixing airflows are calculated in the same way as concentration changes.

Concentration and temperature changes in roadways can be caused by entering methane, by fire-produced contaminants and heat, and by heat entering or leaving the airway. In junctions, they can occur because of mixing of air currents with different concentrations and temperatures. Both processes are fundamentally different, and two separate program sections have been provided.

The calculations start at a node with known temperatures and concentrations. Normally this will be the surface or someplace in the intake airways. With the conditions at their beginnings thus known, roadway calculations are conducted for all airways leaving this node. Next, a check for junctions where the conditions of all entering airways are known is performed. If found, the entering air currents are mixed and roadway calculations are performed for all airways leaving this junction.

This process is interrupted when recirculated air enters a junction. In this case, the alternating airway and junction calculations cannot be continued since concentrations and temperatures of the recirculated entering air are not known. The difficulty is overcome by using an iteration method. Starting out with estimated values for the properties of the recirculated air, the roadway and junction calculations are continued as if they were known. With this assumption, the values, which are then obtained for the recirculated air by the successive roadway and junction calculations, are next used as new, better estimates. The process is repeated until estimated and calculated values agree. Airways with recirculation are placed in a special list in the output to draw attention to the fact that they carry potentially contaminated air into intake airways. It is surprising to note how much recirculation can exist in many mines without being recognized.

Heat and combustion products developed by fires can either be estimated by the user or can be determined by the program as functions of the oxygen supply of the fire. The heat exchange with the airway walls is calculated with the help of Fourier's equation of thermal conduction, for which solutions have been built into the program.

A crucial role in these calculations is played by the rock temperature, which is a function of virgin rock temperature and the airway history. It is possible, in principle, to determine the temperature distribution in the rock and to provide an accurate solution to Fourier's equation, if the airway history is known. Normally, this will not be the case.

Because fire emergency plans deal with short time spans, as compared to the age of the airway at least, and since only thin layers of rock surrounding the airways are affected by the temperature changes, it seems to be accurate enough to work with effective rock temperatures for this layer. These are close to the normal air temperatures, modified by the temperature difference caused by convection, and are determined by the program. If better information exists, it can, of course, be fed into the computer and used. The fire-generated thermal forces are the throttling and natural draft effects. They are determined by making use of the calculated temperature distributions.

Because of its capabilities to calculate concentrations and temperatures and to take thermal forces into account, the program is not only used for fire emergencies but also for ordinary ventilation planning purposes. Several versions exist, developed by program users. The program has found substantial use for fire simulations in high-rise buildings during the last few years.

2.6 TRANSIENT STATE SIMULATION OF FIRES AND VENTILATION SYSTEMS

The transient concentration distribution programs are useful in many ways. The assumption of time-constant airflow rates is justified for the early stages of a fire when a weak fire does not influence the airflow distribution. When, at a later stage, more intense fires may interact noticeably with the ventilation system, with the fire intensity controlled by the air supply to the fire, and with the airflow distribution affected by the fire intensity, this interaction should be taken into account. Correspondingly, initially, a program was written for this condition in which, for the sake of simplicity, steady-state conditions were assumed.

The shortcoming of this program was that it determined the state of a ventilation system at the end of a specified time interval only, with the assumption that the airflow distribution at the end of this interval prevailed from the beginning of the fire throughout the time interval.

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This could be true, but it might be a simplification of reality.

There are several different approaches for a complete transient-state simulation of ventilation systems. The first method investigated was a finite-difference method based on Newton's second law. It starts with the momentum balance of small elements of air masses to set up the governing equations, and ends up with a set of simultaneous equations that have to be solved for the whole system in each time increment. This method was discarded after a lengthy trial for the following two reasons:

   1. With the involvement of simultaneous equations, the calculation load increases rapidly when a ventilation network becomes large.

   2. For most cases in mine ventilation, the airflow can assume steady-state in a time period short enough to justify the application of steady-state theories.

The chosen approach was then to consider the transient process as a sequence of short-time steady-state processes during each of which an equilibrium between ventilating pressures (fan and thermal pressures) and airflow-rate-produced pressure losses exists. If the temperature distribution changes, the equilibrium will be disturbed and a new airflow distribution will result. The new equilibrium for the end of the time interval is found by a sequence of alternating temperature, thermal pressure, and network calculations. The results of the last calculation serve as the input for the succeeding calculation.

Neither the airflow rates at the beginning of the time interval nor at its end are representative of the whole time interval. With the assumption that changes in the airflow rate during the time interval follow a linear pattern, the arithmetic average of the two values is used to represent the average airflow rate.

An interval-oriented simulation technique, which updates its data base in every prefixed time interval, was adopted (Chang, 1987). An event-oriented simulation would be more efficient, but with a transient-state simulation, ventilation system conditions change constantly, which makes events undistinguishable. The control volume approach, with control volumes being blocks of air of uniform composition, was retained. In other words, the time is divided into a series of time intervals; the airflow into air segments.

If data records were set up for every airway in a system, a majority of the efforts would be unnecessary because the variation of ventilation parameters in most airways that were not directly affected by the hot fumes are at most of a secondary significance in shaping the airflow distribution in the system. It is assumed that the mean air temperature and airflow resistance of an airway

will remain unchanged if no significant changes in ventilation conditions occur. The criteria to judge a significant change include whether fumes ever got into the airway and whether drastic condition changes (air temperature change larger than 2 deg C, or fume concentration change larger than 0.1 pct) happened in the beginning junction of the airway. When no significant change happens in an airway, its original resistance and mean air temperature are taken as the values in the present time interval.

This program was ported to the personal computer world and was released as MFIRE in 1988. With the aid of user reports, bug fixes were made and maintenance versions were released.

2.7 CONSIDERATION OF WATER VAPOR

The early releases of MFIRE did not consider water vapor. MFIRE 2.0 and 2.1 were derived from older code which did incorporate the following method for water vapor consideration. The older code lacked robustness and users found small but significant problems under certain circumstances. MFIRE 2.20 returned to the framework of version 1.29 and added the fan features described later. This section is intentionally left in the manual for reference as water vapor consideration will be incorporated in future releases.

Air temperature precalculation is necessary for simulation of thermal disturbances such as mine fires. It is recognized that even seemingly dry airways are to a considerable extent influenced by water migration, evaporation, or condensation. Small water quantities can, due to the large latent heat of water, have great effects. Due to the existence of water evaporation and condensation in a system, mass and heat transfer must be considered concurrently.

Past attempts to describe the effects of water on mine air temperatures fall roughly into two categories. One of them uses statistical tools to systematically interpret field-measured data for empirical relationships among temperature, humidity, and other ventilation parameters. It does not attempt to explain the nature of their dependence or to draw generally valid conclusions. Rather it offers useful equations of localized significance.

The other is a semi-empirical technique that tries to derive functional relationships between temperature and other ventilation parameters. A number of loosely defined factors, coefficients, and more or less justified relations are introduced for this purpose to provide for general applicability. There exist, however, so many assumptions, which are neither theoretically sound nor universally tenable, that the usefulness of this approach has to be limited in range or a lack in accuracy must be expected. There exist by now a large number of approaches to predict the combined dry heat transfer by conduction within the rock and by convection from the

rock to the air. None of these approaches take the parallel mass transfer of water and its temperature effect satisfactorily into account.

The model developed for MFIRE follows a rigorous analytical approach and a rigorous analytical solution can be obtained (Chang and Greuer, 1985). Since the calculation of numerical solutions turns out to be a very time-consuming task, approximations for short time periods, with which one is concerned in emergency planning, were developed also.

Additional difficulties arise from boundary conditions. Water can evaporate or condense on airway walls with pertinent changes in wall temperatures. It can condense as fog in the bulk flow of the air with a concomitant change in the temperature gradient between airway walls and air. To be properly considered, these wall temperature changes have to be recorded. To keep the amount of record-keeping small, so-called stations in intervals of a few hundred feet are established, for which the correct data are recorded. For the space between stations, interpolations are used.

$$\frac{\partial T_r}{\partial t} = \alpha \left(\frac{\partial^2 T_r}{\partial R^2} + \frac{\partial T_r}{Rx \partial R} \right)$$

The governing equation was set up as:
subject to: $T_r = T_{rv}$ at t=0   for all R

            $T_r = T_{rv}$ when t>0 and R $\rightarrow \infty$

and the boundary condition equation:

$$\lambda \frac{\partial T_r}{\partial R} = hx(T_r - T_a) + L_w x D_t x(\phi x X_{ww} - X_w)\ atR = R_o$$

where: D_t = mass transfer coefficient,
       h   = heat transfer coefficient,
       L_w = latent heat of water at wall temperature,
       R   = coordinate in the radial direction,
       R_o = hydraulic radius of airway,
       t   = time,
       T_r = rock temperature,
       T_{rv} = initial rock temperature,
       T_a = air temperature,
       X_w = absolute humidity of air,
       X_{ww} = absolute humidity in the wall layer,
       α = thermal diffusivity,
       λ = thermal conductivity of rock, and
       ϕ = wetness of airway wall

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The governing equation of energy conservation describes the heat transfer in two superimposing processes: the heat transfer between airflow and its surroundings, and the enthalpy flux accompanying the mass transfer of water vapor. Assumptions for this model include: an airway of infinite length, homogeneity and isotropy of rock, negligible heat transfer in the axial direction of the airway, and constant thermal and heat transfer parameters.

In the boundary condition equation, the wetness of the wall is defined as the ratio of wet area to the total surface area. It is assumed that the wet portion and dry portion of a wall share a common humidity ratio and temperature in the wall film, a thin layer close to the wall. When the wall wetness equals the ratio of absolute humidity of air in the main air flow to that in the wall layer film, the vapor content in the wall film is in equilibrium with that of the main flow. The boundary conditions also imply that the mass transfer, or water evaporation and condensation from the wall, occurs in the vicinity of the wall, and the heat absorbed or liberated is either from or towards the wall.

A one-dimensional differential equation can then be set up for an infinitesimal control volume of air based on the energy conservation law. Its solution describes the air temperature variation along an airway on the basis of a known solution to the governing equation of heat transfer.

A non-dimensional wall temperature, frequently called the coefficient of age, is used to relate the governing equation of air-rock heat transfer and air temperature variation. Due to the fact that the initial condition of air temperature at the beginning junction of an airway is needed in computing the air temperature variation in the airway, the air temperature distribution in the ventilation system can only be calculated through an airway-by-airway process.

The air temperature in an airway is calculated as a temperature superposition of two processes. One process is the heat transfer between the airflow and its surroundings. The other is the mass transfer due to water evaporation and/or condensation. The solution is quite complicated and lengthy and is not included here for space and time reasons. (Chang and Greuer, 1985)

The key to solving the governing equation lies in the interpretation of the boundary condition in which the absolute humidity is a complicated function of temperature. The relationship between the saturated water vapor pressure and temperature is replaced by a series of linear segments. Then, the governing equation is separated into two sets of superimposing differential equations with boundary/initial conditions, which can be regarded as a dry air temperature model and a wet-case temperature correction model, respectively.

The superimposition of their solutions gives the air temperature variation for the process of simultaneous heat/mass transfer in the airways.

Though this model works well under normal mining conditions, in some cases, it may not be a good approximation to assume that humidity ratios of airflows into a common junction from different airways are equal to that in the junction. This situation can be corrected by measuring the humidity for each airway separately, if necessary. Another characteristic of the model is that the average wall temperature is used to evaluate the saturated vapor pressure in the wall layer of an airway. Because of this, a specified humidity ratio that conflicts with the model is physically possible. When the humidity ratio of air along an airway is decreasing due to vapor condensation on a wall, the wall wetness loses its meaning and can not be determined. To avoid this problem, the wetness of an airway under condensation must be explicitly specified.

The additional input requirements are simply the wetness of airway walls as a percentage of total surface area in each airway and the relative humidity in junctions.

2.8 MFIRE PERFORMANCE

Research was conducted to validate MFIRE's calculation of temperature distribution in an airway due to a mine fire, as temperatures are the most significant source of ventilation disturbances. Three fire tests were conducted at the Waldo Mine near Magdalena NM. The Waldo Mine is operated by New Mexico Institute of Mining and Technology for experimental and research purposes. Three experiments were conducted; two with wood and one with diesel fuel. A complete description of the mine and tests can be found in the Bureau Open File Report 80-93 "Waldo Mine Fire Experiments of March 1990" by Laage and Carigiet.

The fire site was instrumented in the Waldo Tunnel on the 9th level. Arrays of thermocouples and temperature sensing devices were placed downwind of the fire and into boreholes over the fire. The variation of heat flow rate to the rock was back calculated based on varying temperatures in the rock. The enthalpy changes in the airflow were obtained from the temperature sensing arrays.

Then MFIRE and its functions were used to model fires of constant heat influx for the duration of the experimental fires. The total modeled heat influx for each fire was equal to the fuel loading. Energy curves as functions of time were produced from the measured real fire temperatures and the temperatures predicted by MFIRE. These energy curves were integrated and then compared with the fuel loading from the fires.

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The total heat transfer to rock and air were also calculated. The ability of MFIRE is illustrated in the following two tables.

In Table 1, the total measured and total modeled heat transfer deviation from the actual fuel loading is shown as a percentage of total fuel loading. These deviations are quite small for full-scale fire tests and are near the experimental limits.

TABLE 1
HEAT TRANSFER DEVIATIONS, PERCENT

Experiment number	Measured heat transfer deviation	Modeled heat transfer deviation
1	– 2.5%	+ 2.3%
2	+ 4.1%	– 2.6%
3	– 6.0%	+ 2.8%

Table 2 compares the percentage of heat transferred to the airflow based on the actual fuel loading. This is an important comparison as the heat transfer to the air is the cause of the ventilation disturbances.

Table 2
HEAT TRANSFERRED TO AIRFLOW, PERCENT

Experiment	Heat transfer, measured	Heat transfer, modeled
1	92%	98%
2	96%	93%
3	88%	99%

There are, of course, many sources for experimental error and back calculation assumptions, however, a discussion of these is beyond the scope of this paper. These tables show a very close agreement between the measured and modeled heat transfer to the air as well as to the total fuel loading and these experiments illustrate the overall performance of MFIRE.

3.0 USER SELECTED REFERENCE DENSITY AND TEMPERATURES

3.1 THEORY OF REFERENCE DENSITY

Performing network calculations based on actual volume flow rates makes the consideration of the law of conservation of mass difficult. Most computer programs substitute a "law of volume conservation" instead. Although this may normally not lead to serious errors, it is definitely a serious error when, like in the heated air behind a fire, larger density changes occur. MFIRE is based on mass flow rates.

Three states of ventilation air are discussed in this chapter; the standard air with a density of 0.075 pounds per cubic foot and denoted with a subscript "$_s$", the reference air at a user selected state of density "w^*" and corresponding temperature "T^*" denoted with a superscript "$*$", and an actual in place state where only the variable is used. The reference density and temperature correspond to MFIRE input variables DR and TR respectivly.

Mass flow rates are calculated with the aid of a reference density, w^* and a corresponding reference temperature, T^*. To obtain output which comes close to the actual, density dependent, pressure losses, fan pressures, and volume flow rates, a constant reference density w^* which is close to the prevailing actual density w is used. If one prefers, one can select the standard density $w_s = 0.075$ lb/ft^3 as reference density w^*.

The "reference temperature" is the temperature pertinent to the "reference density" at the prevailing pressures in the ventilation system. It is not used for temperature calculations. Its sole purpose is to express the "reference density". Since it serves only as a scale against which other densities, expressed by their temperatures, are measured, its choice is not very crucial. Summarized with the use of a "reference density" the principle of basing pressure losses, fan pressures, and resistance factors on a standard density is extended to volume flow rates also.

Ventilation network calculations are based on the law of mass conservation and on the law of energy conservation. Unfortunately, we have become accustomed to express mass flow rates by volume flow rates, which are not conserved. And to express energies as ventilation pressures (ft-lb/ft^3 = lb/ft^2 α "wg) or work per unit volume, which leads for the same work due to changing volumes to different numbers for the energy. Many ventilation engineers convert pressure losses H_L, fan pressures H_F and resistance factors R to a standard density of $w_s = 0.075$ lb/ft^3. This gives a correct energy balance and leads in the calculation of pressure losses with

the formula $H_L = R * Q^2$ to correct values, when the actual flowing volume flow rate Q is used.

It has become customary in mining to express flow rates as volume flow rates (cfm = ft^3/min) and energies per unit volume.

$ft-lb/ft^3$ = lb/ft^2= 1/5.2 "wg

Air densities change. Equal mass flow rates result therefore in different volume flow rates and equal energy amounts in different energy amounts per unit volume. Since two of the basic laws used in mine ventilation are the law of mass conservation and the law of energy conservation, the above approach is not practical. It has nevertheless been retained by ventilation engineers, because they find it difficult to visualize mass flow rates in lb/min or energies in ft-lb/lb.

To provide correct energy balances, the U.S. Bureau of Mines has recommended the use of the constant standard density of 0.075 lb/ft^3 when expressing energies per unit volumes. This means essentially to express them as energies per unit mass. If, for instance, an airway has a pressure loss of

H_L = 0.5 "wg at the average air density w = 0.078 lb/ft^3 in the airway,

this would mean an energy of

0.5*5.2 = 2.6 $ft-lb/ft^3$ (lb/ft^2) or 2.6/0.078 = 33.33 ft-lb/lb (ft).

This is the figure which should be used, but since it is too abstract, it is multiplied by the standard density

w_s = 0.075 lb/ft^3.

H_{Ls} = 33.33 ft * 0.075 lb/ft^3 = 2.5 lb/ft^2 or 2.5/5.2 = 0.481 "wg.

Or: H_{Ls} = H_L $\dfrac{w_s}{w}$ = 0.5 $\dfrac{0.075}{0.078}$ = 0.481 "wg.

The same process is employed with all energies, fan pressures as well as pressure losses and natural ventilation pressures, which means that all energies are expressed per unit mass but are multiplied by a constant conversion factor of w_s = 0.075 lb/ft^3. If pressure losses are calculated using the familiar formulas:

H_L = $R*Q^2$

or H_L = $\dfrac{K*L*P*Q^2}{5.2 \ A^3}$, the actual densities w which are contained in

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R and K are replaced by w_s. This is done by multiplying

R or K by $\dfrac{w_s}{w}$:

$R_s = R * w_s/w$ or $K_s = K * w_s/w$

which converts H_L into H_{ls}. The airflow rates Q are in all cases the actual volume flow rates, which vary for constant mass flow rates $\dot{m}$ inversely proportional to the density:
$Q = \dot{m}/w$.

This poses difficulties in ventilation calculations since the law of mass conservation but not a law of volume conservation has to be satisfied.

3.11 AIRFLOW IN MINE PASSAGES

MFIRE input and output is in terms of volume flow rates Q^* at a reference state, which are actually mass flow rates $\dot{m}$ divided by a reference density w^*, irrespective of the magnitude of the actual density w:

$Q^* = Q * w/w^* = \dot{m}/w^*$.

The choice of the reference density is left to the program user. The closer it is to the actual densities w, the less confusion is generated. The term w^* plays the same role as the standard density w_s and if deemed practical, w^* can be selected to be equal to w_s. Mass based energies are then expressed by

$H_L^* = H_L * w^*/w$ or $H_L^* = H_{Ls} * w^*/w_s$

and the pertinent resistance factors by

$K^* = K * w^*/w$ or $K^* = K_s * w^*/w_s$

$R^* = R * w^*/w$ or $R^* = R_s * w^*/w_s$

Pressure loss H_L and volume flow rates Q are related by the familiar resistance equation $H_L = R*Q^2$. If a similar expression in terms of H_L^*, Q^* and R^* shall be used, one obtains from

$H_L^* = H_L * w^*/w$ and $Q^* = Q*w/w^*$ and $R^* = R * w^*/w$ or $R^* = R_s * w^*/w_s$:

$H_L^* = R^*(w^*/w)^2 Q^{*2}$
If in the equations $H_L = R*Q^2$ or $H_{Ls} = R_s*Q^{2,}$ the term H_L^* takes the place of H_L or H_{Ls} and Q^* the place of Q, then R and R_s have to be replaced by the term

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$R^*(w^*/w)^2$.

If density changes are caused by temperature changes, w^*/w can be replaced by

T/T^*,

where T^* is a reference temperature leading to the reference density w^*.

Example
An airway has the following dimensions: L = 1,000 ft; A = 64 ft^2; P = 32 ft;

At State 1, a density of w = 0.078 lb/ft^3, a volume flow rate of Q = 50,000 ft^3/min and a pressure loss of H_L = 0.610 "wg were measured. The mass flow rate is:
$\dot{m}$ = Q*w = 3,900 lb/min.

The resistance of the airway is

  R = H_L/Q^2 = 0.610/(0.5*10^5)^2 = 2.44*10^{-10} "wg/cfm^2.

Its K-factor is

  K = R*5.2*A^3/(L*P) = 103.94*10^{-10}lb*min^2/ft^4.

