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The influence of pressure drop on gas emissions from a mining shaft – an overview

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Abstract

Climate change can make an impact on the mining sector and post-mining sites. Among others, extreme weather events are connected with sudden and deep pressure drops which lead to gas emissions from an underground space to the surface through closed shafts. The tests undertaken in the frameworks of TEXMIN project lead to get measuring data of this phenomenon and will allow validating numerical models for further forecasts and mitigation means. Three examples of the results were presented. They showed that the intensity of pressure drop influences strongly on gas emissions from a closed shaft. Although the pressure drop process should be investigated in detail considering hourly or even more frequent variations of pressure. Considering the variation of emitted gases in the vicinity of the closed shaft they remained increased even 20 – 30 m from the point of emissions.

Keywords

mine closure, gas hazard, carbon dioxide emissions

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Abstract

Climate change can make an impact on the mining sector and post-mining sites. Among others, extreme weather events are connected with sudden and deep pressure drops which lead to gas emissions from an underground space to the surface through closed shafts. The tests undertaken in the frameworks of TEXMIN project lead to get measuring data of this phenomenon and will allow validating numerical models for further forecasts and mitigation means. Three examples of the results were presented. They showed that the intensity of pressure drop influences strongly on gas emissions from a closed shaft. Although the pressure drop process should be investigated in detail considering hourly or even more frequent variations of pressure. Considering the variation of emitted gases in the vicinity of the closed shaft they remained increased even 20–30 m from the point of emissions.

Keywords: mine closure, gas hazard, carbon dioxide emissions

1. Introduction

Mining is a sector particularly exposed to climate change. Changing climatic conditions will influence both, operating and closed mines. Among other factors, possible impact is related to variations in atmospheric pressure [1]. Assessing and minimising the environmental impact of extreme weather events on mining operations is the aim of TEXMIN project (The impact of extreme weather events on mining operations) founded by Research Fund for Coal and Steel and partly founded by Polish Ministry of Science.

One of the specific goals is to identify, quantify and evaluate those impacts brought about by sudden changes in atmospheric pressure and model them for improvement of the understanding of how changing parameters influence the results. The influence of the buoyancy effect is additional aspect being tested when gas flows from an underground location through a closed shaft to the surface.

Significant and more frequent storms will be associated with deep low-pressure systems. These more frequent changes in atmospheric pressure could lead to more gas emissions (particular CH₄ and CO₂) from underground mines [2–4]. Gas emissions depend on the mining method, the depth of the seams, the coal quality and the entrapped gas content within the coal seam [5]. A gas continues to escape from the old workings of abandoned coal mines where it could reach the surface through cracks and crevices caused by mining activity, from shafts and adits which were not completely sealed, or from degassing boreholes [6]. In general, an increased amount of gas will flow to the atmosphere during barometric pressure drops where the pressure in the reservoir will be greater than the barometric pressure [7], although this phenomenon is still under investigations.

The aim of conducted research is to get deeper knowledge on the process by *in situ* measurements.

Then, the results will be the base for validation of further numerical emissions models (to simulate predicted extreme weather events). The results will be also used for risk assessment and for

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determination of mitigation methods at post-mining areas [8–11].

It should be emphasized here that the article is referred to one of the possible cases of gas emissions from closed mines - through the decommissioned shaft. It is when there is hydraulic flow of gases through a shaft which is not filled with backfilling material.

This type of flow has already been studied by [i.e. [12]], and later by, for example, Sułkowski and Wrona [13] provided mathematical models of hydraulic flow and applied them to own computer programs enabling their solution. The first model was based on Torricelli equation. It was assumed that the pressure difference at the outlet of the opening from the reservoir is caused by a decreasing barometric tendency. In this model, a constant density of the mixture was assumed, gas expansion, gas viscosity and process isothermal nature were omitted. It was a simplified model. The second model was a model called "complex", which was based on a system of non-linear differential equations describing the transient air flow in the mine ventilation network. This model took into account the inertia of the flow and the compressibility of gases. Since then, the computing capabilities of computers and software have developed. CFD programs such as Ansys Fluent or Pyrosim have been introduced and developed. The results presented in the article will be used to validate the models in these programs.

