# Coal mine flooding as a cause of methane hazard. The case study of Morcinek mine, Upper Silesian Coal Basin, Poland

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**Keywords**: mine flooding, gas hazard

**ABSTRACT:**
In hydrogeologically impermeable-covered region of USCB, where Morcinek coal mine is situated, the isolative overburden protects the surface from the emission of gasses compressed by the water rebound in the flooded coal mines. Potential gas hazard therefore can only arise in the regions where the shafts break through the overburden. Basing on mining and geological conditions, the volume of the Morcinek coal mine reservoir as well as the course of flooding it have been estimated. Subsequently, using the results of hydrogeological analyses changes of reservoir pressure have been assessed. It enabled to explain that the differences in changes of the molecular composition of pore gases in the backfilling of shafts of the Morcinek mine arose from the different depths of the shafts entries to the mine galleries, and from devastation of the entries isolation from the one of shaft pipe. Moreover, there has been assessed at roughly 14 – 17 years from the stop of coal exploitation the expected duration of potential gas hazards in the region of the shafts.

## INTRODUCTION

The abandonment of a coal mine is connected with the ending or limitation of it's dewatering. This causes flooding of mining excavations with the waters from natural inflow. This process continues until the water rebound in the mine's excavations and surrounding rock mass up to the level determined by the conditions of a state of hydrodynamic quasi balance. Water rebound causes various hazards to the environment as well as to work and public safety. These hazards can also be gas based. Water, filling up capillary and over-capillary spaces in the excavations and rock mass, throws out the gas located there before the end of dewatering (see: Kotarba 2002, Kulczycki & Grzybek 1999).

In case of abandonment of coal mines carried out in the Upper Silesian Coal Basin (USCB), apart from a few exceptions, the possibility of encountering other than water hazards to the neighbouring mines and the ground surface has not been yet considered. So, generally the interdependences between various processes connected with flooding of the excavations has not been taken into account, as a result of which other hazards could happen, possibly also gas based. This attempt, based on hydrogeological researches and prognoses for abandoned Morcinek coal mine has therefore been taken in order to document the influence of mine flooding on the emission of mine gases and the assessment of the gas hazard.

## LOCATION, GEOLOGICAL AND TECHNICAL CONDITIONS OF ABANDONMENT OF MORCINEK COAL MINE

Morcinek coal mine is situated on the southern end of Wariscian USCB, on it's Polish - Czech border (Fig. 1). Tectonically it is situated on the southern side of a wide synclinal structure of the basin called the Main Syncline – in the region of it's covering by the Alpine sub parallel Carpathian overthrust. As a result of this the coal-bearing strata dip slightly here (5 – 20˚) in the NE direction and the disjunctive tectonics dominates them with many faults of Carpathian direction and vertical shifts of up to 250 m.

