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ANALYSIS OF DUSTINESS STATE IN A DRIVEN UNDERGROUND DOG HEADING VENTILATING BY AUXILIARY AIR-DUCT

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Abstract:
Dustiness of the mine atmosphere during carrying out exploitation is one of the most hazardous factors threaten to health and life of employees. Also it is large hazard for all type of mechanical and electrical devices operating in mining headings. Coal dust is also very dangerous due to its possibility of explosion. Currently applied technologies of rock mass mining process, entire transport process of output and applied ventilation system cause that rock and coal dust is presented practically in each of the mining heading. Practically, is impossible to eliminate dust from mining headings. However, one can determine its parameters and potential ways its displacement. In the paper there is presented modeling research methodology of dustiness state in a driven dog heading. Developed model is the basis for this methodology, including the diphase flow of mixture of air and dust in the mining heading. Analysis was performed for real driven dog heading. Based on performed analyses, distributions of particular fraction and movement trajectories of selected dust grains were determined. Developed methodology gives a lot of opportunities for analysis of dustiness state in mining headings and in other compartments. It enables to determine parameters of particular grains and their impact on ventilation parameters of the air stream in the tested headings. Obtained results can also be used to reduce dust hazard.

Key words: *dust, CFD modeling, dog heading, mining exploitation*

INTRODUCTION

Occurrence of dust hazard in coal hard mining is connected mainly with rock mass mining process [1, 2]. Base for this hazard is common presented in mining headings coal and stone dust. Besides mining process, dust is formed during transport and pouring of output, during relocation of machines of longwall complex and heading machine [3, 4]. Additionally the ventilation system transfers dust particles to all area of mine, which cause that practically dust is presented in all headings. This (coal and rock) dust in significant way threatens life and health of mining crew [1, 2, 5, 6, 7]. This hazard depends on its concentration in the atmosphere. It also has very negative impact on operation of machines and all devices situated in these headings. With appropriate dust concentration may come to its explosion, which may result in material losses and very serious hazard for the crew. Additionally, coal dust explosion can be an activating factor for other mining hazards occurring in these headings, e.g.: fire, methane or caving hazard [8, 9, 10, 11, 12, 13, 14].

Dust hazard in the hard coal mining can be considered in three ranges, as coal dust explosion hazard, as hazard of harmful dust for health also hazard for machines and devices. Amount of dust generated in processes of rock mass exploitation in extreme cases can be even up to 3% of the total production [2]. The largest amounts of dust are formed during direct mining of body of the coal, both in the driven mine faces as well as in longwalls [1, 2, 5, 7, 15]. Results shown, that the highest dust concentrations formed during mining production are observed in mine faces of driven dog headings [1, 2, 7]. Results of tests and measurements indicate, that local accumulation of only inhaled dust floating in the mine faces of driven headings may reach up to over 22 mg/m^3 (for respirable dust over 10 mg/m^3), which significantly exceeds the highest permissible concentrations specified in regulations concerning the health aspect [5, 6].

Dust formed during coal mining of body the coal and driving of dog heading and haulage of dust output, floats in the mining atmosphere and through ventilation system goes into majority of mining headings, even those far away from place of its occurrence, causing their pollution. Also depending on the concentration of dustiness in some place of headings may occurs decrease of visibility until it completely disappears [1, 2].

Therefore very significant meaning for assessment of dust hazard degree in a driven mine face of dog heading has knowledge of the location of zones with highest dustiness. This knowledge constitutes the basis for carrying out preventive actions in order to reduce its concentration. Determination of such zones in real conditions is difficult, and in many cases impossible. Also for this reason, it was decided to develop method for determination of dust zones and dust stream parameters with use of the modeling tests. These tests were performed for a real driven dog heading. In a model, its geometry and ventilation parameters were taken into account. It should be emphasized that developed model includes diphase medium, which undoubtedly constitutes a new approach of this topic. Test of such medium is complicated problem and demanding very accurate and scrupulous recognize of particular elements of the model.

In the paper there are presented results of dustiness analysis in driven dog heading ventilating by positive pressure air-duct with use of computational fluid dynamics. For calculations ANSYS Fluent software based on finite volume method, which enable very precisely determine parameters of mixture of mining gases and dusts at any point of tested mining heading.

Authors have hope that developed method based on spatial diphase model will be able to successfully be used for larger scale for diagnose and forecast dustiness state in mining headings.