With a standard density of w_s = 0.075 lb/ft^3, this gives

R_s = 2.44*10^{-10}*0.075/0.078 = 2.346*10^{-10} "wg/cfm^2 and
K_s = 103.94*10^{-10}*0.075/0.078 = 99.942*10^{-10}lb*min^{2}ft^4.

With a reference density of w^* = 0.074 lb/ft^3 this gives
 R^* = R*w^*/w = 2.44*10^{-10}*0.074/0.078 = 2.315*10^{-10} "wg/cfm^2 or
 R^* = R_s*w^*/w_s = 2.346*10^{-10}*0.074/0.075 = 2.315*10^{-10} "wg/cfm^2.

The conversion of K-factors is equivalent. The energy losses are:

H_L = R*Q^2 = 2.44(0.5)^2 = 0.610 "wg
H_{Ls} = R_s*Q^2 = 2.346(0.5)^2 = 0.587 "wg
H_L^* = R^*(w*/w)^{2}Q^{2*} = 2.315(0.074/0.078)^2(0.52703)^2 = 0.579 "wg

All three energy terms express the same energy per unit mass:

H_L/w = 0.610*5.2/0.078 = 40.7 ft-lb/lb
H_{Ls}/w_s = 0.587*5.2/0.075 = 40.7 ft-lb/lb

$H_L^*/w^* = 0.579*5.2/0.074 = 40.7$ ft-lb/lb

In State 2, the mass flowrate remains constant but the density changes from:
 w = 0.078 to
 w = 0.070 lb/ft^3,
 which results in a volume flowrate of

Q = 50,000*0.078/0.070 = 55,714 cfm and $Q^* = \dot{m}/w^* = 52,703$ cfm.

Then:

$H_L = R*Q^2 = 2.44 (0.070/0.078) 0.55714^2 = 0.680$ "wg
$H_{Ls} = R_s*Q^2 = 2.346 * 0.55714^2 = 0.728$ "wg
$H_L^* = R^*(w^*/w)^2 Q^2 = 2.315 (0.074/0.070)^2 0.52703^2 = 0.719$ "wg

Again, all three terms express the same energy.

$H_L/w = 0.680*5.2/0.070 = 50.5$ ft-lb/lb
$H_{Ls}/w_s = 0.728*5.2/0.075 = 50.5$ ft-lb/lb
$H_L^*/w^* = 0.719*5.2/0.074 = 50.5$ ft-lb/lb

	State 1 w = 0.078 lb/ft^3	State 2 w = 0.070lb/ft^3	w_1/w_2 = 1.11	
H_L	0.610	0.680	H_{L1}/H_{L2} = 1/1.11	H_L α 1/w
H_{ls}	0.587	0.728	H_{Ls1}/H_{Ls2} = 1/1.24	H_{Ls} α 1/w^2
H_L^*	0.579	0.719	H_{L1}^*/H_{L2}^* = 1/1.24	H_L^* α 1/w^2

3.12 Pressure PRODUCTION OF FANS

When energy exchanges between fans and air are expressed per mass unit of air (h_F, fanheads), they are functions of air and impeller velocities only. Fan airflow rates Q_F are not influenced by air densities. When energies are expressed per unit volume (H_F, fan pressures), they are proportional to the air density, since the correlation between masses and volumes is the density w.

Consequently, if a fan characteristic $H_{F1} = f(Q_F,w_1)$ is based on a certain air density w_1, the fan and airspeeds (and therefore the volume flow rate Q_F) are kept constant, and the fan is made to work with a different density w_2, the new characteristic

w_2

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$H_{F2} = f(Q_F, w_2)$ can be obtained from $H_{F2} = \dfrac{}{w_1} * f(Q_F, w_1)$

If the characteristic has been given for a standard air density $w_s = 0.075$ lb/ft^3 (when fan characteristics are quoted by manufacturers) the pertinent fan would at a density of w have the characteristic:

$$H_F = \frac{w}{w_s} * f(Q_F, w_s).$$

The airflow rate Q_F is in all cases the actual volume flow rate of the air passing through the fan. When standardized volume flow rates Q^* are used, one has to remember that they are actually mass flow rates divided by a constant reference density w^*:

$$Q_F = \dot{m} / w^*.$$

The actual volume flowrate Q_F of the air through the fan, which controls the energy exchange, is therefore

$$Q_F = Q_F^* (w^*/w).$$

The fan pressure H_F^*, based on a reference density w^*, is

$$H_F^* = H_{FS} (w^*/w_s) \text{ or } H_F^* = H_F (w^*/w).$$

The consequence for basing ventilation network calculations on reference densities is that if fan characteristics have been given:

for actual densities w as $H_F = f(Q_F, w)$

or for standardized densities w_s as $H_{FS} = f(Q_F, w_s)$

they have to be transformed to

$$H_F^* = \frac{w^*}{w} * f(Q_F^* (w^*/w)) \text{ or to}$$

$$H_F^* = \frac{w^*}{w_s} * f(Q_F^* (w^*/w)).$$

Example

The pressure H_{F1} of a fan has at a density of $w_1 = 0.078$ lb/ft^3 and at several airflow rates Q_F been determined as

$$H_{F1} = 1.0 - 2.0 (Q_F * 10^{-5} - 0.4) \text{ "wg}$$

If the density of the air passing through the fan changes to $w_2 = 0.070$ lb/ft^3, one will observe a fan characteristic of

$$H_{F2} = (w_2/w_1) (1.0 - 2.0 (Q_F*10^{-5} - 0.3)) \text{ "wg}$$

If the density changes to $w_s = 0.075$ lb/ft^3, one will observe

$$H_{Fs} = (w_s/w_1) (1.0 - 2.0 (Q_F*10^{-5} - 0.3)) \text{ "wg}$$

It is assumed that this fan works in series with the above described tunnel of 1,000 ft length and 64 ft^2 cross sectional area. The resistance factor of this tunnel had been determined as

$R_1 = 2.44*10^{-10}$ "wg/cfm^2 at a density of $w_1 = 0.078$ lb/ft^3
$R_2 = (w_2/w_1) R_1$ "wg/cfm^2 at a density of $w_2 = 0.070$ lb/ft^3
$R_s = (w_s/w_1) R_1$ "wg/cfm^2 at a density of $w_s = 0.075$ lb/ft^3

Pressure loss in the tunnel H_L and fan pressure H_F balance each other. Air flow rates in the tunnel Q and through the fan Q_F must be equal. One obtains for all three air densities.

$R_1 * Q^2 = 1 - 2.0 (Q_F *10^{-5} - 0.3)$
$Q = Q_F = 49,770$ cfm.

This phenomenon of constant flow rates of air through an airway in series with a fan irrespective of varying densities is to be expected. Pressure losses as well as fan pressures are directly proportional to the density and rise and fall therefore simultaneously.

The use of reference units w^*, Q^*, Q_F^*, H_L^*, and H_F^* should naturally give the same answers as obtained above. One has however to bear in mind that all of these reference units are mass units used at different densities. If, for instance, the volume flow rate Q remains constant but the density w changes, the reference density volume flow rate Q^*, which expresses actually the mass flow rate, will have to change also.

With $H_L^* = R^*(w^*/w)^2Q^{*2}$, $w^* = 0.074$ lb/ft^3, $w_1 = 0.078$ lb/ft^3 and

$w_s = 0.075$ lb/ft^3

and $R_1^* = R_1 \ (w^*/w_1)$
    $R_2^* = R_2 \ (w^*/w_2) = R_1 \ (w_2/w_1) \ (w^*/w_2) = R_1^*$
    $R_3^* = R_3 \ (w^*/w_3) = R_1 \ (w_3/w_1) \ (w^*/w_3) = R_1^*$

one obtains for the pressure losses in the above described tunnel:

$H_{L1}^* = R_1 \ (w^*/w_1) \ (w^*/w_1)^2 \ Q_1^{*2} = R_1^* \ (w^*/w_1)^2 \ Q_1^{*2}$

$$= 2.315*10^{-10} (0.074/0.078)^2 Q_1^{*2} = 2.084*10^{-10} * Q_1^{*2}$$

$$H_{L2}^* = R_1^* (0.074/0.070)^2 Q_2^{*2} = 2.587*10^{-10} * Q_2^{*2}$$

$$H_{Ls}^* = R_1^* (0.074/0.075)^2 Q_s^{*2} = 2.254*10^{-10} * Q_s^{*2}$$

The above described fan characteristic of

$$H_{F1} = 1.0 - 2.0 (Q_F * 10^{-5} - 0.3)$$

for $w_1 = 0.078$ lb/ft^3 has to be transformed to

$$H_{F1}^* = (0.074/0.078) (1.0 - 2.0 (Q_1^* (w^*/w_1) * 10^{-5} - 0.3))$$
$$H_{F2}^* = (0.074/0.078) (1.0 - 2.0 (Q_2^* (w^*/w_2) * 10^{-5} - 0.3))$$
$$H_{Fs}^* = (0.074/0.078) (1.0 - 2.0 (Q_s^* (w^*/w_s) * 10^{-5} - 0.3))$$

The following table compiles some of the data from these formulas.

w (lb/ft^3)	Q^* cfm	$Q^*(w^*/w)$ cfm	H_L^* "wg	H_F^* "wg	$H_L^*(w/w^*)$ "wg	R^* "wg/cfm^2
$w_1 = 0.078$	52,460	49,770	0.5735	0.5735	0.6044	$2.315*10^{-10}$
$w_2 = 0.070$	47,080	49,770	0.5735	0.5735	0.5424	$2.315*10^{-10}$
$w_s = 0.075$	50,443	49,770	0.5735	0.5735	0.5812	$2.315*10^{-10}$

The hypothetical volume flow rates Q^*, which stand for mass flow rates, vary. Multiplied by (w^*/w) one obtains from them the actual flowing volume flow rates $Q = Q^* (w^*/w)$, and they remain constant. The hypothetical pressure losses H_L^* and fan pressures H_F^*, which stand for energies per unit mass or for heads, remain constant. The pressure losses $H_L = H_L^* (w^*/w)$, which stand for energies per unit volume, change with the air density. The resistance factor R^* remains constant, which is a pleasant feature of the use of reference densities. After all, the resistance is a property of the airway and is not changed by ventilation conditions.

3.2 MFIRE INPUT

MFIRE works with masses and reference densities. **All input and output energy and airflows are at the reference state.** That means that the input data for airway resistances are R^*, for air flow rates in fixed quantity airways Q^*, and for pressures in constant pressure sources H_N^* and H_F^*. The friction factor K is at the standard state of 0.075 lb/ft^3 as this is most commonly reported in tables and only used when actual measurements for R

are not available. Resistances calculated with the K factor are
adjusted to the reference state as:

$$R^* = \frac{K*L*P}{5.2 \ A^3} \quad \frac{w^*}{0.075}$$

Most data on fan characteristics are transformed to the standard
density of $w_s = 0.075$ lb/ft^3, before communicated by the
manufacturers or filed by the users. These fan characteristic
must be transformed to the reference state.

When density changes are caused by temperatures, the ratio of
<u>absolute</u> temperatures are used to convert to the reference state.
 The ratio T/T^* is:

$$\frac{\text{in place Temperature} + 460}{\text{reference temperature} + 460}$$

and usually offers only small changes to the ventilation data if
a representative reference state is selected.

3.21 MFIRE CONVERSION RULES

Variable	To convert to reference state
resistance R measured	$R^* = R * w^*/w$ or $R^* = R * T/T^*$
resistance R user calculated	$R^* = R * w^*/w$ or $R^* = R * T/T^*$
resistance R MFIRE calculated	input standard K, length, area, perimeter
Airflow Q measured	$Q^* = Q * w/w^*$ or $Q^* = Q * T^*/T$
Airflow Q to be calculated	estimate Q
friction factor K	Input at standard density of 0.075
fan curve data QF airflow	Remains unchanged
fan curve data PF or H_{fan} pressure	$H_{fan}^* = H_{fan} * w^*/w$ or $H_{fan}^* = H_{fan} * T/T^*$
Fixed pressure fan	$H_{fan}^* = H_{fan} * w^*/w$ or $H_{fan}^* = H_{fan} * T/T^*$
Fixed airflow Q	$Q^* = Q * w/w^*$ or $Q^* = Q * T^*/T$

4.0 PROGRAM INSTALLATION AND OPERATION

The program MFIRE 2.20 consists of three executables: MFIRE0.EXE, MFIRE1.EXE and MFIRE2.EXE. The execution, control and intermediate file handling is handled by a batch file,

MFIRE 2.20 was compiled with Microway FORTRAN and the royalty free ERGO DOS memory extender was bound into the executable. The ERGO DOS memory extender is not compatible with some memory managers. If difficulties are encountered, temporarily disable your memory manager. Networks of up to 500 airways and 350 junctions can be modeled. Input for MFIRE is in the form of a data file. The data file contains lines of numerical data describing the physical mine, the ventilation parameters present, the fans, and the proposed thermal or mechanical disturbances.

Output from MFIRE is sent to the file MFIRE.OUT which is created in the directory where the MFIRE program resides. The output can have up to four levels of increasing detail. Subsequent executions of MFIRE will overwrite the old MFIRE.OUT file with the new MFIRE.OUT file. If archiving of MFIRE.OUT files is desired, they can be renamed with the DOS RENAME command to prevent overwriting. The WFOUT file can be reviewed and/or printed with text editing software.

The equipment and additional software necessary to use MFIRE includes:

1. IBM[1] PC or compatible computer with MS or PC DOS 3.3 or later version;
2. hard disk drive with at least 2 megabytes of disk space;
3. Intel 80386 CPU and 80387 or compatible math-coprocessor;
4. at least 1 Megabytes RAM; and
5. a text editor or suitable word processor. To install the program, the user should make a directory on the hard disk drive. The contents of the program disk are then copied into that directory.

To start MFIRE 2.20, the user types "MFIRE" and follows the
instructions for user responses and the location of the data
file. Two screens of information about the program are presented
followed by a prompt for the user to identify the location of the
data file. The user responds with a standard DOS path and
filename for the input data file. After a data file name is
entered, depending upon the user defined selection of program
features, MFIRE will sequentially perform:

1) General network balancing of volumetric air flow rates.

2) Network balancing considering temperatures, heat exchange with
rock, and natural ventilation. This network balancing involves
balancing the pressure losses and gains in the network meshes to
accommodate mass based flow rates.

3) Dynamic, transient state modeling with user selected dynamic
fire growth and user selected time increments for updating the
ventilation changes and spread of contaminants.

4) Calculation of new ventilation equilibrium due to contaminant
(fire) presence, and distribution of the contaminants (POC,
methane, etc) under the altered steady state conditions.

4.1 CHANGES IN MFIRE 2.20 FROM PREVIOUS VERSIONS

Bug type fixes are described in detail in the file "README.220"
on the distribution disk.

MFIRE 2.20 removed the humidity calculations available in
versions 2.0/2.1.

For the slection of fan curve fitting, the cubic spline and least
squares methods are available. For the handling of the boundary
region of the fan curve, there are three choices: 1) the slopes
of the both right and left boundary region of fan curve are same
as that at the most right and left data points of input fan
characteristic curve or 2) the slope of the right boundary region
of fan curve is sent to zero or 3) the slopes of right and left
boundary region of fan curve are sent to zero. The flexible
choices for fan curve fitting method and the handling of boundary
region of fan curve improve the common suitability and
calculation convergence of program MFIRE for various input data
sets.

5.0 INPUT DATA FILES

Numerical data or input files are used to describe the mine's
ventilation system and physical characteristics necessary for
ventilation calculations as well as the physical or mechanical
disturbance to be modeled and simulated. Data lines are read by
the program and the data items are used to provide information to
the program variables. The data file is in ASCII format,
sometimes called a DOS text format. Creation or modification of a
data file is accomplished with text editor software. Most word
processors are also capable of making the required ASCII type
files. Sample data files are included on the program disk.

When selecting software for editing the data files, the user
should be aware that the software will also be used for viewing
the output of the simulation. An editor or word processor capable
of unlimited file size is necessary. The output file can be
quite large (several megabytes) if a lengthy simulation is
performed. The output can be sent to a printer for a hardcopy
listing however, the user should also be aware that most printers
currently used with PCs print at rates of 100 to 300 characters
per second and large output files may take several hours to
print. Viewing the output with a text editor can save much time
and paper.

5.1 GENERAL STRUCTURE OF DATA FILE

MFIRE 2.20 allows the comment lines utilized by version 1.29. Any
line with a dollar sign "$" in the first column is ignored.
These lines may be used to easily remove or change data such as
fan curves or fire events and to annotate the data file.

Altogether, data lines comprise the following
data groups.

Control line number 1
Airway lines
Junction lines (optional)
Fan lines (optional)
Fire source lines (optional)
Control line number 2 (optional)
Average-value lines (optional)
Time table lines defining condition changes (optional)

A data file must be set up according to the input requirements.
Because errors tend to occur in the preparation of data file, a
template file, INPUT.FMT was created (Appendix 2 of this User
manual). This file consists of instruction lines detailing the
data line groups in the required order and the location of each

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data item on each line as well as the meaning of each data item required. This file serves to remind and prompt the user for data lines and items at the proper locations.

To use the template, simply copy the file INPUTW.FMT to the data disk space, and add data into the data file by adding lines at proper places and following the instructions given in the INPUT.FMT file. The user can then use the DOS RENAME command to uniquely identify the new data file.

5.2 DATA FORMAT

1. Distinction between an integer and a real number is not required. Integer 5 can be 5, or 5.0 in the data file. Real number 3.0 can be 3 or 3.0 in the data file.

2. A comma and a blank space can be used interchangeably as delimiters to separate input values. Two or more blank spaces adjacent to one another act as one blank in separating input values. Blank spaces adjacent to a comma have no effect in separating input values.

3. Zero values can be omitted, but the related delimiters (commas) must be present.

For example, if input is needed for the following data items:
N,R,S,I,T,L,P,M

where: N=5; R=10; S=7.52; I=0; T=-4; L=0; P=0; and M=0

then the following input lines would have the same effect.

5,10.0,7.52,0,-4.0,0,0.0,0
5 10 7.52 0 -4 0 0 0
5 10 7.52 , , -4,,,,

5.3 CHANGES IN MFIRE 2.20 DATA FILE FROM PREVIOUS VERSIONS

1. In Control Line 1, TOUT and CONCT have returned

2. The Surface Data Junction group have returned.

3. The time table of vbersion 1.29 has returned.

4. Comment and Instruction lines are accepted.

5. The variable "NSWT" was added as the the third variable on fan line number 1 to select the fan curve fitting method.

6. The variable "NPLOT" was added as the third fan line to select

the treatment of curve boundry conditions.

5.4 DETAILED DESCRIPTION OF DATA INPUT REQUIREMENTS

1. Control Line number 1 consists of the following variables:

NB,NFNUM,INFLOW,NVPN,NETW,TR,MADJ,ITN,NTEMP,TINC,SPAN,IOUT,TOUT,CONCT,DR

where:

NB is the number of airways in the network. Maximum NB is 500.

NFNUM is the number of fans which have characteristic curve input data. Maximum NFNUM is 10.

INFLOW is the number of contamination sources in the system. Maximum INFLOW is 10.

NVPN is a flag. If there are junction cards to be read in, NVPN must be equal to or less than zero. The junction lines must be omitted if NVPN is greater than zero. When the junction cards are omitted, only the network simulation will be performed.

NETW is a flag. When NETW equals 1, only the network simulation will be performed. The output will consist of conventional network calculations without consideration of contaminant sources.

TR is the reference or air average temperature in the mine in degrees F. If the input value of TR is less than 10 F or higher than 110 F., the default value of 75 F. will be used.

MADJ is the maximum number of iterations in the temperature section. If its input is less than 10 or larger than 80, the default value of 15 will be used.

ITN is the maximum number of iterations in the dynamic simulation section. If its input is less than 10 or larger than 80, the default value of 15 will be used.

NTEMP is a flag. When NTEMP equals 1, only network balancing with consideration of temperature effects are performed. Set NTEMP equal to 0 for the simulation to proceed to transient state and fire modeling.

TINC is the time increment for the dynamic simulation section in sec. If the input value is 0 or less, default value of 15 sec. will be used.

SPAN is the time span for the dynamic simulation of the proposed event in min. The default value is 5 minutes.

IOUT is a marker to define the level of detail of the output file where: 0=brief; 1=normal; -1=detailed; and -2 = most detailed.

TOUT is the time interval for output in minutes. If events are changing significantly, it is not followed.

CONCT is a flag used during development. Set to 0.

DR is the reference density in pounds per cubic foot of air corresponding to the reference temperature, TR.

2. Airway lines. Each line describes a single branch in the network to be modeled. Each line consists of the following variables:

NO,JS,JF,NWTYP,R,Q,KF,LA,A,O,HA,HK,CH4V,CH4PA,TROCK

Where:

NO is the airway identification number (ID). NO must be between 1 and 9980.

JS is the starting junction ID number of the airway. JS must be between 1 and 999.

