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A COMPUTER SIMULATION OF THE INFLUENCE OF FIRE GASES ON THE FLOW AND DISTRIBUTION OF POTENTIAL IN A MINE VENTILATION NETWORK

KOMPUTEROWA SYMULACJA WPŁYWU POŻARU PODZIEMNEGO NA ROZKŁAD POTENCJAŁU SIECI WENTYLACYJNEJ KOPALNI

The application of a concept of an aerodynamic potential in software aids for ventilation engineers and mine safety officers is presented. The use of software enables phenomena occurring both in normal and emergency situations to be predicted. Ventilation engineers in Polish mines use two methods of graphical presentation of flow and pressure distribution in a network. The first is a widely used spatial (isometric) scheme of a network, where flow and pressure values are displayed close to relevant nodes and branches. The second method uses a concept of an aerodynamic potential to illustrate so called potential schemes. Unlike spatial schemes, to date, potential schemes have had to be constructed and updated manually. A new version of the VENTGRAPH ventilation engineers software package enables both schemes to be used. A model of flow in a ventilation network in the presence of a fire and scheme concepts are described. An example of the development and extinction of an underground fire on a potential distribution basis is described.

Key words: mining, mine ventilation, ventilation networks, computer simulation, aerodynamic potential, underground fires

Rozwój metod prognozowania procesu przewietrzania sieci wentylacyjnej kopalni doprowadził do powszechnego stosowania technikę komputerową, która doskonale wspomaga pracę inżyniera wentylacji i dyspozytora kopalni. Tworzy się nowe programy komputerowe, których użyteczność rośnie. Zagadnienia związane z pożarem podziemnym są ciągle aktualne i inspirujące do nowych badań. W wielu kopalniach polskich w działach wentylacji kopalń wdrożono do pracy System Programów Inżyniera Wentylacji — VENTGRAPH (Dziurzyński i in. 1988). Zastosowany w programach komputerowych sposób prezentacji wyników obliczeń wykorzystuje schemat przestrzenny sieci wentylacyjnej. W wentylacji kopalń stosowany jest też schemat potencjalny. W związku z powyższym w niniejszej artykule rozważa się przydatność zastosowanie tego schematu w miejsce dotychczas stosowanego. Należy zaznaczyć, że o ile położenie węzłów sieci wentylacyjnej schematu przestrzennego nie zmienia się w czasie przebiegu zjawisk wywołanych pożarem, to położenie węzłów schematu

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potencjalnego będzie ulegało zmianie. Nowe położenie węzła zależne jest od aktualnej wartości potencjału. Stwarza to konieczność przedstawienia matematycznego modelu rozpatrywanych zjawisk, na podstawie której zostanie podana formuła (22) do obliczenia potencjału aerodynamicznego w każdym rozpatrywanym węźle. Drugim zagadnieniem do rozwiązania jest opracowanie procedur graficznych do kreślenia schematu potencjalnego ze zmieniającym się w czasie symulacji położeniem współrzędnych wyznaczających węzły schematu potencjalnego. Dla przedstawionego modelu matematycznego opracowano program symulacji, za pomocą którego wykonano stosowne symulacje komputerowe. Jako przykład ilustrujący zmieniające się ciśnienia oraz potencjały wywołane przemieszczaniem się gorących gazów pożarowych w sieci wentylacyjnej wybrano jeden z rejonów kopalni P. Uzyskane wyniki komputerowej symulacji przedstawiono na rysunkach będących kopią wyglądu ekranu w trakcie obliczeń.

Słowa kluczowe: górnictwo, wentylacja kopalń, sieci wentylacyjne, symulacja komputerowa, potencjał aerodynamiczny, pożary podziemne

1. Introduction

The development of methods of forecasting the process of aerating a mine by a ventilation network has led to the widespread application of computer technology, which, ideally, aids the work of ventilation engineers and mine safety officers. New computer programmes are being created, and their usefulness continues to increase. Issues connected with underground fires are topical and continue to stimulate new research.

The mine ventilation departments of many Polish mines currently apply the Ventilation Engineer's Programmes System — VENTGRAPH (Dziurzyński et. al. 1998). This system is defined by two specific features — firstly, it has separate programme blocks for the execution of tasks connected with the safe ventilation of a mine and, secondly, it contains procedures enabling the graphical presentation of the results of computer calculations to be applied to the spatial scheme. The spatial scheme of a mine may be mapped in a digital form, with a direct connection between the airway (branch) symbol and parameters characterising the flow therein. At the same time, the results of calculations may be introduced into the scheme. This enables the visualisation of the propagation of fire gases — which parameter is variable over time — on a computer screen (Dziurzyński et. al. 1998; Dziurzyński 1998a). The method of presenting information about the state of the ventilation network adopted in the VENTGRAPH system requires the analysis and combination of three different types of data. These concern the structure of the network, parameters characterising the flow, and the spatial scheme of the ventilation network. These are then displayed on the computer screen.

