Studying aerodynamic resistance of a stope involving CAD packages modeling

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Abstract. In the article, aerodynamic resistance of the stope face is studied in case of selective mining the coal seam. To carry out the research, the methodology of the computational experiment for evaluating the longwall face aerodynamic resistance influence on the efficiency of airing the stope face has been substantiated. The model of the stope face section, equipped with mining and backfilling mechanized complex based on the serial 1KD90 roof support has been developed in the 3D modeling software SolidWorks. The diagrams of the air stream velocity distribution, when it flows in the cross section of the longwall face working space with different positions of stoping equipment and the values of rock-cutting thickness of the seam bottom (rock ledge) have been obtained in the environment of computational module FlowSimulation. The pressure drop along the length of the aerodynamic model of the stope face section has been assessed. The dependences of the average velocity of the air stream flow on the value of rock-cutting thickness have been obtained. The obtained results can be used to improve and modernize the elements of mining and backfilling mechanized complex of machinery and equipment, as well as the technology for selective mining of thin and very thin coal seams in the Western Donbas.

1 Introduction

Studying aerodynamic parameters of mine workings is one of the key tasks in the process of mine ventilation design. Rational aerodynamic longwall parameters make it possible not only to provide a stope with the sufficient air volume but also to improve considerably ventilation stability of that stope [1, 2]. A number of theoretical papers (by such scientists as A.A. Skochinskogo, S.A. Chaplygina, N.Ye. Zhukovskogo, K.F. Prospury, K.K. Fedyaevskogo, A.Ya. Milovicha, and others) deal with both theoretical and experimental studies of body flow. In most cases, the researchers analyzed ventilation stability in terms of general aerodynamic mine working resistance determined either analytically or experimentally [1 – 6].

Nowadays, such studies are little if any. At some mining enterprises, aerodynamic resistance is determined experimentally. As a rule, resistance of mine workings is

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calculated basing upon the reference data.

Mining aerology [7 – 10] highlights three types of aerodynamic resistance – friction resistance, local resistance, and front resistance. General aerodynamic resistance of a ventilation network is calculated using following formula:

$$\sum R_t = \sum R_{fr} + \sum R_{loc} + \sum R_{f.rs}\ , \text{H}\cdot\text{c}^2/\text{m}^8, \tag{1}$$

where $\sum R_{fr}$, $\sum R_{loc}$, $\sum R_{f.rs}$ are total friction, local, and front resistances respectively.

Friction aerodynamic resistance is determined according to expression:

$$R_{fr} = \alpha \frac{PL}{S^3}, \text{H}\cdot\text{c}^2/\text{m}^8, \tag{2}$$

where α is coefficient of friction aerodynamic resistance, H·c^2/m^8; P is longwall perimeter, м; L is longwall length, м; S is cross-section area of a mine working, m^2.

Friction force is stipulated by the air viscosity. It is observed between the air layer and surface of a mine working, equipment and other bodies. In most cases, it acts within the boundaries of flows as well as between them at the moment of flow friction on the surface of structural elements of the support; that results in nonuniform distribution of the velocity of air flow and its deceleration with the formation of boundary layer. According to the literature sources, friction force is 50 – 75% of general resistance of a mine ventilation network; front resistance is 10 – 20%; and local resistance is 15 – 30% [11 – 15].

Changes in the geometry of internal flow boundaries result in local resistances having considerable effect upon the air flow velocity or longwall direction. In general, they occur in mine workings in case of distortion of the flow section (by sudden widening or narrowing of a mine working; turning, division, or merging of flows etc.).

Value of local aerodynamic resistance is found using following expression:

$$R_{loc} = \frac{\xi \rho}{2S^2}, \text{H}\cdot\text{c}^2/\text{m}^8, \tag{3}$$

where ξ is coefficient of local resistance (dimensionless value); ρ is air density, kg/m^3; S is cross-section area of a mine working, m^2.

Front resistance is the resistance to the flow by a body being within that flow. Front resistance of a body being in a mine working is still understudied. When it comes to practice, one should take into account flow-around in terms of different obstacles, i.e. armour elements, props, mine equipment (belt conveyors of various types, electric locomotives, mine cars) – all those factors make up specificity of the consideration of air flow along mine workings. Normally, coefficient of front resistance depends upon the geometry of an object and roughness of its surfaces.

