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# JUSTIFICATION OF A METHODICAL APPROACH OF AEROLOGIC EVALUATION OF METHANE HAZARD IN DEVELOPMENT WORKINGS AT MINES OF VIETNAM

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The methods of evaluation of the aerological conditions to be performed for the purpose of normalization of mining conditions are provided in the present review; the location of possible accumulations of explosive gases during the drift of the development workings are taken into account. To increase the safety of the development working regarding the gas factor, a complex evaluation of a working was developed with respect to the dynamics of methane emission and air coursing along the working which is strongly affected by the character of the leakages from the ventilation ducting. Thereby, there occurs a necessity of the enhancement of a methodical approach of calculation of ventilation of a working which consists in taking into consideration a total aerodynamic resistance of the booster fan including the local resistances of the zones of the working. An integer simulation of the gas-air flows realized on the basis of a software package FLowVision allows to evaluate a change in the methane concentration in the zones of local accumulations.

***Key words***: aerodymanics of unventilated blind workings, explosiveness, local methane accumulation, methane concentration, intersection of workings, aerodynamic resistance, numerical simulation

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**Introduction.** An underground mining extraction of coal at great depth is extensively performed in Vietnam. In such a case, the conditions of underground mining become more challenging due to the increase of the gas content in the seams and the complication of the mine ventilations system. For the increase in the production an implementation of new mining complexes of high performance caused by the growth of the volumes of the preliminary development is necessary. Under the circumstances, a reliable prediction of the locations of methane accumulation within the overall volume of the development workings as well as a reasonable evaluation of the quantity of air needed for the ventilation of the workings in terms of a gas factor are the key elements for ensuring the aerologic safety.

The Vietnamese researches Nguyen Anh Tuan (2009), Chan Tu Ba (2010) et al. studied the issues of the improvement of safety at the coal mines of Vietnam regarding the gas factor. However, for addressing the problems of the current research it is necessary to study the Russian experience which provides the developed on the basis of the fundamental studies modern engineering methods of control the gas factor under the conditions of the development of gas content seams [1, 5, 6, 12]. The methodical approach of the prediction of the gas emissions and calculation of the needed quantities of the air considering the gas factor are stated in the requirement documents [15]. A practice of conducting the operations under the circumstances of a great number of interfering factors showed that the advanced evaluation of the aerogasdynamic conditions performed with respect to the locations of the possible accumulations of explosive gases in the area of the workings is the most reasonable method of ensuring the safety of mining operations.

In the process of the development of the methodical approach of the evaluation of the aerogasdynamic conditions, the following main tasks were handled:

• the analysis of correlation between the immediate, contributing and associated reasons for gas explosions at the coal mines of Vietnam and Russia;

• the study and differentiation of various factors which influence on the development of gas conditions and the dynamics of gas emissions within the network of blind and ventilated development workings;

• the study of the mechanisms of formation of local methane accumulations in the unventilated blind entries;

• the development of the method and leading of the observations for understanding the dynamics of gas conditions in the unventilated blind development entries;

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• the scientific justification and the development of the project methods of calculation and control of the ventilation inside the unventilated blind entries considering the gas factor.

**Methods of research.** In the process of undertaking a study the following issues were completed: the analysis and integration of the scientific and practical experience considering the ventilation of blind development entries of the coal mines of Vietnam and Russia; the processing and the statistic analysis of field data of air and gas surveys; the numerical mathematical simulation of the air and trace gases coursing with the help of a modern software packages; the analytical study of the calculation formulas. The aerologic safety of the development working is suggested to evaluate with respect to the dynamics of methane emission and air coursing along the working, which is significantly affected by the character of leakages from the ventilation ducting [11].

**Results of research.** The field observations were undertaken in order to update the influence pattern of the stated above factors as well as to determine real aerodynamic resistance of the ventilation ducting. The patterns obtained are shown in Fig.1.

The conducted studies showed that the analytical calculation of the leakages along the ventilation ducting in some cases gives the results which differ significantly from the data of the field observations. According to the experiments, considering the ventilation ductings which were observed at the coal mines, only 3.4 % of them have the leakages of air within the limit values reflected in the existing reference documents and reference books and in the rest of cases the leakages are above the limit values [5, 9].

