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STUDY OF MINE FIRES AND MINE VENTILATION
Part I
Computer Simulation of Ventilation Systems Under
the Influence of Mine Fires

Rudolf E. Greuer
Principal Investigator

Michigan Technological University
College of Engineering
Department of Mining Engineering

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FOREWORD

This report was prepared by Michigan Technological University, College of Engineering, Department of Mining Engineering, Houghton, Michigan, under USBM Contract No. S0241032. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PMSRC with Dr. R. F. Chaiken acting as the technical project officer. Mr. D. J. Askin was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 4, 1974 to October 14, 1977. This report was submitted by the author on September 14, 1977. This technical report has been reviewed and approved.

It is hereby certified that no inventions have been made on this project.

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies of the Interior Department's Bureau of Mines or of the U.S. Government.

SUMMARY

The existing computer programs for the simulation of ventilation systems under normal ventilation conditions are reviewed and a suitable program for including the influence of mine fires is selected. New program parts are written for the consideration of methane productions in coal mines, heat and gas productions of mine fires, temperature and air composition changes in ventilation systems, and the ventilation forces resulting from the latter. Other program parts are provided for the detection of danger zones and reversed air currents and for the inclusion of recirculated air currents in the network analysis. Existing program and new program parts are combined.

The resulting new program can be used for a multitude of assignments. It is designed for the practical ventilation engineer and should be applicable to all types of ventilation emergency plans, in particular mine fire plans.

The organization of the program and its mathematical basis are described. A FORTRAN IV listing and several flow diagrams are included. Eight executed examples are discussed, input and output for these examples explained. Storage requirements and execution times are estimated.

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1. INTRODUCTION

Most of the major mine disasters have throughout the history of mining been caused by explosions and fires and both causes remain among the greatest potential hazards in mining. The greatest hazard of mine fires is the poisonous and sometimes explosive combustion products which are carried through the mines by their ventilation.

To combat this hazard, the paths which the combustion products take, must be known for the proper designation of escape routes and the safe and economical performance of fire fighting activities. To predict these paths is complicated by the fact that the fires themselves can cause considerable ventilation disturbances. The volume expansion of the air as it passes through the fire has a constriction or throttle effect. Density differences in non-horizontal communicating airways create buoyancy effects similar to chimney drafts. The intensity of the fires, on the other hand, depends on their oxygen supply, i.e. the airflow rates and oxygen concentration which are provided by the ventilation system.

The conventional analog computers and digital computer programs for ventilation network (airflow distribution) calculations are not capable of taking this mutual interaction between fires and ventilation systems into account. They cannot distinguish between air of different qualities (concentrations, temperatures) either. The preferred compromise has been until now to use these conventional analog computers or digital computer programs and to support them with manual calculations.

This approach can be satisfying when no recirculation of air occurs and the fire generated ventilation forces are relatively small. Concentration of methane and combustion products can in these cases be determined by a sequence of simple mixing processes in the network nodes once the airflow distribution is known. The fire generated ventilation forces, which depend on the air temperature downstream of the fire, can be calculated for an estimated airflow rate through the fire and then inserted in the network calculation. Unchanged temperatures and natural ventilation pressures are assumed for all other air currents. If the airflow rate through the fire, which is then obtained in the network calculation, is too far off the estimate, the process is repeated with

a new, better estimate. The amount of manual work involved in this procedure may be cumbersome but is manageable, if, as in the preparation of emergency plans, sufficient time is available.

With recirculation, temperatures and concentration of several of the air currents, which enter network nodes, are not known and the calculation of the state of the mixture leaving the nodes is therefore not possible. To overcome this difficulty some method of describing the network configuration mathematically or of applying an iterative approximation method has to be used. Recirculation is common in hardrock mines and can be caused by the fire itself in coal mines even though it is not permitted under normal ventilation conditions. With large fire generated ventilation forces the ventilation disturbances become such that the assumption of unchanged temperatures and natural ventilation pressures in all airways except for those immediately downstream of the fire does no longer hold either. In such cases the amount of manual work becomes excessive, or so many simplifying assumptions have to be made that the results of the calculations have only a limited value.

Due to its great importance for escape and fire fighting plans, mining engineers have studied the interaction between ventilation systems and fires for several decades. The large amount of conducted theoretical and experimental work was recently reviewed (7), the still existing gap for coal mine fires is in the process of being closed (3,5). Ventilation network calculations with digital computers are becoming more and more common and with them the availability of reliable data on ventilation systems. In the same way as suitable computer programs for ventilation network calculations have led to considerable improvements in the ordinary ventilation planning work, it can be expected that suitable programs for fire emergencies will lead to improvements in this field also. This report describes such a program and demonstrates its application with a number of examples.

The here introduced program can fulfill the following functions:

- a) it starts with a conventional network calculation for the state of the mine before the emergency;
- b) next, it simulates the production of heat and contaminants in designated locations;

- c) next, it calculates the resulting temperature and concentration distribution based on the airflow obtained in step a, if recirculation occurs it makes use of an iterative approximation method;
- d) next, it calculates the fire generated ventilation forces;
- e) next, it inserts these forces into the network and repeats the network calculation to determine the changed airflow distribution;
- f) next, it repeats steps b through e until an equilibrium is reached;
- g) finally, it analyzes the results for danger zones caused by instable airways, airflow reversals, high temperatures, high concentrations of methane or combustion products.

As this sequence indicates, it was attempted to determine an equilibrium under steady state conditions. The crucial heat exchange between rock and air is, however, calculated under non-steady state conditions, taking the changing rock temperature into account. If the change of the ventilation system with time shall be investigated, it is necessary to execute a series of calculations for different time intervals since the beginning of the emergency event.

The program has the options to execute network, temperature, and concentration calculations combined or separately. It has been made as flexible as possible to make it useful for a multitude of assignments. Methane concentrations are, however, always determined when a change in the airflow distribution takes place, since this is indispensable for coal mines. In its organization the program has been divided into two parts, labeled "network part" (for functions a and e) and "concentration part" (for all the other functions). The network part contains basically an earlier existing program for conventional network calculations. It was attempted to change this existing program and its input data as little as possible in order to make the use of the new program, for users of the conventional network program, as simple as possible.

It has been attempted to keep the amount of input data in the new program small and to extract as much information as possible from these data. Input data are furthermore analyzed for completeness and for such mistakes that occur most frequently. When possible, incomplete data are amended by average values and incorrect data are corrected.

The formulation of heat and combustion products as a function of the oxygen supply to the fire has intentionally been kept very simple. There is no difficulty in amending the program with fire characteristics of any desired properties. But to introduce these, in a form that they are applicable to all types of mines and fuels, would require so many additional explanations and input data that at this stage the introduction of the new program for practical emergency planning would be impeded.

On the whole, this program has been drafted with routine application by practical ventilation engineers in mind. It is, as far as the author knows, the first program of its kind and the necessity of some changes will certainly be felt after it has been exposed to some practical use.

2. REVIEW OF EXISTING PROGRAMS FOR VENTILATION NETWORK CALCULATIONS

Ventilation network calculations, whose goal is the determination of airflow and pressure distributions in mine ventilation systems, have been performed routinely and at a large scale with computers for approximately two and a half decades. Throughout the fifties and the first half of the sixties, analog computers were mainly used for this purpose. They were almost completely replaced by digital computers, after the latter became more and more available, larger, cheaper, and faster. Digital computers, being all purpose computers, can usually perform network calculations more economically than the single purpose analog computers. The first reported ventilation network calculations with digital computers were performed in 1958 and since 1960 they have become routine in West Germany, where large ventilation problems necessitated the wide use of analog computers before. From the mid-sixties on, digital computers were in all major mining countries, either routinely used for network calculations or their use was being investigated. To date such calculations have become a self-understanding part of all ventilation planning. A review of the history of ventilation network calculations with computers and the different programs in use has been given by the author in an earlier report (7).

Normal environmental factors, like concentrations of contaminants or temperatures, are heavily influenced by the airflow distribution. On the other hand, it is quite possible that the airflow distribution is influenced by these environmental factors. There exists an increasing number of attempts to combine ventilation network calculations in digital computer programs with the precalculation of environmental conditions (1,6,8,10,16,19). None of these efforts have, however, progressed far enough to be useful for the simulation of fire emergency situations.

All programs for ventilation network calculations which are presently used employ the CROSS iteration method of balancing pressures around loops. Its principles are described in a large number of earlier papers on network calculations (e.g. 6,20). Experience has shown that this method allows working with the most simple program and organization

of the input data and does not pose any difficulties, time or storagewise, for average sized modern computers. Previous limitations in computer capacity, which led to other programs with lower storage requirements or higher execution speeds, do practically no longer exist. It was, therefore, decided to use for this contract the CROSS method of balancing pressures. It was furthermore decided to utilize and modify a program which already had a large number of users in the U.S. This would make the understanding of the new program, at least for some people, easier. It would, furthermore, allow them to use existing network calculation data for the new program.

There seem to be two different programs for ventilation network calculations in wide use in the U.S. (6); the so-called Pennsylvania State University program (6,20), and the so-called Michigan Technological University program (7). The last published version of the Penn State program (20) was written before 1970. It was described in great detail in 1972 (6). The Michigan Tech program originated in West Germany around 1965 as a new, more compact, version of older existing programs and is widely used by German ventilation engineers. It is very similar to the standard program of the British National Coal Board, which was issued in 1967, since both programs have the same source. Since this program was not a genuine novelty and a large number of copies together with manuals are in circulation, no detailed description of this program was published.

The Penn State and Michigan Tech programs are not very different. They use the same mathematical description of ventilation networks and use essentially the same solution method. Judgment of the quality of a computer program is to a large part based on how familiar one is with the program and the way in which input and output are organized. As long as programs give correct results with the same amount of computer and user effort, they must be considered as being equally useful.

The author, having participated in writing the Michigan Tech program and having carefully studied the Penn State program feels, however, that the former program is simpler to use and it seems to have a better convergence also. The reason is, perhaps, that it was written by practical ventilation engineers who had to perform large numbers of network calculations for their planning purposes. The features which the

author thinks should be changed in the Penn State program are the following:

Airways (branches) should obtain identification numbers, not just sequence numbers; if input cards are placed in a different sequence or if the network changes, these sequence numbers will change also, which is a great inconvenience.

The use of a junction marker array in the "tree building process" limits the junction numbers to a few places or causes a lot of storage waste.

The natural ventilation pressure has to be calculated and inserted manually.

The approximation of the fan characteristic requires 90 statements. The feared undulations of polynomials which led to this occurs, however, only at both ends of the fan characteristic curve.

To use only the airflow rates of fixed quantity airways and the highest flow rates from indicated fan characteristics, or to use for all airways of the first mesh a rate of 100,000 cfm for the calculation of the initial airflow distribution, gives a poor start.

The output comprises a lot of actually unneeded information.

Since the distribution of the Penn State and Michigan Tech programs seem to be of the same order of magnitude, it was decided to use the Michigan Tech network program for the new program.

3. MATHEMATICAL DESCRIPTION OF VENTILATION NETWORKS FOR AIRFLOW AND PRESSURE DISTRIBUTION CALCULATIONS

The mathematical description of ventilation networks is not uniform and considerable confusion exists among practical ventilation engineers in this respect. It seems, therefore, advantageous to explain the principles which have been used in this report.

The networks are considered to be in a steady state. The forces acting on the ventilation system do not change very rapidly so that inertia forces of the air can be neglected. The response of the ventilation system to changing forces is considered as a sequence of equilibrium states to which the steady state mathematical description of network applies.

The mathematical description of ventilation networks can be based on mass flow rates or volume flow rates of air. Ventilation engineers prefer to work with volume flow rates because these flow rates, being the product of cross sectional area and measured airflow speed, are easy to visualize. Moreover, energies (ft-lb) per unit volume (ft^3) have the dimensions of pressures ($\text{ft-lb}/\text{ft}^3 = \text{lb}/\text{ft}^2$) and can, like fan pressures or the pressure losses in airways, be directly read from manometers or barometers. Problems arise from the fact that due to density changes of the air the volume flow rates change also, even when the mass flow rates remain constant. This makes it, in ventilation surveys, difficult to detect genuine air leakage currents. In network calculations, suitable allowances have to be made for the fact that the volume flow rates entering airways are not necessarily equal to the volume flow rates leaving them. Energy balances are distorted by the fact that equal energy quantities (ft-lb/lb) can be expressed by different pressures ($\text{ft-lb}/\text{ft}^3$), which in ventilation pressure surveys usually leads to an overestimate of natural ventilation pressures and requires, in network calculations, suitable adjustments.

The network calculations in this report will, therefore, be based on mass flow rates, but since these and the pertinent energy quantities per unit mass ($\text{ft-lb}/\text{lb} = \text{ft}$, heads) are unfamiliar to many ventilation engineers, they are with the help of reference densities d_r

converted into quantities with the dimensions of volume flow rates and pressures. The reference densities are nothing more than constant factors which are carried through the calculations with the sole aim of obtaining results in familiar units. For their magnitude a value close to the average density in that part of the mine, for which the results of the network calculation are most important, is chosen. They are stated at the beginning of the program together with a reference temperature which corresponds to this density.

This approach requires preparing the input data of the network calculation in the following way. The measured actual flow rates Q , having an average density of d , are converted to the reference volume flow rate Q_r according to

$$Q_r = Q \frac{d_r}{d}$$

The pressure loss H_L which has been obtained from an altimeter survey (15) or read from the manometer of a trailing hose (9) is converted to the reference pressure loss

$$H_{Lr} = H_L \frac{d_r}{d}$$

If pressure losses have been calculated from the formula

$$H_L = \frac{K L O}{5.2 A^3} \left(\frac{Q}{10^5} \right)^2$$

where K = friction factor
 L = airway length
 O = airway perimeter
 A = airway cross sectional area

and if the Bureau of Mines schedule of friction factors has been used (11), the conversion is

$$H_{Lr} = H_L \frac{d_r}{0.075}$$

Measured fan pressure H_F are converted to

$$H_{Fr} = H_F \frac{d_r}{d}$$

Fan pressures obtained from fan characteristics based on a density of 0.075 lb/ft^3 are converted to

$$H_{Fr} = H_F \frac{d_r}{0.075}$$

Natural ventilation heads h_N , which as heat energy converted into mechanical work are represented by the area enclosed in a pressure-volume (p-v) diagram ($h_N = - \oint v dp = - \oint dp/d$), are expressed as natural ventilation pressure

$$H_{Nr} = - \frac{d_r}{5.2} \oint \frac{dp}{d}$$

If resistance factors R have been determined from measured pressure losses H_L and airflow rates Q according to

$$R = H_L / (Q/10^5)^2$$

they have to be converted to

$$R_r = R \left(\frac{d_r}{d}\right)^3$$

in order to make the equation $H_{Lr} = R_r (Q_r/10^5)^2$ fit.

If they have been calculated from Bureau of Mines friction factors (11) with the help of the formula $R = K L Q / (5.2 A^3)$, they have for the same purpose to be converted to

$$R_r = R \frac{d_r^3}{0.075 d^2}$$

It is, in this report, from now on assumed that volume flow rates Q , pressures H and resistance factors R are based on a constant reference density and the subscripts r are, therefore, from now on omitted.

With this agreement and the assumption of steady state flow conditions, ventilation networks can be described by three different sets of equations: resistance equations or equivalents, junction equations, and mesh equations.

Every airway with a flow resistance obeys the resistance equation $H_L = R Q^2$. If the airway has no flow resistance but contains a pressure source H_F , an equation $H_F = f(Q)$ is substituted. If the resistance is made variable in order to keep the airflow rate Q constant (fixed quantity airway) an equation

$$Q = \text{constant}$$

takes the place of the resistance equation.

The law of mass conservation applies to every junction.

$$\sum Q = 0$$

The airflow rate entering a junction must be equal to the airflow rate leaving it. These are the junction equations of networks.

The first law of thermodynamics applies to every mesh, which can be written as

$$\sum H_L - \sum H_F - H_N = 0$$

The sum of all pressure losses in the airways of a mesh is equal to the sum of all pressures generated by pressure sources plus the natural ventilation pressure in this mesh.

If the number of airways in a network is n_b , the number of junctions n_j , and the number of meshes is n_m , there are

n_b resistance or equivalent equations,

$n_j - 1$ junction equations, and

$n_m = n_b - n_j + 1$ mesh equations.

4. PROGRAM DESCRIPTION

4.1 NETWORK PART OF PROGRAM

4.1.1 Section "Read Input Data"

The input data for this program part comprise: one network control card; airway cards; junction cards; fan characteristic cards; and additional airway cards.

Junction and fan characteristic cards may be omitted if the information contained in them is not considered essential to the expected result of the calculation. The option of additional airway cards has been introduced to be capable of using already existing decks or files of airway cards from conventional ventilation network calculations, which do not contain all the information needed for the use of this program.

The network control card has to state:

NB	number of airways
NJ	number of junctions
NFNUM	number of fan characteristics to be read in
NADBC	number of additional airway cards
NVPN	marker; NVPN > 0 indicates that NJ junction cards shall be read in and that natural ventilation pressures shall be calculated from junction card data
NETW)	(values larger than 0 indicate that network, concentration,
NCONC)	marker (and temperature calculations shall be performed; these
NTEMP)	(can be executed independently of each other
MADJ	maximal number of times a network calculation shall be performed in one program run
ITN	maximal number of iterations permitted within network and concentration parts of program
DR	reference density
TR	reference temperature

The two numbers MADJ and ITN are safety switches against endless computer runs with meaningless data.

NB airway cards are needed which can be arranged in any arbitrary sequence. There are three types of airway cards: regular airway cards, marked by NWTYP = 0; fixed quantity airway cards, marked by NWTYP = -1; fan cards, marked by NWTYP = 1.

All airway cards have to state:

NO airway number
 JS junction number of airway beginning
 JF junction number of airway end

Regular airway cards have to state:

R resistance factor of airway when computer is not expected to
 calculate this figure

Fan cards have to state (in the R-column) the fan pressure. This
 will be the acting fan pressure, when no fan characteristics are given.

Fixed quantity cards have to state:

Q desired constant airflow rate

In regular airway and fan cards the statement of an estimated Q
 is optional. When it is in the right order of magnitude it is helpful for
 obtaining a fast solution.

The airway properties:

KF friction factor
 LA airway length
 A cross sectional area
 O perimeter

may be stated at this place in the airway cards. They may be stated later
 in the NADBC additional airway cards, or average properties, read into the
 computer at the beginning of the concentration part, may be used.

For $NVPN > 0$, NJ junction cards have to be provided. Each one
 has to state:

JNO junction number
 T temperature of junction
 Z elevation of junction

Since this information is used for the calculation of the natural ventila-
 tion pressure only, the data do not have to be very accurate. The state-
 ment of:

CH4C methane concentration in junction

is optional. It is used in the concentration part to estimate the methane
 evolution of airways if no better information has been given. It can be
 stated later with the input data of the concentration part, if so desired.
 The possibility to state it here was introduced because the junction cards
 provide ample space.

NFNUM sets of fan characteristic cards have to be provided. Every set comprises one fan identity card, stating:

NOF airway number of fan
MPTS number of points which shall be used to define the fan characteristic

and as many curve point cards as are needed to state:

QF airflow rate at point of fan characteristic
PF fan pressure at point of fan characteristic

for all of the MPTS points. Ten points contained in two cards will usually be sufficient.

4.1.2 Complete Input Data, Output of Input

In this section the NADBC additional network airway cards are read in. They contain:

NOX airway number
KX friction factor K
LX airway length
AX cross sectional area
OX perimeter

A check is made to see if all the additional cards refer to airways which are part of the network. If not, their content is disregarded and a message printed. It is then checked to see if the resistance factor R for every regular airway has been stated. If not, it is checked to see if R can be calculated from the stated airway dimensions, but a stated R always overrides a calculated value. If R has not been stated and cannot be calculated, a network calculation is impossible. The computer shows where data are lacking, prints out the received input data together with the message that no network calculation has been performed and moves on to the concentration part of the program. It does the same if no network calculation is desired ($NETW \leq 0$). As a preparation for the network calculation the counters MADJC and ITCT as well as the markers NSW, NSNVP, NNVP, and MARKN are set to zero.

4.1.3 Arrange Airways to Size and Magnitude $R \cdot Q$

Numerical values of resistance factors are small and are traditionally stated as $R \cdot 10^{10}$. In order to make the resistance equation

$H_L = R Q^2$ fit, Q is, in this formula, expressed in units of 10^5 cfm. This conversion is done in the first pass through this program part when $NSW \leq 0$.

Theoretical investigations have shown that the convergence of the CROSS iteration method is improved when airways with high resistance factors are made so-called "primary" airways, which occur in one mesh only (18). It has been shown by earlier experiences with digital computers that when meshes are formed in this way, an acceptable rate of convergence can be achieved altogether (7) and many existing programs follow this route. Additional practical experience has shown that an even better convergence can be reached when airways with high products $R*Q$ appear in as few meshes as possible, i.e. are made primary airways. This makes the denominator of the CROSS correction formula small and the corrections consequently large.

In preparation for the selection of primary airways, an INU-list is formed. This contains, in its lowest places, the fans for which no fan characteristic has been given (constant pressure fans). The regular airways follow in the order of their increased magnitude $R*Q$. The list is completed with the fixed quantity airways and the fans, for which a fan characteristic has been given (variable pressure fans). The positions of these fans in the airway list is at this time put into a special NFREG-list in order to be able to locate them later on when fan pressures have to be determined.

The reason for this arrangement is that, in the next program section, primary airways are selected from the top of the INU-list. Fixed quantity airways can, according to their definition, have no airflow rate corrections. They should, therefore, occur in as few meshes as possible. Variable pressure fans have to adjust their pressures after every airflow rate correction. To make them primary airways, which are corrected only once in every iteration, keeps the computing effort low. It prevents, furthermore, oscillations of the system, which can occur when a large number of variable pressure fans are cooperating.

4.1.4 Set Up Base System

As with all computer sorting processes, the principles employed in this section are not complicated but are hard to explain. The best

way to understand the procedures, if one desires, is to go through a numerical example. Since the procedures are not new or unique they shall not be discussed in detail here.

Starting out with the airway in the lowest place of the INU-list, the base system or a tree of $N_j - 1$ "secondary" airways is assembled in such a way that all junctions of the network are connected, but no meshes are formed. The number of remaining primary airways is $(N_b - N_j + 1 = N_m)$ equal to the number of meshes. Everyone of the remaining branches will, therefore, when added to the base system, close a mesh. All airways which become part of the base system are entered into a list of secondary airways, the KNO-list. The remaining primary airways are marked by giving their finishing junctions JF a negative sign.

In assembling the base system the airways are scrutinized in ascending order of their places in the INU-list. This means that the KNO-list of secondary airways contains the fixed pressure fans and the airways with the lowest possible products $R*Q$. If a fixed quantity airway has to be entered into the KNO-list, which usually means that all airways entering and leaving a junction are fixed quantity airways, a message is printed and this airway is treated like a regular airway. If an airway, like a dead-end working, is only connected to the network at one end, a message is printed out also.

4.1.5 Form Meshes

Every primary airway, which is either a fixed quantity airway, variable pressure fan, or a regular airway with a high product $R*Q$, will form a mesh with secondary airways. As one can visualize from connecting two branches of a tree (secondary airways), there is only one possibility to form a mesh. The meshes are found by adding to both ends of a primary airway a sequence of secondary airways from the KNO-list until the ends meet. Two lists are used to describe the meshes. The MSL-list contains the whole sequence of primary and secondary airways which forms all the meshes in the network. The MEND-list contains the places of the secondary airways in the MSL-list, which closed a mesh when it was formed. Thus, if the first two meshes would comprise 6 and 10 airways, one would have: $MEND(1) = 6$, $MEND(2) = 16$. The primary airways in these meshes would have

the places MSL(1) and MSL(6+1), the two meshes would occupy the places 1 through 6, and 7 through 16 in the MSL-list.

4.1.6 Satisfy Junction Equations

The CROSS approximation method does not interfere with the junction equations, but these have to be satisfied originally to make the method work. This can be done by placing the airflow rates of every primary airway into all the airways which belong to the mesh of this primary airway. With N_b airflow rates Q existing in the N_b airways and $N_j - 1$ junction equations, $N_b - (N_j - 1) = N_m$ airflow rates can be arbitrarily chosen. N_m is equal to the number of primary airways.

This can be visualized in the following way. If we assume that in every mesh a certain airflow rate is circulated, the junction equations must be satisfied. Whatever flows into the junctions, through which this mesh passes, must flow out of them again. The primary airways, being part of one mesh only, carry this specific airflow rate. The secondary airways carry the airflow rates of all the meshes of which they are a part.

The program accomplishes this by setting the airflow rates of all secondary airways, found from the MSL and MEND-lists, initially to zero. It then takes the airflow rates, which have been indicated for the primary airways in the airway cards, and puts them into the airways of the pertinent meshes. The directions, in which the airflow rates circulating in the meshes pass through the airways, have to be noted. All airflow rates are then for every individual airway summed up, and the result is an airflow distribution which satisfies the junction equations.

4.1.7 Calculate Natural Ventilation Pressure

This section of the program is executed in the first network calculation ($NSNVP \leq 0$) only where junction cards with temperature and elevation data were read in ($NVPN > 0$). If it has to be assumed that heat sources or changed surface temperatures have altered the temperature distribution in the mine, the pertinent natural ventilation pressures are calculated in a different way in another section of the program.

Natural ventilation pressures are caused by the conversion of heat into mechanical energy, which is then available to propel the air and to overcome friction losses. Under steady-state conditions cyclic processes which are provided by every mesh of the ventilation system are necessary for such a conversion. The amount of heat converted into work per unit weight of air h_N is indicated by the area enclosed by the mesh in a pressure (p) . volume (v) diagram ($h_N = - \oint v dp$). Data on specific volumes and pressures are usually not available at mines and are tedious to determine. Data on temperatures and elevations can, however, be easily obtained. The author suggested, therefore, in the early sixties, determining the natural ventilation from:

$$h_N = \frac{1}{T_m} \oint T dz$$

where: T = absolute temperature
 Z = elevation
 T_m = average absolute temperature
 in the mesh under consideration

and to let the computer calculate h_N and incorporate it in the network calculation from information on temperatures and elevations of the network junctions. The error which is caused by substituting $1/T_m \oint T dz$ for $-\oint v dp$ has been investigated (7) and is comparatively small. This method of considering natural ventilation network calculations is a very convenient one, is part of the Michigan Tech program, and has found its way into many other programs also.

For lack of other information, a linear temperature change between junctions is assumed, which is accurate enough for the normal state of mines. The natural ventilation pressure H_N based on a reference density DR can then be calculated from:

$$H_N = \frac{DR}{5.2} \frac{n \sum (T_s * Z_f - T_f * Z_s)}{\sum (T_s + T_f)}$$

where: n = number of airways in mesh
 T_s, Z_s = temperatures and elevations of starting junctions
 of airways in mesh
 T_f, Z_f = temperatures and elevations of finishing junctions
 of airways in mesh

The computer performs this calculation and stores the natural ventilation pressure, which has been obtained for the meshes of the network in a FNVP-list.

4.1.8 Iteration

The CROSS correction, which is used in this program is:

$$Q = - \frac{\sum R_i |Q_i| Q_i - \sum H_{Fi} - H_N}{\sum (2 R_i |Q_i| - dH_{Fi}/dQ_i)}$$

where: R_i, Q_i = resistance and airflow rate of regular airways contained in the mesh

H_{Fi} = pressure of fans contained in the mesh

H_N = natural ventilation pressure of the mesh

dH_{Fi}/dQ_i = gradient of the fan pressure characteristic at airflow rate Q

This correction is applied to every mesh in the network except for those which have a fixed quantity airway as primary airway, and this process is reiterated until either a specified number of iterations has been performed or a specified threshold is no longer exceeded.

For variable pressure fans, the estimated fan pressure contained in the airway card and a gradient $RGRAD = dH_F/dQ = 0$ is assumed in the first iteration. In the following iterations, values determined in the next program section are used. Calculated at first is the numerator of the CROSS correction $DPSUM - FNVP$, then the denominator $RQSUM$, then the correction DQ , then the corrected flow rates Q of the airways in the mesh, finally the sum of all corrections in one iteration $DQSUM = \sum ABS(DQ)$.

4.1.9 Fan Characteristic

The fan characteristics were read into the computer with the fan characteristic cards, in which, for every fan with the airway number NOF for MPTS points, the airflow rates QF and fan pressures PF had been stated. Intermediate fan pressure values $FANP$, at the airflow rate $FANQ$, are determined with the help of LAGRANGE's interpolation formula:

$$FANP = PF_1 \frac{(FANQ - QF_2)(FANQ - QF_3) \dots (FANQ - QF_n)}{(QF_1 - QF_2)(QF_1 - QF_3) \dots (QF_1 - QF_n)} + PF_2 \frac{(FANQ - QF_1)(FANQ - QF_3) \dots (FANQ - QF_n)}{(QF_2 - QF_1)(QF_2 - QF_3) \dots (QF_2 - QF_n)} + \dots$$

$$+ PF_n \frac{(FANQ-QF_1)(FANQ-QF_2)\dots(FANQ-QF_{n-1})}{(QF_n-QF_1)(QF_n-QF_2)\dots(QF_n-QF_{n-1})}$$

This formula permits very simple programming and gives a smooth fit of the fan curves. Exceptions are the boundary regions where undulations can occur. Beyond the last stated point of the characteristic one can have steep extensions. To avoid difficulties in the boundary region, into which the fan might enter during the iteration process, the fan pressure is, for the region to the left of the second point and to the right of the second last point, made equal to the pressures in these points. Fans, which in the last iteration before the output of a result are still in these regions, are entered into a NFCW-list which is later used for printing a warning.

For the gradient of the characteristic $RGRAD = dH_f/dQ$, the slope of a straight connection between the two stated points to the left and the right of the operating point $FANQ$, $FANP$ is used. This approach is good enough since the justification of $RGRAD$ in $CROSS'$ correction formula is questioned anyway (14).

The calculated fan pressures $FANP$ replace the estimated pressures in the R-list of the input data. The counter of iterations, which have been performed with a particular assembly of meshes (IT), and the counter of the total number of iterations performed in the network calculation (ITCT), are raised by one.

4.1.10 Continue in Appropriate Program Section

At least two iterations ($IT = 2$) have to be performed, otherwise the fan characteristics would remain unconsidered. After the second iteration, a check is made to see if the sum of all corrections $DQSUM$ is smaller than $0.002 \cdot 10^5$. If it is, and for $NSNVP \leq 0$, control passes to the next program section. $NSNVP$ is a marker which indicates with $NSNVP \leq 0$, that this is the first network calculation of the program run, and that the sections "calculate natural ventilation pressure" and "calculate resistance of regulators" have to be executed. For $DQSUM \geq 0.002 \cdot 10^5$, a check is made to see if $ITCT$ does not exceed the limit ITN set in the control card. If it does in the last network calculation of the program

run, the marker MARKN will cause the printing of a warning. For $ITCT \leq ITN$, a check is made to see if the number of iterations with the present mesh assembly approaches twenty. This indicates a poor convergence and a new mesh assembly is made by giving control to the section "arrange airways to size and magnitude $R*Q$ ". The marker NSW, which prevents a renewed division of Q by 10^5 , is made positive; the marker NSFLOW is set to zero. $NSFLOW \leq 0$ indicates that a new mesh selection has been made in the network part of the program and that a new flow scheme in the concentration part of the program is therefore necessary.

If this was not the first network calculation of the computer run ($NSNVP > 0$), the next two program sections would be omitted. In preparation for the concentration part of the program, the airflow rates are multiplied by 10^5 . A check is made to determine if, during the last network calculation which the computer was assigned to make ($MADJC \geq MADJ$), an airflow reversal has taken place. If it has, it is an indication that an airway changes its airflow direction in every network calculation. This means that the airway is so unstable that the minute adjustments of temperature and airflow distribution, which are made in consecutive steps, did let the airflow in the airway oscillate. Since the magnitude of the adjustments is well below the perennial changes which occur in real mines, it seemed important to detect these airways rather than to suppress the oscillations by finer adjustment procedures.

4.1.11 Calculate Resistance of Regulators

The concept of fixed quantity airways is a valuable planning aid for the simulation of such airways through which, in the reality of a mine, a certain fixed quantity is allowed to flow irrespective of the state of the rest of the ventilation system. This concept is as old as the use of computers for network calculations and was already part of the first digital computer programs. The adjustment of regulators by mine personnel, with which the airflow rate is kept constant, will not happen in the case of an emergency. The fixed quantity airways have, therefore, to be converted into regular airways to obtain a realistic simulation of their behavior. This can cause problems with fixed quantity airways

which are used to simulate the outflow of compressed air. They should be put in series with a pressure source in the same way as, in reality, the compressed air lines are connected to a compressor.

Fixed quantity airways are, therefore, in this program only treated as fixed quantity airways in the first network calculation of the computer run. After its completion, their resistance is calculated and they are converted into regular airways. This section of the program is consequently executed only once (NSNVP = 0). If the changes in the ventilation system are such that new network calculations become necessary (NSNVP \neq 0), this section is omitted.

The determination of the resistance of fixed quantity airways proceeds in the way that meshes containing them are sorted out with the help of the MSL and MEND-lists. The pressures H_L , acting on the fixed quantity airways, are determined by summing up the pressures in all other airways of these meshes. The resistance is calculated from $R = H_L/Q^2$. Subsequently NWTYP of the fixed quantity airways is changed from -1 to 0, which means they are converted into regular airways.

4.1.12 Output of Results

This output contains the results of the first network calculation. If temperature and concentration calculations are subsequently desired (NCONC > 0, NTEMP > 0), the output will show on which initial network data they were based. If they are not desired (NCONC \leq 0, NTEMP \leq 0), this will be the only output and the computer will print information to that effect. Printed are, for the regular and fixed quantity airways, the airway numbers NO, their junction numbers JS, JF, calculated airflow rates Q, and pressure losses P, resistance factors R, and the stated airway dimension lengths LA, cross sectional areas A, friction factors KF, and perimeters O. A separate table is provided for fans with numbers NO, junctions JS, JF, airflow rates Q, and fan pressures P. Since ventilation planning comprises, frequently, the selection of suitable fans, the characteristics, which were used in the network calculation, are indicated also. Finally, the number of airways and the number of junctions is printed because they may be needed in future plannings, and experience shows that, in their statement, errors occur frequently.

In preparation for the next network part, the markers NSFLOW and ITCT are set to zero.

4.2 CONCENTRATION PART OF PROGRAM

4.2.1 Read and Complete Input Data

The input data for this program part comprise: one concentration control card; one average value card; additional airway cards; additional junction cards; and contamination cards. All cards except for the control card are optional. The computer must, however, receive the input data, which it needs for the assigned calculations somehow, either as average data or as detailed airway data. The concentration control card has to state:

NDIM	additional number of concentration airway cards to follow
NCH4C	additional number of concentration junction cards to follow
NAV	marker for presence of average value card (> 0 yes)
MAXJ	highest junction number used in network
INFLOW	number of cards specifying contamination
JSTART	number of junctions from which concentration calculations shall start; normally this will be the atmosphere
TSTART	temperature in JSTART
TIME	time which has elapsed since beginning of contamination; this is necessary for the temperature calculation where non-steady state conditions have to be assumed, only
CRITSM	accuracy with which the results for smoke, methane, and temperature are expected; when recirculation occurs, an iteration
CRITGS	method has to be used and these are the threshold values at
CRITHT	which iterations stop
WRNPR	pressure losses, smoke concentrations, methane concentrations,
WRNSM	and temperatures which shall be considered to be critical, so
WRNGS	special attention should be drawn to them in output
WRNHT	

The average value card contains average values for:

TAVR	rock temperature
HAAVR	rock diffusivity
HKAVR	rock thermal conductivity
KFAVR	friction factor of airways
LAAVR	airway length
AAVR	airway cross sectional area
OAVR	airway perimeter

This card is optional. It was introduced to keep the amount of input data as small as possible. Rock temperatures, diffusivities, conductivities,

and airway friction factors can in many cases be assumed to be the same for many airways of the mine. Many airways exist in hardrock mines, like raises between levels, which have, essentially, all the same dimensions. If detailed, accurate information is needed, it can always be entered with the airway cards and override the average values. Another reason for the introduction of average values was to prevent the termination of a computer run due to lack of, perhaps, rather insignificant airway properties.

