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Inter gases as one of the ways to reduce the risk of endogenous fires in hard coal mines

doi:10.2478/mape-2019-0018
Date of submission to the Editor: 04/2018
Date of acceptance by the Editor: 07/2018
MAPE 2019, volume 2, issue 1, pp. 183-190

Dawid Szurgacz*
Polska Grupa Górnicza S.A., Poland

Leszek Sobik
KWK ROW RUCH Chwałowice, Poland

Jarosław Brodny
ORCID ID: 0000-0002-6807-4431
Silesian University of Technology, **Poland**

INTRODUCTION

Providing safety for the staff working underground is the basic and fundamental task, and at the same time, issue of the mining industry. In particular, this applies to people working directly in the area of exploitation, a longwall face. Due to the high intensity of exploitation and various natural hazards occurring during this operation, this task is very difficult (Brodny & Tutak, 2016; Brodny & Tutak, 2018b; Felka & Brodny, 2017; Raport, 2017; Tutak & Brodny, 2017a; Tutak & Brodny, 2017b; Tutak & Brodny, 2019). For this reason, various measures are taken to ensure that the working conditions are as safe as possible. The analysis of currently occurring natural hazards associated with the underground exploitation process indicates that ventilation hazards are the most dangerous. These include explosion hazards or methane fire (Szurgacz et al., 2019; Tutak, 2017a; Tutak, 2017b; Wang et. al.,2011; Tutak & Brodny, 2019; Tutak & Brodny, 2017c) and endogenous fire (Brodny & Tutak, 2018a, Tutak, 2017a, Tutak & Brodny, 2017c). These hazards are directly related to the conducted operation and result from the specific construction and properties of the rock mass and coal. This applies above all to the fact that coal accumulates methane and has the ability to self-ignition. Large amounts of methane are released during the mining process, and the coal left in the goaf of coal can trigger an endogenous fire under favourable conditions.

Intensive exploitation based on powered longwall systems also may lead to particularly dangerous endogenous fires. They usually start in goafs. They, as highly porous centres, allow the air flow and the inflow of oxygen to the coal left in them, which may cause spontaneous combustion (Brodny & Tutak, 2018a, Tutak & Brodny, 2018a, Tutak & Brodny, 2017c). The result of such an event is the isolation of the exploited area. This, in turn, causes huge economic losses. A break in operation caused by need to extinguish such a fire can last up to several months.

* dawidszurgacz@vp.pl

Therefore, research is carried out in order to detect the outbreak of a fire early, or to determine the zones conducive to its creation (Brodny & Tutak, 2018a, Tutak & Brodny, 2018a, Tutak & Brodny, 2017c). The obtained results are the basis for conducting preventive activities. One of the methods aimed at limiting the possibility of endogenous fire is adequate ventilation of mining excavations with restriction of air supply (oxygen) to goafs.

Mining companies, therefore, undertake activities in this area in order to improve the operational safety and efficiency of the entire production process. This is necessary due to high competition on the energy raw materials market.

These activities include mainly sealing of mining excavations and isolation of the rock mass with simultaneous inertisation of post-mining goafs. Efforts are also being undertaken to level aerodynamic potentials in order to reduce air leakage through goafs and fire fields. These measures include the use of backfilling panels, mine air analyses, chromatographic analyses of the composition of goaf atmosphere and pyrometers to detect self-heating of coal. Very important element in the whole process of fighting the fire hazard is the ventilation system and the parameters of the ventilation air stream (Szurgacz et al., 2019).

The entire operation planning process must take into account all possible risks that may occur.

The article discusses the method of supplying the inert gases as one of the most commonly used preventive methods in the case of endogenous fires. The air parameters in the outflow airstream were also determined in the case of application of an integrated method developed by the authors of reducing the fire hazard in the area of mining exploitation. In particular, this applies to the determination of the minimum value of volume expenditure when supplying carbon dioxide and nitrogen. Determining this efficiency allows the selection of appropriate parameters of the ventilation system, so that the gases supplied do not pose a threat to the miners working undeground.

