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THE PRELIMINARY ANALYSIS OF DISTRIBUTION OF THE VELOCITY FIELD AND AIR PRESSURE FLOWING THROUGHT THE MINING HEADINGS WITH DIFFERENT GEOMETRY OF CROSS-SECTION

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Abstract:
The basic meaning for the security of persons working in underground mining heading heir ventilation of headings. Providing the fresh air into the active mining heading is a fundamental task of ventilation service in the mine. Very significant impact on the efficiency of the ventilation process has the physical parameters of supplied airflow, such as its amount, speed and pressure. These parameters can be determined based on the "in situ" tests or modeling tests. Carrying out the tests in underground conditions is very expensive and not always available due to exploitation. As an alternative, in such cases the modeling tests can be used, which give more possibilities of analysis the impact of differentials factors on the studied parameters. In the paper there is presented results of modeling of airflow in mining heading, obtained basing on the numerical simulations with use of finite volume method in ANSYS Fluent software. The physical models of headings were prepared basing on the real cross sections of the dog headings. To find the solution of the mathematical model, the k-ε turbulence model was used.

Key words: *airflow, velocity, static pressure, geometry of cross-section, computational fluid dynamics*

INTRODUCTION

The fundamental meaning for the safety of persons working in underground hard coal mine headings has proper ventilation of headings [4]. On the efficiency of ventilation process of mining headings has the parameters of supplied air, such as velocity, pressure and volumetric flow. The velocity of air stream flowing through the mining headings has also significant effect, connecting with microclimate of working environment [2, 3]. The parameters of flowing air through the mining headings are determined based on the *"in situ"* tests. However, due to the environmental conditions in mining headings, including exploitation, and also due to the hazards occurring in headings, measurements of parameters of flowing air stream are not always available to perform.

Nowadays, more often for solving problems associated to process of ventilation of mining headings numerical methods are used. However, it should be noted that obtained results based on the numerical simulations for their reliability should be verified, basing on the experimental tests.

In this paper results of simulations of the impact of cross-section geometry of mining heading on the physical parameters of the airflow are presented. Analysis was performed for straight sections of headings, with the same cross-section for four different geometries of these cross-sections. Assumed geometries of cross-sections of headings in practice are used the most often.

MODEL OF THE AIRFLOW

Computational Fluid Dynamics (CFD) is a simulation method of processes connected with flow of liquids and gases, heat and mass transfer, or chemical reactions [6].

Software based on the Computational Fluid Dynamics (CFD) allow to obtain necessary information, concerning the mass flow of air stream or liquid (distribution of velocity field, distribution of pressure field), heat transfer (temperature field), and also the physical-chemical changes.

To perform the model tests, ANSYS Fluent 13 software was used, which uses the Finite Volume Method. This method is used to solve problems, in which the principle of continuity of the field variable in the considered area has not to be fulfilled [5, 6].

The Finite Volume Method bases on integration of equations which describe the problem of each control volume, resulting in discrete equations, fulfilling laws of conservation within each element.

Problem connected with the airflow through mining headings in the Ansys Fluent software are solved based on the equation of mass conservation and on the equation of momentum conservation, which take the following form [1]:

a. The Mass Conservation Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m \qquad (1)$$

where:

v - velocity, m/s,
ρ - density, kg/m^3,
t - time, s,
S_m - the mass added to the continuous phase from the dispersed second phase, kg/s.

b. The Momentum Conservation Equations

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v}\vec{v}) = -\nabla p + \nabla \cdot (\overline{\overline{\tau}}) + \rho \vec{g} + \vec{F} \qquad (2)$$

where:

p - static pressure, Pa,

$\overline{\overline{\tau}}$ - the stress tensor, Pa,

$\vec{g}$ - the gravitational body force, m/s^2,

$\vec{F}$ - the external body forces, N.

To model the airflow through the mining heading, the k-ε turbulence model, implemented in software, was used. In this model Navier-Stokes Equation was rearranged in so-called an Averaged Navier-Stokes Equation, which includes the additional term – Reynolds stress tensor [2]. For single-phase flow, equations of the kinetic energy of turbulences k and the kinetic energy dissipation speed of turbulences ε take form:

c. k-transport equation

$$\rho\frac{\partial k}{\partial t} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \mu_t S^2 - \rho\varepsilon \qquad (3)$$

d. ε-transport equation

$$\rho\frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{\varepsilon}{k}\left(C_{1\varepsilon}\mu_t S^2 - \rho C_{2\varepsilon}\varepsilon\right) \qquad (4)$$

where:

$C_{1\varepsilon}$, $C_{2\varepsilon}$ - constats,

σ_k, σ_ε - turbulent Prandtl numbers for k and ε.

