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EXPLOSION AND/OR FIRE RISK ASSESSMENT METHODOLOGY: A COMMON APPROACH, STRUCTURED FOR UNDERGROUND COALMINE ENVIRONMENTS

METODA SZACOWANIA RYZYKA WYBUCHU I POŻARÓW: PODEJŚCIE OGÓLNE, DOSTOSOWANE DO ŚRODOWISKA KOPALNI PODZIEMNEJ

In order to meet statutory requirements concerning the workers health and safety, it is necessary for mine managers within Valea Jiului coal basin in Romania to address the potential for underground fires and explosions and their impact on the workforce and the mine ventilation systems. Highlighting the need for a unified and systematic approach of the specific risks, the authors are developing a general framework for fire/explosion risk assessment in gassy mines, based on the quantification of the likelihood of occurrence and gravity of the consequences of such undesired events and employing Root-Cause analysis method. It is emphasized that even a small fire should be regarded as being a major hazard from the point of view of explosion initiation, should a combustible atmosphere arise. The developed methodology, for the assessment of underground fire and explosion risks, is based on the known underground explosion hazards, fire engineering principles and fire test criteria for potentially combustible materials employed in mines.

Keywords: methane, mine fire, spontaneous combustion, explosion, risk assessment, prevention, protection

Z uwagi na konieczność spełnienia ustawowych wymogów odnośnie bezpieczeństwa i zdrowia pracowników, kierownictwa kopalń w obrębie zagłębia węglowego Valeo Julia w Rumuni podjęły badania możliwości wystąpienia podziemnych pożarów i wybuchów oraz ich wpływu na funkcjonowanie górników i sieci wentylacyjnej w kopalni. Wykazano konieczność opracowania jednolitego i systematycznego podejścia do poszczególnych zagrożeń w ujęciu ilościowym opartym na prawdopodobieństwie wystąpienia danego zagrożenia i skali ciężkości jego skutków. W pracach wykorzystano metodę analizy przyczynowo -skutkowej. Należy podkreślić, że nawet niewielki pożar powinien być uznany jako poważne zagrożenie z uwagi na możliwość wywołania wybuchu jeżeli w powietrzu kopalnianym znajdują się

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gazy palne. Opracowana metoda określania zagrożenia pożarem i /lub wybuchem oparta jest na ogólnie znanych zasadach powstawania pożarów i wybuchów, ochrony przeciwpożarowej i kryteriach określania potencjalnych materiałów palnych wykorzystywanych w kopalniach.

Słowa kluczowe: metan, pożar w kopalni, samozapłon, wybuch, ocena ryzyka, działania zapobiegawcze

1. Introduction

Hard coal exploitation in Valea Jiului basin is conducted in difficult mining and geological conditions, causing numerous hazards relating to the health and safety of underground personnel. To the most serious mining hazards belong underground fires and firedamp explosions, which far too many times were the reason of mining catastrophes (Moraru et al., 2010a, 2010b; Moraru & Băbuț, 2010 a). The implementation into the practice of scientific principles of fire and explosion prevention contributed to significant decrease of the fire/explosion hazard in coal mines (Matei et al., 1995). However, in spite of many achievements of science and technology in this field, fires and explosions still occur, creating a potential hazard for miners and contributing to the generation of considerable costs of fire-fighting and rescue actions, temporary output suspension or loss of longwalls. The scientific aspects of conducting fire-fighting actions in hard coal mines, elaborated by W. Budryk (1950) are of vital importance in mining theory and practice.

This concerns both spontaneous and open fires. Mine methane is also one of the main concerns, as a risk factor in coal mining (Strumiński & Madeja-Strumińska, 2008). To improve the precision and reliability in assessing fire/methane hazard in working face of coal mine, it is more and more considered that an integrated, common approach is required, able to be implemented by the existing technical and safety staff, in the condition of Romanian coal mining restructuring process, characterized by mine closure and personnel diminishment.

2. The principles and general framework of the explosion risk assessment in methane gassy mines

The basic principles and the general framework of the explosion and fire risk assessment process in the underground workings within methane gassy collieries are common, as a consequence of the complex interactions between the specific parameters and, even, of the involved substances (Mitchell, 1996). So, a methane – air mixture explosion can raise airborne coal dust particles, which previously were settled on the floor and walls, enriching in this manner the explosive mixture involved in the burning process. On the other hand, one of the direct consequences of methane explosions can be an open – fire, which magnifies the gravity of consequences generated. Likewise, the explosion's ignition trigger can be a spontaneous combustion.

