Environmental problems on the areas of redeveloped hard coal deposits

Henryk Kleta and Franciszek Plewa

Faculty of Mining and Geology, Silesian University of Technology, ul. Akademicka 2, 44-100 Gliwice, Poland

henryk.kleta@polsl.pl

Abstract. The issue of development of deposits in the areas of liquidated mines has been the subject of business activities in Poland for a number of years. This state is undoubtedly influenced by the fact that the Polish energy industry is based on coal and the needs of the steel industry for coking coal. The article presents the basic environmental problems that should be taken under consideration in the areas of re-utilized hard coal deposits. On the basis of selected examples the environmental conditions necessary to be taken into account when planning the re-development of hard coal deposits have been discussed.

1. Introduction

Hard coal deposits are one of the most important components of the national wealth. The volume as well as the accessibility of the deposits determine the national energy security. The hard coal deposits in Poland are found in three basins. Coal is mined in two of them, namely in the Upper-Silesian Coal Basin and the Lublin Coal Basin. Currently, the documented recoverable reserves of hard coal as of 31.12.2016 amount to 58 578 million tons. These include nearly 71.56% of power coal and over 27.09% of coking coal [1]. The environmental conditions are currently the most significant factor when it comes to the possibility of development of hard coal deposits. In post-mining areas that are affected by former mining activity, the changes which cause degradation of the ground surface include especially [2]:

- transformation of surface due to underground and surface mining exploitation,
- deposition of mining wastes and the space required for that purpose,
- contamination of soil with industrial emissions,
- transformation and erosion of soil in agricultural and forest areas.

The greatest hazard for the surface area is posed by mining exploitation conducted at low depths with a caving system without backfilling. The moment of formation of sink holes is practically impossible to forecast which causes a hazard to the surface and all the buildings at the affected area [3]. The collapse of voids resulting from exploitation and maintaining stability in the rock mass for a longer period of time may be caused by another mining exploitation as well as when load is exerted on the surface of the void or during rock-bursts and vibrations of the rock mass and the surface area [4].

2. “Morcinek 1” hard coal deposit

2.1. Short characteristics of the liquidated KWK “Morcinek” mine

The "Morcinek" hard coal mine was liquidated in the years 1998-2002. It was one of the youngest mines in Poland as it was constructed in the years 1978-1993. The exploitation was officially...
commenced in 1986. On October 30th 1998, the exploitation was terminated and the liquidation process was initiated. The liquidation was completed in 2001 [5]. For the KWK “Morcinek” mine and for the protection of the border zone between Poland and Czech Republic, protective pillars were established, which, along with the pillars for the protection of the main headings, took up a large area and significantly limited the development of the mine. Between the depths of approx. 600 m and 1500 m, the presence of 37 coal seams was found within the range from seam 354 to the seam 510. For the depth of 1100 m, that is the depth of the bottom level of the former “Morcinek” mine, 21 recoverable coal seams have been identified in the range between seam 360/1 and 418/2. Generally, the calorific value of coal increases along with the depth, reaching classes from 34.2 in the same seam (404/1, 4.4/1-2) to 37.2. During reconnaissance works, also natural coking of a coal seam was noted to proceed after the coal of the class 37.2. In lower seams, 42-type coking coal is found.

During the construction of the KWK “Morcinek” coal mine, in the Carboniferous formations water inflow occurred in sections of the roof, especially in sandstones beneath Dębowiec conglomerates. In regions that are more distant from the Dębowiec formations and at greater depths, the rock mass was practically free of water and it did not accumulate in parts with more cracks and in locations of faults transitions. The slight inflows that were noted were mostly relic waters and quickly faded. The main inflow was always constituted by waters from the overburden. The inflow of water to the mine has been presented in table 1.

| Year | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Total | 0.56 | 0.95 | 2.15 | 2.98 | 2.48 | 2.08 | 1.52 | 1.43 | 1.70 | 1.73 | 1.87 | 1.29 | 1.71 |
| Shafts | 0.45 | 0.44 | 0.38 | 0.31 | 0.28 | 0.24 | 0.24 | 0.18 | 0.17 | 0.25 | 0.19 | 0.26 | 0.22 |
| Overburden | 0.45 | 0.76 | 1.96 | 2.39 | 2.22 | 1.69 | 1.30 | 1.11 | 1.20 | 1.44 | 1.54 | 1.20 | 1.60 |
| Carboniferous | 0.11 | 0.19 | 0.19 | 0.58 | 0.26 | 0.39 | 0.22 | 0.32 | 0.50 | 0.29 | 0.33 | 0.09 | 0.11 |