However, there are other gas flow cases along with the models that describe them:

- Diffusion flow of gases – i.e. the flow taking place due to the concentration gradient of gases between various elements of the carbon matrix or between the centre of a given element and the walls of adjacent fissures or pores, which leads to automatic balancing of gas concentrations in underground workings, goafs and voids [14–16].
- Gas filtration flow through porous material – caused by the balancing of gas pressure in all the gaps forming the system of connected vessels. The gas flows under pressure towards the surface through all available gaps. They can be fault gaps, cracks, gaps in porous material filling closed workings and holes [17,18]. For example, Dziurzyński [19] developed a model of gas migration from the shaft of a closed mine, but it was assumed that the shaft was completely filled with proppant material and was tightly closed on the surface.

The low permeability of coal seams is the main reason that developing coalbed methane (CBM) as

an energy resource is difficult, so increasing coal seam permeability is the key to CBM model development in China [20].

Additionally, other models were created, for instance:

- Geological model – presented by [21]. It was found that a key role in shaping the migration process of mine gases towards the surface is played by the lithological formation and the thickness of the carboniferous overburden, especially in the tertiary and quaternary layers. In the case of thick and impermeable tertiary layers (Miocene), the migration phenomenon is clearly slowed down (symptoms of gas appear on the surface after a much longer period of time - around 30 years) or even impossible.
- Risk model – [22] – This article presents the principles of this methodology. An application example based on a true case study is then described. This is completed by a presentation of the preventive and monitoring resources recommended and usually applied in order to manage the risk linked to gaseous emissions.

This article presents the first step of the research – the measurements, by three different examples.

2. Materials and methods

2.1. The site – shaft II

The shaft is located in an open space area within the revitalized industrial park (Fig. 1).

The shaft II (which is selected for examinations) is located strictly between two buildings. This location creates a kind of a wind tunnel making south winds as dominant. The shaft is empty (not backfilled) because of water pumping purposes.

Fig. 1. Location of the shaft II.

2.2. Instruments

Following instruments were applied during the tests:

- MultiRae IR Plus, gas analyser,
- Flir E6 – infrared camera (Fig. 2).
- Nova MRU Plus, gas analyser (Fig. 3),
- μ AS-4, digital vane anemometer,
- μ AS, digital vane anemometer,
- Kestrel, portable meteorological station,

2.3. The method

The measurements were based on good practice methods recommended in the document prepared by the Intergovernmental Panel of Climate Change (IPCC) which is titled “PCC Guidelines for National Greenhouse Gas Inventories, Volume 2 Energy, Chapter—Fugitive emissions” (NGER Act 2009) and on an adequate Polish standard (PN-Z-04008-02: 1984).

The research procedure included the following steps:

- Due to determination of the range and the rate of emissions, detection of possible gas velocity and gas concentrations were carried out. It allowed to select adequate measuring instruments and to determine the measuring grid as well as the points of emissions.
- Points of emissions were selected (including the application of IR vision instruments and vane anemometers), then profiles of emissions were determined by the application of gas analysers.
- It was stated that the gas concentration is constant in the profiles. As a result – continuous

Fig. 2. Application of IR camera for detection of the emissions.

Fig. 3. Gas analyzer and vane anemometer measurements of gas emissions.

traverse method was selected to establish average velocity.

At the same time the measuring mesh was determined around the shaft (Fig. 5). The purpose was to check the variation of gas concentrations in vicinity of the shaft at the ground level and at 1 m above the ground when pressure drops. The mesh comprises 15 points located in accordance with their availability and safety features. Point ‘E’ is an emission point (Figs. 4 and 5).

3. Results and discussion

There were eleven series (one preliminary and ten specific series) covering spring 2020 and summer 2020 seasons.

- Example 1 – the results taken on May 23rd 2020 (typical pressure drop) is presented in Figs. 6–8.
- Example 2 – upcoming extreme weather storm, according to the project assumptions, August 22nd 2020 Figs. 9–11.