MATERIALS AND METHODS

Study area

Base for the developed research methodology is model of tested heading taking into account its real geometry and ventilation parameters (measured in real conditions) and equipment. It represents the driven dog heading in one of the Polish hard coal mine. Geometrical parameters of heading together with position of auxiliary air-duct is presented in Figure 1. Diameter of air-duct amounts 0.6 m. Air outlet from air-duct is located in distance 5.0 m from mining of body of the coal. Air-duct was installed at height 2.5 m, in a distance 0.65 m from the side wall of heading. Basic parameters of computational model are presented in Table 1.

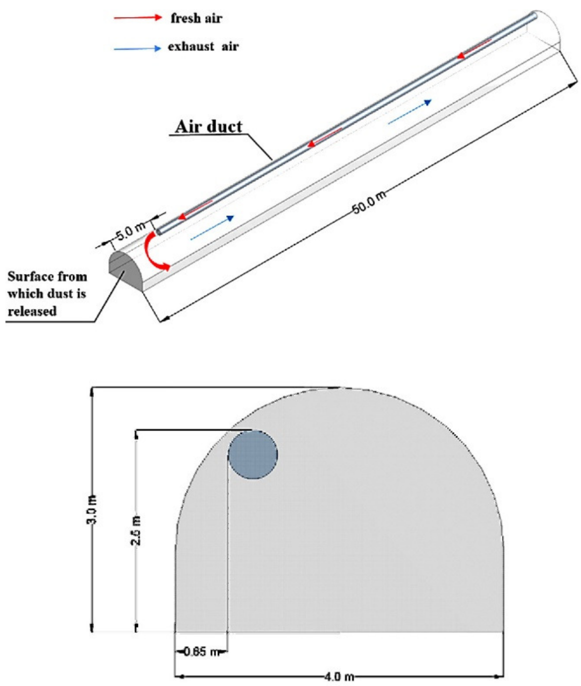

Fig. 1 Geometry of the computational domain

Table 1
Major parameter setting

Name	Parametr setting
Solver Type	Pressure-Based
Viscous Model	k-epsilon realizable
Diameter Distribution	Rosin-Rammler
Tota Flow Rate, kg/s	0.005
Material	Coal-hv
Max Diameter, m	0.001
Min Diameter, m	0.000001
Mean Diameter, m	0.0005

Calculations were performed for transient state. Time of analysis amounted 135 seconds. In studies, one focused on the analysis of dust increase in the face zone from the moment of mining of body the coal. It was also assumed that dust is emitted from heading front. Size composition of dust was described according with Rosin-Rammler distribution [16].

Methods

The flow of air and dust in mining heading was analysed by means of the Finite Volume Method (FVM). This method involves discretisation (in a physical space) of the computational domain (the spatial flow area) into a finite number of non-overlapping control volumes. A control volume may be created, depending on the research tool applied, inside the volume of the fluid element or around the volume element node.

The tests were conducted for a spatial model of the area under analysis, using CFD. The authors' experiences and the results by other researchers indicate that this method is widely applied for analysing phenomena related with the flows of fluids and dust, the transfer of mass and heat or the processes of combustion [17].

The paper made use of the ANSYS Fluent software, which is one of the most popular tools for the CFD method, whereas the discretisation process was carried out by means of the FVM. The methodology for conducting tests by means of this programme encompasses development of a mathematical model of the phenomenon in question, adoption of boundary conditions, performance of calculations and analysis of the results obtained.

Governing equations

For modeling of the two-phase system (gas and solid) Euler-Lagrange approach was used [18]. It was assumed that liquid (gaseous) phase is treated as continuum by solving the Navier-Stokes equation, however disperse phase is solved by tracking large number of particles in the calculated field of continuous phase [19, 20, 21]. In the Eulerian-Lagrangian frame, each particle is individually tracked along its trajectory obtained integrating Newton's second law [22].

The Discrete Phase Model (DPM) is used for tracking the particles in the Lagrangian frame. Howeverthe solid phase exists also in a secondary Eulerian phase, where the particle-particle interactions are calculated using the Kinetic Theory of Granular Flow (KTGF). Thus, the DPM allows for taking into account both, the particle-particle interactions and the particle size distribution [23].

According to the principles of fluid mechanics, flow of air stream through the driven dog heading was treated as a continuous phase and dust as a discrete phase. To find the solution of turbulent airflow the realizable k-ε model was used.

The continuity equation for gas can be written as:

$$\frac{\partial\rho}{\partial t}+\frac{\partial}{\partial x_j}(\partial v_j)=0 \quad (1)$$

Based on the law of mass conservation, the following expression can be acquired [15]:

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\partial w)}{\partial z}=0 \quad (2)$$

The momentum equation can be written as:

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[(\mu+\mu_t)\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)\right] \quad (3)$$

The Lagrange method was used to follow the trajectory of DPM particles. In this method movement of particles take place according with the Newton's second law. Movement of particles is affected by resisting force, gravitational force and force of pressure gradient.