JF is the ending junction ID number of the airway. JF must be between 1 and 999.

NWTYP is the marker for airway type. Values of NWTYP can be: 1 = fan branch (with zero airflow resistance); 0 = normal airway; and -1 = fixed quantity airway (regulator). A regulator will be converted to a normal airway or fan branch after the network balancing is performed depending upon the method by which the user-specified airflow requirement can be satisfied. During the simulation, a fire source branch will automatically be given NWTYP value of 1.

R is the resistance of a normal airway in $1.0*E^{-10}$ in. w.g./$(cfm)^2$. When the input value of R is equal to or less than 0, R will be

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calculated from KF, LA, A and O. If these input data items are not complete, an error message will be issued.

When the input value of R is larger than zero, it will override the value calculated from KF, LA, A and O.

For a fan branch (NWTYP=1), R is the fan pressure in in. w.g. A fan without input for its characteristic curve will be regarded as a fixed-pressure fan and the value of R will be used to define the fan pressure.

Q is the volume airflow rate in the branch in CFM.

KF is the friction factor in $1.0*E^{-10}$ $lbm*min^2/ft^4$. The default value is 100. (Typical Friction Factor values are shown in Table 5 in Appendix 1 of this manual.)

LA is the length of the airway in ft. The default value is 500.

A is the cross-sectional area of airway in ft^2. The default value is 100.0.

O is the perimeter of airway in ft. The default value is 40.0.

HA is the thermal diffusivity of rock in ft^2/hr. The default value is 0.1.

HK is the thermal conductivity of rock in BTU/hr*ft*F The default value is 3.0. (Typical values for HA and HK for various rock types are shown in Table 6 in Appendix 3 of this manual.)

CH4V is the methane emission rate for the whole airway in ft^3/min under the reference conditions (1 atmosphere and TR). If CH4V is zero or less, the methane emission rate in the airway will be calculated from CH4PA.

CH4PA is the methane emission rate per unit surface area of the airway in $ft^3/min*ft^2$ under the reference conditions. If CH4PA is input as zero or less, the methane emission rate will be calculated from the methane concentration in junctions (CH4C). If both CH4V and CH4PA are 0, methane emissions are not considered.

TROCK is the rock temperature in deg. F. of the airway (quasi-equilibrium wall surface temperature before the fire started). It is normally calculated in the program run and does not require input from the user. If the user has better data available, it may be input here to override the calculated value. The acceptable range of user specified rock temperature is from 0 F to 150 F.

3. Junction Lines section 1 are used to describe conditions and locations of the junctions. When NVPN is negative or zero, each junction referenced in the airway data section must have a one line input. Otherwise, the junction lines must be omitted.

Junction Lines section 1 consist of four variables:

JNO,T,Z,CH4C

where,

JNO is the junction ID number. It must be between 1 and 999.

T is the junction temperature in degrees F.

Z is the junction elevation in ft. above a datum level.

CH4C is the methane concentration in pct in the junction. (optional)

Junction lines section 2 identifies atmospheric junctions. These are used when the ventilation system has multiple atmospheric junctions with different elevations. The junctions should be connected with very low resistance and hoigh airflow branches wich represent the surface connection between the junctions. Junction lines section 2 consists of three variables: JAN, JA, JATP where:

JAN is the number of atmospheric junctions. JAN is on the first line of the data group. If only one junction is in the atmosphere, JAN is 1 and JA and JATP are not used.

The rest of the data group consists oflines; each line describing an atmospheric junction with : JA and JATP where:

JA is the ID number of the atmoispheric junction

JATP is a marker for the type of the atmospheric junction. 0 is the value for the starting junction for the simulation and 1 is th value for all other atmospheric junctions.

4. Fan description consists of three lines. Fan line number 1 consists of three variables:

NOF, MPTS, and NSWT

where,

NOF is the ID number of the airway in which the fan is located.

MPTS is the number of data pairs describing the fan characteristics. Maximum MPTS is 10.

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NSWT is a marker to select the type of curve fitting. 1 selects least squares; 2 selects the spline method; 3 allows the computer to auto select and 4 is a combination of manual and automatic.

5. Fan line number 2 consists of data pairs describing the fan characteristic curve in the form:

QF,PF, QF,PF, QF,PF, QF,PF, QF,PF

Where QF is the airflow through the fan in cfm and PF is the fan pressure in in. w.g. corresponding to QF. For each data point, a pair of QF and PF data must be specified. Up to 5 pairs of QF and PF data points may be on a line. A maximum of 10 data points or two lines may be used to describe the fan characteristics. The line order of the input points of the fan curve must be in ascending numerical order from small QF to large QF.

Fan lines numbers 1 and 2 describe one fan. Additional fans are described by adding another set of fan lines numbers 1 and 2. The number of fans described here must equal NFNUM on control line number 1. If NFNUM is zero or less, fan lines 1 and 2 must be omitted.

Fan line nimber thee consists of one variable NPLOT. NPLOT selects the treatment of the fan curve in regions undefined by the fan data set. If NPLOT=1, the curve is extended following it's gradient at both ends. If NPLOT=2, the left boundry is extended following it's gradient and the right boundry is sent to zero. If NPLOT=3, both boundries are sent to zero.

6. Contamination (fire source) lines consist of up to nine variables. Data item INFLOW in control line number 1 indicates the number of contamination sources that are present in the ventilation system. Each of the contamination sources requires a one line data input. If the input value of INFLOW in control line number 1 is zero or less, contamination lines must be omitted.

Contamination lines may include the following data items:

NCENT,CONT,CONC,HEAT,O2MIN,SMPO2,HTPO2,QCENT,TPR

where,

NCENT is the ID number of the airway with a fire source located at the entrance of the incoming airflow.

CONT is the contaminated gas inflow from the contamination source in cfm.

CONC is the concentration of fumes in the contaminated gas, CONT, in pct.

HEAT is the heat influx at the fire source in Btu/min.

O2MIN is the oxygen concentration leaving the fire source in pct.

SMPO2 is the fume production in ft^3 for each ft^3 of oxygen reaching the fire source.

HTPO2 is the heat generation in BTU for each ft^3 of oxygen reaching the fire source.

CONT, CONC and HEAT define a fixed heat input fire source. O2MIN defines an oxygen rich fire. SMPO2 and HTPO2 define a fuel rich fire. When they all have non zero input values, the oxygen rich model overrides fixed heat input fire model, while the fuel rich fire model overrides the oxygen rich model. The oxygen rich and fuel rich fires are primarily research tools. While the oxygen rich and fuel rich fire models were retained in MFIRE 2.0, the fixed heat output model will be suitable for most mining uses.

QCENT is the reference airflow in ft^3 at which the above parameters are defined. When the airflow is less than or greater than QCENT, the heat generation from the fire source will decrease or increase accordingly but in a damped fashion. If QCENT is less than 10 cfm, the damping is not performed.

TPR is the leading time period in min. for an oxygen rich fire to reach full strength. Heat generation is calculated from available oxygen. Increasing the airflow to a fire will increase heat output, however the heat output will lag the increased airflow. The quantity of lag will vary with the fuel type and is user defined with TPR. The effect is linear over the time TPR.

9. Control Line number 2 consists of the following variables:

NAV,JSTART,TSTART,TIME,CRITSM,CRITGS,CRITHT,WRNPR,WRNSM,WRNGS, WRNHT

where:

NAV is a marker. If NAV is 1 or larger an average value card is present in the data file to supply required values which may have been omitted in the data file.

JSTART is the ID number of starting junction in the ventilation system. At the junction of JSTART (usually the atmosphere), conditions never change .

TSTART is the air temperature at the starting junction in deg. F.

TIME: time span to assume quasi-equilibrium in hrs. Default 5.

CRITSM is the accuracy criterion for fume calculation in pct. The default value is 0.005.

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CRITGS is the accuracy criterion for methane calculation in pct. The default value is 0.01.

CRITHT is the accuracy criterion for temperature calculation in deg. F. The default value is 0.1.

WRNPR is the pressure drop criterion in in. w.g. for issuing a warning message. The default value is 0.01.

WRNSM is the fume concentration criterion in pct. for issuing a warning message. The default value is 0.05.

WRNGS is the methane concentration criterion in pct. for issuing a warning message. The default value is 1.0.

WRNHT is the high temperature criterion in deg. F for issuing a warning message. The default value is 100.0 degrees F.

The last seven data items serve as calculation accuracy criteria or warning message issuing criteria. In most cases, the available default values will be suitable. To activate the respective default values, place a zero at that location in the data file.

10. The average value line consists of a set of average values for data items which are required for the program to run. The average value line supplies these data items if they can not be obtained from the data file or default values. These items are used to supply unknown or omitted data. The presence of an average value line is indicated by a value of 1 or greater for the variable NAV in control line number 2. These items include:

HAAVR,HKAVR,KFAVR,LAAVR,AAVR,OAVR
where,

HAAVR is the average thermal diffusivity of rock in ft^2/hr. The default value is 0.1.

HKAVR is the average thermal conductivity of rock in Btu/hr*ft*F. The default value is 3.0.

KFAVR is the average friction factor in $1.0*E^{-10}$ $lbm*min^2/ft^4$. The default value is 100.

LAAVR is the average length of an airway in ft. The default value is 500.

AAVR is the average cross sectional area of an airway in ft^2. The default value is 100.0.

OAVR is the average perimeter of an airway in ft. The default value 40.0

To select a default value, use zero for the respective data item. If the entire set of default values are to be used, set NAV=0 on control line number 2 and omit the average value line.

Time table lines for describing condition changes during the dynamic simulation can consist of seven types of condition changes related to the variable ICODE. Each event is described by one line of data variables. The general input scheme for the line is: TS, ICODE and related data. TS indicates the starting time of the condition change, and ICODE defines the nature of the condition change. NBR identifies the airway where the event occurs. There is no limit for the number of events. The order of events must be from small TS to large TS. Time table lines, ICODEs and the parameters are defined as:

        TS,1,NBR,R

The ICODE 1 changes branch "NBR" to an ordinary airway with airflow resistance equal to "R" at "TS" minutes after time=0. "R" is expressed in 1.E-10 inches W.G./(CFM)^2.

        TS,2,NBR,INDEX
        QF1,PF1,QF2,PF2,QF3,PF3,QF4,PF4,QF5,PF5

The ICODE 2 changes branch "NBR" to a fan branch. The fan is described by "INDEX" number of points on its fan curve. A maximum of 5 points is allowed. Each point on the fan curve is defined by an airflow quantity (QF) and corresponding pressure (PF) value. Quantity is expressed in ft^3/min and pressure is expressed in inches W.G. The points must be listed in ascending order of QF.

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TS,3   NBR,CONT,CONC,HEAT,02MIN,SMPO2,HTPO2,QCENT,TPR

The ICODE 3 changes branch "NBR" to a fire source branch at "TS"
minutes after time=0. The remaining variables CONT, CONC, HEAT,
O2MIN, SMPO2, HTPO2, QCENT, TPR retain the same meanings and are
expressed in the same units as in the contamination source line.

        TS,4,NBR

The ICODE 4 changes fire source branch "NBR" to an ordinary
airway at time "TS" minutes after time=0.

        TS,5,TINC

This input changes the time increment of the dynamic simulation
to a new value "TINC" at "TS" minutes after time=0. "TINC" is
expressed in seconds.

        TS,6,TOUT

The time interval for output is changed to TOUT at TS minutes
after time zero.

        TS,7,JDPP

At time TS detgailed output results will be shown for airways on
the immediate down stream side of the junction JDPP.

6.0 OUTPUT FILES

All output is saved in the file MFIRE.OUT in the directory and/or disk containing the program. The file name MFIRE.OUT is hard-coded into the program. Subsequent MFIRE runs will over write the old file. Simply rename the old MFIRER.OUT file if archiving is desired. The file can be inspected with a text processor and sent to a printer, if needed.

6.1 CONTENTS OF THE OUTPUT FILE

The comment lines, reference temperature, air density, a table of the units of measure for the results and the average values are shown at the start of MFIRE.OUT.

All input data will be shown in the output file if IOUT on Control line number 1 is -1 or less. For each contamination source, a new branch will automatically be set up. The new airway and junction ID numbers will not interfere with the original numbering scheme of the data file.

Next are the results of the selected simulation(s) in the following order: network balancing, network balancing considering temperatures, transient state modeling, and altered equilibrium due to fire and distribution of the contaminants.

Depending upon the contents of the data file and the simulation selected, attention, warning, and error message will be shown at locations where calculations resulted in unusual conditions.

7.0 MFIRE   ERRORS

The usual run time errors will occur when illegal mathematical operations are attempted by MFIRE. A variety of memory management errors are possible as well. MFIRE will run best on a "plain" DOS machine. Disabling non compatible memory managers will usually allow MFIRE to execute.

7.1 DATA FILE ERRORS

Two types of data file errors can occur.

1. An error may occur because the input data file itself is invalid. This may be caused by:

The data file can not be found due to incorrect spelling, drive or path specification. Check the spelling and path at the prompt for location of the data file.

The data file contains non-ASCII symbols. Check the operation of the text processor to insure that only ASCII characters are produced. Delete all non ASCII and/or all out of place characters.

2. Data are accepted by the program, but are incorrect for the data types or ranges or the combination causes a data inconsistency. This may be due to:

An invalid character is located where a numerical value is required.

The input data value is outside the reasonable range.

The input data is insufficient to build the model for simulation.

The input data exceeds the capacity of the program.

7.2 PROGRAM ERROR DETECTION

When the program is running, tracing messages are given on the screen indicating the group and lines of data that have been read and the section of the program that is executing. Program termination indicates that problems are caused by the subsequent (not read) data file section.

For each detected error, a descriptive message starting with:
                * ERR *
is issued and the program terminates.

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When a possibly wrong value and/or its calculated intermediate
result is detected, a descriptive message starting with:
                    * WRN *
is issued and the program continues.

If a modification of input value or calculated intermediate result
is automatically made by the program, a descriptive message
starting with:
                    * ATTN *
is issued and the program continues.

7.3 LOCATING ERRORS

If a message indicates that the error condition occurred due to the
data input file, locate the line and the value of input data item
which caused the error with the screen message, output file message
and the lists of input data.

If no error message is issued but the simulation results are not as
expected, carefully check the list of input data shown in the
output file.

WARNING messages and ATTENTION messages may reveal an error in the
input data even though the program continues to operate. Insure
that the default values or modifications adopted by the program run
are acceptable.

Anomalistic data, though not necessarily incorrect or impossible,
may lead to an anomalous simulation. For example, making a fan
unusually powerful may prevent a normal strength fire from
affecting the airflow distribution in the system. Much care must be
employed before considering an extreme case.   If a message
indicates that the accuracy criterion in the temperature section of
the program was not satisfied, a table detailing the current
parameters of airways which have large fluctuation in the average
air temperature from iteration to iteration is produced. If the
pattern of the parameters is clearly cyclical while the variation
of natural ventilation pressure is stable or cyclical from
iteration to iteration, then, most likely there is no single
equilibrium stage for the event. If the variation of natural
ventilation pressure decreases steadily though slowly, increasing
the value of data item variables MADJ or ITN (on control line
number 1) may allow convergence.

8.0 MODELING FIRES

This section outlines procedures for using MFIRE to model fire events in a mine. The following subsections describe the three types of fires MFIRE can model, criteria for choosing the most suitable fire type for a given situation, specifying the numerical parameters which define a given fire, and interpreting MFIRE output resulting from a fire simulation. A variety of case examples are provided which illustrate the methods discussed. Various data tables are included in the Appendix which can be used to help specify fire parameters.

MFIRE was originally developed as a research tool to aid in analyzing the complex interactions between fires and mine ventilation systems. The primary emphasis was on ventilation aspects, however the method of modeling fires is also quite involved. A thorough understanding of MFIRE's fire models is therefore required if meaningful fire simulation results are to be achieved.

8.1 General Information and Basic Assumptions

MFIRE users can choose from among three types of fires to appropriately model a given fire situation. The three types are:

>   Fixed Heat Input Fire
>   Oxygen Rich Fire
>   Fuel Rich Fire

The characteristics of each fire type, and the selection criteria for determining the fire type which most appropriately suits a given situation are provided below.

For oxygen rich and fuel rich fires, MFIRE assumes complete combustion of a hydrocarbon fuel to produce carbon dioxide (CO_2) and water. Accordingly, throughout MFIRE and its accompanying documentation, the term "fumes" refers to CO_2, and the calculation of fume concentration is based on an idealized ratio multiplier relating oxygen consumed by the fire and CO_2 produced by the fire.

However "real world" fires produce a variety of combustion products, and many MFIRE users are concerned with products other than CO_2, such as carbon monoxide (CO). MFIRE allows the user to model the production of other combustion products by specifying a fume production rate corresponding to the combustion product of interest and the fire scenario simulated.

Another basic assumption incorporated in MFIRE concerns the amount of heat generated by combustion.

MFIRE assumes 437 BTU of heat are produced for each cubic foot (ft^3) of oxygen (O_2) consumed by a fire. Since not all fires necessarily conform to this relationship, some MFIRE users may wish to model fires producing heat at a rate other than 437 BTU/ft^3 of oxygen. This option is available within the program, and the procedure for doing so is described later in this section.

8.2 Fixed Heat Input Fire

The fixed heat input fire refers to a fire which is defined by a specified heat influx and a specified fume production rate. Three MFIRE variables are used to specify a fixed heat input fire are:

       HEAT - heat influx at the fire source,
              expressed in BTU/min

       CONT - fume production rate, expressed
              in ft^3/min

       CONC - concentration of fumes produced,
              expressed in percent

Most MFIRE users will find the fixed heat input fire to be the most generally applicable fire type for routine fire modeling purposes.

Methods for selecting appropriate values for the fixed heat input fire variables to realistically represent a desired fire are discussed in Sections 8.6 through 8.11. Section 8.12 contains examples of these calculations.

8.3 Oxygen Rich and Fuel Rich Fires

Oxygen rich and fuel rich fires are special case fires which describe combustion behaviors somewhat unique to mine situations, and they are distinguished by the mode of pyrolysis. Combustion occurs whenever sufficient pyrolyzed fuel and oxygen are present at or above the ignition temperature. The mode of pyrolysis, or the heating of a fuel surface to generate gaseous fuel necessary for combustion, affects the characteristics of the fire and the extent to which the limited amount of oxygen available is consumed by the fire.

8.4 Oxygen Rich Fire

In the oxygen rich case, heat produced by the fire is transferred to unburned fuel surfaces through convection and radiation, causing pyrolysis in a largely localized process near the flame.

Much of the air passing through the fire zone is not involved in pyrolysis or combustion, resulting in moderate to high oxygen concentrations downstream from the fire.

An oxygen rich fire is defined by the concentration of oxygen contained in the ventilation stream downstream from the fire. MFIRE calculates a corresponding heat influx due to the fire by multiplying the number of cubic feet per minute of oxygen lost through combustion by the standard combustion ratio multiplier (437 BTU per cubic feet of oxygen consumed).

The MFIRE variable which is used to specify an oxygen rich fire is:

O2MIN - O_2 concentration downstream from
        fire, expressed as percent O_2

MFIRE assumes a nominal ambient oxygen concentration of 21 pct. in an uncontaminated air flow.

8.5 Fuel Rich Fire

In the fuel rich case, the fire zone is so large and so hot that the entire quantity of air passing through the fire zone is heated to a temperature sufficient to cause pyrolysis of fuel. The heated air passing though the fire zone pyrolyzes any fuel it contacts. The pyrolyzed fuel burns intensely until all available oxygen in the air stream is depleted. Fuel continues to pyrolyze, but cannot burn due to lack of oxygen. Pyrolyzed but unburned fuel remains in the downstream ventilation, giving rise to the term fuel rich fire.

The heat release rate from a fuel rich fire is defined by the ventilation rate through the fire zone and a user-defined heat release per cubic foot of oxygen delivered to the fire. MFIRE calculates a corresponding heat influx due to the fire by multiplying the number of cubic feet per minute of oxygen lost through combustion (which is simply 21 pct. of the total air flow) by the user-defined heat release per cubic feet of oxygen consumed. Fume production is also defined by the user. The MFIRE variables which are used to specify a fuel rich fire are:

SMPO2 - fume production, expressed in ft^3 of
        fumes per ft^3 of O_2 consumed

HTPO2 - heat generated, expressed in BTU's
        per ft^3 of O_2 consumed

For a given fuel loading and ventilation rate, a fuel rich fire burns more intensely than an oxygen rich fire. Fuel rich fires propagate faster, produce higher temperatures and higher concentrations of combustion products (possibly in the explosive range), and consume more oxygen.

For these reasons, fuel rich fires represent a far greater hazard than oxygen rich fires. Depending on the fuel loading, ventilation rate, and intensity of the ignition source, a fire may start as oxygen rich, only to "jump state" to become fuel rich. Fortunately, fuel rich fires are extremely rare events. It is estimated that less than 0.1 pct. of mine fires reach the fuel rich state.

