

Simulation of methane gas dispersion at the level of a complex ventilation network

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Abstract. Underground coal mining is one of the most difficult human activities. The difficulty consists both of the brute force required for extraction and of the risks that arise. The risks are amplified by the specific underground conditions and are mainly generated by the presence of explosive, toxic, asphyxiating or radioactive gases. The gases and airborne dust are taken up by ventilation currents and discharged into the atmosphere at the level of ventilation shafts. In underground, one of the greatest risks is given by the presence of explosive gases that can accumulate in closed spaces and disperse over long distances. The most important aspect of underground methane dispersion is given by the knowledge of methane gas concentrations on the dispersion alignment which may include areas where the atmosphere is asphyxiating, areas where the atmosphere is explosive and areas where the atmosphere is close to normal. The work includes both the updating of the complex ventilation network of the Vulcan mine and the evaluation and analysis of the dispersion of methane at the level of the ventilation network from the accumulation point to the point of discharge into the atmosphere. For the simulation, the specialized program VENTSIM DESIGN was used.

1 Introduction

In the underground exploitation of useful mineral substances, in general, and in coal mines, in particular, it is necessary to ensure optimal microclimate and security conditions [8]. Ventilation is sometimes described as the lifeblood of a mine [5] and the primary protection against the occurrence of explosive, toxic or asphyxiating atmospheres is represented by the establishment of an efficient ventilation system [4,6,9].

In underground mines, the ventilation system is created using the main fans within the main ventilation stations, located on the surface. To achieve efficient ventilation, it is necessary to know the distribution of air flows at the level of each branch [9]. For this, specialized programs are used, such as VENTSIM DESIGN [15], which allows the modeling, solving and optimization of complex ventilation networks.

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Additionally, with the help of the VENTSIM DESIGN program, the ventilation network can be analyzed from the point of view of gas dispersion, for example methane, at the level of the ventilation network.

2 Ventilation network

In order to carry out simulations regarding methane dispersion at the ventilation network level, it was necessary to update the ventilation network related to the Vulcan mine. The Vulcan Mining Operation is equipped with a main ventilation station, namely the "Puț 10 Valea Arsului" Main Ventilation Station. The underground mining works are ventilated under the depression of the Main Fan Station Puț 10 Valea Arsului, which is equipped with 2 (two) axial type fans, VOD 2.1, with a nominal flow rate of 6000 m³/min. Currently, the main fan station "Puț 10 Valea Arsului" achieves a flow rate of 3,100 m³/min; ($\alpha = 20^\circ$). The main circuit bl. VII Karollus extends over the following horizons: horizon 315, horizon 360 and horizon 480.

Also, to solving the ventilation network, measurements were made at the level of each branch regarding the aerodynamic and air state parameters [3,7,10]. After modeling the ventilation network in the 3D Solid system, specific technical data, namely the profile and shape of the mining works and ventilation constructions, are introduced for each branch.

The next stage consisted of introducing the parameters related to the fans within the main ventilation stations by introducing into the program database the aerodynamic parameters specific to each fan according to the individual characteristic curves [1,2,11].

After completing the previously presented steps, the ventilation network is balanced and solved, after which the animation is activated for both the air currents specific to each branch and for the fans related to the main ventilation station. In this phase, the information specific to each branch is available, respectively the modeled and solved network is ready to perform any necessary simulations. To update the ventilation network of the Vulcan mine, a number of 205 nodes were introduced, respectively a number of 253 branches.

3 Methane dispersion simulation

In the event of the untimely appearance of methane in dangerous concentrations [12,13,14] in active mining operations, the security vulnerability is generated by releases in the form of blowouts, gas and rock eruptions, mine strikes, flooding of mining operations with water, gas and small material generated by underground trapped or technological waters, mine fires and explosions. It is noted that the vast majority of elements that can generate major events involve methane gas. In this case, the gas concentration c must comply with the relationship:

$$c = \frac{qa}{Q} \times k \gg 1 \text{ (\% Vol)} \quad (1)$$

where: qa - absolute methane flow rate; Q – Air flow rate circulated in the analyzed area;

$k = 0.069$ coefficient resulting from the ratio $\frac{100}{24 * 60}$.

It is worth noting that the untimely presence of methane gas at the level of active mining works can generate both explosion phenomena [4;5;7,9] in the presence of an efficient ignition source and asphyxiation at high concentrations, by displacing oxygen with devastating effects on exposed workers.

Establishing a priori the underground environmental conditions after the occurrence of a major event is a complex process that requires the use of computing techniques and specialized programs. It is mentioned that after the occurrence of a major event, the

environmental factors specific to active mining works return to the level of the natural background (the gas-dynamic regime of the coal layer and the rocks in which it is located, the groundwater regime), other factors disappear (exploitation intensity, applied technologies), and other factors remain constant (type of coal, exploitation method, applied ventilation system, exploitation depth). Relevant for establishing the working environment after a major event is information regarding the change in gas concentrations (CH₄) while maintaining constant air flow [14].

