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Research Article

A Scoring-Based Risk Assessment Method Proposal for Methane Explosions in Underground Coal Mines

Ulas Cinar[1*]

[1*] Canakkale Onsekiz Mart University, Occupational Health and Safety Education Application and Research Center, Canakkale, Turkey.
(ORCID: 0000-0003-3924-0768), ulas.cinar@comu.edu.tr

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Abstract

Mining is one of the sectors with the highest number of fatal occupational accidents. According to statistics, the majority of these fatal accidents are caused by methane explosions. In order for the explosion to occur, methane needs to form a certain concentration, sufficient oxygen and igniting elements are required. One of the most important factors that can affect methane formation is the carbon content of coal. As the carbon content increases, the probability of formation of flammable hydrocarbon-derived gas increases. The porous structure is a factor that causes methane to accumulate and create instantaneous concentration. It is known that the formation of the ignition element is directly proportional to the quartz content of the wall rocks. In this study, a new risk assessment method is proposed by assigning scores to the linguistic expressions of all these side parameters. This proposed method enables a proactive approach regardless of exact measurements and forced ventilation principles. It is foreseen that unexpected results can be prevented with the measures to be taken in this direction.

Keywords: Methane, Explosion, Risk Assessment, Coal Mines, Occupational Safety.

Yeraltı Kömür Madenlerinde Grizu Patlamaları İçin Skorlama Tabanlı Risk Değerlendirme Yöntemi Önerisi

Öz

Madencilik, ölümlü iş kazalarının en fazla olduğu sektörlerden biridir. İstatistiklere göre, bu ölümcül kazaların çoğu metan patlamalarından kaynaklanmaktadır. Patlamanın olabilmesi için metanın belirli bir konsantrasyon oluşturması, yeterli oksijen ve tutuşturucu elementlere ihtiyaç vardır. Metan oluşumunu etkileyebilecek en önemli faktörlerden biri kömürün karbon içeriğidir. Karbon içeriği arttıkça, yanıcı hidrokarbon türevi gaz oluşma olasılığı artar. Gözenekli yapı, metanın birikmesine ve anlık konsantrasyon oluşturmasına neden olan bir faktördür. Ateşleme elemanının oluşumunun yan kayaçların kuvars içeriği ile doğru orantılı olduğu bilinmektedir. Bu çalışmada, tüm bu yan parametrelerin dilsel ifadelerine puan verilerek yeni bir risk değerlendirme yöntemi önerilmiştir. Önerilen bu yöntem, kesin ölçümler ve cebri havalandırma ilkelerinden bağımsız olarak proaktif bir yaklaşım sağlar. Bu doğrultuda alınacak tedbirlerle beklenmeyen sonuçların önüne geçilebileceği öngörülmektedir.

Anahtar Kelimeler: Grizu, Patlama, Risk Analizi, Kömür, İş Güvenliği.

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[*] Corresponding Author: ulas.cinar@comu.edu.tr

1. Introduction

Mining is one of the sectors that should be considered as a priority in terms of occupational health and safety due to very dangerous activities (Cinar and Cebi, 2020). Nowadays, many studies are carried out to optimize current costs (Ozdemir and Ugurlu, 2021; Ugurlu, 2021). However, occupational accidents cause significant costs to companies directly or indirectly.

According to the statistics of the ILO (International Labor Organization), those working in mining sector are at least 3 times more likely to be exposed to accidents than those working in different sectors (ILO, 2022). In our country, approximately 10% of all occupational accidents and approximately 30% of fatal or severely damaged occupational accidents occur in the mining sector every year (Ceyhan, 2012; CASGEM, 2018). In our country, the highest number of work accident and occupational disease records in the mining sector were realized in quarries and coal enterprises. 89% of the total occupational accident and occupational disease cases in the sector were observed in these areas (Bilim v.d., 2018).

Methane, which is the main cause of the majority of fatal accidents in underground coal mines, is a flammable, colorless, odorless and gaseous hydrocarbon (C_nH_{2n+2}) derivative compound at normal temperature and pressure values (Segers, 1998). Methane – Air mixture is called “Grizu” and therefore methane-induced explosions are qualified as “Grizu Explosion” (Yasar, 2015).

Fatal accidents in 514 coal mines in the United States have been subjected to a statistical analysis of 100 years. It has been reported that 10390 of 11615 fatal accidents occurred during this period as a result of grizu explosion (Kowalski-Trakofler and Brnich, 2010). In a 130-year study conducted in Zonguldak coal mines in our country, 815 deaths were recorded as a result of 67 grizu explosions (Mevsim, 2016).

Grizu explosions occur as a result of a kind of chain combustion reaction. The three basic elements (Flammable Material, Oxygen and Heat) required for the combustion reaction must be present in sufficient quantities (Bickerton, 2012). In order for gases to explode, they must build up concentration in confined spaces. According to these concentration percentages, lower explosion and upper explosion limits of each gas were determined. Since there is not enough combustible material below the lower explosion limit, since the oxygen content will drop below 12% above the upper explosion limit, a combustion reaction does not occur and an explosion cannot be mentioned (Dursen and Yasun, 2012). The lower explosion limit for methane gas is 5% and the upper explosion limit is 15% (Tong v.d., 2009).