If additional concentration airway cards are wanted, NDIM in the concentration control card has stated how many of them. They contain:

NOX	airway number
CH4VX	methane volume production rate in airway
CH4PAX	methane volume production rate per unit surface area in airway
TROCKX	average rock temperature in airway
HAX	thermal diffusivity of rock in airway
HKX	thermal conductivity of rock in airway
DZRDY	elevation change in airway

Except for NOX, all of this information is optional. DZRDY must, however, be unequal to zero if it shall override elevation changes calculated from junction elevations, because the computer cannot decide if it is equal to zero or if it has been forgotten. If it is equal to zero, it should be given a small positive or negative value close to zero.

If additional concentration junction cards are wanted, NCH4C in the concentration control card has stated how many of them. They contain only:

JNOX	junction number
CH4CX	methane concentration in junction

and are used if one wants to determine the methane evolution from concentrations in junctions and this was not entered into the junction cards in the network part of the program.

If contamination enters the ventilation system, INFLOW contamination cards have to be used. Besides the airway number they contain three sections: the first one with a specified contamination which can be anything; the second one applying to oxygen rich fires; the third one applying to fuel rich fires or any type of fire. As discussed in the introduction, this is a preliminary stage which can be improved once the necessity exists. The contamination cards contain:

NCENT number of airways into which the contaminants enter

Section 1

CONT volume flow rate of contaminated inflow

CONC concentration of contaminant in inflow

HEAT heat entering airway

Section 2

O2MIN oxygen concentration with which fumes leave fire zone

Section 3

SMPO2 smoke production per ft³ of oxygen delivery

HTPO2 heat production per ft³ of oxygen delivery

Section 2 overrides section 1, section 3 overrides section 1 and 2.

Control card, optional average value card, and optional additional airway cards are read in. Methane evolution rate per airway CH4VX and per unit area of airway CH4PAX, rock temperature TROCKX, thermal diffusivity HAX and conductivity HKX, and elevation change DZRDX, are placed in the airway files CH4V, CH4PA, TROCK, HA, HK, and DZRD. A check is made to see if the number of airway cards in the input was equal to the stated number of cards NDIM. If not, a message is printed and the calculation terminated.

The airway files are then completed. For every airway a check is made to see if data for thermal diffusivity HA and conductivity HK from the just received additional airway cards, and if data for the friction factor KF, the airway length LA, the cross sectional area A, and the perimeter O from the network part of the program exist. If they don't, average values from the average value card are substituted. If this card does not exist, a message is printed and the calculation terminated. The elevation change DZRD cannot be checked because it may in reality be equal to zero. Before an average value is substituted for the rock temperature TROCK, it is first checked to see if junction cards exist in the network part (NVPN > 0). If yes, the airway is marked by giving its airway number NO a different sign than the rest of the airways. Temperatures T and elevations Z of starting and finishing junctions of these airways are then retrieved from the junction files of the network part of the program. Rock temperatures are calculated from these in the following way. When the assumption is made that the increase of rock temperature with depth has, due to the

heat exchange between rock and air, become the same as the increase of rock temperature with depth, the air temperature change can, for steady state heat transfer, be described by (7):

$$t = t_{r0} - g_a LA \sin \beta + (t_1 - t_{r0}) \exp(-\alpha \circ LA/G CP)$$

where: t_{r0} = rock temperature at beginning of airway
 t_1 = air temperature at beginning of airway
 g_a = autocompression gradient
 β = slope angle (positive for ascending, negative for descending ventilation)
 α = convection coefficient
 G = weight flow rate
 CP = specific heat of air

If, for the convection coefficient, the approximation:

$$\alpha = 0.4 v^{0.8}$$

(7) where: α = convection coefficient (Btu/ft²-hr-°F)
 v = air speed (ft/sec)

is used, the exponent can be converted to:

$$X*LA = \alpha \circ LA/G CP = 0.014 \circ LA/(A^{0.8} Q^{0.2})$$

With $DZRD = LA \sin \beta$ and the definition of an average rock temperature

$$T_{ROCK} = t_{r0} - \frac{g_a}{2} DZRD$$

one obtains for the rock temperature

$$T_{ROCK} = \frac{t_2 - t_1 * \exp(-X*LA) + DZRD * g_a}{(1 - \exp(-X*LA))} - \frac{g_a}{2} DZRD$$

Elevation changes $DZRD$ are calculated as the difference between the two elevations if $DZRD$, in the files, is equal to zero. It is for this reason that $DZRD$ in the input data should not be made exactly equal to zero, even for a horizontal airway, which it usually isn't anyway in so-called level airways.

4.2.2 Set Up JNO List

If no junction number cards were, in the network part of the program, read into the computer, no junction number list (JNO-list) yet exists.

It is set up in this program section together with a check, if the stated number of junctions is equal to the actual number, and, when necessary, with a correction. This is a frequent source of error when concentration calculations are performed only. The reason is that the number of junctions must be obtained by marking them in a check-list, whereas the number of airways can simply be obtained by counting the airway cards. It can be disputed whether junction cards and information on junctions serve a useful purpose. The calculation of the natural ventilation pressure in this way is, however, so widespread that in this program junction cards were retained. The occasionally made comment of storage waste is not true. Since the number of junctions is, with at least three airways entering or leaving a junction, equal to or smaller than $2/3$ of the airway number, it takes, at the most, the same space to store temperature and elevation data junction-wise with a special junction number list than to do it airway-wise.

4.2.3 Calculate Methane Evolution

With a junction number list established, potential additional NCH4C junction cards can be read in. They contain, besides the junction number, only methane concentrations CH4C in junctions, which are placed into the pertinent list. A check is made again to see if all cards refer to junctions of the network. When not, a message is printed but no termination of calculations takes place since information on methane evolution is provided from several sides.

For all ventilation planning in coal mines, it is very important to assess the methane evolution since changes in the airflow distribution will cause changes in the methane concentration distribution also. Airflow reductions can lead to dangerous concentrations, the main concern in all fire fighting operations. It is justified to consider the rate of methane release from coal faces, ribs, and pillars as roughly constant over short time periods. Even the increased methane production caused by mining operations will, when the operations stop, only gradually taper off (2,12).

The rate of methane evolution per airway CH4V is introduced into this program in three different ways. It is in the additional airway cards

either stated directly (CH4VX) or stated per unit surface area (CH4PAX) and then multiplied by the surface area LA*O. If both statements have not been given, it is calculated from the methane concentrations in junctions by assuming that the concentration change between starting and finishing junction of an airway multiplied by its airflow rate is equal to its methane production.

This last approach is a convenient one since methane concentrations in junctions, like temperatures, are, by most ventilation engineers, known by heart for their mine. It is, however, a crude approach since it is accurate only when merging air currents have the same concentrations. If the printout of the input data for concentrations and temperature calculations shows that the methane production obtained in this way is unrealistic for some airways, it has to be stated directly. Methane evolutions CH4V obtained from direct statements CH4VX override all other values; those indirectly obtained from CH4PAX override the ones derived from junction concentrations.

At the end of this section, the contamination cards are read in.

4.2.4 Output of Input

To allow a critical assessment of the quality of results obtained with the help of this program, all important input data, which are not contained in the network output, are printed out. These data comprise a table with airway numbers NO, starting and finishing junctions JS, JF, elevation differences DZRD, rock temperatures TROCK, methane evolution CH4V, thermal conductivity HK, and thermal diffusivity HA. The time after the beginning of the contamination TIME, number JSTART and temperature TSTART of that junction, from which the calculation starts, are given also. Finally, the contamination with NCENT, CONT, CONC, HEAT, O2MIN, SMPO2, and HTPO2 is listed, or, if no contamination occurs, a relevant message is printed.

4.2.5 Flowscheme

All airways are checked for negative airflow rates. If any are detected, the flow is made positive by exchanging starting and finishing

junctions. This makes a new mesh selection necessary in following network calculations and the marker NSFLOW is, therefore, set equal to zero. With the exchange of junctions, the sign of the elevation change DZRD has to be changed also.

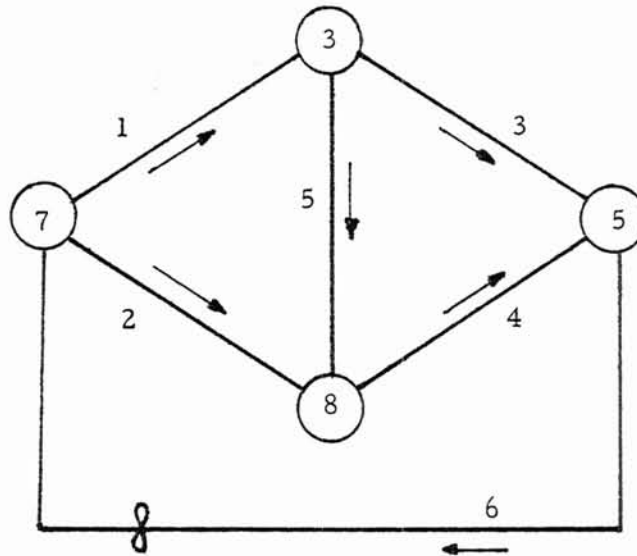
For the purpose of identifying airways with airflow reversals in the output, they are placed into a NREV file and their total number is counted by NRCT. Since the possibility exists that in the iteration process between the network and concentrations parts of the program, an airway experiences airflow reversal repeatedly, it is checked to see if this airway is not already in the NREV file. If it is, this means that an even number of reversals has taken place and that the airflow in this airway has its original direction again. It is therefore removed from the NREV file. After all airways have been checked, the NREV file is compacted and NRCT set to its proper value.

For the purpose of calculating temperatures and concentrations, one has to know which air currents go into the same junction and are mixed there and which air currents leave from the same junction and have consequently the same properties. Since the number of airways connected to a junction can change in wide limits, it is not advisable to compile this information in a multidimensional array in which many places could remain empty. Instead a series of one-dimensional arrays is used, which was, for the same reasons, the approach with the mesh-lists in the network part of the program also. The procedures chosen for assembling these arrays are similar to the ones used by GEIGER (6). The following 5 arrays are set up:

JNOL	list of all junction numbers arranged according to magnitude of numbers
NGOUT	list of all airways going away from junctions
LOUT	list of last place occupied in NGOUT-list by a series of airways leaving a particular junction
NGIN	list of all airways entering junctions
MIN	list of last places occupied in NGIN-list by a series of airways entering a particular junction

The example given in Fig. 1 may make this procedure clearer. The first junction number considered is $JNOL(1) = 3$. $LOUT(1) = 2$ indicates that airways $NGOUT(1) = 3$ and $NGOUT(2) = 5$ leave this junction. $MIN(1) = 1$ indicates that airway $NGIN(1) = 1$ enters it. The second junction number

Fig. 1: Flowscheme of a simple network described with the help of onedimensional arrays



JNOL	NGOUT	LOUT	NGIN	MIN
3	3	2	1	1
5	5	3	3	3
7	6	5	4	4
8	1	6	6	6
	2		2	
	4		5	

JNOL	JNO	JLR
3	8	4
5	7	3
7	5	2
8	3	1

is $JNOL(2) = 5$. Airways leaving this junction occupy the places $LOUT(1) + 1 = 3$ through $LOUT(2) = 3$ in the $NGOUT$ -list, consequently $NGOUT(3) = 6$ is the only airway leaving this junction. Airways entering this junction occupy the places $MIN(1) + 1 = 2$ through $MIN(2) = 3$ in the $NGIN$ -list, consequently $NGIN(2) = 3$ and $NGIN(3) = 4$ are entering this junction. The procedures for all other junctions are the same.

4.2.6 Relate JNO- and JNOL-Lists

In the $JNOL$ -list the junction numbers are arranged according to their magnitude. If a JNO -list has been created by ($NVPN > 0$) reading junction cards in the network part of the program into the computer, the junction numbers in this list can be in any arbitrary sequence which is convenient for input and output. Both lists are correlated by the JLR -list which indicates in which place a junction from the $JNOL$ -list is contained in the JNO -list. Fig. 1 shows, for instance, that the junction $JNOL(1) = 3$ can from $JLR(1) = 4$ be located as $JNO(4) = 3$.

In this section the contaminant concentrations in junctions $PROP$ and $PRCH4$ are set equal to zero also.

4.2.7 Indices of Starting Junction (Atmosphere)

The indices of the junction at which one wants the temperature and concentration calculation to begin are determined. They are $MSTART$ for the $JNOL$ -list and $ISTART$ for the JNO -list. The temperature of this junction is set to $TSTART$, which had been stated in the control card. The counter MRC and the marker $MARKC$ are set to zero.

4.2.8 Conditions at Roadway Ends

4.2.8.1 General Remarks

Determined with the help of this program are: contaminant concentrations; methane concentrations; and temperatures.

Changes of concentrations and temperatures can occur in roadways due to contaminants, methane, and heat entering or leaving the air. They can occur in junctions due to mixing of air currents with different

concentrations and temperatures. Since the processes in roadways and junctions are completely different, two different program sections have been provided.

Contaminant concentrations in roadways have received the name RDPROP, in junctions PROP, at roadway beginnings PROPJS. Methane concentrations have received the names RDCH4, PRCH4, and CH4JS. Temperatures have received the names TRD, T, and TJS.

Temperature calculations are performed only when demanded (NTEMP > 0). Concentration calculations are performed when demanded (NCONC > 0), but also when only temperature calculations were desired, since varying temperatures can cause varying airflow distributions and, therefore, varying methane concentrations.

The concentration calculations have, at this stage, been kept quite simple since the program requires that entering or leaving contaminants be specified. The temperature calculations have, however, become relatively comprehensive and complicated. On the one hand, the techniques for precalculating mine temperatures are more advanced than those for precalculating contaminant productions. On the other hand, the author attached more importance to these temperature precalculations since ventilation disturbances are mainly caused by thermal forces, not by concentration changes.

Roadway calculations start out with setting the properties PROPJS, CH4JS, TJS at the beginning of roadways, leaving a junction equal to the equivalent properties PROP, PRCH4, T in this junction when the properties are known. For the first calculations this junction will be the starting junction JSTART, later on every junction, for which the calculations of the program section "conditions in junctions", could be completed. The roadways coming out of the junctions are found from the LOUT- and NGOUT-lists and identical calculations are performed for all of them. At the start of every calculation the counter ICFTM is set to zero.

4.2.8.2 Concentration Changes and Added Heat in Airways

A check is made to see if contaminants or heat enter the airway (NO = NCENT). If not, the volume flow rate of the pure (100% concentration) contaminant CONTAM, the volume flow rate of the gas current carrying

the contaminant $CONTQ$, and the heat addition $HEATAD$ are set equal to zero. If a contaminant or heat enters the mine air, it can be specified in the contamination cards in several ways. In section 1 the volume flow rate of the gas current carrying the contaminant $CONT$, its concentration $CONC$ (%), and the heat $HEAT$ are specified. $CONTAM$, $CONTQ$ and $HEATAD$ are determined from:

$$CONTAM = CONT * CONC / 100$$

$$CONTQ = CONT$$

$$HEATAD = HEAT$$

$CONT$ and $HEAT$ can have negative signs for gas absorptions and heat sinks. If the inflow $CONT$ is so large that it influences the airflow distribution, which will very rarely be the case, a fixed quantity airway similar to compressed air discharges should be provided for it.

Section 2 of the contamination card applies to oxygen rich fires and states the oxygen concentration $O2MIN$ with which the fumes leave the fire zone. The assumption is made that all consumed oxygen is converted into CO_2 . The oxygen concentration entering the fire zone is $0.21 - PROPJS$, the oxygen consumption is $0.21 - PROPJS - O2MIN/100$, the volume flow rate of CO_2 consequently:

$$CONTAM = (0.21 - PROPJS - O2MIN/100) * Q$$

No additional gas enters the mine:

$$CONTQ = 0$$

The rate of heat generation is, with 437 Btu/ft^3 of consumed oxygen:

$$HEATAD = CONTAM * 437$$

Section 3 applies to fuel rich fires and contaminant and heat production, $SMPO2$ and $HTPO2$ per ft^3 of oxygen delivery, have to be stated. One obtains:

$$CONTAM = (0.21 - PROPJS) * Q * SMPO2$$

$$HEATAD = (0.21 - PROPJS) * Q * HTPO2$$

$$CONTQ = 0$$

At this place, a suitable function relating contaminant and heat production with the oxygen supply can easily be introduced, if so desired and such a function is available.

Contamination and methane concentration at the end of the roadway can then be calculated from:

$$RDPROP = [PROPJS(Q-CONTQ) + CONTAM]/Q$$

$$RDCH4 = [CH4JS(Q-CH4V) + CH4V]/Q$$

If a temperature calculation is desired (NTEMP > 0), the heat addition HEATAD finds use; if it is not desired TRD is set equal to zero, JF made negative to mark the completed roadway calculation, and the rest of this program section is omitted.

4.2.8.3 Temperature Changes in Airways

The air temperature is increased by heat addition and subsequently reduced again by heat transfer to the airway walls. The temperature increase:

$$\Delta t = t - t_1 \text{ is}$$

$$\Delta t = HEATAD/(Q*DR*CP)$$

where: t_1 = temperature before heat addition

DR = reference density

CP = specific heat of air

If for CP a temperature function $CP = a + b*t$ is assumed, one obtains:

$$t = -(a/b - t_1)/2 + \sqrt{((a/b - t_1)/2)^2 + a*t_1/b + HEATAD/(Q*DR*b)}$$

and with $a = 0.2376 \text{ Btu/lb}^\circ\text{F}$, $b = 0.000024 \text{ Btu/lb}^\circ\text{F}^\circ\text{F}$,

$$t = -4950 - t_1/2 + \sqrt{(4950 - t_1/2)^2 + 9900 t_1 + HEATAD*10^6/(Q*24*DR)}$$

This equation is based on pure air. One might dispute if the assumption of temperature variable specific heats is necessary, since the influence of the air composition is neglected, but the introduction of variable specific heats causes no great difficulties.

Heat transfer to the airway walls lets the air temperature drop from an initial value of t_1 to t , which for horizontal airways can be calculated from (7):

$$t = t_r + (t_1 - t_r) \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0))$$

where: t_r = rock temperature

$R_0 = 2 A/O =$ hydraulic radius

$K(\alpha)$, the so-called "coefficient of age", is a dimensionless scale for the thickness of the insulating rock layer surrounding airways which increases with age. Its use allows treating non-steady state heat transfer like a steady state process and has, therefore, in mine ventilation become common practice.

In non-horizontal airways, the change of rock temperature with depth and the so-called "autocompression heat", the increase of air temperature with air pressure, have to be included. If one makes the justified assumption that the rock immediately surrounding an airway has, with some age of the airway, assumed the same temperature as the air ordinarily passing through it, geothermal and autocompression gradients become the same and the temperature can be calculated from (7):

$$t = t_{r0} - g_a LA \sin \beta + (t_1 - t_{r0}) \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0))$$

where: g_a = autocompression gradient

β = slope angle (positive for ascending, negative for descending ventilation)

t_{r0} = rock temperature at airway beginning

If an average rock temperature $TROCK = t_{r0} - g_a * DZRD/2$ is defined, one obtains with $DZRD = LA * \sin \beta$:

$$t = TROCK + (t_1 - TROCK) \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0)) - g_a * DZRD/2 * (1 + \exp(-HK*LA*O*K(\alpha)/(Q*DR*CP*R_0)))$$

The autocompression gradient g_a can be calculated from the mechanical heat equivalent 778.26 ft-lb/Btu and CP as:

$$g_a = 1/(778.26*CP) \text{ } ^\circ\text{F/ft}$$

The coefficient of age $K(\alpha)$ is a function of the dimensionless Fourier (FO) and Biot (BI) numbers. They are defined as:

$$FO = \text{TIME} * HA/R_0^2$$

$$BI = HC * R_0/HK$$

where HA and HK are the previously introduced thermal diffusivity and conductivity and HC is the convection coefficient.

$K(\alpha)$ has been calculated by several researchers whose results are in good agreement (7). A solution for short periods of heat exchange has been provided by SCERBAN and Kremnev (17) which reads:

$$K(\alpha) = BI - BI^2 * f(x) / (0.375 + BI)$$

$$\text{where } f(x) = \left[1 - \exp(x^2) * \left(1 - \frac{2}{\sqrt{\pi}} \int_0^x \exp(-x^2) dx \right) \right]$$

$$\text{and } x = (0.375 + BI) \sqrt{FO}$$

For the calculation of the error function

$$\phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-x^2) dx$$

in this computer program, the author introduced the power series:

$$\phi(x) \approx \frac{2}{\sqrt{\pi}} \sum_{n=0}^{\infty} \frac{(-1)^n}{n} * \frac{x^{2n+1}}{2n+1} \quad \text{for } x \leq 2.5$$

$$\frac{\sqrt{\pi}}{2} [1 - \phi(x)] \approx \frac{\exp(-x^2)}{2x} \left[1 - \frac{1}{2x^2} + \frac{1*3}{(2x^2)^2} - \frac{1*3*5}{(2x^2)^3} + \dots \right]$$

for $x > 2.5$

Development of the series is stopped when the terms in the brackets become smaller than 10^{-5} .

The convection coefficient HC is a function of air thermal conductivity HKA, Reynolds number RN, Prandtl number PR, and airway dimensions. A formula proposed by KREITH (13) for the turbulent flow in smooth ducts seems to be an average among the many suggestions found in the literature (7). It reads:

$$HC = 0.023 \frac{HKA}{2R_0} RN^{0.8} PR^{0.333}$$

With the Prandtl number being essentially independent of the air temperature, and having a value of 0.70 between 0 and 1600°F and with $R_0 = 2A/0$, this becomes:

$$HC = 0.005 \frac{HKA \cdot 0}{A} RN^{0.8}$$

A correction for rough walls can be made by introducing the correction factor (7):

$$COR = \left(\frac{f}{f_0} \right) (100/RN)^{0.125}$$

where: f = friction coefficient of rough wall
 f_0 = friction coefficient of hydraulically smooth wall

The friction coefficient f is proportional to the friction factor KF . For a density of 0.075 lb/ft³ the relationship is $f = KF/809$, for a reference density DR it is $f = KF \cdot 0.075 / (809 \cdot DR)$.

f_0 (FRO in the program) can be obtained from:

$$f_0 = 0.032 + 0.221/RN^{0.237}$$

The thermal conductivity of air can be approximated by:

$$HKA = 0.015 (T/492)^{0.81} \text{ Btu/ft h } ^\circ\text{F}$$

where: T = absolute air temperature ($^\circ\text{R}$)

The temperature dependence of air viscosity $VISC$ and weight WT , both of which are needed for the Reynolds number, can be expressed by:

$$VISC = 10^{-4} * 1.43 \left(\frac{T}{492} \right)^{1.75} \text{ ft}^2/\text{sec}$$

$$WT = DR * (TR + 460)/T$$

where: TR = reference temperature

and the Reynolds number:

$$RN = V D_0 / Visc$$

where: D_o = hydraulic diameter = 4 A/O
 V = air velocity

with $V = Q \cdot DR / (60 \cdot A \cdot WT)$

$RN = DR \cdot Q / (15 \cdot WT \cdot O \cdot VISC)$

The program starts the temperature calculation by setting the temperature at the beginning of the airway TJS equal to the pertinent junction temperature T. If a heat addition takes place (HEATAD = 0), the temperature behind the heat source is determined and made equal to TJS. It is stored in the TFSI file also because it is needed in later program sections.

For the calculation of WT, VISC, CP, and HKA, the average temperature in the roadway is needed. It is tentatively (ICFTM = 0) assumed to be the arithmetic mean between starting and rock temperature ($TM = (TJS + TROCK) / 2$). If after the completion of the temperature calculation the result shows that the temperature at the end of the roadway TRD is more than 50°F different from TROCK, a new TM is assumed (ICFTM = 1). Since the temperature along an airway follows an exponential curve of the type:

$$TRD = TROCK + (TJS - TROCK) \exp(-X \cdot LA)$$

the factor X can be calculated from the last calculated TRD value as:

$$X = \frac{1}{LA} \left[\ln \frac{(TJS - TROCK)}{(TRD - TROCK)} \right]$$

and TM can be determined as the integral mean $1/LA \int TRD \cdot dLA$ as:

$$TM = TROCK + \frac{(TJS - TROCK)}{LA \cdot X} (1 - \exp(-X \cdot LA))$$

This procedure of assuming a new TM is repeated until the calculated values for TRD vary less than 50°F. Since TM is, at this place, only needed to take the changes of the air properties WT, VISC, CP, and HKA with temperature into account, this threshold of 50°F seems to be stringent enough. After these properties have been determined, Reynolds number RN, convection coefficient HC, Fourier number FO, Biot number BI, and coefficient of COAGE are calculated. The exponent in the temperature formula:

$$HK \cdot LA \cdot O \cdot COAGE / (Q \cdot DR \cdot CP \cdot R_o)$$

becomes with $R_o = 2$ A/O and the factor 60 min/hr, when HK is, as customary, expressed per hour but Q is stated per minute:

$$XNEW = HK*LA*O^2*COAGE/(120*DR*Q*CP*A)$$

and TRD can be calculated. XNEW is placed in a file for future use. After the calculation has been completed, the roadway is marked by making its finishing junction JF negative.

4.2.9 Conditions in Junctions

Junctions, for which the junction calculations have been completed, receive a negative number JNO. They are disregarded in this program section. For the other junctions with a positive JNO, the airways going into a junction are located from the MIN- and NGIN-lists. In order to be able to perform a junction calculation the roadway calculations for these airways must have been completed, which means that they must all have negative finishing junctions. If they don't, the junction is disregarded. For the rest, the air quantities Q flowing into the junction (SUMAIR), the contaminant quantities RDPROP * Q (SUMPR), the methane quantities RDCH4 * Q, and the enthalpies TRD * Q * CP (SUMHT) are all summed up. Contaminant and methane concentrations in the junction are calculated from:

$$PROP = SUMPR/SUMAIR$$

$$PRCH4 = SUMCH4/SUMAIR$$

the temperatures from:

$$T = SUMHT/(SUMAIR*CP)$$

which with $CP = 0.2376 + 0.000024 * T$ results in:

$$T = -4950 + \sqrt{4950^2 + SUMHT/(SUMAIR*0.000024)}$$

The program returns to the section "conditions at roadway ends" where the number JNO of the junctions, with completed junction calculations, is made negative.

4.2.10 Recirculation, First Approximation

If, in the previous section, no junctions with a positive JNO can be found for which all entering airways have negative finishing junctions

JF, recirculation occurs in the network. The alternating roadway and junction calculations cannot be continued since concentrations and temperature of recirculated air entering a junction are not known. This difficulty is overcome by introducing estimated concentrations and temperatures for all recirculated airflows, with which the junction and roadway calculations are completed. The results obtained for the recirculated airflows are then taken as new, better estimates and the concentration and temperature calculations for the network are repeated. This process is continued until the differences between results and estimates are smaller than the thresholds CRITSM, CRITGS, CRITHT stated in the control card.

A variety of methods was tried to overcome the recirculation problem. With the complexity of most ventilation networks, only iteration methods seem to be practical. The herein described procedure, which is similar to the adjustment of trigonometric height measurements, showed the best convergence.

The program section starts by setting NREC = 1. NREC helps in searching for junctions where the ratio of recirculated air QREC to not recirculated air QIN is $QREC/QIN \leq NREC/2$. If no such junction can be found, NREC is stepwise increased.

All junction numbers JNO are then checked for their signs. Negative junction numbers are counted by L and then disregarded because the junction calculations have been completed for them. Positive junction numbers JNO are one after the other compared with the finishing junctions JF of airways. Junctions JNO, for which no negative JF can be found ($JNO + JF \neq 0, N \leq 0$), are disregarded because no airway with a complete roadway calculation exists for them. The remaining junctions JNO are the ones where recirculated air enters the intake air.

To find reasonable first estimates for the recirculated air, concentrations RDPROP, RDCH4, and temperatures TRD for the airways with completed roadway calculations ($JNO + JF = 0$) as well as their airflow rates Q are summed up (SRPR, SRCH4, STRD, QIN) and average values AVRPR, AVRCH4, AVTRD are calculated. The airways with recirculated air are entered into a temporary file (MEMREC) first and their airflow rates are summed up also (QREC). If a comparison shows that the recirculated airflow

rate Q_{REC} for an airway is smaller than one half of the not recirculated air Q_{IN} ($Q_{REC} * 2 / Q_{IN} - N_{REC} \leq 0$), the airway and the first estimates for its concentrations and temperature are entered into the permanent recirculation files. If Q_{REC} is larger than $1/2 Q_{IN}$, the next positive junction JNO is tried. If no junction with $Q_{REC} \leq 1/2 Q_{IN}$ could be found, N_{REC} is increased by 1 which changes the criterion to $Q_{REC} \leq Q_{IN}$. If again no junction can be found, N_{REC} is increased to 3 and so on.

The recirculation files have been introduced to avoid the repetition of this search procedure in every step of the iteration process, in which concentrations and temperatures of recirculated airflows are determined. Airways with recirculation are counted with MRC , their place in the airway list is transcribed from the temporary file $MEMREC$ into $NOREC$, and the first estimates for their concentrations and temperatures are entered into $ESTPR$, $ESTCH4$, $ESTTR$. After this, they receive these estimated values as their roadway end properties $RDPROP$, $RDCH4$, TRD , and their finishing junctions are made negative as if the roadway calculation had been completed. The place of the pertinent junction in the $JNOL$ -list is located and the junction calculation for this junction completed. The program statements for doing this are essentially the same as in the program section "conditions in junctions". The program returns to the section "conditions at roadway ends".

4.2.11 Recirculation, Preparation for Iteration

If in the previous program section it has been found that all junction numbers JNO are negative ($L \geq NJ$), the calculation of concentrations and temperatures is complete. All finishing junctions JF and junction numbers JNO are made positive again. If the counter MRC for the recirculation files indicates that no recirculation exists ($MRC = 0$), the rest of this program section is omitted. For $MRC > 0$ the differences $DIFPR$, $DIFCH4$, $DIFTRD$ between last estimated values $ESTPR$, $ESTCH4$, $ESTTR$ and last calculated results $RDPROP$, $RDCH4$, TRD are determined for every airway with recirculation. If these differences are larger than the thresholds $CRITSM$, $CRITGS$, $CRITHT$, a marker L is made > 0 . The last calculated properties $RDPROP$, $RDCH4$, TRD are made the new estimates $ESTPR$, $ESTCH4$, $ESTTR$, and the finishing junctions JF are made negative. If this

was the last iteration, these junctions will be the only negative ones in the JF-list and can be used to identify recirculation paths. The iteration counter ITCT is raised by one. If a positive marker L indicates that more iterations are necessary, it is checked to see if the maximum number ITN, which had been stated in the control card, is not exceeded. If not, the computer goes back to the beginning of the section "conditions at roadway ends" to start another iteration. If ITN would be exceeded, the marker MARKC is made positive for an appropriate message. If temperature and network calculations were demanded, the next program section is entered, if not, this section is omitted and a message printed.

4.2.12 Calculation of Natural Ventilation Pressure

This section determines the thermal forces which are caused by changed temperature distributions and introduces them into the ventilation system.

The energy per unit mass, which is required to overcome the flow resistance of an airway, is proportional to the velocity of the air in the airway. The same applies to the pressure loss when the latter is based on a constant reference density. If the density of the air changes, energy or pressure losses will change inversely proportional to the square of the density ratios. If the density change is caused by temperature changes, energy or pressure losses will change proportional to the square of the absolute temperature ratios. This change can, in a mass flow rate based network calculation, be accounted for by multiplying the resistance factor R by a factor $(T_2/T_1)^2$, where the subscripts 1 and 2 denote the old and new temperatures.

Since temperatures along the length LA of an airway vary, it is necessary to use a mean square temperature T_m^2 , which for accurate calculations should be:

$$T_m^2 = \frac{1}{LA} \int T^2 dLA$$

With the previously quoted formula (section "conditions at roadway ends"):

$$t = t_r + (t_1 - t_r) \exp(-X*LA) - \frac{g \text{ DZRD}}{2} (1 + \exp(-X*LA))$$

one obtains with the abbreviations:

$$E = g_a * DZRD / 2, \quad B = (t_1 - t_{rock}), \quad XNEW = X * LA$$

$$T_m^2 = (T_{rock} - E)^2 + \frac{(E - B)^2}{2 * XNEW} (1 - \exp(-2 * XNEW))$$

$$+ \frac{2}{XNEW} (T_{rock} - E) * (B - E) * (1 - \exp(-XNEW))$$

The natural ventilation pressure can be calculated from:

$$H_N = \frac{DR}{5.2} * \frac{1}{T_m} \int T \, dZ$$

$\int T \, dZ$ can be replaced by $\Sigma t_m * DZRD$ when one assumes airways with constant slopes. This requires knowing the mean temperature $t_m = 1/LA \int t \, dLA$ in the airways. It can be calculated from the above formula for t as:

$$t_m = t_{rock} + \frac{B}{XNEW} (1 - \exp(-XNEW)) - E(1 + (1 - \exp(-XNEW))/XNEW)$$

The program starts this section by setting the temperature at the beginnings of airways $T1$ equal to the temperature T of the starting junction JS . If contamination in an airway occurs ($NCENT = NO$), $T1$ is set equal to the calculated temperature $TFSI$ behind the contamination source. The mean temperature $TMRD$ (i.e. t_m) and mean square absolute temperature $TMSQR$ (i.e. T_m^2) are calculated next for every airway. To account for the pressure loss changes with temperature, the resistance factor R is set to new adjusted values which are the product of $RSTD$ and the ratio $TMSQR / (TR + 460)^2$. $RSTD$ is the resistance factor of the airways based on the reference temperature TR .

If the marker $NSFLOW \leq 0$ indicates that an airflow reversal has taken place, a new mesh selection is necessary before the natural ventilation pressure can be calculated. The rest of this program section is, therefore, omitted. With $NSFLOW > 0$, the natural ventilation pressures are calculated for all meshes of the network.

Since it is the thermal forces (i.e. the changed flow resistances and natural ventilation pressures and among these mainly the latter) which can alter the temperature distribution and with it the thermal forces again, the changes of natural ventilation pressures from one iteration to

the next one are made the threshold for the decision whether more iterations should be performed. The natural ventilation pressure FNVP of the last iteration is therefore preserved as ONVP before a new value FNVP is calculated. $\oint T \, dZ = \sum t_m \cdot DZRD$ is calculated by summing up in HSU the products $FRNVP = TMRD \cdot DZRD$ for all airways of a mesh. The direction in which the computer progressed in forming the mesh is accounted for by FACT (+1 for direction JS to JF, -1 for direction JF to JS). The average temperature in the mesh is calculated as the weighed arithmetic mean by summing up in TSU all absolute values of FRNVP and dividing them by two times the total elevation change in the mesh.

Errors in the statement of DZRD can make the sum of all elevation changes around a mesh unequal to zero. This means that the temperature-elevation plot of the mesh is not closed which can, even for small errors in DZRD, cause very large errors for the natural ventilation pressure. The sum of all positive elevation changes ZUP and all negative changes ZDOWN in traversing around the mesh is, therefore, determined. For $ZUP \neq ZDOWN$ the mesh is closed by substituting the reference temperature for the gap.

The differences between old and new natural ventilation pressures are calculated and their absolute values summed up in DNVP.

4.2.13 Reroute to Appropriate Program Section

Calculations of the natural ventilation pressure are necessary at two places in the program: within the network calculation; at the completion of the temperature calculation in order to find out if such significant changes have taken place that a new network calculation is required.