2.2. The “Morcinek 1” hard coal deposit and the characteristics of the terrain in its area
The “Morcinek 1” hard coal deposit is located in the Silesian voivodeship (figure 1). It lies within the outline of Zebrzydowice (Kaczyce) and Hażlach (Pogwizdów) communes. The landscape of the area above the “Morcinek 1” hard coal deposit is highly diversified, exhibiting numerous elevations, valleys and steep slopes by streams. The area in concern is cut by the Olza river – the right-side tributary of Odra, as well as the Piotrówka river. Olza flows in a vast, flat valley along the western boundary of the area in concern. The watercourses which serve the drainage of the area are the right-sided tributaries of Olza and left-sided tributaries of Piotrówka. These also include the Kaczyckie (Kaczor) stream and the unnamed streams constituting indirect tributaries of Olza. Moreover, surface water bodies located along the streams are present in the area in concern. The surface of the area of the “Morcinek 1” deposit is also developed with scattered residential and service buildings as well as the Kaczyce, Brzezówka and Pogwizdów villages with cluster development. The respective villages and developments are connected by a network of local roadways. Also the Zebrzydowice-Cieszyn railway runs through the area in concern. Moreover, drinking water pipelines, gas lines, communication lines and power lines are found in the area.

2.3. General characteristics of the effects of the exploitation conducted by the liquidated KWK “Morcinek” coal mine
The twelve years of mining activity of the liquidated “Morcinek” mine have had an impact on the transformation of the surface, which was subject to both intentional transformations accompanying the deposition of wastes and unintentional effects accompanying the underground mining activity, causing continuous and discontinuous surface deformations. The morphology of the area exhibit forms that are both concave (subsidence troughs) and convex (an embanked and filled sedimentation basin and a barren rock dump).
The effects of the mining exploitation in the form of subsidence were found at an area of approximately 5.6 km², encompassing developed areas, including mostly the scattered agricultural development in the Kaczyce and Pogwizdów villages. The maximal levels of subsidence occurred in two regions [6]. In the first region the subsidence reached approximately 8 m, while in the second region, the maximal values reached approx. 2.5 m. The subsidence has not caused significant hydrogeological changes (overflow) on the surface.

The mining exploitation formerly conducted in the liquidated “Morcinek” coal mine has not caused discontinuous deformations. The deformations that have emerged have not disturbed the hydrological ratios in the former “Morcinek” mine exploitation area. Also, no significant changes of hydrographical and hydrogeological conditions such as overflows, flooding, changes in stream gradients and levels were noted.

As a result of the drainage of the liquidated KWK “Morcinek” coal mine, a cone of depression was formed in the hydraulically connected complex of the waterlogged strata in the area of the Dębowiec formations and the water-bearing Carboniferous formations. The cone, which was located in the region of the main shafts I, II and II (formerly the “Morcinek” mine), reached the depth of approximately 1000 m and reached the radius of approx. 3300 m, stretching to the Dębowiec formations.

The geological documentation states that 14.46 million m³ of water was pumped out during the existence of the “Morcinek” coal mine. After the pumping has ended, the mine would be gradually flooded. It was forecasted that after 4 years, the entire level 950 would be flooded up to the floor of the headings at the 800 m level (-550 m a.s.l.). After 9 more years, the water was supposed to fill the headings of the mine up to the floor of the 650 level and continue to fill the cone in the Dębowiec formations [5, 7].

The characteristics of the water filling the goafs of the former KWK “Morcinek” coal mine are highly variable depending on the location. In the region near the outcrop, beneath the Dębowiec formations in the western part, the mineralization of water is the lowest due to the highest infiltration of external water. During the construction of the Kaczyce shafts, the mineralization of water in the

Figure 1. Areas of coal deposits GZW [www.pgi.gov.pl].
Dębowiec formations and at the level of the roof of the Carboniferous formations was from 7 to 15 g/dm³. Along with the depth, the salinity of water increased, reaching the mineralization from several dozen up to over 100 g/dm³ and – in some locations – relic water occurred with mineralization reaching up to 200 g/dm³.