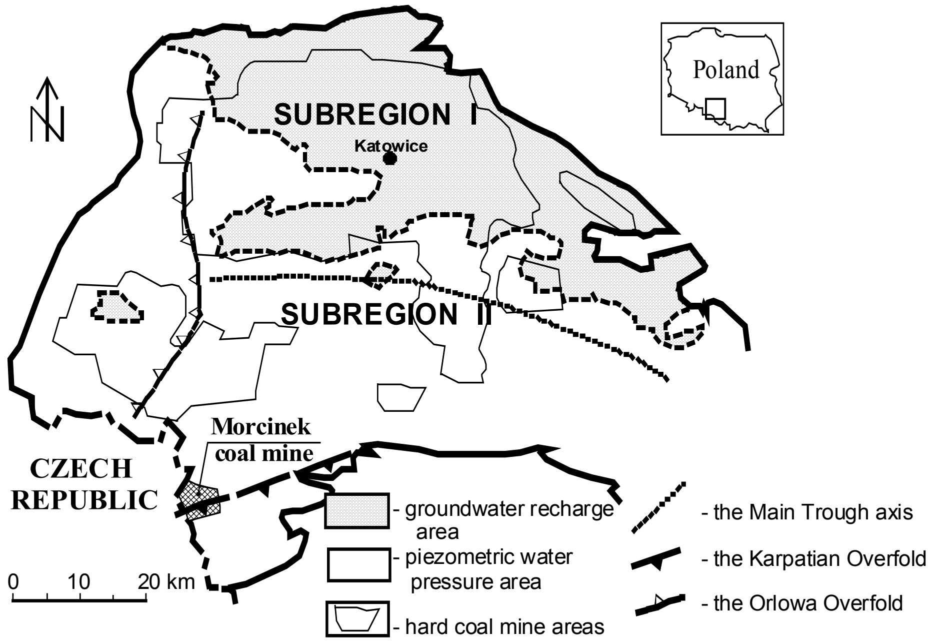


**Fig. 1. Localization of the Morcinek coal mine on the background of both tectonic and hydrogeological division of the USCB (hydrogeological subregions acc. to Różkowski 2003).**

Within the boundaries of the mine the coal bearing formation is composed of Carboniferous deposits. In the upper part they consist mainly of mudstones and claystones with coal beds (the lower part of Mudstone Series – Westphalian A), deeper however lay mainly sandstones and conglomerates with interbeddings of coal (Upper Silesian Sandstone Series – Namurian B and C). The object of exploitation were only the coal beds on the verge of both series. The rocks in their surrounding are characterised by medium values of strength stress, reaching 67 MPa in maximum. Carboniferous measures are covered by overburden build by Tertiary and Quaternary deposits, as well as overthrusted Carpathian flysch, representing Lower Cretaceous and Tertiary measures. Among those the key role is of the Tertiary cover of a thickness from 500 up to 1100 m, made chiefly from Miocene claystones, and only in the floor from thicker layer of coarsegrained drifts.

Described character of the overburden results in the fact, that, according to A. Różkowski (2003) Morcinek coal mine hydrogeologically lies in the subregion II of USCB (Fig. 1). Insulative character of the overburden makes the water inflows into the mines in this subregion many times smaller than in the subregion I. Rate of water inflow to the excavations of the Morcinek coal mine, measured just before the abandonment of the mine, equalled about 0.8 cu m/min.

The deposit of Morcinek coal mine was opened out by the shafts I, II, III and V. From shaft V (of a minimal significance) only about 700 m of a blind cross-cut, without intersections were made. The other shafts were connected by cross-cuts at the levels of 800 m, 950 m, 1100 m and, excluding shaft II, also at the level of 650 m (Nawrat 1999). The connection of all levels was also provided by a net of development, exploitation and preparatory headings. After the liquidation of the shafts those headings, along with the post exploitation and natural fractured zones of the rock mass, and also with dewatered pores of coarsegrained drifts, created anthropogenic reservoir for mining gases and flowing waters.

Before the mine abandonment coal had been exploited for less than 20 years, from coal seams of thickness varying between 1.6 and 4.2 m, only using the roof brake down system. Headings were not backfilled or removed in any other way. Because they were mostly made at the depth of over 800 m, the assumption can be made, that they underwent the processes of squashing. The coal exploitation has been ended in October of 1998, the dewatering of excavations on 1st April 1999, and their ventilation in 31st August 1999, while in the December 2000 the liquidation of shafts has also been completed. In the shafts degasification pipelines were left reaching the level 950 m, and in the shaft III also the level 650 m. Such prepared shafts were then filled up.

The backfilling of shaft I consisted mainly of coal washing stone with the addition of fly ash from power plant (Jakubów & Nawrat 2000, Grzybek 2000). Only at the head the shaft was sealed at the top with 12 meter claystone cork, over-filled with 4 meter thick layer of crushed stone and sand with cement, on which a concrete slab was placed. There, in the closing slab, were left a window, in order to control the backfilling, and holes into the aggregate layer just over the claystone cork, and a hole TP-3 reaching below the cork. In May and June of 2000 in this hole a methane concentration of 94 – 98 % was measured. The other shafts were liquidated in a similar manner, although a gas explosion in shaft III forced mixing filling materials with water and inertinisation of mining atmosphere by compression of 214 thousand cubic meters of nitrogen at the level of 950 m (Jakubów & Nawrat 2000).