If the former is the case and the natural ventilation pressures are wanted for a network calculation, this is indicated by the marker $NNVP > 0$ and the program returns to the section "iteration" of the network part. The marker NNVP and the counter ITCT are set to zero. If the latter is the case, it is checked to see if the average change in the natural ventilation pressure between the last two iterations was larger than 0.001 inches watergauge per mesh. If it was smaller, the calculation is considered to be completed and the section "output of results" is entered. If it was larger, it is checked to see if the maximum number of

iterations MADJ between network and concentration part, which had been stated in the control card, has been reached ($MADJC - MADJ \geq 0$). In this case a message is printed before the output section is entered also. For ($MADJC - MADJ < 0$, the counter MADJC is raised by one, the counter ITCT and the marker MARKN are reset to zero, the marker NSNVP is set to one, all finishing junctions JF are made positive and the airflow rates Q are divided by 10^5 again. If $NSFLOW \leq 0$ indicates that a new mesh selection is necessary, NSW is made equal to one and the section "arrange airways to size and magnitude $R*Q$ " is entered. For $NSFLOW > 0$, the calculation is continued in the section "iteration".

4.2.14 Output of Results

The pressure losses for the regular airways are calculated and the fan pressure extracted from the R-file. If the stated maximum number of iterations ITN was exceeded in the network part ($MARKN > 0$) or in the concentration part ($MARKC > 0$), warnings are printed.

A table with the results of the calculations for the states of the airway ends comes next. It lists airway numbers NO, junctions JS and JF, calculated airflow rates Q , temperatures TRD, smoke concentrations RDPROP, methane concentrations RDCH4, and pressure losses P. The term "smoke" stands for "contaminant" because it is shorter and this program will mainly be used for fire emergency plans. Airflow rates and pressures are based on reference densities.

Another table with the results of the calculations for the junctions follows. It contains junction numbers JNO, temperatures T, smoke concentrations PROP, and methane concentrations PRCH4. The number of iterations MADJC between network and concentration parts of the program is printed next.

The list of all finishing junctions JF is then scrutinized for negative values which indicate recirculation. The pertinent airways and their junctions are printed out together with an explanation that a recirculation path is closed at this place.

Next, it is checked to see if any threshold limits for critical states (WRNPR, WRNGS, WRNSM, WRNHT) were specified. If not, a message is

printed. If yes, all airways are checked for critical states and if any are detected they are placed in a printed list of airways together with the critical conditions. The same is done for junctions.

With the help of the counter NRCT and the NREV-list, which were both established at the beginning of the section "flowscheme", airways with airflow reversal are finally printed out. To make the airways in the printed list appear in the same sequence as in all other airway lists, they have to be extracted in this sequence from the NREV-list. With this last list, the output is complete.

4.3 COOPERATION OF PROGRAM SECTIONS

The cooperation of the different program sections is shown in Figs. 2a - 2e. The computer nomenclature, which has been used in these figures, is listed in Table 1.

Fig. 2a shows all existing major connections between program sections. Fig. 2b indicates which connections are used when only a network calculation is desired. Fig. 2c does the same for a concentration or temperature calculation without a network calculation. Fig. 2d refers to a combined network, concentration, and temperature calculation (NETW=1, NCONC=1, NTEMP=1), where the stated number of iterations is sufficient ($ITCT < ITN$, $MADJC < MADJ$), where no airflow reversals occur in the iteration process (which would make new mesh selections necessary), and where no recirculation occurs. Fig. 2e shows the same for the case of airflow reversals during the iteration process.

Figs. 2d and 2e are simplifications. Normally airflow reversals will happen at some stages of the iteration process and not happen at others. The reversals, in turn, can cause or remove recirculation. An insufficient number of iterations will be the rule at the start of the calculations also. The usual flowchart will, therefore, resemble Fig. 2a more than Figs. 2d or 2e.

4.4. EXAMPLES FOR PROGRAM USE

4.4.1 General Remarks

The program has been designed in such a way that it can be used for all mine ventilation systems, coal mines and hardrock mines alike. It

CONCENTRATION PART

NETWORK PART

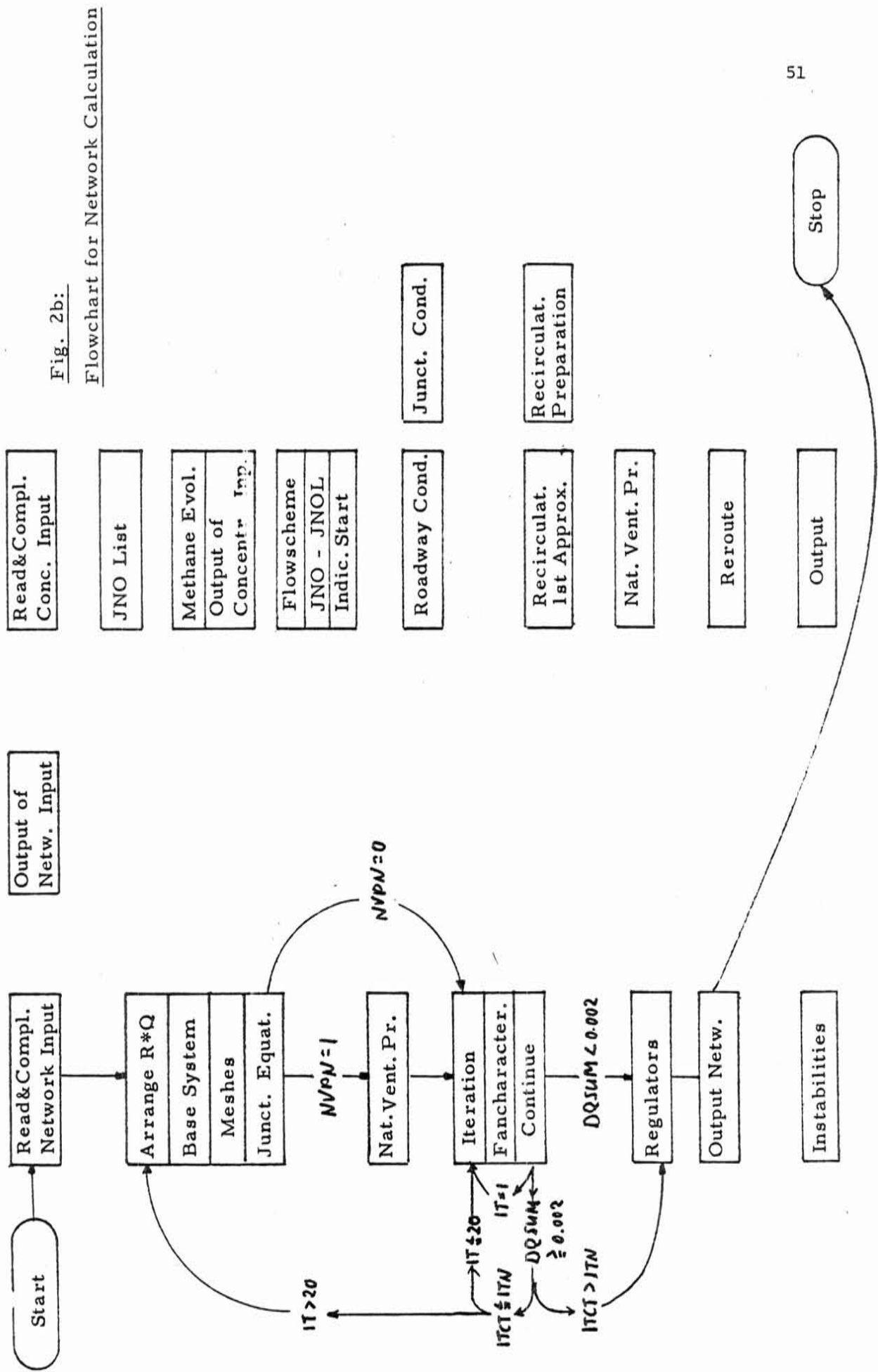
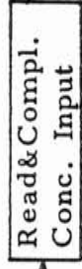
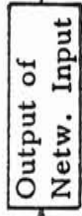


Fig. 2b:

Flowchart for Network Calculation

NETWORK PART



CONCENTRATION PART

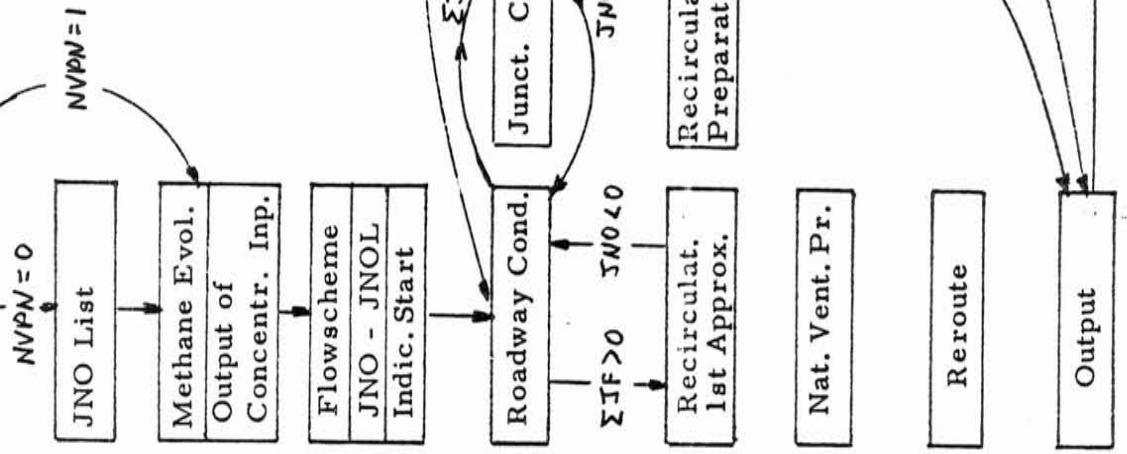
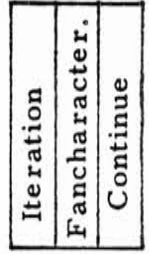
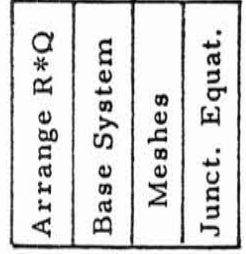


Fig. 2c: Flowchart for Concentration and Temperature Calculation with Recirculation



NETWORK PART

CONCENTRATION PART

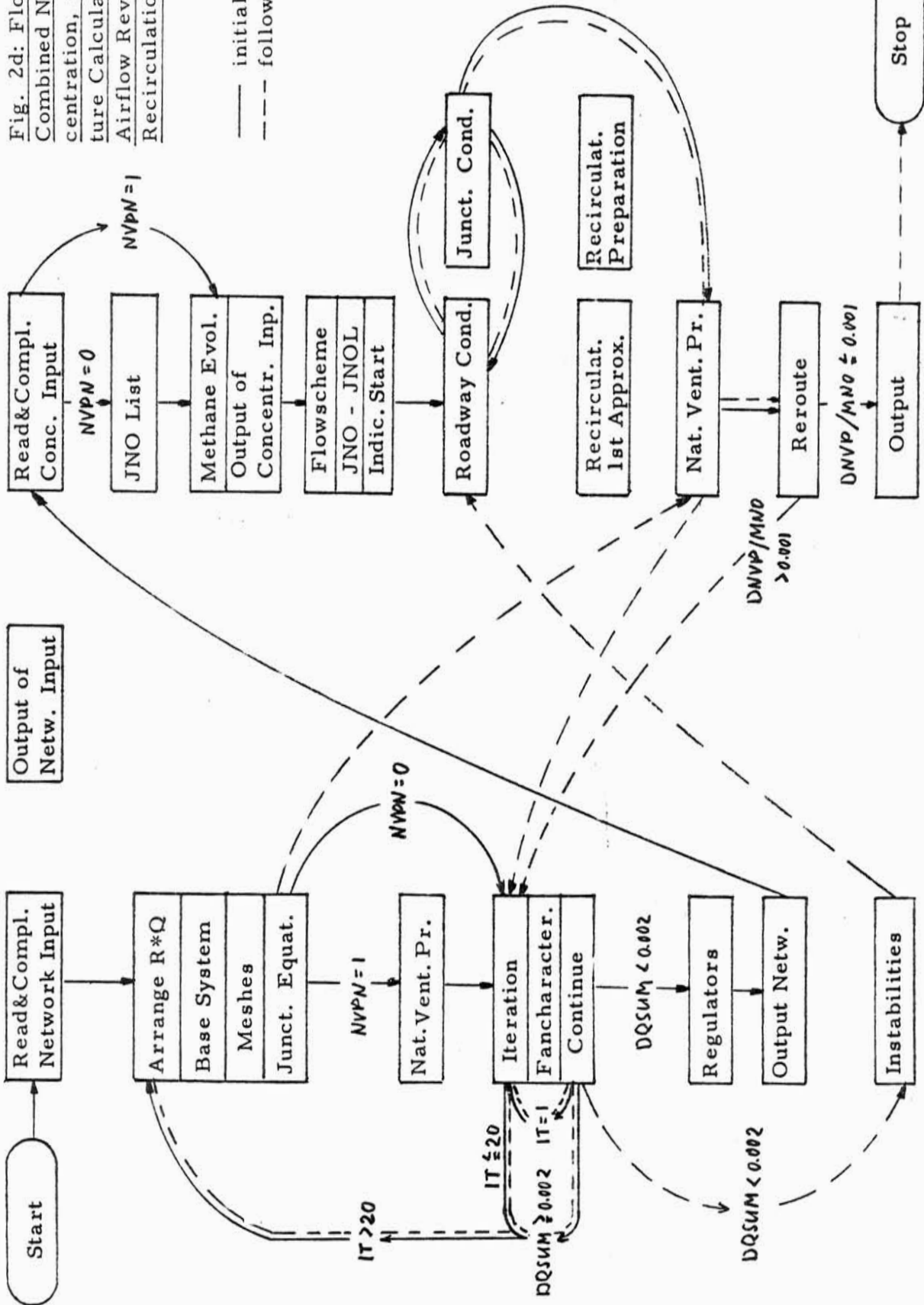


Fig. 2d: Flowchart for Combined Network, Concentration, and Temperature Calculations Without Airflow Reversals or Recirculation

— initial course
 - - - following courses

NETWORK PART

CONCENTRATION PART

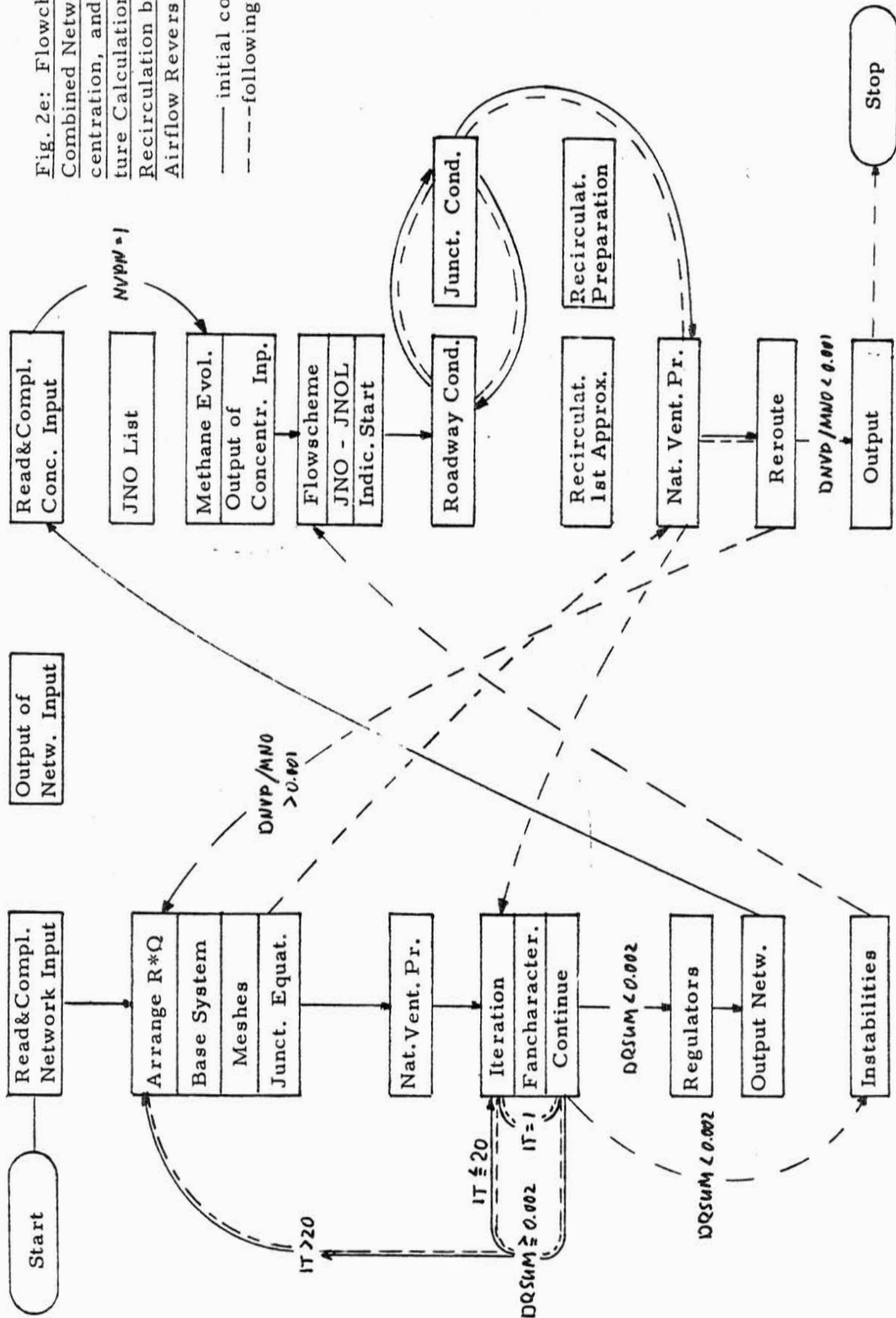


Fig. 2e: Flowchart for Combined Network, Concentration, and Temperature Calculations with Recirculation but without Airflow Reversals

— initial course
 - - - following courses

Table 1: Computer Nomenclature for Cooperation of Program Sections

CRITGS	thresholds for corrections in iterations of concentration part
CRITHT	of program
CRITSM	
DIFCH4	change in properties between last two iterations of concentra-
DIFPR	tion part of program
DIFTRD	
DNVP/MNO	average change of natural ventilation pressure per mesh
0.001	threshold for adjustment of natural ventilation pressure to
	changed temperature distribution (0.001 inches watergauge)
CQSUM	sum of all corrections in one network iteration
0.002	threshold for corrections in network iterations (200 cfm)
IT	counter of iterations in network part for every given mesh
	assmebly
ITCT	counter of iterations in network and concentration parts of
	program
ITN	maximal allowed number of iterations
JF	finishing junction of airway; a negative sign of JF is used as
	marker for completed roadway calculations
$\Sigma JF < 0$	roadway calculations for all airways going into one particular
	junction have been completed
JNO	junction number; a negative sign of JNO is used as marker for
	completed junction calculations
$\Sigma JNO < 0$	all junction calculations have been completed
MADJ	maximal allowed number of exchanges between network and concen-
	tration parts of program
MADJC	counter of exchanges between network and concentration parts
MARKD > 0	no resistance nor dimensions were stated for an airway
MRC	counter of airways closing recirculation paths
NCONC > 0	a concentration calculation shall be performed

Table 1 (continued)

NETW>0	a network calculation shall be performed
NNVP>0	this is a natural ventilation pressure calculation within the network part of the program
NVPN>0	junction cards were used and read into the computer
NTEMP>0	a temperature calculation shall be performed

can perform network (flow distribution), concentration, and temperature calculations separately as well as combined. Concentration calculations can be performed for methane and other contaminants, separately or combined. The quantities of contaminants entering the ventilation system can be stated directly as flow rates and concentrations or, as for fires, as a function of the oxygen supply.

Rather than demonstrating all possible combinations, a number of examples shall be given which are all different from each other but still relatively close to mine ventilation realities. The examples have been selected for an easy understanding of how to use the program rather than for a demonstration of the program capabilities. All examples are based on the same comparatively small ventilation network to make the understanding simple and not to burden this report with too much input and output information. The program has been used so far for mines with up to 180 airways.

The selected ventilation system is that of a small multilevel coal mine with single entries and longwall faces. This type of mine was chosen because it represents something like a blend of hardrock and coal ventilation systems. Sufficient nonhorizontal airways, like in many hardrock mines, exist for the development of large thermal drafts and at the same time methane evolution is taking place. Fig. 3 shows the ventilation plan of this system. Those input data, which were used in all examples, are compiled in Tables 2 through 6.

The data from Tables 2 through 4 are read into the computer in the network part of the program. Table 2 lists the contents of the airway and additional airway cards, table 3 the contents of the junction cards. Information on temperatures and elevations of junctions is required only when a network calculation with natural ventilation pressures, based on actually observed temperatures, is desired. If not, elevation differences can be stated and temperatures can be calculated in the concentration part of the program and can be entered here or later via additional junction cards. Table 4 lists the points of the fan characteristic which are entered with the fan characteristic cards. Fig. 4 shows a plot of these fan characteristics.

The input, which during the concentration part of the program is read into the computer has been kept to a minimum. Table 5 lists methane

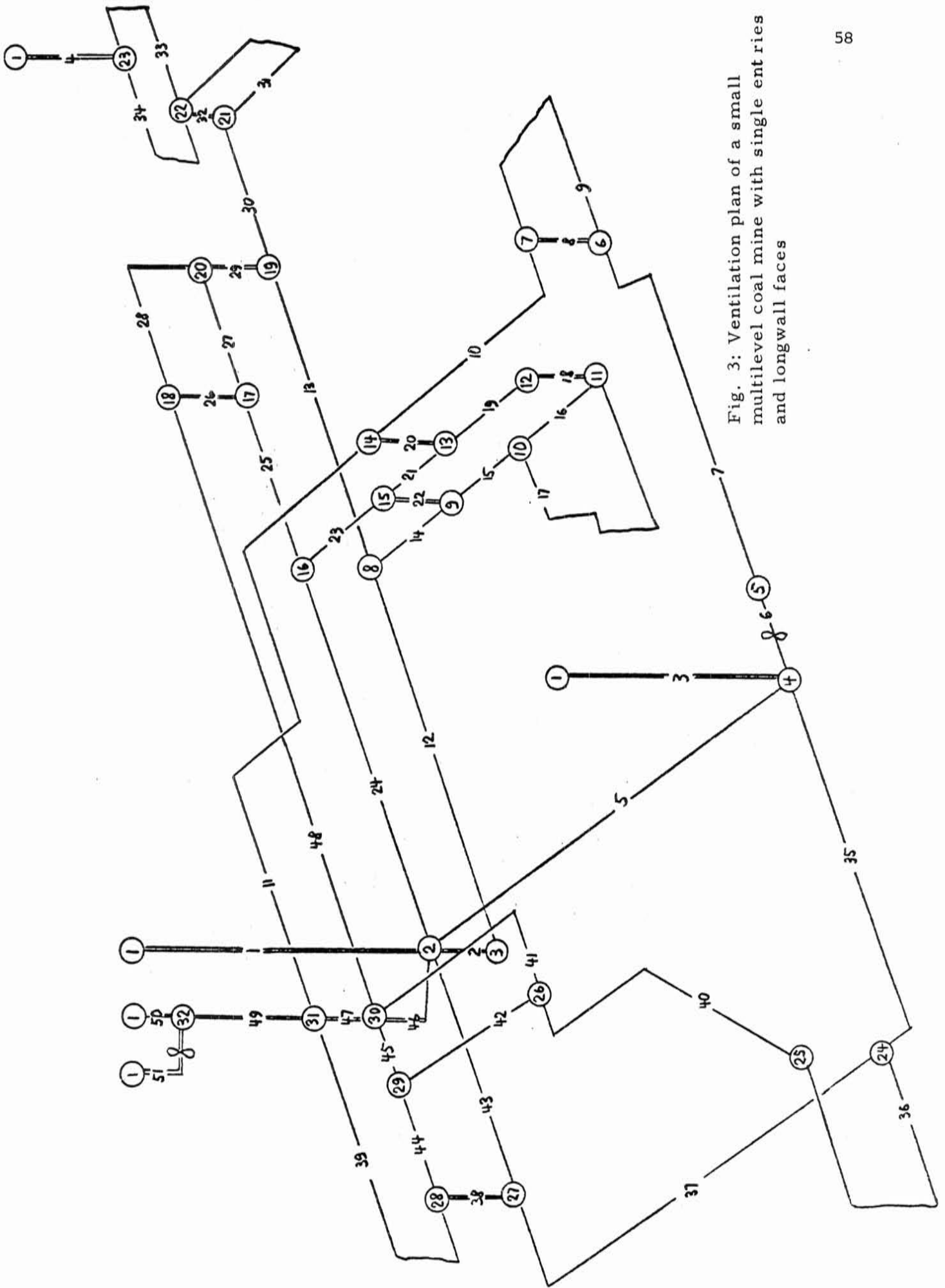


Fig. 3: Ventilation plan of a small multilevel coal mine with single ent ries and longwall faces

Fig. 4: Fan characteristics

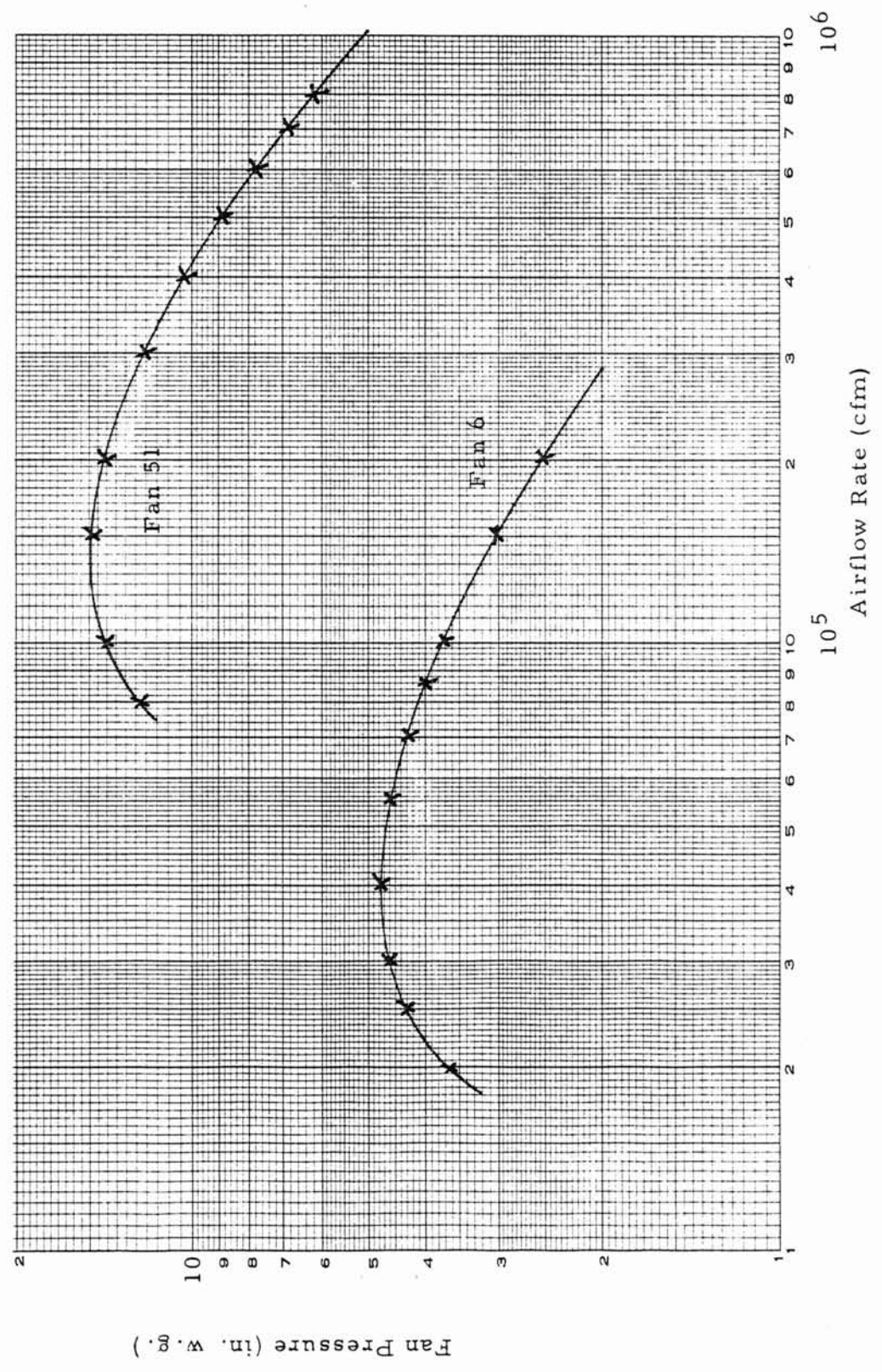


Table 2: Input Data for Airways
NO NETWORK CALCULATION HAS BEEN PERFORMED, THESE ARE THE INPUT DATA

AIRWAY	FROM	TO	AIRFLOW	AIRWAY	AIRWAY TYPE	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	1	2	200000	0	2597	20000	156	250	50	0
2	1	3	600000	0	325	20000	479	250	50	0
3	1	4	1000000	0	227	20000	479	250	50	0
4	2	5	350000	0	580	80000	400	100	55	0
5	2	6	600000	0	900	80000	400	100	55	0
6	4	7	600000	1	100	12000	307	100	55	0
7	5	7	500000	0	274	1889	233	350	44	0
8	6	7	700000	0	1750	80000	233	100	55	0
9	7	10	700000	0	1650	80000	239	100	55	0
10	7	11	536000	0	4500	80000	202	100	55	0
11	8	11	200000	0	2700	80000	360	100	55	0
12	8	11	550000	0	600	80000	437	100	55	0
13	8	9	360000	0	600	80000	437	100	55	0
14	8	9	300000	0	600	80000	437	100	55	0
15	10	11	350000	0	1109	12000	500	350	44	0
16	11	12	350000	0	824	12000	772	350	44	0
17	11	13	80000	0	524	12000	000	350	44	0
18	11	13	50000	0	550	80000	108	100	55	0
19	11	13	60000	0	318	12000	065	100	55	0
20	11	13	48000	0	600	80000	702	100	55	0
21	11	13	100000	0	2600	12000	285	100	55	0
22	11	13	60000	0	228	12000	966	100	55	0
23	11	13	200000	0	817	80000	531	100	55	0
24	11	13	500000	0	1333	12000	565	100	55	0
25	11	13	130000	0	1103	12000	475	100	55	0
26	11	13	300000	0	1313	12000	375	100	55	0
27	11	13	200000	0	1300	12000	019	100	55	0
28	11	13	150000	0	1800	80000	500	100	55	0
29	11	13	200000	0	2400	80000	524	100	55	0
30	11	13	200000	0	2600	80000	572	100	55	0
31	11	13	1000000	0	2300	12000	456	100	55	0
32	11	13	400000	0	2000	12000	000	100	55	0
33	11	13	300000	0	2000	80000	360	100	55	0
34	11	13	500000	0	2700	80000	055	100	55	0
35	11	13	300000	0	1105	80000	265	100	55	0
36	11	13	400000	0	1050	80000	285	100	55	0
37	11	13	300000	0	1105	80000	385	100	55	0
38	11	13	500000	0	1050	80000	065	100	55	0
39	11	13	300000	0	1105	80000	285	100	55	0
40	11	13	400000	0	1050	80000	385	100	55	0
41	11	13	300000	0	1105	80000	065	100	55	0
42	11	13	200000	0	1105	80000	285	100	55	0
43	11	13	100000	0	1105	80000	385	100	55	0
44	11	13	200000	0	1105	80000	065	100	55	0
45	11	13	300000	0	1105	80000	285	100	55	0
46	11	13	400000	0	1105	80000	385	100	55	0
47	11	13	300000	0	1105	80000	065	100	55	0
48	11	13	200000	0	1105	80000	285	100	55	0
49	11	13	100000	0	1105	80000	385	100	55	0
50	11	13	200000	1	42	2	610	1250	34	5
51	11	13	300000	1	51	2	000	1250	34	5
52	11	13	400000	1	61	2	000	1250	34	5
53	11	13	500000	1	71	2	000	1250	34	5
54	11	13	600000	1	81	2	000	1250	34	5
55	11	13	700000	1	91	2	000	1250	34	5
56	11	13	800000	1	101	2	000	1250	34	5
57	11	13	900000	1	111	2	000	1250	34	5
58	11	13	1000000	1	121	2	000	1250	34	5
59	11	13	1100000	1	131	2	000	1250	34	5
60	11	13	1200000	1	141	2	000	1250	34	5

Table 3: List of Junction Cards Containing Junction Numbers JNO, Temperatures T, elevations Z, and methane concentrations CH4C

JNO	T	Z	CH4C	JNO	T	Z	CH4C
1	50.0	+114	-	17	77.9	-2463	-
2	65.0	-2465	-	18	78.3	-2235	-
3	67.3	-2790	-	19	82.5	-2785	0.80
4	64.3	-2463	-	20	80.9	-2452	-
5	64.5	-2462	0.12	21	82.8	-2786	0.85
6	69.8	-2462	0.20	22	73.2	-2473	0.70
7	75.6	-1938	0.80	23	65.2	-2466	-
8	72.5	-2787	0.12	24	69.9	-2462	0.15
9	75.6	-2785	0.25	25	80.6	-2245	0.90
10	77.0	-2785	0.30	26	86.5	-2247	0.95
11	78.8	-2287	0.90	27	70.5	-2465	-
12	79.3	-2468	0.95	28	68.5	-2235	-
13	82.4	-2465	0.90	29	72.0	-2239	-
14	81.6	-1942	0.85	30	76.8	-2240	-
15	83.2	-2467	0.90	31	76.4	-1943	-
16	78.5	-2466	0.90	32	65.7	+88	-

Table 4: Fan Characteristics

Fan No 6									
20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52
Fan No 51									
80000.	10.25	100000.	14.00	150000.	14.90	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.20

Table 5: List of Additional Airway Cards in Concentration Part of Program

Airway Number	Methane Production
9	320.0
33	120.0
34	20.0
36	250.0

Table 6: List of Additional Junction Cards in Concentration Part of Program

Junction Number	Methane Concentration
27	0.60
28	0.60

Table 7

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	2	-2579.0	58.2	0	3	1000
2	1	3	-325.0	67.2	0	3	1000
3	1	4	-2577.0	76.2	0	3	1000
4	2	5	-2558.2	58.4	0	3	1000
5	1	6	1.0	65.7	0	3	1000
6	1	7	524.0	69.3	72	3	1000
7	1	8	-1.0	80.6	30	3	1000
8	1	9	-1.0	77.1	320	3	1000
9	1	10	3.2	82.4	35	3	1000
10	1	11	2.2	72.6	64	3	1000
11	1	12	2.0	82.7	136	3	1000
12	1	13	2.0	77.4	167	3	1000
13	1	14	2.0	77.3	36	3	1000
14	1	15	2.0	79.1	30	3	1000
15	1	16	3.0	84.0	17	3	1000
16	1	17	5.2	88.0	3	3	1000
17	1	18	3.1	83.0	39	3	1000
18	1	19	2.8	92.4	133	3	1000
19	1	20	1.0	76.5	0	3	1000
20	1	21	3.0	78.8	0	3	1000
21	1	22	2.1	77.9	0	3	1000
22	1	23	3.0	77.8	0	3	1000
23	1	24	3.0	82.2	0	3	1000
24	1	25	3.0	82.2	0	3	1000
25	1	26	3.0	82.7	64	3	1000
26	1	27	3.0	87.3	120	3	1000
27	1	28	1.7	70.4	165	3	1000
28	1	29	2.3	81.3	290	3	1000
29	1	30	2.2	77.0	0	3	1000
30	1	31	2.0	77.7	22	3	1000
31	1	32	2.0	86.3	0	3	1000
32	1	33	2.0	77.1	0	3	1000
33	1	34	2.0	85.0	0	3	1000
34	1	35	2.0	86.1	0	3	1000
35	1	36	2.0	88.1	0	3	1000
36	1	37	2.0	77.1	0	3	1000
37	1	38	2.0	43.0	0	3	1000
38	1	39	2.0	43.0	0	3	1000
39	1	40	2.0	43.0	0	3	1000
40	1	41	2.0	43.0	0	3	1000
41	1	42	2.0	43.0	0	3	1000
42	1	43	2.0	43.0	0	3	1000
43	1	44	2.0	43.0	0	3	1000
44	1	45	2.0	43.0	0	3	1000
45	1	46	2.0	43.0	0	3	1000
46	1	47	2.0	43.0	0	3	1000
47	1	48	2.0	43.0	0	3	1000
48	1	49	2.0	43.0	0	3	1000
49	1	50	2.0	43.0	0	3	1000

productions for the active longwall faces, Table 6 some additional methane concentrations in junctions. Methane productions in other airways, elevation differences, and rock temperatures have not been stated. They are calculated from methane concentrations, elevations, and temperatures in junctions, which are contained in the junction cards. Thermal conductivities and diffusivities have not been stated for individual airways either, instead average values from the average value card are used. Table 7 gives a summary of the input which was used in this way for the concentration part of the program.

