https://doi.org/10.32056/KOMAG2022.2.3

Innovative technology for inertization of goaf in operating longwall panel – presentation of gained experience

Received: 04.05.2022

Accepted: 20.05.2022

Published online: 01.06.2022

Author's affiliations and addresses:

[1] „AZIS" Mining Sp. z o. o.
oś. 1-Maja 16 K,
44-304 Wodzisław Śląski, Poland

*** Correspondence:**

e-mail: lasek@azis.pl

Marian LASEK [1*], Zbigniew CZERNECKI [1], Antoni JAKUBÓW [1]

Abstract:

The article presents an innovative technology of fire prevention in goaves, based on injection of nitrogen and carbon dioxide inert gases mixture from treatment of exhaust gases from a methane combusting gas engine. The developed innovative technology and the constructed prototype of the installation producing inert gases are the final result of the research project entitled "Innovative and effective technology of inerting the goaf active or dammed longwall in an underground mining plant, extracting hard coal, using mixtures of inert gases obtained from the purification of exhaust gases from a gas engine and preventing the formation of endogenous fires", co-financed by the National Center for Research and Development (NCBR). The prototype installation was demonstrated in real conditions at the "Borynia" part of "Borynia-Zofiówka" mine, where, at the end of the research project, the prototype and the developed fire prevention technology with the use of gas engine exhaust gases were optimized and validated. Until now, under normal conditions in a hard coal mine, the fumes generated as a result of methane combustion in gas engines were emitted directly to the atmosphere. Innovative inerting technology, processing and reusing the exhaust gases produced by methane-fueled gas engines, in ecological context will contribute to the reduction of pollutant emissions in the mining sector, and, with mixing at the same time the carbon dioxide and nitrogen in the proper ratio in the mixture, it will fully utilize the advantages of each of these gases, as known when used in separate form. As a result, considering the possibility of generating a much higher amount of inert gases per time unit compared to the available technologies, and combining the physicochemical properties of nitrogen and carbon dioxide in one mixture, the innovative technological solution significantly increases the effectiveness of fire prevention, thus reducing the possibility of an endogenous fire.

Keywords: endogenous fires, fire hazard prevention, intertization, diesel engine, catalyst, purification of exhaust gases

1. Introduction

Currently, in hard coal mines, inert gases are supplied through a pipeline system to endogenous fire zones with insufficient efficiency in the result of technological and cost limitations. The issue of ventilation optimization of, goaf sealing and inertization of extinguishing technology to improve the safety of mines in longwall faces is also analysed through numerical modelling (CFD) [1,2,3]. To enable effective feeding the gases through the pipeline system, inert gases must meet certain physical and chemical parameters, and the generating equipment must function stably [4,5]. In the case of using the exhaust gases produced by gas engines, it is necessary to clean them of the excessive content of oxygen, carbon monoxide, nitrogen oxides and other harmful substances, as well as cooling them to a temperature of ≈ 20 ° C and compressing them to a pressure of ≈ 6 bar.

The developed innovative technology and the manufactured prototype of the installation producing inert gases are the final result of the research project [6]. Number of tests and optimization of the prototype, including stabilization of composition and amount of inert gases at the appropriate level, assessment of the effectiveness of fire prevention based on chromatographic measurements of the air flowing from the goaf, monitoring the technical parameters of the installation and its impact on the operation of the gas engine [7] enabled obtaining the stability of technological processes and parameters for inert gases. The refined and optimized innovative technology will enable feeding the mixture of inert gases of different specific gravity and in much larger amount to a given hazardous place, filling the space in the goaf with inert gas, ensuring effective fire prevention.

