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INFLUENCE OF BAROMETRIC PRESSURE CHANGES ON VENTILATION CONDITIONS IN DEEP MINES

WPŁYW ZMIAN CIŚNIENIA BAROMETRYCZNEGO NA WARUNKI PRZEWIETRZANIA W KOPALNIACH GŁĘBINOWYCH

Barometric air pressure and its changes have a critical impact on ventilation conditions in the underground workings of deep mines. Changes in pressure are particularly important because they are responsible for the transient states of ventilation conditions, therefore, assessing the scale of pressure change is essential. Unfortunately, previously for many years in the Polish mining industry barometric pressure was recorded only on tapes of mechanical barographs by the ventilation department on the surface and therefore such dependencies of methane concentration due to barometric pressure changes have not been properly documented. Today, after the implementation in mines of instruments enabling the monitoring of absolute pressure in the workings of mines (Wasilewski, 2009) the conditions have been created to study the influence of pressure changes on changes of air parameters in the mine workings. Barometric pressure changes were observed and recorded over a course of approximately two years using monitoring system that utilized high accuracy pressure sensors on the surface and in selected workings of an underground mine.

This paper presents a statistical analysis of the data that we generated from assessing pressure changes on the surface and at selected underground points in the mine. In the article, which presents the results of the first part of the study, some examples of when significant changes in pressure prior to the tragic events, which were not accompanied by changes in the methane concentration in mine workings, will also be shown. Interestingly, we found that the relationship between methane ignitions and explosions in longwall gob mined via the cave-in method is associated with changes in the barometric pressure.

Several instances of methane ignitions and explosions in the gob of cave-in longwalls in recent years were compared with background barometric pressure changes. Research carried out in within the strategic project "Improving work safety in the mines" allowed to record air parameters changes inside the gob of longwalls and show the influence of pressure changes on changes in methane and oxygen concentration in the gob, which will be shown in the second part of the article to be published in the near future.

Keywords: control and monitoring, barometric pressure, gas hazards in underground mines

Ciśnienie barometryczne powietrza i jego zmiany mają istotny wpływ na warunki przewietrzania w wyrobiskach podziemnych kopalń głębinowych. Zmiany ciśnienia są szczególnie istotne, ponieważ

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powodują stany nieustalone warunków przewietrzania, stąd każda próba oceny skali tych zjawisk jest interesująca. Niestety wcześniej przez wiele lat w polskim górnictwie ciśnienie barometryczne było rejestrowane, jedynie na taśmach barografów mechanicznych, w dziale wentylacji na powierzchni stąd takie zależności zmian stężenia metanu w wyniku zmian ciśnienia barometrycznego nie zostały właściwie udokumentowane. Obecnie po wprowadzeniu do kopalń urządzeń umożliwiających monitorowanie ciśnienia bezwzględnego w wyrobiskach kopalń (Wasilewski, 2009) powstają warunki do badania wpływu zmian ciśnienia na zmiany parametrów powietrza w wyrobiska kopalni. Jest to tym bardziej interesujące, że jak pokazały obserwacje nie można wykluczyć związku zapaleń i wybuchów metanu w zrobach ścian zawałowych, ze zmianami ciśnienia barometrycznego. Trwające ponad dwa lata obserwacje zmian ciśnienia barometrycznego wraz z rejestracją ciśnienia (z dużą dokładnością) prowadzono w kopalnianym systemie monitorowania parametrów powietrza, za pomocą czujników ciśnienia umieszczonych na zrębie szybu oraz w wybranych wyrobiskach na dole kopalni.

W artykule przedstawiono ważniejsze wyniki analizy statystycznej oraz dokonano próby oceny zmian ciśnienia na powierzchni i w wybranych punktach kopalni pod ziemią. W artykule, który prezentuje wyniki pierwszej część badań, zostaną również pokazane przykłady kiedy znaczne zmiany ciśnienia przed tragicznymi zdarzeniami, którym nie towarzyszyły zmiany stężenia metanu w wyrobiskach kopalni.

Na tle zmian ciśnienia barometrycznego pokazano momenty wystąpienia zdarzeń zapalenia i wybuchów metanu w zrobach ścian zawałowych w ostatnich latach. Badania prowadzone w projekcie strategicznym pt. „Poprawa bezpieczeństwa pracy w kopalniach" pozwoliły zarejestrować zmiany parametrów powietrza wewnątrz zrobów ścian i pokazać wpływ zmian ciśnienia na zmiany stężania metanu i tlenu w zrobach, co zostanie pokazane w drugiej części artykułu, który jest przygotowywany i będzie opublikowany w najbliższym czasie.

Słowa kluczowe: kontrola i monitorowanie, ciśnienie barometryczne powietrza, zagrożenia gazowe w kopalniach głębinowych

1. Introduction

It is known that barometric pressure and its disturbances can strongly influence ventilation conditions in deep mines (Fauconnier, 1992; Hemp, 1998; Wasilewski, 2004). It is obvious that although under normal ventilation conditions they do not cause a direct hazardous state so in an emergency state, during methane or coal dust explosion and also an outburst, the air pressure, and in fact its changes as a pressure wave, can constitute an essential hazard to the health and lives of the miners. Additionally, the outflow of gas from the gob is dependent on the barometric pressure changes, in mining practice known as "the breathing of gob". Barometric pressure also reflects the states of other air parameters in the workings of deep mines (Roszczynialski et al., 1992), including the rate of flow, the volume of flow or mass, density, natural pressure drop, and the depression at the fan.

Barometric air pressure on the mine surface has a slow, changeable character by nature. The transient state of ventilation in deep mines can be controlled by intentional adjustments of a ventilation device, but also by disturbances that are entirely accidental. Under some conditions, such as during methane explosions or outbursts, these transient states are characterized by sudden, unstable changes in pressure, as well as high-amplitude of air and gas flows. Such ventilation changes can cause long-lasting gas-dynamic processes that cover a considerable area. Many instances of transient ventilation changes in mine air during explosions and outbursts are recorded and were detected using stationary air parameter sensors situated in mine workings with large dynamics in the automatic gasometric system (Wasilewski, 2005).

The change in pressure can cause changes in the concentration of methane in the mine, which can be registered by methanometers of automatic gasometric system still prior to an event occurrence. In the event of an initial occurrence, for instance, a short-circuit, sparking from the shearer or as a result of blasting it can lead to ignition and explosion of methane. In such a case, an increase in the concentration of methane was caused by the change of barometric pressure. Such changes are shown for the case of ignition and explosion of methane in the Pokoj mine in 2007.

Observations and investigations of the circumstances and causes of accidents carried out by the State Mining Authority Commission show that the pressure change is not always accompanied by changes in the concentration of methane in a mine working, which were recorded by sensors of automatic gasometric system prior to an event. It can be assumed, and such assumption was adopted repeatedly by the Commission in reports after disasters, that change of pressure changed the distribution of gases in gob, for instance, transfer of explosive gases threshold towards an initiation direction, which was located inside the gob, as for instance a slot fire or a fire source, then the explosion occurred inside the gob and its effects were seen in the space of the workings only after the occurrence in the form of a sudden throw out of methane and carbon oxide. Such an explanation was adopted by the Commission in the cases of two explosions in Halemba mine in 2006, and in Wesola mine in 2008.