The output has, in all examples, been organized in the same way. It starts (Table -a) with the results of a conventional network calculation executed with the Michigan Tech program. This network calculation is always performed as a check if the input data for the network description are correct and complete. In many cases these data will already exist from previous network calculations. A list of fan operating points in the network calculations comes next (Table -b). Additionally used input is listed in Table -c. The results of the concentration and temperature calculations and of the new network calculation, which takes the thermal forces developed by the new temperature distribution into account, are shown in Tables -d and -e. Table -d list temperatures, smoke (contaminant) concentrations, methane concentrations, air flow rates and pressure losses for airway ends. The two last quantities are based on reference densities. Pressure losses in airways were added because their magnitude is a criterion for the stability of airways. Table -e contains temperatures, smoke and methane concentrations for junctions. Table -f lists airways and junctions with critical conditions and airways with airflow reversals to draw the attention of the program user to these. The number of iterative adjustments between network and concentration parts of the program is stated in Table -e. If this number has been too small for completion of the calculation, a message is printed out in Table -b.

4.4.2 Executed Examples

4.4.2.1 Example 1: Simulation of a Normal Ventilation State

This example brings a simulation of the normal ventilation system without any contamination. The results are contained in Tables 8 a - f.

Table 8a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	PERIMETER
1	2	3	152	0.00	2.5	0.00	1.0	0.00
1	1	2	142	0.00	2.5	0.00	1.0	0.00
1	1	3	135	0.00	2.5	0.00	1.0	0.00
1	1	4	127	0.00	2.5	0.00	1.0	0.00
1	1	5	120	0.00	2.5	0.00	1.0	0.00
1	1	6	113	0.00	2.5	0.00	1.0	0.00
1	1	7	106	0.00	2.5	0.00	1.0	0.00
1	1	8	99	0.00	2.5	0.00	1.0	0.00
1	1	9	92	0.00	2.5	0.00	1.0	0.00
1	1	10	85	0.00	2.5	0.00	1.0	0.00
1	1	11	78	0.00	2.5	0.00	1.0	0.00
1	1	12	71	0.00	2.5	0.00	1.0	0.00
1	1	13	64	0.00	2.5	0.00	1.0	0.00
1	1	14	57	0.00	2.5	0.00	1.0	0.00
1	1	15	50	0.00	2.5	0.00	1.0	0.00
1	1	16	43	0.00	2.5	0.00	1.0	0.00
1	1	17	36	0.00	2.5	0.00	1.0	0.00
1	1	18	29	0.00	2.5	0.00	1.0	0.00
1	1	19	22	0.00	2.5	0.00	1.0	0.00
1	1	20	15	0.00	2.5	0.00	1.0	0.00
1	1	21	8	0.00	2.5	0.00	1.0	0.00
1	1	22	1	0.00	2.5	0.00	1.0	0.00

Table 8b:

FANS

AIRWAY FROM	TO	AIRFLOW	FAN PRESSURE
51	5	58908.	4.495
32	1	315091.	11.719

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

70000:	4:58	25000:	4:30	100000:	4:40	150000:	4:78	200000:	4:58
80000:	12:25	100000:	14:00	150000:	14:30	200000:	14:05	300000:	12:00
400000:	10:25	500000:	8:85	600000:	7:80	700000:	6:90	800000:	6:20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 2.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

NO CONTAMINATION WAS SPECIFIED

Table 8c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK	TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
		1	23	0	0	0	0	0
		2	25	0	0	0	0	0
		3	27	0	0	0	0	0
		4	25	0	0	0	0	0
		5	24	0	0	0	0	0
		6	24	0	0	0	0	0
		7	24	0	0	0	0	0
		8	24	0	0	0	0	0
		9	24	0	0	0	0	0
		10	24	0	0	0	0	0
		11	24	0	0	0	0	0
		12	24	0	0	0	0	0
		13	24	0	0	0	0	0
		14	24	0	0	0	0	0
		15	24	0	0	0	0	0
		16	24	0	0	0	0	0
		17	24	0	0	0	0	0
		18	24	0	0	0	0	0
		19	24	0	0	0	0	0
		20	24	0	0	0	0	0
		21	24	0	0	0	0	0
		22	24	0	0	0	0	0
		23	24	0	0	0	0	0
		24	24	0	0	0	0	0
		25	24	0	0	0	0	0
		26	24	0	0	0	0	0
		27	24	0	0	0	0	0
		28	24	0	0	0	0	0
		29	24	0	0	0	0	0
		30	24	0	0	0	0	0
		31	24	0	0	0	0	0
		32	24	0	0	0	0	0
		33	24	0	0	0	0	0
		34	24	0	0	0	0	0
		35	24	0	0	0	0	0
		36	24	0	0	0	0	0
		37	24	0	0	0	0	0
		38	24	0	0	0	0	0
		39	24	0	0	0	0	0
		40	24	0	0	0	0	0
		41	24	0	0	0	0	0
		42	24	0	0	0	0	0
		43	24	0	0	0	0	0
		44	24	0	0	0	0	0
		45	24	0	0	0	0	0
		46	24	0	0	0	0	0
		47	24	0	0	0	0	0
		48	24	0	0	0	0	0
		49	24	0	0	0	0	0
		50	24	0	0	0	0	0
		51	24	0	0	0	0	0
		52	24	0	0	0	0	0
		53	24	0	0	0	0	0
		54	24	0	0	0	0	0
		55	24	0	0	0	0	0
		56	24	0	0	0	0	0
		57	24	0	0	0	0	0
		58	24	0	0	0	0	0
		59	24	0	0	0	0	0
		60	24	0	0	0	0	0
		61	24	0	0	0	0	0
		62	24	0	0	0	0	0
		63	24	0	0	0	0	0
		64	24	0	0	0	0	0
		65	24	0	0	0	0	0
		66	24	0	0	0	0	0
		67	24	0	0	0	0	0
		68	24	0	0	0	0	0
		69	24	0	0	0	0	0
		70	24	0	0	0	0	0
		71	24	0	0	0	0	0
		72	24	0	0	0	0	0
		73	24	0	0	0	0	0
		74	24	0	0	0	0	0
		75	24	0	0	0	0	0
		76	24	0	0	0	0	0
		77	24	0	0	0	0	0
		78	24	0	0	0	0	0
		79	24	0	0	0	0	0
		80	24	0	0	0	0	0
		81	24	0	0	0	0	0
		82	24	0	0	0	0	0
		83	24	0	0	0	0	0
		84	24	0	0	0	0	0
		85	24	0	0	0	0	0
		86	24	0	0	0	0	0
		87	24	0	0	0	0	0
		88	24	0	0	0	0	0
		89	24	0	0	0	0	0
		90	24	0	0	0	0	0
		91	24	0	0	0	0	0
		92	24	0	0	0	0	0
		93	24	0	0	0	0	0
		94	24	0	0	0	0	0
		95	24	0	0	0	0	0
		96	24	0	0	0	0	0
		97	24	0	0	0	0	0
		98	24	0	0	0	0	0
		99	24	0	0	0	0	0
		100	24	0	0	0	0	0

Table 8d:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	149241.	64.95	0000	00	340
2	2	3	41341.	67.32	0000	00	008
3	3	4	113363.	64.32	0000	00	064
4	4	5	125533.	65.27	0000	00	000
5	5	6	594.	34.6	0000	026	570
6	6	7	544.	46	0000	12	020
7	7	8	548.	74	0000	6	000
8	8	9	596.	89	0000	4	000
9	9	10	544.	42	0000	1	000
10	10	11	526.	44	0000	1	000
11	11	12	575.	38	0000	1	000
12	12	13	408.	84	0000	7	000
13	13	14	509.	39	0000	5	000
14	14	15	550.	00	0000	3	000
15	15	16	550.	10	0000	3	000
16	16	17	502.	40	0000	2	000
17	17	18	502.	57	0000	2	000
18	18	19	502.	40	0000	2	000
19	19	20	502.	40	0000	2	000
20	20	21	502.	40	0000	2	000
21	21	22	502.	40	0000	2	000
22	22	23	502.	40	0000	2	000
23	23	24	502.	40	0000	2	000
24	24	25	502.	40	0000	2	000
25	25	26	502.	40	0000	2	000
26	26	27	502.	40	0000	2	000
27	27	28	502.	40	0000	2	000
28	28	29	502.	40	0000	2	000
29	29	30	502.	40	0000	2	000
30	30	31	502.	40	0000	2	000
31	31	32	502.	40	0000	2	000
32	32	33	502.	40	0000	2	000
33	33	34	502.	40	0000	2	000
34	34	35	502.	40	0000	2	000
35	35	36	502.	40	0000	2	000
36	36	37	502.	40	0000	2	000
37	37	38	502.	40	0000	2	000
38	38	39	502.	40	0000	2	000
39	39	40	502.	40	0000	2	000
40	40	41	502.	40	0000	2	000
41	41	42	502.	40	0000	2	000
42	42	43	502.	40	0000	2	000
43	43	44	502.	40	0000	2	000
44	44	45	502.	40	0000	2	000
45	45	46	502.	40	0000	2	000
46	46	47	502.	40	0000	2	000
47	47	48	502.	40	0000	2	000
48	48	49	502.	40	0000	2	000
49	49	50	502.	40	0000	2	000
50	50	51	502.	40	0000	2	000
51	51	52	502.	40	0000	2	000
52	52	53	502.	40	0000	2	000
53	53	54	502.	40	0000	2	000
54	54	55	502.	40	0000	2	000
55	55	56	502.	40	0000	2	000
56	56	57	502.	40	0000	2	000
57	57	58	502.	40	0000	2	000
58	58	59	502.	40	0000	2	000
59	59	60	502.	40	0000	2	000
60	60	61	502.	40	0000	2	000
61	61	62	502.	40	0000	2	000
62	62	63	502.	40	0000	2	000
63	63	64	502.	40	0000	2	000
64	64	65	502.	40	0000	2	000
65	65	66	502.	40	0000	2	000
66	66	67	502.	40	0000	2	000
67	67	68	502.	40	0000	2	000
68	68	69	502.	40	0000	2	000
69	69	70	502.	40	0000	2	000
70	70	71	502.	40	0000	2	000
71	71	72	502.	40	0000	2	000
72	72	73	502.	40	0000	2	000
73	73	74	502.	40	0000	2	000
74	74	75	502.	40	0000	2	000
75	75	76	502.	40	0000	2	000
76	76	77	502.	40	0000	2	000
77	77	78	502.	40	0000	2	000
78	78	79	502.	40	0000	2	000
79	79	80	502.	40	0000	2	000
80	80	81	502.	40	0000	2	000
81	81	82	502.	40	0000	2	000
82	82	83	502.	40	0000	2	000
83	83	84	502.	40	0000	2	000
84	84	85	502.	40	0000	2	000
85	85	86	502.	40	0000	2	000
86	86	87	502.	40	0000	2	000
87	87	88	502.	40	0000	2	000
88	88	89	502.	40	0000	2	000
89	89	90	502.	40	0000	2	000
90	90	91	502.	40	0000	2	000
91	91	92	502.	40	0000	2	000
92	92	93	502.	40	0000	2	000
93	93	94	502.	40	0000	2	000
94	94	95	502.	40	0000	2	000
95	95	96	502.	40	0000	2	000
96	96	97	502.	40	0000	2	000
97	97	98	502.	40	0000	2	000
98	98	99	502.	40	0000	2	000
99	99	100	502.	40	0000	2	000

Table 8e:

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.00	.0000	.0000	2	64.95	.0000	.0000
2	67.32	.0000	.0000	4	64.32	.0000	.0000
3	67.40	.0000	.0211	6	69.64	.0000	.0000
4	77.50	.0000	.2597	8	72.81	.0000	.0000
5	78.27	.0000	.5984	10	79.97	.0000	.0000
6	78.33	.0000	.8657	12	80.97	.0000	.0000
7	82.62	.0000	.8657	14	78.48	.0000	.0000
8	82.59	.0000	.7426	16	78.93	.0000	.0000
9	87.24	.0000	.7426	18	80.19	.0000	.0000
10	87.25	.0000	.9088	20	73.40	.0000	.0000
11	87.45	.0000	.9468	22	69.33	.0000	.0000
12	77.15	.0000	.6683	24	68.07	.0000	.0000
13	77.15	.0000	.6683	26	65.61	.0000	.0000
14	77.15	.0000	.6683	28	65.61	.0000	.0000
15	77.15	.0000	.6683	30	65.61	.0000	.0000

NUMBER OF ITERATIONS 1

Table 8f:

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	REFER TO AIRWAY ENDS	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILATION AT PRESSURE LOWER THAN .010 INCHES WG
20	00	3	.0000	.0000		67.3	.008
21	14	13	.088	.0000		81.9	.006
22	20	29	.74	.0000		77.8	.004
23	26	29	.96	.0000		71.9	.003

Table 9a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

AIRWAY	FROM	TO	AIRFLOW	PRESSURE	REGULAR AIRWAYS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1	2	3	14	0.380	0	2	0.00	1.56	5	5
1	2	4	23	0.637	0	3	0.00	4.79	5	5
1	2	5	47	2.289	0	5	0.00	4.07	10	5
1	2	6	77	9.944	0	7	0.00	2.33	10	5
1	3	7	74	9.447	0	5	0.00	2.39	10	5
1	3	8	82	12.064	0	5	0.00	2.02	10	5
1	3	9	90	8.064	0	5	0.00	3.99	10	5
1	4	10	08	0.064	0	6	0.00	4.82	10	5
1	4	11	15	0.064	0	6	0.00	4.35	10	5
1	4	12	32	0.064	0	6	0.00	3.50	10	5
1	4	13	42	0.064	0	6	0.00	7.00	10	5
1	4	14	20	0.064	0	6	0.00	7.00	10	5
1	4	15	24	0.064	0	6	0.00	7.00	10	5
1	4	16	22	0.064	0	6	0.00	7.00	10	5
1	4	17	22	0.064	0	6	0.00	7.00	10	5
1	4	18	42	0.064	0	6	0.00	7.00	10	5
1	4	19	22	0.064	0	6	0.00	7.00	10	5
1	4	20	22	0.064	0	6	0.00	7.00	10	5
1	4	21	22	0.064	0	6	0.00	7.00	10	5
1	4	22	22	0.064	0	6	0.00	7.00	10	5
1	4	23	42	0.064	0	6	0.00	7.00	10	5
1	4	24	22	0.064	0	6	0.00	7.00	10	5
1	4	25	22	0.064	0	6	0.00	7.00	10	5
1	4	26	22	0.064	0	6	0.00	7.00	10	5
1	4	27	22	0.064	0	6	0.00	7.00	10	5
1	4	28	22	0.064	0	6	0.00	7.00	10	5
1	4	29	22	0.064	0	6	0.00	7.00	10	5
1	4	30	22	0.064	0	6	0.00	7.00	10	5
1	4	31	22	0.064	0	6	0.00	7.00	10	5
1	4	32	22	0.064	0	6	0.00	7.00	10	5
1	4	33	22	0.064	0	6	0.00	7.00	10	5
1	4	34	22	0.064	0	6	0.00	7.00	10	5
1	4	35	22	0.064	0	6	0.00	7.00	10	5
1	4	36	22	0.064	0	6	0.00	7.00	10	5
1	4	37	22	0.064	0	6	0.00	7.00	10	5
1	4	38	22	0.064	0	6	0.00	7.00	10	5
1	4	39	22	0.064	0	6	0.00	7.00	10	5
1	4	40	22	0.064	0	6	0.00	7.00	10	5
1	4	41	22	0.064	0	6	0.00	7.00	10	5
1	4	42	22	0.064	0	6	0.00	7.00	10	5
1	4	43	22	0.064	0	6	0.00	7.00	10	5
1	4	44	22	0.064	0	6	0.00	7.00	10	5
1	4	45	22	0.064	0	6	0.00	7.00	10	5
1	4	46	22	0.064	0	6	0.00	7.00	10	5
1	4	47	22	0.064	0	6	0.00	7.00	10	5
1	4	48	22	0.064	0	6	0.00	7.00	10	5
1	4	49	22	0.064	0	6	0.00	7.00	10	5
1	4	50	22	0.064	0	6	0.00	7.00	10	5
1	4	51	22	0.064	0	6	0.00	7.00	10	5
1	4	52	22	0.064	0	6	0.00	7.00	10	5
1	4	53	22	0.064	0	6	0.00	7.00	10	5
1	4	54	22	0.064	0	6	0.00	7.00	10	5
1	4	55	22	0.064	0	6	0.00	7.00	10	5
1	4	56	22	0.064	0	6	0.00	7.00	10	5
1	4	57	22	0.064	0	6	0.00	7.00	10	5
1	4	58	22	0.064	0	6	0.00	7.00	10	5
1	4	59	22	0.064	0	6	0.00	7.00	10	5
1	4	60	22	0.064	0	6	0.00	7.00	10	5
1	4	61	22	0.064	0	6	0.00	7.00	10	5
1	4	62	22	0.064	0	6	0.00	7.00	10	5
1	4	63	22	0.064	0	6	0.00	7.00	10	5
1	4	64	22	0.064	0	6	0.00	7.00	10	5
1	4	65	22	0.064	0	6	0.00	7.00	10	5
1	4	66	22	0.064	0	6	0.00	7.00	10	5
1	4	67	22	0.064	0	6	0.00	7.00	10	5
1	4	68	22	0.064	0	6	0.00	7.00	10	5
1	4	69	22	0.064	0	6	0.00	7.00	10	5
1	4	70	22	0.064	0	6	0.00	7.00	10	5
1	4	71	22	0.064	0	6	0.00	7.00	10	5
1	4	72	22	0.064	0	6	0.00	7.00	10	5
1	4	73	22	0.064	0	6	0.00	7.00	10	5
1	4	74	22	0.064	0	6	0.00	7.00	10	5
1	4	75	22	0.064	0	6	0.00	7.00	10	5
1	4	76	22	0.064	0	6	0.00	7.00	10	5
1	4	77	22	0.064	0	6	0.00	7.00	10	5
1	4	78	22	0.064	0	6	0.00	7.00	10	5
1	4	79	22	0.064	0	6	0.00	7.00	10	5
1	4	80	22	0.064	0	6	0.00	7.00	10	5
1	4	81	22	0.064	0	6	0.00	7.00	10	5
1	4	82	22	0.064	0	6	0.00	7.00	10	5
1	4	83	22	0.064	0	6	0.00	7.00	10	5
1	4	84	22	0.064	0	6	0.00	7.00	10	5
1	4	85	22	0.064	0	6	0.00	7.00	10	5
1	4	86	22	0.064	0	6	0.00	7.00	10	5
1	4	87	22	0.064	0	6	0.00	7.00	10	5
1	4	88	22	0.064	0	6	0.00	7.00	10	5
1	4	89	22	0.064	0	6	0.00	7.00	10	5
1	4	90	22	0.064	0	6	0.00	7.00	10	5
1	4	91	22	0.064	0	6	0.00	7.00	10	5
1	4	92	22	0.064	0	6	0.00	7.00	10	5
1	4	93	22	0.064	0	6	0.00	7.00	10	5
1	4	94	22	0.064	0	6	0.00	7.00	10	5
1	4	95	22	0.064	0	6	0.00	7.00	10	5
1	4	96	22	0.064	0	6	0.00	7.00	10	5
1	4	97	22	0.064	0	6	0.00	7.00	10	5
1	4	98	22	0.064	0	6	0.00	7.00	10	5
1	4	99	22	0.064	0	6	0.00	7.00	10	5
1	4	100	22	0.064	0	6	0.00	7.00	10	5

Table 9b:

FANS

AIRWAY	FROM	TO	AIRFLOW	FAN PRESSURE
6	4	5	58908.	4.495
51	32	1	315091.	11.718

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

20000.	3.60	25000.	4.30	30000.	4.60	40000.	4.78	55000.	4.58
70000.	4.29	85000.	3.96	100000.	3.70	150000.	3.00	200000.	2.52
80000.	12.25	100000.	14.00	150000.	14.80	200000.	14.05	300000.	12.00
400000.	10.25	500000.	8.85	600000.	7.80	700000.	6.90	800000.	6.20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 6.00 HOURS

A TEMPERATURE OF 90.0 WAS ASSIGNED TO JUNCTION NO 1

NO CONTAMINATION WAS SPECIFIED

Table 9c:

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	1	0	20	0	0	0
2	2	2	0	20	0	0	0
3	3	3	0	20	0	0	0
4	4	4	0	20	0	0	0
5	5	5	0	20	0	0	0
6	6	6	0	20	0	0	0
7	7	7	0	20	0	0	0
8	8	8	0	20	0	0	0
9	9	9	0	20	0	0	0
10	10	10	0	20	0	0	0
11	11	11	0	20	0	0	0
12	12	12	0	20	0	0	0
13	13	13	0	20	0	0	0
14	14	14	0	20	0	0	0
15	15	15	0	20	0	0	0
16	16	16	0	20	0	0	0
17	17	17	0	20	0	0	0
18	18	18	0	20	0	0	0
19	19	19	0	20	0	0	0
20	20	20	0	20	0	0	0
21	21	21	0	20	0	0	0
22	22	22	0	20	0	0	0
23	23	23	0	20	0	0	0
24	24	24	0	20	0	0	0
25	25	25	0	20	0	0	0
26	26	26	0	20	0	0	0
27	27	27	0	20	0	0	0
28	28	28	0	20	0	0	0
29	29	29	0	20	0	0	0
30	30	30	0	20	0	0	0
31	31	31	0	20	0	0	0
32	32	32	0	20	0	0	0
33	33	33	0	20	0	0	0
34	34	34	0	20	0	0	0
35	35	35	0	20	0	0	0
36	36	36	0	20	0	0	0
37	37	37	0	20	0	0	0
38	38	38	0	20	0	0	0
39	39	39	0	20	0	0	0
40	40	40	0	20	0	0	0
41	41	41	0	20	0	0	0
42	42	42	0	20	0	0	0
43	43	43	0	20	0	0	0
44	44	44	0	20	0	0	0
45	45	45	0	20	0	0	0
46	46	46	0	20	0	0	0
47	47	47	0	20	0	0	0
48	48	48	0	20	0	0	0
49	49	49	0	20	0	0	0
50	50	50	0	20	0	0	0
51	51	51	0	20	0	0	0
52	52	52	0	20	0	0	0
53	53	53	0	20	0	0	0
54	54	54	0	20	0	0	0
55	55	55	0	20	0	0	0
56	56	56	0	20	0	0	0
57	57	57	0	20	0	0	0
58	58	58	0	20	0	0	0
59	59	59	0	20	0	0	0
60	60	60	0	20	0	0	0
61	61	61	0	20	0	0	0
62	62	62	0	20	0	0	0
63	63	63	0	20	0	0	0
64	64	64	0	20	0	0	0
65	65	65	0	20	0	0	0
66	66	66	0	20	0	0	0
67	67	67	0	20	0	0	0
68	68	68	0	20	0	0	0
69	69	69	0	20	0	0	0
70	70	70	0	20	0	0	0
71	71	71	0	20	0	0	0
72	72	72	0	20	0	0	0
73	73	73	0	20	0	0	0
74	74	74	0	20	0	0	0
75	75	75	0	20	0	0	0
76	76	76	0	20	0	0	0
77	77	77	0	20	0	0	0
78	78	78	0	20	0	0	0
79	79	79	0	20	0	0	0
80	80	80	0	20	0	0	0
81	81	81	0	20	0	0	0
82	82	82	0	20	0	0	0
83	83	83	0	20	0	0	0
84	84	84	0	20	0	0	0
85	85	85	0	20	0	0	0
86	86	86	0	20	0	0	0
87	87	87	0	20	0	0	0
88	88	88	0	20	0	0	0
89	89	89	0	20	0	0	0
90	90	90	0	20	0	0	0
91	91	91	0	20	0	0	0
92	92	92	0	20	0	0	0
93	93	93	0	20	0	0	0
94	94	94	0	20	0	0	0
95	95	95	0	20	0	0	0
96	96	96	0	20	0	0	0
97	97	97	0	20	0	0	0
98	98	98	0	20	0	0	0
99	99	99	0	20	0	0	0
100	100	100	0	20	0	0	0

Table 9d:

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	1	2	134267.	74.06	0000	00	298
2	1	3	34014.	73.33	0000	00	006
3	1	4	110970.	71.87	0000	00	028
4	1	23	139336.	66.40	0000	00	088
5	2	4	8806.	69.49	0000	00	197
6	2	5	8646.	69.44	0000	00	226
7	2	6	3790.	77.63	0000	00	240
8	2	7	3746.	74.00	0000	00	284
9	2	8	2201.	73.37	0000	00	400
10	2	9	3045.	72.57	0000	00	447
11	2	10	3045.	72.57	0000	00	479
12	2	11	6004.	72.57	0000	00	556
13	2	12	6004.	72.57	0000	00	528
14	2	13	6004.	72.57	0000	00	502
15	2	14	6004.	72.57	0000	00	559
16	2	15	6004.	72.57	0000	00	500
17	2	16	6004.	72.57	0000	00	559
18	2	17	6004.	72.57	0000	00	500
19	2	18	6004.	72.57	0000	00	559
20	2	19	6004.	72.57	0000	00	500
21	2	20	6004.	72.57	0000	00	559
22	2	21	6004.	72.57	0000	00	500
23	2	22	6004.	72.57	0000	00	559
24	2	23	6004.	72.57	0000	00	500
25	2	24	6004.	72.57	0000	00	559
26	2	25	6004.	72.57	0000	00	500
27	2	26	6004.	72.57	0000	00	559
28	2	27	6004.	72.57	0000	00	500
29	2	28	6004.	72.57	0000	00	559
30	2	29	6004.	72.57	0000	00	500
31	2	30	6004.	72.57	0000	00	559
32	2	31	6004.	72.57	0000	00	500
33	2	32	6004.	72.57	0000	00	559
34	2	33	6004.	72.57	0000	00	500
35	2	34	6004.	72.57	0000	00	559
36	2	35	6004.	72.57	0000	00	500
37	2	36	6004.	72.57	0000	00	559
38	2	37	6004.	72.57	0000	00	500
39	2	38	6004.	72.57	0000	00	559
40	2	39	6004.	72.57	0000	00	500
41	2	40	6004.	72.57	0000	00	559
42	2	41	6004.	72.57	0000	00	500
43	2	42	6004.	72.57	0000	00	559
44	2	43	6004.	72.57	0000	00	500
45	2	44	6004.	72.57	0000	00	559
46	2	45	6004.	72.57	0000	00	500
47	2	46	6004.	72.57	0000	00	559
48	2	47	6004.	72.57	0000	00	500
49	2	48	6004.	72.57	0000	00	559
50	2	49	6004.	72.57	0000	00	500
51	2	50	6004.	72.57	0000	00	559
52	2	51	6004.	72.57	0000	00	500
53	2	52	6004.	72.57	0000	00	559
54	2	53	6004.	72.57	0000	00	500
55	2	54	6004.	72.57	0000	00	559
56	2	55	6004.	72.57	0000	00	500
57	2	56	6004.	72.57	0000	00	559
58	2	57	6004.	72.57	0000	00	500
59	2	58	6004.	72.57	0000	00	559
60	2	59	6004.	72.57	0000	00	500
61	2	60	6004.	72.57	0000	00	559
62	2	61	6004.	72.57	0000	00	500
63	2	62	6004.	72.57	0000	00	559
64	2	63	6004.	72.57	0000	00	500
65	2	64	6004.	72.57	0000	00	559
66	2	65	6004.	72.57	0000	00	500
67	2	66	6004.	72.57	0000	00	559
68	2	67	6004.	72.57	0000	00	500
69	2	68	6004.	72.57	0000	00	559
70	2	69	6004.	72.57	0000	00	500
71	2	70	6004.	72.57	0000	00	559
72	2	71	6004.	72.57	0000	00	500
73	2	72	6004.	72.57	0000	00	559
74	2	73	6004.	72.57	0000	00	500
75	2	74	6004.	72.57	0000	00	559
76	2	75	6004.	72.57	0000	00	500
77	2	76	6004.	72.57	0000	00	559
78	2	77	6004.	72.57	0000	00	500
79	2	78	6004.	72.57	0000	00	559
80	2	79	6004.	72.57	0000	00	500
81	2	80	6004.	72.57	0000	00	559
82	2	81	6004.	72.57	0000	00	500
83	2	82	6004.	72.57	0000	00	559
84	2	83	6004.	72.57	0000	00	500
85	2	84	6004.	72.57	0000	00	559
86	2	85	6004.	72.57	0000	00	500
87	2	86	6004.	72.57	0000	00	559
88	2	87	6004.	72.57	0000	00	500
89	2	88	6004.	72.57	0000	00	559
90	2	89	6004.	72.57	0000	00	500
91	2	90	6004.	72.57	0000	00	559
92	2	91	6004.	72.57	0000	00	500
93	2	92	6004.	72.57	0000	00	559
94	2	93	6004.	72.57	0000	00	500
95	2	94	6004.	72.57	0000	00	559
96	2	95	6004.	72.57	0000	00	500
97	2	96	6004.	72.57	0000	00	559
98	2	97	6004.	72.57	0000	00	500
99	2	98	6004.	72.57	0000	00	559
100	2	99	6004.	72.57	0000	00	500

Tables 9e and 9f:

JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	90.00	.0000	.0000	2	74.06	.0000	.0000
2	73.37	.0000	.0000	4	70.35	.0000	.0000
3	79.52	.0000	.1226	6	69.87	.0000	.0049
7	75.53	.0000	.1926	8	72.57	.0000	.1397
9	78.16	.0000	.3054	0	75.72	.0000	.3568
11	77.17	.0000	.9730	2	79.63	.0000	.8543
13	78.47	.0000	.9649	4	79.33	.0000	.8946
15	77.50	.0000	.7249	6	78.41	.0000	.8615
17	77.45	.0000	.6130	8	80.81	.0000	.7272
19	77.00	.0000	.6108	0	73.01	.0000	.4577
21	77.28	.0000	.9587	2	70.11	.0000	.1522
23	77.15	.0000	.7069	4	86.56	.0000	.6858
		.0000	.7169	6	69.60	.0000	.6780

NUMBER OF ITERATIONS 5

IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS

AIRWAY	FROM	TO	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95. DEGREES	LOW VENTILATION PRESSURE LOWER THAN .010 INCHES WG
2	3	3	.0000	.0000	73.53	.0064
1	1	1	.0000	.0000	82.08	.4664
2	1	1	.0000	.0000	78.05	.1569
2	2	2	.0000	.0000	77.05	.6350
2	2	2	.0000	.0000	77.03	.0009
1	2	2	.0000	.0000	86.03	1.0844
1	2	2	.0000	.0000	75.00	.0277
1	2	2	.0000	.0000	107.03	.0002
4	2	2	.0000	.0000	1	12.161
5	2	2	.0000	.0000		

26

1.0

.0000

MORE

TEMPERATURE THAN 95.0 DEGREES

IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS
METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT
SMOKE CONCENTRATION HIGHER THAN .050 PERCENT

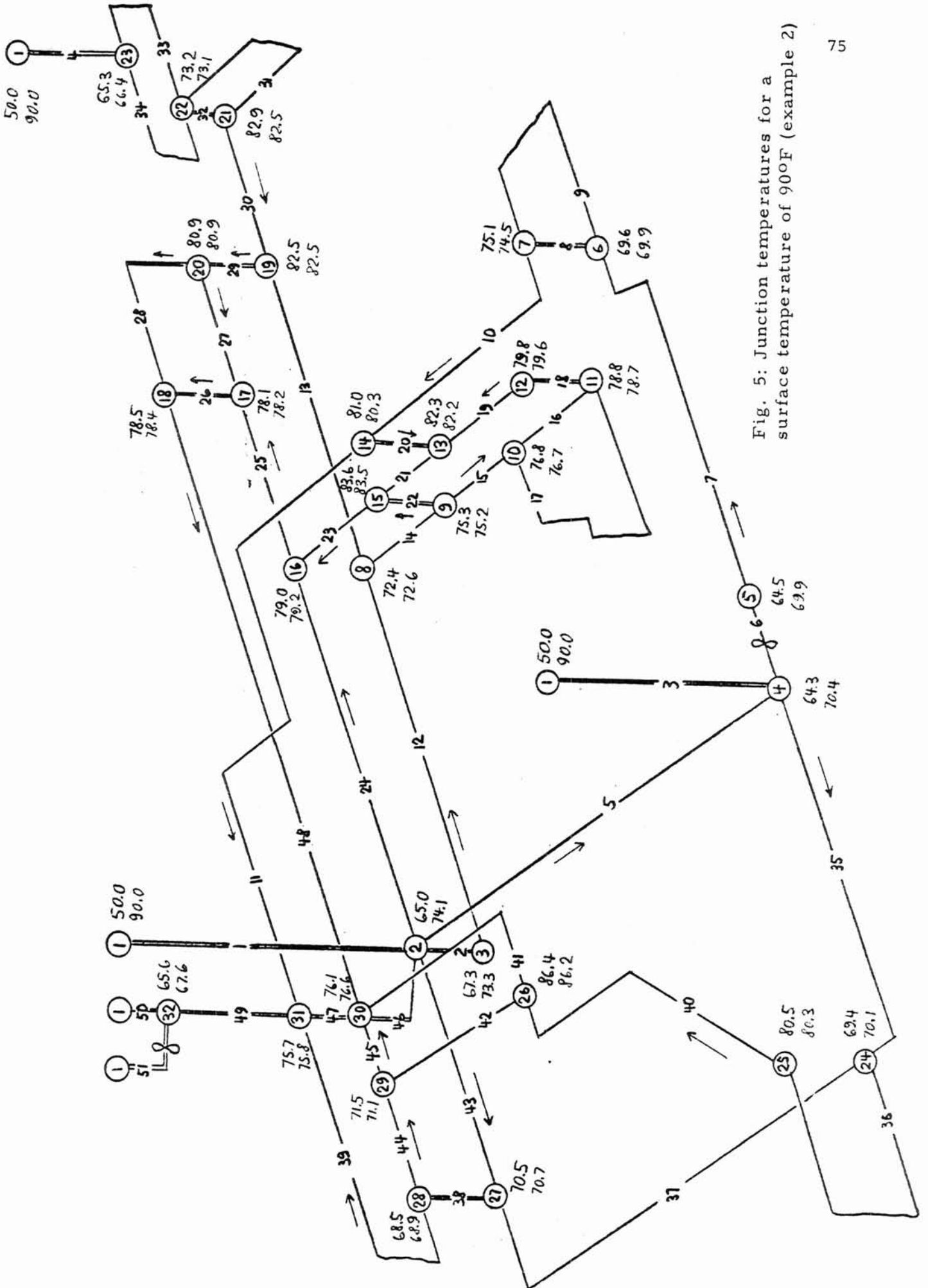


Fig. 5: Junction temperatures for a surface temperature of 90°F (example 2)

A comparison of the junction temperatures and junction methane concentrations from Table 8e with the input data from Table 3 shows good agreement. A comparison between airflow rates in Table 8a and Table 8d shows an acceptable but not complete agreement. The reason is that the Michigan Tech program assumes, for the temperatures on which the calculation of natural ventilation pressures are based, linear changes along the airways whereas the change in reality is exponential.

4.4.2.2 Example 2: Changed Surface Temperature

This example investigates how a change in the surface temperature from 50°F to 90°F has after 6 hours effected the airflow distribution. The results are contained in Tables 9 a - f. A comparison of calculated temperatures with those from example 1 shows that the temperatures increase mainly in the intake airways whereas in the return airways they remain virtually unchanged. This reduces the natural ventilation in the meshes going through the intake shafts and subsequently the airflow entering the mine. The result is a slight increase in methane concentrations which at several places rise to above 1%.