## THE OUTLINE OF METHODOLOGY OF ASSESSING VOLUME AND TIME OF MINING EXCAVATIONS FLOODING

The process of mining excavations flooding depends on many factors, of which the most important are volume of spaces able to take in water and the rate of the water inflow. Prognosis of the volume of Morcinek coal mine reservoir and it's flooding time was based on the methodology of assessing the water capacity of the goafs, mining galleries, post exploitation fractures and water storage capacity of the rock mass.

Methodology of assessing the water capacity of goafs was developed by M. Rogoż (1974, 1978, 2004). It suggests multiplying the volume of exploited rocks by the values of the water capacity coefficient of the goafs "c", calculated for given geologic and mining conditions from experimentally determined correlations (Fig. 2). Assuming certain simplifications, related to both fractures extension and volume of post-mining subsidence troughs, by using coefficient "c" it is also possible to assess the water capacity of post exploitation fractures. The capacity of separated galleries on the other hand is calculated basing on their dimensioning and taking into account the level of their compression, while the water capacity of the shafts on density and compressibility of filling materials (Bromek & Bukowski 2002).

Water storage capacity of a Carboniferous rock mass is estimated using the index of water capacity of rock mass $d_{ch}$, determined during a controlled flooding of mining excavations (Bukowski 1999, 2000, 2002). This index is defined as quotient of actual amount of water out into the goafs, mining excavations and post exploitations fractures and the volume estimated using the above mentioned methodology. Generally it is a multiplier for the sum of volume components of reservoir created in the goafs, post exploitation fractures and galleries. It is a correction of the reservoir volume, calculated without taking into consideration the water storage capacity emerged as a result of dewatering the rock pores and fracturing of the rock mass by mining exploitation. Little number of water reservoirs created under full control of flooding process, made it impossible so far to establish more than just a few values for the $d_{ch}$ index (Fig. 3).

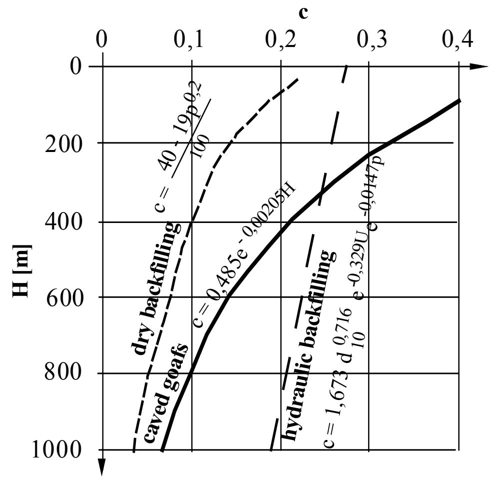


**Fig. 2. Values of water capacity coefficient of the goafs (acc. to Rogoż 2004; modified); p – rock mass pressure, $d_{10}$ – effective grain size, U – coefficient of graining non-uniformity**