When only CONT, CONC, and HEAT have non-zero values in an input data file, a fixed heat input fire is modeled. If these variables have non-zero values, but O2MIN also has a non-zero value, the oxygen rich case overrides the fixed heat input fire, and an oxygen rich fire is modeled. Likewise, if the foregoing variables have non-zero values, but SMPO2 or HTPO2 also have non-zero values, the fuel rich case overrides the fixed heat input and oxygen rich cases, and a fuel rich fire is modeled.

8.6 Estimating Fire Parameters

Although the MFIRE program will accurately model any of the three fire types described above, the user must properly specify numerical values for the fire variables if the results are to be meaningful.

The two critical parameters which define the intensity of the fire and its effects on a mine's ventilation system are heat release rate and fume production rate. The heat release rate determines the thermal energy released into the mine. This thermal energy creates throttling and buoyancy effects, which in turn, cause changes in air flow rates, changes in methane concentrations due to dilution effects, reversals, recirculation, etc. The fume production rate determines the amount of combustion fumes produced by the fire and therefore, the concentration of fumes throughout the network.

For fixed heat input fires, the heat release rate and fume production rate are inserted directly into the MFIRE input data file by the user. Normally, the user finds it necessary to calculate values for these parameters using fundamental combustion data for the fuel or fuels involved in the simulated fire. These calculations are performed separate from the MFIRE program, and the results are the direct determination of values for the variables HEAT and CONT.

For oxygen rich and fuel rich fires, heat release rate and fume production rate are specified indirectly by the user when values are assigned to the variables O2MIN, HTPO2, and SMPO2. However, for meaningful oxygen rich and fuel rich fires to be simulated, the user may need to perform similar calculations as are required when specifying parameters for a fixed heat input fire.

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These calculations are performed separately from the MFIRE program to determine heat release rate and fume production rate using fundamental combustion data for the fuel or fuels involved in the simulated fire. Once the heat release and fume production rates are known, values for O2MIN, HTPO2, and SMPO2 can be easily derived.

8.7 Heat Release Rate and Burning Rate

Heat release rate is determined by the following formula:

$$H_r = B_r \times H_v$$

where:

H_r is heat release rate, expressed in BTU/min

B_r is burning rate, expressed in lbs/min; and

H_v is heating value of the fuel, expressed in BTU/lb

Burning rates are estimated or measured. For example, if a 100-pound stack of wood burns in 40 minutes, the average burning rate is 2.5 lbs/min.

8.8 Complex Assemblies and Multiple Fuels

Although simple in theory, specifying burning rates for many mine fire scenarios can be quite tricky. For example, an MFIRE user may wish to model a fire involving multiple fuel sources combined into a highly complex assembly - for example, a load-haul-dump or a conveyor drive.

This problem has been addressed for residential and commercial occupancies. Full scale fire tests have been conducted, and burning rate, heat release rate, and fume production rate data have been experimentally obtained for common residential and office furnishings such as upholstered chairs, sofas, carpeting, computer work stations, etc. However, actual experimental data on burning rates and heat release rates for "real world" mine fire hazards are not available. This forces the MFIRE user to estimate these critical parameters.

The recommended method for estimating burning rates, heat release rates, and fume production rates for a complex assembly presenting multiple fuels involves 4 steps:

   1. conceptualize a specific fire scenario and subdivide the fire into discrete phases;

2. for each phase, individually determine heat release rate and fume production rate for each fuel material;

3. sum the heat release rates and fume production rates for each phase;

4. use the Time Table feature of MFIRE to specify a "new" fire corresponding to the time sequence and fire parameters of each phase.

Normally, a complex fire scenario can be subdivided into a sequence of phases, with each phase defined by its duration and fuels involved. Each phase should represent a different stage in the growth and development of the fire. Ideally, each phase would involve steady-state burning of a specific combination of fuel materials. As a fire grows in intensity or a different fuel material becomes involved, a new phase would start. When all the phases are combined into a continuous sequence, they approximate the total fire, only in a step-wise fashion. Case example 7 at the end of this chapter illustrates the application of this methodology.

Clearly, this process is imprecise at best. The conceptualized fire scenario may or may not be realistic. The estimated burning rates of the individual fuels may or may not be reasonable. The step-wise approximation of the total fire may be a significant departure from reality. Therefore, MFIRE users are urged to perform multiple simulations using input data which spans a range of possible values, and analyze the results to assess overall effects.

For example, a user might be concerned about the potential for the air flow in a certain escapeway to be contaminated by combustion products from a fire occurring at a distant location in the mine. To minimize unnecessary calculations, this user might wish to initially perform a simulation of a fire which is significantly larger than could be realistically expected at that location. Very little effort would be required to "guess" at these unrealistically high values for the fire parameters. If this size fire produces a level of contamination in the escapeway or other ventilation disturbances which are considered to be acceptable (ie: such that escape would not be impaired), no further analysis may be necessary. If this size fire produces an unacceptable level of contamination, the extra time and effort required to "fine tune" the estimates of fire parameters might then be justified.

8.9 Ventilation Velocity Effects

Another complicating factor is the effect of ventilation velocity on burning rates and resulting heat release rates.

Within practical ranges of ventilation velocity, burning rates tend to increase with increased ventilation velocity and decrease with decreased ventilation velocity. Thus, if a fire causes an increase or decrease in ventilation, it should cause a corresponding increase or decrease in burning rate.

This complication is automatically accommodated within MFIRE when an optional reference airflow rate variable is used. As ventilation flows change due to a fire, heat release rates for the fire are automatically adjusted upward or downward accordingly. A damping factor maintains heat release rates within reasonable limits, preventing upward adjustments from exceeding double, and downward adjustments from falling lower than one-half, the initial heat release rate of the fire.

8.10 Heating Values of Fuels

Heating values of fuels are determined experimentally and published in the engineering literature. Heating values of standard fuels such as wood (various species and moisture content), coal (various seams and sources), coke, petroleum oil products, etc. are published in handbooks of mechanical engineering, fire protection engineering, combustion engineering, and chemistry and physics. Heating values of some specialized mining materials (conveyor belt, brattice, etc.) have been experimentally determined by the Bureau of Mines and published in various Bureau reports. Heating values for a representative sample of mine combustibles are provided in Table 1 of the Appendix.

8.11 Fume Production

Fume production rates are determined by the following formula:

$$F_{r(CP)} = H_r \times ß$$

where:

$F_{r(CP)}$ is the fume production rate for the combustion product of interest, expressed in ft^3/min;

H_r is heat release rate, expressed in BTU/min; and

$ß$ is the production rate constant for the combustion product of interest

Values of $ß$ for the two most common combustion products, CO_2 and CO, have been experimentally derived for a variety of mine combustibles during both flaming and smoldering combustion. These $ß$ values are contained in Table 2 in the Appendix.

The basic relationships between the various fire parameters are summarized in Table 3 in Appendix 3. Table 4 in Appendix 1 shows conversion factors to perform unit conversions for ß values (ß values often appear in the literature in SI units, however MFIRE requires ß values to be expressed in English units).

Fume production rates are expressed in ft^3/min in an MFIRE input data file, while "fumes" in an MFIRE output, are expressed in percent. Expressing fumes in percent form in the output file can be somewhat confusing and cumbersome, particularly for simulations of small to moderate sized fires where fume concentrations may be orders of magnitude less than 1%. This is especially true for simulations of CO production, since CO concentrations are usually expressed in parts per million (ppm). To aid in interpreting output, users are reminded that the conversion factor between percent and ppm is "x 10,000." For example:

```
0.001%  = 10 ppm
0.01%   = 100 ppm
0.1%    = 1,000 ppm
1%      = 10,000 ppm
```

8.12 Fire Modeling Examples

Several examples are provided to illustrate the methods for determining appropriate numerical values for the critical fire parameters required for MFIRE fire simulations.

Example 1

Determine heat release rate and CO and CO_2 production from a transformer oil spill fire. The fire is contained in a 12 by 15 ft area (180 ft^2), and the spill occurred in a mine entry having a ventilation rate of 120,000 CFM. The fuel has a heating value of 20,000 BTU/lb, a specific gravity of 0.72 (density of 45 lb/ft^3), and a known burning rate, which is expressed as depth of fuel burned per unit time, of 8 in/hr (0.011 ft/min).

1a. For heat release rate:

$$H_r = B_r \times H_v$$

$$= 180 \text{ ft}^2 \times 0.011 \text{ ft/min} \times 45 \text{ lb/ft}^3 \times 20,000 \text{ BTU/lb}$$

$$= 1,782,000 \text{ BTU/min}$$

1b. For CO_2 production rate:

$$F_{r(CP)} = H_r \times ß$$

$$= 1,782,000 \text{ BTU/min} \times 0.0015 \text{ ft}^3/\text{BTU}$$

$$= 2673 \text{ ft}^3/\text{min of } CO_2$$

1c. For CO production rate:

$$F_{r(CP)} = H_r \times ß$$

$$= 1,782,000 \text{ BTU/min} \times 0.00009 \text{ ft}^3/\text{BTU}$$

$$= 160.4 \text{ ft}^3/\text{min of CO}$$

For this example, if a fixed heat input fire were to be modeled, values for the fire variables would be as follows:

HEAT = 1782000   (1,782,000 BTU/min)

CONT = 2673   (for CO_2, 2673 ft^3/min)

CONT = 160   (for CO, 160 ft^3/min)

CONC = 100   (contaminate assumed at 100 pct.)

Example 2

Determine heat release rate and CO and CO_2 production from a fire in a pile of Pittsburgh seam coal. The cone-shaped pile is 15 ft in dia and 6 ft high (360 ft^3), and the bulk density of the broken coal is 50 lb/ft^3. The pile burns with visible flames, and is completely consumed over a 48 hr period.

2a. For heat release rate:

$$H_r = B_r \text{ x } H_v$$

$$= 6.25 \text{ lb/min x } 14,000 \text{ BTU/lb}$$

$$= 87,500 \text{ BTU/min}$$

2b. For CO_2 production rate:

$$F_{r(CP)} = H_r \text{ x } ß$$

$$= 87,500 \text{ BTU/min x } 0.0017 \text{ } ft^3/BTU$$

$$= 149 \text{ } ft^3/min$$

2c. For CO production rate:

$$F_{r(CP)} = H_r \text{ x } ß$$

$$= 87,500 \text{ BTU/min x } 0.00014 \text{ } ft^3/BTU$$

$$= 12.3 \text{ } ft^3/min \text{ of CO}$$

Example 3

Determine heat release rate and CO and CO_2 production from a wood crib fire. The 8 ft high crib is constructed from 4 ft long Douglas fir (density of 35 lbs/ft^3) 6x6's, solid stacked. The crib is completely consumed in 3 hrs, resulting in an average burning rate of 25 lbs/min.

3a. For heat release rate:

H_r = B_r x H_v

= 25 lb/min x 8,000 BTU/lb

= 200,000 BTU/min

3b. For CO_2 production rate:

$F_{r(CP)}$ = H_r x ß

= 200,000 BTU/min x 0.0020 ft^3/BTU

= 400 ft^3/min of CO_2

3c. For CO production rate:

$F_{r(CP)}$ = H_r x ß

= 200,000 BTU/min x 0.00005 ft^3/BTU

= 10 ft^3/min of CO

Example 4

Estimate the downstream oxygen concentration from a coal pile fire for modeling an O_2 rich type fire. (Use the coal pile fire from Case Example 2, and assume 50,000 CFM ventilation.)

87,500 BTU/min ÷ 437 BTU/ft^3 O$_2$ = 200 ft^3/min O$_2$ consumed

O$_2$ inflow = 0.21 x 50,000   = 10,500 ft^3/min O$_2$

10,500 ft^3/min O$_2$ – 200 ft^3/min O$_2$ = 10,300 ft^3/min O$_2$

10,300 ft^3/min O$_2$ ÷ 50,000 ft^3/min   = 0.206

downstream O$_2$ = 20.6%

Example 5

How large a fire is required to reduce the downstream O_2 content of the ventilation stream to 16%? (Assume 50,000 CFM)

O_2 depletion   = 21% - 16% = 5%
5% O_2 x 50,000 ft^3/min   = 2,500 ft^3/min O_2
2,500 ft^3/min O_2 x 437 BTU/ft^3 O_2 = 1,092,500 BTU/min

A fire generating 1,092,500 BTU/min would consume 10 barrels of diesel oil/hour, 4 tons of wood/hour, or 2.7 tons of coal/hour.

Example 6

How large a fire is required to produce a "fuel rich" fire state? (assume 50,000 CFM ventilation, and recall that a "fuel rich" fire consumes all O_2 inflow)

$$50,000 \text{ ft}^3/\text{min} \times 0.21 = 10,500 \text{ ft}^3/\text{min } O_2$$
$$10,500 \text{ ft}^3/\text{min } O_2 \times 437 \text{ BTU/ft}^3 O_2 = 4,588,500 \text{ BTU/min}$$

A fire generating 4,588,500 BTU/min would consume over 40 barrels of diesel oil/hour, 17 tons of wood/hour, or 11 tons of coal/hour.

Example 7

Estimate heat release rate and CO production from a fire on a diesel-powered load-haul-dump vehicle. The fire starts when a pin-hole leak occurs in a 4,000 PSI hydraulic line which sprays fuel onto a hot exhaust manifold. After 1 minute, various hoses and electrical wiring begin to burn. Two minutes later, the hoses burn through, providing additional liquid hydrocarbon fuel (HC). Eight minutes later, pressure in the hydraulic system has decayed, stopping the original pin-hole leak and greatly reducing the hydrocarbon fire, however both rear tires begin to burn.

At T = 0 minute, oil begins to leak and the fire ignites almost immediately (assume 0.5 mm orifice):

$$H_{r(pin\ hole)} = 20,000\ BTU/lb \times 4\ lb/Min = 80,000\ BTU/Min$$

$$CO_{(pin\ hole)} = 0.00009\ ft^3/BTU \times 80,000\ BTU/Min = 7.2\ ft^3/Min$$

At T = 1 minute, pin hole leak continues; hoses and wiring begin burning:

$$H_{r(pin\ hole)} = 20,000\ BTU/lb \times 4\ lb/Min = 80,000\ BTU/Min$$

$$H_{r(hoses)} = 14,000\ BTU/lb \times 2\ lb/Min = 28,000\ BTU/Min$$

$$H_{r(wiring)} = 15,500\ BTU/lb \times 1\ lb/Min = 15,500\ BTU/Min$$

$$H_{r(total)} = H_{r(pin\ hole)} + H_{r(hoses)} + H_{r(wiring)}$$

$$= 80,000 + 28,000 + 15,500 = 123,500\ BTU/Min$$

$$CO_{(pin\ hole)} = 0.00009\ ft^3/BTU \times 80,000\ BTU/min = 7.2\ ft^3/min$$

$$CO_{(hoses)} = 0.00012\ ft^3/BTU \times 28,000\ BTU/min = 3.4\ ft^3/min$$

$$CO_{(wiring)} = 0.00012\ ft^3/BTU \times 15,500\ BTU/min = 1.9\ ft^3/min$$

$$CO_{(total)} = CO_{(pin\ hole)} + CO_{(hoses)} + CO_{(wiring)}$$

$$= 7.2 + 3.4 + 1.9$$

$$= 12.5\ ft^3/BTU$$

At T = 3 minutes, hoses burn through, releasing additional liquid hydrocarbons (estimate 10 Gal/Min):

$H_{r(HC's)}$ = 20,000 BTU/lb x 60 lb/Min = 1,200,000 BTU/min

$H_{r(total)}$ = $H_{r(pin\ hole)}$ + $H_{r(hoses)}$ + $H_{r(wiring)}$ + $H_{r(HC's)}$

= 80,000 + 28,000 + 15,500 + 1,200,000

= 1,323,500 BTU/min

$CO_{(HC's)}$ = 0.00009 ft^3/BTU x 1,200,000 BTU/min = 108 ft^3/min

$CO_{(total)}$ = $CO_{(pin\ hole)}$ + $CO_{(hoses)}$ + $CO_{(wiring)}$ + $CO_{(HC's)}$

= 7.2 + 3.4 + 1.9 + 108

= 120.5 ft^3/BTU

At T = 11 minutes, hydraulic system pressure decay has reduced HC fuel flow from original pin hole leak and subsequent hose burn-through, however hoses and wiring continues to burn and rear tires are burning:

$H_{r(HC's)}$ = 20,000 BTU/Min x 2 lb/Min = 40,000 BTU/Min

$H_{r(tires)}$ = 14,100 BTU/Min x 8 lb/Min = 112,800 BTU/Min

$H_{r(total)}$ = $H_{r(hoses)}$ + $H_{r(wiring)}$ + $H_{r(HC's)}$ + $H_{r(tires)}$

= 28,000 + 15,500 + 40,000 + 112,800

= 196,300 BTU/Min

$CO_{(HC's)}$ = 0.00009 ft^3/BTU x 40,000 BTU = 3.6 ft^3/min

$CO_{(tires)}$ = 0.00012 ft^3/BTU x 112,800 BTU = 13.5 ft^3/min

$CO_{(total)}$ = $CO_{(hoses)}$ + $CO_{(wiring)}$ + $CO_{(HC's)}$ + $CO_{(tires)}$

= 3.4 + 1.9 + 3.6 + 13.5

= 22.4 ft^3/BTU

9.0 MFIRE APPLICATION EXAMPLES

The following examples illustrate various MFIRE fire modeling capabilities. They are intended as tutorial aids to help acquaint new MFIRE users with techniques for modeling fires and for interpreting results of fire simulations.

The simulations are based on two mine networks; one a multi-level mine, the other a single-level mine.

9.1 Multi-Level Mine Example

The multi-level mine ventilation network is depicted in Figure 1. A main fan, in a blowing mode, is used to course ventilation air into the mine on the bottom level. Air flows upward through drifts, raises, and old stopes, and exits the mine's upper levels through two portals.

For this example, a fire is simulated in branch 9, which is a 110 foot long inclined drift connecting two mine levels having an elevation difference of 76 feet. Ventilation disturbances and CO levels will be noted every 15 seconds over a 15 minute period.

The simulation involves a transformer oil fire, and the fixed heat input fire type (dry conditions) is modeled. Properties of the oil are the same as in Example 1 in the previous section (20,000 BTU/lb, 8 in/hr burning rate, 45 lb/ft^3 density, ß for CO of 0.00009 ft^3/BTU). Flame spread across the spilled fuel is quite rapid, so the fire achieves steady-state burning without a prolonged incipient or smoldering stage. The spill covers an area of 4 ft by 8 ft.

The heat release rate for this fire is:

4 ft x 8 ft x 0.011 ft/min x 45 lb/ft^3 x 20,000 BTU/lb = 316,800 BTU/min

and the CO production rate is:

316,800 BTU/min x 0.00009 ft^3/BTU = 28.5 ft^3/min

The appropriate values for the fixed heat input fire variables are:

CONT = 28.5

CONC = 100

HEAT = 316800

71
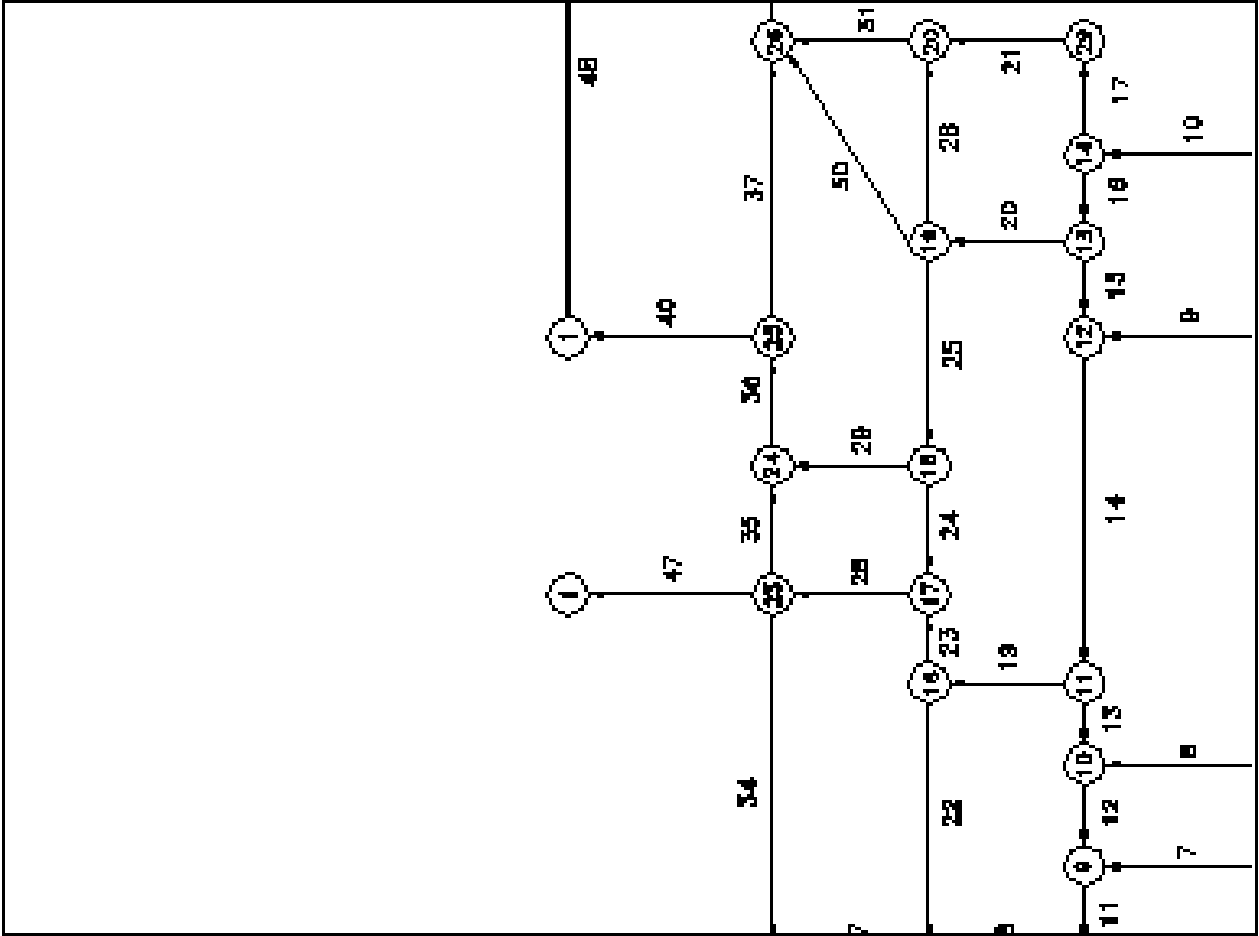
Therefore, the Time Table Lines list as follows:

 0,3, 9 , 28.5, 100,316800, 0 , 0 , 0 , .75 , 0

corresponding to the variables:

TS,ICODE,NBR,CONT,CONC,HEAT,O2MIN,SMPO2,HTPO2,QCENT,TPR

Figure 2 shows the network at the start of the simulation (T = 0),
and highlights the location of branch 9, the network branch
containing the fire. Figure 3 shows the network 30 seconds after
the start of the simulation. Note the extent of ventilation
disturbances caused by the fire in less than 1 minute. These
disturbances include fume contamination of 8 network branches, 7
reversals, and 1 recirculation path. Also note branch 14, which
initially became contaminated, and then reversed, drawing fume-
laden air back through junction 12.