Junction temperatures based on 50°F and 90°F (lower placed figures) from Tables 8 and 9 have been plotted into Fig. 5. In some places the calculated temperatures for 90°F surface temperature are lower than those for 50°F. The explanation is that for the 90°F an elapsed time period of 6 hrs instead of 2 hrs was assumed. This allows the buildup of a thicker layer of insulating rock around the airways.

For airway 50 (the leakage from the surface into the fan drift), a temperature of 107°F has been calculated. The reason is that the rock temperature for this airway was determined from the temperature difference between junctions 1 and 32. The genuine temperature rise in airway 50, which has no practical importance, would have been obtained by stating the genuine rock temperature of this airway in the input data.

4.4.2.3 Example 3: Main Fan Failure

It is assumed that the surface fan fails (airway 51) but that the underground booster fan continues to work. The surface temperature is 50°F, the time after the event 15 minutes.

Table 10a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

AIRWAY	FROM	TO	AIRFLOW	PRESSURE	LOSS	REGULAR	LENGTH	AREA	RESISTANCE	K	PERIMETER
1		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
3		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
4		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
5		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
6		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
7		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
8		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
9		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
10		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
11		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
12		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
13		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
14		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
15		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
16		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
17		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
18		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
19		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
20		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
21		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
22		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
23		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
24		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
25		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
26		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
27		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
28		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
29		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
30		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
31		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
32		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
33		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
34		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
35		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
36		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
37		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
38		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
39		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
40		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
41		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
42		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
43		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
44		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
45		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
46		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
47		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
48		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
49		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00
50		2	381	0.00	0.00	0.00	597	0.00	0.00	50	0.00

Table 10b:

FANS

AIRWAY FROM	TO	AIRFLOW	FAN PRESSURE
6	5	52280.	4.638

THESE CHARACTERISTICS WERE STORED FOR FANS 6

20000:	3.60	25000:	4.30	30000:	4.60	40000:	4.78	55000:	4.58
70000:	4.29	85000:	3.96	100000:	3.70	150000:	3.00	200000:	2.52

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT .25 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

NO CONTAMINATION WAS SPECIFIED

NO TEMPERATURE DETERMINATION WAS DEMANDED

Table 10d:

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	\$ SMOKE	METHANE	PRESSURE
10	10	10	10	0000	0000	0000	0000
11	11	11	11	0000	0000	0000	0000
12	12	12	12	0000	0000	0000	0000
13	13	13	13	0000	0000	0000	0000
14	14	14	14	0000	0000	0000	0000
15	15	15	15	0000	0000	0000	0000
16	16	16	16	0000	0000	0000	0000
17	17	17	17	0000	0000	0000	0000
18	18	18	18	0000	0000	0000	0000
19	19	19	19	0000	0000	0000	0000
20	20	20	20	0000	0000	0000	0000
21	21	21	21	0000	0000	0000	0000
22	22	22	22	0000	0000	0000	0000
23	23	23	23	0000	0000	0000	0000
24	24	24	24	0000	0000	0000	0000
25	25	25	25	0000	0000	0000	0000
26	26	26	26	0000	0000	0000	0000
27	27	27	27	0000	0000	0000	0000
28	28	28	28	0000	0000	0000	0000
29	29	29	29	0000	0000	0000	0000
30	30	30	30	0000	0000	0000	0000
31	31	31	31	0000	0000	0000	0000
32	32	32	32	0000	0000	0000	0000
33	33	33	33	0000	0000	0000	0000
34	34	34	34	0000	0000	0000	0000
35	35	35	35	0000	0000	0000	0000
36	36	36	36	0000	0000	0000	0000
37	37	37	37	0000	0000	0000	0000
38	38	38	38	0000	0000	0000	0000
39	39	39	39	0000	0000	0000	0000
40	40	40	40	0000	0000	0000	0000

Table 10e:

JUNCTION	TEMPERATURE	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.00	.0000	.0000	.0000	2	.00	.0000	.427
2	.00	.0000	.0000	1.3516	4	.00	.0000	1.3154
3	.00	.0000	.0000	.8825	6	.00	.0000	1.0339
4	.00	.0000	.0000	5.9778	8	.00	.0000	1.4497
5	.00	.0000	.0000	1.5321	10	.00	.0000	1.7977
6	.00	.0000	.0000	9.8166	12	.00	.0000	1.9821
7	.00	.0000	.0000	9.8166	14	.00	.0000	1.9821
8	.00	.0000	.0000	9.2073	16	.00	.0000	1.7810
9	.00	.0000	.0000	8.0000	18	.00	.0000	1.7810
10	.00	.0000	.0000	2.9268	20	.00	.0000	2.2860
11	.00	.0000	.0000	7.4185	22	.00	.0000	1.9470
12	.00	.0000	.0000	7.2071	24	.00	.0000	1.9470
13	.00	.0000	.0000	.2071	26	.00	.0000	1.3201
14	.00	.0000	.0000	.0000	28	.00	.0000	1.3201
15	.00	.0000	.0000	.0000	30	.00	.0000	.0000
16	.00	.0000	.0000	.0000	32	.00	.0000	.0000
17	.00	.0000	.0000	.0000	34	.00	.0000	.0000
18	.00	.0000	.0000	.0000	36	.00	.0000	.0000
19	.00	.0000	.0000	.0000	38	.00	.0000	.0000
20	.00	.0000	.0000	.0000	40	.00	.0000	.0000
21	.00	.0000	.0000	.0000	42	.00	.0000	.0000
22	.00	.0000	.0000	.0000	44	.00	.0000	.0000
23	.00	.0000	.0000	.0000	46	.00	.0000	.0000
24	.00	.0000	.0000	.0000	48	.00	.0000	.0000
25	.00	.0000	.0000	.0000	50	.00	.0000	.0000
26	.00	.0000	.0000	.0000	52	.00	.0000	.0000
27	.00	.0000	.0000	.0000	54	.00	.0000	.0000
28	.00	.0000	.0000	.0000	56	.00	.0000	.0000
29	.00	.0000	.0000	.0000	58	.00	.0000	.0000
30	.00	.0000	.0000	.0000	60	.00	.0000	.0000

NUMBER OF ITERATIONS INTO JUNCTION NO 2
 WITH AIRWAY NO 24 INTO JUNCTION NO 2

A RECIRCULATION PATH IS BEING CLOSED

Table 10f:

AIRWAY FROM TO METHANE IN THE FOLLOWING AIRWAYS EXIST TO CRITICAL CONDITIONS
 (THE CONCENTRATION HIGHER THAN 1.0 PERCENT) BECOME LOWER THAN
 1.0 PERCENT) HIGHER THAN 1.0 PERCENT) TEMPERATURE HIGHER THAN
 95 DEGREES LOW VENTILATION LOWER THAN PRESSURE
 HIGHER THAN 0.10 INCHES WG

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----

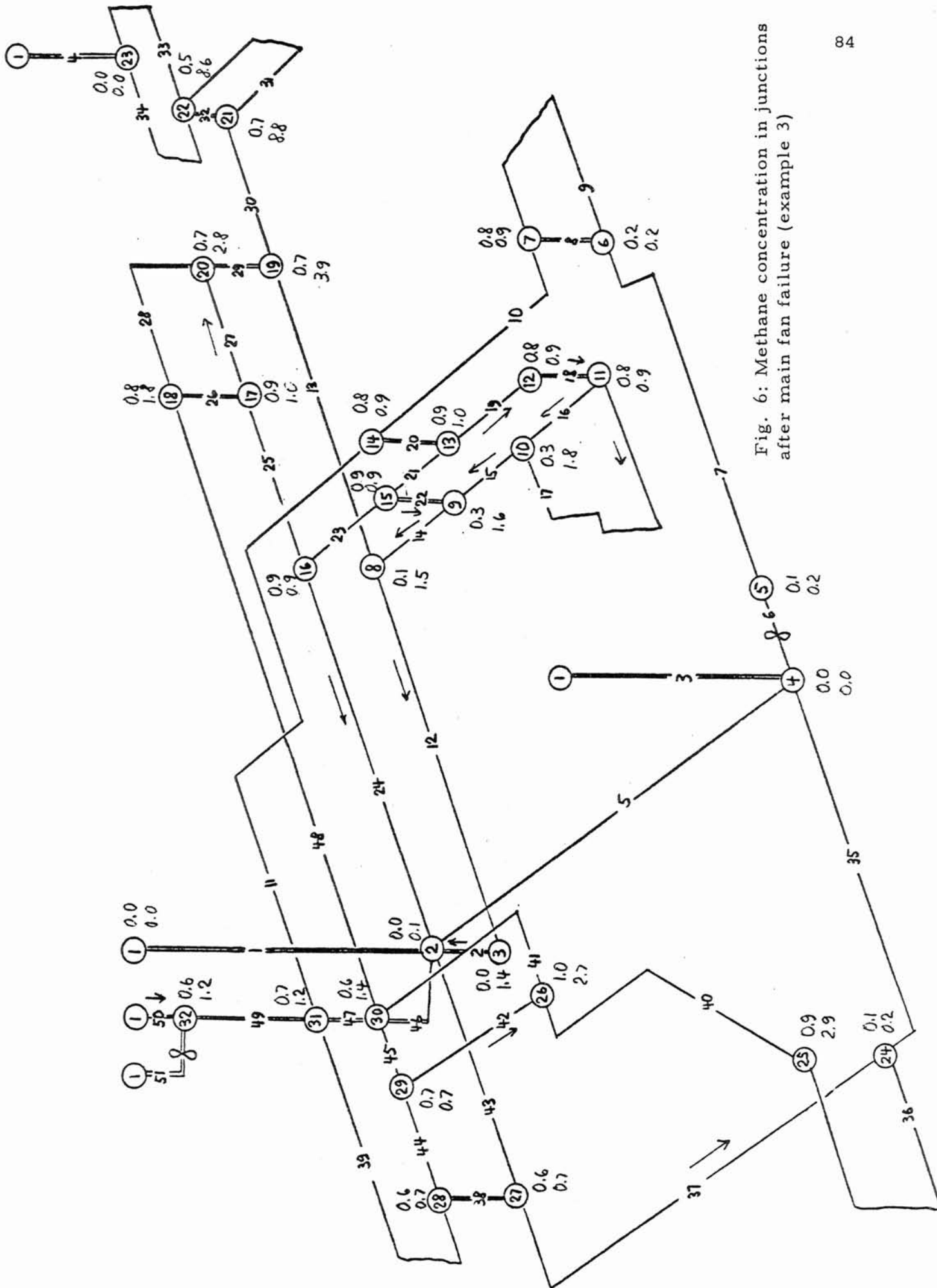


Fig. 6: Methane concentration in junctions after main fan failure (example 3)

A problem of this type, where a large part of the mine is ventilated by small natural ventilation pressures only, can give problems to the program in its herein presented form. These pressures are smaller than the tolerances which have been allowed in the CROSS approximation method in order to keep the number of iterations low. This means that the CROSS method can, for the same input data, come up with different answers for the airflow directions. This has no practical importance. Airways with pressure losses lower than the chosen tolerances are so unstable that a precalculation of their airflow rates or directions makes little practical sense.

In this program, every time that an airflow reversal takes place in a computer run, a new flowscheme and mesh assembly has to be set up, followed by a new network calculation with the help of the CROSS method. The result can be a continuous oscillation of airflow directions in the unstable airways. The obvious remedy, to make the tolerances smaller, offers little advantage. One does no longer get convergence problems, but the results are no more convincing.

A better way for problems of this type is to assume that the temperature distribution remains constant and to perform only one network calculation followed by a concentration calculation but not by a temperature calculation. Tables 10 a - f show the results. In judging these, one should keep in mind that the airways with low pressure losses must be considered unstable. The output draws special attention to recirculation and the airways with airflow reversals also. Fig. 6 shows the methane concentration of junctions before (Table 8) and after (lower placed figures) (Table 10) the main fan failure. Arrows mark airways with airflow reversal.

4.4.2.4 Example 4: Fire In a Horizontal Airway

A fire is assumed at the beginning of airway 5 (NCENT). It is estimated that 30,000 cfm of air (CONT) travels through the fire zone, leaves a smoke (carbon dioxide) concentration of 1.00% (CONC), and produces a heat of $15 \cdot 10^4$ Btu/min (HEAT). The results of the calculations are shown in Tables 11 a - f. One sees that the fumes coming from the fire have cooled down to almost normal temperatures before they leave

Table 11a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	LENGTH	AREA	RESISTANCE	K	PERIMETER
1			1525	300	25	00	158	25	50
2			1144	300	25	00	149	25	50
3			309	300	25	00	40	25	50
4			309	300	25	00	40	25	50
5			309	300	25	00	40	25	50
6			309	300	25	00	40	25	50
7			309	300	25	00	40	25	50
8			309	300	25	00	40	25	50
9			309	300	25	00	40	25	50
10			309	300	25	00	40	25	50
11			309	300	25	00	40	25	50
12			309	300	25	00	40	25	50
13			309	300	25	00	40	25	50
14			309	300	25	00	40	25	50
15			309	300	25	00	40	25	50
16			309	300	25	00	40	25	50
17			309	300	25	00	40	25	50
18			309	300	25	00	40	25	50
19			309	300	25	00	40	25	50
20			309	300	25	00	40	25	50
21			309	300	25	00	40	25	50
22			309	300	25	00	40	25	50
23			309	300	25	00	40	25	50
24			309	300	25	00	40	25	50
25			309	300	25	00	40	25	50
26			309	300	25	00	40	25	50
27			309	300	25	00	40	25	50
28			309	300	25	00	40	25	50
29			309	300	25	00	40	25	50
30			309	300	25	00	40	25	50
31			309	300	25	00	40	25	50
32			309	300	25	00	40	25	50
33			309	300	25	00	40	25	50
34			309	300	25	00	40	25	50
35			309	300	25	00	40	25	50
36			309	300	25	00	40	25	50
37			309	300	25	00	40	25	50
38			309	300	25	00	40	25	50
39			309	300	25	00	40	25	50
40			309	300	25	00	40	25	50
41			309	300	25	00	40	25	50
42			309	300	25	00	40	25	50
43			309	300	25	00	40	25	50
44			309	300	25	00	40	25	50
45			309	300	25	00	40	25	50
46			309	300	25	00	40	25	50
47			309	300	25	00	40	25	50
48			309	300	25	00	40	25	50
49			309	300	25	00	40	25	50
50			309	300	25	00	40	25	50

Table 11b:

FANS

AIRWAY FROM	TO	AIRFLOW	FAN PRESSURE
6	5	58908.	4.498
51	1	315091.	11.719

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

70000: 3:29	25000: 4:32	30000: 4:60	40000: 4:78	55000: 4:52
80000: 12:25	85000: 3:52	100000: 4:70	150000: 3:00	200000: 2:52
400000: 10:25	100000: 14:08	150000: 14:30	200000: 14:05	300000: 12:00
	500000: 14:08	600000: 14:30	700000: 16:30	800000: 16:20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 1.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONCENTRATION	HEAT	OXYGEN CONCENTRATION	SMOKE	PRODUCTION PER % OXYGEN
5	50000.0	1.00	150000.00	BEHIND FIRE	.00	HEAT .00

Table 11e:

JUNCTION	TEMPERATURE	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.0	55.0	0.00	0.00	2	65.0	0.00	0.00
2	74.5	69.2	0.00	0.00	4	69.2	0.00	0.00
3	74.5	72.8	0.00	0.00	6	72.8	0.00	0.00
4	74.5	77.9	0.00	0.00	8	77.9	0.00	0.00
5	74.5	78.1	0.00	0.00	10	78.1	0.00	0.00
6	74.5	78.0	0.00	0.00	12	78.0	0.00	0.00
7	74.5	76.3	0.00	0.00	14	76.3	0.00	0.00
8	74.5	68.6	0.00	0.00	16	68.6	0.00	0.00
9	74.5	65.4	0.00	0.00	18	65.4	0.00	0.00
10	74.5	64.4	0.00	0.00	20	64.4	0.00	0.00
11	74.5	64.4	0.00	0.00	22	64.4	0.00	0.00
12	74.5	64.4	0.00	0.00	24	64.4	0.00	0.00
13	74.5	64.4	0.00	0.00	26	64.4	0.00	0.00
14	74.5	64.4	0.00	0.00	28	64.4	0.00	0.00
15	74.5	64.4	0.00	0.00	30	64.4	0.00	0.00
16	74.5	64.4	0.00	0.00	32	64.4	0.00	0.00
17	74.5	64.4	0.00	0.00	34	64.4	0.00	0.00
18	74.5	64.4	0.00	0.00	36	64.4	0.00	0.00
19	74.5	64.4	0.00	0.00	38	64.4	0.00	0.00
20	74.5	64.4	0.00	0.00	40	64.4	0.00	0.00
21	74.5	64.4	0.00	0.00	42	64.4	0.00	0.00
22	74.5	64.4	0.00	0.00	44	64.4	0.00	0.00
23	74.5	64.4	0.00	0.00	46	64.4	0.00	0.00
24	74.5	64.4	0.00	0.00	48	64.4	0.00	0.00
25	74.5	64.4	0.00	0.00	50	64.4	0.00	0.00
26	74.5	64.4	0.00	0.00	52	64.4	0.00	0.00
27	74.5	64.4	0.00	0.00	54	64.4	0.00	0.00
28	74.5	64.4	0.00	0.00	56	64.4	0.00	0.00
29	74.5	64.4	0.00	0.00	58	64.4	0.00	0.00
30	74.5	64.4	0.00	0.00	60	64.4	0.00	0.00

NUMBER OF ITERATIONS 1

Table 11f:

AIRWAY FROM	TO	IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS (THE CONCENTRATION IS HIGHER THAN 1.0 PERCENT OR THE CONCENTRATION IS HIGHER THAN 0.50 PERCENT EXCEPT WHERE SMOKE RELEASE CONCENTRATION IS NUMBER 8)	CRITICAL CONDITIONS EXIST HIGHER THAN 0.50 PERCENT	CRITICAL CONDITIONS EXIST HIGHER THAN 0.50 PERCENT	TEMPERATURE HIGHER THAN 95 DEGREES	LOW VENTILATION PRESSURE HIGHER THAN 0.10 INCHES WG	TEMPERATURE HIGHER THAN 95 DEGREES
25	1	0	0	0	7	4	0
25	2	0	0	0	6	4	0
25	3	0	0	0	6	7	8
25	4	0	0	0	6	9	8
25	5	0	0	0	7	5	2
25	6	0	0	0	7	1	0
25	7	0	0	0	7	6	9
25	8	0	0	0	8	1	0
25	9	0	0	0	8	0	2
25	10	0	0	0	9	8	5
25	11	0	0	0	9	5	5
25	12	0	0	0	9	4	9
25	13	0	0	0	9	9	9
25	14	0	0	0	9	6	7
25	15	0	0	0	9	7	5
25	16	0	0	0	9	8	5
25	17	0	0	0	9	9	8
25	18	0	0	0	9	9	8
25	19	0	0	0	9	9	8
25	20	0	0	0	9	9	8
25	21	0	0	0	9	9	8
25	22	0	0	0	9	9	8
25	23	0	0	0	9	9	8
25	24	0	0	0	9	9	8
25	25	0	0	0	9	9	8
25	26	0	0	0	9	9	8
25	27	0	0	0	9	9	8
25	28	0	0	0	9	9	8
25	29	0	0	0	9	9	8
25	30	0	0	0	9	9	8
25	31	0	0	0	9	9	8
25	32	0	0	0	9	9	8
25	33	0	0	0	9	9	8
25	34	0	0	0	9	9	8
25	35	0	0	0	9	9	8
25	36	0	0	0	9	9	8
25	37	0	0	0	9	9	8
25	38	0	0	0	9	9	8
25	39	0	0	0	9	9	8
25	40	0	0	0	9	9	8
25	41	0	0	0	9	9	8
25	42	0	0	0	9	9	8
25	43	0	0	0	9	9	8
25	44	0	0	0	9	9	8
25	45	0	0	0	9	9	8
25	46	0	0	0	9	9	8
25	47	0	0	0	9	9	8
25	48	0	0	0	9	9	8
25	49	0	0	0	9	9	8
25	50	0	0	0	9	9	8
25	51	0	0	0	9	9	8
25	52	0	0	0	9	9	8
25	53	0	0	0	9	9	8
25	54	0	0	0	9	9	8
25	55	0	0	0	9	9	8
25	56	0	0	0	9	9	8
25	57	0	0	0	9	9	8
25	58	0	0	0	9	9	8
25	59	0	0	0	9	9	8
25	60	0	0	0	9	9	8
25	61	0	0	0	9	9	8
25	62	0	0	0	9	9	8
25	63	0	0	0	9	9	8
25	64	0	0	0	9	9	8
25	65	0	0	0	9	9	8
25	66	0	0	0	9	9	8
25	67	0	0	0	9	9	8
25	68	0	0	0	9	9	8
25	69	0	0	0	9	9	8
25	70	0	0	0	9	9	8
25	71	0	0	0	9	9	8
25	72	0	0	0	9	9	8
25	73	0	0	0	9	9	8
25	74	0	0	0	9	9	8
25	75	0	0	0	9	9	8
25	76	0	0	0	9	9	8
25	77	0	0	0	9	9	8
25	78	0	0	0	9	9	8
25	79	0	0	0	9	9	8
25	80	0	0	0	9	9	8
25	81	0	0	0	9	9	8
25	82	0	0	0	9	9	8
25	83	0	0	0	9	9	8
25	84	0	0	0	9	9	8
25	85	0	0	0	9	9	8
25	86	0	0	0	9	9	8
25	87	0	0	0	9	9	8
25	88	0	0	0	9	9	8
25	89	0	0	0	9	9	8
25	90	0	0	0	9	9	8
25	91	0	0	0	9	9	8
25	92	0	0	0	9	9	8
25	93	0	0	0	9	9	8
25	94	0	0	0	9	9	8
25	95	0	0	0	9	9	8
25	96	0	0	0	9	9	8
25	97	0	0	0	9	9	8
25	98	0	0	0	9	9	8
25	99	0	0	0	9	9	8
25	100	0	0	0	9	9	8

Table 12a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	REGULAR AIRWAYS	LENGTH	AREA	RESISTANCE	K	PERIMETER
57	1	2	157	0.000	1	25	0.000	1.56	55	0.000
56	1	2	157	0.000	1	25	0.000	1.47	55	0.000
55	1	2	157	0.000	1	25	0.000	1.49	55	0.000
54	1	2	157	0.000	1	25	0.000	1.47	55	0.000
53	1	2	157	0.000	1	25	0.000	1.47	55	0.000
52	1	2	157	0.000	1	25	0.000	1.47	55	0.000
51	1	2	157	0.000	1	25	0.000	1.47	55	0.000
50	1	2	157	0.000	1	25	0.000	1.47	55	0.000
49	1	2	157	0.000	1	25	0.000	1.47	55	0.000
48	1	2	157	0.000	1	25	0.000	1.47	55	0.000
47	1	2	157	0.000	1	25	0.000	1.47	55	0.000
46	1	2	157	0.000	1	25	0.000	1.47	55	0.000
45	1	2	157	0.000	1	25	0.000	1.47	55	0.000
44	1	2	157	0.000	1	25	0.000	1.47	55	0.000
43	1	2	157	0.000	1	25	0.000	1.47	55	0.000
42	1	2	157	0.000	1	25	0.000	1.47	55	0.000
41	1	2	157	0.000	1	25	0.000	1.47	55	0.000
40	1	2	157	0.000	1	25	0.000	1.47	55	0.000
39	1	2	157	0.000	1	25	0.000	1.47	55	0.000
38	1	2	157	0.000	1	25	0.000	1.47	55	0.000
37	1	2	157	0.000	1	25	0.000	1.47	55	0.000
36	1	2	157	0.000	1	25	0.000	1.47	55	0.000
35	1	2	157	0.000	1	25	0.000	1.47	55	0.000
34	1	2	157	0.000	1	25	0.000	1.47	55	0.000
33	1	2	157	0.000	1	25	0.000	1.47	55	0.000
32	1	2	157	0.000	1	25	0.000	1.47	55	0.000
31	1	2	157	0.000	1	25	0.000	1.47	55	0.000
30	1	2	157	0.000	1	25	0.000	1.47	55	0.000
29	1	2	157	0.000	1	25	0.000	1.47	55	0.000
28	1	2	157	0.000	1	25	0.000	1.47	55	0.000
27	1	2	157	0.000	1	25	0.000	1.47	55	0.000
26	1	2	157	0.000	1	25	0.000	1.47	55	0.000
25	1	2	157	0.000	1	25	0.000	1.47	55	0.000
24	1	2	157	0.000	1	25	0.000	1.47	55	0.000
23	1	2	157	0.000	1	25	0.000	1.47	55	0.000
22	1	2	157	0.000	1	25	0.000	1.47	55	0.000
21	1	2	157	0.000	1	25	0.000	1.47	55	0.000
20	1	2	157	0.000	1	25	0.000	1.47	55	0.000
19	1	2	157	0.000	1	25	0.000	1.47	55	0.000
18	1	2	157	0.000	1	25	0.000	1.47	55	0.000
17	1	2	157	0.000	1	25	0.000	1.47	55	0.000
16	1	2	157	0.000	1	25	0.000	1.47	55	0.000
15	1	2	157	0.000	1	25	0.000	1.47	55	0.000
14	1	2	157	0.000	1	25	0.000	1.47	55	0.000
13	1	2	157	0.000	1	25	0.000	1.47	55	0.000
12	1	2	157	0.000	1	25	0.000	1.47	55	0.000
11	1	2	157	0.000	1	25	0.000	1.47	55	0.000
10	1	2	157	0.000	1	25	0.000	1.47	55	0.000
9	1	2	157	0.000	1	25	0.000	1.47	55	0.000
8	1	2	157	0.000	1	25	0.000	1.47	55	0.000
7	1	2	157	0.000	1	25	0.000	1.47	55	0.000
6	1	2	157	0.000	1	25	0.000	1.47	55	0.000
5	1	2	157	0.000	1	25	0.000	1.47	55	0.000
4	1	2	157	0.000	1	25	0.000	1.47	55	0.000
3	1	2	157	0.000	1	25	0.000	1.47	55	0.000
2	1	2	157	0.000	1	25	0.000	1.47	55	0.000
1	1	2	157	0.000	1	25	0.000	1.47	55	0.000

Table 12b:

FANS

AIRWAY FROM	TO	AIRFLOW	FAN PRESSURE
6	5	58908.	4.495
51	1	315091.	11.718

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

70000:	7:59	85000:	4:36	100000:	4:48	130000:	4:78	55000:	4:58
80000:	12:25	100000:	14:00	150000:	14:30	200000:	14:05	300000:	12:00
400000:	10:25	500000:	8:85	600000:	14:80	700000:	6:90	800000:	6:20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 1.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONTAMINATION	HEAT	OXYGEN CONCENTRATION	PRODUCTION PER %
18	0.00	0.00	0.00	BEHIND FIRE	SMOKE
				10.00	0.00
					OXYGEN
					HEAT
					0.00

Table 12e:

JUNCTION	TEMPERATURE	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.0	0.0	0.0	0.0	2	64.9	0.0	0.0	0	64.9	0.0	0.0
2	67.4	0.0	0.0	0.0	4	64.9	0.0	0.0	4	64.9	0.0	0.0
3	77.2	0.0	0.0	0.0	6	72.0	0.0	0.0	6	72.0	0.0	0.0
4	77.2	0.0	0.0	0.0	8	76.0	0.0	0.0	8	76.0	0.0	0.0
5	77.2	0.0	0.0	0.0	10	81.4	0.0	0.0	10	81.4	0.0	0.0
6	77.2	0.0	0.0	0.0	12	85.9	0.0	0.0	12	85.9	0.0	0.0
7	77.2	0.0	0.0	0.0	14	89.9	0.0	0.0	14	89.9	0.0	0.0
8	77.2	0.0	0.0	0.0	16	90.0	0.0	0.0	16	90.0	0.0	0.0
9	77.2	0.0	0.0	0.0	18	90.0	0.0	0.0	18	90.0	0.0	0.0
10	77.2	0.0	0.0	0.0	20	90.0	0.0	0.0	20	90.0	0.0	0.0
11	77.2	0.0	0.0	0.0	22	90.0	0.0	0.0	22	90.0	0.0	0.0
12	77.2	0.0	0.0	0.0	24	90.0	0.0	0.0	24	90.0	0.0	0.0
13	77.2	0.0	0.0	0.0	26	90.0	0.0	0.0	26	90.0	0.0	0.0
14	77.2	0.0	0.0	0.0	28	90.0	0.0	0.0	28	90.0	0.0	0.0
15	77.2	0.0	0.0	0.0	30	90.0	0.0	0.0	30	90.0	0.0	0.0
16	77.2	0.0	0.0	0.0	32	90.0	0.0	0.0	32	90.0	0.0	0.0
17	77.2	0.0	0.0	0.0	34	90.0	0.0	0.0	34	90.0	0.0	0.0
18	77.2	0.0	0.0	0.0	36	90.0	0.0	0.0	36	90.0	0.0	0.0
19	77.2	0.0	0.0	0.0	38	90.0	0.0	0.0	38	90.0	0.0	0.0
20	77.2	0.0	0.0	0.0	40	90.0	0.0	0.0	40	90.0	0.0	0.0
21	77.2	0.0	0.0	0.0	42	90.0	0.0	0.0	42	90.0	0.0	0.0
22	77.2	0.0	0.0	0.0	44	90.0	0.0	0.0	44	90.0	0.0	0.0
23	77.2	0.0	0.0	0.0	46	90.0	0.0	0.0	46	90.0	0.0	0.0
24	77.2	0.0	0.0	0.0	48	90.0	0.0	0.0	48	90.0	0.0	0.0
25	77.2	0.0	0.0	0.0	50	90.0	0.0	0.0	50	90.0	0.0	0.0
26	77.2	0.0	0.0	0.0	52	90.0	0.0	0.0	52	90.0	0.0	0.0
27	77.2	0.0	0.0	0.0	54	90.0	0.0	0.0	54	90.0	0.0	0.0
28	77.2	0.0	0.0	0.0	56	90.0	0.0	0.0	56	90.0	0.0	0.0
29	77.2	0.0	0.0	0.0	58	90.0	0.0	0.0	58	90.0	0.0	0.0
30	77.2	0.0	0.0	0.0	60	90.0	0.0	0.0	60	90.0	0.0	0.0
31	77.2	0.0	0.0	0.0	62	90.0	0.0	0.0	62	90.0	0.0	0.0
32	77.2	0.0	0.0	0.0	64	90.0	0.0	0.0	64	90.0	0.0	0.0
33	77.2	0.0	0.0	0.0	66	90.0	0.0	0.0	66	90.0	0.0	0.0
34	77.2	0.0	0.0	0.0	68	90.0	0.0	0.0	68	90.0	0.0	0.0
35	77.2	0.0	0.0	0.0	70	90.0	0.0	0.0	70	90.0	0.0	0.0
36	77.2	0.0	0.0	0.0	72	90.0	0.0	0.0	72	90.0	0.0	0.0
37	77.2	0.0	0.0	0.0	74	90.0	0.0	0.0	74	90.0	0.0	0.0
38	77.2	0.0	0.0	0.0	76	90.0	0.0	0.0	76	90.0	0.0	0.0
39	77.2	0.0	0.0	0.0	78	90.0	0.0	0.0	78	90.0	0.0	0.0
40	77.2	0.0	0.0	0.0	80	90.0	0.0	0.0	80	90.0	0.0	0.0
41	77.2	0.0	0.0	0.0	82	90.0	0.0	0.0	82	90.0	0.0	0.0
42	77.2	0.0	0.0	0.0	84	90.0	0.0	0.0	84	90.0	0.0	0.0
43	77.2	0.0	0.0	0.0	86	90.0	0.0	0.0	86	90.0	0.0	0.0
44	77.2	0.0	0.0	0.0	88	90.0	0.0	0.0	88	90.0	0.0	0.0
45	77.2	0.0	0.0	0.0	90	90.0	0.0	0.0	90	90.0	0.0	0.0

NUMBER OF ITERATIONS 4

Table 12f:

AIRWAY FROM	AIRWAY TO	IN THE FOLLOWING AIRWAYS EXIST CRITICAL END TEMPERATURE HIGHER THAN 95 DEGREES	LOW VENTILATION MORE THAN .010 INCHES WG	TEMPERATURE HIGHER THAN 95 DEGREES	VENTILATION MORE THAN .010 INCHES WG
1	1	0	0	76	4
1	2	0	0	61	4
1	3	0	0	62	1
1	4	0	0	1	1
1	5	0	0	1	5
1	6	0	0	1	7
1	7	0	0	1	0
1	8	0	0	1	5
1	9	0	0	1	7
1	10	0	0	1	8
1	11	0	0	1	5
1	12	0	0	1	8
1	13	0	0	1	5
1	14	0	0	1	8
1	15	0	0	1	5
1	16	0	0	1	8
1	17	0	0	1	5
1	18	0	0	1	8
1	19	0	0	1	5
1	20	0	0	1	8

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	IN THE FOLLOWING JUNCTIONS EXIST CRITICAL CONDITIONS	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	TEMPERATURE HIGHER THAN 95 DEGREES
1	0	0	0	64
1	0	0	0	28
1	0	0	0	16
1	0	0	0	10
1	0	0	0	8
1	0	0	0	7
1	0	0	0	8
1	0	0	0	7
1	0	0	0	7
1	0	0	0	6
1	0	0	0	6
1	0	0	0	5
1	0	0	0	4
1	0	0	0	3
1	0	0	0	2
1	0	0	0	1

REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWING PLACES
 AIRWAY 20 IS NOW CARRYING AIR FROM 13 TO 14

Table 13a:

ORDINARY AIRFLOW AND PRESSURE DISTRIBUTION BEFORE EVENT (BASED ON THE LISTED INPUT DATA)

AIRWAY	FROM	TO	AIRFLOW	PRESSURE LOSS	REGULAR AIRWAYS	LENGTH	AREA	RESISTANCE	PERIMETER
1	2	1	152	30	1	25	0.0000	188	525
1	1	2	144	30	1	25	0.0000	20	525
1	1	3	74	12	1	15	0.0000	4	525
1	1	4	2	1	1	10	0.0000	12	525
1	1	5	2	1	1	10	0.0000	12	525
1	1	6	2	1	1	10	0.0000	12	525
1	1	7	2	1	1	10	0.0000	12	525
1	1	8	2	1	1	10	0.0000	12	525
1	1	9	2	1	1	10	0.0000	12	525
1	1	10	2	1	1	10	0.0000	12	525
1	1	11	2	1	1	10	0.0000	12	525
1	1	12	2	1	1	10	0.0000	12	525
1	1	13	2	1	1	10	0.0000	12	525
1	1	14	2	1	1	10	0.0000	12	525
1	1	15	2	1	1	10	0.0000	12	525
1	1	16	2	1	1	10	0.0000	12	525
1	1	17	2	1	1	10	0.0000	12	525
1	1	18	2	1	1	10	0.0000	12	525
1	1	19	2	1	1	10	0.0000	12	525
1	1	20	2	1	1	10	0.0000	12	525
1	1	21	2	1	1	10	0.0000	12	525
1	1	22	2	1	1	10	0.0000	12	525
1	1	23	2	1	1	10	0.0000	12	525
1	1	24	2	1	1	10	0.0000	12	525
1	1	25	2	1	1	10	0.0000	12	525
1	1	26	2	1	1	10	0.0000	12	525
1	1	27	2	1	1	10	0.0000	12	525
1	1	28	2	1	1	10	0.0000	12	525
1	1	29	2	1	1	10	0.0000	12	525
1	1	30	2	1	1	10	0.0000	12	525
1	1	31	2	1	1	10	0.0000	12	525
1	1	32	2	1	1	10	0.0000	12	525
1	1	33	2	1	1	10	0.0000	12	525
1	1	34	2	1	1	10	0.0000	12	525
1	1	35	2	1	1	10	0.0000	12	525
1	1	36	2	1	1	10	0.0000	12	525
1	1	37	2	1	1	10	0.0000	12	525
1	1	38	2	1	1	10	0.0000	12	525
1	1	39	2	1	1	10	0.0000	12	525
1	1	40	2	1	1	10	0.0000	12	525
1	1	41	2	1	1	10	0.0000	12	525
1	1	42	2	1	1	10	0.0000	12	525
1	1	43	2	1	1	10	0.0000	12	525
1	1	44	2	1	1	10	0.0000	12	525
1	1	45	2	1	1	10	0.0000	12	525
1	1	46	2	1	1	10	0.0000	12	525
1	1	47	2	1	1	10	0.0000	12	525
1	1	48	2	1	1	10	0.0000	12	525
1	1	49	2	1	1	10	0.0000	12	525
1	1	50	2	1	1	10	0.0000	12	525
1	1	51	2	1	1	10	0.0000	12	525
1	1	52	2	1	1	10	0.0000	12	525
1	1	53	2	1	1	10	0.0000	12	525
1	1	54	2	1	1	10	0.0000	12	525
1	1	55	2	1	1	10	0.0000	12	525
1	1	56	2	1	1	10	0.0000	12	525
1	1	57	2	1	1	10	0.0000	12	525
1	1	58	2	1	1	10	0.0000	12	525
1	1	59	2	1	1	10	0.0000	12	525
1	1	60	2	1	1	10	0.0000	12	525