2. Barometric pressure and its influence on pressure within the mine ventilation network

We observed mine pressure changes over a period of more than two years in order to determine the range of barometric pressure changes, pressure change dynamics, and the influence of surface pressure changes on underground pressure changes. The barometric pressure was recorded using an automatic gasometrical system that was positioned at the mine surface at the shaft's carcass and also at selected underground sites. A precise, intrinsically safe barometric pressure sensor with an accuracy of ± 10 Pa was used for the investigations. The system recorded barometric pressure changes in a registration cycle of 10 seconds and automatically stored the readings in a database. To our knowledge, this is the first practical application of simultaneous on-line monitoring of barometric pressure in underground mine ventilation systems.

2.1. Barometric pressure at the surface and its changes

The recorded data allowed us to assess and analyze barometric pressure changes at the surface as well as in the underground workings of the mine. The data demonstrate that, in general, barometric pressure change is a slow, variable process that is subject to both slow long-term changes and seasonal fluctuations, but also to short-term changes (Fig. 1).

2.2. Barometric pressure changes in the mine′s workings

Observations from barometric pressure recordings in underground sites (Wasilewski, 2005) confirm that the air pressure in a mine's workings is controlled by barometric pressure changes at the mine surface (Figs 2 and 3). In addition to changes that are triggered by oscillations of barometric pressure at the surface, the underground air pressure shows changes that are induced by local disturbances, including technological disturbances. This observation is especially evident in recordings that are taken at the intake of a shaft's bottom, where oscillations of pressure are

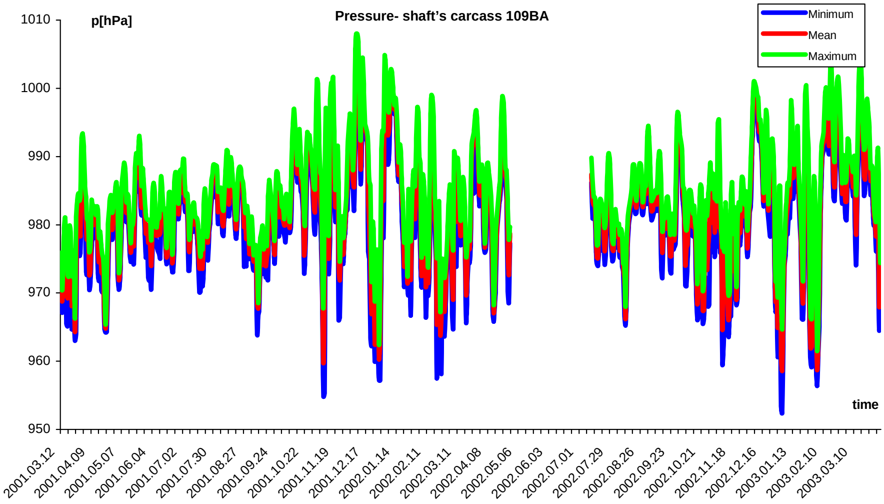


Fig. 1. Barometric pressure changes at the mine surface recorded over a period of two years

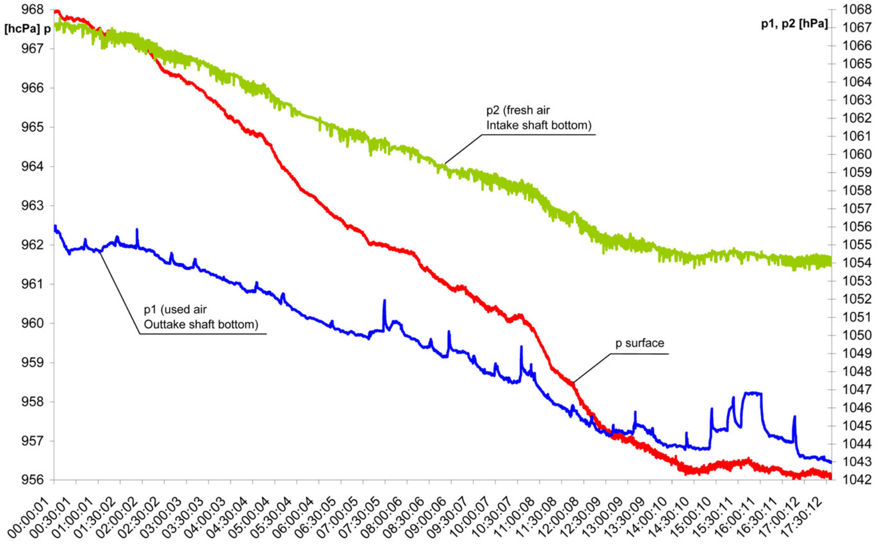
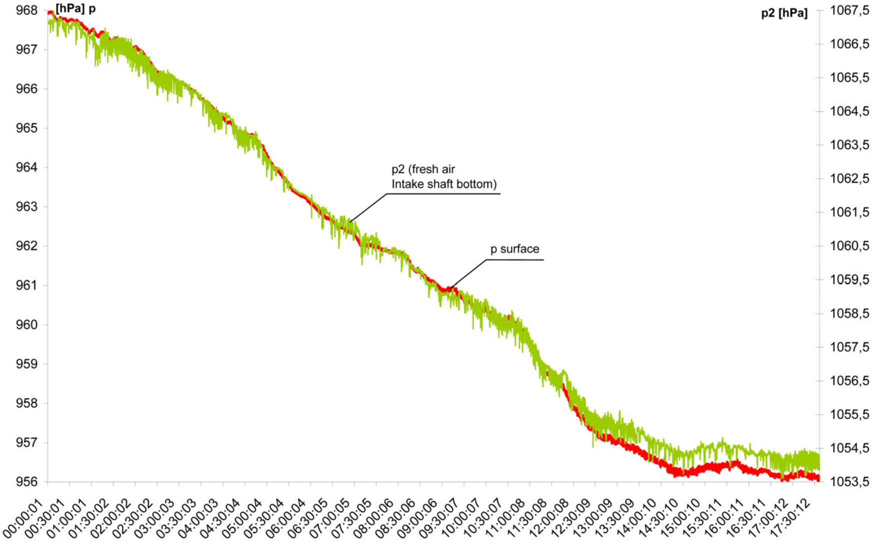


Fig. 2. Air pressure recorded at the surface and in the workings of the mine

most noticeable. The relationship of pressure changes and shaft cage movements confirmed the results of correlation analyses for the pressure signals.