Front resistance force of an object is determined according to formula [16 – 20]:

$$R_{f.rs} = C_x S_b \frac{\rho}{2} v^2\ , \text{H}, \tag{4}$$

where C_x is dimensionless coefficient of front resistance depending upon Reynolds number and geometry of an object; S_b is area of object projection to the mine working cross section, m^2; v is velocity of the oncoming air flow, m/s.

To study front resistance force of a support in a stope, it is required to integrate distribution of pressures along the mine working cross-section for further determination of the force applied within the point, i.e. to evaluate oncoming effect of the environment for a motionless body. In that case, resistance of a stream-lined body may be determined by friction resistance and front resistance (form resistance). Friction resistance will depend upon shear stresses occurring between the air layers as well as upon the roughness of the support surface. Form resistance is demonstrated by means of considerable vortex formation being the result of the impact of a moving flow with the motionless objects as well as after flow separation from the surface of a body which that air flows around.

Main objective of the study is to develop a methodology for evaluating aerodynamic resistance of a longwall as for the efficiency of stope ventilation.

2 Numerical modeling approach

Evaluation of the parameters for mine working support and determination of their rational geometry, in terms of which value of aerodynamic resistance will be minimal, is a topical problem.

That problem may be solved by modeling in CAD systems. Currently, there are numerous programs to study that task [21 – 24]. A methodology consisting of three stages is proposed to be used for the research:

1. Development of 3D-model taking into consideration real geometrical parameters of a production unit (Fig. 1 represents its general view).

Consider a case of selective mining of thin seams involving coal-cutting with a floor layer based upon the application of MKD-90 complex with a stowage conveyer.

Stage one involves construction of sketch design for all the site elements; then, it is used as the base for developing 3D surfaces in SolidWorks software package.

In the case of selective mining of thin seams when coal-cutting with bottom rocks, which is based on the using of the complex MKD-90 in the version with a filling conveyor.

At the first stage, it is making sketch design of all elements of the site, and then on its basis, 3D surfaces are created in the SolidWorks software suite.

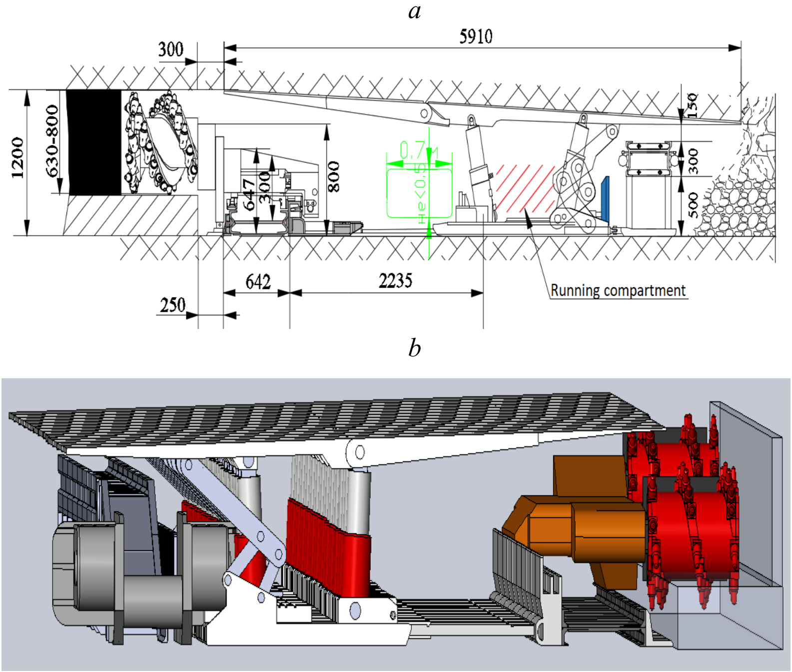

Fig. 1. General view of a longwall: a – geometrical parameters of a powered complex; b – 3D-model of a powered complex.

Further, it is required to set volume and boundaries of the modeling area as well as boundary calculation conditions (aerodynamic parameters, air consumption to ventilate mine workings, total pressure of the environment, spacing of support spacing, surface roughness etc.) in the FlowSimulation module as it is shown on Fig. 2.