The analysis of the results of the field observations showed that the value of leakages along the ducting may properly follow the equation of the form $y = 1 + a(1 - x)^n$. The approximation results are represented by the following pattern

$$\frac{Q(x)}{Q_f} = 1 + (k_{\text{duc}} - 1)\left(1 - \frac{x}{L_{\text{duc}}}\right)^n, \quad (1)$$

where $k_{\text{duc}}$ – air leakage factor within the limits of the effective length $L_{\text{duc}}$ of the ventilation ducting.

The estimated amount of the air running through any cross-section of the working taking into account air leakages along the working may be expressed by the following pattern

$$Q(x) = Q_{\text{duc}}(x) = Q_f + (Q_{\text{wor}} - Q_f)\left(1 - \frac{x}{L_{\text{duc}}}\right)^n. \quad (2)$$

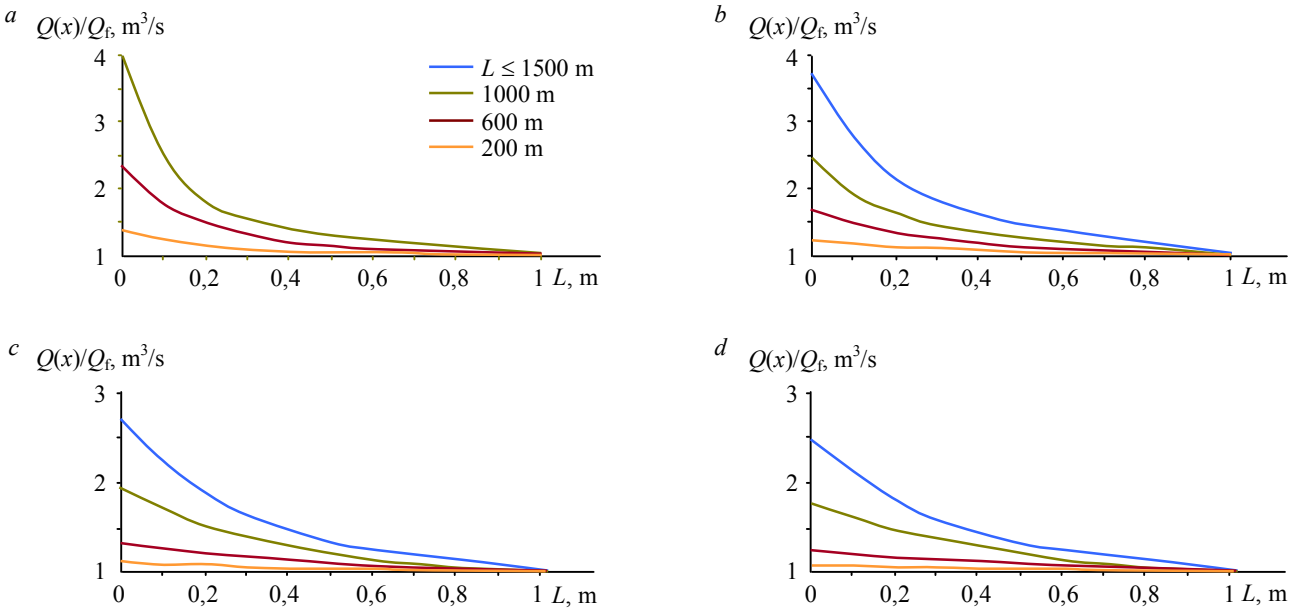



Fig.1. The representative patterns of distribution of the rate along the dimensionless length of the working for the workings of various length and diameter of the ducting (section length 20 m, $Q_f \leq 5$ m$^3$/s)
$a$ – $d_{\text{duc}} = 0.6$ m; $b$ – $d_{\text{duc}} = 0.8$ m; $c$ – $d_{\text{duc}} = 1.0$ m; $d$ – $d_{\text{duc}} = 1.2$ m