The ventilation network of the Vulcan mine, modeled and solved, allows for simulations of technically possible situations underground. Additionally, the VENTSIM DESIGN program [15] allows for simulations regarding the dispersion of explosive gases at the ventilation network level, in relation to the source of release. In this regard, in order to establish the dispersion of methane [12] in the event of its untimely appearance in dangerous concentrations in active mining works, a simulation was carried out with the object of longwall BS no. 1/3/VIII from EM Vulcan. The longwall BS no. 1/3/VIII from EM Vulcan is closed due to the occurrence of a mine fire. Due to the mine fire, methane concentrations are very high. The simulation takes into account the reduction in time of the degree of sealing of the isolation constructions and the migration of significant quantities of gases at high concentrations on the alignment of active mining works.

To carry out the simulation, the dispersion of methane was taken into account at the level of the entire ventilation network of the Vulcan mine, figure 1.

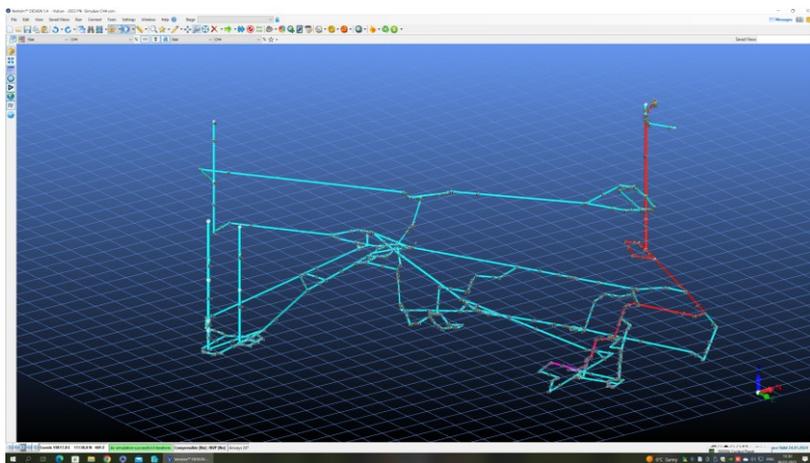


Fig. 1. CH₄ dispersion at the level of the ventilation network of the Vulcan mine

To simulate the dispersion of methane at the level of the ventilation network related to the Vulcan mine, the longwall with undermined coal bank no. 1/3/VIII was chosen, which is closed with isolation structures at the level of the access and evacuation routes. The closure was necessary because an endogenous fire phenomenon occurred that generated, through development and isolation, high concentrations of gases detected by specific measurements. Due to the change in the degree of sealing over time, either due to the deformation of the isolation structures or through dynamic phenomena of gas expansion in the closed area due to the high temperature in the fire area, an air circulation through the closed area resulted, which led to the migration of methane gas in a concentration of 50%Vol. along the alignment of the active mining works towards the main ventilation station Well X. Figures 2 and 3. show details regarding the dispersion of methane at the level of the ventilation network related to the Vulcan mine, representing the methane gas evacuation route.