MODEL OF THE MINING HEADING

An airflow through the three-dimensional models of the mining headings was subjected to CFD numerical analysis. The models have the following geometry of cross-sections: trapezoidal, rectangular and arc. The length of each model of heading amounted to 25 m, and cross-section area 17.2 m. In a Figure 1, analyzed models of mining headings with overall boundary conditions are presented.

Assumed models were submitted to discretization, whose results for heading with arc cross-section are presented in Figure 2.

In order to accurate reproduce determined parameters for all models, concentration of the mesh at boundary layers was performed.

Simulation calculations were performed for the air, whose input parameters for all geometrical models of headings were the same (density 1.225 kg/m^3, and viscosity 1.7894e^{-05} Pa·s).

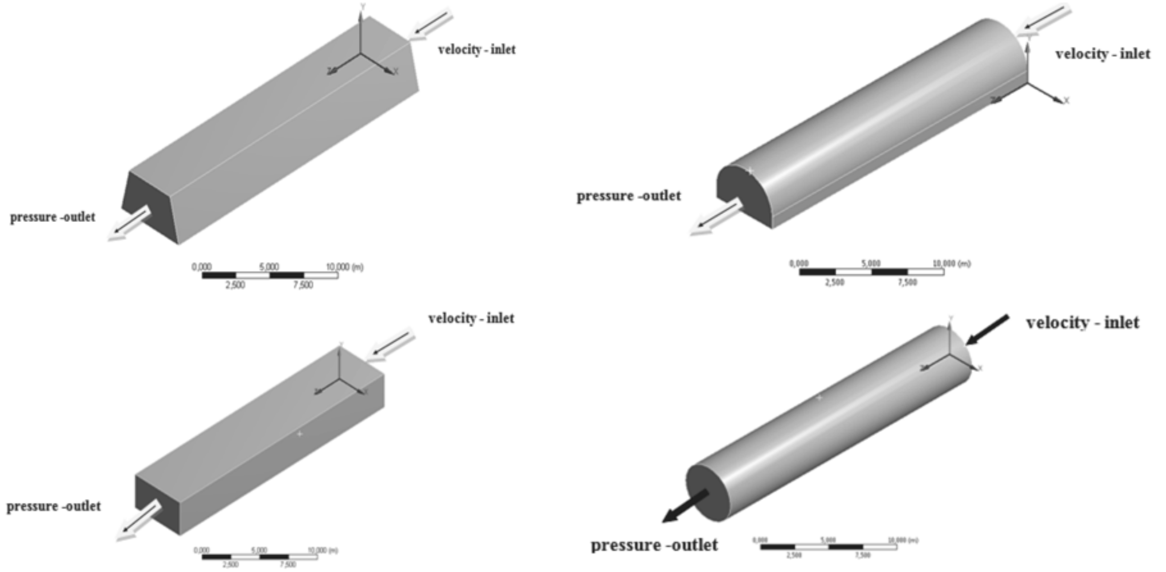

Fig. 1 Models of mining headings

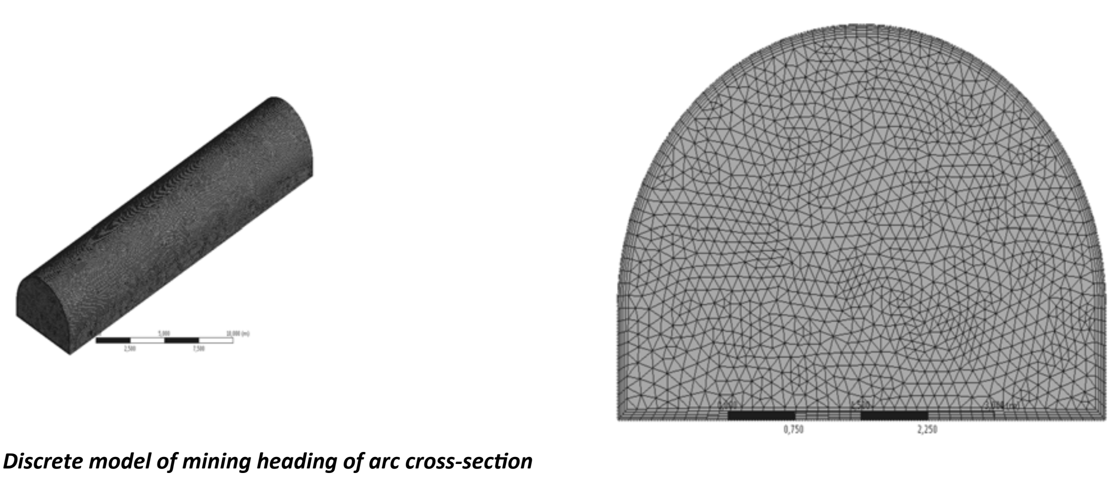

Fig. 2 Discrete model of mining heading of arc cross-section

