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HYBRID TECHNOLOGY OF HARD COAL MINING FROM SEAMS LOCATED AT GREAT DEPTHS

TECHNOLOGIA HYBRYDOWA EKSPLOATACJI WĘGLA KAMIENNEGO Z POKŁADÓW ZALEGAJĄCYCH NA DUŻYCH GŁĘBOKOŚCIACH

Learning to control fire changed the life of man considerably. Learning to convert the energy derived from combustion of coal or hydrocarbons into another type of energy, such as steam pressure or electricity, has put him on the path of scientific and technological revolution, stimulating dynamic development.

Since the dawn of time, fossil fuels have been serving as the mankind's natural reservoir of energy in an increasingly great capacity. A completely incomprehensible refusal to use fossil fuels causes some local populations, who do not possess a comprehensive knowledge of the subject, to protest and even generate social conflicts as an expression of their dislike for the extraction of minerals. Our times are marked by the search for more efficient ways of utilizing fossil fuels by introducing non-conventional technologies of exploiting conventional energy sources. During apartheid, South Africa demonstrated that cheap coal can easily satisfy total demand for liquid and gaseous fuels.

In consideration of current high prices of hydrocarbon media (oil and gas), gasification or liquefaction of coal seems to be the innovative technology convergent with contemporary expectations of both energy producers as well as environmentalists. Known mainly from literature reports, underground coal gasification technologies can be brought down to two basic methods:

– shaftless method – drilling, in which the gasified seam is uncovered using boreholes drilled from the surface,
– shaft method, in which the existing infrastructure of underground mines is used to uncover the seams.

This paper presents a hybrid shaft-drilling approach to the acquisition of primary energy carriers (methane and syngas) from coal seams located at great depths. A major advantage of this method is the fact that the use of conventional coal mining technology requires the seams located at great depths to be placed on the off-balance sheet, while the hybrid method of underground gasification enables them to become a source of additional energy for the economy. It should be noted, however, that the shaft-drilling method cannot be considered as an alternative to conventional methods of coal extraction, but rather as a complementary and cheaper way of utilizing resources located almost beyond the technical capabilities of conventional extraction methods due to the associated natural hazards and high costs of combating them.

This article presents a completely different approach to the issue of underground coal gasification. Repurposing of the already fully depreciated mining infrastructure for the gasification process may result in a large value added of synthesis gas production and very positive economic effect.

Keywords: hard coal, methane drainage of a coal bed, underground coal gasification, hybrid coal exploitation

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Od kiedy Człowiek nauczył sie panować nad ogniem Jego życie uległo znaczącym zmianom, natomiast kiedy energię spalanego węgla czy węglowodorów nauczył się zamieniać na inny rodzaj energii jak ciśnienie pary czy energię elektryczną, wkroczyła na drogę rewolucji naukowo-technicznej i dynamicznego rozwoju.

Od zarania dziejów paliwa kopalne są naturalnym rezerwuarem energii potrzebnej ludzkości w coraz większej ilości. Kompletnie niezrozumiałe negowanie korzystania z paliw kopalnych sprawiają, że niektóre grupy ludności lokalnej, nie mając wszechstronnej wiedzy, są skłonne do protestów, a nawet do generowania konfliktów społecznych, będących wyrazem niechęci do wydobywania jakichkolwiek kopalin. Procesem znamiennym dla naszych czasów jest poszukiwanie coraz efektywniejszych sposobów wykorzystania paliw kopalnych przez wprowadzenie niekonwencjonalnych technologii pozyskiwania energii z klasycznych surowców energetycznych. Afryka Południowa w czasach apartheidu pokazała, że mając tani węgiel kamienny – jako surowiec energetyczny można z łatwością zabezpieczyć w całości zapotrzebowanie na paliwa płynne i gazowe.

Obecnie przy wysokich cenach nośników węglowodorowych (ropy i gazu) zgazowanie lub upłynnianie węgla, wydaje się być w naszych warunkach technologią innowacyjną zbieżną ze współczesnymi oczekiwaniami zarówno producentów energii, jak też obrońców środowiska. Znane, głównie z doniesień literaturowych technologie podziemnego zgazowania węgla sprowadzają się do dwóch zasadniczych metod:

– bezszybowej – wiertniczej, w której zgazowywane złoże udostępnione jest otworami wiertniczymi wywierconymi z powierzchni terenu,
– szybowej, w której do udostępnienia złoża wykorzystuje się podziemną infrastrukturę istniejącej kopalni.

W niniejszej pracy zostanie zaprezentowana metoda mieszana szybowo-wiertnicza, za pomocą której proponować się będzie pozyskanie pierwotnych nośników energii (metanu i gazu syntezowego) ze złóż węgla kamiennego, zalegających na dużej głębokości. Dużym atutem metody jest fakt, że przy klasycznej technologii wydobycia węgla, jego pokłady zaliczone na dużej głębokości zaliczone muszą być do zasobów pozabilansowych, natomiast przy podziemnym zgazowaniu metodą hybrydową mogą stać się źródłem dodatkowej energii dla gospodarki. Należy jednak podkreślić, że metoda szybowo-wiertnicza nie może być traktowana jako alternatywa dla klasycznego wydobycia węgla, ale jako jego uzupełnienie i tańsze sięgniecie po zasoby praktycznie leżące poza możliwościami technicznymi wydobycia metodą klasyczną, głownie ze względu na bardzo duże zagrożenia naturalne oraz wysokie koszty ich zwalczania.