Figure 4 shows the network after 2-1/2 minutes. Branch 14 has
reversed again, coursing air in its original direction. All other
reversed branches have maintained their altered flow direction, and
branch 28 has also reversed. Fume-laden air has reached the
surface through branch 40.

Figure 5 shows the network after 6 minutes. Fume-laden air has now
reached the surface through branches 32, 39, 47, and 40. Note also
that the fume front has nearly closed the recirculation path.

Figure 6 shows the network after 15 minutes. Fumes have nearly
filled the upper portions of the mine, including the recirculation
path. Flow in branch 14 has again reversed direction, and is
coursing air and fumes from junction 11 to junction 12. This
reversal, if it is sustained, will eventually cause branches 14 and
19 to purge themselves of fumes.

FIRE IN BRANCH 9 AT T = 0 MINUTES

KEY

– SURFACE AIRWAY

– JUNCTION

– AIRWAY

– AIR FLOW REVERSAL

– FUMES IN AIRWAY

FIGURE 2

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FIRE IN BRANCH 9 AT T = 0.5 MINUTES

FIGURE 3

FIGURE 4

FIRE IN BRANCH 9 AT T = 2.5 MINUTES

FIRE IN BRANCH 9 AT T = 6 MINUTES

KEY

- SURFACE AIRWAY
- JUNCTION
- AIRWAY
- AIR FLOW REVERSAL
- FUMES IN AIRWAY

FIGURE 5

77
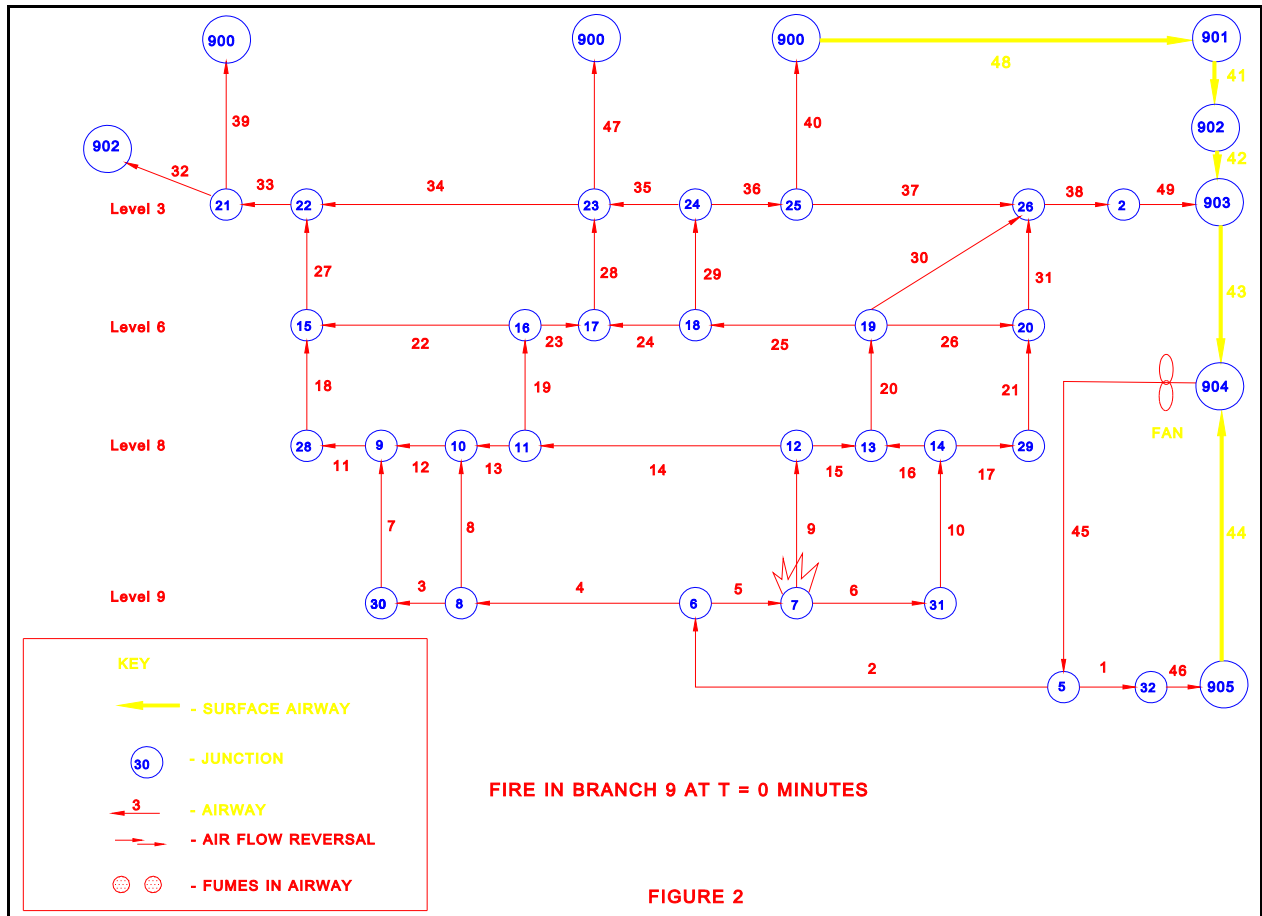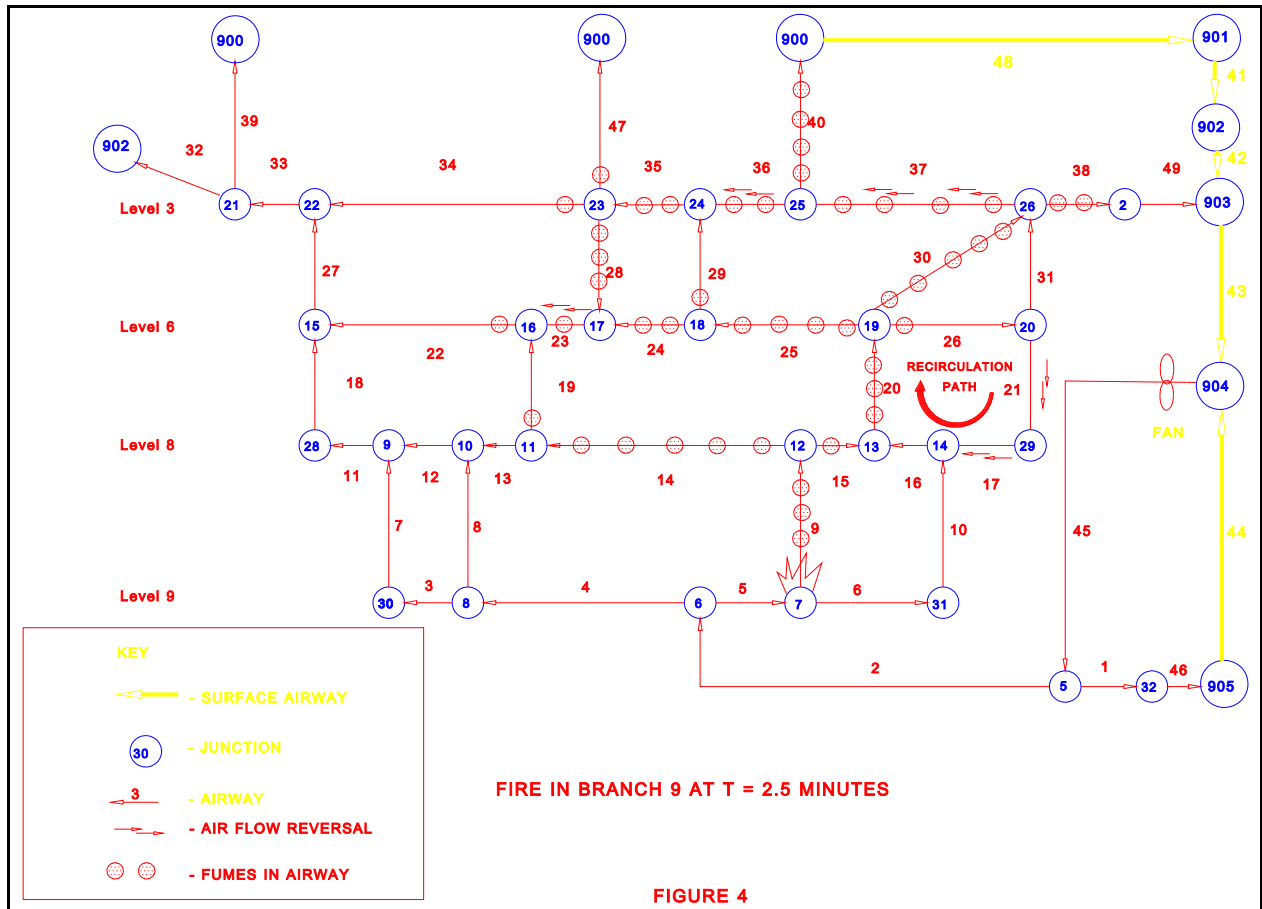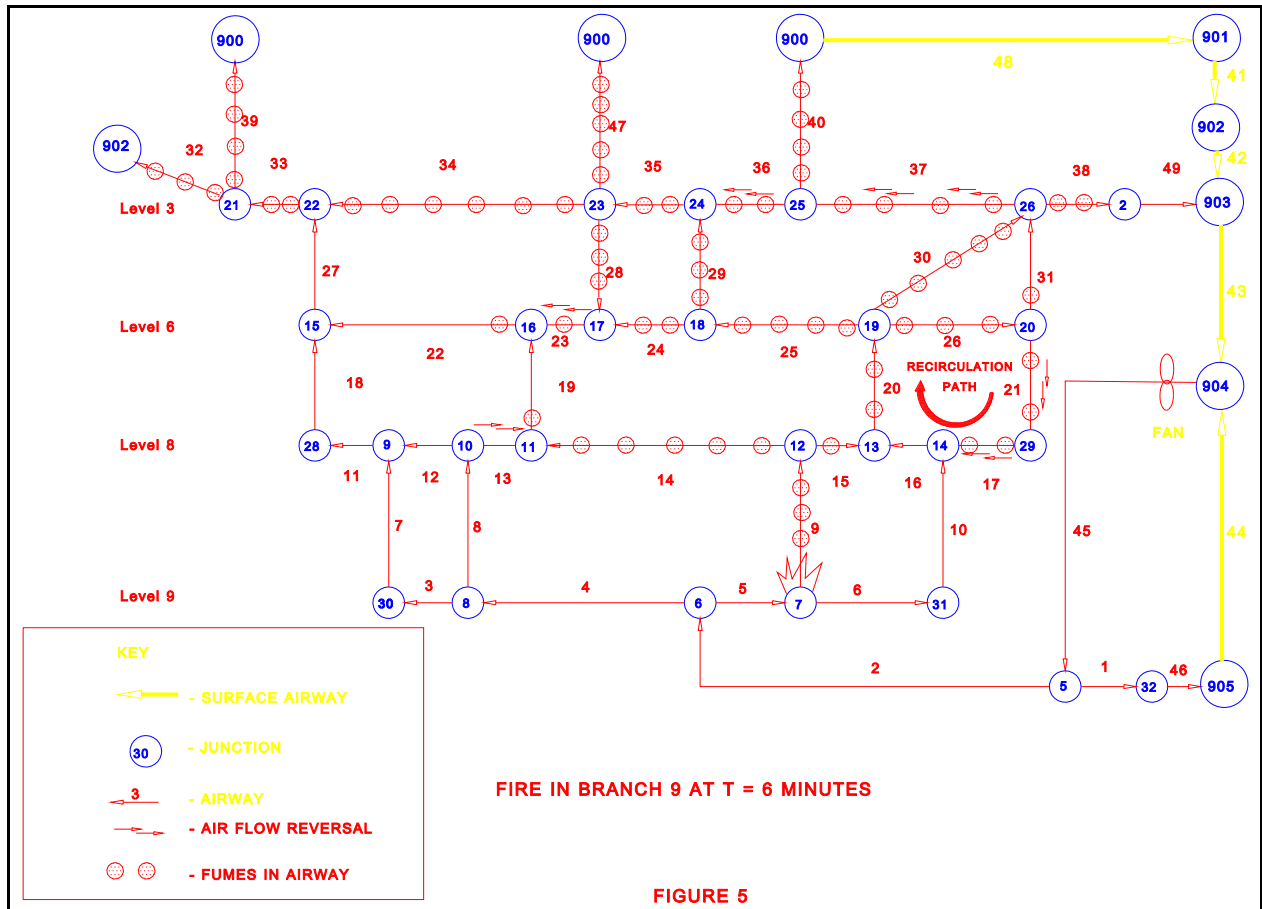
9.2 Single-Level Mine Examples

The single-level mine is depicted in Figure 7, a simple 3 section coal mine. Fresh air enters the mine through branch 1 and splits at junction 2. Branch 2 supplies air to junction 8, a working section. Methane is liberated in this working section at the rate of 230 ft^3/min, which divides equally between branches 3 and 4. Branch 5 splits at junction 3 to form branches 16 and 9, which supply air to working sections at junctions 5 and 4 respectively. These working sections also liberate 230 ft^3/min of methane, which is equally distributed between branches 15, 7, 8, and 10. Placement of appropriately sized regulators in branches 21, 22, 23, 24, and 25 results in methane concentration of 0.68 pct in section returns and the main return.

Two example simulations are provided. In the first example, a fire occurs in branch 26, followed by the unfurling of parachute stoppings in the intake to pressurize the intake and reduce air flow to the fire. In the other example, a fire also occurs in branch 26, but in this case, a roof fall occurs in branch 3 due to the fire.

Simulated Fire

The simulated fire, which is the same in both examples, occurs on a diesel-powered utility vehicle. The primary combustibles are diesel fuel, hydraulic oil, lubricating oil, rubber, and grease. The fire's heat release rate is estimated at 80,000 BTU/min and CO production is estimated at 11.5 ft^3/min. The fire is initiated at time = 0 for both examples. The appropriate values for the fixed heat input fire variables are:

CONT = 11.5

CONC = 100

HEAT = 80000

Therefore, the Time Table Lines for the fire list as follows:

0,3,26 , 11.5, 100, 80000, 0 , 0 , 0 , .75 , 0

corresponding to the variables:

TS,ICODE,NBR,CONT,CONC,HEAT,O2MIN,SMPO2,HTPO2,QCENT,TPR

Figure 7

79
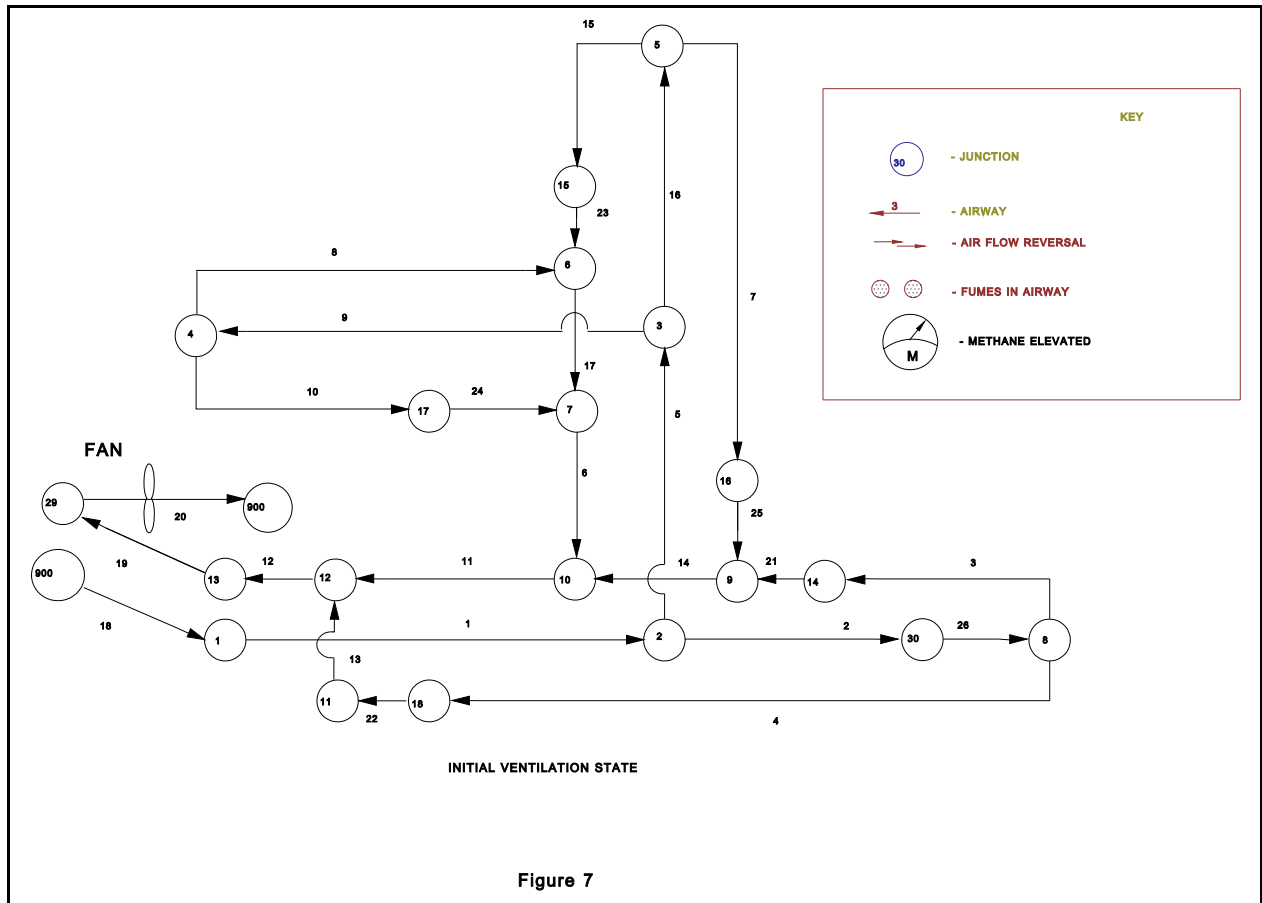
Example of the Effect of a Parachute Stopping

Parachute stoppings are unfurled in the intake, which is branch 2, at time = 15 minutes. Resistance of the stoppings is estimated at 500. Therefore, the Time Table Lines for the new resistance list as follows:

15,1,2,500

corresponding to the variables:

TS,ICODE,NBR,R

Figure 8 shows the fire located in branch 26 at time = 0 minutes. At time = 3 minutes, shown in Figure 9, fumes have advanced into branches 3 and 4. At time = 9 minutes, shown in Figure 10, fumes have advanced into branch 21 and continue to fill branch 4. At time = 15 minutes, shown in Figure 11, the resistance of branch 2 has been increased to R = 500 by unfurling parachute stoppings. Fumes have advanced to branch 11 and continue to fill branch 4.