Our study shows that the waves of pressure that are induced by pressure disturbances, such as by switching off a fan, propagate within the mine's workings at the speed of sound (~300 m/s). The data also demonstrated that the changes in pressure are attenuated in the network, and the amplitude of these changes decreases as the distance from the source of the disturbance increases.

surface – the intake shaft's carcass and underground – the intake shaft's bottom



surface – the intake shaft's carcass and underground – the outtake shaft's bottom

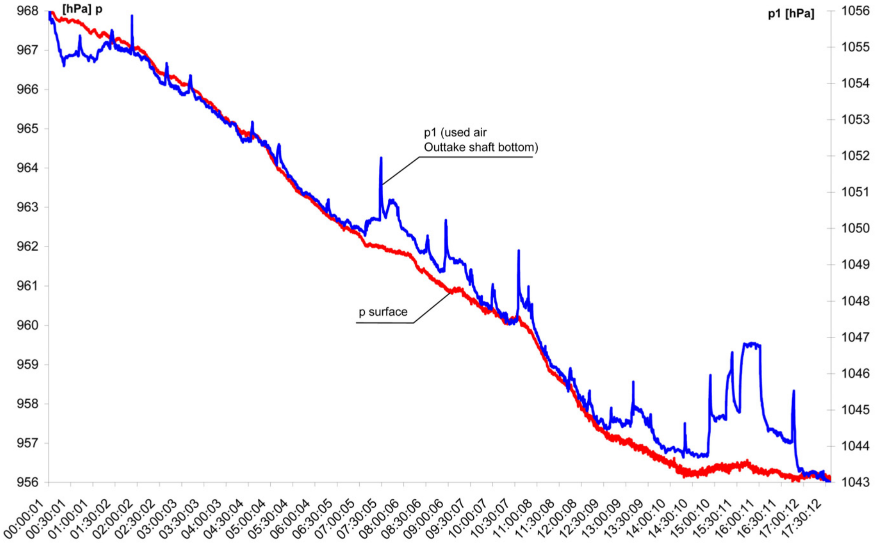


Fig. 3. Comparison of the course of pressures recorded at the mine

Local pressure disturbances are another factor that can influence pressure current changes in a mine's workings. These include disturbances that are triggered by temporary ventilation short-circuits or by changes in the ventilation stoppings (opening/closing) caused by underground traffic or the movement of equipment such as the shaft's cage, a shearer at a longwall, or other machines. Absolute pressure disturbances can reach up to several hPa.

3. Investigation of the changeability of barometric pressure in the mine

3.1. Assessment of changes in barometric pressure in long time horizon

A visual assessment and the signals change are results of the preliminary analysis of signals. These were executed both for the pressure recorded at the surface and in the underground mine workings. The preliminary analysis determined the range of pressure changes and their dynamic properties, such as the rate of pressure changes over time.

The data was recorded in monitoring system at 10-second intervals over the course of one year. A data file containing over 3 million recordings data was generated for each measuring point, and for the purpose of the analysis, data filtration was performed (data thinning) with periods of filtration of one hour or one day. Therefore, the minimum, maximum, and mean pressure values were determined for each hour (360 data points) and for each day (8640 data points). These data files were then subjected to a detailed statistical analysis.

The defined maximum and minimum values were recorded each day and the average values were determined. Additionally, other parameters that assist in evaluating pressure changes within include the following:

- the amplitude of the changes (maximum – minimum values)
- the duration of the changes
- the average of the rate of change (amplitude / duration)
- the maximum rate of pressure change

Then, for the most interesting changes (drops/increases) in barometric pressure at the mine surface, assessments were carried out of pressure changes in the mine's underground workings, and an comparison was made to determine the dependence of pressure changes recorded underground on barometric pressure changes at the surface, as illustrated in the figures below.

Seasonal changes

The two-year investigation of barometric pressure changes at the mine surface clearly indicated seasonal changes. The course of air pressure at the surface of the mine during the summer was calm with rare sudden changes. However, in the late autumn and winter seasons (November - February) rapid changes in pressure from one day to the next were observed. The amplitudes of these changes were clearly higher than those in other periods of the year (Fig. 1). The simultaneous observations of barometric pressure at the mine surface and underground confirmed that pressure changes that are recorded underground mimic the barometric pressure changes at the surface. For example, the pressure changes at the mine surface and underground during late autumn demonstrate a coordinated pattern (Fig. 4).

Medium-term changes

It has been assumed for this assessment that are barometric pressure changes that were observed from one week to another. The most interesting barometric pressure changes were rapid changes at the mine surface and their corresponding pressure changes underground. The

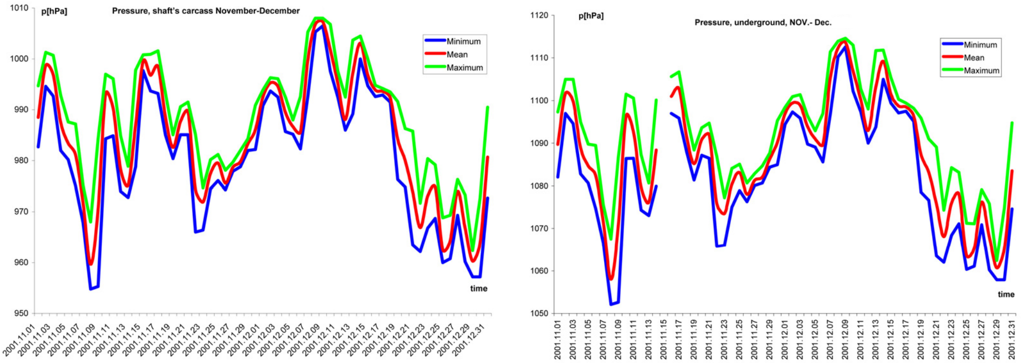


Fig. 4. Pressure changes at the surface and underground during late autumn

fastest pressure changes and the changes with the greatest amplitude were observed during late autumn (Fig. 5). During one week in autumn, pressure oscillations often exceeded 50 hPa and were transferred underground to produce an equivalent effect there. The scale of these changes is equal to the pressure drop at the main fan of the mine's ventilation system.

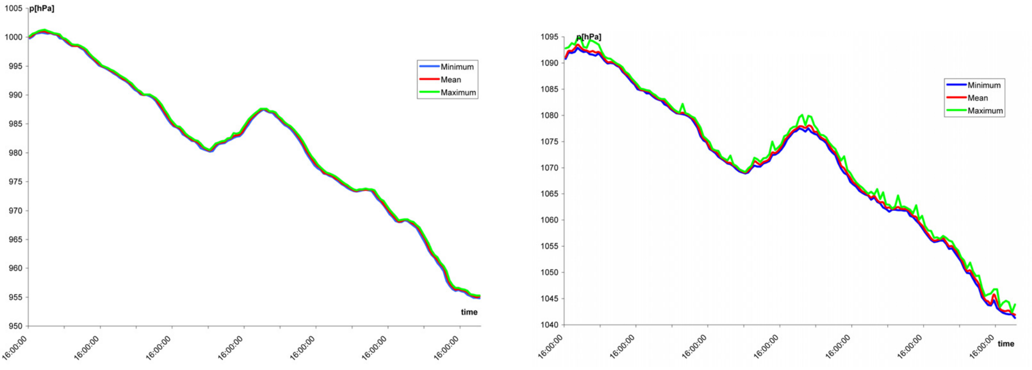


Fig. 5. Weekly barometric pressure changes at the mine surface and underground

Short-term changes

Air pressure is generally thought to change slowly. However, short-term pressure changes occur every day. The changes in pressure from day to day are important to monitor because they can have a critical influence on the ventilation conditions in the mine. Sudden pressure drops can influence methane emission and the emission of gob gases as well as fire gases from sealed off fire areas. Thus, observations were conducted to determine the maximum range of this parameter's change and the rates of pressure drop during the day and night. The most violent changes in pressure occurred on 21.11-22.11 when the barometric pressure consistently dropped over a course of 30 hours, with a total drop that reached close to 30 hPa (Fig. 6). The maximum rate of change determines the dynamics of the barometric pressure changes and the so-called "baric drop" reached as much as 4 hPa/hour.