2. Materials and Methods

Analysis of the installation and product stabilization effectiveness in real conditions

After building a prototype installation, each device and system was commissioned, and then, after technical acceptance, a trial run of the installation was approved. Three series of exhaust and inert gas parameters were measured during the trial run. The results of oxygen content measurement exceeding the legal limit of 3% in the inert gas mixture forced a number of changes to the gas flow during the purification process. For this purpose, the system of nitrogen and oxygen generators was changed from serial to parallel. Work was carried out to separate the oxygen generator into two generators operating in series. By-passes were made to supply the gas mixture with a reduced oxygen content to the second oxygen generator. Discharge valves were installed in the gas columns during the oxygen desorption in the generator. Desorption gases in the nitrogen generator were discharged of to the atmosphere [8].

After the validation work on the installation, gases were into the area of the designated longwall A-32 in seam 404/1łg and chromatographic analyses of gas samples were made by the GIG (Central Mining Institute) laboratory. To assess correctness of the installation operation, safety of the personnel and the longwall mining operations, on April 14-23, 2021, daily samples were taken for laboratory analysis - two gas samples from the installation and four gas samples from the A-32 longwall area of the longwall 404/1łg [9.10].

Results from the analysis of gases composition from the installation were the basis for development of documentation at the Central Mining Institute [10] "Evaluation of the efficiency of the catalytic gas cleaning system based on precise chromatographic analysis of gases collected at the system outlet", stating that:

– not exceeding the criterion of O_2 equal to 3% in the inert gas fed through the pipeline, specified in the Regulation of the Minister of Energy of March 16, 2017 on mine rescue [11] confirms the efficiency of the catalytic gas purification system. In the analyzed period from April 14-23, 2021, the oxygen concentration at the outlet of the system was on average 2.6% and it met the condition of not exceeding 3% of the oxygen content in the gas supplied through the pipeline.

– in the above period, the average nitrogen concentration was 95.73%, while the average carbon dioxide concentration was 1.5%. The maximum concentrations of gases relevant to the fire hazard assessment point were: ethylene up to 1.78 ppm, propylene up to 0.02 ppm, acetylene 0.014 ppm, carbon monoxide 52 ppm and hydrogen 0.8 ppm.

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– based on the precise chromatographic analysis of the gases taken at the outlet of the catalytic system, its full effectiveness in gas purification was confirmed.

Results of air composition in the longwall area were the basis for the development by the Central Mining Institute of the documentation entitled "Study of the safety of the crew employed in the workings of KWK" Borynia-Zofiówka" Ruch "Borynia" mine adjacent to the inertisation [10]. Examples of test results for gas samples from the area of the A-32 longwall, seam 404/1 łg are presented in Table 1.

Table 1. Results of chromatographic analysis of gas samples [10]

Laboratorium Samozapalności Węgla

JSW S.A. KWK „Borynia-Zofiówka" Ruch "Borynia"

Lp	Nr wor-ka	Miejsce i data pobrania próbki	C_2H_6 Etan ppm	C_2H_4 Etylen ppm	C_3H_8 Propan ppm	C_3H_6 Propylen ppm	C_2H_2 Acetylen ppm	CO Tlenek węgla ppm	O_2 Tlen %	N_2 Azot %	CO_2 Dwutle-nek węgla %	CH_4 Metan %	H_2 Wodór ppm
18	*1311*	chodnik A-32a - na linii likwidacji - zza TO (datapobrania - 2021.04.16 -) - (woda 1337)	26,9	0,02	8,35	0,03	0,002	3	5,01	92,68	0,32	1,99	4,7
		Data wykonania analizy: **2021.04.20 *(wtorek)***											
		Rejon pobrania próbek: **śc. A-32 w pokł. 404/1 łg**											
19	*1444*	chodnik A-32a - 10m przed przecinką A-31 (wylot) (datapobrania - 2021.04.19 -)	5,59	0,02	0,5	0,01	0,003	1	20,55	78,67	0,12	0,67	1,1
20	*1379*	chodnik A-32a - 10m przed przecinką A-31 (wylot) (datapobrania - 2021.04.19 -) - (woda 1338)	10,9	0,02	0,69	0,01	0,005	1	20,53	78,58	0,13	0,76	1,4
21	*1295*	zza ostatniej sekcji (datapobrania - 2021.04.19 -)	30,2	0,02	8,3	0,01	0,004	1	13,56	84,12	0,29	2,03	3,0
22	*1336*	zza ostatniej sekcji (datapobrania - 2021.04.19 -) - (woda 1326)	33,4	0,02	8,84	0,03	0,003	3	13,81	83,74	0,30	2,15	3,3
23	*1182*	chodnik A-32a - na linii likwidacji (datapobrania - 2021.04.19 -)	32,3	0,02	9,	0,02	0,002	3	12,87	84,80	0,29	2,04	3,0
24	*1357*	chodnik A-32a - na linii likwidacji - zza TO (datapobrania - 2021.04.19 -) - (woda 1324)	35,5	0,02	9,58	0,02	0,002	3	11,86	85,58	0,31	2,25	3,3
		Data wykonania analizy: **2021.04.21 *(środa)***											
		Rejon pobrania próbek: **śc. A-32 w pokł. 404/1 łg**											
25	*silnik 07*	chodnik A-32a - 10m przed przecinką A-31 (wylot) (datapobrania - 2021.04.20 -) - (woda - silnik 08)	11,2	0,02	0,91	0,01	0,004	1	20,38	78,76	0,14	0,72	0,9
26	*silnik 14*	zza ostatniej sekcji (datapobrania - 2021.04.20 -) - (woda silnik 11)	31,2	0,04	7,3	0,02	0,010	3	19,41	77,99	0,29	2,31	2,8