At time = 18 minutes, shown in Figure 12, branches 21 and 3 have reversed due to the increase in flow through branches 5, 16, 7, and 25 resulting from the increased resistance in branch 2. Air from branch 25 now splits at junction 9, with flow toward both junction 10 and junction 14. The reversal of branches 21 and 3 has caused the fumes in that system of returns to be divided. Uncontaminated air from branch 25 is pushing fume-laden air outby through branches 11 and 12, but inby through branches 21 and 3. The increase in flow through branch 5 also reduces the methane concentration in the returns from both junction 5 and junction 4.

At time = 24 minutes, shown in Figure 13, Fumes continue to be pushed inby through branch 3 and outby through branches 19, 20, and 4. At time = 30 minutes, shown in Figure 14 and corresponding to the end of the simulation, fumes continue to be pushed inby through branch 3, and outby through branches 4 and 22. All fumes which had contaminated branches 14, 11, 12, 19, and 20 have been exhausted. In addition, due to the low flow through branch 3, the methane concentration has risen above 1.0 pct in that branch.

FIRE IN AIRWAY 26; TIME = 0

Figure 8

FIRE IN AIRWAY 26; TIME = 3 MINUTES

Figure 9

FIRE IN AIRWAY 26;   TIME = 9 MINUTES

Figure 10

KEY

- JUNCTION
- AIRWAY
- AIR FLOW REVERSAL
- FUMES IN AIRWAY
- METHANE ELEVATED

FAN

PARACHUTE STOPPING

FIRE IN AIRWAY 26; TIME = 15 MINUTES

Figure 11

FIRE IN AIRWAY 26; TIME = 18 MINUTES

Figure 12

KEY

- JUNCTION
- AIRWAY
- AIR FLOW REVERSAL
- FUMES IN AIRWAY
- METHANE ELEVATED

FAN

PARACHUTE STOPPING

FIRE IN AIRWAY 26; TIME = 24 MINUTES

Figure 13

Figure 14

It should be noted that when fumes enter a branch but have not yet reached the end of the branch, the table labeled "TEMPERATURE AND CONCENTRATION AT AIRWAY ENDS, PRESSURE IN AIRWAYS" will list the fume concentration for that branch as 0.00. This table will not display a fume concentration for a given branch until the fume front has reached the end of that branch. When fumes have entered, but not completely filled a branch, the position of the fume front, expressed as the distance from the beginning of the branch, is displayed in the table labeled "DATA FOR THE FUME FRONT IN AIRWAYS."

When a fume front is retreating rather than advancing, as occurs in this example at time = 30 minutes in branch 3, the "TEMPERATURE AND CONCENTRATION AT AIRWAY ENDS" table will continue to indicate a fume concentration until the branch is completely purged.

Example of the Effect of a Roof Fall

The initial ventilation conditions and the first few minutes of the fire are same as in the first example (Figures 7-10). Thus, the Time Table Lines which define the fire are the same as the previous example:

0,3,26 , 11.5, 100, 80000, 0 , 0 , 0 , .75 , 0

corresponding to the variables:
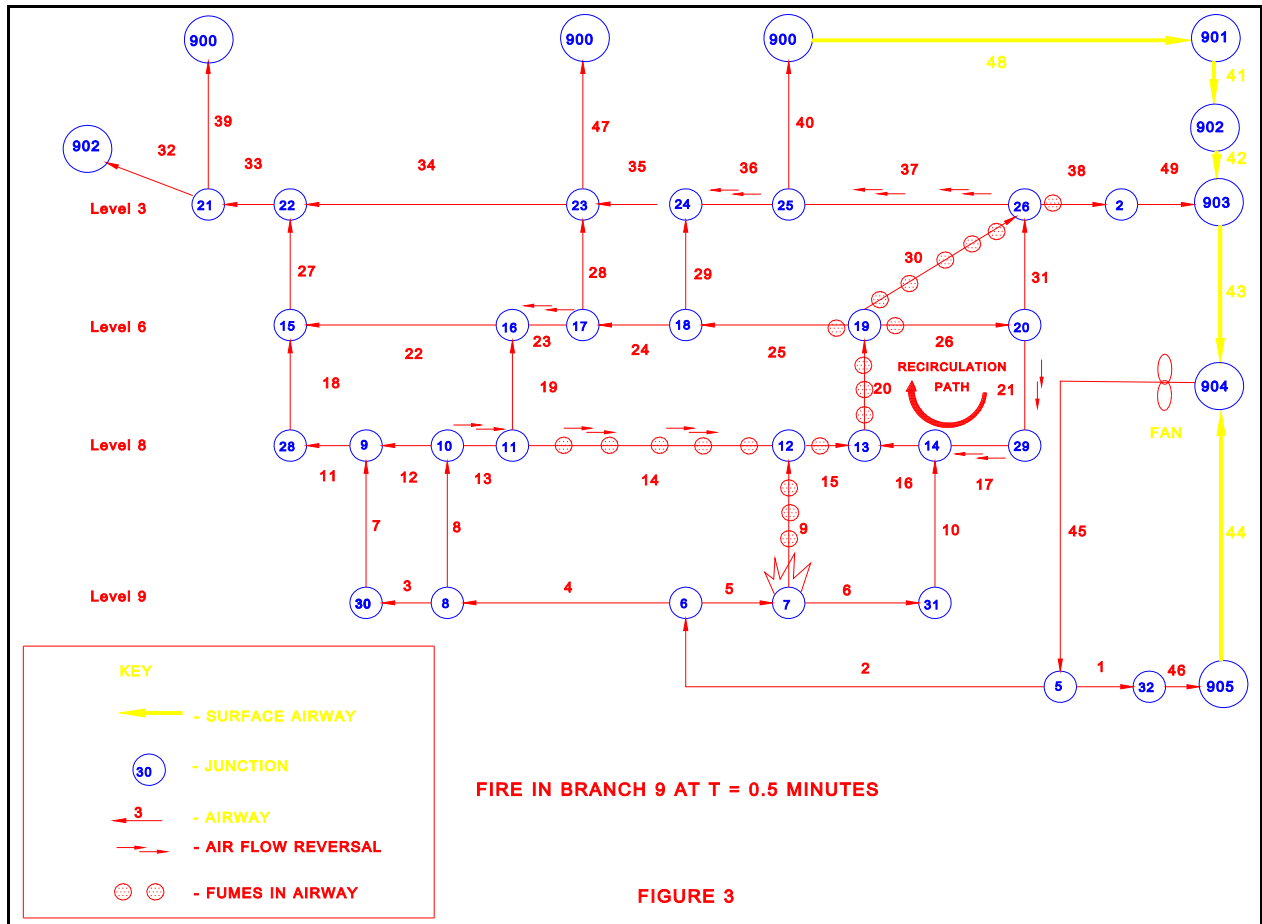
TS,ICODE,NBR,CONT,CONC,HEAT,O2MIN,SMPO2,HTPO2,QCENT,TPR

However at time = 15 minutes, shown in Figure 15, a roof fall occurs in branch 3. The resistance in this branch is immediately increased to R = 500.

Therefore, the Time Table Lines for the new resistance list as follows:

15,1,3,500

corresponding to the variables:

TS,ICODE,NBR,R

At time = 24 minutes, shown in Figure 16, fumes have nearly filled branch 4 and have been exhausted from the mine through branch 20. In branch 3, the methane concentration has exceeded 1 pct due to inadequate dilution resulting from restricted air flow caused by the roof fall. At time = 30 minutes, shown in Figure 17, fumes continue to be exhausted, and have advanced into branch 13. Also, the methane concentration continues to exceed 1 pct in branch 3.

FIRE IN AIRWAY 26; ROOF FALL IN AIRWAY 3; TIME = 15 MINUTES

Figure 15

FIRE IN AIRWAY 26; ROOF FALL IN AIRWAY 3; TIME = 24 MINUTES

Figure 16

KEY

- JUNCTION
- AIRWAY
- AIR FLOW REVERSAL
- FUMES IN AIRWAY
- METHANE ELEVATED

FAN

ROOF FALL

FIRE IN AIRWAY 26; ROOF FALL IN AIRWAY 3; TIME = 30 MINUTES

Figure 17

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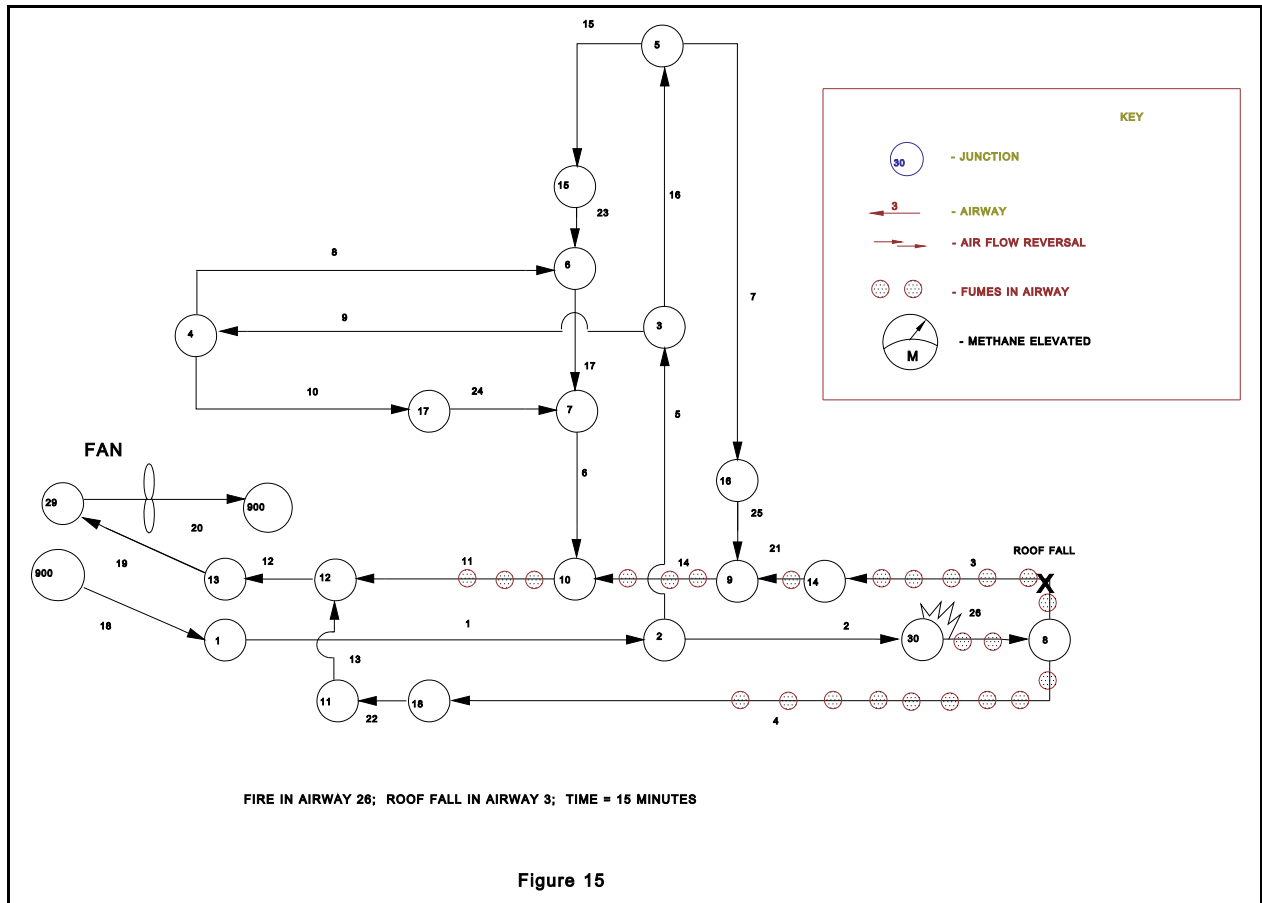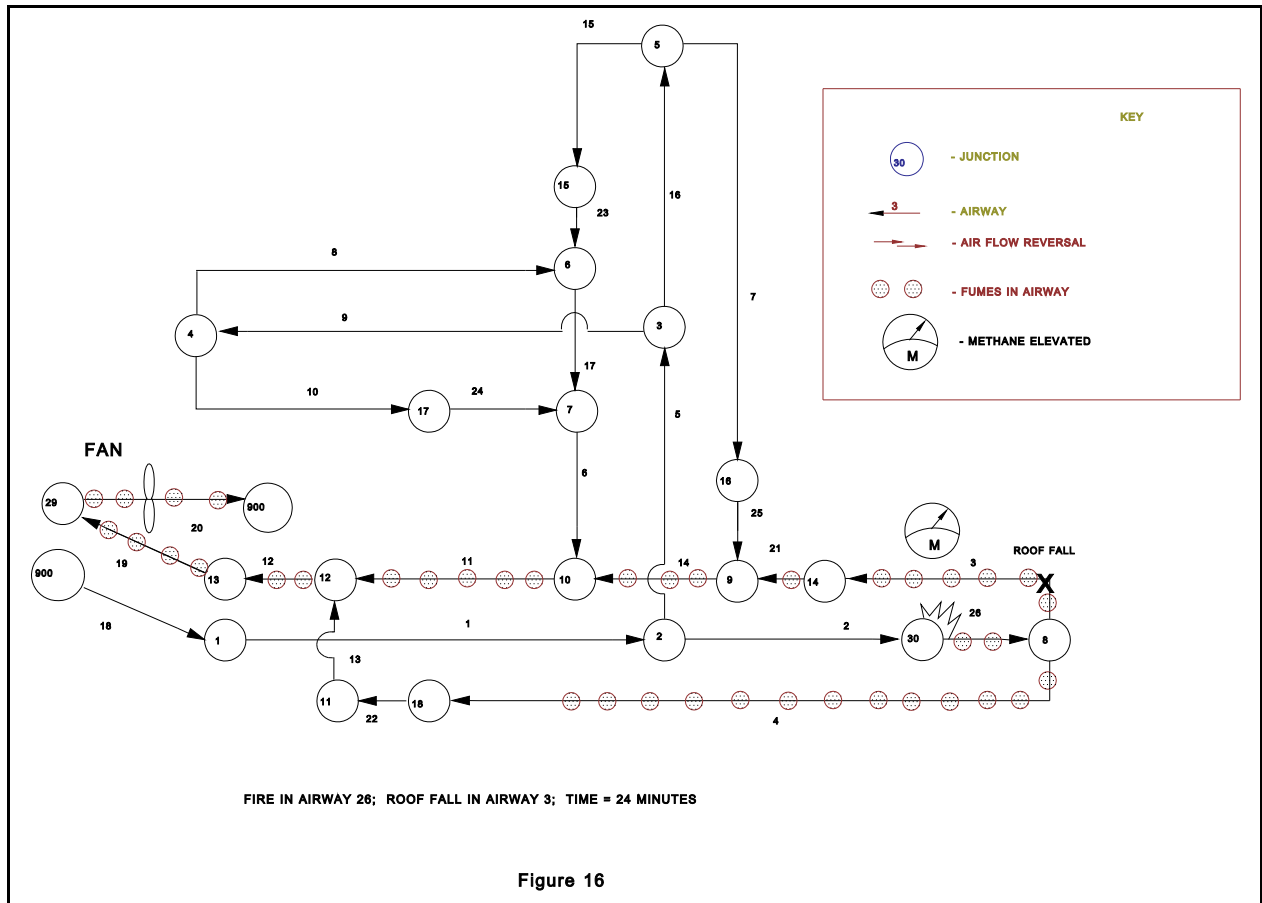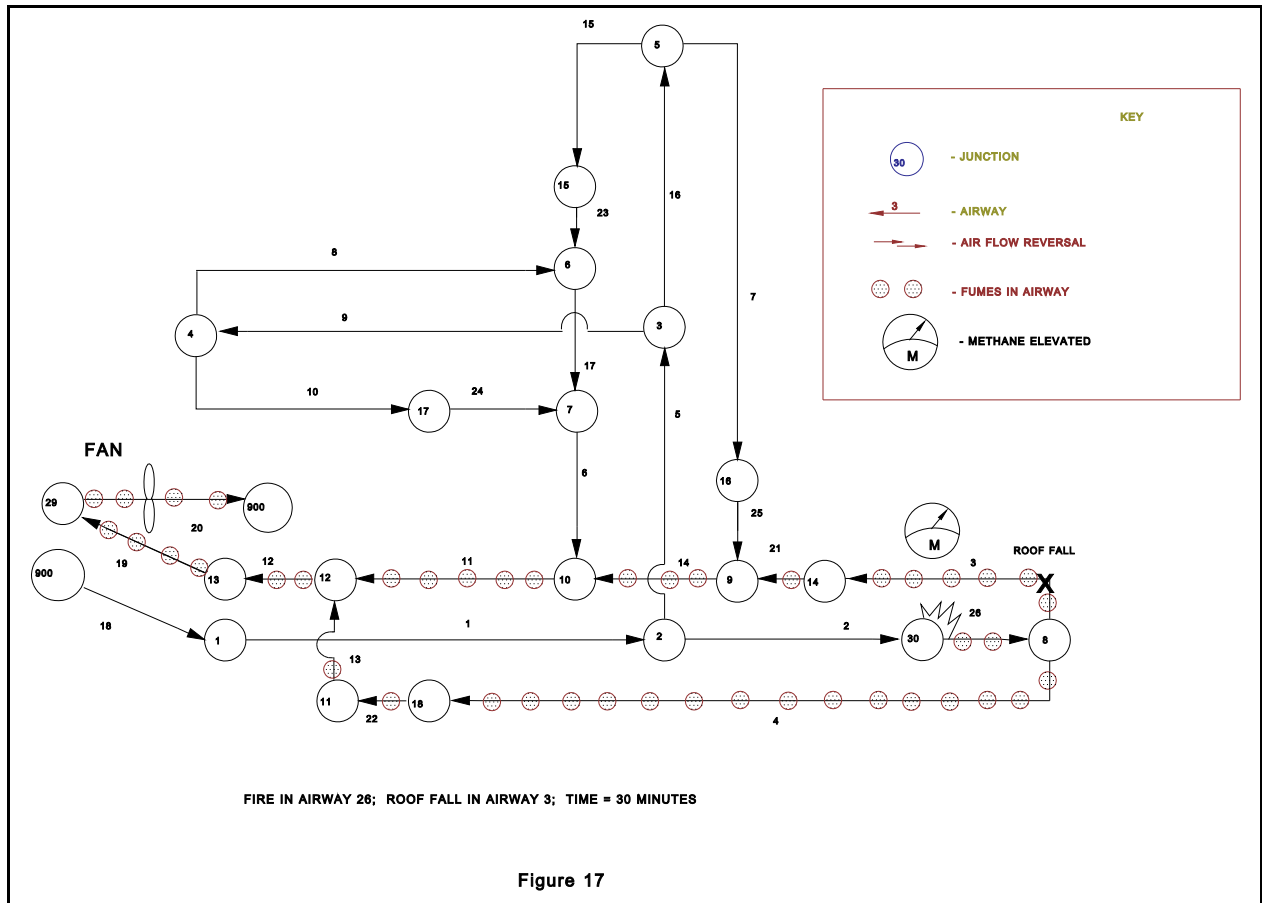
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APPENDIX 1   INPUT PARAMETER TABLES

TABLE 1 - HEATING VALUES OF MINE COMBUSTIBLES

Fuel	Type or Source	Heating Value (BTU/lb)
Coal	WV; Pocahontas No. 3	14,400[1,2]
	PA; Pittsburgh	14,000[1,2]
	IL; No.5	10,800[1,2]
	WY; No. 3	10,700[1,2]
	CO; Fox Hill	8,600[1,2]
Wood	White Pine	8,000[1]
	Douglas Fir	8,000[1]
	Red Oak	7,700[1]
	Elm	7,700[1]
Petroleum Oil	Gasoline	20,800[1]
	Diesel	20,000[1]
	Kerosene	19,800[1]
	Texas Crude	19,400[1]
	Transformer Fluid	18,200[1,3]
Conveyor Belt	Styrene Butadiene Rubber	13,300[3]
	Polyvinyl Chloride	10,500[3]
	Neoprene	10,000[3]
Brattice Cloth	Polyvinyl Chloride	10,100[3]
	Jute	5,800[3]
Vent Duct	Rigid Fiberglass Reinforced Polyester Resin	3,900[4]

[1] Baumeister, T. and L.S. Marks, Standard Handbook for Mechanical Engineers, McGraw-Hill, New York, NY, 1967.

[2] as received

[3] Egan, M.R., Summary of Combustion Products From Mine Materials: Their Relevance to Mine Fire Detection, U.S. Bureau of Mines Information Circular 9272, 1990.