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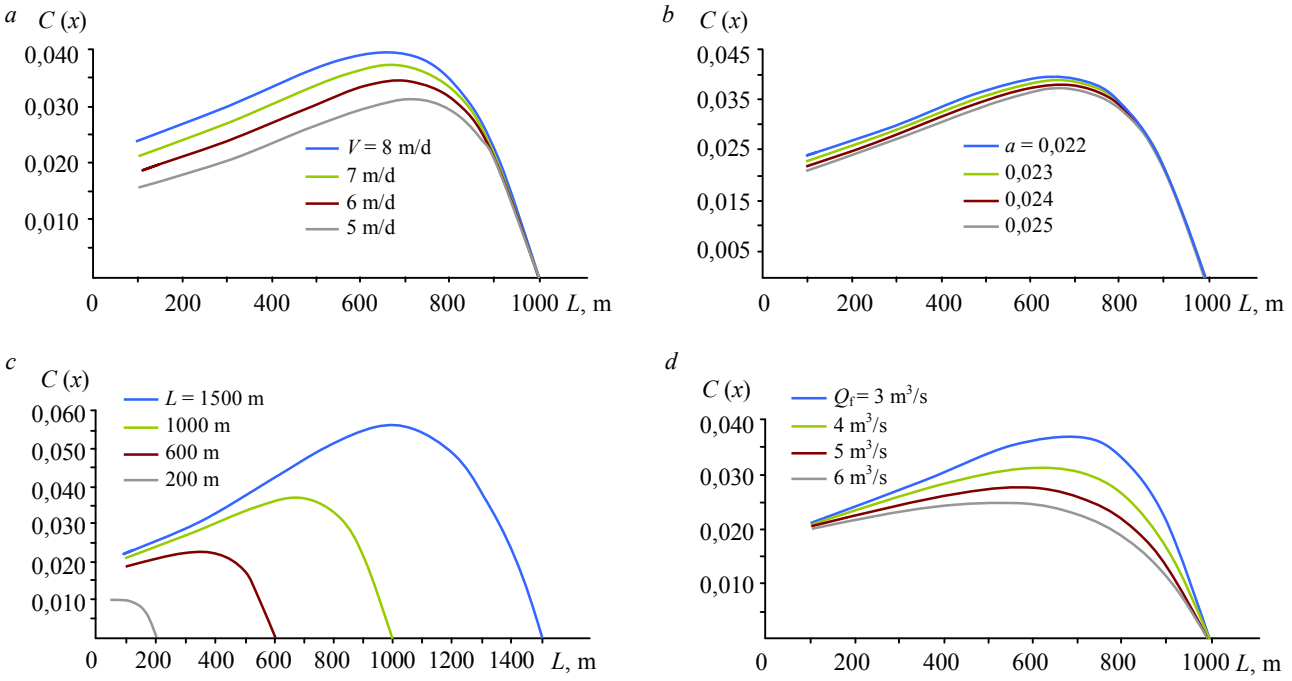



Fig.2. The types of pattern reflecting a change in methane concentration along the working in case of leakages in a ducting for various values of the design parameters: *a* – tunneling speed *V*; *b* – coefficient *a*; *c* – length of a working *L*; *d* – amount of air delivered to the face $Q_f$

The obtained pattern (2) qualitatively coincides with the results of the field observations and allows to determine the quantitative value of the leakages of the air from the ventilation ducting to the blind part of the working.

The pattern describing a change in methane concentration in the zone of a working of *x* length in case of leakages in the ducting and gas emission may be presented as the following [6]:

$$C(x) = \left(\frac{P}{Q(x)}\right)\left(\frac{g_0 V}{a}\right)\left(1 - e^{\frac{-a(L-x)}{V}}\right), \quad (3)$$

where *a* – a factor describing a degree of reduction of the specific volume velocity of methane emission through the free face of the coal, 1/day; $g_0$ – an initial value of the specific volume velocity of methane emission, ($m^3$/(min·$m^2$); *V* – tunneling speed, m/day; *P* – a perimeter of the gas discharging surface in the working, m.

The expression (3) is a pattern which reflects a change in the methane concentration taking into account the leakages from the ventilation ducting along the working [6]. At the intermediate point between the face and the throat there is a maximum of the pattern with the highest concentration of methane (Fig.2).

The analysis of the obtained patterns shows that the following factors contribute to the offset of the point of high concentration of methane towards the throat [6]: the reduction of leakages from the ducting; the increase of the development of a working; the increase of the length of a working; the increase of the air delivered to the face.

To control methane level in the zone of the elevated concentration, an installation of extra sensors which would contribute to the increase of aerological safety in the development workings is necessary [6, 16].

As a part of the study, a revised calculation of all possible resistances of the elements of unventilated workings for the cases of various rates and angles of intersection of workings was made. The following types of resistances which are not taken into account during the routine calculation were considered in the paper: turnings, narrowing, expansion of the workings, friction of support, intersection of workings. The schemes for calculation are presented in Fig.3.