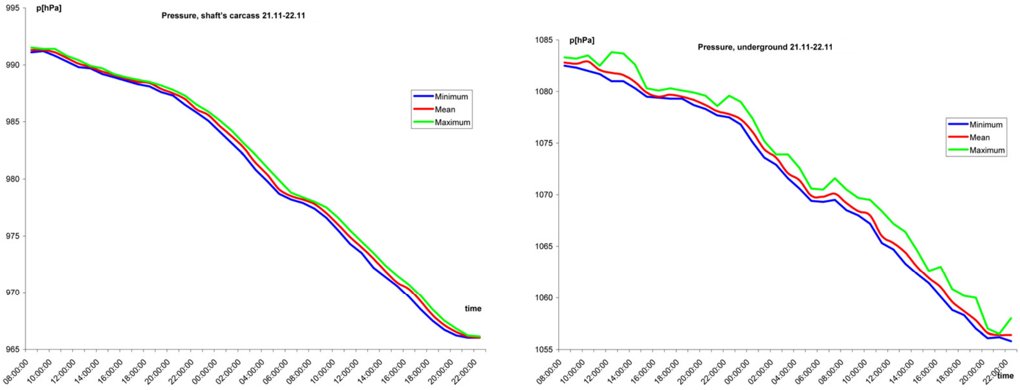


Fig. 6. Daily changes in barometric pressure at the surface and underground

3.2. Statistical analysis of the time series of pressure changes in the mine workings

In order to confirm earlier observations and to perform a quantitative assessment, we performed a statistical analysis of the barometric pressure values that were recorded at the surface and in the underground workings of the mine. Time dependences of the pressure signals on the basis of a correlation analysis have been presented in the earlier works (Wasilewski, 2004, 2005).

Minimum ($x_{\min}$) and maximum ($x_{\max}$) values were determined within the framework of a detailed analysis. The spread (Δx) and the average value ($\overline{x}$) in a given file were determined, as well as the standard deviation (s), average deviation ($\overline{s}$) and fluctuations (s^2) in the spread of the data. This analysis assessed the pressure change data over the course of a year using both an hourly and a daily cycle (Table 1). Additionally, in order to assess the range of change, a spread was determined at each hour and at each day as ($x_r = x_{\max} - x_{\min}$), acknowledging that this parameter reflects the dynamics of changes in the analyzed data. The hourly and daily spreads were also analyzed and statistical parameters for them were determined (Table 2).

The final results of the analysis are presented in Tables 1 and 2. The majority of the statistically analyzed data demonstrated a clear seasonal pattern for barometric pressure changes. During a given 24-hour cycle, a seasonal pattern was clearly identifiable. The maximum changes in pressure during winter months were read 29 hPa/day and the maximum changes in summer months were 10.6 hPa/day (Table 2).

Surface barometric pressure changes during the summer season compared to the autumn-winter period (Table 1) confirm the considerable statistical differences in pressure changes across seasons. In the autumn-winter period the amplitude of pressure changes (Δx) is over twice as high as in the summer. Similarly, the changeability of data represented by standard deviation (s) and mean deviation (s_{mean}) is almost 2.7 times greater in autumn-winter than in summer and the fluctuation (s^2) is more than 7 times greater. Similar seasonal differences were obtained for daily (24 hour) spreads (Table 2).

The analysis of the pressure changes that were recorded underground (Table 1) shows that pressure changes in the workings of the mines essentially follow the barometric pressure changes at the surface. The amplitude of changes and the parameters of changeability during the autumn-winter period are nearly twice as large as changes during summer. A number of disturbances, including technological disturbances, influence the pressure in workings (Fig. 3); but, seasonal changes underground, although clear, must be interpreted with appropriate caution.

TABLE 1

Results of a seasonal analysis of a time series of daily average barometric pressures

Parameter	Surface		Underground- fresh air		Underground – used air	
	Summer	Autumn-winter	Summer	Autumn-winter	Summer	Autumn-winter
$x_{\min}$	970.1	954.8	1041.6	1041.3	1040.8	1040.7
$x_{\max}$	993.0	1008.0	1078.9	1109.9	1087.9	1114.6
Δx	22.9	53.2	31.3	68.6	37.1	69.9
$\overline{x}$	981.83	984.27	1061.38	1081.42	1066.55	1079.11
s	4.23	11.31	7.14	12.77	11.20	17.67
$\overline{s}$	3.55	9.55	5.93	10.57	9.98	14.98
s^2	17.89	128.0	51.01	163.2	125.61	312.17

TABLE 2

Results of a seasonal analysis of a time series of a daily spread of barometric pressure

Parameter	Surface		Underground- fresh air		Underground – used air	
	Summer	Autumn-winter	Summer	Autumn-winter	Summer	Autumn-winter
$x_{\min}$	1.3	1.3	1.8	0	2.0	0
$x_{\max}$	10.6	29.0	17.8	33.0	17.1	34.2
Δx	9.3	27.7	16.0	33.0	15.1	34.2
$\overline{x}$	4.14	7.89	5.91	9.58	6.15	8.98
s	2.07	4.96	2.48	5.40	2.44	5.63
$\overline{s}$	1.62	3.87	1.86	4.29	1.90	4.33
s^2	4.29	24.59	6.15	29.21	5.94	31.74

Summary of the analysis

Our investigation of barometric pressure changes was performed over a long-term period of time and recorded barometric pressure changes at the surface of a mine. We found that these changes are comparatively slow, undergo short-term oscillations of small amplitude, and are associated with seasonal changes. The greatest changes in pressure occurred during late autumn or winter and particularly dangerous "baric drops" were observed during these periods. The maximum changes (drops) in pressures over a 24-hour time period occurred in the autumn-winter season and measured up to 30 hPa, with a maximum rate of change of barometric pressure reaching up to 4 hPa per hour. It is interesting that the greatest disasters and accidents connected with ignitions and explosions in gob in recent years occurred most frequently during the autumn-winter period. Therefore, a further investigation of the relationship of these events with barometric pressure changes is warranted.

We confirmed the results of earlier analyses and demonstrated that the pressure changes in the underground workings of mines follow the changes at the surface. However, these underground changes are also influenced by more random components resulting from local pressure disturbances.