TABLE 2 - CO_2 AND CO PRODUCTION CONSTANTS (ß VALUES)[1]

Fuel; Type and Source	Fire State	β_{CO2}(ft^3/BTU)	β_{CO}(ft^3/BTU)
Wood; Douglas Fir	Flaming	0.0020	0.00005
Coal; Pittsburgh Seam	Flaming	0.0017	0.00014
Coal; Pittsburgh Seam	Smoldering	0.0017	0.00021
Oil; Transformer	Flaming	0.0015	0.00009
Belt; Styrene Butadiene	Flaming	0.0015	0.00010
Belt; Neoprene	Flaming	0.0015	0.00020
Rubber	Flaming	0.0015	0.00012
Brattice; PVC	Flaming	0.0009	0.00011
Brattice; PVC	Smoldering	0.0010	0.00009
Brattice; Jute	Flaming	0.0016	0.00003
Brattice; Jute	Smoldering	0.0016	0.00002
Vent Duct; Rigid	Flaming	0.0017	0.00013

1 Egan, M.R., Summary of Combustion Products From Mine Materials: Their Relevance to Mine Fire Detection, U.S. Bureau of Mines Information Circular 9272, 1990.

TABLE 3 - RELATIONSHIPS OF BASIC FIRE PARAMETERS

* Burning Rate x Heating Value = Heat Release Rate
* Heat Release Rate ÷ 437 = O_2 Consumption Rate
* Heat Release Rate x $ß_{CO2}$ = CO_2 Production Rate
* Heat Release Rate x $ß_{CO}$ = CO Production Rate

DATA SOURCES FOR FIRE PARAMETERS

Burning Rate......Measure or Estimate
Heating Value.....Varies by Fuel.......Published Literature
$ß_{CO2}$.............. Varies by Fuel.......Published Literature
$ß_{CO}$.............. Varies by Fuel.......Published Literature

TABLE 4 - $ß_{CO_2}$ AND $ß_{CO}$ PRODUCTION CONSTANT UNIT CONVERSIONS

Published ß values are often expressed in SI units, usually as g/kj, however, MFIRE utilizes English System units. The above unit   conversions can be used to convert ß values from SI to English units.

A. To convert $ß_{CO_2}$ value from g/kJ to ft^3/BTU...

 g/kJ ($ß_{CO_2}$) x 0.0022 lb/g ÷ 44 lb/lb-mol x 359 ft^3/lb-mol ÷ 0.948 BTU/kJ
            or
 g/kJ ($ß_{CO_2}$) x 1.89 x 10^{-2} = ft^3/BTU

B. To convert $ß_{CO}$ value from g/kJ to ft^3/BTU...

 g/kJ ($ß_{CO}$) x 0.0022 lb/g ÷ 28 lb/lb-mol x 359 ft^3/lb-mol ÷ 0.948 BTU/kJ
            or
 g/kJ ($ß_{CO}$) x 2.98 x 10^{-2} = ft^3/BTU

TABLE 5   FRICTION FACTORS[1]

Airway Type	Degree of Surface Irregularity	Straight			Sinuous or Curved								
					Slightly			Moderately			Highly		
		Amount of Obstruction - C=Clean, S=Slight, M=Moderate											
		C	S	M	C	S	M	C	S	M	C	S	M
Smooth/Lined	Minimum	10	15	25	20	25	35	25	30	40	35	40	50
	Average	15	20	30	25	30	40	30	35	45	40	45	55
	Maximum	20	25	35	30	35	45	35	40	50	45	50	60
Sedimentary Rock or Coal	Minimum	30	35	45	40	45	55	45	50	60	55	60	70
	Average	55	60	70	65	70	80	70	75	85	80	85	95
	Maximum	70	75	85	80	85	95	85	95	100	95	100	110
Timbered (5-ft centers)	Minimum	80	85	95	90	95	105	95	100	110	105	110	120
	Average	95	100	110	105	110	120	110	115	125	120	125	135
	Maximum	105	110	120	115	120	130	120	125	135	130	135	145
Igneous Rock	Minimum	90	95	105	100	105	115	105	110	120	115	120	130
	Average	145	150	160	155	160	165	160	165	175	170	175	195
	Maximum	195	200	210	205	210	220	210	215	225	220	225	235

Friction Factor Units are $1.0*E^{-10}$ $lbm*min^2/ft^4$

[1] McElroy, G.E., Engineering Factors in the Ventilation of Metal Mines, U.S. Bureau of Mines, Bulletin 385, 1932

TABLE 6   THERMAL PROPERTIES OF ROCK

The thermal properties of rock required for MFIRE input are thermal conductivity, k, and thermal diffusivity, α. A third thermal property, constant pressure specific heat, C_p, may be used along with density, ρ, to relate k and α as,

   $k = \alpha * \rho * C_p$

MFIRE uses thermal conductivity in units of BTU/hr*ft*°F and thermal diffusivity in units of ft^2/hr. Multiply SI thermal conductivity in units of W/m*°K by 0.5782 to obtain thermal conductivity in units of BTU/hr*ft*°F. Likewise, multiply SI thermal diffusivity units of m^2/s by 38,750 to obtain thermal diffusivity units of ft^2/hr.

The data in this appendix were assembled or calculated or extrapolated from various sources and is intended to provide a starting point for MFIRE users. Published data from other sources may range ± 100 pct or more from these values due to measurement methods and rock variations. In situ conditions, especially porosity and pore fluid greatly influence data values. In most cases the exact value is not critical as most of the thermal energy from a mine fire is carried away from the fire by the airflow and transferred to the rock at low rates over comparatively long distances and consequently a large surface area. If parametric simulations with MFIRE show that these values are critical to the outcome of a particular simulation, the user should thoroughly investigate the thermal properties of the rock in question.

ROCK/MATERIAL	Thermal conductivity, k	Thermal Diffusivity, α
	BTU/hr*ft*°F	ft^2/hr
brick	0.4	0.02
basalt	0.6 – 1.4	0.02 – 0.04
calcite	0.2	0.006
clay	0.8	0.004
anthracite coal	0.2	0.006
concrete	0.5 – 0.8	0.02 – 0.03
diabase	1.1 – 1.3	0.03 – 0.04
dolo-stone	0.8 – 3.6	0.02
granite	1.0 – 3.4	0.03 – 0.09
limestone	0.7 – 3.6	0.02 – 0.1
marble	1.2 – 3.2	0.03 – 0.08
sandstone	0.9 – 2.2	0.03 – 0.06

APPENDIX 2   INPUT DATA FILE TEMPLATE

```
$-------------------------------------------------------------------$
$                                                                   $
$      ***   INPUT FORMAT INSTRUCTION FILE FOR PROGRAM MFIRE   ***  $
$                                                                   $
$    GENERAL RULES FOR DATA INPUT:                                  $
$                                                                   $
$  * NO NEED TO DISTINGUISH INTERGER AND REAL NUMBERS. SYMBOLS USED $
$  IN NUMERICAL INPUT COMPRISE THE FOLLOWING LIST:                  $
$             1 2 3 4 5 6 7 8 9 0 . , - + BLANK                     $
$  * FREE FORMAT ALLOWED. COMMA AND BLANK SPACE CAN BOTH BE DELIMINA-$
$  TORS. SEQUENTIALLY DISTRIBUTED BLANK SPACES ACT AS ONE DELIMINATOR.$
$  BLANKS ADJACENT TO A COMMA HAS NO EFFECT IN SEPARATING INPUT TERMS.$
$  * ZERO INPUT CAN BE OMITTED BUT ITS DELIMINATOR CAN'T EXCEPT BEING $
$  THE LAST ONE IN A LINE.                                          $
$  * A LINE WHOSE FIRST NON-BLANK SYMBOL IS "$" IS AN INSTRUCTION   $
$  LINE WHICH WILL BE IGNORED IN A PROGRAM RUN.                     $
$  * A LINE WHOSE FIRST NON-BLANK SYMBOL IS NEITHER ONE USED IN THE $
$  ABOVE LIST FOR NUMERICAL INPUT NOR "$", OR WHICH CONTAINS MORE   $
$  THAN 3 SYMBOLS OUTSIDE OF THE LIST, IS A COMMENT LINE WHICH WILL $
$  BE SHOWN IN THE OUTPUT FILE.                                     $
$-------------------------------------------------------------------$

$-------------------------------------------------------------------$
$  (1) COMMENTS  (OPTIONAL)                                         $
$                                                                   $
$     YOU MAY PUT NOTES HERE TO REMIND YOU IN THE FUTURE. THEY WILL BE $
$  SHOWN IN THE OUTPUT FILE. THE NUMBER OF TOTAL ACTIVE COMMENT LINES $
$  IS 50. THE ACTIVE WIDTH OF A LINE IS 72 COLUMNS.                 $
$---------------    INPUT YOUR COMMENTS HERE    --------------------$

$-------------------------------------------------------------------$
$  (2) CONTROL CARD I:                                              $
$     NB,NFNUM,INFLOW,NVPN,NETW,TR,MADJ,ITN,NTEMP,TINC,SPAN,IOUT,TOUT $
$     CONCT,DR                                                      $
$                                                                   $
$     NB: NUMBER OF AIRWAYS IN NETWORK, MAX. 500                    $
$     NFNUM: NUMBER OF FAN CHARACTERISTICS, MAX. 10.                $
$     INFLOW: NUMBER OF CONTAMINATION SOURCES, MAX. 10.             $
$     NVPN: MARKER FOR PRESENCE OF JUNCTION CARDS, 0: PRESENT.      $
$     NETW: MARKER, 1: ONLY THE NETWORK PART WILL BE PERFORMED.     $
$     TR: REFERENCE TEMPERATURE OF AIR, DEG. F. DEFAULT VALUE 75.   $
$     MADJ: MAX. NO. OF ITERATION IN TEMP. PART. DEFAULT 20.        $
$     ITN: MAX. NO. OF ITERATION IN DYNAMIC PART, DEFAULT 20.       $
$     NTEMP: MARKER. 1: SIMULATION GOES ONLY UP TO TEMPERATURE PART. $
$     TINC: TIME INCREMENT IN DYNAMIC SIMULATION PART, SEC.         $
$     SPAN: TIME SPAN OF DYNAMIC SIMULATION, MIN.                   $
$     IOUT: OUTPUT, 0: BRIEF; 1: NORMAL; -1: DETAIL; -2; MORE DETAILED.$
$     TOUT: TIME INTERVAL FOR OUTPUT, IN MIN.                       $
```

```
$      CONCT: MARKER. 1: SIMULATION GO TO TRANSIENT CONCENTRATION ONLY  $
$                     0: SIMULATION GO TO ALL TRANSIENT STATE           $
$      DR: REFERENCE DENSITY IN LBM/FT3, DEFAULT BASED ON TR AND 1 ATM. $
$                                                                       $
$            ***   INPUT DATA FOR CONTROL CARD I HERE    ***            $
$NB,NFNUM,INFLOW,NVPN,NETW,TR,MADJ,ITN,NTEMP,TINC,SPAN,IOUT,TOUT,CONCT,DR

$  AIRWAY LINES HERE
$      NO,JS,JF,NWTYP,R,Q,KF,LA,A,O,HA,HK,CH4V,CH4PA,TROCK              $
$                                                                       $
$  * IF NB IS 2 OR LARGER, THE NUMBER OF AIRWAY CARDS (LINES) MUST BE   $
$   NB. IF NB IS 1 OR LESS, THE AIRWAY CARDS MUST END WITH 9999.        $
$   * KF,LA,A,O,HA,HK HAVE THEIR AVERAGE OR DEFAULT VALUES WHICH ARE    $
$   ACTIVATED BY INPUTING ZERO FOR THE RESPECTIVE TERMS.               $
$   * TROCK DOES NOT NEED TO INPUT EXCEPT WHEN YOU WANT TO OVERRIDE THE$
$   PROGRAM CALCULATED VALUE.                                          $
$   * COMMENT LINES ARE ACTIVE IN THIS DATA PARAGRAPH.                 $
$                                                                       $
$    NO:    AIRWAY ID NUMBER (1 TO 9980).                              $
$    JS:    JUNCTION ID NUMBER OF AIRWAY BEGINNING (1 TO 999).         $
$    JF:    JUNCTION ID NUMBER OF AIRWAY END (1 TO 999).               $
$   NWTYP: AIRWAY TYPE, 1: FAN; 0: ORDINARY; -1: FIXED-Q.              $
$    R:     RESISTANCE OF AIRWAY 1.E-10 IN. W.G./(CFM)2.               $
$    Q:     AIRFLOW RATE IN CFM.                                       $
$    KF:    FRICTION FACTOR IN 1.E-10 LBM*MIN2/FT4.                    $
$    LA:    AIRWAY LENGTH IN FT.                                       $
$    A:     AIRWAY CROSS SECTIONAL AREA IN FT**2.                      $
$    O:     AIRWAY PERIMETER IN FT.                                    $
$    HA:    THERMAL DIFFUSIVITY OF ROCK, FT2/HR.                       $
$    HK:    THERMAL CONDUCTIVITY OF ROCK, BTU/HR*FT*F.                 $
$    CH4V:  METHANE EMISION RATE IN AIRWAYS FT3/MIN.                   $
$    CH4PA: METHANE EMISION RATE PER UNIT SURFACE AREA, FT/MIN.        $
$    TROCK: AVERAGE ROCK TEMPERATURE IN AIRWAY, DEGREE F.              $
$                                                                       $
$            ***    INPUT DATA FOR AIRWAY CARDS HERE    ***             $
$-------- NO,JS,JF,NWTYP,R,Q,KF,LA,A,O,HA,HK,CH4V,CH4PA,TROCK ---------$

$----------------------------------------------------------------------$
$   (4) JUNCTION CARDS:                                                 $
$     JNO,T,Z,CH4C                                                      $
$                                                                       $
$   * IF NVPN IS 0 OR LESS, EACH JUNCTION SPECIFIED IN JS AND JF  MUST $
$   HAVE  A ONE-LINE INPUT HERE. OTHERWISE JUNCTION CARDS MUST BE       $
$   OMITTED.                                                            $
$                                                                       $
$    JNO:   JUNCTION ID NUMBER (1 TO 999)                              $
$    T:     TEMPERATURE OF AIR IN JUNCTIONS, DEGREE F.                 $
$    Z:     ELEVATION OF JUNCTIONS, FT.                                $
$    CH4C:  METHANE CONCENTRATION IN JUNCTIONS, PERCENTAGE.            $
$                                                                       $
$            ***    INPUT JUNCTION CARDS HERE    ***                    $
$------------------------- JNO,T,Z,CH4C ------------------------------$
```

```
$-------------------------------------------------------------------$
$     (5) JUNCTION CARDS II (JUNCTIONS IN THE ATMOSPHERE)           $
$   A STARTING JUNCTION IS THE JUNCTION WHERE ATMOSPHERE CONDITIONS $
$ ARE DEFINED. ALL OTHER JUNCTIONS ON THE SURFACE ARE JUNCTIONS IN  $
$ THE ATMOSPHERE.                                                   $
$   IF THERE ARE MORE THAN ONE JUNCTION IN THE ATMOSPHERE, JUNCTION $
$ CARD II IS EMPLOYED. OTHERWISE, ONLY NUMBER "1" IS READ IN.       $
$                                                                   $
$   JAN: THE NUMBER OF THE JUNCTIONS IN THE ATMOSPHERE              $
$   JA:  JUNCTION ID NUMBER                                         $
$   JATP: JUNCTION TYPE:                                            $
$         0: STARTING JUNCTION                                      $
$         1: OTHER ATMOSPHERE JUNCTIONS EXCEPT STARTING JUNCTION    $
$                                                                   $
$       ****    INPUT DATA FOR JUNCTION CARD II HERE    ****        $
$                                                          $
$----------------------- JAN ---------------------------------------$
$----------------------- JA,JATP -----------------------------------$


$-------------------------------------------------------------------$
$     FAN CARDS I AND II COMPRISE A DATA GROUP WHICH MUST REPEAT NFNUM $
$   TIMES FOR NFNUM FAN CURVES. IF NFNUM IS 0 OR LESS, FAN CARDS I AND $
$   II MUST BE OMITTED.                                             $
$                                                                   $
$   (5) FAN CARD I:                                                 $
$     NOF,MPTS,NSWT                                                 $
$     NOF:    ID NUMBER OF FAN BRANCH.                              $
$     MPTS:   NUMBER OF POINTS DEFINING FAN CHAR, MAXIMUM 10.       $
$     NSWT:   SELECTION OF FAN CURVE FITTING, 1: LEAST SQUARES      $
$             2: SPLINE  3. AUTO  4.AUTO+MANUAL                     $
$   (6) FAN CARD II:  (IF MPTS IS LARGER THAN 5, CONTINUE IN 2ND LINE.)$
$     QF,PF,QF,PF,QF,PF,QF,PF,QF,PF                                 $
$     QF:     AIRFLOW AT GIVEN POINT OF FAN CHAR, CFM.              $
$     PF:     PRESSURE AT GIVEN POINT OF FAN CHAR, IN.W.G.          $
$   (7) FAN CARD III: NPLOT                                         $
$     NPLOT: TREATMENT OF THE BOUNDARY RANGE OF FAN CURVE           $
$             1: EXTEND FAN CURVE BY FOLLOWING GRADIENTS OF TWO ENDS. $
$             2: EXTEND FAN CURVE AS ABOVE AT LEFT BOUNDARY REGION AND $
$                SEND GRADIENT OF RIGHT BOUNDARY REGION TO ZERO.    $
$             3. SEND GRADIENT OF BOTH SIDES OF BOUNDARY REGION TO ZERO.$
$             ***    INPUT FAN CARDS I,II, AND III HERE    ***      $
$----------------------- NOF,MPTS,NSWT ----------------------------$
$----------------- QF,PF,QF,PF,QF,PF,QF,PF,QF,PF -------------------$
$---------------------------NPLOT----------------------------------$



$-------------------------------------------------------------------$
$   (7) CONTAMINATION (HEAT SOURCE) CARDS:                          $
$     NCENT,CONT,CONC,HEAT,O2MIN,SMPO2,HTPO2,QCENT,TPR              $
$                                                                   $
```

```
$     * EACH HEAT SOURCE MUST HAVE  A ONE-LINE INPUT HERE. THE NUMBER OF $
$    TOTAL FIRE SOURCES WAS SPECIFIED BY "INFLOW" IN CONTROL CARD I.     $
$                                                                        $
$      NCENT: ID NUMBER OF AIRWAYS WHERE HEAT SOURCES LOCATE.            $
$      CONT:  VOLUME FLOW RATE OF CONTAMINATED GAS INFLOW IN CFM.        $
$      CONC:  CONCENTRATION OF CONTAMINANT IN GAS INFLOW, %.             $
$      HEAT:  HEAT ENTERING OR LEAVING AIRWAY IN BTU/MIN.                $
$      O2MIN: OXYGEN CONCENTRATION OF AIR CURRECT LEAVING FIRE ZONE, %.  $
$      SMPO2: CONTAMINANT PRODUCTION PER FT**3 OF OXYGEN DELIVERY.       $
$      HTPO2: HEAT PRODUCTION (BTU) PER FT**3 OF OXYGEN DELIVERY.        $
$      QCENT: REF. Q DEFINING FIRE CHARACTERISTICS, CFM.                 $
$      TPR: LEADING TIME PERIOD IN MIN. FOR FIRE TO REACH FULL STRENGTH.$
$                                                                        $
$             ***    INPUT DATA FOR FIRE SOURCES HERE      ***           $
$---------- NCENT,CONT,CONC,HEAT,O2MIN,SMPO2,HTPO2,QCENT,TPR ----------$


$------------------------------------------------------------------------$
$    (8) CONTROL CARD II                                                 $
$    NAV,JSTART,TSTART,TIME,CRITSM,CRITGS,CRITHT,WRNPR,WRNSM,WRNGS,WRNHT$
$                                                                        $
$    * A SET OF DEFAULT VALUES ARE AVAILABLE. THEY CAN BE ACTIVATED BY   $
$    INPUTING ZERO FOR THE RESPECTIVE TERMS.                             $
$                                                                        $
$      NAV: MARKER. 1 OR LARGER: AVERAGE-VALUE CARD IS PRESENT.          $
$      JSTART: STARTING JUNCTION (ATMOSPHERE).                           $
$      TSTART: TEMPERATURE AT THE START JUNCTION, DEGREE F.              $
$      TIME: TIME SPAN TO ASSUME QUASI-EQUILIBRIUM, HOUR. DEFAULT 10.    $
$      CRITSM: ACCURACY IN FUME CALCULATION, %. DEFAULT 0.005.           $
$      CRITGS: ACCURACY IN METHAME CALCULATION, %, DEFAULT .01.          $
$      CRITHT: ACCURACY IN TEMPERATURE CALCULATION, F. DEFAULT 0.1.      $
$      WRNPR: PRESSURE DROP WARNING CRITERIA, IN.W.G. DEFAULT 0.01.      $
$      WRNSM: FUME CONCENTRATION WARNING CRITERIA, %. DEFAULT 0.05.      $
$      WRNGS: METHANE CONCENTRATION WARNING CRITERIA, %. DEFAULT 1.0.    $
$      WRNHT: HIGH TEMPERATURE WARNING CRITERIA, F. DEFAULT 100.0.       $
$                                                                        $
$             ***     INPUT DATA FOR CONTROL CARD II HERE     ***        $
$- NAV,JSTART,TSTART,TIME,CRITSM,CRITGS,CRITHT,WRNPR,WRNSM,WRNGS,WRNHT-$


$------------------------------------------------------------------------$
$    (9) AVERAGE-VALUE CARD:                                             $
$      HAAVR,HKAVR,KFAVR,LAAVR,AAVR,OAVR                                 $
$                                                                        $
$      IT MUST EXIST IF NAV IN CONTROL CARD II IS 1 OR LARGER. A DEFAULT$
$    VALUE CAN BE ACTIVATED BY INPUTING ZERO FOR THE RESPECTIVE TERM.    $
$    WHEN NAV IS ZERO OR LESS, THE WHOLE SET OF DEFAULT VALUES WILL BE   $
$    TAKEN.                                                              $
$                                                                        $
$      HAAVR: AVERAGE THERMAL DIFFUSIVITY OF ROCK, FT2/HR. DEFAULT 0.1. $
$      HKAVR: AVERAGE THERMAL CONDUCTIVITY OF ROCK, BTU/HR*FT*F.         $
$             DEFAULT 3.0.                                               $
```

```
$      KFAVR: FRICTION FACTOR, 1.E-10 LBM*MIN2/FT4. DEFAULT 100.        $
$      LAAVR: AVERAGE LENGTH OF AIRWAY, FT. DEFAULT 500.                $
$      AAVR: AVERAGE SECTIONAL AREA OF AIRWAY, FT2. DEFAULT 100.        $
$      OAVR: AVERAGE PERIMETER, FT. DEFAULT 40.                         $
$                                                                       $
$         ***   INPUT AVERAGE-VALUE CARD HERE IF NEEDED   ***           $
$---------------- HAAVR,HKAVR,KFAVR,LAAVR,AAVR,OAVR -----------------$

$----------------------------------------------------------------------$
$     (10) TIME TABLE FOR CONDITION CHANGES:                            $
$                                                                       $
$      THIS TIME TABLE CAN CONTAIN THE FOLLOWING CONDITION CHANGES. IT $
$ MUST END WITH A ONE-LINE INPUT OF A VALUE LARGER THAN "SPAN" IN       $
$ CONTROL CARD I. THIS TIME TABLE MUST EXIST, BUT MAY CONTAIN ONLY      $
$ THE ENDING LINE. THE ORDER OF CHANGING CONDITIONS MUST BE ARRANGED$
$ ACCORDING TO THE RESPECTIVE OCCURING TIME.                           $
$                                                                       $
$ 1) TS,1,NBR,R                                                         $
$     THIS INPUT CHANGES BRANCH "NBR" TO AN ORDINARY AIRWAY WITH        $
$  AIRFLOW RESISTANCE EQUAL TO "R" AT "TS" MIN. AFTER TIME ZERO.        $
$     TS: OCCURING TIME OF THE CHANGE CONDITION, MIN.                   $
$     NBR: AIRWAY ID NUMBER.                                            $
$     R: RESISTANCE OF AIRWAY 1.E-10 IN. W.G./(CFM)2.                   $
$ 2) TS,2,NBR,INDEX,QF1,PF1,QF2,PF2,QF3,PF3,QF4,PF4,QF5,PF5             $
$     THIS INPUT CHANGES BRANCH "NBR" TO A FAN BRANCH WITH ITS          $
$  CHARACTERISTICS SPECIFIED BY "QF1" TO "PF5".                         $
$     INDEX: NUMBER OF DATA POINTS TO DEFINE FAN CHAR. MAX. 5.          $
$     QF: AIRFLOW RATE IN FT**3/MIN.                                    $
$     PF: CORRESPONDING FAN PRESSURE IN IN. W.G.                        $
$ 3) TS,3,NBR,CONT,CONC,HEAT,02MIN,SMPO2,HTPO2,QCENT,TPR                $
$     THIS INPUT CHANGES BRANCH "NBR" TO A FIRE SOURCE BRANCH WITH      $
$  FIRE CHAR. SPECIFIED BY "CONT" TO "TPR", WHICH RETAIN THE SAME       $
$  MEANING AS IN FIRE SOURCE CARD (7). REFER BACK TO (7) FOR DETAIL $
$ 4) TS,4,NBR                                                           $
$     THIS INPUT CHANGES FIRE BRANCH "NBR" TO AN ORDINARY AIRWAY AT     $
$  TIME "TS".                                                           $
$ 5) TS,5,TINC                                                          $
$     THIS INPUT CHANGES TIME INCREMENT IN SYNAMIC SIMULATION TO A      $
$  NEW VALUE "TINC" IN SEC.                                             $
$ 6) TS,6,TOUT                                                          $
$     THIS INPUT CHANGES OUTPUT INTERVAL TO A NEW VALUE OF "TOUT"       $
$  MIN.                                                                 $
$ 7) TS,7,JDPP                                                          $
$     THIS INPUT FORCES DETAILED RECORDS TO BE SET UP FOR AIRWAYS       $
$  WHICH ARE ON THE IMMEDIATE DOWN-STREAM SIDE OF JUNCTION "JDPP"       $
$  AT "TS" MIN. AFTER TIME ZERO.                                        $
$                                                                       $
$         ***    INPUT CONDITION CHANGE TIME TABLE HERE    ***          $
$-- (IT MUST END WITH A ONE-LINE VALUE LARGER THAN "SPAN" IN CARD I) --$
```