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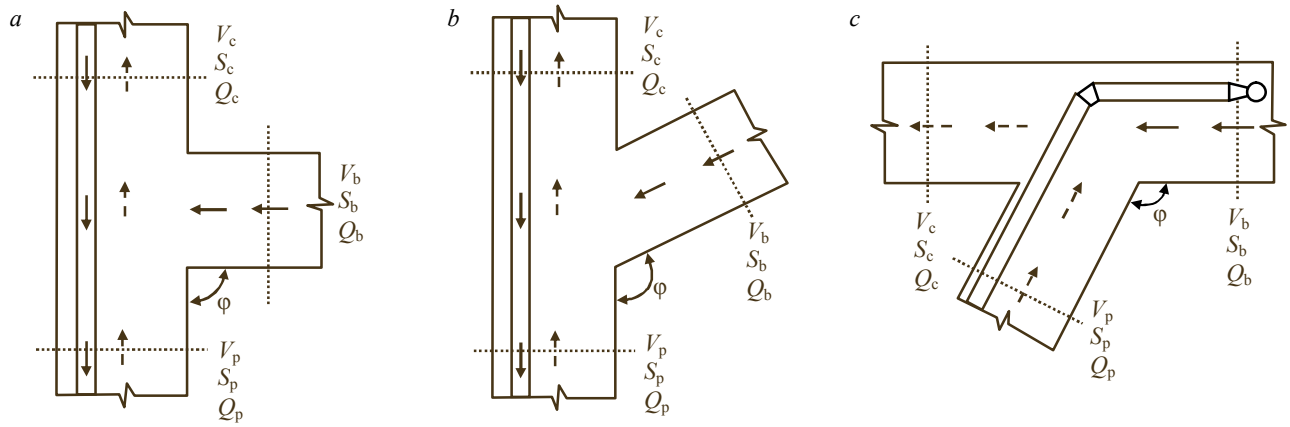



Fig.3. Schemes for calculation of the local resistances of intersections:
*a* – for $\varphi \le 90°$; *b* – for $180° > \varphi > 90°$ forward pass of a stream; *c* – for $180° > \varphi > 90°$ pass of a stream with an angle

The calculation of a local resistance coefficient of the inflow intersection was made by the patterns which are used in aerology and industrial ventilation for the angles $\varphi \le 90°$ under conditions of the forward pass of the air stream [7, 10] (Fig.3, *a*):
for angle $\varphi = 90°$

$$\xi_{ii} = \frac{\alpha\chi\left(V_p^2 - 2V_p V_c \frac{Q_p}{Q_c} + V_c^2\right)}{V_p^2};$$

for angle $\varphi < 90°$

$$\xi_{ii} = \frac{\alpha\chi\left(V_p^2 - 2V_c \left(\frac{Q_p}{Q_c} V_p + \frac{Q_b}{Q_c} V_b \cos\varphi\right) V_c^2\right)}{V_p^2},$$

where $Q_p$, $Q_b$, $Q_c$ – air rates in the workings, $m^3/s$; α – coefficient of friction, $(N \cdot s^2)/m^8$; φ – angle of intersection; χ – correcting coefficient of the form of section; $S_p$, $S_b$, $S_c$ – cross-section areas of the workings, $m^2$.

The value of a local resistance of the intersection is calculated by the formula

$$R_{ii} = \frac{\alpha\chi\rho\left(V_p^2 - 2V_p V_c \frac{Q_p}{Q_c} + V_c^2\right)}{2Q_p^2}.$$

Under the certain conditions the parameter $\xi_{ii}$ may reach considerable values. When $\xi_i = 65$ depending on the values of the cross-section areas the relative value of the intersection will give extra 4-6 % to the resistance of the ducting of 1000 m length.

For calculating the intersection of the workings with the angle $180° > \varphi > 90°$ for various rates and angles the formulas which were obtained by trial on the basis of physical simulation may be used [3] (Fig.3, *b*, *c*).

For the forward pass of a stream and for the stream pass with an angle the coefficients of the local resistance of the inflow intersection were calculated by the corresponding formulas:

$$\xi_{ii} = \frac{6{,}27}{\rho(1+\cos\varphi)} \frac{S_b}{S_p} \left(\frac{Q_b}{Q_p}\right)^2;$$

$$\xi_{ii} = \frac{12{,}44}{\rho(1+\cos\varphi)} \frac{S_b}{S_p} \left(\frac{Q_b}{Q_p}\right)^2.$$