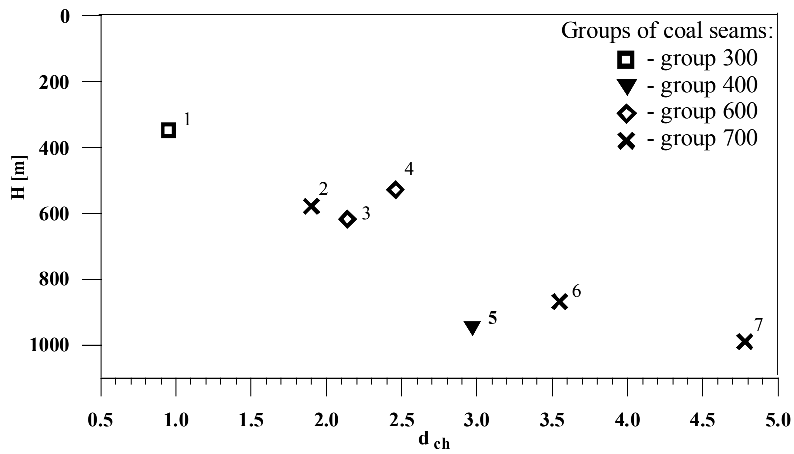


**Fig. 3. Values of index of water storage capacity of the rock mass (acc. to Bukowski 2002; modified)**

The range of the water inflow most of the time is estimated basing on observations just before the stop of dewatering, but taking into account the period of many years beforehand. One of methods of evaluation of the water inflow at the time of the mine flooding is using the correlation between the rate of water inflow and the rebounding water pressure. It is assumed for calculation, with certain simplifications, that inflows situated over the

water level are constant, while those situated below lessen proportionally to the lowering of depression in the water supplying complex of water horizons and that they are derived from water horizons of piezometric water level and the same height of static water level. (Rogoż & Posyłek 1993, Rogoż 2004).
The flooding time of mining excavations and surrounding them rock mass, in designed during the calculations depth intervals, is a quotient of estimated for those intervals volumes (capacities) of free spaces and average intensities of the inflow. The total time of mine flooding is a sum of calculated flooding times of all the separate intervals.

**THE CALCULATIONS OF THE WATER CAPACITY OF THE MORCINEK COAL MINE RESERVOIR**

The volume of free spaces of the reservoir of the abandoned Morcinek coal mine was estimated according to the above mentioned methodology of water capacity assessing. In almost 20 depth intervals, designed for calculations, the assigned values of water capacity coefficients ranged from 0,0538 (H ≈ 1050 m) to 0,1122 (H ≈ 650 m) – for goafs, from 0,7 to 0,9 – for galleries, and from 0,05 to 0,08 – for shafts.
A wider comment is required for the method of assigning the values of the water storage capacity index of the rock mass "$d_{ch}$". The studies of storage capacity of the rock mass in still working Morcinek coal mine were carried out in 1997, during a fire extinguishing controlled flooding of longwall gobs and galleries at the depth of 1000 – 1080 m. The value of the $d_{ch}$ index for this part of the deposit was estimated than to 2.97 (Bukowski 1999). The value of the index "$d_{ch}$", estimated in the surrounding of not much water absorbing rock mass, was justified mainly by the intensity of the tectonic phenomena and relatively high strength of Carboniferous rocks and derived from that fact high stability of free spaces in the excavations and the rock mass. The factor, which made the index value higher was short usage time of the gobs (Bukowski 2004) – ranging from few weeks to 3 years; on the other hand the one that made it lower was quick (2 cu m/min) rate of flooding (Bukowski 1999).
Because of that it was considered that the calculated index value does not reflect the changes in the storage capacity in the hole vertical profile of the mine. The volume evaluation was therefore based on the trend of depth variability of the index, resulting from it's values assigned for different coal mines and different USCB conditions (Bukowski 2002). Despite small number of designations (Fig. 3), carried out in various litologic, tectonic and geomechanical conditions, for the calculation purposes in the Morcinek coal mine, for working out, the following regression equation was applied, between the values of the $d_{ch}$ index and the depth (H, m):

$$d_{ch} = 0.6839e^{0.018H} \tag{1}$$

This equation was found with the correlation coefficient 0.912 and at the significance level of 0.004. Calculated values of the $d_{ch}$ index ranged from 4,5 (H≈1050 m) to 2,1 (H≈600 m).
The volume calculations were made excluding the excavations already sunk and filled with fly ash - water mixtures. The results of the calculations of the total volume of the free spaces are shown in the Figure 4.
Prognosis of the Morcinek coal mine flooding was done assuming, that the water level stabilise at the datum of about 0.00 m above the see level, i.e. at the depth of 241 m. The result of the prognosis, made for the period since the end of dewatering the mine, is presented in the Figure 5.