As the inlet boundary conditions there was assumed a velocity field of the air stream equal to 3.5 m/s, intensity of turbulences of the order of 10%, and the hydraulic diameter equal to 3.8 m. For all geometriacal models of heading, the outlet of heading was defined as outlet boundary condition, whereas walls were defined as impermeable, which sufrace roughness coresponded to height of 0.3 m.

Calculations were performed for the pressure (as reference value) equal to 101325 Pa. Also the resistances for the flowing air stream, caused by the support of dog heading were neglected.

So developed models was subjected to numerical analysis.

THE TESTS RESULTS

Based on performed simulations, distributions of velocity and pressure fields for each of the analyzed mining headings were determined.

In a Figure 3, 4, 5 and 6, distributions of velocities and static pressure in analyzed headings were shown. In Figures marked with letter c the distributions of velocity fields at outlet of headings are shown.

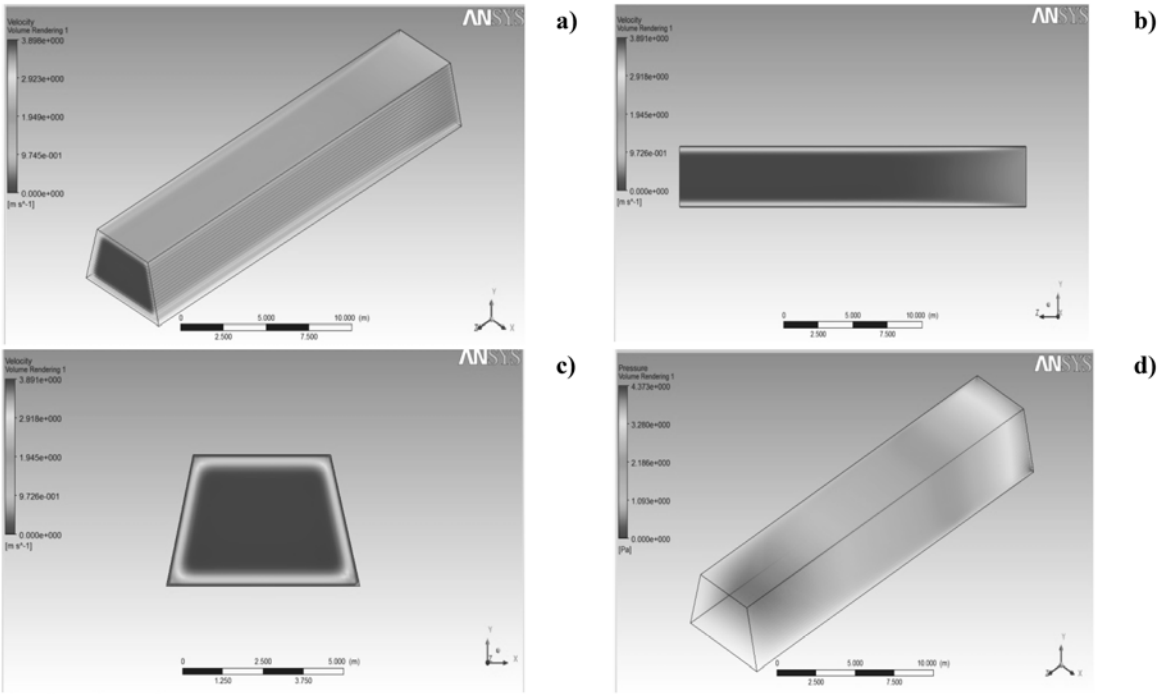

Fig. 3 Distribution of velocity (a, b and c) and static pressure (d) of the air stream, flowing through the mining heading of trapezoidal cross-section