Transients, brought about in the network by an underground fire, lead to a complex distribution of parameters within the ventilation network, which change both over time and space. To display of these distributions requires the use of additional media. Sixteen of the colours that are available on the screen of an IBM PC computer screen are used in programmes designed for the simulation of such phenomena. In comparison with calculations for steady states, the on-screen data provides graphical information based on the significance of various colours to show, for example, the distribution of oxygen concentration in fire gases. This method enables the spatial distribution of a selected parameter within the entire network, and of the changes that are taking place in the course of the simulation to be seen readily. The solutions applied, due to the clear colour picture, considerably facilitate the interpretation of the changes that are taking place in the network, and thus help correct decisions during simulated rescue operations to be reached.

The method of presenting the results of calculations described above incorporates a spatial scheme of the ventilation network. Another scheme applied in the ventilation of mines is the potential scheme. In this connection, the authors this article have considered the usefulness of this scheme in comparison with the method hitherto applied. It should be stressed that whilst the locations of nodes of a ventilation network in the spatial scheme do not change during the course of the fire-related phenomena, the theoretical position of nodes of a ventilation network in the potential scheme will have an effect. The new location of a node will depend on its current potential value. This necessitates the presentation of an analytical mathematical model of the phenomena, which is employed as the basis for the elaboration of a formula to calculate the aerodynamic potential in each node being considered. The second issue that must be resolved concerns the elaboration of graphical procedures for drawing the potential scheme with co-ordinates to determine the positional changes of nodes, when applying the potential solution during the simulation period.

2. Numerical simulation of the propagation of fire gases — mathematical model

2.1. Flow of air and fire gases within the heading

The mathematical model applied for the description of the examined phenomena constitutes a functional basis for the simulation programme (Dziurzyński 1998a). The equations of the model should describe all relevant phenomena with sufficient precision whilst applying the simplest approach possible. These dichotomous requirements render the selection of equations for the model extremely difficult, and thus it is often necessary to reach a compromise between the quality of the description and the complexity of the elaborated model. In the case of the simulation of a fire in a ventilation network, the mathematical model should take the following phenomena into account (Dziurzyński 1998a, 1985):

- changes in the air flow parameters of each network branches, i.e. in the velocity of flow, the temperature profile, the concentration of combustion products, and in the concentration of oxygen,
- the mixing processes taking place in the nodes of the ventilation network,
- the influence of parameters characterising the flow on the propagation of air in the network; the possibility of the reversal of flow as a result of the localised changes of ventilation pressure due to the presence of fire gases,

- a description of the process of combustion of fuel at the the fire (consumption of oxygen in the focus, thermal balance, etc.),
- a simulation of activities carried out in the course of a rescue operation: construction of fire seals, utilisation of inert gases, etc., and their influence on the other simulated processes.

The programme for simulating the propagation of a mixture of air and fire gases in a network of mine headings utilises a one-dimensional system of equations of motion for the steady state, as well as equations of continuity, momentum, energy and ideal gas law, which in accordance with the assumptions adopted have been presented as follows (Dziurzyński 1998a, 1985):
the dynamic equation for the steady state:

$$v\frac{\partial(v\rho)}{\partial s}+\frac{\partial p}{\partial s}+g\rho\frac{dz}{ds}+j+j_{rt}\delta(s-s_{rt})=h_w(s-s_w) \tag{1}$$

the equation of continuity:

$$\frac{\partial(v\rho)}{\partial s}=0 \tag{2}$$

the equation of energy:

$$c_p=\left(\frac{\partial T}{\partial t}+v\frac{\partial(T)}{\partial s}\right)=q_{sk} \tag{3}$$

the equation of state of the ideal gas:

$$p=\rho RT \tag{4}$$

where:

s — designates the spatial co-ordinate measured along the axis of the heading [m],
t — time [s],
z — height co-ordinate, directed upwards [m],
$v(s,t)$ — mixture flow velocity [m/s],
$p(s,t)$ — absolute pressure [Pa],
$\rho(s,t)$ — density of the mixture of air and fire gases [kg/m^3],
R — gas constant of the mixture of air and fire gases [J/kgK],
$T(s,t)$ — temperature of the mixture of air and fire gases [K],
q_{sk} — quantity of heat exchanged between flowing in the airway mixture of air and fire gases and adjacent rocks expressed per unit of time and liquid mass [J/skg],
c_p — specific heat of the mixture [J/kgK],
j_{rt} — pressure drop due to local resistance (stopping) [Pa],
s_{rt} — co-ordinate of the point of occurrence of local losses,
$\delta(s-s_{rt})$ — Dirac delta function [1/m],
$\delta(s-s_w)$ — Dirac delta function [1/m],

$\delta(s - s_{rt})$ — static fan head [Pa],
s_w — fan location co-ordinate,
$j(s,t)$ — hydraulic gradient [Pa/m], as per the formula:

$$j = \frac{\lambda \rho O_b}{8A} v|v| \tag{5}$$

λ — non-dimensional resistance coefficient,
O_b — heading circumference [m],
A — transverse area of the heading [m^2].