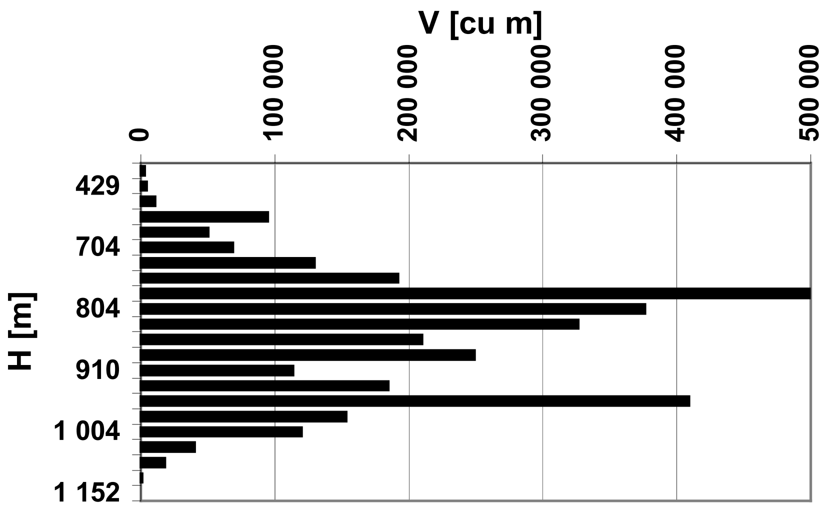


**Fig. 4. Depth (H, m) profile of total water capacity (volume – V, cu m) of anthropogenic reservoir of abandoned Morcinek coal mine.**

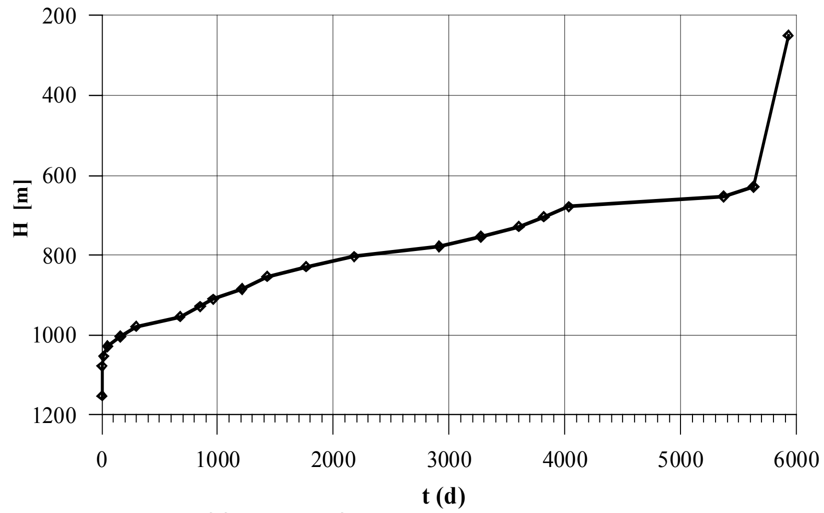


**Fig. 5. Prognosis of flooding of Morcinek mine reservoir; H – depth, t – time.**

**GAS OBSERVATIONS AND MEASUREMENTS DURING MINING EXCAVATIONS FLOODING.**

After the abandonment of Morcinek coal mine, starting from 3rd January 2001, periodic analysis of molecular composition of pore gases in the aggregate layers, which top the backfilling of the shafts, have been made. In collected gas samples volume concentrations of nitrogen, carbon dioxide, methane, oxygen and others were measured. After 520 days (shaft III) and 890 days (shafts I & II) from the beginning of the measurements a significant change in the molecular composition of the pore gases was found. Initially gas composition in each of the shafts was similar to the composition of the atmospheric air owing to the influence of atmospheric conditions. However, after the above mentioned periods there have been observed a significant increase in the concentration of methane and decrease in the concentration of oxygen and nitrogen (Fig. 6). In shafts II and III those changes were accompanied by the growth of carbon dioxide concentration up to about 5%. In shaft II it was simultaneous to the increase of methane concentration, while in shaft III this was delayed by near six months. The molecular composition of gases in shafts I and III became therefore similar to the molecular composition of natural gases typical for coal seams of high methane zones in this region of USCB (see: Gawlik & Grzybek 2002, Kotas 1994), while in shaft II gas composition probably signified interaction between the influence of both atmospheric and mine air.