4. The relationship between methane ignitions and explosions in the longwall gob resulting in cave-ins and changes in barometric pressure

Longwall systems of exploitation most often running with roof cave-in accepted in Polish coal mining cause the creation of gob as a gas reservoirs. The gob space is not controlled and the gas concentration and distribution in these spaces is poorly understood (Cimr et al., 2006).

Stable ventilation conditions, the distribution of gases, and the removal of explosive mixtures from the longwall channel and from the workings, in which conditions are optimal for an ignition or explosion to occur, constitute the essential elements for securing safe ventilation conditions in longwall areas. Obviously, ignition or explosion sources can also be harbored within a gas reservoir, such as in the space of the gob, and include crevice fires or falling, sparking roof rocks that create debris. It is essential for the air-gas mixtures in these gob spaces to be non-explosive. This can be achieved with the use of high methane concentrations or by making the gases inert with carbon dioxide or nitrogen. The transient states of pressure distribution around and inside of the gob can cause uncontrolled migration of gases and lead to dangerous situations.

The influence of barometric pressure changes on the migration of gob gases is well known in the mining practice. Therefore, for many years now mines record pressure changes with signals and warnings and use banners to announce "Attention – baric drop." Until now it was assumed than pressure drops are dangerous only because they can cause the outflow of gases to a channel of a longwall or to adjoining excavations, or cause the outflow of fire gases from sealed off fire areas. Assuming that an ignition or explosion source is somewhere in the gob a rapid or long-lasting increase in pressure might be dangerous. The migration of gases from the gob to an explosive atmosphere, such as a crevice fire or a site of spontaneous heating, might lead to an ignition or explosion within the gob.

We observed that changes in barometric pressure vary across seasons. These changes are considerably greater during autumn-winter periods and more violent in the summer months. It might be interesting to connect the occurrences of ignitions or explosions in Polish mines in recent years with seasonal changes in barometric pressure.

In response to various mining disasters/incidents, the President of the Higher Mining Authority (WUG) appointed a Committee of Inquiry to determine the causes and circumstances of these events. We have analyzed cases that the Committee recognized to be associated with ignitions or ignitions and explosions of methane in which the source of either the ignition or the explosion was located in the gob of longwall faces that were mined with cave-in (Table 5). The majority of methane ignitions, with the exception of one event in the Budryk mine in 2002, occurred during the autumn-winter months (Fig. 7) when increased oscillations of barometric pressure were recorded.

In recent years, it has been appreciated that adverse events in the mine gob and sealed off workings often take place without distinct signals or changes in the circulating air composition in adjacent workings that are monitored by an automatic gas measuring system, therefore, early detection of these events is difficult. At the same time, it is difficult to explore the direct causes of events that occur in such closed spaces because there is no monitoring of the distribution and concentration of gases, their migration, or sources of spontaneous combustion or crevice fires within the gob. The analysis is only based on periodically taken air samples by gas samplers for laboratory analysis.

TABLE 3

Methane ignitions and explosions in the gob and in sealed off workings
in Polish coal mines between 1990-2008

Item	**Mine's name**	**Date**	**Cause of an event**	**Site of an event**
Ignition of methane				
1	Wesola	**12.03.1999**	Sparking of roof rocks during drawing off of support	Longwall's gob
2	Budryk	**17.07. 2002**	Sparking of roof rocks during drawing off of support	Longwall's gob
3	Bielszowice	**24.02.2003**	Crevice fire in the fencing along the gob	Crossing of a longwall with a ventilation gate
Ignition and explosion of methane				
1	Slask	**18.12.1990**	Spontaneous combustion or sparking of roof rocks during drawing off of support	Longwall's gob
2	Sosnica	**7.11.2003**	Spontaneous combustion	Longwall's gob
3	Bielszowice	**12.02.2005**	Spontaneous combustion	Longwall's gob
4	Halemba	**21.11.2006**	Spontaneous combustion	Gob of a liquidated longwall
5	Myslowice-Wesola	**13.01.2008**	Spontaneous combustion	Sealed off exploratory cross-cut of a longwall

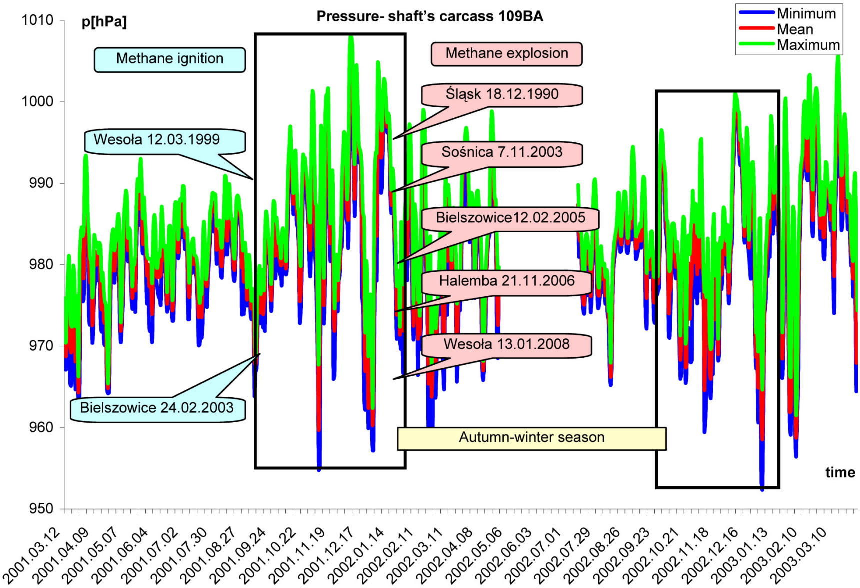


Fig. 7. Ignitions and explosions of methane in the gob relative to seasonal changes in pressure

While investigating how the dynamics of barometric pressure changes at the mine surface can influence the concentration of methane in excavations within the mine, it was noted that, in the case of a large gob bordering mine workings, changes in methane concentration recorded in bordering workings can have great inertia and can be manifested with a considerable delay (Wasilewski, 1997). This observation makes it more difficult to perform a quantitative assessment of the relationship between changes in pressure and the outflow of gases. Computer simulations become more and more helpful for these sorts of analyses (Dziurzyński, 2002), as long as the simulation model can be validated by in situ data collected during experiments and from automatic gasometric systems.

5. Changes in pressure during or prior to incidents and disasters

5.1. Methane ignition during blasting works

Longwall 183 was mined in seam 418 at horizon 790 m. Seam 418 was classified to the III category of rock burst hazard, II category of methane hazard, class B of dust hazard and I degree of water hazard. An attempt was undertaken to determine the causes and circumstances of methane ignition during shot-firing works on 28.07.2007 at 5:41. The area of longwall 183 was secured with methanometers, of which 10 were located directly in the longwall or in fresh air and return air current outflowing from the longwall. Methanometers were integrated into the monitoring system, with the sampling period every 10 seconds . The diagram of the sensors' displacement was shown in Figure 8.