Consequently, we consider that the risk assessment approach should be carried out in an integrated manner, propounding the entire set of influence factors, funded on an arborescent causality approach, as depicted in figure 1 (Moraru & Băbuț, 2000, 2009).

A risk assessment procedure for the assessment and management of explosions/fires in underground mine workings should always be developed based on several main principles issued from the past work and acquired experience (Cioca et al., 2010; Moraru & Băbuț, 2010b). For

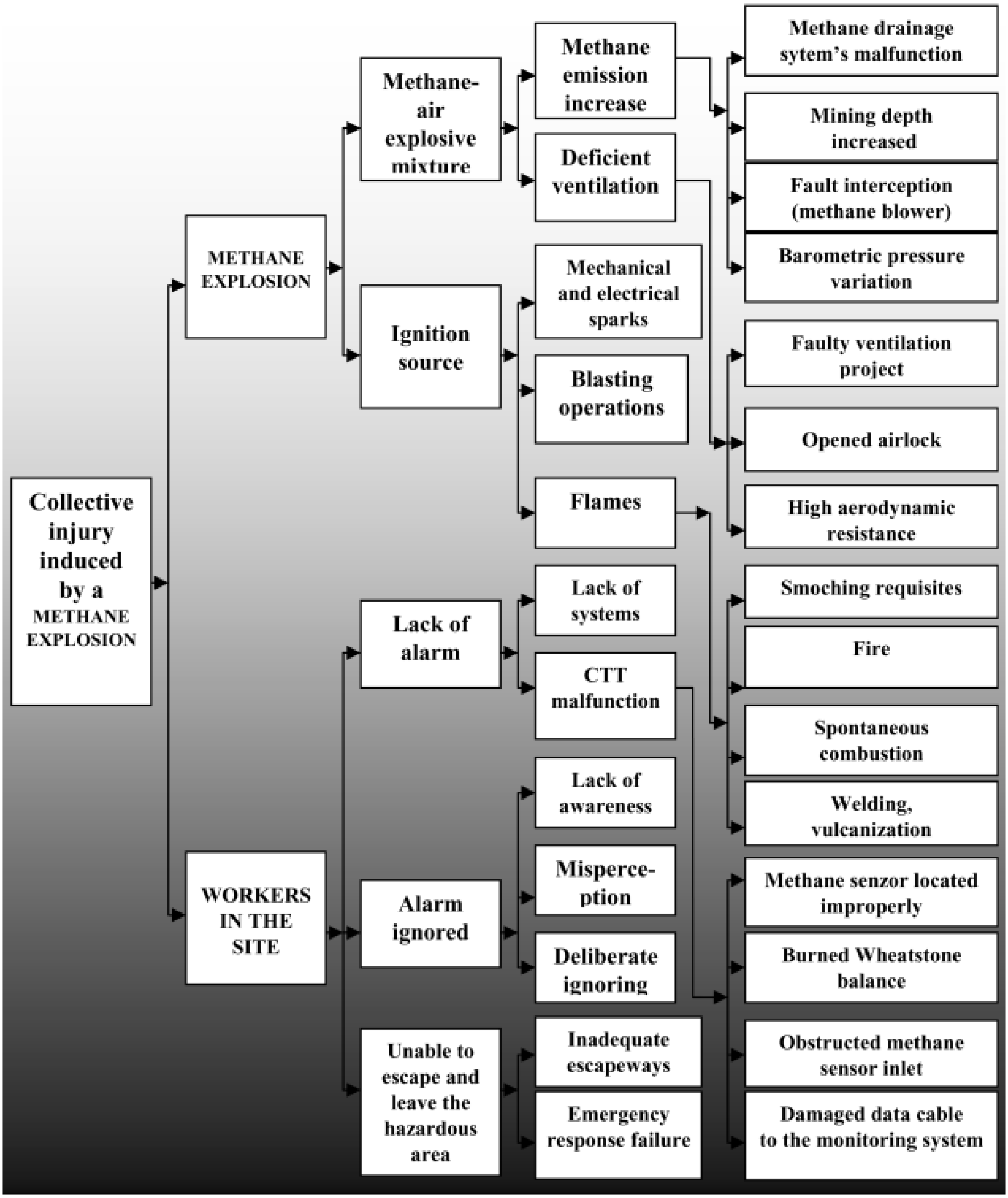

Fig. 1. Reduced Root – Cause tree for the undesired event „Collective injury induced by a methane explosion“

reasons related to the brief character of this paper, we are presenting only the basic principles on which the general assessment framework is grounded, as it is set up below:

a. **Identification of materials present and method of material selection.**
   – Identify and list materials present, quantify and location;
   – Review tests used as a basis for selection of such materials and their shortcomings;
   – Consider how fire resistance changes in use, for instance due to contamination with coal dust or other combustible material.