Detailed analysis of data in Figure 6 shows that after the above mentioned periods, in shafts I and III significant growth in the methane concentration took place, comparing to the slight growth of it in shaft II. The changes in methane concentrations in shafts I and III do not indicate a correlation, as oppose to shafts I & II, where the correlation occurs (r = 0.94). Moreover in shaft I, after reaching it's maximum, methane concentration generally remains at a high level above 80%, while in shaft III it constantly decreases in spite of temporary variations. Nevertheless the methane concentrations in both shafts indicate inverse proportion to the nitrogen concentration, while in shaft II such correlation occurs between methane and oxygen (Fig. 6).

All this indicates that the explanation of causes of differentiation in progresses of pore gas composition changes in each shaft requires the knowledge about both the history of their liquidation and characteristics of the reservoir inside mining excavations. The results of Morcinek coal mine flooding prognosis (Fig. 5) illustrate that as long as the ventilation was sustained (153 days since the stop of dewatering) roughly 174 thousands cubic metres of the reservoir have been flooded, and the water level have reached the depth of about 992 m. At the point, when further movement of the water level caused compression of mining gases, the volume of the reservoir part above water level can be hence estimated at about 3080 thousand cubic metres. However, during the days when the described significant changes in molecular composition of the pore gases took place in shaft III or I and II it can be estimated at respectively: 2012 thousand cu m or 1652 thousand cu m, with the water level at the depth of about 873 m and 833 m.

These calculations imply that at the point of pore gases composition change in shaft III the shafts entries at the levels 1100 m and 950 m have already been flooded. So, mining gases migration to shafts could only progress through their connections with the cross-cuts at levels 650 m and 800 m. Lower methane concentration and the presence of oxygen in connected only with the level 800 m shaft II indicate, however, that the main role here was played by the level 650 m. At the same time, flooding of the level 950 m explains the time of appearance of the higher nitrogen concentration in the pore gases of the shaft III, which took place after the rough increase of methane concentration (Fig. 6c). An assumption can also be made that it is chiefly the nitrogen compressed after the already mentioned methane explosion. The delay of it's outflow through the shaft III, comparing with the outflow of methane, indicates it's migration to the shaft through galleries and goafs between levels 950m and both 800 m and 650 m.

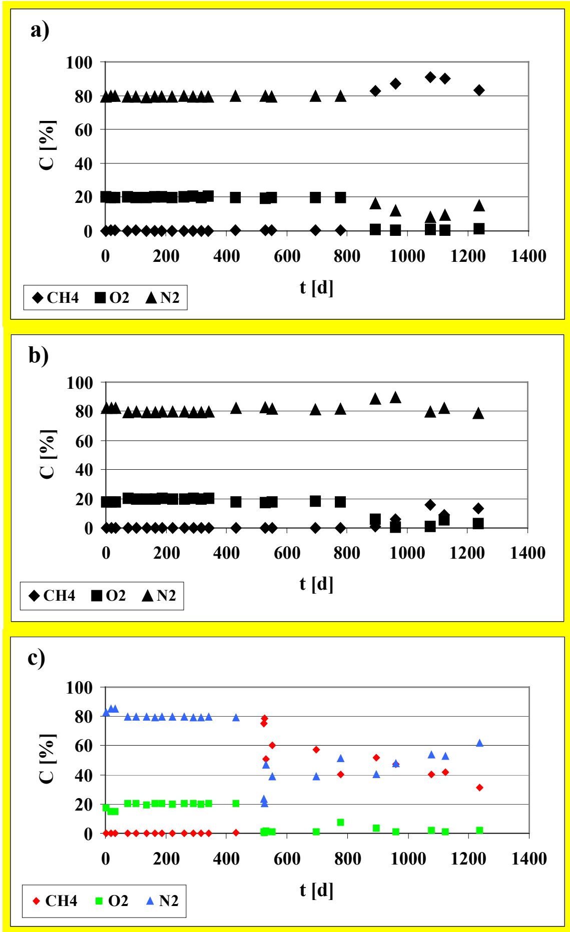


**Fig. 6. Concentrations (C) of pore gases in the aggregate layers, which top the backfilling of shafts I (a), II (b) i III (c) of Morcinek coal mine versus time (t) after starting its measurements**