Placing (5) in (1), whilst taking into consideration (2), after integration along the length of the airway L_i, and following additional transformations we arrive at:

$$(p_{L_i} - p_{wl_i}) + g\rho_{sr_i}(z_{L_i} - z_{0_i}) + \frac{R_i}{\rho_{sr_i}^2} G_i |G_i| + w'_i = h_{w_i} \tag{6}$$

where:

$G_i = \rho_i v_i A_i$ — mass mixture mass flow rate [kg/s],

$\rho_{sr_i} = \frac{1}{L_i}\int_0^{L_i} \rho_i ds$ — average density in heading number i [kg/m^3],

$R_i = \lambda \frac{\rho_{sr} L_i P_i}{A_i^3}$ — aerodynamic resistance of heading number i [kg/m^7],

w'_i — pressure drop due to local resistance (stopping) in heading number i [Pa],

L_i — length of heading number i [m].

Following integration along the length of the heading and the application of nodal and mesh equations for the network, equations (5) constitute the mathematical model of the flow of air and fire gases in the mine heading. This system of equations is solved using Cross's method, which makes it possible to determine the propagation of the mass flow rates of air and fire gases. A developing fire, located in one of the headings, generates heat that is transported along the headings, changing the initial density distribution of the flowing air and fire gases.

2.2. Changes in the concentration of components of the mixture of air and fire gases

Designating mass per unit volume of one of the components of air, namely oxygen, as ρ_{O_2} we arrive at the following formula for the mass concentration of air C_{CO_2}:

$$C_{CO_2} = \frac{\rho_{O_2}}{\rho} \tag{7}$$

In order to determine changes in the concentration of methane during the flow of the mixture in a heading, we adopt the following equation of continuity:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho v)}{\partial s}=0 \tag{8}$$

and also for the component of this mixture of oxygen:

$$\frac{\partial \rho_{O_2}}{\partial t}+\frac{\partial(\rho_{CH_4} v)}{\partial s}=0 \tag{9}$$

Taking into consideration equation (8) and formula (7) in equation (9) and following transformations, we arrive at an equation which determines changes in the distribution of oxygen concentration caused by the proliferation of the mixture of air and fire gases at a flow velocity *v*:

$$\frac{\partial C_{O_2}}{\partial t}+v\frac{\partial C_{O_2}}{\partial s}=0 \tag{10}$$

Equation (10) makes it possible to calculate changes in the distribution of oxygen concentration caused by flow at a velocity *v*.

2.3. Exchange of heat between the flowing mixture and the rock mass

Heat exchanged between the surface of the heading and the flowing mixture of air and fire gases is determined by means of Newton's equation (Staniszewski 1979):

$$q_{sk}=\frac{kO_b}{\rho A}\{T(s,t)-\theta(s,t)\} \tag{11}$$

where:

- T — temperature of the flowing air and fire gases [K],
- θ — temperature of the adjacent rock surface [K],
- k — coefficient of complex heat exchange through convection and radiation [W/m²K].

As in hitherto applied models, we have assumed that in order to determine the temperature of the adjacent surfaces, to use the simplified form of the equation of thermal conduction is sufficient:

$$\frac{\partial \theta}{\partial t}=\frac{\lambda_S}{\rho_S c_S}\frac{\partial^2 \theta}{\partial r^2} \tag{12}$$

with the boundary condition being given by the dependence:

$$\lambda_S \frac{\partial \theta}{\partial r}\bigg|_{r=r_0} = -k(T-\theta) \tag{13}$$

where:

λ_S [W/mK], c_S [J/kgK], ρ_S [kg/m^3] — coefficient of thermal conduction, specific heat of rocks and rock density, respectively.

2.4. Model of the fire

2.4.1. Simplifying assumptions

In our considerations we are concerned with an area of a heading being cut in coal. This area is supplied with oxygen, which is contained in the mixture of air and gases. As a result of the influx of heat or of the processes of self-heating of coal and accumulation of heat the temperature rises. When a certain mass of coal reaches flash-point, a process of intensive combustion is initiated; we refer to this as a fire (Dziurzyński 1998a,1985).