Drag force, gravity, pressure gradient force, lift force and the turbulence dispersion effects on particles are considered because other forces are considered not significant enough to affect the particle's motion [24, 25].

The governing equation is given by:

$$m_p=\frac{dv_p}{dt}=m_p g+F_d+F \quad (4)$$

where:

m_p is the particle mass,

v_p is particle velocity,

F is the sum of pressure gradient force, lift force and turbulence dispersion effects on particles, F_d is the drag force.

The drag force F_d is given by:

$$F_d=\frac{3}{4}\frac{C_d Re}{d_p|V_r|_r} \quad (5)$$

where:

Re is the Reynolds number,

d_p is particle diameter,

V_r is the relative velocity between and the gas phase, which is defined as $V_r = v_p - v_g$,

C_d is the drag coefficient.

The drag coefficient is expressed by:

$$C_d=\begin{cases}\frac{24}{Re\cdot C_c} for\ Re\leq 1\\ \frac{24(1+0.15\,Re^{0.687}\quad)}{Re\ Re\leq}\\ 0.44\ for\ Re>1000\end{cases} \quad (6)$$

where:

C_c is the Cunningham slip correction factor, which is given by:

$$C_c=1+\frac{\lambda}{d_p}\left(2.514+0.8e^{\frac{-0.55d_p}{\lambda}}\right) \quad (7)$$

where:

λ is the mean free path of gas molecules.

Finally, the settling velocity of the dust particles with different sizes can be calculated by [26]:

$$v_p=\sqrt{\frac{4(\rho_p-\rho_g)gd_p}{3\rho_g C_d}} \quad (8)$$

The continuity equation of particle phase can be described as [27]:

$$\frac{\partial|\rho_p v_{pi}|}{\partial x_i}=-\frac{\partial}{\partial x_i}\left(\frac{v_p}{\delta_p}\frac{\partial\rho_p}{\partial x_i}\right)+S_p \quad (9)$$

where:

v_{pi} is the velocity component of the particle phase, m·s^{-1};

S is the source phase of the particle phase, kg·s^{-1}.

The momentum equation of the particle phase can be written as [28]:

$$\frac{\partial(\rho_p v_{pi} v_{pj})}{\partial x_i}=\frac{\varphi_g\partial p}{\partial x_i}+\rho_g g_i(v_{gi}-u_{pi})+u_{pi}S_p+F_1+F_m \quad (10)$$

where:

g_i is the gravitational acceleration component, m·s^{-2},

F_1 is the viscous momentum transport of the particle turbulent flow.

RESULTS AND DISSCUISON

Tests of dustiness occurring in the driven dog heading were performed for model in which two-phase medium formed from continuous phase of the air and discrete phase in a form of dust grain. In the analysis interactions between these phases were taken into account.

As a result of performed analyses, series of interesting results relating both to ventilation parameters of air stream and to the distribution of dust grains themselves were obtained. Example of airflow trajectories (without dust) through driven heading is presented in Figure 2.

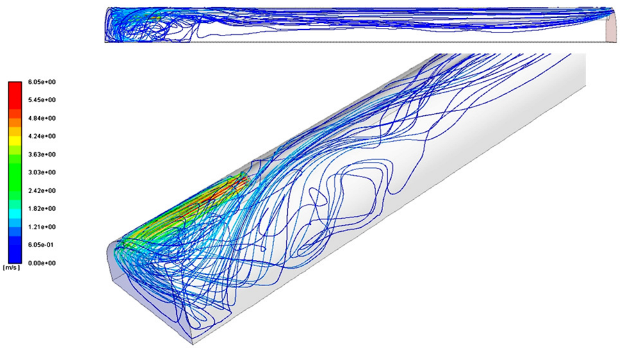

Fig. 2 Simulation results of the airflow behaviors in the dog heading face

Based on obtained results one can conclude that the highest air velocity occurs in the region of mine face zone, in the region of air outlet from the air-duct. Also in this zone an area of high air recirculation is presented. In this region of heading the airflow is the most chaotic (turbulent) taking into account entire length of the analyzed heading.

In next stage, analysis of dustiness state in heading depending on operation time was performed. Particularly, focuses on determination of dustiness increase in mine face zone during mining of body of the coal. Whereas intensity of dust emission during mining amounted 0.005 kg/s and it was constant for the entire test period (135 seconds). Dustiness state in subsequent phase of the analysis considering size of dust particles is presented in Figure 3.