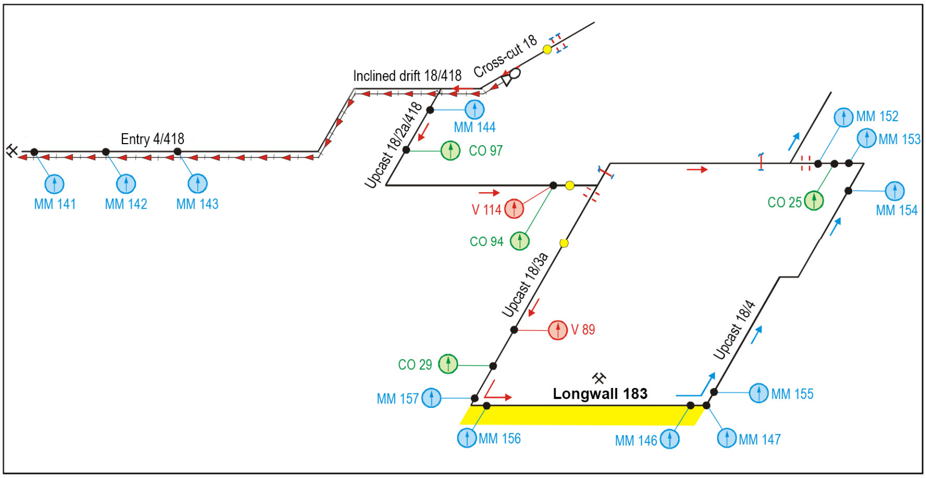


Fig. 8. Diagram of the ventilation of the longwall region at the Pokoj mine

During the week before the incident, as a result of conducting a blasting, the number of transgressions of critical values was significant and the maximum values of methane concentration higher than in previous weeks. The increase in daily maximum values lasted until the last day prior to the incident, when it was 4.1% CH_4 (MM156) at the inlet to the longwall and 2.4% CH_4 (MM147) and 1.4% CH_4 (MM155) at the outlet from the longwall respectively.

In the period preceding the incident a great variability observed in the methane concentration was observed also as a result of changes in the absolute pressure on the surfaces (see Fig. 9). During the so-called. "barometric drop" one can observe change in methane concentration at the outlet from the longwall from 0.75% CH_4 to nearly 2.0% CH_4.

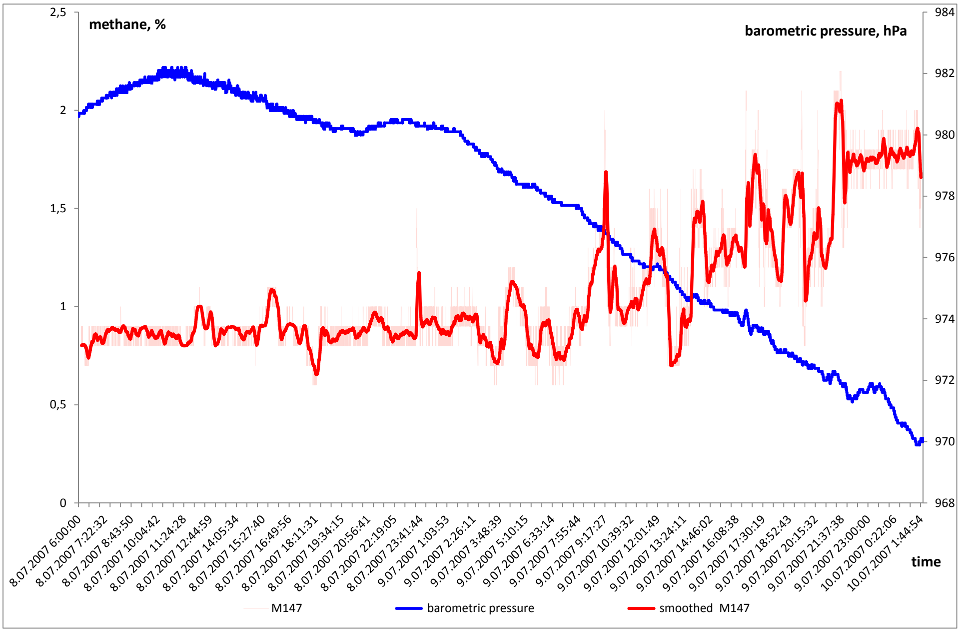


Fig. 9. The influence of barometric pressure change on methane concentration at the outlet from the longwall 183

5.2. Ignition and explosion of methane in the region of a liquidated longwall at the Halemba mine

An ignition and methane explosion, as well as a coal dust explosion occurred in the region of a liquidated longwall on the 1030 m horizon in the Halemba mine on 21.11.2006. This is considered to be one of the most tragic events in the history of Polish mining. The event occurred during removal and transportation to a rise gallery of longwall support elements.

The seam was classified as a category IV of methane hazard, a degree III of rockburst hazard, a class B of coal dust explosion hazard, and a group I of spontaneous combustion hazard. The ventilation scheme of the longwall liquidation is shown in Figure 10. The western segment (left) was ventilated by two air ducts that forced air to the drawing off site of a section of the support. The eastern segment (right) was ventilated with a circulating air current. Immediately preceding the event, the fire hazard was maintained at an average level and there were no symptoms indicating its build-up.

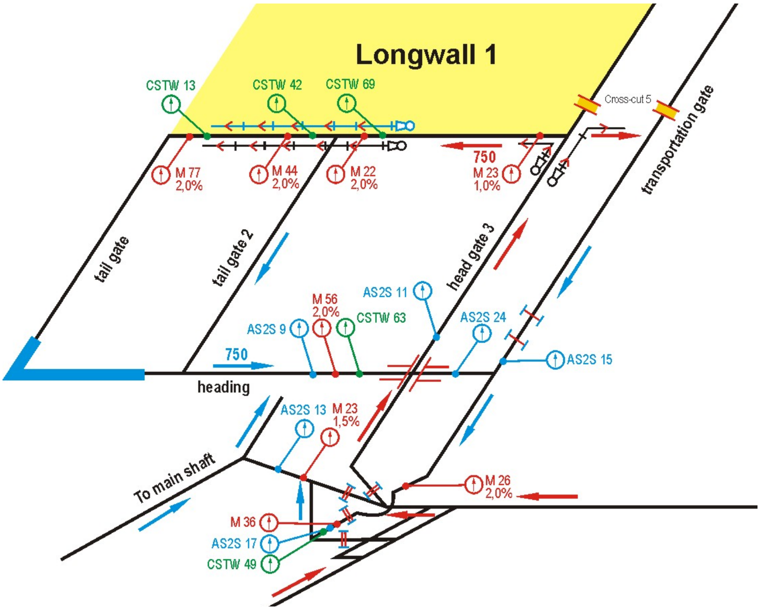


Fig. 10. The ventilation scheme for the region of a liquidated longwall in the Halemba mine

The initiation site for the methane ignition remains unknown, and the cause of the ignition is not clear-cut. However, the initiation site for the coal dust explosion was in the last western section of the longwall. The explosion's range extended to liquidated longwall 1, part of rise gallery 2, rise gallery 3, and part of haulage cross-cut 2 on the side of rise gallery 3.