b. **Establish possibility of ignition.**
   – Review acceptance criteria, e.g. flame size or maximum permissible temperatures allowed under tests, to establish case of ignitability;
   – Establish maximum permissible temperatures under regulations applied to the mine;
   – Review method of use of materials: consider possible fault conditions or other scenarios which may lead to higher temperatures being achieved.

c. **Consider possibility of explosion/fire growth.**
   – Establish likelihood of fire spreading beyond source;
   – Include size of original fire and material involved ;
   – Include consideration of fire resistance data for items which may be subject to flame impingement.

d. **Availability of explosion/fire detection systems.**
   – Will personal be able to detect a fire;
   – Use of environmental monitoring;
   – Use of smoke detectors, infrared detectors or other measuring systems and devices to look for hot spots.

e. **What fire suppression systems are present?**
   – Are any fire detection systems in place?
   – What is the method of warning control staff of a fire, so that the emergency procedures can be started?
   – What type are the fire suppression systems and how effective are they?
   – Consider nature of possible fuels and typical extinguishing media;
   – How are extinguishing substances to be applied (injection into engine compartments, deluge etc.)?
   – Do any standards exists specifying details of fire suppression systems, if not how is the system to be installed?

f. **Communication and evacuation.**
   – Are reliable communication systems in place to coordinate fire and rescue operations?
   – Are practice drills undertaken?
   – How will the spread of post-explosion or post-combustion gasses and smokes affect fire suppression and rescue measures?
   – Can the ventilation system be used to assist fire suppression and rescue operations? Is there a residual risk for ventilation reversal?

By applying the above synthesized basic principles it should be possible to identify the prevention safety barriers for unwanted events like methane and coal dust explosions and/or mine fires in the underground environment.

3. The structure of the integrated risk assessment methodology for explosion/fire risk assessment

Basically, the integrated methodology proposed for implementation in the specific conditions of the underground environment of Valea Jiului collieries, involves the completion of the steps described below.

STEP 1: Identification of fuels and ignition sources (others then methane gas) which can be involved in the dynamic phenomenon propagation, simultaneously with considerations given to workplace activities, job tasks and equipments characteristics to the analyzed unit (face, sector, ventilation circuit, etc).

STEP 2: Establishing the potential for ignition of fuels.

Consider the likelihood of a fire or explosion occurring for all combinations of fuels and ignition sources identified and assign an overall risk rating. Also to be considered at this stage are any effects local air flow may have on hindering fire detection, or increasing the spread of fire.

Also, consideration must be given to the movement of a body of gas by the mine ventilation system into areas where sparks or flames may be present. For example, around mineral cutting or drilling equipment, shot firing, areas of coal seams undergoing spontaneous combustion, failed items of electrical or mechanical equipment generating sparks etc.

Risk reduction measures will be required for any area having a combined risk rating exceeding a present value.

STEP 3: Risk reduction measures – reducing ignition probability.

Methods for reducing risk in areas identified as having a high fire or explosion potential will include both means of reducing the likelihood of ignition and reducing the quantity of fuel present. Such measures may include:

- *Equipment design* – evaluate design to determine if risk can be reduced through design changes;
- *Operating procedures* – the threat of explosion/fire can be reduced through effective implementation of company policies and procedures; the safety philosophy should be grounded on the dualism resulting from the connection of top management commitment with an adequate level of safety culture (in correlation to the standard ISO 31000: Risk management – Principles and guidelines for implementation, cited in Moraru & Băbuț, 2010c);
- *Review of maintenance intervals*;
- *Reduction in the amount of combustible materials* through use of low flammability alternative;
- *Design, installation and maintenance of systems to limit the range of an explosion consequences*. For example, in the case of Valea Jiului collieries stone dust/water through barriers, explosion doors etc.

STEP 4: Identification of fire/explosion protection and warning systems, installation and accessibility.