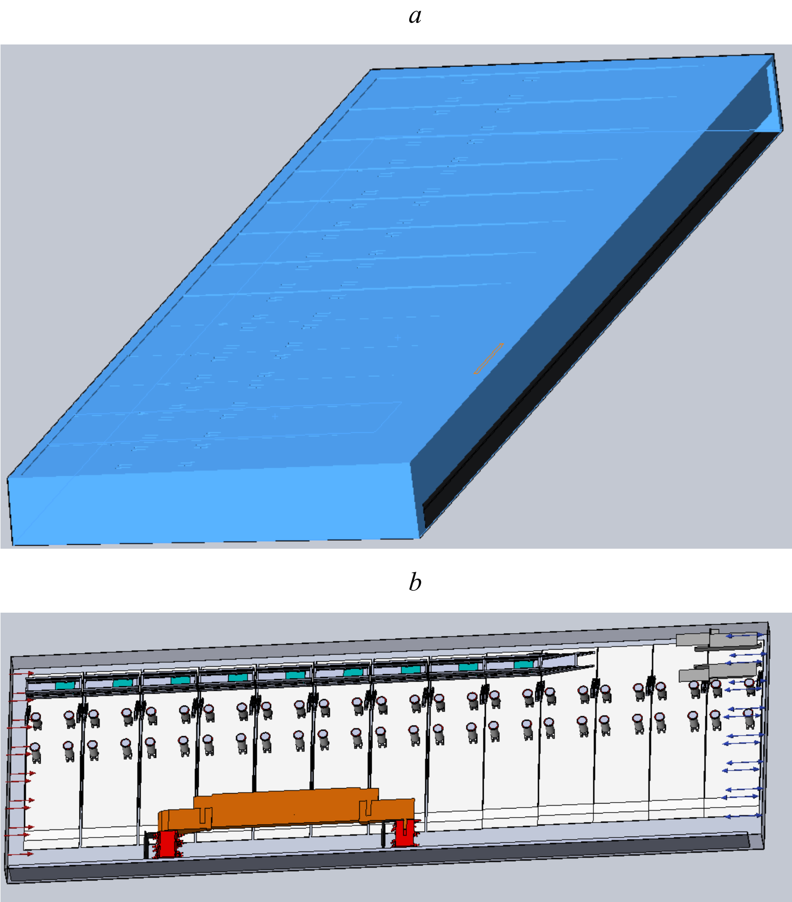

Fig. 2. Setting modeling area for powered support (a) and specifying boundary conditions (b).

2. Determining purposes of the study as well as parameters and areas of a network (its curvature angle and minimal dimension of the element should be selected basing upon the specified research objective), i.e. evaluating fields of velocities and pressure difference of the air flow within the complex-geometry sites of a production unit.

While modeling, following is being used to describe air motion along the mine workings [25 – 28]:

– differential equation of the flow continuity:

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}=0;$$

– Navier-Stokes system of equations:

$$\left.\begin{aligned}
\rho\left(\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}+v_z\frac{\partial v_z}{\partial z}\right)&=\rho X-\frac{\partial p}{\partial x}+\mu\Delta v_x;\\
\rho\left(\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}+v_z\frac{\partial v_y}{\partial z}\right)&=\rho Y-\frac{\partial p}{\partial y}+\mu\Delta v_y;\\
\rho\left(\frac{\partial v_z}{\partial t}+v_x\frac{\partial v_z}{\partial x}+v_y\frac{\partial v_z}{\partial y}+v_z\frac{\partial v_z}{\partial z}\right)&=\rho Z-\frac{\partial p}{\partial z}+\mu\Delta v_z.
\end{aligned}\right\}$$