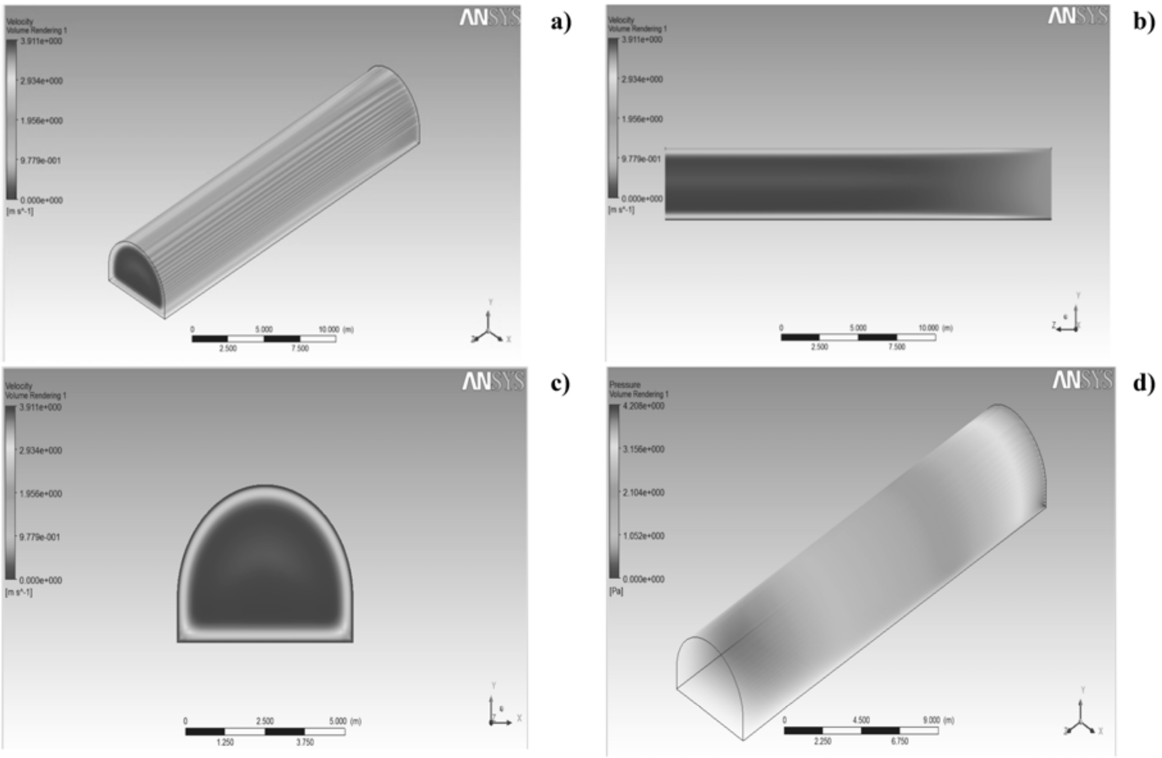

Fig. 4 Distribution of velocity (a, b and c) and static pressure (d) of the air stream, flowing through the mining heading of arc cross-section