The term "*focus of the fire*" is taken to mean a certain discrete area, the temperature of which exceeds the so-called *flash-point* of coal. When analysing the complex process of mass and energy exchange at the focus of the fire, we shall consider the following phenomena:

- oxygen loss resulting from the process of combustion of coal and the changes in the concentration of oxygen in the mixture of air flowing through the area of the fire and thereby caused,
- generation of fire gases, considered jointly ($CO + CO_2 + C_nH_n + \ldots$),
- heat emission as a result of the process of combustion of coal in the fire.

We have devised equations describing the process of combustion of coal. We are interested in determining the following factors.

Changes in the concentration of oxygen

The intensity of the combustion process is determined by a quantity commonly referred to as the *rate of combustion*:

$$k_s = \frac{1}{A_f}\frac{dM_p}{dt} \tag{14}$$

where:

A_f — area of the fuel covered by combustion [m^2],

M_p — mass of the fuel [kg],

k_s — rate of combustion of coal expressed as the mass of coal burned in a unit of time per unit of area of the burning focus of the fire [kg/m^{2}s].

The rate of combustion may also be expressed on the basis of the loss of oxygen mass:

$$k_s = \frac{1}{A_f} k_p \frac{dM_{O_2}}{dt} \tag{15}$$

where:

k_p — oxygen mass per unit of mass of combusted fuel.

We assume that the loss of oxygen mass per unit of time is proportional to the area of the burning fuel and concentration of oxygen:

$$\frac{dM_{O_2}}{dt} = \psi A_f C \tag{16}$$

where:

ψ — coefficient of proportionality (Dziurzyński 1998a) [kg/m^{2}s],
C — current concentration of oxygen in the mixture within the area covering the focus of the fire.

In addition, the oxygen mass balance effected for the area of the heading covered by the fire enables equations for the concentration of oxygen C in fire gases to be written.

$$\rho_{O_2} l_p A \frac{dC}{dt} = G_0 C_0 - GC - \frac{dM_{O_2}}{dt} \tag{17}$$

where:

ρ_{O_2} — oxygen density [kg/m^3],
G_0 — stream of air and gases flowing into the focus of the fire [kg/s],
l_p — length of area covered by the focus of the fire [m],
G — stream of air and gases flowing out of the focus of the fire [kg/s].

Changes in the temperature of the focus of the fire

We must now examine the thermal balance within the area of focus of the fire, from which we will determine the temperature of the burning fuel T_p, that is:

$$c_{wp} M_p \frac{dT_p}{dt} = q_{og} + q_2 + q_3 \tag{18}$$

where:

T_p — temperature of the burning fuel (of the focus of the fire),
c_{wp}— specific heat of the burning fuel,
M_p— mass of the fuel (coal) covered by the fire,

and:

$$q_{og} = k_s W_d A_f \tag{19}$$

heat emitted during combustion per unit of time

$$q_2 = -kA_p(T_p - T) \tag{20}$$

heat taken from the burning fuel by the air and fire gases flowing through the section of the heading covered by the fire in a unit of time

$$q_3 = -\lambda_s A_p \frac{dT_p}{dr} \tag{21}$$

is the heat passed across in a unit of time from the burning fuel to the rock mass.

The symbols utilised in the above formulae designate the following:

W_d — net calorific value of the gas fuel [J/kg],

T — temperature of fire gases,

$\frac{dT_p}{dr}$ — temperature gradient on the edge of the rock mass adjacent to the burning fuel (coal).

The above equations and formulae make it possible to determine the influence of phenomena occurring within the focus of the fire on the change in the propagation of air and fire gases within the mine ventilation network. It should be stressed that the adopted mathematical flow model takes into consideration changes brought about by changes in composition and temperature. Consequently, on the basis of the model presented above, the authors have evolved a professional computer simulation programme called POŻAR, which operates under the VENTGRAPH system and enables the analysis of the ventilation network during the propagation of air and fire gases.

3. Determining the potential in nodes of the mine ventilation network

The equations and formulae presented in section 2 constitute the elements of the mathematical model of the programme simulating the propagation of the mixture of air and fire gases in the heading of a mine. The application of nodal and mesh equations enables the derivation of equation (6) for a network of headings. The solution of this system of equations makes it possible to determine the value of the mass flow rate of the mixture of air and fire gases and also to calculate the value of pressure in the ventilation node. The events occurring at the focus of the fire result in the influx of a mass of fire gases and a change in the density distribution of the flowing mixture. This influences changes in pressure in the ventilation node during the underground fire.