Fig. 4. Determination of the main point of emissions for the shaft II.

Fig. 5. Measuring points in vicinity of II shaft.

– Example 3 – CO₂ and O₂ distribution in vicinity of shaft II, 3rd June 2020, Figs. 12–15.

3.1. Example 1 – May 23rd 2020

On May 23, 2020, the tests of gas emissions from shaft II began at 9:00 AM and finished at 6:00 PM. At that time, the atmospheric pressure decreased from 991.7 hPa to 988.6 hPa. Therefore, pressure drop was 3.1 hPa within 9 h. There are, however, two stages in the downward trend. The first from 9:00 AM to 1:00 PM, during which the pressure dropped by only 0.4 hPa (the pressure drop intensity was 0.1 hPa/h at that time) and the second, during which the pressure dropped by 2.7 hPa during 5 h. During this period, the average rate of pressure drop was 0.54 hPa/h.

Fig. 6. Pressure variation and emissions velocity at the point E on 23.05.2020.

Fig. 6 shows an increase in the gas emissions velocity from 1:00 PM to 6:00 PM from 0.29 m/s to 0.51 m/s. In the time period from 8:00 AM to 1:00 PM, the speed increased from 0.28 m/s to 0.43 m/s.

Regardless of the variable emissions velocity, during 9:00 AM – 1:00 PM, the concentration of CO₂ in the emitted gases increased from 0.06% vol. up to 0.29% vol. and later until 18:00–0.48% vol. (Fig. 7).

Analysing Fig. 8, it can be seen that the oxygen concentration in the emitted mixture decreased from the value of 20.8% vol. down to 20.1% vol. during the time from 9:00 AM to 6:00 PM, but from 8:00 AM to 1:00 PM, when the pressure drop rate was 0.1 hPa/h, oxygen concentration decreased by 0.4% vol. in the first hour of the pressure drop, then it remained at this level until 1:00 PM. Then, when pressure drop rate increased it started to fall once again.

3.2. Example 2 – August 22nd 2020

As the TEXMIN project aims to assess the impact of extreme weather events, including their influence on closed mines, on August 22nd 2020, measurements of gas emissions from shaft II were carried out in the period before the approaching intense storm (Figs. 9–11).

The measurements were carried out from 2:00 PM to 6:00 PM. The pressure dropped by 5:00 PM from the value of 982.5 hPa to 981.0 hPa, but by analysing the meteograms of the history of pressure changes at that time, the reduction lasted from 11:00 AM when the pressure value was 983.5 hPa. Thus, the pressure drop lasted 6 h and

Fig. 7. Pressure variation and CO₂ concentration at the point E on 23.05.2020.

Fig. 8. Pressure variation and O₂ concentration at the point E on 23.05.2020.

the pressure dropped by 2.5 hPa. Therefore, the pressure drop rate was 0.41 hPa. At 5:00 PM the atmospheric front passed through the measuring point and the pressure began to rise. By 6:00 PM it had increased to 982.0 hPa. An intense storm began at this time, which made further measurements impossible.

When analysing Fig. 9–10, it can be seen that from 5:00 PM to 6:00 PM the emissions from shaft II stopped. The emissions velocity dropped from 0.41 m/s to 0 m/s. At that time, the concentration of CO₂ in emitted gases also decreased from 2.37% vol. to background value (0.056% vol.) and the oxygen concentration increased from 18.4% vol. to 20.9% vol. (Figs. 10 and 11).

3.3. Example 3 – June 3rd 2020

Figs. 12–15 show the examples of the results obtained from the measurements of the distribution of CO₂ and O₂ concentrations around the shaft II on June 3rd 2020 at 9:00 AM.