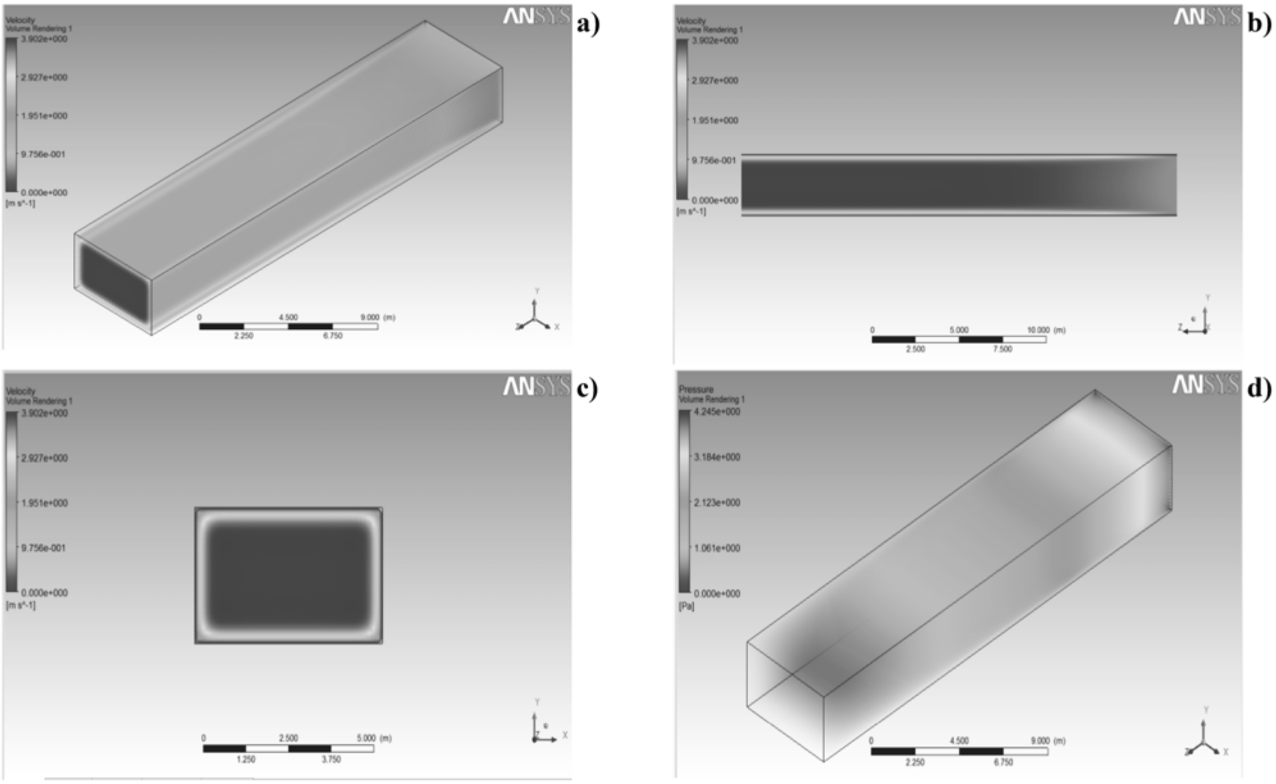

Fig. 5 Distribution of velocity (a, b and c) and static pressure (d) of the air stream, flowing through the mining heading of rectangular cross-section