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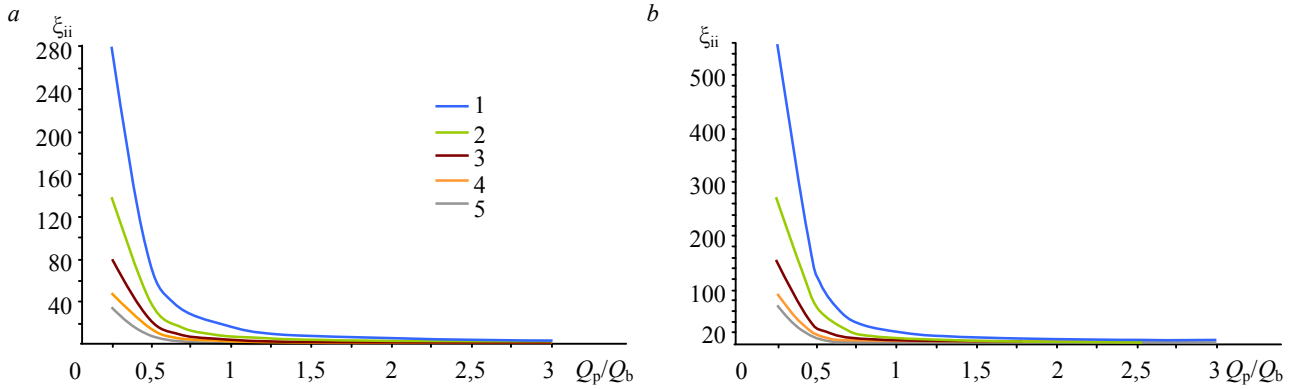



Fig.4. Results of calculation of the coefficients of local resistance (for φ = 135°):
*a* – for forward pass of a stream; *b* – for pass of a stream with an angle
1 – square cross-section; 2 – arch; 3 – complex; 4 – rectangular; 5 – round

The results shown in Fig.4 confirm that for the small values of air rates relations the coefficient of local resistance of intersection for the forward pass of a stream will be equal to a maximum value $\xi_{ii} = 280$; for the pass of a stream with an angle ($\varphi = 135°$) for small values of air rates relations the coefficient of the local resistance of intersection will be equal to the maximum value $\xi_{ii} = 554$. Thereby, the total resistance of a working with consideration for the resistance of the intersection increases for more than 14-28 % comparatively to the resistance of a ducting.

On the basis of the results of analytic studies we may conclude that similar types of aerodynamic resistances should be taken into account under the certain conditions for calculations of the ventilation of blind entries.

The suggested enhancement of the methodic approach of calculation of the ventilation of the development working will allow to determine the additional resistance of the booster fan of the zones of a working including the local resistances of the intersections.

The main task of the studies was to estimate a possibility of using the software product FlowVision for mathematical simulation of air flows stream in the areas of possible local accumulations and location of mining equipment with the geometry parameters of design models corresponding to the real conditions. For this purpose mathematical 3D-models of the workings and cutouts of certain cross-sections and configurations to be the geometric boundaries of the air flows stream were created in the VRML format. To create 3D-models in the STL format a software package of SolidEdge (Siemens) was used. Further the models were imported to the FlowVision program where the Navier-Stokes equations were numerically solved for the incompressible liquid. These 3D-models are geometry boundaries for the air flows stream [2, 13, 14].

An "incompressible liquid" flow was taken as a model and the following initial conditions were set: a temperature 293 K; a pressure 101000 Pa; a molecular mass 28.9 g/mol; a density 1.21 kg/m$^3$; a dynamic viscosity $1.82 \cdot 10^{-6}$ Pa·s. The boundary conditions are the following: a wall with the logarithmic boundary layer and roughness – 0.2; an inflow and outflow with the given speed 0.15 m/s – a flat surface [17]. The following tasks were completed during modeling of the process of air flows ducting:

• an evaluation of the adequacy of a picture of a field of velocities to real conditions was performed;

• fields of velocities for the case of ventilation of the development workings were obtained.

During the simulation of gas traces coursing the conditions under which two substances (air and methane) will interact were additionally included; the inflow and outflow of methane with the given velocity. The following parameters were set: the length of the unventilated blind working, the length of a zone with a through flow, a T-junction of a dead-end pass and a working with the through flow, a width of a working, an area of cross-section.