APPENDIX 3 PROGRAM LISTING OF MFIRE VARIABLES

```
C      NB: NUMBER OF AIRWAYS IN NETWORK.
C      NJ: NUMBER OF JUNCTIONS IN NETWORK.
C      NFNUM: NUMBER OF FAN CHARACTERISTICS.
C      NVPN: MARKER FOR PRESENCE OF JUNCTION CARDS, 0: PRESENT.
C      NETW: MARKER, 1: ONLY THE NETWORK PART WILL BE PERFORMED.
C      NTEMP: MARKER, 1: ONLY UP TO THE TEMP. PART WILL BE PERFORMED.
C      MADJ: MAX. NO. OF ITERATION IN TEMP. PART.
C      ITN: MAX. NO. OF ITERATION IN NON-STEADY STATE SIMULATION.
C      DR: REFERENCE DENSITY OF AIR, LBM/FT3.
C      TR: REFERENCE TEMPERATURE OF AIR, DEG. F.
C      TINC: TIME INCREMENT IN SIMULATION, SEC..
C      SPAN: TIME SPAN OF SIMULATION, MIN..
C      IOUT: OUTPUT. 0: BRIEF; 1: NORMAL; -1: DETAIL; -2: MORE DETAILED.
C      TOUT: TIME INTERVAL FOR OUTPUT, MIN.
C      CONCT: MARKER. 1: SIMULATION FOR TRANSITE CONCENTRATION SIMULA-
C                      TION ONLY
C      NAV: MARKER FOR PRESENCE OF AVE. VALUE CARDS.
C      MAXJ: HIGHEST JUNCTION NUMBER.
C      INFLOW: NUMBER OF CONTAMINATION CARDS.
C      CRITSM: ACCURACY OF FUME CALCULATION.
C      CRITGS: ACCURACY OF METHAME CALCULATION.
C      CRITHT: ACCURACY OF TEMPERATURE CALCULATION.
C      NO(NMX): AIRWAY NUMBER.
C      JS(NMX): JUNCTION NUMBER OF AIRWAY BEGINNING.
C      JF(NMX): JUNCTION NUMBER OF AIRWAY END.
C      NWTYP(NMX): AIRWAY TYPE.
C      R(NMX): RESISTANCE OF AIRWAY 1.E-10 IN. W.G./(CFM)**2.
C      Q(NMX): BALANCED AIRFLOW RATE, ASSUMING EQUILIBRIA, CFM
C      P(NMX): CALCULATED PRESSURE LOSS IN IN. W.G..
C      KF(NMX): FRICTION FACTOR.
C      LA(NMX): AIRWAY LENGTH IN FT.
C      A(NMX): AIRWAY CROSS SECTIONAL AREA IN FT**2.
C      O(NMX): AIRWAY PERIMETER IN FT.
C      RSTD(NMX): RESISTANCE FACTOR BASED ON TR.
C      DZRD(NMX): ELEVATION CHANGE IN AIRWAY IN FT.
C      FRNVP(NMX): PRODUCT TMRD*DZRD.
C      NREV(NMX): NUMBER OF AIRFLOW REVERSALS IN AN INTERVAL.
C      RDCH4(NMX): METHANE CONCENTRATION AT ROADWAY ENDS.
C      RDPROP(NMX): CONTAMINANT CONCENTRATION AT ROADWAY ENDS.
C      TRD(NMX): TEMPERATURE AT ROADWAY ENDS.
C      TJS(NMX): TEMPERATURE AT ROADWAY BEGINNING.
C      RDOP(NMX): BACKUP ARRAY FOR RDPROP.
C      RCH4(NMX): BACKUP ARRAY FOR RDCH4.
C      FFRNVP(NMX): DZRD/TMRD.
C      RA(NMX): BACKUP ARRAY FOR R.
C      NNREV(NMX): NUMBER OF AIRFLOW REVERSALS SINCE TIME ZERO..
C      NOF(IMX): AIRWAY NUMBER OF FAN.
C      NFREG(IMX): LIST OF FANS WITH CHARACTERISTICS.
C      RGRAD(IMX): SLOPE OF FAN CHARACTERISTIC.
C      NFCW(IMX): LIST OF FANS WHOSE CHAR. EXCEEDED.
C      MPTS(IMX): NUMBER OF POINTS DEFINING FAN CHAR.
C      QF(IMX,IMY): AIRFLOW AT GIVEN POINT OF FAN CHAR.
C      PF(IMX,IMY): PRESSURE AT GIVEN POINT OF FAN CHAR.
C      NSKP(IMX): MARKER INDICATING PERFORMANCE OF SPLINE.
C      NEGQ(IMX): MARKER INDICATING AIRFLOW REVERSAL IN FAN BRANCH.
C      JSB(NMX): BACKUP ARRAY FOR JS.
C      NSWT(NMX): SWTCH TO SELECTED FAN CURVE FITTING METHOD
C                 1 LEAST SQUARE 2.SPLINE 3.AUTOMATIC 4.AUTO+MANUAL

C      MNO: NUMBER OF MESHES IN NETWORK.
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C      MEND(NMY): LIST OF MESH ENDS IN MSL-LIST.
C      MSL(LMX): LIST OF ALL INDEPENDENT MESHES.
C      FNVP(NMY): LIST OF NVP IN MESHES.
C      RQ(NMX): AUXILIARY LIST OF R*Q.
C      INU(NMX): AUXILIARY LIST FOR FORMING BASE SYST.
C      KNO(NXX): LIST OF AIRWAYS IN BASE SYSTEM.
C      KJS(NXX): LIST OF JUNCTIONS IN BASE SYSTEM.
C      KJF(NXX): LIST OF JUNCTIONS IN BASE SYSTEM.
C      JNO(NMY): JUNCTION NUMBER.
C      T(NMY): TEMPERATURE OF AIR IN JUNCTIONS.
C      Z(NMY): ELEVATION OF JUNCTIONS.
C      CH4C(NMY): METHANE CONCENTRATION IN JUNCTION.
C      JNOL(NMY): LIST OF JUNCTION NUMBERS IN INCREASING ORDER.
C      PROP(NMY): CONTAMINANT CONCENTRATION IN JUNCTION.
C      PRCH4(NMY): METHANE CONCENTRATION IN JUNCTION.
C      JLR(NMY): LIST RELATING JNO- AND JNOL-LISTS.
C      TROCK(NMX): AVERAGE ROCK TEMPERATURE IN AIRWAY.
C      TMRD(NMX): MEAN TEMPERATURE OF AIR IN AIRWAY.
C      HA(NMX): THERMAL DIFFUSIVITY OF ROCK.
C      HK(NMX): THERMAL CONDUCTIVITY OF ROCK.
C      NCENT(NMX): NUMBER OF AIRWAYS INTO WHICH FUME ENTERS.
C      CH4V(NMX): METHANE EMISION RATE IN AIRWAYS.
C      CH4PA(NMX): METHANE EMISION RATE PER UNIT SURFACE AREA.
C      CONT(IMX): VOLUME FLOW RATE OF CONTAMINATED GAS INFLOW.
C      CONC(IMX): CONCENTRATION OF CONTAMINANT IN GAS INFLOW.
C      HEAT(IMX): HEAT ENTERING AIRWAY.
C      O2MIN(IMX): OXYGEN CONCENTRATION OF FUMES LEAVING FIRE ZONE
C      SMPO2(IMX): CONTAMINANT PRODUCTION PER CUBIC FT OF OXYGEN.
C      HTPO2(IMX): HEAT PRODUCTION PER CUBIC FT OF OXYGEN DELIVERY
C      TFSI(IMX): AIR TEMPERATURE BEHIND HEAT SOURCE.
C      O2BEH(IMX): OXYGEN CONTENT BEHIND FIRE SOURCES.
C      TPR(IMX): TRANSITION TIME OF FIRE IN MIN.
C      HTAD(IMX): REDUCED HEAT INPUT DUE TO HIGH AIR TEMPERATURE.
C      QCENT(IMX): "STD. Q' AT WHCIH FIRE TAKES THE INPUT PARAMETERS.
C      NGIN(NMX): LIST OF AIRWAYS ENTERING JUNCTION.
C      MMIN(NMX): LIST OF LAST AIRWAY PER JUNCTION IN NGIN-LIST.
C      NGOUT(NMX): LIST OF AIRWAYS LEAVING JUNCTION.
C      LOUT(NMX): LIST OF LAST AIRWAY PER JUNCTION IN NGOUT-LIST.
C      MEMREC(NMX): TEMPORARY LIST OF AIRWAYS CARRYING RECIRC. AIR.
C      NOREC(NMX): PERMANENT LIST OF AIRWAYS.
C      ESTPR(NMX): ESTIMATED CONCENTRATION FOR RECIRCULATED AIR.
C      ESTCH4(NMX): ESTIMATED METHANE CONCENTRATION.
C      ESTTR(NMX): ESTIMATED TEMPERATURE.
C
C      XNEW(NMX): EXPONENT FOR TEMPERATURE CALCULATION.
C      DCOAGE(NMX): COEFFICIENT OF AGE.
C      TIME: TIME ASSUMING QUASI-EQUILIBRIA.
C      TSTART: TEMPERATURE AT THE START JUNCTION.
C      JSTART: START JUNCTION (ATMOSPHERE).
C      TLEFT(NMX): TIME INCREMENT FOR MAKING UP A NORMAL INTERVAL.
C      SUMQ(NMY): TOTAL AIRFLOW RATES ENTERING JUNCTION.
C      SUMC(NMY): TOTAL CONTAMINANT FLOW RATES ENTERING JUNCTION.
C      SUMM(NMY): TOTAL METHANE FLOW RATES ENTERING JUNCTION.
C      SMHEAT(NMY): TOTAL ENTHALPY/REFRENCE DENSITY ENTERING JUNCTI
C      PROPS(NMX): BACKUP ARRAY FOR PROP.
C      PRCH4S(NMX): BACKUP ARRAY FOR PRCH4.
C      QQ(NMX): DAMPED AND TIME-AVERAGED AIRFLOW RATE.
C      QTP(NMX): BACKUP ARRAY FOR Q, FIXED IN EACH INTERVAL.
C      TTJS(NMX): BACKUP ARRAY FOR TJS.
C      TTRD(NMX): BACKUP ARRAY FOR TRD.
C      TAS(NMX): BACKUP ARRAY OF T.
C      BI(NMX): BIOT NUMBER.
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C       WRNPR: PRESSURE DROP WARNING CRITERIA.
C       WRNGS: METHANE CONCENTRATION WARNING CRITERIA.
C       WRNSM: FUME CONCENTRATION WARNING CRITERIA.
C       WRNHT: HIGH TEMPERATURE WARNING CRITERIA.
C       IOMIT(IMX): AIRWAYS FOR WHICH DETAILED DATA RECORDS WERE OMITTED.
C       ROMIT(IMX,3): DATA AT STARTING J OF DATA-OMITTED AIRWAY.
C       IAC: COUNTER OF IOMIT AND ROMIT.
C       DELTAT: SPAN OF TIME INCREMENT.
C       TACC: CUMULATED TIME AFTER EVENT IN SEC.
C       SUMFNV: SUM OF NVP CORRECTION IN SYSTEM.
C       IBTN(NMX): ARRAY HOLDING ADDRESS OF RECORD FOR AIRWAY (N
C       DPPA(NMZ,10,5): MASTER DATA STORAGE ARRAY IN DYNAMIC SIMULATI
C       NSAC(NMX,2): DATA RECORD STATUS OF AIRWAY (NMX).
C       TMRDA(NMX): BACKUP ARRAY FOR TMRD.
C       DELTAQ(NMX): VARIATION OF AIRFLOW IN AIRWAYS.
C       DPPB(NMZ,10,5): BACKUP ARRAY FOR DPPA.
C       NSACB(NMX,2): BACKUP ARRAY FOR NSAC.
C       GBTN(10,5): AUXILIARY ARRAY FOR DATA TRANSFER.
C       JCH(NMY): MARKER INDICATING JUNCTION COND. CHANGE.
C       TAUXA(NMZ,10): AIR TEMP. AT REAR ENDING OF SEGMENTS.
C       TAUXB(NMZ,10): BACKUP ARRAY FOR TAUXA.
C       TAUXC(NMZ): AIR TEMP. BEYOND THE FIRST SEGMENT.
C       TAUXD(NMZ): BACKUP ARRAY OF TAUXC.
C       FMASS(NMZ): MASS OF AIR BEYOND THE FIRST SEGMENT.
C       JDP: NUMBER OF JUNCTIONS INITIATING DATA RECORDS.
C       JDPP(IMX): JUNCTIONS WHICH INITIATE DATA RECORDS.
C       QRCD(NMX,10): AIRFLOW RATES DURING ITERATIONS.
C       TMRCD(NMX,10): MEAN AIR TEMP. IN AIRWAYS DURING ITERATION.
C       HRM(IMX): VARIATION OF NVP PER MESH DURING ITERATION.
C       JAN:  TOTAL NUMBER OF ATMOSPHERE JUNCTIONS
C       JAJ:  NUMBER OF ATMOSPHERE JUNCTIONS EXCEPT STARTING JUNCTION
C       JA1(10):  JUNCTION ID NUMBER (IN ATMOSPHERE)
C       JATP(10): JUNCTION TYPE (IN ATMOSPHERE)
C       JSTAR(10): JUNCTIONC CONNECTED WITH ENTRY AIRWAYS EXCEPT STARING
C                    JUNCTION
C       TSTAR(10): TEMPERATURE IN THE JUNCTION AT ARRAY (JSTAR)
C       MSTAR(10): JUNCTION NUMBER CORRESPONDING TO ARRAY (JNOL)
C       ISTAR(10): JUNCTION NUMBER CORRESPONDING TO ARRAY (JNO)
C       TTT: INTERMEDIATE ARRAY FOR TEMPERATURE WHEN SIMULATE FOR TRANSIENT
C           CONCENTRATION SIMULATION ONLY (CONCT=1).
C       TJSS:INTERMEDIATE ARRAY OFR TTJS WHEN CONCT=1.
C       TRDD: INTERMEDIATE ARRAY FOR TTRD WHEN CONCT=1.
C       QQQ:  INTERMEDIATE ARRAY FOR QQQ WHEN CONCT=1.
C       COF: THE COEFFIENT OF FAN EQUATION FITTED BY LEAST SQUARES.
C       ND: THE DEGREE OF FAN EQUATION FITTED BY LEAST SQUARES.
C       N1A: THE NUMBER OF COEFFICIENTS OF FAN EQUATION.
C       NSWT: TO SELECT FAN CURVE FITTING METHOD
C                 1 LEAST SQUARE 2.SPLINE 3.AUTOMATIC 4.AUTO+MANUAL
C       NCOF: ARRAY FOR THE NUMBER OF COEFFICIENTS OF FAN EQUATION
C       INIFAN: THE FLAG SHOWS THE LARGE STATE CHANGE IN SYSTEM AND THE
C                MESHES REFORM DESIRED.
C       NPLOT: TREATMENT OF THE BOUNDARY RANGE OF FAN CURVE
C                1: EXTEND FAN CURVE BY FOLLOWING GRADIENTS OF TWO ENDS.
C                2: EXTEND FAN CURVE AS ABOVE AT LEFT BOUNDARY REGION AND
C                    SEND GRADIENT OF RIGHT BOUNDARY REGION TO ZERO.
C                3. SEND GRADIENT OF BOTH SIDES OF BOUNDARY RANGE TO ZERO.
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APPENDIX 4   ADDITIONAL INFORMATION SOURCES

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