Until 2013, natural flooding of the goafs proceeded and methane was exploited from the anthropogenic deposit that has formed in the goafs, based on the license to conduct a reconnaissance of methane deposits from coal seams in the “Kaczyce 1” mining area, granted by the Minister of Environment in the year 2000.

In case of establishing a new mine for the “Morcinek 1” deposit, the main hazard will be constituted by the methane from the gas reservoir formed in the goafs of the liquidated KWK “Morcinek” coal mine. Due to the chemical composition, the water in the Carboniferous formations will exhibit magnesium aggressiveness and may be acidic and contain aggressive CO₂. This will be accompanied by high outflow of methane. Moreover, the temperature of the Carboniferous water may be high and the natural water outflowing from the goafs will be warm. In case of an outbreak of water from the “Morcinek” coal mine, it should be expected that the temperature of water may reach 40–50°C.

3. “Brzezinka 3” deposit in Mysłowice
3.1. General characteristics of the effects of the exploitation conducted by the liquidated KWK “Morcinek” coal mine

The “Brzezinka 3” coal deposit is located within the administrative territory of the Mysłowice city. The area of the deposit is 7.27 km².

The “Brzezinka 3” deposit (figure 2) is adjacent to the developed “Mysłowice,” “Wesoła” and “Brzezinka 1” deposits, the latter being documented by Tauron Wydobycie S.A. – Sobieski Mining Plant and the “Niwka-Modrzejów” and “Jan Kanty” deposits formerly exploited by liquidated mines.

![Figure 2. Deposition scheme of the deposit “Morcinek 1”.](image-url)
The deposit is documented and classified in the B assessment category from the roof of the saddle beds up to the floor of the 510 seam, that is, the depth of 1050 m. The reserves of hard coal in “Brzezinka 3” are deposited in the 510 seam of the saddle beds. The coal is of 31 and 32 types.

The 510 seam in the “Brzezinka 3” deposit is of a considerable thickness and is found at depths from approx. 700 m in the northern part of the deposit up to 1050 m at the south. Thickness lower than 4.0 m (1.1 m), has only been noted in the Brzezinka 10 borehole located in the south, right behind the boundary of the deposit. The 510 seam was formerly exploited in adjacent deposits: „Niwka-Modrzejów,” „Mysłowice” and „Wesola”.

3.2. Hazards posed to the surface by old goafs resulting from past mining exploitation

The beginnings of mining in the area outlined by the “Brzezinka 3” deposit date back to the first half of the 19th century. In the deposit in concern, shallow 215, 216 and 304 seams were exploited by the former “Przemsza” mine and the resulting vast goafs at the depths of 150 ÷ 200 m are probably flooded [8].

Until 1931, over a dozen of mining plants existed in the area in concern, including i.a.; “Theodor,” “Louise,” “Leopoldine,” “Hans,” “Wanda,” “Nowa Przemsza,” “Bartelmus,” “Carlssegen,” “Friedrichsgluck,” “Maximilian,” “Josepha,” all of which conducted mining activity. The deposit was mostly exploited using a shortwall system with caving and a system of headings. In outcrop areas, the coal seams were made available using drifts and – rarely – the deposit was exploited using open pits.

In the years 1971-1982, the “Jan Kanty” mine exploited the 304/2 seam over the northern part of the “Brzezinka 3” deposit using open-end mining with caving and a longwall system with hydraulic supports and caving (to a lesser extent).

Based on the data regarding the shallow exploitation within the area of the “Brzezinka 3” deposit and the cases of discontinuous deformations occurring formerly at that area, it may be concluded that in case of commencing an exploitation of that deposit, significant hazard may be posed to the surface area.

The case of the M. Rej housing estate in Mysłowice – Brzezinka may serve as an example illustrating the subsidence hazard in that area. The M. Rej housing area is constituted by free-standing or semi-detached residential houses, mostly 2-floor, with full basements and small ground-plan dimensions. The 301 seam in the area of the M. Rej estate was exploited by the “Nowa Przemsza” coal mine. The exploitation was conducted in the years 1851 – 1885 and 1929 – 1930 using a shortwall system with caving at a mean depth of approx. 37 m. The thickness of exploitation was from 3 m to 4 m. As it has been shown by boreholes, the headings have not fully collapsed and thus pose a hazard to the surface area [4]. In the years 1880 – 1912, seam 304 (Luiza) was exploited beneath the seam 301 and the exploitation was conducted using a shortwall system with caving with exploitation thickness of approx. 4.0 m. The depth of the exploitation was approx. 170 m. Due to the thick benches of sandstone present between the seams 301 and 304, the exploitation of the 304 seam did not cause the reactivation of the goafs of the 301 seam and the collapse of the voids that are present therein.