Table 13b:

FANS

AIRWAY FROM TO AIRFLOW FAN PRESSURE
 51 32 4 68908 4.495
 11.718

THESE CHARACTERISTICS WERE STORED FOR FANS 6 51

70000:	3:60	25000:	4:30	30000:	4:60	40000:	4:78	55000:	4:58
70000:	4:29	85000:	3:36	100000:	3:70	150000:	3:00	200000:	2:52
80000:	12:25	100000:	14:00	150000:	14:20	200000:	14:05	300000:	12:00
400000:	10:25	500000:	8:85	600000:	7:80	700000:	6:90	800000:	6:20

THE STATED NUMBER OF AIRWAYS WAS 51 THE STATED NUMBER OF JUNCTIONS WAS 32

TIME AFTER BEGINNING OF EVENT 1.00 HOURS

A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONCENTRAT.	HEAT	OXYGEN CONCENTRATION	PRODUCTION PER	% OXYGEN:
20	0.00	0.00	0.00	BEHIND FIRE	SMOKE	HEAT
				0.00	1.00	300.00

Table 13c:

INPUT DATA FOR CONCENTRATION AND TEMPERATURE CALCULATIONS

AIRWAY	FROM	TO	ELEVATION	DIFF.	ROCK	TEMP.	METHANE	PROD.	CONDUCTIVITY	DIFFUSIVITY
1	2	1	2575	0	0	74	0	0	0	0
2	1	2	2577	0	0	32	0	0	0	0
3	1	2	2580	0	0	59	0	0	0	0
4	1	2	3244	0	0	47	0	0	0	0
5	1	2	3244	0	0	20	0	0	0	0
6	1	2	3152	0	0	1	0	0	0	0
7	1	2	3152	0	0	1	0	0	0	0
8	1	2	3152	0	0	27	0	0	0	0
9	1	2	3152	0	0	105	0	0	0	0
10	1	2	3152	0	0	3	0	0	0	0
11	1	2	3152	0	0	1	0	0	0	0
12	1	2	3152	0	0	17	0	0	0	0
13	1	2	3152	0	0	212	0	0	0	0

Table 13e:

JUNCTION	TEMPERATURE	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.7	64.9	0.0	0.0	2	64.9	0.0	0.0
2	67.5	69.2	0.0	0.0	3	69.2	0.0	0.0
3	72.8	73.6	0.0	0.0	4	73.6	0.0	0.0
4	78.2	79.8	0.0	0.0	5	79.8	0.0	0.0
5	82.4	84.8	0.0	0.0	6	84.8	0.0	0.0
6	85.0	88.0	0.0	0.0	7	88.0	0.0	0.0
7	88.0	91.0	0.0	0.0	8	91.0	0.0	0.0
8	91.0	94.0	0.0	0.0	9	94.0	0.0	0.0
9	94.0	97.0	0.0	0.0	10	97.0	0.0	0.0
10	97.0	100.0	0.0	0.0	11	100.0	0.0	0.0
11	100.0	103.0	0.0	0.0	12	103.0	0.0	0.0
12	103.0	106.0	0.0	0.0	13	106.0	0.0	0.0
13	106.0	109.0	0.0	0.0	14	109.0	0.0	0.0
14	109.0	112.0	0.0	0.0	15	112.0	0.0	0.0
15	112.0	115.0	0.0	0.0	16	115.0	0.0	0.0
16	115.0	118.0	0.0	0.0	17	118.0	0.0	0.0
17	118.0	121.0	0.0	0.0	18	121.0	0.0	0.0
18	121.0	124.0	0.0	0.0	19	124.0	0.0	0.0
19	124.0	127.0	0.0	0.0	20	127.0	0.0	0.0
20	127.0	130.0	0.0	0.0	21	130.0	0.0	0.0
21	130.0	133.0	0.0	0.0	22	133.0	0.0	0.0
22	133.0	136.0	0.0	0.0	23	136.0	0.0	0.0
23	136.0	139.0	0.0	0.0	24	139.0	0.0	0.0
24	139.0	142.0	0.0	0.0	25	142.0	0.0	0.0
25	142.0	145.0	0.0	0.0	26	145.0	0.0	0.0
26	145.0	148.0	0.0	0.0	27	148.0	0.0	0.0
27	148.0	151.0	0.0	0.0	28	151.0	0.0	0.0
28	151.0	154.0	0.0	0.0	29	154.0	0.0	0.0
29	154.0	157.0	0.0	0.0	30	157.0	0.0	0.0
30	157.0	160.0	0.0	0.0	31	160.0	0.0	0.0
31	160.0	163.0	0.0	0.0	32	163.0	0.0	0.0
32	163.0	166.0	0.0	0.0	33	166.0	0.0	0.0
33	166.0	169.0	0.0	0.0	34	169.0	0.0	0.0
34	169.0	172.0	0.0	0.0	35	172.0	0.0	0.0
35	172.0	175.0	0.0	0.0	36	175.0	0.0	0.0
36	175.0	178.0	0.0	0.0	37	178.0	0.0	0.0
37	178.0	181.0	0.0	0.0	38	181.0	0.0	0.0
38	181.0	184.0	0.0	0.0	39	184.0	0.0	0.0
39	184.0	187.0	0.0	0.0	40	187.0	0.0	0.0
40	187.0	190.0	0.0	0.0	41	190.0	0.0	0.0
41	190.0	193.0	0.0	0.0	42	193.0	0.0	0.0
42	193.0	196.0	0.0	0.0	43	196.0	0.0	0.0
43	196.0	199.0	0.0	0.0	44	199.0	0.0	0.0
44	199.0	202.0	0.0	0.0	45	202.0	0.0	0.0
45	202.0	205.0	0.0	0.0	46	205.0	0.0	0.0
46	205.0	208.0	0.0	0.0	47	208.0	0.0	0.0
47	208.0	211.0	0.0	0.0	48	211.0	0.0	0.0
48	211.0	214.0	0.0	0.0	49	214.0	0.0	0.0
49	214.0	217.0	0.0	0.0	50	217.0	0.0	0.0
50	217.0	220.0	0.0	0.0	51	220.0	0.0	0.0
51	220.0	223.0	0.0	0.0	52	223.0	0.0	0.0
52	223.0	226.0	0.0	0.0	53	226.0	0.0	0.0
53	226.0	229.0	0.0	0.0	54	229.0	0.0	0.0
54	229.0	232.0	0.0	0.0	55	232.0	0.0	0.0
55	232.0	235.0	0.0	0.0	56	235.0	0.0	0.0
56	235.0	238.0	0.0	0.0	57	238.0	0.0	0.0
57	238.0	241.0	0.0	0.0	58	241.0	0.0	0.0
58	241.0	244.0	0.0	0.0	59	244.0	0.0	0.0
59	244.0	247.0	0.0	0.0	60	247.0	0.0	0.0
60	247.0	250.0	0.0	0.0	61	250.0	0.0	0.0
61	250.0	253.0	0.0	0.0	62	253.0	0.0	0.0
62	253.0	256.0	0.0	0.0	63	256.0	0.0	0.0
63	256.0	259.0	0.0	0.0	64	259.0	0.0	0.0
64	259.0	262.0	0.0	0.0	65	262.0	0.0	0.0
65	262.0	265.0	0.0	0.0	66	265.0	0.0	0.0
66	265.0	268.0	0.0	0.0	67	268.0	0.0	0.0
67	268.0	271.0	0.0	0.0	68	271.0	0.0	0.0
68	271.0	274.0	0.0	0.0	69	274.0	0.0	0.0
69	274.0	277.0	0.0	0.0	70	277.0	0.0	0.0
70	277.0	280.0	0.0	0.0	71	280.0	0.0	0.0
71	280.0	283.0	0.0	0.0	72	283.0	0.0	0.0
72	283.0	286.0	0.0	0.0	73	286.0	0.0	0.0
73	286.0	289.0	0.0	0.0	74	289.0	0.0	0.0
74	289.0	292.0	0.0	0.0	75	292.0	0.0	0.0
75	292.0	295.0	0.0	0.0	76	295.0	0.0	0.0
76	295.0	298.0	0.0	0.0	77	298.0	0.0	0.0
77	298.0	301.0	0.0	0.0	78	301.0	0.0	0.0
78	301.0	304.0	0.0	0.0	79	304.0	0.0	0.0
79	304.0	307.0	0.0	0.0	80	307.0	0.0	0.0
80	307.0	310.0	0.0	0.0	81	310.0	0.0	0.0
81	310.0	313.0	0.0	0.0	82	313.0	0.0	0.0
82	313.0	316.0	0.0	0.0	83	316.0	0.0	0.0
83	316.0	319.0	0.0	0.0	84	319.0	0.0	0.0
84	319.0	322.0	0.0	0.0	85	322.0	0.0	0.0
85	322.0	325.0	0.0	0.0	86	325.0	0.0	0.0
86	325.0	328.0	0.0	0.0	87	328.0	0.0	0.0
87	328.0	331.0	0.0	0.0	88	331.0	0.0	0.0
88	331.0	334.0	0.0	0.0	89	334.0	0.0	0.0
89	334.0	337.0	0.0	0.0	90	337.0	0.0	0.0
90	337.0	340.0	0.0	0.0	91	340.0	0.0	0.0
91	340.0	343.0	0.0	0.0	92	343.0	0.0	0.0
92	343.0	346.0	0.0	0.0	93	346.0	0.0	0.0
93	346.0	349.0	0.0	0.0	94	349.0	0.0	0.0
94	349.0	352.0	0.0	0.0	95	352.0	0.0	0.0
95	352.0	355.0	0.0	0.0	96	355.0	0.0	0.0
96	355.0	358.0	0.0	0.0	97	358.0	0.0	0.0
97	358.0	361.0	0.0	0.0	98	361.0	0.0	0.0
98	361.0	364.0	0.0	0.0	99	364.0	0.0	0.0
99	364.0	367.0	0.0	0.0	100	367.0	0.0	0.0

NUMBER OF ITERATIONS 4

Table 13f:

AIRWAY FROM	TO	IN THE FOLLOWING AIRWAYS REVERSE AIRFLOW IS CRITICAL END CONDITIONS OF STATEMENT CONCENTRATION HIGHER THAN 1.0 PERCENT	EXIST TO CRITICAL END CONDITIONS CONCENTRATION HIGHER THAN 95.0 DEGREES	TEMPERATURE HIGHER THAN 95.0 DEGREES	VENTILATED THAN LOW VENTILATED THAN 0.10 INCHES WG
800	74	57	0000	78.27	84.1
100	13	10.5	0000	75.65	33.4
200	14	11	0004	77.03	39.0
300	15	23.5	0000	77.33	6.1
400	16	34.8	0000	71.69	10.7
500	17	64	0000	75.69	10.7
1000	18	64	0000	75.69	5.0
1000	19	64	0000	75.69	0.0
1000	20	64	0000	75.69	0.0
1000	21	64	0000	75.69	0.0
1000	22	64	0000	75.69	0.0
1000	23	64	0000	75.69	0.0
1000	24	64	0000	75.69	0.0
1000	25	64	0000	75.69	0.0
1000	26	64	0000	75.69	0.0
1000	27	64	0000	75.69	0.0
1000	28	64	0000	75.69	0.0
1000	29	64	0000	75.69	0.0
1000	30	64	0000	75.69	0.0
1000	31	64	0000	75.69	0.0
1000	32	64	0000	75.69	0.0
1000	33	64	0000	75.69	0.0
1000	34	64	0000	75.69	0.0
1000	35	64	0000	75.69	0.0
1000	36	64	0000	75.69	0.0
1000	37	64	0000	75.69	0.0
1000	38	64	0000	75.69	0.0
1000	39	64	0000	75.69	0.0
1000	40	64	0000	75.69	0.0
1000	41	64	0000	75.69	0.0
1000	42	64	0000	75.69	0.0
1000	43	64	0000	75.69	0.0
1000	44	64	0000	75.69	0.0
1000	45	64	0000	75.69	0.0
1000	46	64	0000	75.69	0.0
1000	47	64	0000	75.69	0.0
1000	48	64	0000	75.69	0.0
1000	49	64	0000	75.69	0.0
1000	50	64	0000	75.69	0.0
1000	51	64	0000	75.69	0.0
1000	52	64	0000	75.69	0.0
1000	53	64	0000	75.69	0.0
1000	54	64	0000	75.69	0.0
1000	55	64	0000	75.69	0.0
1000	56	64	0000	75.69	0.0
1000	57	64	0000	75.69	0.0
1000	58	64	0000	75.69	0.0
1000	59	64	0000	75.69	0.0
1000	60	64	0000	75.69	0.0
1000	61	64	0000	75.69	0.0
1000	62	64	0000	75.69	0.0
1000	63	64	0000	75.69	0.0
1000	64	64	0000	75.69	0.0
1000	65	64	0000	75.69	0.0
1000	66	64	0000	75.69	0.0
1000	67	64	0000	75.69	0.0
1000	68	64	0000	75.69	0.0
1000	69	64	0000	75.69	0.0
1000	70	64	0000	75.69	0.0
1000	71	64	0000	75.69	0.0
1000	72	64	0000	75.69	0.0
1000	73	64	0000	75.69	0.0
1000	74	64	0000	75.69	0.0
1000	75	64	0000	75.69	0.0
1000	76	64	0000	75.69	0.0
1000	77	64	0000	75.69	0.0
1000	78	64	0000	75.69	0.0
1000	79	64	0000	75.69	0.0
1000	80	64	0000	75.69	0.0
1000	81	64	0000	75.69	0.0
1000	82	64	0000	75.69	0.0
1000	83	64	0000	75.69	0.0
1000	84	64	0000	75.69	0.0
1000	85	64	0000	75.69	0.0
1000	86	64	0000	75.69	0.0
1000	87	64	0000	75.69	0.0
1000	88	64	0000	75.69	0.0
1000	89	64	0000	75.69	0.0
1000	90	64	0000	75.69	0.0
1000	91	64	0000	75.69	0.0
1000	92	64	0000	75.69	0.0
1000	93	64	0000	75.69	0.0
1000	94	64	0000	75.69	0.0
1000	95	64	0000	75.69	0.0
1000	96	64	0000	75.69	0.0
1000	97	64	0000	75.69	0.0
1000	98	64	0000	75.69	0.0
1000	99	64	0000	75.69	0.0
1000	100	64	0000	75.69	0.0

REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWING PLACES

AIRWAY 20 IS NOW CARRYING AIR FROM 13 TO 14

15.8
441.9
76.2
65.9

TEMPERATURE DEGREES
MORE THAN 95.0 DEGREES

airway 5. Consequently, there is no substantial change in the air flow or temperature distribution. Since airway 5 is an intake airway, almost the whole mine is filled with smoke except for the part ventilated from intake shaft 4.

4.4.2.5 Example 5: Oxygen Rich Fire at Bottom of Timbered Raise

A fully developed fire burns at the bottom of raise airway 18. This raise is timbered and it is assumed that the fumes leave the fire zone with an oxygen concentration of 16% (O₂MIN). The results of the calculation are shown in Tables 12 a - f. The natural ventilation of the fire will increase the air flow in airway 18 from approximately 24,000 cfm to 40,000 cfm (based on the reference density). Raise 20, which is an unstable descensionally ventilated airway, will experience a stable air flow reversal and transport approximately 10,000 cfm of fumes up to the next higher level, where an additional contamination of airway 11 takes place.

4.4.2.6 Example 6: Fuel Rich Fire in a Descensionally Ventilated Raise

A smoldering fire is assumed in raise airway 20. Since the raise is poorly ventilated, the possibility of considerable preheating shall be considered, leading to a fuel rich fire. In this, all of the oxygen in the air supply is consumed. The smoke production (SMPO₂) per ft³ of oxygen is estimated to be 1 ft³, the heat production (HTPO₂) 300 Btu. The results are shown in Tables 13 a - f. Raise 20 develops a very powerful natural draft, transporting approximately 31,000 cfm of smoke up into airway 11. Since 11 is the return for airways 8, 9, and 10, these airways will experience air flow reduction and methane concentration increases to above 1%.

In the design of the program it has been assumed that the location of a fire is at the beginning of the airway in which the fire occurs. If an air flow reversal in an airway with fire occurs, the program will move the fire zone from one end of the airway to the other end. This feature had been introduced to assume, for the detection of instabilities, the worst possible conditions. If this approach becomes unrealistic, one has to consider the fire zone as a separate airway whose location is fixed. This shall be demonstrated with the next example.

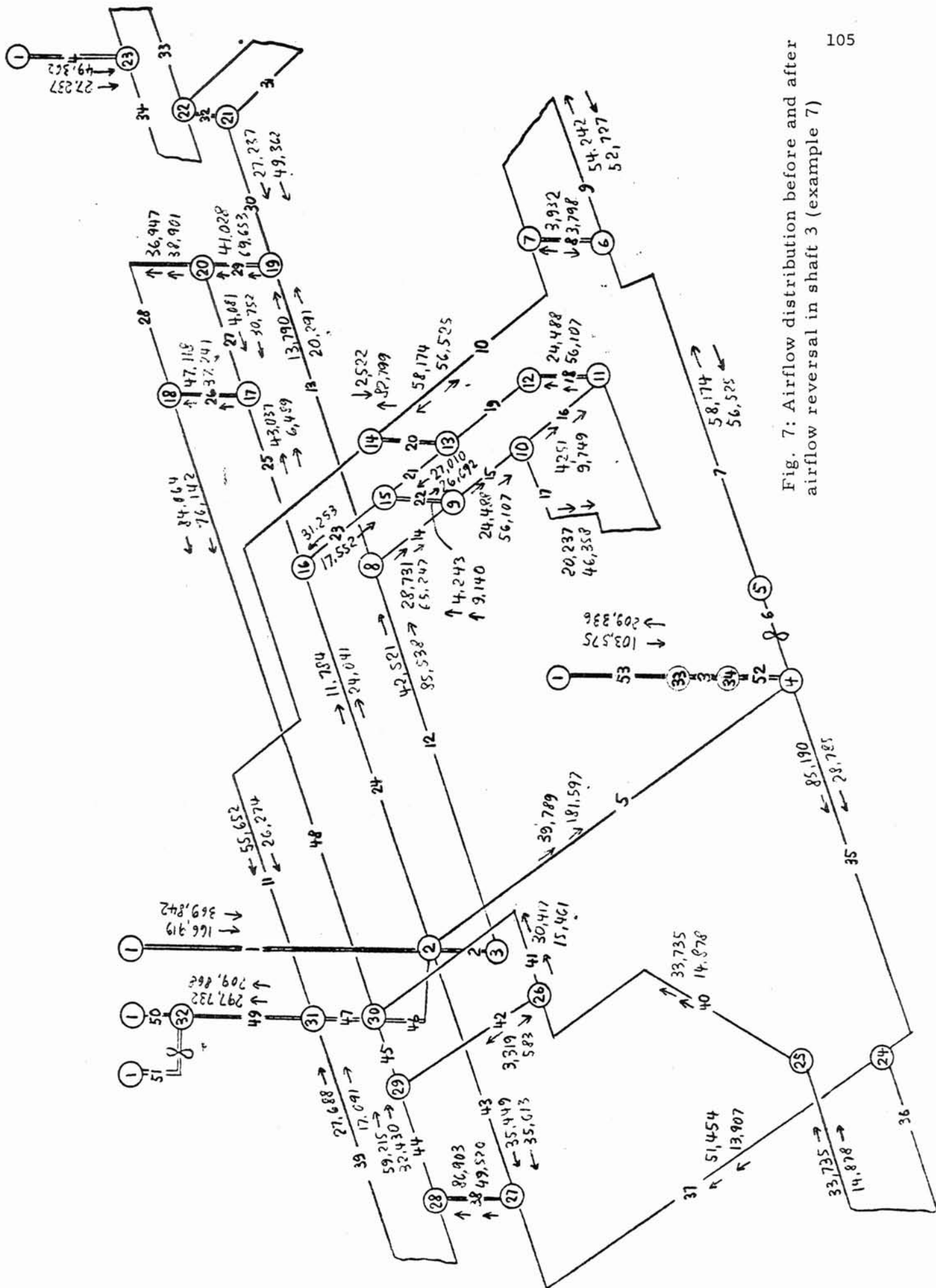


Fig. 7: Airflow distribution before and after airflow reversal in shaft 3 (example 7)

Table 14a:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	2	24	64	0	0	54
3	3	40	67	0	0	51
2	4	55	72	5	0	53
5	5	16	75	1	0	59
6	6	15	78	1	0	60
7	7	16	77	1	0	57
8	8	15	76	1	0	58
0	9	45	75	1	0	57
1	10	54	74	0	0	56
2	11	43	73	0	0	55
3	12	32	72	0	0	54
4	13	22	71	0	0	53
5	14	12	70	0	0	52
6	15	2	69	0	0	51
7	16	0	68	0	0	50
8	17	0	67	0	0	49
9	18	0	66	0	0	48
0	19	0	65	0	0	47
1	20	0	64	0	0	46
2	21	0	63	0	0	45
3	22	0	62	0	0	44
4	23	0	61	0	0	43
5	24	0	60	0	0	42
6	25	0	59	0	0	41
7	26	0	58	0	0	40
8	27	0	57	0	0	39
9	28	0	56	0	0	38
0	29	0	55	0	0	37
1	30	0	54	0	0	36
2	31	0	53	0	0	35
3	32	0	52	0	0	34
4	33	0	51	0	0	33
5	34	0	50	0	0	32
6	35	0	49	0	0	31
7	36	0	48	0	0	30
8	37	0	47	0	0	29
9	38	0	46	0	0	28
0	39	0	45	0	0	27
1	40	0	44	0	0	26
2	41	0	43	0	0	25
3	42	0	42	0	0	24
4	43	0	41	0	0	23
5	44	0	40	0	0	22
6	45	0	39	0	0	21
7	46	0	38	0	0	20
8	47	0	37	0	0	19
9	48	0	36	0	0	18
0	49	0	35	0	0	17
1	50	0	34	0	0	16
2	51	0	33	0	0	15
3	52	0	32	0	0	14
4	53	0	31	0	0	13
5	54	0	30	0	0	12
6	55	0	29	0	0	11
7	56	0	28	0	0	10
8	57	0	27	0	0	9
9	58	0	26	0	0	8
0	59	0	25	0	0	7
1	60	0	24	0	0	6
2	61	0	23	0	0	5
3	62	0	22	0	0	4
4	63	0	21	0	0	3
5	64	0	20	0	0	2
6	65	0	19	0	0	1
7	66	0	18	0	0	0
8	67	0	17	0	0	0
9	68	0	16	0	0	0
0	69	0	15	0	0	0
1	70	0	14	0	0	0
2	71	0	13	0	0	0
3	72	0	12	0	0	0
4	73	0	11	0	0	0
5	74	0	10	0	0	0
6	75	0	9	0	0	0
7	76	0	8	0	0	0
8	77	0	7	0	0	0
9	78	0	6	0	0	0
0	79	0	5	0	0	0
1	80	0	4	0	0	0
2	81	0	3	0	0	0
3	82	0	2	0	0	0
4	83	0	1	0	0	0
5	84	0	0	0	0	0
6	85	0	0	0	0	0
7	86	0	0	0	0	0
8	87	0	0	0	0	0
9	88	0	0	0	0	0
0	89	0	0	0	0	0
1	90	0	0	0	0	0
2	91	0	0	0	0	0
3	92	0	0	0	0	0
4	93	0	0	0	0	0
5	94	0	0	0	0	0
6	95	0	0	0	0	0
7	96	0	0	0	0	0
8	97	0	0	0	0	0
9	98	0	0	0	0	0
0	99	0	0	0	0	0
1	100	0	0	0	0	0

Table 14b:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY FROM	AIRWAY TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
3	2	17687	64.3	0.0	0.0	724
3	2	25989	67.3	0.0	0.0	806
3	2	37719	65.2	0.0	0.0	688
3	2	49859	65.2	0.0	0.0	686
3	2	5978	65.2	0.0	0.0	678
3	2	34859	65.2	0.0	0.0	201
3	2	44859	65.2	0.0	0.0	135
3	2	54859	65.2	0.0	0.0	75
3	2	14859	65.2	0.0	0.0	075
3	2	24859	65.2	0.0	0.0	075
3	2	34859	65.2	0.0	0.0	075
3	2	44859	65.2	0.0	0.0	075
3	2	54859	65.2	0.0	0.0	075
3	2	64859	65.2	0.0	0.0	075
3	2	74859	65.2	0.0	0.0	075
3	2	84859	65.2	0.0	0.0	075
3	2	94859	65.2	0.0	0.0	075
3	2	104859	65.2	0.0	0.0	075
3	2	114859	65.2	0.0	0.0	075
3	2	124859	65.2	0.0	0.0	075
3	2	134859	65.2	0.0	0.0	075
3	2	144859	65.2	0.0	0.0	075
3	2	154859	65.2	0.0	0.0	075
3	2	164859	65.2	0.0	0.0	075
3	2	174859	65.2	0.0	0.0	075
3	2	184859	65.2	0.0	0.0	075
3	2	194859	65.2	0.0	0.0	075
3	2	204859	65.2	0.0	0.0	075
3	2	214859	65.2	0.0	0.0	075
3	2	224859	65.2	0.0	0.0	075
3	2	234859	65.2	0.0	0.0	075
3	2	244859	65.2	0.0	0.0	075
3	2	254859	65.2	0.0	0.0	075
3	2	264859	65.2	0.0	0.0	075
3	2	274859	65.2	0.0	0.0	075
3	2	284859	65.2	0.0	0.0	075
3	2	294859	65.2	0.0	0.0	075
3	2	304859	65.2	0.0	0.0	075
3	2	314859	65.2	0.0	0.0	075
3	2	324859	65.2	0.0	0.0	075
3	2	334859	65.2	0.0	0.0	075
3	2	344859	65.2	0.0	0.0	075
3	2	354859	65.2	0.0	0.0	075
3	2	364859	65.2	0.0	0.0	075
3	2	374859	65.2	0.0	0.0	075
3	2	384859	65.2	0.0	0.0	075
3	2	394859	65.2	0.0	0.0	075
3	2	404859	65.2	0.0	0.0	075
3	2	414859	65.2	0.0	0.0	075
3	2	424859	65.2	0.0	0.0	075
3	2	434859	65.2	0.0	0.0	075
3	2	444859	65.2	0.0	0.0	075
3	2	454859	65.2	0.0	0.0	075
3	2	464859	65.2	0.0	0.0	075
3	2	474859	65.2	0.0	0.0	075
3	2	484859	65.2	0.0	0.0	075
3	2	494859	65.2	0.0	0.0	075
3	2	504859	65.2	0.0	0.0	075
3	2	514859	65.2	0.0	0.0	075
3	2	524859	65.2	0.0	0.0	075
3	2	534859	65.2	0.0	0.0	075
3	2	544859	65.2	0.0	0.0	075
3	2	554859	65.2	0.0	0.0	075
3	2	564859	65.2	0.0	0.0	075
3	2	574859	65.2	0.0	0.0	075
3	2	584859	65.2	0.0	0.0	075
3	2	594859	65.2	0.0	0.0	075
3	2	604859	65.2	0.0	0.0	075
3	2	614859	65.2	0.0	0.0	075
3	2	624859	65.2	0.0	0.0	075
3	2	634859	65.2	0.0	0.0	075
3	2	644859	65.2	0.0	0.0	075
3	2	654859	65.2	0.0	0.0	075
3	2	664859	65.2	0.0	0.0	075
3	2	674859	65.2	0.0	0.0	075
3	2	684859	65.2	0.0	0.0	075
3	2	694859	65.2	0.0	0.0	075
3	2	704859	65.2	0.0	0.0	075
3	2	714859	65.2	0.0	0.0	075
3	2	724859	65.2	0.0	0.0	075
3	2	734859	65.2	0.0	0.0	075
3	2	744859	65.2	0.0	0.0	075
3	2	754859	65.2	0.0	0.0	075
3	2	764859	65.2	0.0	0.0	075
3	2	774859	65.2	0.0	0.0	075
3	2	784859	65.2	0.0	0.0	075
3	2	794859	65.2	0.0	0.0	075
3	2	804859	65.2	0.0	0.0	075
3	2	814859	65.2	0.0	0.0	075
3	2	824859	65.2	0.0	0.0	075
3	2	834859	65.2	0.0	0.0	075
3	2	844859	65.2	0.0	0.0	075
3	2	854859	65.2	0.0	0.0	075
3	2	864859	65.2	0.0	0.0	075
3	2	874859	65.2	0.0	0.0	075
3	2	884859	65.2	0.0	0.0	075
3	2	894859	65.2	0.0	0.0	075
3	2	904859	65.2	0.0	0.0	075
3	2	914859	65.2	0.0	0.0	075
3	2	924859	65.2	0.0	0.0	075
3	2	934859	65.2	0.0	0.0	075
3	2	944859	65.2	0.0	0.0	075
3	2	954859	65.2	0.0	0.0	075
3	2	964859	65.2	0.0	0.0	075
3	2	974859	65.2	0.0	0.0	075
3	2	984859	65.2	0.0	0.0	075
3	2	994859	65.2	0.0	0.0	075
3	2	1004859	65.2	0.0	0.0	075

Table 14c:

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SHOKE	METHANE	PRESSURE
1	1	2	26	64	0	0	785
3	3	3	49	67	0	0	710
4	1	3	13	63	5	0	020
5	1	4	01	65	0	0	090
6	1	4	13	64	0	0	090
7	1	5	13	65	0	0	070
8	1	6	48	68	0	0	055
9	1	7	32	70	0	0	027
0	1	8	44	73	6	0	077
1	1	9	45	75	0	0	089
2	1	10	63	77	0	0	110
3	1	11	32	77	0	0	130
4	1	12	37	78	0	0	130
5	1	13	43	80	0	0	105
6	1	14	43	82	0	0	150
7	1	15	32	82	0	0	150
8	1	16	43	83	0	0	168
9	1	17	43	83	0	0	180
0	1	18	48	84	0	0	180
1	1	19	37	84	0	0	169
2	1	20	50	85	0	0	140
3	1	21	29	85	0	0	130
4	1	22	46	87	0	0	105
5	1	23	47	87	0	0	150
6	1	24	47	87	0	0	180
7	1	25	47	87	0	0	180
8	1	26	47	88	0	0	169
9	1	27	47	88	0	0	140
0	1	28	47	88	0	0	120
1	1	29	47	89	0	0	107
2	1	30	47	89	0	0	158
3	1	31	47	89	0	0	187
4	1	32	47	90	0	0	167
5	1	33	47	90	0	0	158
6	1	34	47	91	0	0	187
7	1	35	47	91	0	0	102
8	1	36	47	91	0	0	02
9	1	37	47	91	0	0	02
0	1	38	47	91	0	0	02
1	1	39	47	91	0	0	02
2	1	40	47	91	0	0	02
3	1	41	47	91	0	0	02
4	1	42	47	91	0	0	02
5	1	43	47	91	0	0	02
6	1	44	47	91	0	0	02
7	1	45	47	91	0	0	02
8	1	46	47	91	0	0	02
9	1	47	47	91	0	0	02
0	1	48	47	91	0	0	02
1	1	49	47	91	0	0	02
2	1	50	47	91	0	0	02
3	1	51	47	91	0	0	02
4	1	52	47	91	0	0	02
5	1	53	47	91	0	0	02
6	1	54	47	91	0	0	02
7	1	55	47	91	0	0	02
8	1	56	47	91	0	0	02
9	1	57	47	91	0	0	02
0	1	58	47	91	0	0	02
1	1	59	47	91	0	0	02
2	1	60	47	91	0	0	02
3	1	61	47	91	0	0	02
4	1	62	47	91	0	0	02
5	1	63	47	91	0	0	02
6	1	64	47	91	0	0	02
7	1	65	47	91	0	0	02
8	1	66	47	91	0	0	02
9	1	67	47	91	0	0	02
0	1	68	47	91	0	0	02
1	1	69	47	91	0	0	02
2	1	70	47	91	0	0	02
3	1	71	47	91	0	0	02
4	1	72	47	91	0	0	02
5	1	73	47	91	0	0	02
6	1	74	47	91	0	0	02
7	1	75	47	91	0	0	02
8	1	76	47	91	0	0	02
9	1	77	47	91	0	0	02
0	1	78	47	91	0	0	02
1	1	79	47	91	0	0	02
2	1	80	47	91	0	0	02
3	1	81	47	91	0	0	02
4	1	82	47	91	0	0	02
5	1	83	47	91	0	0	02
6	1	84	47	91	0	0	02
7	1	85	47	91	0	0	02
8	1	86	47	91	0	0	02
9	1	87	47	91	0	0	02
0	1	88	47	91	0	0	02
1	1	89	47	91	0	0	02
2	1	90	47	91	0	0	02
3	1	91	47	91	0	0	02
4	1	92	47	91	0	0	02
5	1	93	47	91	0	0	02
6	1	94	47	91	0	0	02
7	1	95	47	91	0	0	02
8	1	96	47	91	0	0	02
9	1	97	47	91	0	0	02
0	1	98	47	91	0	0	02
1	1	99	47	91	0	0	02
2	1	100	47	91	0	0	02

Table 15b:

AIRWAY		FANS		AIRFLOW		FAN PRESSURE	
FROM	TO	FROM	TO	FROM	TO	FROM	TO
6	5	5	1	58174	4.51	4.51	
51	32	32	1	314043	11.73	11.73	
THESE CHARACTERISTICS WERE STORED FOR FANS 6 51							
20000	3:29	25000	4:30	30000	4:40	40000	4:78
70000	4:29	85000	3:96	100000	3:70	150000	3:00
80000	12:25	100000	14:00	150000	14:30	200000	14:05
400000	10:25	500000	8:85	600000	7:80	700000	6:90
THE STATED NUMBER OF AIRWAYS WAS 53 THE STATED NUMBER OF JUNCTIONS WAS 34							
TIME AFTER BEGINNING OF EVENT .50 HOURS							
A TEMPERATURE OF 50.0 WAS ASSIGNED TO JUNCTION NO 1							
THE FOLLOWING CONTAMINATION WAS ASSUMED							
AIRWAY 3	FLOWRATE	CONCENTRATION	HEAT	OXYGEN CONCENTRATION	SMOKE	PRODUCTION PER %	OXYGEN HEAT
	3.0	.00	.00	BEHIND FIRE	.00	HEAT	.00
				16.00			

Table 15c:

AIRWAY	FROM	TO	ELEVATION DIFF.	ROCK	TEMP.	METHANE PROD.	CONDUCTIVITY	DIFFUSIVITY
1	1	1	0	8	25.4	0	0	1000
2	2	2	0	8	25.4	0	0	1000
3	3	3	0	8	25.4	0	0	1000
4	4	4	0	8	25.4	0	0	1000
5	5	5	0	8	25.4	0	0	1000
6	6	6	0	8	25.4	0	0	1000
7	7	7	0	8	25.4	0	0	1000
8	8	8	0	8	25.4	0	0	1000
9	9	9	0	8	25.4	0	0	1000
10	10	10	0	8	25.4	0	0	1000
11	11	11	0	8	25.4	0	0	1000
12	12	12	0	8	25.4	0	0	1000
13	13	13	0	8	25.4	0	0	1000
14	14	14	0	8	25.4	0	0	1000
15	15	15	0	8	25.4	0	0	1000
16	16	16	0	8	25.4	0	0	1000
17	17	17	0	8	25.4	0	0	1000
18	18	18	0	8	25.4	0	0	1000
19	19	19	0	8	25.4	0	0	1000
20	20	20	0	8	25.4	0	0	1000
21	21	21	0	8	25.4	0	0	1000
22	22	22	0	8	25.4	0	0	1000
23	23	23	0	8	25.4	0	0	1000
24	24	24	0	8	25.4	0	0	1000
25	25	25	0	8	25.4	0	0	1000
26	26	26	0	8	25.4	0	0	1000
27	27	27	0	8	25.4	0	0	1000
28	28	28	0	8	25.4	0	0	1000
29	29	29	0	8	25.4	0	0	1000
30	30	30	0	8	25.4	0	0	1000
31	31	31	0	8	25.4	0	0	1000
32	32	32	0	8	25.4	0	0	1000
33	33	33	0	8	25.4	0	0	1000
34	34	34	0	8	25.4	0	0	1000
35	35	35	0	8	25.4	0	0	1000
36	36	36	0	8	25.4	0	0	1000
37	37	37	0	8	25.4	0	0	1000
38	38	38	0	8	25.4	0	0	1000
39	39	39	0	8	25.4	0	0	1000
40	40	40	0	8	25.4	0	0	1000
41	41	41	0	8	25.4	0	0	1000
42	42	42	0	8	25.4	0	0	1000
43	43	43	0	8	25.4	0	0	1000
44	44	44	0	8	25.4	0	0	1000
45	45	45	0	8	25.4	0	0	1000
46	46	46	0	8	25.4	0	0	1000
47	47	47	0	8	25.4	0	0	1000
48	48	48	0	8	25.4	0	0	1000
49	49	49	0	8	25.4	0	0	1000
50	50	50	0	8	25.4	0	0	1000
51	51	51	0	8	25.4	0	0	1000
52	52	52	0	8	25.4	0	0	1000
53	53	53	0	8	25.4	0	0	1000
54	54	54	0	8	25.4	0	0	1000
55	55	55	0	8	25.4	0	0	1000
56	56	56	0	8	25.4	0	0	1000
57	57	57	0	8	25.4	0	0	1000
58	58	58	0	8	25.4	0	0	1000
59	59	59	0	8	25.4	0	0	1000
60	60	60	0	8	25.4	0	0	1000
61	61	61	0	8	25.4	0	0	1000
62	62	62	0	8	25.4	0	0	1000
63	63	63	0	8	25.4	0	0	1000
64	64	64	0	8	25.4	0	0	1000
65	65	65	0	8	25.4	0	0	1000
66	66	66	0	8	25.4	0	0	1000
67	67	67	0	8	25.4	0	0	1000
68	68	68	0	8	25.4	0	0	1000
69	69	69	0	8	25.4	0	0	1000
70	70	70	0	8	25.4	0	0	1000
71	71	71	0	8	25.4	0	0	1000
72	72	72	0	8	25.4	0	0	1000
73	73	73	0	8	25.4	0	0	1000
74	74	74	0	8	25.4	0	0	1000
75	75	75	0	8	25.4	0	0	1000
76	76	76	0	8	25.4	0	0	1000
77	77	77	0	8	25.4	0	0	1000
78	78	78	0	8	25.4	0	0	1000
79	79	79	0	8	25.4	0	0	1000
80	80	80	0	8	25.4	0	0	1000
81	81	81	0	8	25.4	0	0	1000
82	82	82	0	8	25.4	0	0	1000
83	83	83	0	8	25.4	0	0	1000
84	84	84	0	8	25.4	0	0	1000
85	85	85	0	8	25.4	0	0	1000
86	86	86	0	8	25.4	0	0	1000
87	87	87	0	8	25.4	0	0	1000
88	88	88	0	8	25.4	0	0	1000
89	89	89	0	8	25.4	0	0	1000
90	90	90	0	8	25.4	0	0	1000
91	91	91	0	8	25.4	0	0	1000
92	92	92	0	8	25.4	0	0	1000
93	93	93	0	8	25.4	0	0	1000
94	94	94	0	8	25.4	0	0	1000
95	95	95	0	8	25.4	0	0	1000
96	96	96	0	8	25.4	0	0	1000
97	97	97	0	8	25.4	0	0	1000
98	98	98	0	8	25.4	0	0	1000
99	99	99	0	8	25.4	0	0	1000
100	100	100	0	8	25.4	0	0	1000

Table 15f:

AIRWAY	FROM	TO	IN THE FOLLOWING AIRWAYS EXIST CRITICAL CONDITIONS (THE STATED NUMBERS REFER TO AIRWAY ENDS)	TEMPERATURE HIGHER THAN 95.0 DEGREES	LOW VENTILATION PRESSURE LOWER THAN .010 INCHES WG
37	34	33	0	**9.5	32.8
6	5	4	0	0	54.7
6	7	5	0	0	44.4
6	7	5	0	0	75.3
6	7	5	0	0	87.3
6	7	5	0	0	10.7
6	7	5	0	0	10.6
6	7	5	0	0	24.6
6	7	5	0	0	43.0
6	7	5	0	0	00.0
6	7	5	0	0	00.3
6	7	5	0	0	13.8
6	7	5	0	0	08.8
6	7	5	0	0	11.8

JUNCTION	METHANE CONCENTRATION HIGHER THAN 1.0 PERCENT	SMOKE CONCENTRATION HIGHER THAN .050 PERCENT	CRITICAL CONDITIONS	TEMPERATURE MORE THAN 95.0 DEGREES
1	1	0	206	10.1
2	1	0	77	79.7
3	1	0	76	80.0
4	1	0	77	86.0
5	1	0	77	70.4
6	1	0	77	68.2
7	1	0	77	72.8
8	1	0	77	72.8
9	1	0	77	72.8
10	1	0	77	72.8
11	1	0	77	72.8
12	1	0	77	72.8
13	1	0	77	72.8
14	1	0	77	72.8
15	1	0	77	72.8
16	1	0	77	72.8
17	1	0	77	72.8
18	1	0	77	72.8
19	1	0	77	72.8
20	1	0	77	72.8
21	1	0	77	72.8
22	1	0	77	72.8
23	1	0	77	72.8
24	1	0	77	72.8
25	1	0	77	72.8
26	1	0	77	72.8
27	1	0	77	72.8
28	1	0	77	72.8
29	1	0	77	72.8
30	1	0	77	72.8
31	1	0	77	72.8
32	1	0	77	72.8
33	1	0	77	72.8
34	1	0	77	72.8
35	1	0	77	72.8
36	1	0	77	72.8
37	1	0	77	72.8
38	1	0	77	72.8
39	1	0	77	72.8
40	1	0	77	72.8
41	1	0	77	72.8
42	1	0	77	72.8
43	1	0	77	72.8
44	1	0	77	72.8
45	1	0	77	72.8
46	1	0	77	72.8
47	1	0	77	72.8
48	1	0	77	72.8
49	1	0	77	72.8
50	1	0	77	72.8
51	1	0	77	72.8
52	1	0	77	72.8
53	1	0	77	72.8
54	1	0	77	72.8
55	1	0	77	72.8
56	1	0	77	72.8
57	1	0	77	72.8
58	1	0	77	72.8
59	1	0	77	72.8
60	1	0	77	72.8
61	1	0	77	72.8
62	1	0	77	72.8
63	1	0	77	72.8
64	1	0	77	72.8
65	1	0	77	72.8
66	1	0	77	72.8
67	1	0	77	72.8
68	1	0	77	72.8
69	1	0	77	72.8
70	1	0	77	72.8
71	1	0	77	72.8
72	1	0	77	72.8
73	1	0	77	72.8
74	1	0	77	72.8
75	1	0	77	72.8
76	1	0	77	72.8
77	1	0	77	72.8
78	1	0	77	72.8
79	1	0	77	72.8
80	1	0	77	72.8
81	1	0	77	72.8
82	1	0	77	72.8
83	1	0	77	72.8
84	1	0	77	72.8
85	1	0	77	72.8
86	1	0	77	72.8
87	1	0	77	72.8
88	1	0	77	72.8
89	1	0	77	72.8
90	1	0	77	72.8
91	1	0	77	72.8
92	1	0	77	72.8
93	1	0	77	72.8
94	1	0	77	72.8
95	1	0	77	72.8
96	1	0	77	72.8
97	1	0	77	72.8
98	1	0	77	72.8
99	1	0	77	72.8
100	1	0	77	72.8

REVERSAL OF AIRFLOW HAS OCCURRED IN THE FOLLOWING PLACES

AIRWAY	FROM	TO	TEMPERATURE HIGHER THAN 95.0 DEGREES
3	34	33	10.1
6	35	4	79.7
8	7	5	80.0
9	7	5	86.0
10	7	5	70.4
13	14	6	68.2
15	14	6	72.8
16	14	6	72.8
19	14	6	72.8
24	14	6	72.8
33	14	6	72.8

Table 16a:

THE FOLLOWING CONTAMINATION WAS ASSUMED

AIRWAY	FLOWRATE	CONCENTRATION	HEAT	OXYGEN CONCENTRATION	PRODUCTION PER % OXYGEN
1	100.00	100.00	.00	BEHIND FIRE	HEAT
					.00

Table 16b:

JUNCTION	TEMPERATURE	TEMPERATURE	SMOKE	METHANE	JUNCTION	TEMPERATURE	SMOKE	METHANE
1	50.0	65.07	.000	.000	2	64.3	.000	.000
2	74.5	69.2	.000	.000	4	77.5	.000	.000
3	75.7	77.8	.000	.000	6	81.2	.000	.000
4	76.0	78.1	.000	.000	8	81.5	.000	.000
5	76.0	78.1	.000	.000	10	81.5	.000	.000
6	76.0	78.1	.000	.000	12	81.5	.000	.000
7	76.0	78.1	.000	.000	14	81.5	.000	.000
8	76.0	78.1	.000	.000	16	81.5	.000	.000
9	76.0	78.1	.000	.000	18	81.5	.000	.000
10	76.0	78.1	.000	.000	20	81.5	.000	.000
11	76.0	78.1	.000	.000	22	81.5	.000	.000
12	76.0	78.1	.000	.000	24	81.5	.000	.000
13	76.0	78.1	.000	.000	26	81.5	.000	.000
14	76.0	78.1	.000	.000	28	81.5	.000	.000
15	76.0	78.1	.000	.000	30	81.5	.000	.000
16	76.0	78.1	.000	.000	32	81.5	.000	.000
17	76.0	78.1	.000	.000	34	81.5	.000	.000
18	76.0	78.1	.000	.000	36	81.5	.000	.000
19	76.0	78.1	.000	.000	38	81.5	.000	.000
20	76.0	78.1	.000	.000	40	81.5	.000	.000
21	76.0	78.1	.000	.000	42	81.5	.000	.000
22	76.0	78.1	.000	.000	44	81.5	.000	.000
23	76.0	78.1	.000	.000	46	81.5	.000	.000
24	76.0	78.1	.000	.000	48	81.5	.000	.000
25	76.0	78.1	.000	.000	50	81.5	.000	.000
26	76.0	78.1	.000	.000	52	81.5	.000	.000
27	76.0	78.1	.000	.000	54	81.5	.000	.000
28	76.0	78.1	.000	.000	56	81.5	.000	.000
29	76.0	78.1	.000	.000	58	81.5	.000	.000
30	76.0	78.1	.000	.000	60	81.5	.000	.000
31	76.0	78.1	.000	.000	62	81.5	.000	.000
32	76.0	78.1	.000	.000	64	81.5	.000	.000
33	76.0	78.1	.000	.000	66	81.5	.000	.000
34	76.0	78.1	.000	.000	68	81.5	.000	.000
35	76.0	78.1	.000	.000	70	81.5	.000	.000
36	76.0	78.1	.000	.000	72	81.5	.000	.000
37	76.0	78.1	.000	.000	74	81.5	.000	.000
38	76.0	78.1	.000	.000	76	81.5	.000	.000
39	76.0	78.1	.000	.000	78	81.5	.000	.000
40	76.0	78.1	.000	.000	80	81.5	.000	.000
41	76.0	78.1	.000	.000	82	81.5	.000	.000
42	76.0	78.1	.000	.000	84	81.5	.000	.000
43	76.0	78.1	.000	.000	86	81.5	.000	.000
44	76.0	78.1	.000	.000	88	81.5	.000	.000
45	76.0	78.1	.000	.000	90	81.5	.000	.000
46	76.0	78.1	.000	.000	92	81.5	.000	.000
47	76.0	78.1	.000	.000	94	81.5	.000	.000
48	76.0	78.1	.000	.000	96	81.5	.000	.000
49	76.0	78.1	.000	.000	98	81.5	.000	.000
50	76.0	78.1	.000	.000	100	81.5	.000	.000

NUMBER OF ITERATIONS 1

Table 16b:

TEMPERATURES AND CONCENTRATIONS AT AIRWAY ENDS, PRESSURES IN AIRWAYS

AIRWAY	FROM	TO	AIRFLOW	TEMPERATURE	SMOKE	METHANE	PRESSURE
1	2	3	149032	65.07	.0000	.00	540
1	2	3	1	64.5	0.0000	0.00	505
1	2	3	2	64.5	0.0000	0.00	505
1	2	3	3	64.5	0.0000	0.00	505
1	2	3	4	64.5	0.0000	0.00	505
1	2	3	5	64.5	0.0000	0.00	505
1	2	3	6	64.5	0.0000	0.00	505
1	2	3	7	64.5	0.0000	0.00	505
1	2	3	8	64.5	0.0000	0.00	505
1	2	3	9	64.5	0.0000	0.00	505
1	2	3	10	64.5	0.0000	0.00	505
1	2	3	11	64.5	0.0000	0.00	505
1	2	3	12	64.5	0.0000	0.00	505
1	2	3	13	64.5	0.0000	0.00	505
1	2	3	14	64.5	0.0000	0.00	505
1	2	3	15	64.5	0.0000	0.00	505
1	2	3	16	64.5	0.0000	0.00	505
1	2	3	17	64.5	0.0000	0.00	505
1	2	3	18	64.5	0.0000	0.00	505
1	2	3	19	64.5	0.0000	0.00	505
1	2	3	20	64.5	0.0000	0.00	505
1	2	3	21	64.5	0.0000	0.00	505
1	2	3	22	64.5	0.0000	0.00	505
1	2	3	23	64.5	0.0000	0.00	505
1	2	3	24	64.5	0.0000	0.00	505
1	2	3	25	64.5	0.0000	0.00	505
1	2	3	26	64.5	0.0000	0.00	505
1	2	3	27	64.5	0.0000	0.00	505
1	2	3	28	64.5	0.0000	0.00	505
1	2	3	29	64.5	0.0000	0.00	505
1	2	3	30	64.5	0.0000	0.00	505
1	2	3	31	64.5	0.0000	0.00	505
1	2	3	32	64.5	0.0000	0.00	505
1	2	3	33	64.5	0.0000	0.00	505
1	2	3	34	64.5	0.0000	0.00	505
1	2	3	35	64.5	0.0000	0.00	505
1	2	3	36	64.5	0.0000	0.00	505
1	2	3	37	64.5	0.0000	0.00	505
1	2	3	38	64.5	0.0000	0.00	505
1	2	3	39	64.5	0.0000	0.00	505
1	2	3	40	64.5	0.0000	0.00	505
1	2	3	41	64.5	0.0000	0.00	505
1	2	3	42	64.5	0.0000	0.00	505
1	2	3	43	64.5	0.0000	0.00	505
1	2	3	44	64.5	0.0000	0.00	505
1	2	3	45	64.5	0.0000	0.00	505
1	2	3	46	64.5	0.0000	0.00	505
1	2	3	47	64.5	0.0000	0.00	505
1	2	3	48	64.5	0.0000	0.00	505
1	2	3	49	64.5	0.0000	0.00	505
1	2	3	50	64.5	0.0000	0.00	505
1	2	3	51	64.5	0.0000	0.00	505
1	2	3	52	64.5	0.0000	0.00	505
1	2	3	53	64.5	0.0000	0.00	505
1	2	3	54	64.5	0.0000	0.00	505
1	2	3	55	64.5	0.0000	0.00	505
1	2	3	56	64.5	0.0000	0.00	505
1	2	3	57	64.5	0.0000	0.00	505
1	2	3	58	64.5	0.0000	0.00	505
1	2	3	59	64.5	0.0000	0.00	505
1	2	3	60	64.5	0.0000	0.00	505
1	2	3	61	64.5	0.0000	0.00	505
1	2	3	62	64.5	0.0000	0.00	505
1	2	3	63	64.5	0.0000	0.00	505
1	2	3	64	64.5	0.0000	0.00	505
1	2	3	65	64.5	0.0000	0.00	505
1	2	3	66	64.5	0.0000	0.00	505
1	2	3	67	64.5	0.0000	0.00	505
1	2	3	68	64.5	0.0000	0.00	505
1	2	3	69	64.5	0.0000	0.00	505
1	2	3	70	64.5	0.0000	0.00	505
1	2	3	71	64.5	0.0000	0.00	505
1	2	3	72	64.5	0.0000	0.00	505
1	2	3	73	64.5	0.0000	0.00	505
1	2	3	74	64.5	0.0000	0.00	505
1	2	3	75	64.5	0.0000	0.00	505
1	2	3	76	64.5	0.0000	0.00	505
1	2	3	77	64.5	0.0000	0.00	505
1	2	3	78	64.5	0.0000	0.00	505
1	2	3	79	64.5	0.0000	0.00	505
1	2	3	80	64.5	0.0000	0.00	505
1	2	3	81	64.5	0.0000	0.00	505
1	2	3	82	64.5	0.0000	0.00	505
1	2	3	83	64.5	0.0000	0.00	505
1	2	3	84	64.5	0.0000	0.00	505
1	2	3	85	64.5	0.0000	0.00	505
1	2	3	86	64.5	0.0000	0.00	505
1	2	3	87	64.5	0.0000	0.00	505
1	2	3	88	64.5	0.0000	0.00	505
1	2	3	89	64.5	0.0000	0.00	505
1	2	3	90	64.5	0.0000	0.00	505
1	2	3	91	64.5	0.0000	0.00	505
1	2	3	92	64.5	0.0000	0.00	505
1	2	3	93	64.5	0.0000	0.00	505
1	2	3	94	64.5	0.0000	0.00	505
1	2	3	95	64.5	0.0000	0.00	505
1	2	3	96	64.5	0.0000	0.00	505
1	2	3	97	64.5	0.0000	0.00	505
1	2	3	98	64.5	0.0000	0.00	505
1	2	3	99	64.5	0.0000	0.00	505
1	2	3	100	64.5	0.0000	0.00	505

4.4.2.7 Example 7: Oxygen Rich Fire in an Intake Shaft

It shall be investigated if a fire in the timbered shaft airway 3 is capable of reversing the air flow in this shaft. For this purpose the shaft simulation is divided into three parts: an upper section airway 53; a lower section airway 52; and the fire zone airway 3. A length of 27 ft is assumed for the fire zone, the remaining shaft length is 2550 ft (Fig. 7). Tentatively different locations are selected for the fire zone until an air flow reversal occurs. With the section below the fire zone being 50, 75, or 100 ft long, not sufficient natural ventilation pressure is developed for a reversal, although the air flow rate through the shaft drops from approximately 103,000 cfm normal to 40,000, 27,000, and 17,000 cfm (Table 14 a - c). With the section below the fire zone being 125 ft long, the reversal in the shaft has taken place (Tables 15 a - f) and a large air flow rate of 207,000 cfm is exhausting. This in turn causes reversals and high methane concentrations in a number of other airways. Fig. 7 shows a plot of original air flow rates (Table 15a) and final air flow rates (Table 15d) with the lower placed figures indicating the latter state.

Should the fire start at the top of the shaft, one will have a somehow different phenomenon. Air flow reversal will occur fast but will be maintained only when the fire zone is more than 100 ft below the surface. Otherwise the natural ventilation pressure will, after the reversal, be too weak to maintain this flow direction and a very unstable state with fluctuations of the air flow will develop.

4.4.2.8 Example 8: Layout of Fire Warning System

It shall be investigated if a fire warning system installed at the upcast shaft airway 49 can detect spontaneous combustion in the gob area of longwall face airway 17. For this purpose one releases 100 cfm of contaminant (CONT) with a concentration (CONC) of 100.00% into airway 17. Table 16 shows that this results in a concentration of 0.0347% in upcast shaft 49 and of 0.1218% in return airway 48. If a detection of 5 ppm CO can be accomplished, the spontaneous combustion source must release at least $100 \times 5 / 347 = 1.44$ cfm of CO for an instrument installation at the surface and $100 \times 5 / 1218 = 0.41$ cfm for an installation in airway 48.

4.5 ORGANIZATION OF INPUT

4.5.1 Common Input Cards

The sequence of input data is: 1 network control card; NB airway cards; NJ junction cards (optional); NFNUM sets of fan characteristic cards (optional), each set comprising 1 fan identity card, 1 or more curve point cards; NADBC additional network airway cards (optional).

If a concentration or temperature calculation is desired, these cards are followed by: 1 concentration control card; 1 average value card (optional); NDIM additional concentration airway cards; NCH4C additional concentration junction cards (optional); INFLOW contamination cards (optional).

The term "optional" does not mean that all of the optional cards can be omitted. There must be sufficient input information for the given assignment. Otherwise a message will state what is lacking and the calculation will be terminated.

The network control card contains:

```
NB NJ NFNUM NADBC NVPN NETW NCONC NTEMP MADJ ITN DR TR
FORMAT (10I5,2F10.5)
```

These symbols have been explained in the program description. In example 1 this control card reads:

```
51 32 2 3 1 1 1 1 10 30 .075 70.0
```

The NB airway cards contain:

```
NO JS JF NWTYP R Q KF LA A O
FORMAT (4I5,F10.3,F10.0,2I10,2F10.1)
```

For instance, airway card 1, which remained unchanged in all examples, reads:

```
1 1 2 0 0.156 200000 250 2597 200.0 50.0
```

The NJ junction cards contain:

```
JNO T Z CH4C (optional)
FORMAT (I5,T11,F5.1,T20,F6.0,F5.2)
```

For instance, junction card 1 read in all described examples:

```
1 50.0 114
```

The NFNUM sets of fan characteristic cards contain the fan identity card with:

```
NOF MPTS
```

FORMAT (2I5)

and the curve point cards with:

QF PF QF PF QF PF QF PF QF PF

FORMAT (5(F8.0,F6.2))

For instance, the set for fan No. 6, which was used throughout all examples, reads:

```
6 10
20000 3.60 25000 4.30 30000 4.60 40000 4.78 55000 4.58
70000 4.19 85000 3.96 100000 3.70 150000 3.00 200000 2.52
```

The NADBC additional airway cards contain:

NOX KX LX AX OX

FORMAT (I5,T4I,2I10,2F10.1)

For instance, card 45 reads in all described examples:

```
45 100 300 80.0 35.0
```

The concentration control card contains:

NDIM NCH4C NAV MAXJ INFLOW JSTART TSTART TIME CRITSM CRITGS
CITHT WRNPR WRNSM WRNGS WRNHT

FORMAT (6I5,F5.1,F8.2,F7.5,F5.3,F6.3,F4.2,F6.4,F4.1,F5.0)

In example 1 this control card reads:

```
5 2 1 32 0 1 50.0 2.0 0.005 0.10 0.20 0.01 0.05
1.0 95.0
```

The magnitude of the iteration thresholds CRITSM, CRITGS, CRITHT is a matter of personal preference. Low values will require more iterations but give more accurate results and vice versa. The selection of the warning thresholds depends on what one considers to be a state requiring special attention.

The average value card contains:

TAVR HAAVR HKAVER KFAVR LAAVR AAVR OAVR

FORMAT (3F10.5,2I10,2F10.2)

It reads in the calculations of this report:

```
70.0 0.10 3.0 100 1000 100.0 100.0
```

Only HAAVR and HKAVER were used in the calculations.

The NDIM additional concentration cards contain:

NOX CH4VX CH4PAX TROCKX HAX HKX DZRDX

FORMAT (I5,F10.2,4F10.5,F10.1)

In the described examples, 5 such cards were used stating the methane production CH4VX of the longwall faces only. Card 1 reads, for instance:

```
9  320.0
```

The NCH4C additional concentration junction cards contain:

```
JNOX  CH4CX
```

```
FORMAT (I5,T26,F5.2)
```

These calculations used two such cards for the input of two additional junction concentrations. The first of the cards reads, for instance:

```
27  0.60
```

The INFLOW contamination cards contain:

```
NCENT  CONT  CONC  HEAT  O2MIN  SMPO2  HTP02
```

```
FORMAT (I5,F10.0,F10.5,F10.2,3F10.5)
```

Patterns for these cards will be given later.

In all of the described examples all input cards, except for the network and concentration control cards, and the contamination cards, did not change, since the network did not change either. Two new airway and two new junction cards were added, only in example 7.

4.5.2 Control and Contamination Cards

In example 1 a simulation of the normal ventilation system without any contamination was demanded. This requires a network, concentration, and temperature calculation. It was assumed that the surface temperature is 50.0°F. The time after the ventilation change (which in this case did not take place) was arbitrarily set to 2 hrs.

The network control card states in this case:

```
51  32  2  3  1  1  1  1  10  30  0.075  70.0
```

and the concentration control card states:

```
5  2  1  32  0  1  50.0  2.0  0.005  0.10  0.20  0.01  0.05
1.0  95
```

There are no contamination cards since INFLOW = 0.

In example 2 the normal ventilation system, without contamination but with a surface temperature of 90.0°F 6 hrs after the temperature change, was simulated. This requires a network, concentration, and temperature calculation.

The network control card remains the same as in example 1, the concentration control card changes to:

```
5  2  1  32  0  1  90.0  6.0  0.005  0.10  0.20  0.01  0.05
1.0  95
```

No contamination cards are needed.

In example 3 a failure of the surface fan 51 was assumed. The surface temperature is 50°F, the time after the fan failure 0.25 hrs. Only a network and concentration calculation, but no temperature calculation, was performed. To indicate the fan failure the network airway card 51 has to be changed from NWTYP = 1 to NWTYP = 0. Into the R column, which for the airway cards of NWTYP = 1 states the fan pressure, the flow resistance of the idling fan has to be inserted. The set of fan characteristic cards for fan 51 has to be removed.

The network control card reads consequently:

```
51  32  1  3  1  1  1  0  10  30  0.075  70.0
```

the concentration control card reads:

```
5  2  1  32  0  1  50.0  0.25  0.005  0.10  0.20  0.01  0.05
1.0  95
```

No contamination cards are needed.

In example 4 a fire was assumed at the beginning of airway 5, producing 30,000 cfm of contaminated air (CONT) with a smoke concentration of 1.0% (CONC) and $15 \cdot 10^4$ Btu/min heat production (HEAT). Of interest is a time period 1 hour after the event. The network control card remains the same as in examples 1 and 2, the concentration control card reads:

```
5  2  1  32  1  1  50.0  1.0  0.005  0.10  0.20  0.01  0.05
1.0  95
```

The contamination card reads:

```
5  30000.  1.0  150000.00  0.  0.  0.
```

In example 5 an oxygen rich timber fire was assumed at the bottom of raise 18 which reduces the oxygen concentration of the air traveling through the fire zone to 16.0% (O2MIN). Network and concentration control cards remain the same as in example 4, but the contamination card changes to:

```
18  0.  0.  0.  16.0  0.  0.
```

In example 6 a fuel rich fire in raise 20 is assumed which produces 1 cfm of smoke with 100% concentration and 300 Btu of heat per cfm of oxygen. The network and concentration control cards remain the same as in the previous example, the contamination card changes to:

20 0. 0. 0. 0. 1.00 300.00

In example 7, O₂-rich timber fires are assumed at different locations in shaft 3. Two new airways, 52, 53, and two new junctions, 33, 34, are introduced. Their network airway and junction cards have to be added. The number of airways NB, and the number of junctions NJ, and the highest junction number MAXJ, change. The network control card reads, therefore:

53 34 2 3 1 1 1 1 10 30 0.075 70.0

the concentration control card reads:

5 2 1 34 1 1 50.0 0.5 0.005 0.10 0.20 0.01 0.05
1.0 95

and the contamination card reads:

3 0. 0. 0. 16.0 0. 0.

In example 8 a contaminant volume of 100.00 cfm (CONT) with a concentration of 100.0% (CONC) is released into airway 17. No heat is added. The network control card reads:

51 32 2 3 1 1 1 1 10 30 0.075 70.0

the concentration control card reads:

5 2 1 32 1 1 50.0 0.1 0.005 0.10 0.20 0.01 0.05
1.0 95

and the contamination card reads:

17 100. 100.00 0. 0. 0. 0.

4.6 STORAGE REQUIREMENTS

The storage requirements for the execution of this program are not small, but not excessive either. NB (number of airways) places are needed for the arrays:

NO, JS, JF, Q, NGOUT, NGIN, RDPROP, TRD, LA, A, O, KF, CH4V, CH4PA, TROCK, HA, HK, DZRD, RDCH4, XNEW, R, RST, FRNVP, NWTYP, P, RQ, INU, KJS, KJF, KNO. These are 30 arrays which, with the EQUIVALENCE (P,RQ), (CH4PA,RDCH4), (NGOUT,INU), (NGIN,KJF), (MIN,KNO), can be reduced to 26.

NJ (number of junctions) places are needed for the arrays:

LOUT, MIN, JNOL, JNO, JLR, PROP, CH4C, T, Z, PRCH4

These are 10 arrays which with EQUIVALENCE (CH4C,PRCH4), (Z,PROP), (LOUT, KJS) can be reduced to 6.

NFNUM (number of fans) places are needed for the arrays:

NOF, MPTS, NFREG, NFCW, RGRA

MPTS (number of curve points) * NFNUM places are needed for the arrays:

QF, PF

NB - NJ + 1 places are needed for the arrays:

FNVP, MEND

How large the array MSL has to be is hard to predict, since the number of airways in meshes depends very much on the network configuration. A figure of 5 to 10 times the number of airways NB will usually be sufficient.

As many places as recirculation paths exist, are needed for the arrays:

MEMREC, NOREC, ESTPR, ESTCH4, ESTTR

A number of $1/5 \cdot NB$ should be sufficient even for bad cases.

As many places as airways with inflow of contaminants exist are needed for the arrays:

HEAT, NCENT, CONT, CONC, O2MIN, SMPO2, HTP02, TFSI

How many places the array NREV requires depends on the type of calculations. This array registers the airways with airflow reversal. In the worst case this can be all NB airways, but normally a smaller number of $1/3 \cdot NB$ should be sufficient.

With the assumption of $NJ = 2/3 \cdot NB$, $NFNUM = 1/30 \cdot NB$ and $MPTS = 10$ this adds up to approximately $40 \cdot NB$. Few network calculations use more than $NB = 200$ airway simulations.

4.7 EXECUTION TIME

This depends on the number of iterations, which have to be performed. In the described examples it never exceeded 10 seconds with a UNIVAC 1110. As a safeguard against excessive time consumptions, which can happen in unstable networks with oscillating air currents, the thresholds ITN and MADJ are stated in the network control card.