Analysis of safety for the area of A-32 longwall, seam 404/1 łg. and workings in which the pipeline for feeding exhaust gas as inert gas is located, takes the following into account:

– safety in workings, where a pipeline for feeding the exhaust gas as inert gas is located, considering the possible unsealing the pipeline and gas outflow directly into the streamlined air stream,

– safety in the area of the longwall exit and, in the workings, discharging used air from the longwall, due to the constant outflow of goaf gases mixed with the supplied exhaust gases (treated as inert gas) in the amount of approx. 2/3 of the total amount of air stream, i.e. to Workings A-32a.

– possibility of disturbing the assessment of endogenous fire hazard, based on fire indicators (quantitative and qualitative) due to: constant outflow of goaf gases mixed with supplied exhaust gases (treated as inert gas) in the amount of approx. 2/3 of their total amount to the air flow, i.e. to Workings A-32a, which determines the amount of CO and the concentration of CO in the context of criteria, compliant with the regulations, and the increase in the amount of CO in the composition of goaf gases, due to the presence of this gas in the exhaust gases, taken into account together with oxygen and nitrogen when determining the Graham Index.

Results of the research work indicate the correctness of the installation in terms of inert gas parameters given in the mining regulations, as well as state that the amounts and concentrations of gases from goafs flowing into the workings or in the event of a complete rupture of the pipeline under the most unfavourable feeding conditions will not pose a threat to the safety of the mining personnel operating in the workings adjacent to the inerting zone [10].

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Due to geological conditions, the A-32 longwall, seam 404/1łg, which were tested and for which the gas supply was planned, was stopped and its decommissioning started.

The earlier decommissioning of the A-32 longwall in seam 404/1łg did not allow for the assessment of the effectiveness of the innovative technology of inerting the goaf of the longwall panel.

In connection with the above, the mine has designated the B-34 longwall in seam 407/1-2. Due to unpredictable geological disturbances after starting the mining operation of B-34 Longwall in seam 407/1-2, the advance of mining operations decreased to approx. 5-10 meters per month. Additionally, coal was left in the goaf of B-34 Longwall, which increased the fire risk. Therefore, the mining plant operations manager approved *The Preventive Work Plan for Longwall B-34 in seam 407/1-2 (update)*. The plan of preventive work shows that it was ordered to use - depending on the conditions - feeding inert gas, which was nitrogen produced from the atmospheric air, backfilling the goaf with a water-ash mixture, feeding inert gases such as nitrogen or purified exhaust gas, feeding water through the holes.