The documentation of the phenomena occurring at the area of the M. Rej estate in Mysłowice – Brzezinka since 1977 indicates that the area of that estate was subject to typical shallow exploitation, where discontinuous deformations occur. Below, the most significant discontinuous deformations which have occurred at the area of the estate have been listed.

The most hazardous effects were caused by a sink hole in the form of an elliptical cone with the dimensions of 3.5 x 5.0 m and the depth of 4.0 m, that formed on May 3rd 1977 in the area of Różana street. Four detached family houses and a transformer station were in the range of the sinkhole. A breakage of a water pipeline and outflow of water was noted in the sinkhole. The sinkhole was backfilled, however, due to the continued subsidence, the building No. 3 was damaged beyond repair. The liquidation of the sinkhole was completed on 14.07.1977.

On August 2nd, 1977, 3 sinkholes were noted in the area of Malinowa street. On August 3rd 1977, a sinkhole was noted by Różana street, in a garden, next to a cesspit. The dimensions of the sinkhole were 1.0 m x 0.5 m and its depth was 1.0 m.
Also on August 3rd 1977, a sinkhole was noted in the area of Jaśminowa street, with a volume of approx. 6 m$^3$. In 1979, also in the vicinity of a building at Jaśminowa street, a sinkhole was formed with a diameter of 2.0 m and a depth of 4.5 m. In 1982, the sinkhole renewed reaching the depth of 4.5 m. In 1979, a sinkhole appeared at Jaśminowa street with a diameter of approx. 2.0 m and a depth of 1.0 m. In June 1985 a sinkhole formed in the area of a residential building at M. Rej street. This sinkhole, with a diameter of 3.0 m and the depth of 0.8 m, occurred in the area of the “Stefania” shaft reaching the 301 seam. The sinkhole was backfilled and in September and October 1985, 5 boreholes were made in that area, while the boreholes No. 1 and 2 were filled with pressure-pumped fly-ash.

While analyzing the geological and mining conditions and the sinkholes that formed to that moment, it should be concluded that the hazards caused by discontinuous deformations in the M. Rej residential area have been affected by several factors, especially:

- the existence of a former shallow exploitation conducted using caving system in the 301 seam at the depth of approx. 33 m to 37 m,
- the existence of voids in the goafs of the 301 seams and over the 301 seam at varying depths, found by means of boreholes, electro-resistivity and gravimetric measurements,
- the lack of an insulating layer in the roof of the Carboniferous formations, causing the infiltration of precipitation water and the water from the damaged water pipelines and soakaways into the rock mass,
- shocks caused by the traffic within the residential area and – especially – outside of the area (express road).

It is commonly assumed that the process of void formation proceeds according to a certain model based on the so-called pressure arch theory [2]. In case of wider headings, the void reaches the surface and forms a sinkhole. At lower widths of headings, the void should be bound within the rock mass area.

In such case, for the sinkhole to form, additional circumstances must occur – such as the disturbance of hydrological ratios, scouring etc. This fact has been confirmed by the sinkholes which formed to that moment. The lack of the insulating layer above the weathered sandstones caused the infiltration of surface water into the rock mass and, as a consequence, led to changes in the hydrological ratio, resulting in the displacement of the rock material. The roof layers of these voids became fractured and caused collapses travelling to the surface, causing the formation of sinkholes. Because in practice it is impossible to eliminate the infiltration of water, and the goafs resulting from the old shallow exploitation of the 301 seam occur under the entire residential area, it may be concluded that a comprehensive protection of the M. Rej residential area is not possible even under the condition of precise location of the voids in the rock mass. This is because there are no effective methods of backfilling flooded voids.

Based on the analysis of data obtained in old boreholes and the results of the conducted study, it may be concluded that a large number of voids exists at various depths over the roof of the 301 seam [4]. This implies that it is highly probable that not only primary voids occur in the goafs of the shallow workings, but also secondary voids exist at various depths. In favorable conditions, these voids may contribute to the formation of sinkholes in the future.