DETERMINATION OF THE AMOUNT OF AIR IN A LONGWALL EXCAVATION WHEN SUPPLYING INTER GASES

The use of fire prevention based on inert gases is aimed at reducing the oxygen content to the limit preventing the further development of the fire. Inertisation is defined as the replacement of air or a combustible atmosphere with an inert gas. Carbon dioxide (CO_2) and nitrogen (N_2) are the inert gases most commonly used in mines. This method is aimed at limiting the possibility of a fire or limiting its spread in the initial phase of its ignition. The main idea of this method is to isolate the fire field by limiting the supply of oxygen to the zone in which the fire may or has already begun. Factors that determine the effectiveness of this method are the time and manner of inert gas injection, the location of the place where the fire occurred and the place (area) in which it may occur. In this numerical methods are very helpful. They allow to determine the zones in which the conditions for endogenous fire are met (Brodny & Tutak, 2018a, Tutak & Brodny, 2018a, Tutak & Brodny, 2017c). As already mentioned, the main task of using inert gases is to reduce the oxygen content to the limit preventing the further development of the fire. This is related to the appropriate determination of the parameters of the injected gases and installations for production of these gases and their transport to the zone in danger.

Another elements in the process of limiting the risk of endogenous fires are dependencies between the oxygen content in the air, the presence of fuel (in this case coal) and thermal energy necessary for the emergence and development of endogenous fire. Diagrams describing the relationships between these factors and the effect of inert gases on endogenous fires are presented in Figures 1.

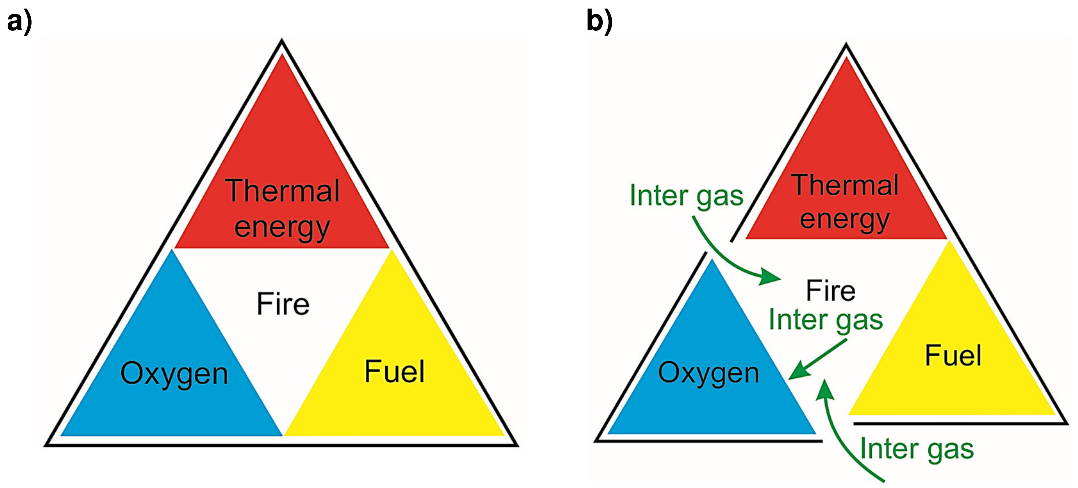

Fig. 1 Factors influencing the creation of endogenous fire (a) and impact of inert gas on the development of endogenous fire (b)

Determination of the minimum amount of air in outflow airstreams, with built-in installation for feeding carbon dioxide

The most commonly used gas is carbon dioxide. The use of this gas, however, requires a number of conditions to be met, so that its use does not pose an additional threat to the working staff. These are the level of concentration of this gas in the outflow airstream. The concentration of this gas can not exceed 1%. If it exceeds this value, it will pose a threat. For this reason, the ventilation system must be properly designed. It is obvious that carbon dioxide supplied to goafs, as a result of their porosity and the movement of air, escapes into mine workings. Therefore, it is reasonable to carry out the inerting process so that the amount of this gas getting into active mining excavations is as small as possible.