There were 31 miners working in the hazardous zone, and twenty-three of them lost their lives in this disaster.

The expert investigations and the inquiries (Report of the Committee of Inquiry WUG, 2007) that were undertaken following the Halemba event did not exclude the possibility that a crevice fire could have occurred in a pillar between rise gallery 3 and a parallel haulage entry (in the region of an earlier rockburst occurrence) or in the rockmass adjacent to the gob. This potential crevice fire's gaseous products were undetectable due to insufficient quantities for detection. It was reported that a very high level of absolute gassiness in the longwall affected the existing fire hazard in the gob of the longwall. An increase in methane content in the gob gases occurred in the space and reduced the level of available oxygen, thus interrupting oxygenation of spontaneous combustion. In turn, the renewed inflow of oxygen fueled further spontaneous combustion and led to the development of a fire. It is important to note that the events that occurred in the gob of the longwall were out of control, and the Committee did not exclude the possibility that a spontaneous combustion in the gob of the longwall caused the methane ignition.

The hypothesis that the migration of explosive gases in the gob caused the ignition and explosions is more probable when it is considered in the context of the changes in barometric pressure. The changes in barometric pressure at the mine surface during the time period immediately preceding the event, from 20.11-21.11.2006, demonstrate that the methane ignition and explosion occurred during the final period of a baric pressure drop that lasted more than 24 hours, where the pressure dropped by more than 15 hPa (Fig. 11).

Change in barometric pressure caused only a small increase but with a constant upward trend in methane concentration during the time preceding the event in the liquidation part of the longwall (Fig. 12).

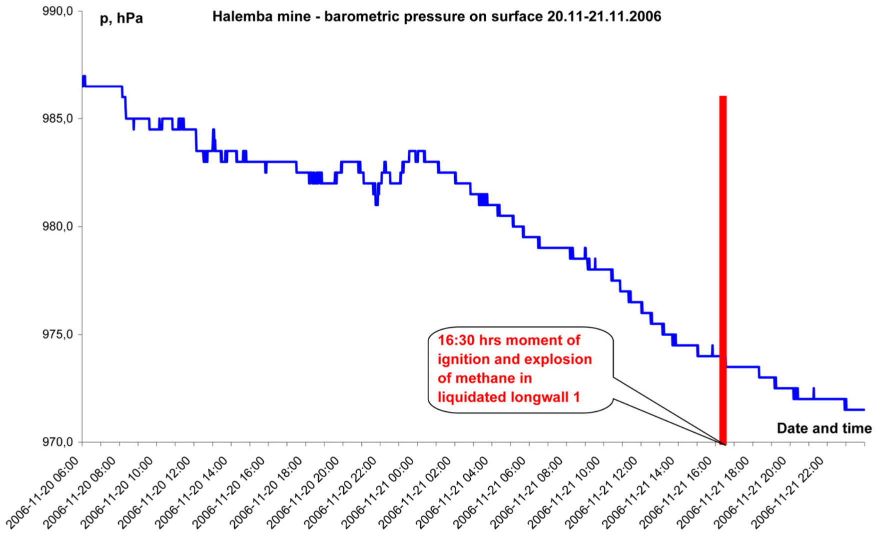


Fig. 11. Changes in barometric pressure at the surface during the time preceding a methane ignition and explosion on 21.11.2006 at the Halemba coal mine

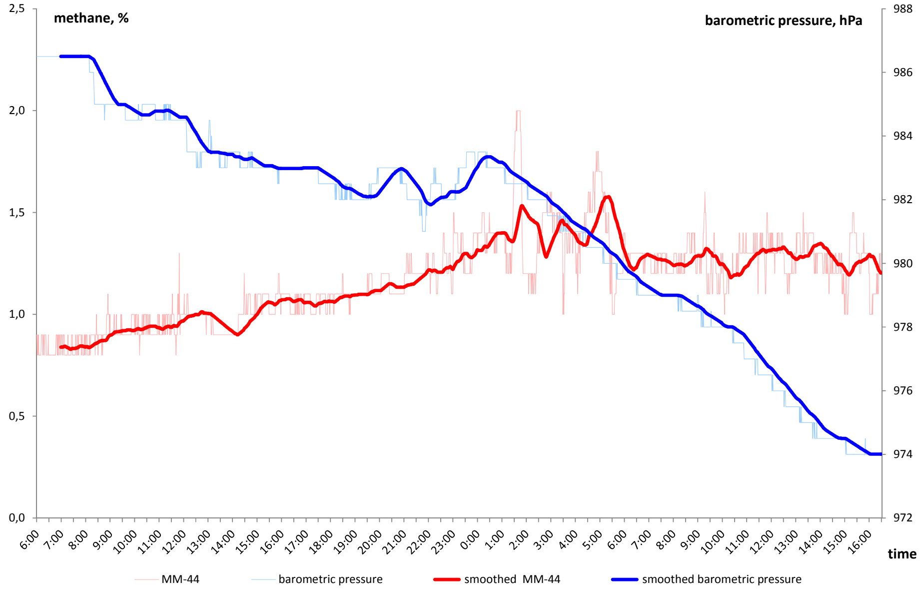


Fig. 12. The influence of barometric pressure change on methane concentration on 21.11.2006 in the region of a liquidated longwall at the Halemba mine

5.3. The ignition and explosion of methane in an exploratory drift of the longwall at the Myslowice-Wesola mine

On 13.01.2008 in the region of an exploration drift of the longwall on the 665 m horizon in the Myslowice-Wesola mine, a methane ignition and explosion took the lives of two miners.

A seam with the thickness of 10 m was classified as a category IV of methane hazard, a degree III of rockburst hazard, a class B of coal dust explosion hazard, and group III in terms of susceptibility to spontaneous combustion. Absolute gassiness in the region was 3.4 m^3CH_4/min, and the region was ventilated with an air current that had a flow rate of 810 m^3/min.

A 230.5-m exploration drift of the longwall (Fig. 13) and a 33-m IX east entry were sealed off with a 0.25 m-thick isolation stopping (Number 426) made from concrete cobbles.

On Sunday 13.01.2008, two employees were sent to the region to perform a routine monitoring of the ventilation in the mine workings on non operating day. A man from the supervisory mine personnel and a man that was monitoring dewatering happened to be in the region. In total, there were six miners present. At about 9:20 a.m., a methane ignition and explosion, followed by a coal dust explosion, occurred in the region of an exploration drift of the longwall that was isolated by the No. 426 stopping in part of the entry IX- eastern. The No. 426 isolation stopping was destroyed by the impact wave from the explosion of methane. One miner lost his life on-site, and a second miner died later from injuries that were caused by the effects of high temperature, fire gases, and the impact wave. Three miners that were located at a more distant site evacuated from the hazardous area and rescued a fourth miner on the way, who survived despite the high temperatures and a high concentration of carbon dioxide.