Beginning of the longwall panel due to difficult geological conditions limiting its progress enabled the start of inertization only from September 27, 2021. An attempt to feed inert gas into the goaf from one of the workings showed the need to increase the pumping pressure to about 6 bar to feed about 2000 m^3/h of inert gas . It was agreed with the mine representatives that it is necessary to build the second line of the supply pipeline between the DN150 mm pipeline and the pipeline branch into two single lines DN100 mm in B-33 decline and B-32a workings, seam 407/1-2. Installation of two lines of the DN100 mm pipeline on the above-mentioned section, allowed to increase the volume of inert gases supplied and to enable the feeding it into the goaf from both near-longwall roadways of B-34 longwall, seam 407/1-2.

Upon the decision of ventilation service, in the period from 27/09/2021-19/01/2022, the goaf of B-34 longwall in seam 407/1-2 was interted with the determined amount of gases. In total, during 1,733 hours and 40 minutes, 4,042,985 m^3 of inert gases, including 30,743 m^3 of carbon dioxide, were pumped into the goaf of the longwall panel. The highest obtained amount of injected gas (nitrogen and carbon dioxide mixture) was 3590 m^3/h [9].

3. Results

Assessment of the impact of gas consumption on the operation of a gas engine

The project "Comprehensive development of the duct from the exhaust gas branch of the electricity generator at KWK" Borynia-Zofiówka "Ruch" Borynia " mine" and the thermally insulated exhaust gas duct feeding the gas from the tee to the flue gas treatment installation, were designed. On the basis of the design, a branch with a flanged stub pipe was made, a throttle for the required tightness with a quick-closing electric actuator was installed as well as a 75 m long flue gas duct made of an insulated DN500 pipeline made of acid-resistant steel was installed. The flue gas duct in the area of the installation is ended with a quick-closing throttle with a pneumatic actuator.

In order to protect the installation against the emergence of explosive methane concentration in emergency states, a laser gas analyser was installed on the vertical section of the duct, connected to the control system and initiating an impulse to quick-closing throttles installed behind the tee and at the end of the duct.

When the inert gas generation installation is stopped, the exhaust gas is discharged through the existing chimney, and after the inert gas generation installation is started, the pressure controller - the fan - causes the exhaust gas to flow to the above-mentioned installation. Proper synchronization of the operation of the innovative installation with the operation of the gas engine ensures failure-free operation of the devices [8]. During the operation of the installation for generating the inert gases from exhaust gases, there were many interruptions in the engine operation, without the installation failure, but only its shutdown. There were also emergency states of the engine operation, causing the flow of methane above the set alarm threshold, and then the safety devices shut off the exhaust gas supply to the installation with throttles, shutting down the installation. The exhaust gas consumption in the amount of about 5000 m^3/h found during the operation of the installation did not cause any problems with the gas engine operation.

Validation and optimalization of the installation prototype

During the operation of the installation and supply of gases to the goaf, longwall A-32, seam 404 / 1łg, there were emergency breaks in the operation of compressors and reduced gas parameters of the generators. During the service inspection of the devices, contamination, even clogging of inlet gas filters in generators and contaminated oil in compressors were found. After the analysis of pollutants, it was decided to replace the filters and oil in the devices, dismantle the catalyst in the KAT2 reactor (low reduction efficiency, and the reduction is provided by coal and zeolite deposits in the generators), and an additional filter was installed in the reactor enclosure. Due to the very good reduction of NOx in the beds of PSA generators (nitrogen and oxygen) as well as the large corrosive effect of ammonia on the equipment in the KS-1 compression station, dosing of urea (ammonia water) for reduction of NOx compounds was abandoned. As part of the measures taken, the activated carbon deposit in the nitrogen generator was replaced, connections and drier elements in gas compression stations were replaced, the cooler in the 1st stage compressor of the oxygen generator was renovated, and the oil and filters were replaced more frequently.

After realization of the above work, the installation was started reporting its proper operation.