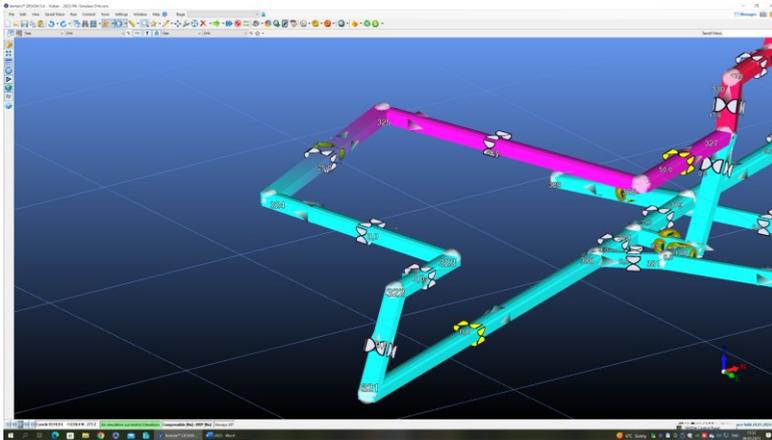


Fig. 2. CH₄ dispersion at the level of longwall B.S. no. 1, str. 3, bl. VIII

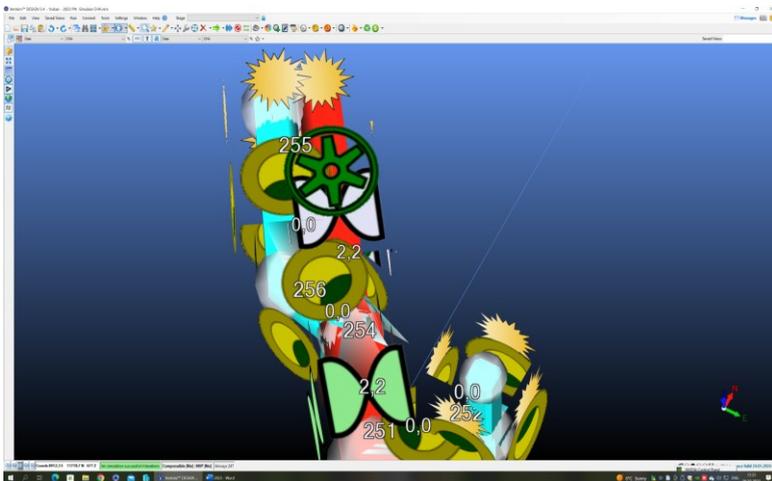


Fig. 3. Detail regarding CH₄ dispersion at the active fan level

Following the simulation of methane dispersion at the level of the ventilation network, the following results were obtained: The CH₄ concentration at the level of the longwell with undermined coal bank no. 1 str. 3 bl. VIII with unique number 440, was 50% vol; On the exhaust air rise of the longwell no. 1 str. 3 bl. VIII, oriz 255-315, with unique number 366, the concentration of CH₄ was 17.8% vol; On the exhaust air rise of the longwell no. 1 str. 3 bl. VIII, oriz 315-360, with unique number 231, the concentration of CH₄ was 5.6% vol; On the exhaust air rise of the longwell no. 1 str. 3 bl. VIII with unique number 264, the concentration of CH₄ was 5.2% vol; On the ventilation shaft, branch with unique number 274, the concentration of CH₄ was 2.3% vol; At the main ventilation station level, branch with unique number 304, the CH₄ concentration was 2.2% vol.

4 Discussions

It is mentioned that the main sources of methane emission at the level of an ventilation network are represented by closed longwells. As a result, a methane emission source was associated at the longwell level at a concentration of 50%Vol. The methane dispersion simulation taken into account the severe damage to the isolation structures which allowed the circulation of an air flow at the longwell level and the progressive dilution of methane on the

dispersion alignment. Thus, a methane flow rate migrated from the closed area of 1.1 m³/s was taken into account, which leads to the idea that the gas release-dispersion regime is of a descending variable type. The gas migration route from the source to the atmosphere was: longwell BS no. 1/3/VIII, rise no. 1/VIII oriz 255-315, rise no. 1/VIII oriz 315-360, exhaust circuit oriz 360 blVIII-IX, Well X Carolus, ventilation channel, active fan, atmosphere.

The methane concentrations from the main release source are dispersed along the alignment of the mining works for exhausting the contaminated air to the main ventilation station. This affects the methane exhaust circuit at the level of the rise no. 1/3/VIII, horizon 255-315 where dangerous methane concentrations can cause asphyxiation phenomena. The methane exhaust circuit that includes the rise no. 1/3/VIII horizon 315-360 and the exhaust route at the level of horizon 360 including the main transverse gallery bl IX, presents dangerous concentrations that in the presence of an efficient ignition source can generate explosion phenomena. The rest of the exhaust circuit, which includes oriz 360, 480, the X Carolus ventilation shaft and the ventilation channel, has methane concentrations that can become dangerous due to the addition of methane gas from other sources of release from the ventilation network and which, by increasing, can enter in the explosive triangle.

It is mentioned that the migration of methane gas from the source of release, in our case longwell no. 1/3/VIII, along the exhaust route, has a discontinuous character.

5 Conclusions

As a result of the update of the complex ventilation network related to the Vulcan mine and the simulation of methane dispersion at the ventilation network level, the following conclusions were drawn: In order to establish the dispersion of gases in the event of an untimely appearance of methane, it was necessary to model and solve the ventilation network of the Vulcan mine using the specialized program VENTSIM DESIGN were used a number of 205 nodes and 253 branches; In order to establish the dispersion of gases under the conditions of untimely appearance of methane in dangerous concentrations in active mining works, a simulation was carried out having as its object longwall no. 1/3/VIII from EM Vulcan. Thus, at the level of the branch with unique number 366, compared to the methane concentration, an oxygen concentration of 16.5% vol results, well below the minimum limit allowed underground of 19% vol. The movement of working personnel is prohibited in this area due to the risk of asphyxiation and explosion by adding fresh air. At the level of the branches with unique numbers 231 and 264, compared to the methane concentration, an oxygen concentration of between 19.5% vol and 19.6% vol. The movement of working personnel is prohibited in this area due to the imminent risk of explosion. At the level of branches with unique numbers 274 and 304, in relation to the methane concentration, an oxygen concentration between 20.3% vol and 20.4% vol is obtained. The movement of working personnel is prohibited in this area due to methane concentrations above the specific fresh air limit of 0.5% vol, respectively the risk of explosion due to the addition of methane from other sources. This information is extremely useful for the personnel responsible for the safety and health of workers to establish the specific protective measures and to establish the evacuation routes in case of major events.

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