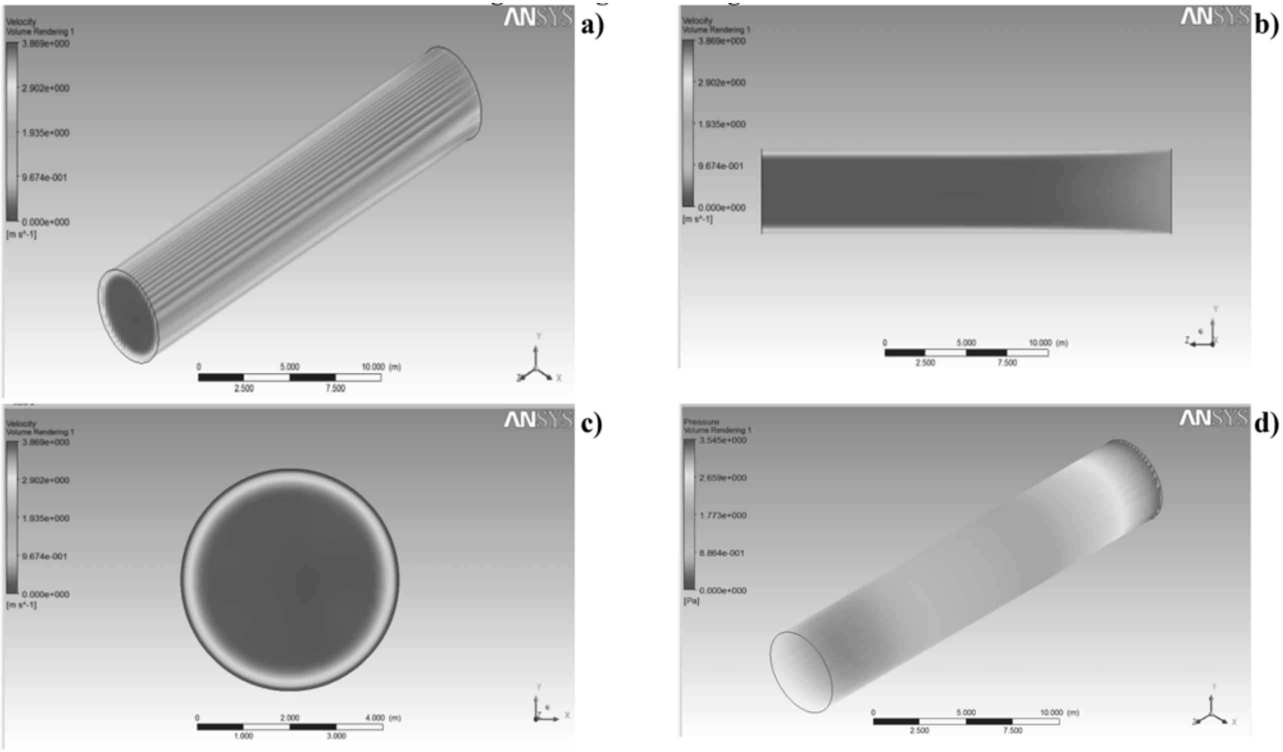

Fig.6 Distribution of velocity (a, b and c) and static pressure (d) of the air stream, flowing through the mining heading of circular cross-section

On a base of obtained velocity fields of air stream at outlet of each of headings, its maximal, minimal, and average value was determined. Results are presented in a Figure 7.

Analyzing obtained results one can state, that the largest differences at outlet of heading occurring for minimal velocity. In a case of mining headings of trapezoidal and circular cross-section, this value equals to 1.02 m/s, and for other headings 1.12 m/s. In a case of average and maximal velocities of air stream, differences are small.

In Figures 8 and 9, distributions of velocities in cross-sections at outlet of mining headings along horizontal line pass through theirs middles are presented.

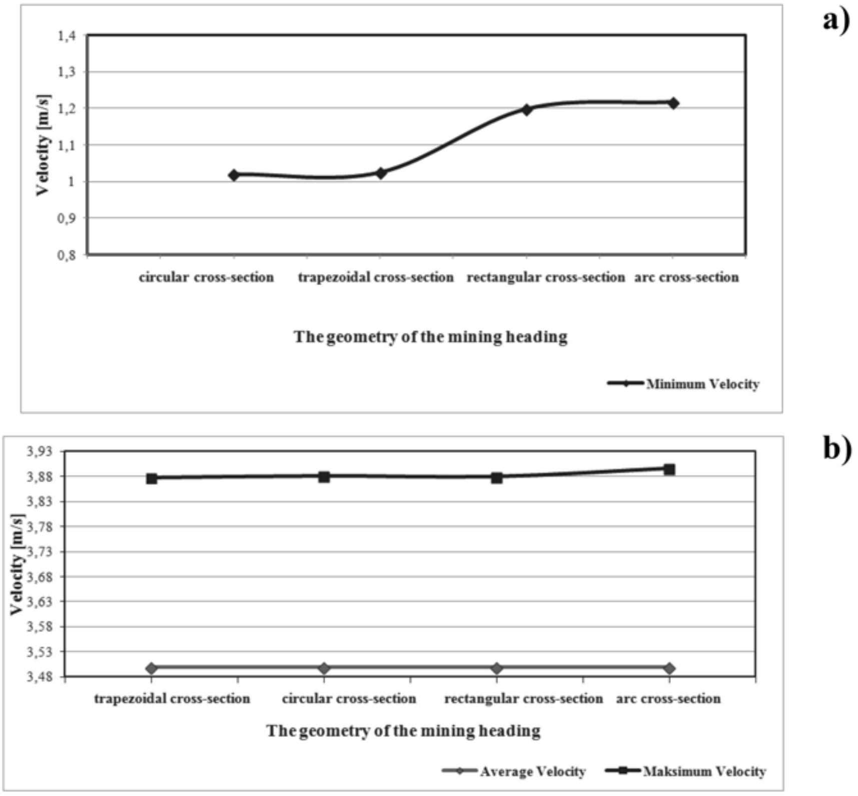

Fig. 7 The averages, maximum (a) and minimum (b) values of velocity at outlet of heading