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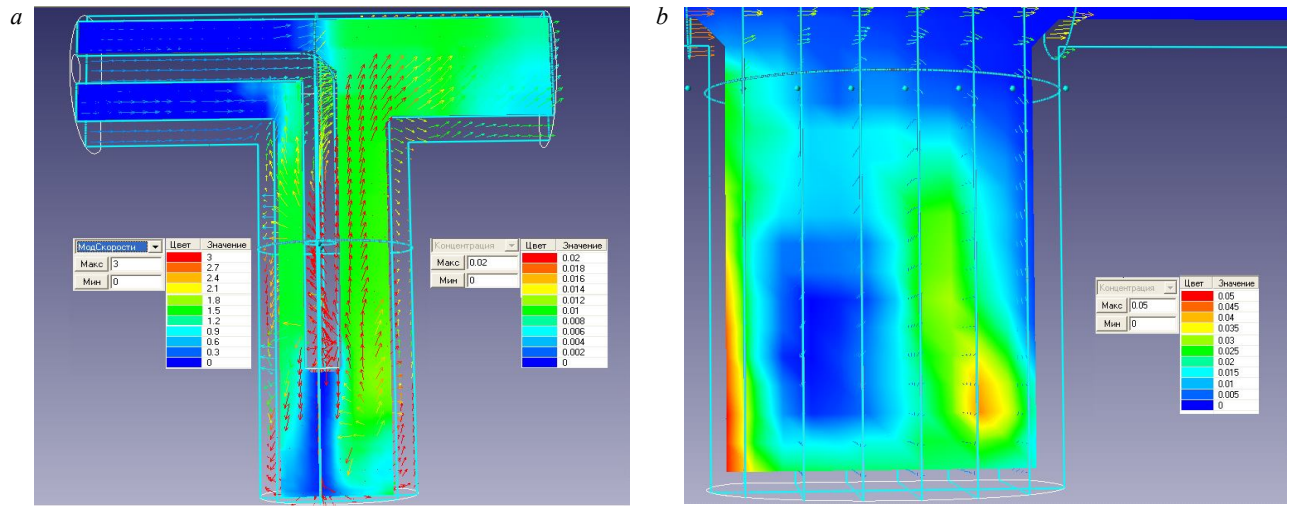



Fig.5. The distribution of the velocities of a flow and the fields of methane concentration in the blind entry (*a*); in the outcut (*b*)

The examples of visualization of the velocities of air flows and the distribution of the fields of concentration and emission of methane in the adjoining workings – outcuts are shown in Fig. 5.

As a part of a study, there was revealed that the location of an equipment in the dead-ends and outcuts affects the aerodynamic picture of the flows and encourages the occurring of possible local accumulations of methane of the elevated concentration [8].

Thus, the dynamics and monitoring of the explosive concentrations of methane in the face space and along the unventilated blind development entries may be performed with the help of mathematic simulation [16,17].

## Conclusions

1. An integration and a comparative analysis of the aerologic safety of the mines of Vietnam showed that the near accident the reasons for which are connected with the peculiarities of aerogasdynamic processes may be eliminated only in case of a timely detection of explosive accumulations of methane not only in the face space but also in the rest working area of the unventilated blind entries in the zones of air stagnation formed as the result of a change in the configuration and cross-section area, intersections of the workings, location of the equipment.

2. The basis of the developed method of aerologic evaluation of methane hazard in the development working is composed by the obtained pattern which reflects the change in methane concentration in case of the leakages from the ventilation ducting distributed along the working. The analysis of a pattern demonstrates that the field of methane concentration reaches a maximum at the intermediate point between the face and the throat of a working; additional measures of control should be applied in such points.

3. Aerodynamic resistances of the intersections of the workings reach the maximum values, which are not taken into account during routine calculation of the resistance of a fan; a form of a cross-section, a rate relation in the workings and an angle of a junction influence to a great extent on the value of the aerodynamic resistance.

4. An enhancement of the methodic approach of calculation of the development entries was suggested as the most efficient solution focused on the increase of the effectiveness of ventilation; the main idea consists in taking into consideration of the total aerodynamic resistance of the booster fan which should include the resistance of not only a ducting but also the additional local resistances of the zones of a working.

5. An integer simulation of the gas-air flows realized on the basis of the software package FLowVision allows to evaluate a change in the methane concentration in the zones of local accumu-

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lations. Conformance with the geometric similarity is considered to be a key element in the simulation of the field conditions; the location of the equipment in the dead-ends and cutouts as well as a change in the form of junction influence on the aerodynamic picture of the air flows and encourage the occurrence of the local accumulations of methane of the elevated concentrations.

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