Content of each gas in the exhaust gases and its parameters differ significantly between the years 2016-2019 and the years 2021-2022, probably due to the intake of methane from another part of the mine, which has a higher sulphur content. During the flue gas measurements, a higher oxygen concentration was observed - up to 13% - a lower concentration of carbon dioxide, about 4%, and a significant increase in the content of sulphur as SO_2 from <3.3 to 53 mg/m^3. Such a change in exhaust gas parameters regarding the oxygen and carbon dioxide negatively affects the achievement of inert gas proper parameters, while such a large increase in sulphur content causes the formation of acids during flue gas cleaning, which destroy each component of the installation made of materials not resistant to acids.

Validation of the installation after commissioning and after design changes, such as: changing the nitrogen and oxygen generator operating system from in series to parallel, dividing of the oxygen generator into two generators with lower power operating in series allowed to obtain proper parameters of the inert gas and allowed inerting the requires area of the mine.

Comments indicated by the mine ventilation services regarding the reduction of CO concentration in the supplied inert gas forced the change of the nitrogen generator operation to the production of nitrogen from the atmospheric air. It is true that these changes resulted in a decrease in the percentage of inert gas obtained from gas engine exhaust gas cleaning in the total inert gas stream, but they decreased the concentration of carbon monoxide in the inert gas mixture to an acceptable 15-20 ppm.

The R&D work led to designing and manufacturing the prototype of an installation for producing inert gas as a mixture of nitrogen and carbon dioxide resulting from the purification of exhaust gas from a gas engine fuelled with methane from mine methane drainage to ensure the safe operation of hard coal mine [5]. Such purification of engine exhaust gases to produce inert gas allows for obtaining gas that serves not only to improve safety by using it in the inertization of goaf walls in the prevention against endogenous fire hazards, but also is an important element of environmental protection by blocking part of carbon dioxide in workings.

The inert gases can be fed to the goaf in the amount that will not cause outflow of goaf gases (e.g. carbon monoxide, methane, carbon dioxide) resulting in exceeding their permissible concentrations in the mine air. During continuous feeding the inert gases containing about 1.5-2.5% CO_2 to B-34 def. 407/1-2 goafs for several days, its concentration equal to 1% was found during the measurements in the area of the end powered roof support - which is the limit value for this gas in the circulating air. In the conditions of the longwall B-34 of the 407/1-2, for which the inertization with a mixture of gases produced in the installation and supplying CO_2 in the amount of 5, 10, or 15% in the mixture could be impossible due to its outflow into the mine air, exceeding the permissible concentrations in the mine air. In real conditions, the continuous inertization of such large volumes of carbon dioxide in inert gas to the active gobs of mining walls may be very difficult or even impossible.

Increased content of such gases such as carbon monoxide, ethylene, propylene, acetylene, hydrogen, in inert gas should be monitored each time before starting inertization by analysing the air flowing from the goaf and assessing the background concentration of such gases, to not exceed the accepted concentration are the basis for the assessment of fire hazard status.

Testing the innovative technology in real conditions in the mine confirmed its effectiveness in controlling the endogenous fires, safety of the crew employed in underground workings and effectiveness of the catalytic gas cleaning system [10].

4. Conclusions

It was confirmed that the following project objectives and tests were achieved:

– At the stage I theoretical studies for specifying the assumptions for inertization process and the assessment of its effectiveness were developed, mathematical models of gas flow in the goaf and the place of their outflow were developed made, what was confirmed during in-situ tests [12],

– at the stages II and III, the R&D project led to designing and manufacturing the prototype installation, which was tested in real conditions in the mining plant, not posing any hazard. Effective fire prevention for endogenous fires of inert gases obtained in the process of cleaning the exhaust gases from the gas engine, as a mixture of nitrogen and carbon dioxide, was proved [10].

The differences in the obtained concentration of some gases in the inert gases mixture are the result of a very high variability of the fuel supplying the engine, different engine operation, and thus the enormous variability of the composition of exhaust gases. It can be concluded with a high degree of probability that each new installation in a different mine will produce gases with different parameters, and the same installation in different periods of operation will also produce gases of different parameters.

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