This stage is divided into three phases:

- **Phase 1** – Considerations of fire/explosions types. This entails using information from STEP 1 on fuel types and quantities to determine type of suppression system, how the agent is to be applied, the method of detection and areas where rapid fire spread may occur, requiring early detection and system activation.

– **Phase 2** – Fire detection equipment. The purpose of this section is to ensure consideration of all relevant areas, not just sitting of detectors. Also important is correct routing of signal cables from detectors, accessibility of enunciation panels etc. Explosion detection equipment–concerns environmental monitoring including firedamp measurements or hand-held instruments used by officials etc.
– **Phase 3** – Visibility and use of fire fighting equipment. Here the purpose is to ensure adequate signage of fire fighting equipment, case of accessibility, staff training etc. At each stage a column will be included to highlight where further action is required.

STEP 5: Means of escape.

Considerations will be given to the means of escape given a fire or explosion, and the choice of self rescuer given the nature and toxicity of anticipated smoke. Establish how many people are at risk and method of notifying personnel of choice of escape route.

STEP 6: Establish residual risk.

To be completed for those areas for which a high risk rating was derived. This is a basic stage, which often is missing in the Valea Jiului collieries practice, in which the information regarding the residual risk is gathered and transmitted to workers. For example, they can be notified that when the self rescuer's hose is damaged, the worker can breathe directly from the filtering cartridge. The final stages of the assessment are referring to issues for emergency plan, ongoing requirements and outstanding actions, as it follows:

STEP 7: Prepare a table summarizing areas where fire or explosion is though possible, the main fuel and toxicity of smoke, evacuation routes considered (including the case of ventilation flow reversal) and the effects of possible disruption of communications.

STEP 8: Prepare a table or list of ongoing safety requirements and further measures which must be met for systems put in place to remain operational and effective, e.g. staff training, testing of fire fighting equipment, regular stone dusting etc.

STEP 9: Prepare and act upon a list of outstanding actions identified during the assessment to ensure that systems put in place are effective. This involves the prioritization of risks, resource allocation and practical implementation of identified measures.

During the risk assessment and management process, it is of major importance the real (not formal) involvement of the key workers, following a well-established communication-consultation procedure.

4. Conclusions

As fire is not the only underground hazard of significance, the proposed methodology has been developed by combination of the principles outlined above, with additional consideration of explosion. The methodology will involve the completion of a number of check sheets to allow the user to establish the likelihood of fire or explosion, the number of personnel at risk, methods of evacuation and areas where a more detailed examination is required. Having identified prime areas for investigation, a more detailed analysis should be undertaken as part of the mine's emergency preparedness documentation.

The first stage is concerned with establishing the potential for fire and explosion, either through workplace activities, or accidental ignition of combustible material. The first stage is to study the areas or operation of concern to identify combustible materials and potential ignition sources (either permanent or arising through fault conditions). The likelihood of fire/explosion occurrence is then evaluated by:

- Noting the coexistence of potential ignition sources ;
- Noting the likelihood of an explosive atmosphere occurrence;
- Study of past fire and explosion incidents in a particular operation, as they may have a high probability of reoccurrence;
- Study of maintenance routines – are they being met, is maintenance of an adequate standard, could maintenance operations themselves lead to an increased fire/explosion risk, are there any changes in the frequency of faults which may indicate either inadequate maintenance or the equipment is coming to the end of its lifetime, are replacement parts those recommended by the equipment supplier;
- Establish if the risk of fire/explosion is affected by standards of housekeeping.

As stated above it is also of importance to give practical consideration of workplace activities which could a fire/explosion, as well as identifying potential fuels and ignition sources. Such activities may include obvious areas such as mineral extraction/cutting, hot works such as grinding, cutting, welding, or possibly smoking, along with less obvious hazards such as working on electrical equipment where electrical fires may result from accidental shorting or damage to equipment, or working on methane drainage systems, where methane leaks could result in fire or explosion.

When undertaking a risk assessment it is of importance to consider the range of hazards proposed by personnel of all disciplines present in the affected area. This may include the mine manager, with whom ultimate responsibility lies, electrical and mechanical engineers, mine safety personnel and worker's representatives. Depending on the perceived severity of the hazard difficulty in fire fighting or the length of the escape route, it may also be prudent to consult the Mine Rescue Service, or other emergency service who may attempt to undertake rescue or fire fighting underground.

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