If methane gas at a concentration of 2% or more is detected in the measurements made from the furnace air, the work is stopped and the work is restarted after it is eliminated and the concentration is reduced to acceptable levels (Kissell, 2006). Ventilation is the most effective method for methane disposal, and therefore the application of uncontrolled natural ventilation is prohibited, especially in coal mines. The mechanized ventilation system should be applied in a controlled manner according to the gas density of the mine (Aydin and Kesimal, 2007).

Although ambient air measurements and mechanized ventilation systems are applied regularly and in a controlled manner, there are side factors that directly or indirectly affect grizu explosions. The most important of these factors is the type of coal. The main material of coal is carbon, and the higher the carbon content, the higher the potential to form (C_nH_{2n+2}) derivative flammable gas by reacting with hydrogen in the air (Calderon v.d., 2016).

The second important factor is the geological and mineralogical structures. Porous and hollow structures create space for the methane gas to accumulate. This situation causes two important problems. Methane gas can form an explosive effect by creating a concentration outside of the ambient air in hollow structures, or it can create an explosive atmosphere in the ambient air instantly by spraying from the accumulated methane porous structures (Esen v.d., 2017).

Another factor is the igniter, which is one of the three main components in the realization of the combustion reaction. Although ex-proof equipment is preferred during production, the contact between the cutting and drilling tools and the rocks instantaneously creates hot surfaces. Especially the quartz content in the host rocks increases this risk (Okten and Yazici, 1986).

In this study, a new risk assessment scale has been proposed to express the risk situation numerically by assigning scores to the linguistic expressions of the side elements that may directly or indirectly affect the factors causing firestorm explosions, independent of mandatory application and numerical measurements.

2. Material and Method

A risk assessment scale was created with three sub-parameters affecting the main factors of methane explosions. The first of these is the type of coal produced. Coal is classified according to the carbon content it contains. If the carbon content is about 60%, it is called “Peat”, if it is about 70%, “Lignite”, if it is between 80 – 90%, it is called “Hard Coal”, and if it is about 95%, it is called “Anthracite” (Kavaz, 2019). The higher the carbon content, the higher the potential to form methane by reacting with the hydrogen in the air. The risk scores against linguistic expressions are given in Table 1.

The porous structure is an important factor in terms of methane accumulation and sudden concentration. Risk scores were created according to porosity and given in Table 2.

The igniting element is a factor required for the reaction to start. The higher the quartz content in the host rocks, the more ignition is triggered. Risk scores were created according to the quartz content of the wall rock and given in Table 3.

Table 1. Risk Scores by Coal Type

Coal Type	***Risk Score***
Peat	*1*
Lignite	*3*
Hard Coal	*4*
Anthracite	*5*

Table 2. Risk Scores by Porosity

Porosity	***Risk Score***
Very Low	*1*
Low	*2*
Middle	*3*
High	*4*
Very High	*5*

Table 3. Risk Scores by Quartz Content of the Wall Rock

Quartz Content of the Wall Rock (%)	***Risk Score***
$x < 20$	*1*
$20 \leq x < 50$	*2*
$50 \leq x < 70$	*3*
$70 \leq x$	*4*

The risk scores corresponding to linguistic expressions [Coal Type (R_t), Porosity (R_p), Quartz Content of Wall Rock (R_q)] are multiplied as given in Equation (1) to obtain the final risk score (R_s).

$$R_s = R_t * R_p * R_q \tag{1}$$

Linguistic risk expressions for methane explosions according to the final risk score are given in Table 4.

Table 4. Risk Chart

	R_s
Very Low Risk	$x < 10$
Low Risk	$10 \leq x < 15$
Middle Risk	$15 \leq x < 30$
High Risk	$30 \leq x < 50$
Very High Risk	$50 \leq x$

3. Results and Discussion

Risk scores were determined by assigning scores corresponding to linguistic expressions according to the proposed method for the 5 coal mines whose properties are given in Table 5, and these final risk scores are given in Table 6.

Table 5. Properties of Coal Mines

	Coal Type	***Porosity***	***Quartz Content of the Wall Rock (%)***
A	*Lignite*	*High*	*44*
B	*Hard Coal*	*Middle*	*52*
C	*Lignite*	*Low*	*37*
D	*Lignite*	*Middle*	*62*
E	*Hard Coal*	*Low*	*48*

Table 6. Risk Score Chart

	RISK SCORE CHART			
	Coal Type	***Porosity***	***Quartz Content of the Wall Rock (%)***	***Risk Score***
A	*3*	*4*	*2*	*24*
B	*4*	*3*	*3*	*36*
C	*3*	*2*	*2*	*12*
D	*3*	*3*	*3*	*27*

4. Conclusion

Gas measurements and ventilation criteria are standard and mandatory in coal mines. The activities to be carried out according to the methane measurements are also determined. However, risk analyzes must be performed proactively. The risk can be expressed more clearly when the factors affecting methane formation, methane concentration and reaction triggering factors are considered. Instant and precise measurements will shape the final action plan. However, with the proposed risk assessment method, negative consequences can be prevented by taking precautionary measures.

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