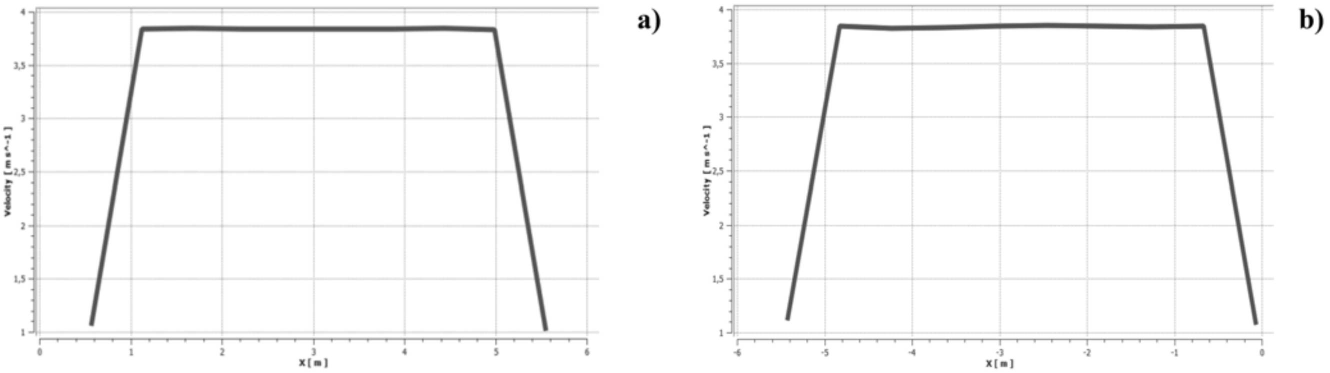

Fig. 8 Distributions of velocity at outlet of heading of trapezoidal (a) and arc (b) cross-section

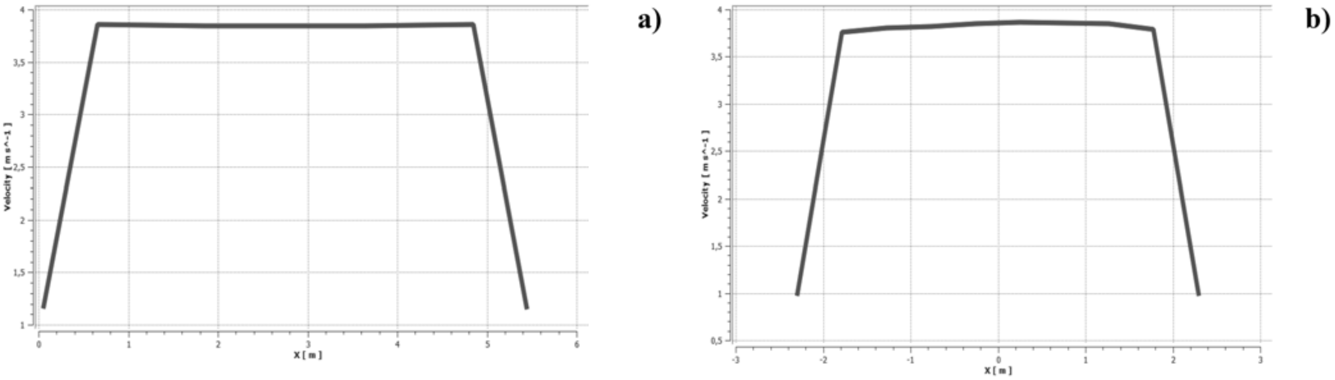

Fig. 9 Distributions of velocity at outlet of heading of rectangular (a) and circular (b) cross-section

Based on presented distributions one can state, that in the vicinity of boundary layer the velocity of flowing air stream decreases, as a result of resistances connected with set surface roughness.

Using determined pressure fields in Figures 10 and 11, course of changes in static pressure along horizontal axis, passing through their middle of cross-sections in analyzed headings are presented.