5. TABLE OF TEXT NOMENCLATURE

Text Symbol	Computer Symbol	Text Page	Dimension	Definition
A	A	12	ft ²	airway cross sectional area
α	HC	29	$\frac{\text{Btu}}{\text{ft}^2 \text{ hr } ^\circ\text{F}}$	convection coefficient
β		29		slope angle
BI	BI	39		Biot Number
COR	COR	40		correction of convection coefficient for rough walls
CP	CP	29	Btu/lb °F	specific heat of air
D _O		40	ft	hydraulic diameter of airway
d		12	lb/ft ³	actual average air density in airway
d _r	DR	12	lb/ft ³	reference air density
FO	FO	39		Fourier Number
f		40		friction coefficient for rough walls
f _O	FRO	40		friction coefficient for hydraulically smooth wall
G		29	lb/hr	weight flow rate of air
g _a		29	°F/ft	auto compression gradient
H _F		12	in. wg.	actual fan pressure
H _{Fr}	FANP	12	in. wg.	reference fan pressure
H _L		12	in. wg.	actual pressure loss
H _{Lr}	P	12	in. wg.	reference pressure loss
h _N		13	ft	natural ventilation head
H _N		14	in. wg.	natural ventilation pressure

Table of Text Nomenclature (continued)

Text Symbol	Computer Symbol	Text Page	Dimension	Definition
H_{Nr}	FNVP	13	in. wg.	reference natural ventilation pressure
K	KF	12	$10^{10} \frac{\text{lb} \cdot \text{min}^2}{\text{ft}^4}$	friction factor
$K(\alpha)$	COAGE	38		coefficient of age
L	LA	12	ft	airway length
n_b	NB	14		number of airways in network
n_j	NJ	14		number of junctions in network
n_m		14		number of meshes in network
O	O	12	ft	airway perimeter
P		13	lb/ft ²	static air pressure
Q		12	ft ³ /min	actual volume flow rate
Q_r	Q	12	ft ³ /min	reference volume flow rate
R	R	13	$10^{10} \frac{\text{in. wg.}}{(\text{ft}^3/\text{min})^2}$	resistance factor
R_r	RSTD	13		reference resistance factor
R_o		38	ft	hydraulic radius
T		15	°R	absolute air temperature
t	TRD	37	°F	temperature of air in airway
TM	TM	41	°F	estimated average air temperature in airway
T_m	TM	21	°R	average absolute air temperature in airway
t_m	TMRD	46	°F	mean air temperature in airway
T_m^2	TMSQR	45	(°R) ²	mean square absolute air temperature in airway
t_r	TROCK	38	°F	rock temperature

Table of Text Nomenclature (continued)

Text Symbol	Computer Symbol	Text Page	Dimension	Definition
TR	TR	40	°F	reference temperature
t_l	TJS	29	°F	air temperature at beginning of airway
t_{ro}	TRS	29	°F	rock temperature at beginning of airway
T_s, T_f	T0, T1	21	°R	absolute temperatures of starting and finishing junctions of airway
v		13	ft ³ /lb	specific volume of air
V		29	ft/sec	air velocity
VISC	VISC	40	ft ² /sec	kinematic viscosity of air
WT	WT	40	lb/ft ³	specific weight of air
X	X	29	ft ⁻¹	quantity $\alpha O / (G * CP)$
X	X	39		quantity $(0.375 + BI) \sqrt{FO}$
XNEW	XNEW	42		exponent in formula for air temperature in airways
Z	Z	21	ft	elevation
Z_s, Z_f	Z0, Z1	21	ft	elevations of starting and finishing junctions of airways

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10 MARKD='6,408)  
11 MARKD=0  
12 DO 16 NWTYP(I), 16,12,16  
13 IF (NR(I)) 13,13,16  
14 IF (NR(I)) 14,14,15  
15 IF (NR(I)) 14,409, NB(I)  
16 MARKD=16  
17 GR(I)=K*(I)*LA(I)*Q(I)/(5.2*A(I)**3)*DR/0.075  
18 RSTDC(I)=R(I)  
C 17 IF (MARKD) 18,18,17  
19 WRITE (MARKD) 6,410  
20 WRITE (K) 6,411 (NO(K), JS(K), JF(K), Q(K), NWTYP(K), LA(K), A(K), R(K), KF(  
1 K), TO, 153  
IF (CNEFW) 17,17,19  
21 IF SWD=0  
22 MADJ=0  
23 NNVP=0  
24 MARKN=0  
25 IRRANGE AIRWAYS TO SIZE AND MAGNITUDE R*Q  
26 NBL=1  
27 DO 28 NWTYP(K), 25,26,27  
28 IF (NWK) 21,21,22  
29 IF (NWK) 21,21,22  
30 IF (NWK) 21,21,22  
31 IF (NWK) 21,21,22  
32 IF (NWK) 21,21,22  
33 IF (NWK) 21,21,22  
34 IF (NWK) 21,21,22  
35 IF (NWK) 21,21,22  
36 IF (NWK) 21,21,22  
37 IF (NWK) 21,21,22  
38 IF (NWK) 21,21,22  
39 IF (NWK) 21,21,22  
40 IF (NWK) 21,21,22  
41 IF (NWK) 21,21,22  
42 IF (NWK) 21,21,22  
43 IF (NWK) 21,21,22  
44 IF (NWK) 21,21,22  
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46 IF (NWK) 21,21,22  
47 IF (NWK) 21,21,22  
48 IF (NWK) 21,21,22  
49 IF (NWK) 21,21,22  
50 IF (NWK) 21,21,22
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32 NRE TU=1
33 IF (RQ(MMIN)-RQ(K)) 34,34,33
34 MMINT INUE
INU(NBL)=MMIN
NBL=NBL+1
NWTYP(MMI-IN)=0
IF T UP BASE SYSTEM 35,35,29
C 35 INU=INU(1)
KJF(NJ)=JS(IND)
KJS(NJ-1)=JS(IND)
JJS(IND)=-JS(IND)
KJF(NJ-1)=JF(IND)
KNUM(NJ-1)=IND
KNUM=KNJ-1
DO 43 NUC=2, NB
36 IF INU(NUC)
IF (JS(IND)) 43,37,37
37 NO=0
NO=41 K=KNUM, NJ
38 IF (JS(IND)-KJF(K)) 39,38,39
39 IF (JF(IND)-KJF(K)) 41,40,41
40 INUE=1
41 NON(N1)=43,47,42
42 JJS(IND)=-JS(IND)
JF(IND)=-JF(IND)
43 CF INUE-1 44,52,44
44 IF (K=1) NB
45 IF (JS(K)) 46,46,45
46 WCON(6,412) NO(K)
CGO TO 52
47 IF (NWTYP(IND)) 48,49,49
48 IF (NWTYP(6,413) NO(IND))
49 WKNU(NUM-1)
50 IF (KNUM) 50,50,51
KJF(NJ)=JF(IND)
KJS(NJ)=JS(IND)
KNUM=KNUM-1
51 JS(IND)=JS(IND)
GO TO 36
KJS(NJ)=JS(IND)
KJF(NJ)=JF(IND)
KNUM=KNUM-1
JS(IND)=JS(IND)

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52 TO K=1,NB
53 JF=ABS(JS(K))
54 MNO=0
55 DEF(K)=JF(K),NB
56 MNO=2,K=1,NB
57 JF(K)=JF(K),54,62,62
58 MNO=MNO+1
59 JBM=JF(K)
60 JK=K
61 MESC=MESC+1
62 MESC(MNO)=MESC
63 MSL(MESC)=NK,NJ
64 DEF(K)=JF(K),56,62,62
65 JBM=JF(K)
66 JK=K
67 JBM=JF(K),56,62,62

52 TO K=1,NB
53 JF=ABS(JS(K))
54 MNO=0
55 DEF(K)=JF(K),NB
56 MNO=2,K=1,NB
57 JF(K)=JF(K),54,62,62
58 MNO=MNO+1
59 JBM=JF(K)
60 JK=K
61 MESC=MESC+1
62 MESC(MNO)=MESC
63 MSL(MESC)=NK,NJ
64 DEF(K)=JF(K),56,62,62
65 JBM=JF(K)
66 JK=K
67 JBM=JF(K),56,62,62

52 TO K=1,NB
53 JF=ABS(JS(K))
54 MNO=0
55 DEF(K)=JF(K),NB
56 MNO=2,K=1,NB
57 JF(K)=JF(K),54,62,62
58 MNO=MNO+1
59 JBM=JF(K)
60 JK=K
61 MESC=MESC+1
62 MESC(MNO)=MESC
63 MSL(MESC)=NK,NJ
64 DEF(K)=JF(K),56,62,62
65 JBM=JF(K)
66 JK=K
67 JBM=JF(K),56,62,62

52 TO K=1,NB
53 JF=ABS(JS(K))
54 MNO=0
55 DEF(K)=JF(K),NB
56 MNO=2,K=1,NB
57 JF(K)=JF(K),54,62,62
58 MNO=MNO+1
59 JBM=JF(K)
60 JK=K
61 MESC=MESC+1
62 MESC(MNO)=MESC
63 MSL(MESC)=NK,NJ
64 DEF(K)=JF(K),56,62,62
65 JBM=JF(K)
66 JK=K
67 JBM=JF(K),56,62,62

52 TO K=1,NB
53 JF=ABS(JS(K))
54 MNO=0
55 DEF(K)=JF(K),NB
56 MNO=2,K=1,NB
57 JF(K)=JF(K),54,62,62
58 MNO=MNO+1
59 JBM=JF(K)
60 JK=K
61 MESC=MESC+1
62 MESC(MNO)=MESC
63 MSL(MESC)=NK,NJ
64 DEF(K)=JF(K),56,62,62
65 JBM=JF(K)
66 JK=K
67 JBM=JF(K),56,62,62

52 TO K=1,NB
53 JF=ABS(JS(K))
54 MNO=0
55 DEF(K)=JF(K),NB
56 MNO=2,K=1,NB
57 JF(K)=JF(K),54,62,62
58 MNO=MNO+1
59 JBM=JF(K)
60 JK=K
61 MESC=MESC+1
62 MESC(MNO)=MESC
63 MSL(MESC)=NK,NJ
64 DEF(K)=JF(K),56,62,62
65 JBM=JF(K)
66 JK=K
67 JBM=JF(K),56,62,62

52 TO K=1,NB
53 JF=ABS(JS(K))
54 MNO=0
55 DEF(K)=JF(K),NB
56 MNO=2,K=1,NB
57 JF(K)=JF(K),54,62,62
58 MNO=MNO+1
59 JBM=JF(K)
60 JK=K
61 MESC=MESC+1
62 MESC(MNO)=MESC
63 MSL(MESC)=NK,NJ
64 DEF(K)=JF(K),56,62,62
65 JBM=JF(K)
66 JK=K
67 JBM=JF(K),56,62,62

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DO 69 J=M, MENDW  
N=MSL(J)  
IF (N) 68, 69, 69  
IN=NT  
FAC(Q(N))+Q1*FACT  
QBEGW=MENDW+1  
CALCULATE NATURAL VENTILATION PRESSURE  
IF (NSVP) 71, 71, 72  
IF (NSFLOW) 85, 85, 74  
INVP=1  
GO TO 337  
GBEGW=1  
DO 84 K=MNO  
MENDW=MEND(K)  
MNV(K)=0.  
NT=0  
SU=0.  
DO 85 J=MBEGW, MENDW  
NX=MSL(J)  
IX=(NX) 75, 76, 76  
DF=80  
IF (J) -JNO(L) 78, 77, 78  
IF (L) +460.  
Z0=Z(J)  
IF (J) -JNO(L) 80, 79, 80  
IF (L) +460.  
CONTINUE  
H=H-T1*Z0  
IF (N) 81, 82, 82  
FNVP(K)=FNVP(K)+H  
TSU=TSU+T1  
NT=NT+1  
FMVVP(K)=FNVP(K)*DR/(5.2*TM)  
MBERA=1  
IT=0  
DQSUM=0.  
DO 91 K=1, MNO  
MENDW=MEND(K)  
DPSUM=0.  
RQSUM=0.
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N=MSL(MBEGW)
IF (N) 87,88,88
N=-N(NW(TYP(N)+1) 89,99,89
DO 96 J=MBEGW,MENDW
N=MSL(J)
IF (N) 90,91,91
N=-N
FAC(T=1,TYP(N)) 96,92,93
IFQ2(N)*ABS(Q(N),I)*2
RQSUM=ERQSUM+RQ2
DP2SUM=DP2SUM+ABS(Q(N))
GPSUM=DP2SUM+FACT*DP
DO 94 I=1,NFNUM
IF (I) LEG(L)-N 94,95,94
CONTINUE
RQSUM-RGRAD(L)
CONTINUE
RQSUM-FNVP(K))/RQSUM
DO 98 J=MBEGW,MENDW
N=MSL(J)
IF (N) 97,98,98
N=-N
FAC(T=1,N)-(DQ*FACT)
Q(N)=QSUM+ABS(DQ)
MBEGW=MENDW+1
FANCHARACTERISTICS
DO 114 J=1,NFNUM
NECW(J)=0
DO 100 K=1,NB
IF (NOF(J)-NO(K)) 100,101,100
CONTINUE
CONTINUE
NPTS=MP(J)
FANREG(K)*100000.
NBL=DF(J,2)
QBR=DF(J,NBDR)
IF (FAN(Q,J,2)
R(K)=PF(J,1)
CONTINUE
IF (FAN(QBR) 105,105,104

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127 MENDW=MEND(K)
128 NX=MSL(MBEGW)
129 IF (NX) 127,128,128
130 IF (NW+YP(NX)) 129,137,137
131 M=MBEGW+1
132 DO 134 J=M, MENDW
133 F=MSL(J)
134 IF (N) 130,131,131
135 F=1-YP(N)
136 IF (NW+YP(N)) 133,133,132
137 DP=TO 134
138 DP=R(N)*Q(N)*ABS(Q(N))
139 DP=SUM(DPN) 136,136,135
140 IF (NVP(N)) 136,136,135
141 DP=SUM(DPN)-F(NVP(N))
142 RSTD(NX)=R(NX)
143 NW+YP(NX)=0
144 MBEGW=MENDW+1
145 OUTPUT OF RESULTS
146 DO 140 L=1,NB
147 IF (NW+YP(L)) 138,138,139
148 P(L)=R(L)*Q(L)*AR(Q(L))
149 GO TO 140
150 P(L)=R(L)
151 CONTINUE (6,415)
152 WRITE (6,416)
153 L=0
154 DO 143 K=1,NB
155 IF (NW+YP(K)) 142,142,141
156 L=L+1
157 GO TO 143
158 Q(K)=Q(K)*100.00
159 WRITE (6,417) NO(K),JS(K),JF(K),Q(K),P(K),LA(K),A(K),R(K),KF(K),OK
160 K)
161 CONTINUE
162 IF (L) 144,144,145
163 WRITE (6,418)
164 GO TO 150
165 WRITE (6,419)
166 IF (NW+YP(K)) 147,147,146
167 Q(K)=Q(K)*100.00
168 WRITE (6,420) NO(K),JS(K),JF(K),Q(K),P(K)
169 CONTINUE
170 IF (NFNUM) 150,150,148

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148 WRITE (6,421) (NOF(K),K=1,NFNUM)
DO 149 K=1,NFNUM
L=MPIS(K)
WRITE (6,422) (QF(K,I),PF(K,I),I=1,L)
WRITE (6,423) NB,NJ
DO 150 K=1,NFNUM
DWRNFN(K)
IF (NWRN) 152,152,151
WRITE (6,424) NOF(K)
CONTINUE

151
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153 IF (NCOMP) 154,154,156
154 IF (NTE(6,425))
155 GO TO 141
156 PSFLOW=0
NICTE=0
READ AND COMPLETE INPUT DATA
1 CRITIC(5,CRITHT,WRNPR,WRNSM,WRNGS,WRNHT)
1 READ (NAV) 158,158,159
1 READ (NAM) 164,164,159
LO=0 162 I=1,NDIM
READ (5,426) NDX,CH4VX,CH4PAX,TROCKX,HAX,HKX,DZRD
DO 160 J=1,NB
IF (NOX=NO(J)) 160,161,160
CONTINUE
L=LY(I)
CH4PA(J)=CH4VX
TROCK(J)=TROCKX
HAX(J)=HAX
DZRD(J)=DZRD
NOCTIND(I)=NO(J)
CONTINUE-L) 163,164,163
WRITE (6,429)
GO TO 141
DO 164 I=1,NB
GO (NO(I)) 168,168,165
IF (NAV) 166,166,167
WRITE (6,430)
GO TO 401

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167      NO(I)
      NA(I)=NAVR
      HK(I)=HKA(I)
      HGO(I)=HKA(I)
      IF(CH(AV,I)) 166,166,169
      IF(CH(AA,I)) 170,170,171
      IF(CH(HA,I)) 172,172,173
      IF(CH(KA,I)) 174,174,175
      IF(CH(KF,I)) 174,174,175
      IF(CH(KI,I)) 176,176,177
      IF(CH(LA,AAV)) 178,178,179
      IF(CH(AA,I)) 180,180,181
      AF(I)=OAVR(I)
      OF(I)=OACK(I) 182,182,185
      IF(CH(VN,I)) 183,183,184
      IF(CH(VK,I))=TAVR
      TROCK(I)=185
      GO(I)=185
      CON(I)=NUE
      DO(I)=187
      IF(CH(NJ,I))=1,NB
      NO(J)=NO(J) 186,186,187
      GSE(I)=0.0
      EEF(I)=0.0
      TRF(I)=0.0
      LME=0
      DO(I)=1,NJ
      IF(CH(J)-JNO(I)) 189,188,189
      TRS(I)=1
      LGO(I)=191
      IF(CH(JF,I))=JNO(I) 191,190,191
      TRF(I)=1
      MF(I)=1
      IF(CH(L+M-2)) 192,195,192
      CON(I)=196
      GO(I)=DZRD(J) 195,194,195
      IF(DZRD(J))=EF-ES
      DZ=0.014*(J)*0.8*(ABS(Q(J))**0.2)
      XTROCK(J)=(TRF-TRS*EXP{-X*LA(J)+DZRD(J)/187.})/(1.-EXP{-X*LA(J)})-D

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450* 451* 452* 453* 454* 455* 456* 457* 458* 459* 460* 461* 462* 463* 464* 465* 466* 467* 468* 469* 470* 471* 472* 473* 474* 475* 476* 477* 478* 479* 480* 481* 482* 483* 484* 485* 486* 487* 488* 489* 490* 491* 492* 493* 494* 495* 496* 497* 498* 499* 01603 01604 01605 01606 01607 01612 01615 01616 01621 01625 01626 01631 01633 01635 01641 01642 01645 01650 01651 01652 01653 01655 01660 01663 01664 01665 01666 01667 01670 01671 01672 01673 01676 01670 01702 01703 01704 01705 01710 01711 01712 01713 01716 01720 01721 01724 01725 01726

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236 DO 237 J=1,NB  
IF (JS(J)-I) 237,236,237  
237 LGOUT(I,L)=J  
CONTINUE  
LMM=239 J=1,NB  
DO 239 JF(J)-I) 239,238,239  
238 MF=M+1  
NGINTINUE  
239 CONTINUE  
MIN(M,EQ.M).AND.(K.EQ.L)) GO TO 240  
IF NOL(N)=I  
NENT+1  
240 CON+1 NUE JNO AND JNQL LISTS  
REL(243,I)=0  
241 PRCHA(I)=0  
DO 241 NOE  
IF ON(I)=JNO(J) 241,242,241  
242 CONTINUE  
243 JON(I)=J  
IND(244,I)=J  
DO 244 NOE OF STARTING JUNCTION (ATMOSPHERE)  
IF ON(I)=JSTART) 244,245,244  
244 MSTART=JLR(I)  
245 IT(I)=JSTART  
MRC=0  
246 MARKY=0  
247 C=0  
L=0  
248 NPROP=J  
JX=L  
CH4J8=PRCH4(L)  
JNO(L)=JNO(L)  
249 JY=1  
IF (NSTART-I) 249,250,249  
JZ=LOUT(NSTART)+1  
250 DO 250 K=JY,JZ  
ICFIM=0  
INM=0
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003642	DO	251	LNT=1, INFLOW
003642	IF		(NCONT(L)-NO(I)) 251,252,251
003647	CONTAM=0.0		
003647	HEATAD=0.0		
003650	TFS=0.0		
003651	GO TO 262		
003652	NM=1		
003653	IF	252	T(L)) 253,254,253
003655	CONT(L)*CONC(L)/100.	253	
003656	CON TO 255		
003661	CONTAM=0.0	254	
003664	HEATAD=0.0	255	
003668	HEATAD=0.0	256	
003670	HEATAD=0.0	257	
003672	HEATAD=0.0	258	
003674	HEATAD=0.0	259	
003675	HEATAD=0.0		
003677	HEATAD=0.0		
003700	HEATAD=0.0		
003703	HEATAD=0.0		
003710	HEATAD=0.0		
003711	HEATAD=0.0		
003717	HEATAD=0.0		
003725	HEATAD=0.0		
003732	HEATAD=0.0		
003742	HEATAD=0.0		
003755	HEATAD=0.0		
003756	HEATAD=0.0		
003760	HEATAD=0.0		
003764	HEATAD=0.0		
003766	HEATAD=0.0		
003772	HEATAD=0.0		
004010	HEATAD=0.0		
004021	HEATAD=0.0		
004024	HEATAD=0.0		
004026	HEATAD=0.0		
004033	HEATAD=0.0		
004043	HEATAD=0.0		
004046	HEATAD=0.0		
004052	HEATAD=0.0		
004064	HEATAD=0.0		


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251  DO 251 LNT=1, INFLOW
    IF (NCONT(L)-NO(I)) 251,252,251
    CONTAM=0.0
    HEATAD=0.0
    TFS=0.0
    GO TO 262

252  NM=1
253  IF T(L)) 253,254,253
    CONT(L)*CONC(L)/100.
254  CON TO 255
255  CONTAM=0.0
256  HEATAD=0.0
257  HEATAD=0.0
258  HEATAD=0.0
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269  HEATAD=0.0
270  HEATAD=0.0
271  HEATAD=0.0
272  HEATAD=0.0

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273 DR*(TR+460.)/(TM+460.)/((460.0+TM)/492.)*1.75  
WISC=0.000145*(0.00024*TM+492.)*0.81  
CHKAG(I)*DR/(152.1*WISC)  
RNRN=0.00032+0.221/RN**0.237  
PFR=0.000100/RN**0.25  
COR=(K(I)*0.075)/(809*DR*FR0)**POT  
HFO=0.005*HKA*(I)*RN**0.8*COR/A(I)  
FBI=HC*3.5+BI)*SQRT(I)*HK(I)  
XF=(X-2.5) 274,277,277  
IF=0  
SUMTEXSUMT+ADD  
SUMT+1  
N=INT(ABS(ADDI*X**2*(2*N-1)/(N*(2*N+1)))  
AF=(AB0-(EXP(X**2)))*(1.0-(2.0/SQRT(PI)))*SUMT)  
IFX=1.0 275,275,275  
GOTO 281  
SUMT=0  
ADDI=SUMT+ADD  
SUMT+1  
N=INT(ADDI*(2*N-1)/(2.0*X**2))  
AF=(ABS(OLADDT)-0.00001)/D(I) 280,279,279  
IFX=1.0*SUMT/(SQRT(PI)*X)  
COAGW(I)=BI**2*(0.000175+BI)  
XNEW(I)=HK(I)*LA(I)*0(I)**2.*COAGE/(120.*DR*Q(I)*CP*A(I))  
IF(LD=CTROCK(I) 282,282,283  
GOTO 284  
TOLD=TRTROCK(I)  
TRD(I)=T+EXP(-XNEW(I))  
1P)=ABS(TOLD-TRD(I))  
IFDM=ADM-50.) 286,286,285  
IFCTM=170  
GOTO 270  
JFF(I)=JF(I) 288,287,287  
JF(I)=JF(I)  
COND=INT(I) IN JUNCTIONS  
DO 294 I=1,NJ  
L=JLR(I)
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IF (JNO(L)) 294,289,289  
JY=1  
I=-1  
J=290  
MIN(I)+1  
JY=MIN(I)  
SUMPR=0.0  
SUMCH4=0.0  
SUMH2=0.0  
DO 293 K=JY,JZ  
IF (JY=K) 292,294,294  
SUMPR=SUMPR+Q(J)  
SUMCH4=SUMCH4+RDCH4(J)*Q(J)  
SUMHT=SUMHT+TRD(J)*Q(J)*(0.2376+0.000024*TRD(J))  
CONTINUE  
NSTART=I  
PRCH4(L)=SUMPR/SUMAIR  
PRCH4(L)=SUMCH4/SUMAIR  
RTCONT=4950.*2.+SUMHT/(SUMAIR*0.000024)  
RT(L)=-248  
GO TO INUE  
CONTINUE  
REC=1  
L=0  
DO 303 I=1,NJ  
IF (JNO(I)) 296,296,297  
L=L+1  
GO TO 303  
NREC=0  
MRPH4=0.0  
STRDF=0.0  
QRE=0.0  
DO 301 J=1,NB  
IF (JNO(I)+JF(J)) 299,298,299  
NPRE=1  
SRPR=RDPROP(J)*Q(J)  
SRCH4=SRCH4+RDCH4(J)  
STRD=STRD+TRD(J)  
QIN=QIN+Q(J)  
GO TO 301  
IF (JNO(I)-JF(J)) 301,300,301  
MREC=QRE+Q(J)
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CONTINUE 303,303,302  
IF (N) 303,303,302  
AVRPR=SRRC/GIN  
AVTRD=STRD/N  
IF (Q) 303,303,302  
GO TO 303  
DO 305 MRCC(L)=1,M  
K=MRCC(L)  
NORREC(MRC)=K  
ESTPROP(MRC)=K  
EDPTCH4(MRC)=K  
EDCH4(K)=ESTCH4(MRC)  
ESTTR(MRC)=AVTRD  
JFK(K)=JFK  
CONTINUE  
DO 306 J=1,NJ  
IF (J) 306,307,306  
CONTINUE  
JY=1  
IF (J) 308,309,308  
JZ=MIN(J,0)  
SUMPR=0.0  
SUMCH=0.0  
SUMH=0.0  
DO 310 K=JY,JZ  
M=NGIN(K)  
SUMPR=SUMPR+Q(M)*Q(M)  
SUMCH=SUMCH+RDCH4(M)*Q(M)  
SUMHT=SUMHT+TRD(M)*Q(M)  
CONSTANT=SUMPR/SUMAIR  
IP(L)=SUMCH4/SUMAIR  
PRCH4(L)=950.0**2+SUMHT/(SUMAIR*0.000024)  
RT(L)=950.0**2+SQRT(RTCONT)  
GO TO 248  
IF (L) 312,313,313  
NREC=NREC+1  
RECIRC=248  
GO TO 248  
RECIRC=1,NB  
DO 314
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336 CONTINUE 349,349,337
337 IF (MNO=1)
    DNVP=0
    DO 346 K=1,MNO
    ONVP=VP(K)
    MENDW=MEND(K)
    FNVP(K)=0
    ZDOWN=0.0
    HSU=0
    DO 343 J=MBEGW,MENDW
    DMSL(J)
    IF (CN) 338,339,339
    FAX=-1
    NX=-N
    GO TO 340
    FAX=1
    NX=N
    HSU=HSU+FACT*FRNVP(NX)
    HSU=HSU+ABS(FRNVP(NX))
    IF (DZRD(NX)*FACT) 342,343,341
    IUP=ZUP+DZRD(NX)*FACT
    GO TO 343
    ZDOWN=ZDOWN+DZRD(NX)*FACT
    CONTINUE
    HSU=HSU-(ZUP+ZDOWN)*TR
    TSU=TSU-(ZUP+ZDOWN)*TR
    FNVP(K)=HSU*DR/(5.2*(TSU/(ZUP+ZDOWN)+460.))
    DNVP=DNVP+ABS(ONVP-FNVP(K))
    MBEGW=MENDW+1
    REROUTE PROGRAM TO APPROPRIATE PROGRAM SECTION
    IF (CNVP) 348,348,347
    NITC=0
    GO TO 85
    IF (DNVP/MNO=0) 355,355,349
    IF (MADJC-MADJ) 350,354,354
    NSNVJC=MADJC+1
    MADJC=0
    I=1,NB
    DO 352 J(I),351,352,352
    IF (J)=JF(I)
    Q(I)=Q(I)/10000
    IF (NSFLOW) 353,353,85
    NSW=1
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TO 20
OUTPUT OF RESULTS
WRITE(0,44) NB
WDO 358 L=1,NB
IF (NHTYP(L)) 356,356,357
GO (L) TO 358
CON (L) INUKN) 361,361,360
IF (MARKN) (6,44)
IF (MARKC) 363,363,362
WRITE (6,445)
WRITE (6,446)
WRITE (6,447) (NO(I),JS(I),JF(I),Q(I),TRD(I),RDPROP(I),RDCH4(I),P(
WRITE (6,448) (JNQ(I),T(I),PROP(I),PRCH4(I),I=1,NJ)
WRITE (6,449) MADJ
WRITE (6,450) C
LD=0 365 I=1,NB
IF (JF(I)) 364,365,365
IF (YABS(JF(I)))
WRITE (6,451) NO(I),JFF
L=1+NUE 367,367,366
CON (L) 364,52
IF (L) (ORNPR+WRNGS+WRNSM+WRNHT
WRN SUM=WRNSUM) 368,368,369
IF (WRNSUM) 368,368,369
WRITE (6,453)
GO TO 369
LD=0 381 I=1,NB
K=0
L=0
M=0
N=0
IF (100.*RDCH4(I)-WRNGS) 371,370,370
IF (100.*RDPROP(I)-WRNSM) 373,372,372
IF (100.*RD(I)-WRNHT) 375,374,374
IF (M+I)
IF (P(I)-WRNPR) 376,377,377
IF (K+L+M+N) 381,381,378
IF (J) 380,379,380
WRITE (6,454) WRNGS,WRNSM,WRNHT,WRNPR
J=J+1
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380 JFF=IABS(JF(I))
381 WRITE(6,455) NO(I),JS(I),JFF,RDCH4(I),RDPROP(I),TRD(I),P(I)
CONTINUE
382 IF(J) 382,382,383
WRITE(6,456)
GO TO 394
383 J=0 393 I=1,NJ
K=0
L=0
M=0
IF(K+1) 385,384,384
IF(L+1) 387,386,386
IF(M+1) 389,388,388
IF(K+L+M) 393,393,390
IF(J) 392,391,391
WRITE(6,457) WRNGS,WRNSM,WRNHT
J=J+1
WRITE(6,458) JNO(I),PRCH4(I),PROP(I),T(I)
CONTINUE-1) 401,395,396
IF(NRCT=6) 459
WRNREV(I)
K=NRREV(JF(K))
WRITE(6,460) NO(K),JS(K),JFF
GO TO 401
WRITE(6,459)
L=NRREV(NREV(I))
MEM(I)
I=2,NRCT
DO 399 NRREV-NREV(I),399,399,398
IF(NRREV(I))
CONTINUE
L=L+1
IF(L-NRCT) 400,400,401
JFF=IABS(JF(MINREV))
WRITE(6,460) NO(MINREV),JS(MINREV),JFF
NREV(MEM)=NB+1
GO TO 397
STOP
FORMAT$
FORMAT (10I5,2F10.5)
FORMAT (4I5,F10.3,F10.0,2I10,2F10.1)

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8. LIST OF COMPUTER SYMBOLS WHICH ARE EXPLAINED IN TEXT

Computer Symbol	Text Page	Definition
A	16	airway cross sectional area
AAVR	26	average airway cross sectional area
AVRCH4	43	average methane concentration of unrecirculated air currents entering junction
AVRPR	43	average contaminant concentration of unrecirculated air currents entering junction
AVTRD	43	average temperature of unrecirculated air currents entering junction
AX	17	airway cross sectional area
CH4C	16	methane concentration in junction
CH4CX	27	methane concentration in junction
CH4JS	35	methane concentration at roadway beginning
CH4PA	28	methane volume production rate per ft ² of surface area in airway
CH4PAX	27	methane production rate per ft ² surface area in airway
CH4V	28	methane volume production rate in airway
CH4VX	27	methane production rate in airway
COAGE	41	coefficient of age
CONC	28	concentration of contaminant in gas inflow
CONT	28	volume flow rate of contaminated gas inflow
CONTAM	35	volume flow rate of contaminant
CONTQ	35	volume flow rate of gas inflow carrying the contaminant
COR	40	correction of HC for rough walls
CRITGS	26	accuracy of methane concentration calculation when recirculation occurs
CRITHT	26	accuracy of temperature calculation when recirculation occurs
CRITSM	26	accuracy of contamination calculation when recirculation occurs

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
DNVP	47	difference between natural ventilation pressures in last two iterations
DPSUM	22	sum of pressure losses around mesh
DQ	22	CROSS correction per mesh
DQSUM	22	sum of DQ for all meshes of network
DR	15	reference density
DZRD	28	elevation change in airway
DZRD _X	27	elevation change in airway
ESTCH4	44	estimated methane concentration for recirculated air
ESTPR	44	estimated contaminant concentration for recirculated air
ESTTR	44	estimated temperature for recirculated air
FACT	47	factor indicating direction of elevation change
FANP	22	fan pressure at airflow rate FANQ
FANQ	22	airflow rate passing through fan
FNVP	21	list of natural ventilation pressures in meshes
FRNVP	47	product TMRD*DZRD
HA	28	thermal diffusivity of rock in airway
HA _{AVR}	26	average rock diffusivity
HAX	27	thermal diffusivity of rock in airway
HC	39	convection coefficient
HEAT	28	heat entering airway
HEATAD	36	heat addition to air
HK	28	thermal conductivity of rock in airway
HKA	39	thermal conductivity of air

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
HKAVER	26	average rock thermal conductivity
HKX	27	thermal conductivity of rock in airway
HSU	47	sum of quantities FRNVP
HTPO2	28	heat production per ft ³ of oxygen delivery
ICFTM	41	marker
INFLOW	26	number of contamination cards
INU	18	auxiliary list for forming base system
ISTART	34	index of JSTART in JNO-list
IT	22	iteration counter
ITCT	47	iteration counter
ITN	15	maximal number of iterations in network and concentration calculations
JF	16	junction number of airway end
JLR	34	list relating JNO- and JNOL-lists
JS	16	junction number of airway beginning
JSTART	26	number of junction from where concentration calculation shall start
JNO	16	junction number
JNOL	32	list of junction numbers in increasing order
JNOX	27	junction number
KF	16	friction factor
KFAVR	26	average friction number
KNO	19	list of airways in base system
KX	17	friction factor

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
LA	16	airway length
LA AVR	26	average airway length
LOUT	32	list of last airway per junction in NGOUT-list
LX	17	airway length
MADJ	15	maximal number of network calculations in one program run
MADJC	17	iteration counter
MARKC	34	marker
MARKN	17	marker
MAXJ	26	highest junction number
MEMREC	43	temporary list of airways carrying recirculated air
MEND	19	list of mesh ends in MSL-list
MIN	32	list of last airway per junction in NGIN-list
MPTS	17	number of points used to define fan characteristics
MSL	19	list of all independent meshes
MSTART	34	index of JSTART in JNOL-list
NADBC	15	number of additional airway cards
NAV	26	marker for presence of average value card
NB	15	number of airways in network
NCENT	28	number of airways into which contaminants enter
NCH4C	26	additional number of concentration junction cards
NCONC	15	marker for desired concentration calculation
NDIM	26	additional number of concentration airway cards
NETW	15	marker for desired network calculation

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
NFNUM	15	number of fan characteristics to be read into computer
NFREG	18	list of fans with characteristic
NGIN	32	list of airways entering junction
NGOUT	32	list of airways leaving junction
NJ	15	number of junctions in network
NO	16	airway number
NOF	17	airway number of fan
NOREC	44	permanent list of airways carrying recirculated air
NOX	17	airway number
NOX	27	airway number
NNVP	17	marker
NRCT	32	number of airways with airflow reversal
NREC	43	marker
NREV	32	list of airways with airflow reversal
NSFLOW	24	marker
NSNVP	17	marker
NSW	17	marker
NTEMP	15	marker for desired temperature calculation
NVPN	15	marker for presence of junction cards
NWTTYP	15	airway type
O	16	airway perimeter
OAVR	26	average airway perimeter
ONVP	47	natural ventilation pressure in last iteration

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
O2MIN	28	oxygen concentration of fumes leaving fire zone
OX	17	airway perimeter
P	25	calculated pressure losses and fan pressures
PF	17	fan pressure at given point of fan characteristic
PR	39	Prandtl number
PRCH4	35	methane concentration in junction
PROP	35	contaminant concentration in junction
PROPJS	35	contaminant concentration at roadway beginning
Q	16	airflow rate
QF	17	airflow rate at given point of fan characteristic
QIN	43	sum of unrecirculated airflow rates entering junction
QREC	43	recirculated air entering junction
R	16	resistance factor of airway
RDCH4	35	methane concentration at roadway ends
RDPROP	35	contaminant concentration at roadway ends
RGRAD	22	slope of fan characteristic
RN	39	Reynolds number
RSTD	46	resistance factor based on reference temperature TR
SMPO2	28	contaminant production per ft ³ of oxygen delivery
SRCH4	43	sum of methane concentrations of unrecirculated airflows entering junction
SRPR	43	sum of unrecirculated contaminant flow rates entering junction
STRD	43	sum of temperatures of unrecirculated airflows entering junction
SUMAIR	42	total airflow rate entering junction

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
SUMCH4	42	total methane flow rate entering junction
SUMHT	42	total enthalpy/reference density entering junction
SUMPR	42	total contaminant flow rate entering junction
T	16	temperature of air in junction
TFSI	46	air temperature behind heat source
TIME	26	time since beginning of contamination
TJS	35	temperature at roadway beginning
TM	41	estimated average air temperature
TMRD	46	mean temperature of air in airway
TMSQR	46	mean square absolute temperature
T1	46	air temperature at beginning of airway
TR	15	reference temperature
TRD	35	temperature at roadway end
TROCK	28	average rock temperature in airway
TROCKX	27	average rock temperature in airway
TSTART	26	temperature in JSTART
TSU	47	sum of absolute quantities FRNVP (in concentration part of program)
WRNGS	26	threshold value for critical methane concentration
WRNHT	26	threshold value for critical temperature
WRNPR	26	threshold value for critical pressure loss
WRNSM	26	threshold value for critical contamination
XNEW	42	exponent in formula for calculation of temperatures in roadways

List of Computer Symbols Which Are Explained in Text (continued)

Computer Symbol	Text Page	Definition
Z	16	elevation of junction
ZDOWN	47	sum of all negative elevation changes in mesh
ZUP	47	sum of all positive elevation changes in mesh

9. LIST OF ADDITIONAL COMPUTER SYMBOLS NOT QUOTED IN TEXT

(This list does not contain some temporary used indices and counters whose meaning and function, when reading the program, can be easily recognized)

Computer Symbol	Definition
ADDT	intermediate quantity for calculation of COAGE
BI	Biot number
CH4S,CH4F	methane concentrations in starting and finishing junctions of airway
CP	specific heat of air
DIFCH4	difference in last two iterations for methane concentration
DIFTRD	difference in last two iterations for air temperatures
ES,EF	elevations of starting and finishing junctions of airway
FO	Fourier number
FRO	coefficient of friction for hydraulically smooth walls
FX	intermediate quantity for calculation of COAGE
KJF	temporary list for assembling base system
KJS	temporary list for assembling base system
MARKD	marker
MBEGW	first airway in mesh
MENDW	last airway in mesh
MESC	mesh counter
MNO	number of meshes in network
NBL	counter

List of Additional Computer Symbols Not Quoted in Text (continued)

Computer Symbol	Definition
NBU	counter
NFCW	list of fans whose characteristic is exceeded
NRETU	marker
POT	exponent for COR
OLADDT	intermediate quantity for calculation of COAGE
QBL	lowest airflow rate used of fan characteristic
QBR	highest airflow rate used of fan characteristic
RQ	product $R*Q$
RQSUM	sum of all products $2*R*Q$
SUMT	intermediate quantity for calculation of COAGE
T0, T1	absolute temperatures of starting and finishing junctions of airway (in network part of program)
TOLD	last calculated temperature at airway end
TRS, TRF	temperatures of starting and finishing junctions of airways
TSU	sum of absolute temperatures of all junctions in mesh (used in network part of program)
VART	content of square root for calculating temperature behind a heat source
VISC	kinematic viscosity of air
WT	specific weight of air
X	quantity $\alpha_0/(G*CP)$

List of Additional Computer Symbols Not Quoted in Text (continued)

Computer Symbols	Definition
X	quantity $(0.375 + BI) \sqrt{FO}$
Z0,Z1	elevations of starting and finishing junctions of airway