To ensure work safety in excavations with a built-in pipeline for supplying carbon dioxide, it is important to determine the minimum amount of air that allows to maintain $CO_2 < 1\%$. The minimum value of the volumetric efficiency necessary to maintain the permissible concentration value of this gas determines axis with the following relationship:

$$V\,min\,c\,o_2 = Va\frac{Sco_2rur - Sco_2dop}{Sco_2dop - Sco_2wyr} \quad (1)$$

where:

Vmin co_2 – minimal amount of air to maintain $CO_2 < 1\%$, m^3/min,
Va – efficiency from which inert gas is supplied (carbon dioxide), m^3/min,
Sco_2rur – CO_2 concentration in the pipeline, %,
Sco_2dop – concentration of CO_2 acceptable in mine air 1.0, %,
Sco_2wyr – concentration of CO_2 in excavations, %.

The determined expenditure is the basis for determining the operating parameters of the entire ventilation system used in the area covered by the inertization.

Determination of the minimum amount of air in outflow airstreams, with built-in installation for supplying nitrogen

In addition to carbon dioxide, nitrogen is also used as an inert gas. As in the case of carbon dioxide, also when supplying nitrogen, it is necessary to determine the minimum value of efficiency of supplied air, so as not to exceed the permissible concentrations of this gas in mining excavations where mining works are carried out. In order to ensure work safety in excavations with a built-in installation for feeding nitrogen, the minimum amount of air is determined in accordance with the relationship (2):

$$\dot{V}\, min\, o_2 = \dot{V} a \frac{So_2 dop - So_2 rur}{So_2 wyr - So_2 dop} \tag{2}$$

where:

$\dot{V}\, min\, o_2$ – minimum air quantity to maintain $O_2 < 19\%$, m^3/min,

$\dot{V} a$ – efficiency with which inert gas is fed (nitrogen), m^3/min,

So_2rur – O_2 concentration in the pipeline (max. 3%), %,

So_2dop – O_2 concentration allowed in mine air (min. 19%), %,

So_2wyr – O_2 concentration in excavations, %.

Also, in this case, the determined value of this capacity is the basis for the selection of a ventilation system.

RESEARCH ON THE AMOUNT OF AIR FLOWIN OUTFLOW AIR STREAMS

According to the dependences presented in the previous chapter, the minimum amount of air in outflow air streams was determined, the results of which are presented in Table 1. For the calculated amount of air in workings in which the nitrogen supply pipeline is routed in the event of damage to the installation, the oxygen content in the air will not fall below the quantity defined by regulations (19%). In the case of using carbon dioxide as an inert gas, its concentration in the outflow air streams will not exceed 1%.

Table 1
Test results defining the amount of air in out-flowing air streams

Longwall	Seam	Length, m	Seam inclination o	Heightm	Length m	Average progress of mining m/mc	Airflow in the longwall m3/min	$\dot{V}$ min co2	$\dot{V}$ min o2
S/z I-III	408/1	250	28	3.0	780	83	700	568.7	75.7
S/z I-II	405/1	240	18	2.2	500	95	850	379.1	50.4
S/z II-II	404/5	242	20	4.2	380	85	900	454.9	63.1
S/z II-II	404/3	245	18	3.3	240	86	800	511.8	88.2
S/z II-PI	404/5	230	22	3.8	470	90	650	341.2	68.1
S/z I-PI	404/9	250	22	2.0	560	88	600	113.7	50.4
S/z IIa-III	405/2	230	24	2.0	508	80	800	189.9	68.1

The presented results concern seven mining longwalls from three seams located in one mine of the Polska Grupa Górnicza, a leading mining company in Poland, in which the exploitation is carried out.
In order to improve the efficiency of the process of limiting the threat of endogenous fires, a model of U ventilation system was developed (Figure 2). This system is currently most commonly used in the operation of longwalls in underground coal mining in Poland. The essence of this method consists in the simultaneous application of many methods of fire prevention.