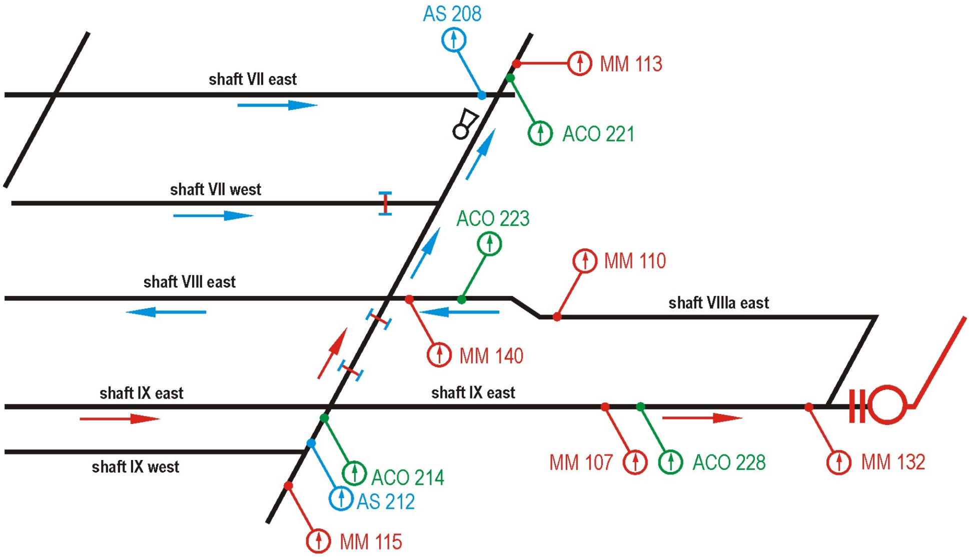


Fig. 13. Diagram of the ventilation of the longwall region at the Myslowice-Wesola mine

The Committee of Inquiry that investigated the cause and circumstances pertaining to this mining accident (Report of Committee of Inquiry WUG, 2008) determined that a spontaneous combustion caused the ignition and explosion of methane accumulated in the sealed off section of the IX- eastern entry and in the drift of the longwall. The Committee also considered that a lack of tightness of the No. 426 isolation stopping could have been one factor that contributed to the initiation of the methane ignition and explosion and could have caused the inflow of oxygen to the site of the fire.

The hypothesis that the sealed-off workings lacked tightness and caused the migration of explosive gases as the source of spontaneous combustion seems more probable when it is considered with the changes in barometric pressure. The recorded changes in barometric pressure at the mine surface during the time preceding the event (12.01-13.01.2008) demonstrate that the ignition and explosion of methane occurred during a considerable increase in barometric pressure that reached about 12 hPa over a 24-hour period (Fig. 14). It is possible that a lack of tightness at the isolation stopping could have influenced oxygen migration and the generation of an explosive mixture of flammable gases within a sealed-off space. Therefore, both violent drops in barometric pressure ("baric drops") and pressure changes in general could cause the uncontrolled migration of gases in a sealed-off space and in a gob, thus having a negative impact on the hazardous state of methane ignition and explosion.

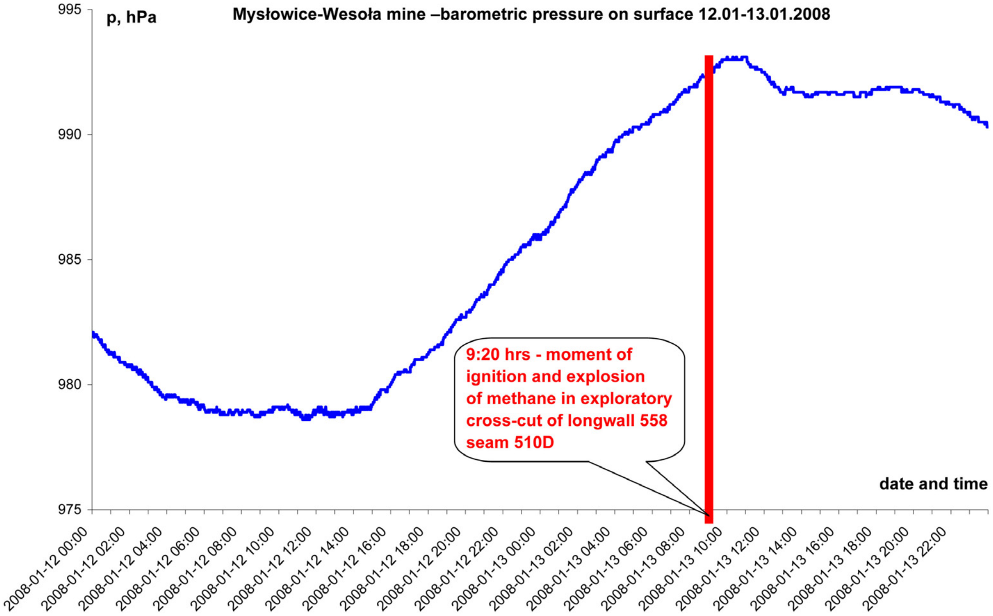


Fig. 14. Changes in barometric pressure at the mine surface during the time preceding the ignition and explosion of methane on 13.01.2008 at the Myslowice-Wesola coal mine

6. Conclusions

Barometric pressure changes at the mine surface and underground were measured continually over the course of two years and demonstrated that the following:

- Changes in barometric pressure are subject to short-term oscillations of small amplitude and long-term seasonal changes. The greatest difference in pressure changes occurred during late autumn and winter. The maximum change (drop) in pressure during a 24-hour period reached up to 30 hPa, and the maximum rate of barometric pressure changes was 4 hPa/hour.
- Changes in barometric pressure at the surface are transferred underground, and changes in pressure in mining excavations are controlled by changes in barometric pressure at the surface. Irrespective of changes in barometric pressure at the surface, the pressure recorded underground was subject to considerable local disturbances, including technological disturbances. Therefore, single or occasional measurements of absolute pressure in mine workings can be affected by serious errors.
- Pressure changes can induce significant changes in methane concentration in the workings of the mine, which in the case of an initial occurrence, a for instance, from electrical short-circuit, sparking from the shearer or as the result of shot-firing works can lead to an ignition and explosion of methane.l sparks from a combine or as a result of firing explosives can result in ignition or explosion of methane.
- In recent years, ignitions and explosions of methane that occurred within the gob in Polish coal mines most often occurred during the autumn-winter period. It would be interesting to attempt to find a relationship between these occurrences and seasonal barometric pressure changes.
- The processes that take place in the mining gob and sealed off spaces are beyond our control, so it seems to be important to seal off these spaces with the use of tight, explosion-proof stoppings.
- The research conducted within the project, using modern measuring instruments, allowed to register changes in concentration of methane, carbon monoxide and oxygen inside the gob of the longwalls and also show the impact of pressure changes on changes in the concentrations of these gases in the gob, which is currently the subject of the analyses, and their results will be published in the second part of the article.
- Although absolute pressure monitoring can be helpful, in order to effectively warn miners about pressure changes, automatic barometry using stationary barometric pressure sensors in the underground workings is possible and recommended.

Acknowledgement

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