The estimation of volume of the reservoir part over water level enables to assess the reservoir pressures acting on the shaft's backfilling. Considering average mine gases composition in compliance with the data from hole TP-3 ($CH_4$ – 95.4 %, $CO_2$ – 0.6 %, $O_2$ – 0.4 %, $N_2$ – 3.6 %) and with the starting atmospheric pressure at the level of the shaft heads of 99.8 kPa, using the formula (Szostak & Chrząszcz 2000):

$$P_d = P_g e^{0.000144gH} \qquad (2)$$

where: $P_d$ – bottom reservoir pressure, kPa,
$P_g$ – reservoir pressure at the shaft head, kPa,
g – specific gravity of gas in relation to the air.

it is possible to calculate that the starting reservoir pressure at the level of 650 m equalled to 105.34 kPa. Using the Boyle – Mariotts law it is possible to estimate that on 520 and 890 days of gas measurements, analogous reservoir pressures equalled to: 161.27 kPa and 196.46 kPa. At the level of the shaft head those were: 152.78 kPa – on 520 day, and 186.12 kPa – on 890 day.

Coming from these calculations we can infer that the previous mine gases emission from shaft III was a result of smaller than in shafts I and II resistance of it's flow. It enabled the emission to occur at the reservoir pressure lower by almost 35 kPa. The reasons of lowering the flow resistance in shaft III can be looked from mainly in the effects of the methane explosion, which took place there.

The calculations of the pressures at the shaft head correspond well with measurements of static head pressure in the Kaczyce 1/01 borehole, drilled to the Morcinek coal mine goafs, roughly 350 m to the SE from shaft I, which differ by only 3.4 – 9.1 %. It confirms the correctness of the results of reservoir volume calculations and it's flooding prognosis. It can be inferred that possible hazard caused by the methane emission from the shafts will persist until the flooding of level 650 m, hence till about 2012, i.e. almost 14 years after the stop of coal exploitation. Whereas the gas symptoms will be observed for further 3 years, until the stabilisation of the water level in the shafts.

**SUMMARY**

In hydrogeologically impermeable-covered region of USCB, where Morcinek coal mine is situated, the cover of the overburden has an insulative characteristics. It efficiently protects the ground level from the emission of gasses compressed by the water rebound in the flooded coal mines. Potential gas hazards therefore can only arise in the regions where the shafts break through the overburden. Hence, considering the hazards in the mining area, emphasis has been put on gas compression in mining excavations and their emission. Basing on assessment of mining – geological conditions and the data concerning the abandonment of the coal mine the volumes of water and gas reservoir in the Morcinek coal mine has been estimated as well as the course of flooding it. Subsequently, using the results of hydrogeological analyses, reservoir pressures of the mine gases have been assessed. These pressures were calculated for assigned moments of molecular composition changes of pore gases in the backfilling of the shafts, corresponding with the appearance of the mine atmosphere influence in the backfilling. It enabled to explain that the differences in the progress of changes in the composition of pore gases arose not only from the difference in depth of the shafts entries to the mine galleries (the flow mainly through the hollow ones), but also from devastation of the entries isolation from the shaft pipe in one of the shafts. Moreover, the comparison of calculated reservoir pressures, relating to the heads of the shafts, with the measurements of head pressures in a borehole drilled to the goafs of Morcinek coal mine proved these estimates, made with the hydrogeological methods to be correct and enabled to assess the expected duration of potential gas hazards in the region of removed shafts. This period, equal to the time of level 650 m flooding and stabilisation of the water level in shafts, was estimated at roughly 14 – 17 years from the stop of coal exploitation.

The study has been done within a scientific project, carried out from 2003 – 2005, founded by The Polish Ministry of Science and Information Society Technologies.

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