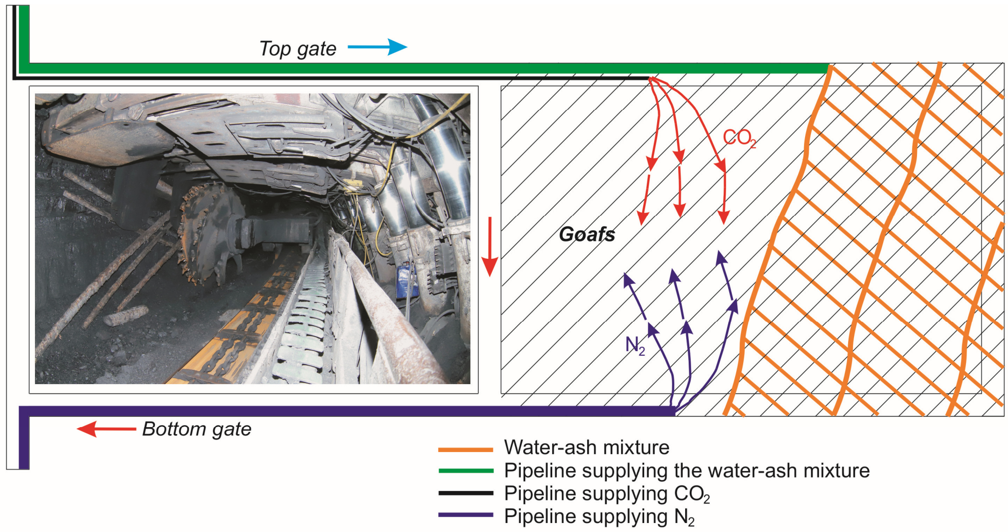

Fig. 2 An integrated method to reduce the fire hazard in the area of mining exploitation

The analysis of ventilation systems and parameters of flowing air in the tested longwalls did not include the movement of individual devices and the air resistance caused by the presence of the longwall support. These simplifications in this case, according to the authors, have little effect on the results.
The length of the longwalls in which the tests were carried out ranges from 230 m to 250 m, their panel lenghts range from 500-780 m, longitudinal slope: from 18° to 28°, lateral inclination: from 2° to 19°, while their height is from 2 m up to 4.2 m. An important role influencing the effectiveness and safety of inert gas inertisation is to take into account the coefficient of permeability of the goafs, which mainly depends on the type of roof rocks forming the caving and the distance from the front of the longwall. The coefficient of permeability of goaf in the subject areas was varied due to the sealing of goafs with ash and water mixtures. This is in compliance with the developed method shown in Figure 2.
The results were used as a basis of determination of values of air flow taking into account both inert gases used. Figure 3 presents the results of the analysis for carbon dioxide. For each of the tested longwalls, the limit value of air efficiency was determined, and the value used for maintaining other ventilation parameters.
Figure 4 presents the limit values of the efficiency delivered to the air workings due to the maintenance of the content of oxygen in this air.

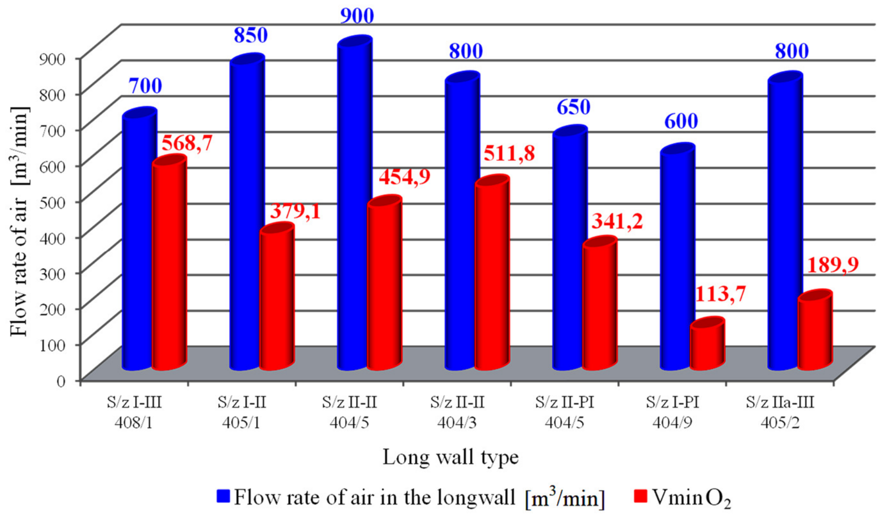

Fig. 3 Dependence of air flow in mining longwalls from $V_{min}O_2$ – minimal amount of air to maintain O_2 < 1% [m³/min]