3.1. Determining aerodynamic potential

In ventilation networks, slow flows of humid air usually occur, accompanied by changes of mass, momentum and energy. During this process the air in a mine undergoes changes which may be considered as a thermodynamic cycle. Thus, many projects concerned with researching flow have made use of the thermodynamic method (Bystroń 1999). One of these methods consists of comparing actual with ideal flow. Under conditions of ideal flow, air undergoes reversible changes without any loss or exchange of energy with the environment (adiabatic changes). Since during this process entropy S remains unaltered, it is commonly known as the reversible isentrope or adiabate, whilst its parameters are designated by the S index. It is a well-known fact that if the air failed to exchange energy with its environment and remained motionless, its static pressure p_S and density ρ_S would change according to its depth, as given by the following dependencies:

$$p_S = p_0 \left[1 - \frac{\kappa - 1}{\kappa} \frac{\rho_0}{p_0} g(z - z_0) \right]^{\frac{\kappa}{\kappa - 1}} \tag{22}$$

$$\rho_S = \rho_0 \left[1 - \frac{\kappa - 1}{\kappa} \frac{\rho_0}{p_0} g(z - z_0) \right]^{\frac{1}{\kappa - 1}} \tag{23}$$

where:

p_0, ρ_0, z_0 — designate — accordingly — pressure, air density and the depth of the selected network section, the so-called reference node (usually the inlet to the downcast shaft), while $\kappa = 1.4$ is the isentropic exponents.

In a real process of ventilation an influx and dissipation of energy and an exchange of mass occurs, connected with inflows of gases from the rock mass and the humidification of the air, and thus the actual distribution of densities and pressures (and of temperatures) differs from the ideal, or theoretical model. Research into these differences may provide extensive information about the state of ventilation. The concept of aerodynamic potential, developed in the works of H. Bystroń (Budryk 1929; Bystroń 1995, 1999, 1999a), is applied here to a great extent. On the basis of measurements, we may calculate the aerodynamic potential for each heading section, and thereby determine the distribution or area of potential within the network. In practice, it is recommended that potentials for inlet and outlet sections of headings are determined by means of ventilation measurements. The results may be illustrated in the form of a potential diagram, where the canonical diagram is transformed in such a way that the co-ordinate $\boldsymbol{y}$ (vertical axis) of nodes and characteristic points of the network corresponds to the value of the potential.

Potential taken in relation to a unit of volume Φ_v of gases [J/m^3] is defined as the difference between actual static pressure p and ideal conditions:

$$\Phi_v = p - p_S \tag{24}$$

while the potential in relation to a unit of mass Φ [J/kg] is additionally assumed to be related to density ρ_S:

$$\Phi := \frac{p - p_S}{\rho_S} \tag{25}$$

Here, the author H. Bystroń (1999a) applies two approaches:

a) he assumes the actual state to be conditional upon the air remaining motionless:

- method 1 then, p_S ρ_S are determined by formulae (24) and (25), or

b) he makes a comparison between flow without loss with an average velocity as being equal to the actual velocity:

- method 2 then, the formulae for p_S ρ_S contain average flow velocity,

and thus we obtain:

$$p_S = p_0 \left[1 - \frac{\kappa - 1}{\kappa} \frac{\rho_0}{p_0} \left\{ g(z - z_0) + \frac{1}{2}(v^2 - v_0^2) \right\} \right]^{\frac{\kappa}{\kappa - 1}} \tag{26}$$

$$\rho_S = \rho_0 \left[1 - \frac{\kappa - 1}{\kappa} \frac{\rho_0}{p_0} \left\{ g(z - z_0) + \frac{1}{2}(v^2 - v_0^2) \right\} \right]^{\frac{1}{\kappa - 1}} \tag{27}$$

where:

v_0 — designates the velocity in a selected reference node section.

The formulae presented above enable the determination of the aerodynamic potential in the node of a ventilation network. For further analyses we have selected formulae connected with method 1, which have been applied in the computer programme. In order to calculate the value of potential, we must obtain the value of pressure in the node of the network; this may be calculated by means of the equation of motion (6) and from the following dependence:

$$p_S = \sum_{i=1}^{N_n} \sigma_{\varpi,i} \Delta p_i + p_0 \tag{28}$$

where:

p_S — pressure in the node of the network,

$$i = 1, 2, 3, \ldots, N_n$$

$$\varpi = 1, 2, 3, \ldots, D_n$$

$\sigma_{\varpi,i}$ — path-branch matrix, the elements of which assume the following values

$$\sigma_{\varpi,i} = 1 - 1{,}0$$

depending on whether branch number i lies in accordance with the orientation of the path, is inconsistent with it, or does not consist a part of the ventilation path, while D_n is the number of the ventilation paths and N_n is the total number of branches covered by a given ventilation system;

$\Delta p_i = p_L - p_{wl}$ — differential pressure between the inlet and outlet of branch number *I*.