At that time, pressure was 975.5 hPa and it was the final stage of the pressure drop starting on June 2nd 2020 at 11:00 AM at a pressure of 982.0 hPa. Thus, the pressure drop lasted 20 h and the pressure drop was 6.5 hPa. Therefore, the pressure drop rate was 0.33 hPa/h. The pressure value stabilized from 7:00 AM on June 3rd 2020. The concentration of CO₂ in the emitted gases was 7.51% vol. and the oxygen concentration was 6.8% vol. The emissions velocity was 0.1 m/s (as a result of slowing down the

Fig. 9. Pressure variation and emissions velocity at the point E on 22.08.2020.

Fig. 10. Pressure variation and CO₂ concentration at the point E on 22.08.2020.

Fig. 11. Pressure variation and O_2 concentration at the point E on 22.08.2020.

pressure drop). The ambient temperature was 17.1 °C and the temperature of the emitted gases was 15.9 °C. The wind speed 0.4–0.8 m/s was from the south.

Analysing the results (Figs. 12 and 13) it can be seen that at the ground level CO_2 concentration is 7.51% vol. at the E point. Within a radius of 20 m from the shaft the value is higher than 0.4%. Considering values at the height of 1 m, there is CO_2 concentration 4.5% vol. above point E. Within a radius of 25 m from the shaft the value is higher than 0.2% vol.

Analysing the results (Figs. 14 and 15) it can be seen that at the ground level O_2 concentration is 6.8% vol. at the E point. Within a radius of 20 m from the shaft the value is lower than 20.4% vol. Considering values at the height of 1 m, there is O_2 concentration 18.8% vol. above point E. Within a radius of 30 m from the shaft the value is lower than 20.7% vol.

4. Insights and conclusions

Basing on presented examples following insights and conclusions can be drawn:

1. On May 23rd 2020, two stages of pressure drop were observed, the first less intense (0.1 hPa/h) and the second more intense (0.54 hPa/h). The change in the intensity of emission influenced on the gas emissions rate (increase in the second stage) and the change in oxygen concentration (more intense decrease in the second stage). The concentration of CO_2 in the emitted gases increased with the same intensity during both stages of the pressure drop.
2. On August 22nd 2020 pressure was falling before the upcoming storm (an extreme weather event). At 5:00 PM, an hour before the storm, baric tendency had changed to pressure rise. At 6:00 PM emissions stopped. Carbon dioxide concentration and oxygen concentration returned to background values. During that time (5:00 PM–6:00 PM) the emissions velocity dropped from 0.41 m/s to 0 m/s. Concentration of CO_2 in emitted gases also decreased from 2.37% vol. to background value (0.056% vol.) and the oxygen concentration increased from 18.4% vol. to 20.9% vol. This observation leads to a conclusion that the pressure drop process should be investigated in detail considering hourly or even more frequent variations of pressure.
3. On June 3rd 2020, isoline maps of CO_2 and O_2 concentration were determined in vicinity of the shaft II. The article presents exemplary results for 9:00 AM, when the CO_2 concentration was 7.51%, and the O_2 concentration was 6.8% vol. in

Fig. 12. Concentration of CO_2 at ground level in vicinity of II shaft on June, 3rd 2020, 9:00 AM.

Fig. 13. Concentration of CO₂ at 1 m in vicinity of II shaft on June, 3rd 2020, 9:00 AM.

Fig. 14. Concentration of O₂ at ground level in vicinity of II shaft on June, 3rd 2020, 9:00 AM.

Fig. 15. Concentration of O₂ at 1 m in vicinity of II shaft on June, 3rd 2020, 9:00 AM.

the gases emitted from the shaft (point E). The CO₂ concentration at ground level within a radius of 20 m from the shaft was higher than 0.4%, and at 1 m within a radius of 25 m from the shaft the value was higher than 0.2% vol. Considering oxygen concentration, at the ground level within a radius of 20 m from the shaft the value was lower than 20.4% vol. and at 1 m within a radius of 30 m from the shaft the value was lower than 20.7% vol.

The results will be the base for further numerical modelling, when the results will be used for validation of the models as well as for development of risk mitigation strategies (i.e. determination of a safe distance from a closed shaft).

Ethical statement

The authors state that the research was conducted according to ethical standards.

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Conflicts of interest

None declared.

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