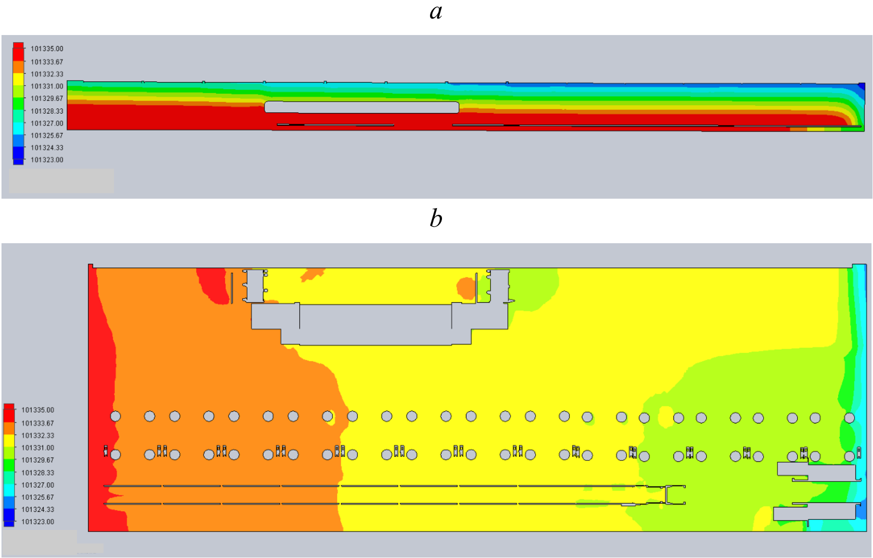

Fig. 3. Evaluating pressure difference along the length of a hydrodynamic model.

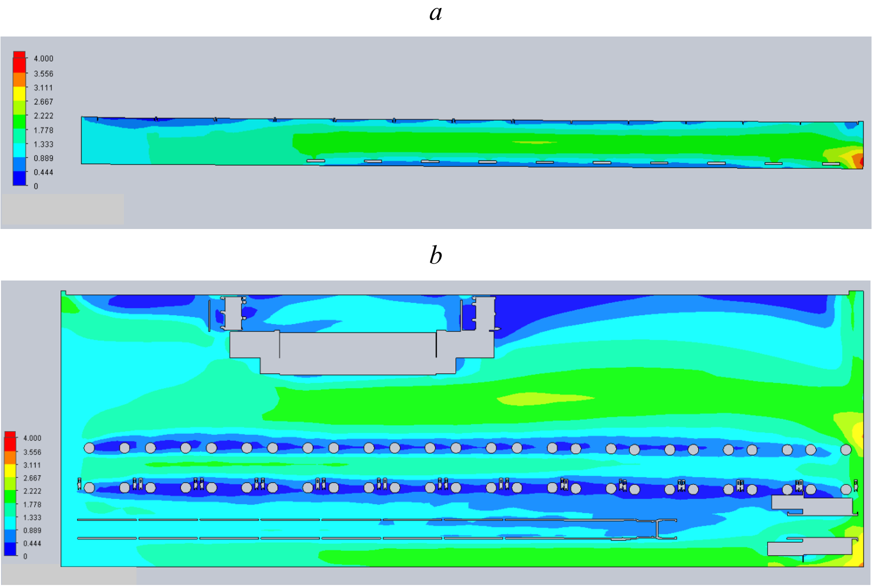

Fig. 4. Evaluating average velocity of the flow in terms of flow motion through a powered support.

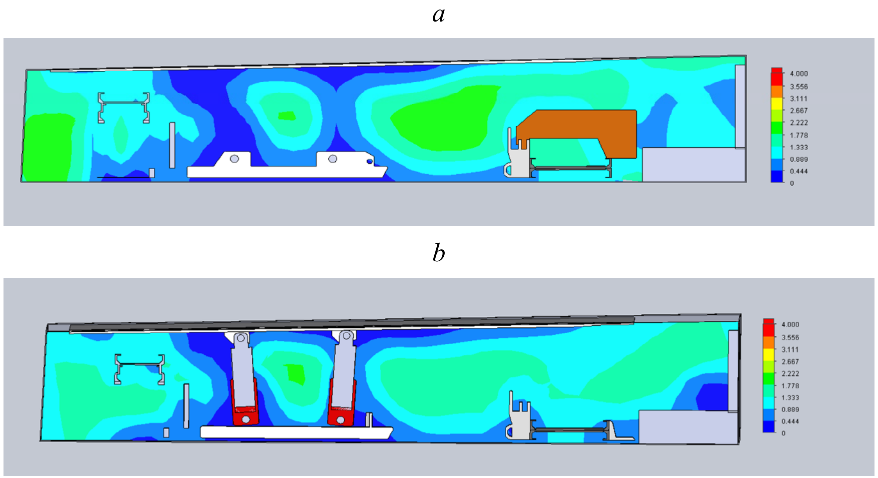

Fig. 5. Distribution of the air motion velocity along the longwall cross-section: a – with a shearer; b – with props of a powered.