The quantity Δp_i present in formula (28) may be determined from the equation of motion (6) given for branch number *i*. Introducing dependence (6) to (28), we obtain:

$$p_S = p_0 + \sum_{i=1}^{N_n} \sigma_{\varpi,i} \left(h_{w_i} - g\rho_{sr_i}(z_{L_i} - z_{0_i}) - \frac{R_i}{\rho_{sr_i}^2} G_i |G_i| - w'_i \right) \tag{29}$$

Formula (29) makes it possible to calculate the value of pressure in the node of the ventilation network.

4. Application of the potential diagram for depicting the flow of fire gases in a network of mine headings

4.1. Preparing the potential diagram

The ventilation network of a mine is usually depicted by means of spatial, canonical and potential diagrams. In order to illustrate the pressure ratios in a mine ventilation network, we use potential diagrams, which are also a calibrated canonical diagram. Determining the potential diagram by means of, for example, H. Bystroń's method necessitates the taking of special ventilation measurements in the mine, the calculation of potential in the nodes of the ventilation network and — finally — the execution of measurements of the natural accumulation of energy (thermal depression). Once these values are calculated and a spatial or — better still — canonical diagram is obtained, it is possible to develop a potential diagram. This operation is extremely time-consuming, due to the considerable complexity of the ventilation network and the necessity to obtain a lucid and legible drawing of the potential diagram.

The ever-increasing role of computers and their application in the ventilation departments of mines necessitate constant supplementation of available software for systems intended to assist the work of ventilation engineers. In this respect the authors have elaborated a computer programme which enables the semi-automatic evolution of the potential diagram to be made. This programme operates under the VENTGRAPH system and uses its data base. In addition, the drawing developed by the SCHEMAT programme may be further processed using the EDRYS programme. The authors are convinced that this programme serves to significantly improve the elaboration of the potential diagram. The drawing of the potential diagram thus obtained fulfils the conditions for its application using the POŻAR computer programme for the graphical presentation of the results of the computer simulation. At the same time, the drawing is an initial picture which enables the flow of fire gases in the network of headings presented by means of the potential diagram to be seen readily. The POŻAR programme has been modified and extended by the addition of certain new procedures:

- calculation of current values of pressure in the nodes of the ventilation network on the basis of formula (29),
- calculation of current values of aerodynamic potential in the nodes of the ventilation network; formula (22),
- modification of the location of the ventilation node in accordance with its new aerodynamic potential value,

- modification of the location of descriptions of the nodes on the drawing of the potential diagram,
- modification of the method of depicting fire gases moving through the branch as a constituent element of the diagram.

4.2. Example of the computer simulation of the propagation of fire gases

In order to provide an example illustrating the changing pressure and potential values brought about by the movement of hot fire gases within the ventilation network, the authors have selected one of the areas of mine P. Data concerning parameters profiling this area were obtained from the ventilation department of the mine. A spatial diagram (Fig. 1) and potential diagram (Fig. 2) were derived and subsequently imaged digitally using the EDRYS programme. In the course of the simulation, the drawings (copies of the computer screen displays) were supplemented with the results of simulation calculations forecasting the process of ventilation as disrupted by the developing fire.