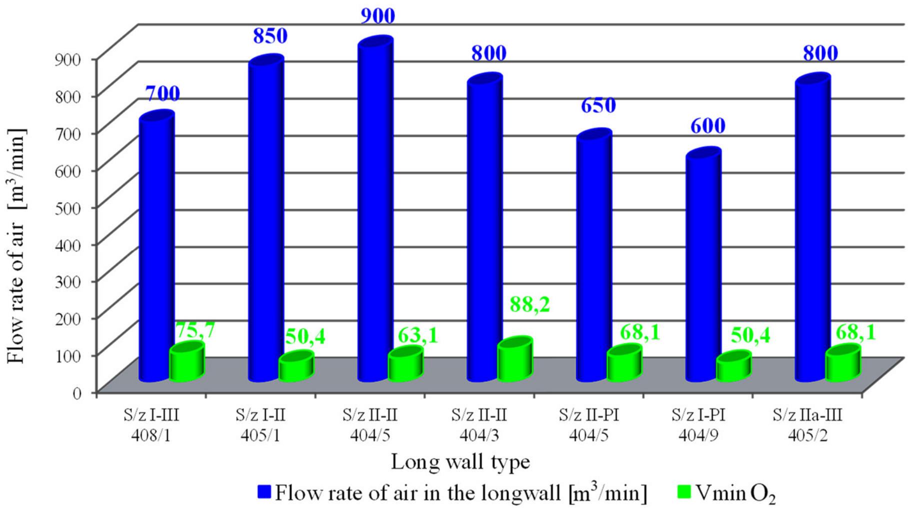

Fig. 4 Dependence of air flow in mining walls from $V_{min}O_2$ – minimal amount of air to maintain O_2 < 19% [m³/min]

The analysis of the obtained results indicates that both conditions are met. Actual capacities of air delivered to the tested areas are much higher than the limits. In the cases mentioned in this article, the inertisation of goafs should proceed without any problems and is not expected to pose an additional threat to the miners working underground.

CONCLUSION

Underground mining exploitation is inseparably connected with the occurrence of various types of threats. The threat of endogenous fires presented in this paper is a significant problem of modern coal mining. The coal left in the goaf under favourable conditions can become very dangerous and lead to a fire. Its effects can be very disadvantageous for mining companies. An endogenous fire is a threat to the miners and can cause large economic losses. It is therefore necessary to take all possible and economically justified actions to prevent such events. In this respect, extensive use of modern technologies and scientific research is necessary. This process includes proper diagnosis of the threat condition, analysis of possible solutions and their practical application. A very important element of this process is the correct recognition of the location and probability of an endogenous fire.

The easiest and at the same time the cheapest measure of endogenous fires prevention seems to be the development of an optimal method of ventilation of excavations. One of the directions of activities in this area is also the development of an effective and efficient method of using inert gases. This should be supported by additional activities including the sealing of goafs, rock mass insulation with simultaneous inertisation of post-mining goafs and inactive mining excavations. Comprehensive activities covering all these measures should effectively limit this threat.

The results presented in the paper have a great chance of reducing the risk of fires. During the exploitation of the tested longwalls, no such fires were reported. Exploitation in some of them is still carried out and effectiveness of the applied measures will be revealed in the future. Preliminary results clearly indicate that only comprehensive and supported by appropriate research activities create opportunities to reduce fire threats.

ACKNOWLEDGEMENTS

The work is the result of research conducted as part of the project carried out by Polska Grupa Górnicza S.A. "Learning Organization".

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Abstract. Endogenous fires are currently one of the most common threats in hard coal mines. They are very dangerous for the staff and can cause very large economical loses. Therefore, the scope of activities aimed at limiting the possibility of these fires and reduction of their consequences constantly broadens. The paper presents the results of research aimed at determining the efficiency of the ventilation system applied to reduce the risk of endogenous fires in the areas where inert gases are used. The calculations included carbon dioxide and nitrogen. Inertisation is one of the ways of combating endogenous fires. This method is included in the developed comprehensive method to reduce the possibility of these fires. The results obtained and the method developed and later applied, should have a significant impact on improving the safety of operations in the scope of occurrence and consequences of endogenous fires.

Keywords: air flow, longwall complex, inert gases