The factors that may activate the voids include:

- the effects of mining exploitation,
- changes in hydrological ratios,
- vibrations caused by traffic,
- construction of heavy buildings at the surface.

The presented example of hazard posed by discontinuous deformations indicates that this hazard may not be fundamentally liquidated due to the following reasons:

- there is no practical possibility of detecting all the voids that are present beneath the residential area,
- there is no effective method of backfilling flooded voids,
there is no possibility of preventing the infiltration of surface water into the rock mass.

Despite the long time that has passed since the shallow exploitation has ended, it may thus be concluded that the hazard caused to the surface by the discontinuous deformations persists and the time of its liquidation may not be determined. In case of conducting future mining exploitation in that area, also the drainage of the rock mass would occur, which would be disadvantageous in view of the hazard posed by discontinuous deformations resulting from the reactivation and displacement of the voids “suspended” in the rock mass towards the surface.

4. Conclusion

In view of the provided examples from two selected hard coal deposits, the following conclusions may be formulated regarding the environmental conditions related to the future development of the deposits:

- the most significant environmental conditions for the redevelopment of a hard coal deposit include the changes of the hydrogeological conditions which have occurred after the mining exploitation has ended, the changes in methane conditions and the reach of the former shallow mining exploitation in view of the hazards posed to the surface by discontinuous deformations,
- the exploitation of coal should only be allowable in the part of the deposit where no former shallow goafs are present or where studies and preventative and protective works were conducted to eliminate the reactivation of the old shallow goafs,
- while examining the redevelopment of deposits within the area of liquidated mines, the actual resistance of surface structures (buildings, lines) to static and dynamic effects of mining exploitation should be considered,
- while determining the resistance category of newly developed structures at areas where liquidated mines once operated, the potential redevelopment of deposits should be considered.

References

[1] Szuflicki M, Malon A and Tymiński M 2016 Bilans zasobów złóż kopalń w Polsce wg stanu na 31 XII 2016 r. (Warszawa: Państwowy Instytut Geologiczny)

[2] Chudek M 2010 Mechanika górotworu z podstawami zarządzania ochroną środowiska w obszarach górniczych i pogórniczych (Gliwice: Wydawnictwo Politechniki Śląskiej)

[3] Kleta H and Plewa F 2001 Zagrożenie powierzchni terenu po zakończeniu wieloletniej eksploatacji górniczej na przykładzie kopalni „Siersza” Zeszyty Naukowe Politechniki Śląskiej seria Górnictwo 250

[4] Kleta H and Zych J 2015 Opinia naukowa dot. Raportu o oddziaływaniu na środowisko przedsięwzięcia polegającego na wydobywaniu węgla kamiennego wraz z kopaliną towarzyszącą ze złoża „Brzezinka 3” Politechnika Śląska Gliwice

[5] Collaborative work 2012 Dokumentacja hydrogeologiczna określająca warunki hydrogeologiczne w związku z zamieszczonym wykonywaniem odwodnienia w celu wydobywania metanu z węgla kamiennego ze złoża „Kaczce I” według stanu na listopad 2011 roku Państwowy Instytut Geologiczny Państwowy Instytut Badawczy Oddział Górnośląski im. St. Doktorowicza Hrebniickiego Sosnowiec

[6] Collaborative work 2015 Projekt koncepcyjny dotyczący sposobu udostępnienia złoża węgla kamiennego „Morcinek 1” wraz z metanem jako kopaliną towarzyszącą Kraków

[7] Collaborative work 2013 Opinia hydrogeologiczna określająca warunki prowadzenia robót górniczych przez NWR „KARBONIA” S.A. w obrębie obszaru „Morcinek 1” Główny Instytut Górnicwa Zakład Geologii i Geoizyki Katowice

[8] Collaborative work 2015 Raport o oddziaływaniu na środowisko przedsięwzięcia polegającego na wydobywaniu węgla kamiennego wraz z kopaliną towarzyszącą ze złoża „Brzezinka 3” oraz na budowie, prowadzeniu i likwidacji zakładu górniczego „Brzezinka 3” Dokumentacja pracy badawczo – rozwojowej Główny Instytut Górnicwa Katowice