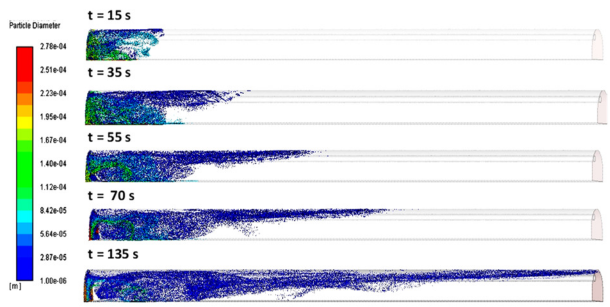

Fig. 3 Distribution of different-sized dusts in the dog heading at various time points

During analysis distributions dust concentration. In Figure 4 there is presented dust concentration distribution (for t = 135 seconds).

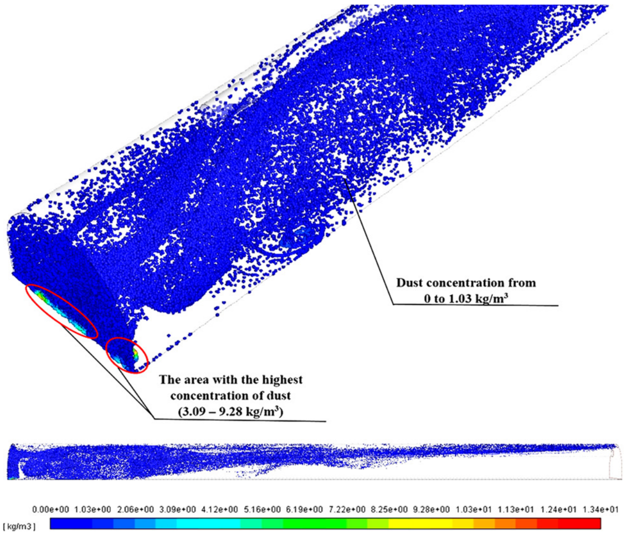

Fig. 4 Dust concentration distributions in 135 seconds

Obtained results enable to observe changes of dustiness state in tested heading together with exploitation time. It can also precisely determine way of air stream propagation. Obtained results also enable to determine position of particular dust grains for selected analysis time. In Figure 5 there is presented dust stream distribution with grains size amounted to 1 mm in tested headings after 135 seconds.

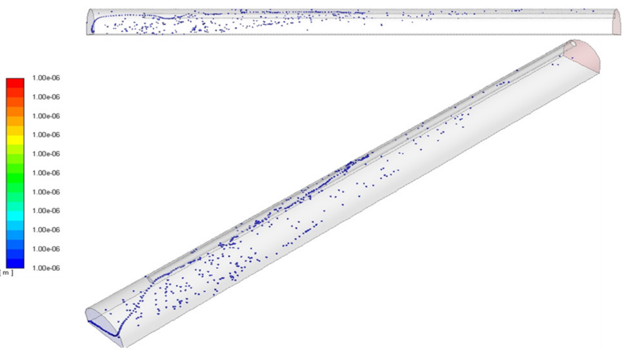

Fig. 5 Track single particle stream (particle diameter = 0.000001 m for t = 35 s)

Dust particles with smaller diameter are suspected in the air stream and are spread over entire length of heading. Due to inertial forces, large dust particles are not carried by flowing air stream and fall just near the surface of the mining of body of the coal. In a result, in this place the most dust accumulates at the seam floor of heading.

CONCLUSIONS

Dustiness of mining headings, especially driven dog headings and their mine faces is a big problem during their implementation. Developed research methodology enables the analysis of dustiness state in such headings. For different composition of potential dust one can determine its distribution in mining heading during the exploitation process. Particularly, it can be used to determine ventilation parameters in selected heading and for selection of security system for employees and devices ahead of dust effect.

Obtained results clearly indicate, that main cause of dust dispersion in mining heading is flow of air stream through this heading. The analysis of distribution of dust and trajectories of particular grains indicates that its concentration is very nonuniform. Definitely this distribution depends on size of dust grains and physical parameters of air stream supplied to heading.

Presented methodology based on developed model enables to perform wide multi-variant analysis of dustiness state considering different parameters of tested phenomenon. Also it should be emphasize that developed model includes analysis of two-phase medium (gas flow and solid). It definitely constitutes a new approach to analysis of the dustiness state in mining headings. Universality of this methodology enables to its application for dustiness state analysis in other compartments. The flow air-particles was described using two-phase Euler-Lagrange model with a gaseous continuous phase and dispersed phase composed of solid particles (dust).

The results obtained can be used in the selection of systems for reducing dust in mining excavations.

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