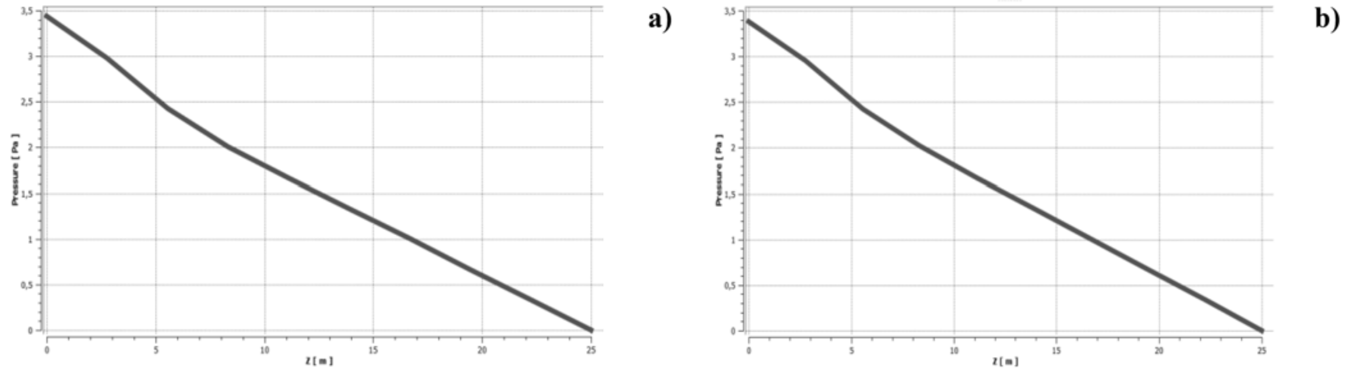

Fig. 10 Static pressure drop along the heading trapezoidal (a) and arc (b) cross-section

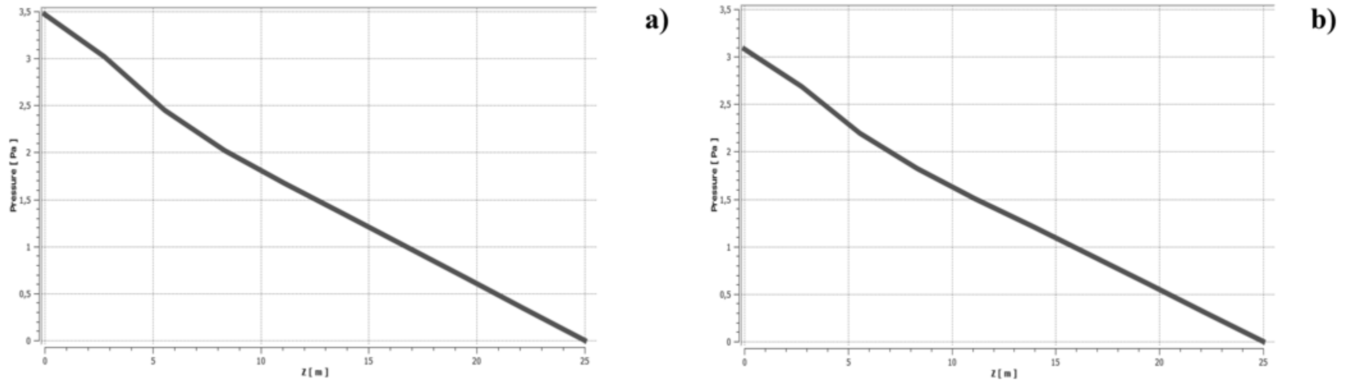

Fig. 11 Static pressure drop along the heading of rectangular (a) and circular (b) cross-section

Analyzing obtained results one can conclude, that during flow of air stream through the heading, pressure drops are observed as a result of friction of heading's wall. In a range of the performed analyses one can conclude that the pressure drops are small. The smallest static pressure drop of flowing air stream occurred in heading of circular cross-section, whereas the biggest – in headings of trapezoidal and rectangular cross-section.

CONSLUSION

Based on obtained results one can state, that the shape of cross-section of heading has an effect on the physical parameters of the air stream flowing through this heading. This is confirmed by determined pressure drops of air stream along the tested headings.

Performed analyses showed that regardless of the shape of the cross-section of headings, there is a tendency for the formation of the boundary layer, where the velocity of air stream significantly deviates from the central part of the geometry of mining heading.

Based on performed results one can state, that application of numerical methods to analysis of airflow through the mining heading give a lot of opportunities for analysis physical parameters of this flow.

Direct measurements of these parameters for the air stream flowing in mining heading are expensive, time-consuming and often also dangerous.

Therefore, it is reasonable to conclude, that the simulation can be a supplement, and in many cases an alternative for the tests carried out in real conditions. The obtained results should be regarded as preliminary, and the developed models, as a basis for further analysis of airflow through the mining headings.

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