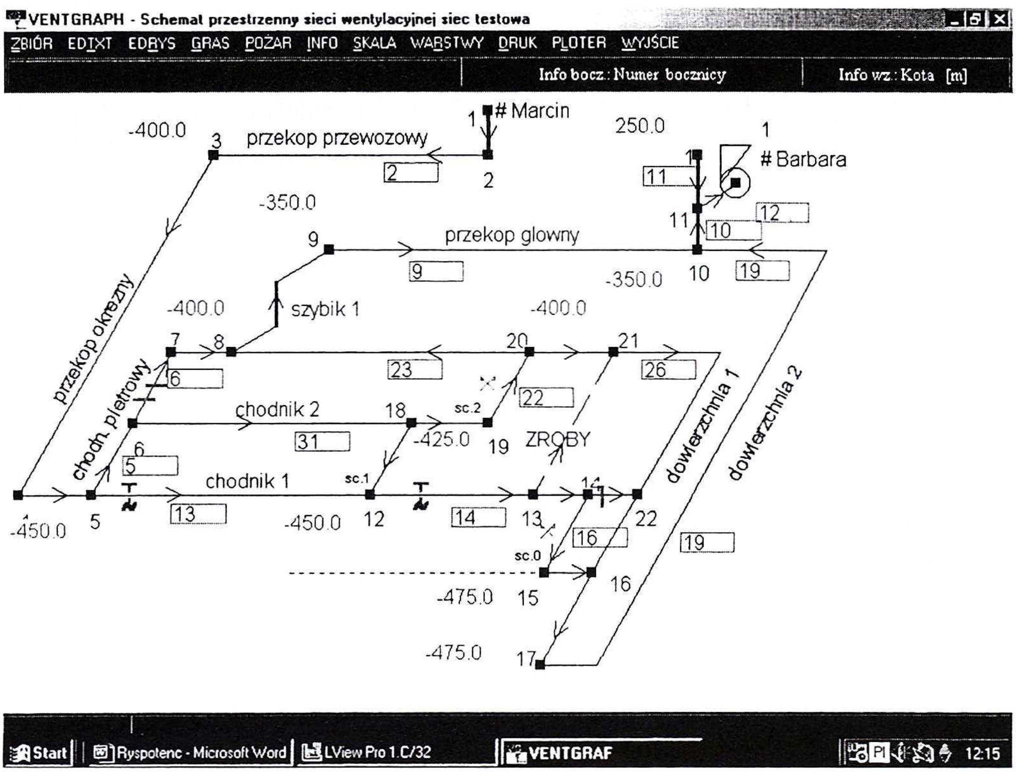

Fig. 1. Spatial diagram of an exemplary ventilation network — computer simulation, initial stage

Rys. 1. Schemat przestrzenny przykładowej sieci wentylacyjnej — symulacja komputerowa, stan początkowy

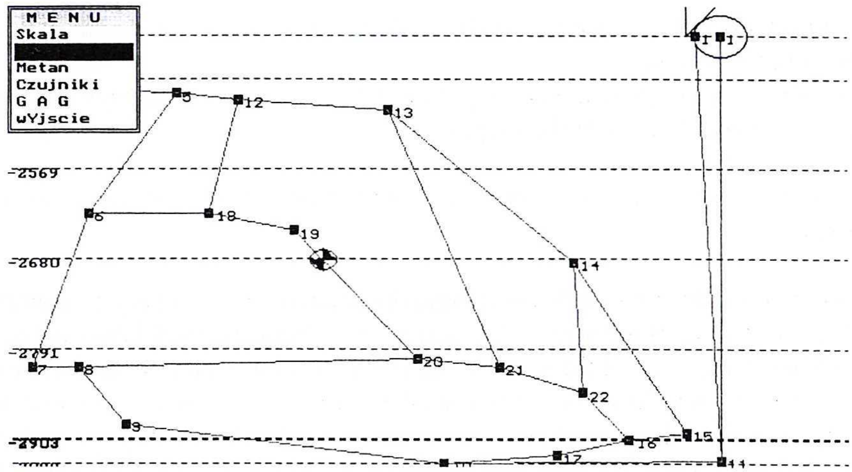

Fig. 2. Potential diagram of an exemplary ventilation network — focus of the fire in branch 19–20

Rys. 2. Schemat potencjalny przykładowej sieci wentylacyjnej — ognisko pożaru w bocznicy 19–20

A fire is developing in branch 19–20 (beginning of longwall sc.2). The initial value of potential of the point of location of the fire is $\Phi_v = -2680$ [J/m^3]. Fig. 3 presents the propagation of air and fire gases 95 minutes after the commencement of the simulation. The thick green line designates headings in which fire gases are currently present.

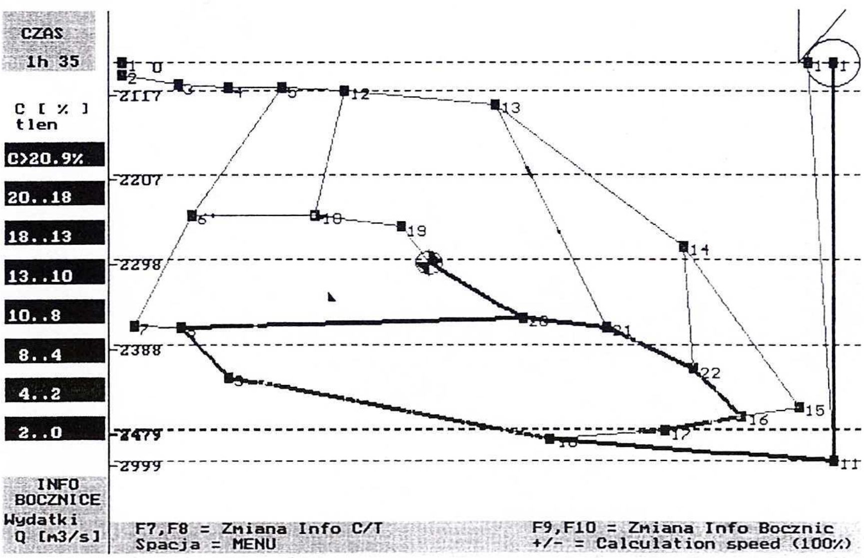

Fig. 3. Potential diagram of an exemplary ventilation network — focus of the fire in branch 19–20, computer simulation