According to the Safety Rules [6, 8, 15], velocity of air motion in a stope is limited: $V_{\min} = 0.25$ m/s; $V_{\max} = 4$ m/s.

3. Analysis of the results as for distribution of air flow velocity and pressure difference fields being evaluated according to the cross section of the modeled production unit (Figs. 3 and 4).

3 Expirement results

The considered physical pattern of the flow streamlining demonstrates that increase in the seam thickness results in the lengthening of props of all the rows. Since the value of front resistance depends upon geometrical parameters of the support, then, in this case, it will grow. Front resistance depends upon stands, jacks, caps, constituents and props of the support etc. Similarly, decrease in seam thickness results in the fact that the degree of cross-section filling increases causing the increase in overall aerodynamic resistance by means of reduced inside cross-section.

Fig. 6 shows that air flow is characterized by nonuniform distribution. Vortexual flows are formed between the props while areas at the periphery demonstrate the formation of stagnation zones with low velocity (about 0.5 m/s). Nonlinearity, formed by the props, causes vortexual motion; that results in additional energy losses of the main fan. Moreover, deformed flow effects considerably the average velocity of air motion in the longwall.

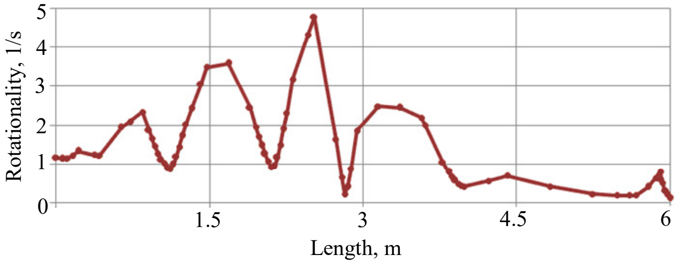

Fig. 6. Graphs of the evaluation of air flow vorticity across the longwall width.

The paper has analyzed the effect of coal-cutting height upon the average velocity in the longwall (Fig. 7).

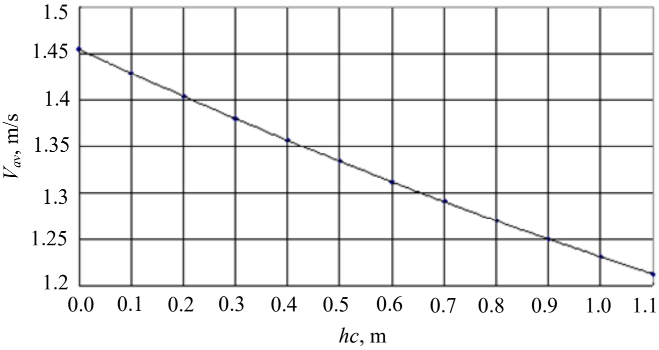

Fig. 7. Dependence of average velocity upon the coal-cutting height.

Analysis of the obtained results has demonstrated that velocity in the longwall reduces in terms of quadratic dependence along with the increasing coal-cutting height.

$$v_{av} = 0.0364 \cdot h_c^2 - 0.256 \cdot h_c + 1.454 . \tag{5}$$

4 Conclusions

The obtained results make it possible to modernize structural components of a powered support taking into consideration aerodynamic resistance; besides, that allows elaborating recommendations as for provision of the face area with fresh air taking into account the coal-cutting height. Innovative engineering solutions involving changes in geometrical parameters of mine sections should be elaborated by considering areas of mine working cross-sections. Detecting areas of accumulation of hazardous substances (dust, gas) at the design stage will help reduce risks of accidents by means of more efficient selection of ventilation schemes for mine workings and create more comfortable working conditions for miners. Further studies will be aimed at improving methodological basics of modeling and optimizing calculations taking into consideration specific features of the production units.

The research is carried out within the framework of scientific topics “Resource-saving geotechnical and hydrodynamic parametrization of the extraction of low-capacity mineral raw materials in an technogenically loaded environment”, financed by the state budget of Ukraine (State registration No. 0117U006753).

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