Rys. 3. Schemat potencjalny przykładowej sieci wentylacyjnej — ognisko pożaru w bocznicy 19–20, symulacja komputerowa

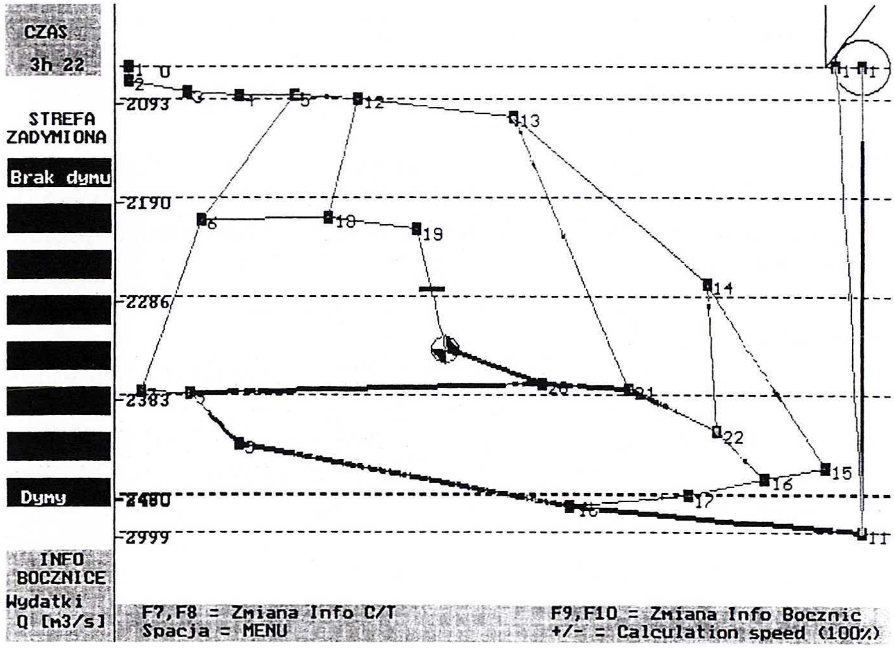

Fig. 4. Potential diagram of an exemplary ventilation network — fundamental stopping in branch 19 – Fire, computer simulation, time = 3 h 22 min

Rys. 4. Schemat potencjalny przykładowej sieci wentylacyjnej — taśma zasadnicza w bocznicy 19 – Pożar, symulacja komputerowa, czas 3 h 22 min

The value of the potential at the point of location of the focus of the fire has decreased and currently equals $\Phi_v = -2298$ [J/m^3]. In order to inhibit the further development of the fire, it has been decided to limit the inflow of fresh air to the the fire by the construction of a fundamental fire seal close to the inflow to the fire.

Fig. 4 shows the effects of these actions on the propagation of the mixture of air and fire gases. The erection of the fundamental fire seal has brought about a change in the direction of flow in headings 20–21 and 21–22. The reversal of the direction of flow has made it possible to eliminate smoke from this area, which covers the following headings: 20–21, 21–22, 22–16, 16–17 and 17–10. The value of the potential at the focus of the fire has changed and currently equals $\Phi_v = -2336$ [J/m^3].

5. Summary

The present study, the results of which are presented numerically, is concerned with the arrival at solutions in a situation where fire gases are propagated in a network following the occurrence of a fire at the beginning of wall sc. 2, air split 19–20 (Fig. 1). Figs. 2, 3 and 4 show the change in the value of the potential of nodes within the network during the development of the fire and following the erection of a fundamental fire seal. We may observe the following:

- new location of nodes of the network on the potential diagram, these differing in relation to the value of the potential,
- the influence of fire-related phenomena on the change in the value of the potential in the nodes of the ventilation network. As regards the point of location of fire, we may state that the development of the fire leads to a decrease in the absolute value of the potential. The erection of a fire seal causes the absolute value of the potential to increase; these changes are, however, dependent on the value of resistance of the seal.

Influence of the flow of hot fire gases on changes in the distribution of pressure, which determines the value of aerodynamic potential.

In addition, the method of presenting the potential diagram of a ventilation network described, combined with the possibility of simultaneously updating potential value calculations, makes it possible to observe the influence of forecast changes under ventilation conditions leading to the equalising of potential around the fire area. As a result, it is possible to evaluate all selected ventilation operations rapidly.

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