Artykuł prezentuje kompletnie inne podejście do problemu podziemnego zgazowania węgla kamiennego. Korzystając w procesie zgazowania z infrastruktury górniczej już w pełni zamortyzowanej wartość dodana w produkcji gazu syntezowego może być bardzo duża, a efekt ekonomiczny bardzo korzystny.

Słowa kluczowe: węgiel kamienny, odmetanowanie pokładów węgla, podziemna zgazowanie węgla, hybrydowa eksploatacja

1. Introduction

High price of oil and the more or less correct theory about man-made causes of climate change brought the process of underground coal gasification, which has been known for almost 100 years, back to the research laboratories of coal and energy manufacturing plants. National Research and Development Centre approached this issue by funding a project entitled **“Development of coal gasification technology for highly efficient production of fuels and electricity”**, implemented by some of the most competent scientific research units under the leadership of AGH (Strugała et al., 2011; Strugała & Czerski, 2012).

Underground gasification involves partial combustion of the seam in order to utilize the resulting heat in multiple chemical processes, such as partial oxidation of carbon to form carbon monoxide, carbon hydrogenation into a hydrocarbon like methane or methanol, or obtaining pure hydrogen. The mixture of these gases combined with nitrogen and carbon dioxide is called synthesis gas, hereinafter abbreviated as “syngas”. Its value depends primarily on the quality parameters of the gasified coal, the gasifying medium, as well as the pressure and moisture conditions inside the reactor.

Previous experiments carried out worldwide point to a moderate possibility of using this method for industrial scale energy production, but the research efforts are still in progress and becoming more and more intensified. Following the introduction of navigated drilling into the industrial practice, the Linc Energy company in Australia developed and built the so-called fifth generation georeactor in Chinchilla, which is currently undergoing extensive testing (Czaja et al., 2013).

The company is also very actively engaged in the "Polanka-Wielkie Drogi" (PWD) project in Poland, which involves conducting drilling research in order to accurately diagnose the conditions and technical parameters of the seam with regard to its possible exploitation using the underground gasification technology.

2. The geological conditions and size of the gasifier in the process of underground coal gasification (UCG)

Based on studies conducted by Linc Energy, we can now conclude that the process is controlled and controllable. However, these results need to be approached with great caution. Geological and mining conditions in Chinchilla are modelled, and may even be described as perfect. The geological profile of the seam is shown in Figure 1.

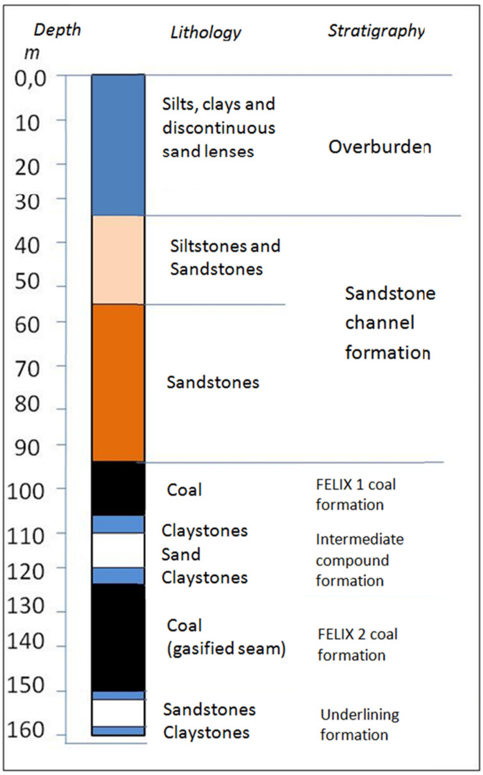


Fig. 1. Lithological profile of the Chinchilla seam (Queensland – Australia)

The success achieved in Chinchilla absolutely cannot be transferred directly to the Polish coal deposits. Just as the attempts at using the American technology of coal bed methane extraction failed due to conditions in Poland being different from those in America, so the characteristics of Polish Carboniferous coal deposits are completely different from Australian Jurassic coal.

The main obstacles preventing us from making a simple inference about the success of this method are as follows:

a) the installation in Chinchilla **is built on a seam with mining, geological and environmental parameters ideal for this technology**, consisting of:
   - coal bed width around 10 m located at a depth of around 140 m;
   - quality of coal in the gasified seam classified as very good for the kinetics of the gasification process:
     – combustion heat in the range of 21-23 MJ/kg,
     – total moisture content 10,1%,
     – ash content 19,3 %,
     – volatile matter content < 40,0%,
     – non-volatile matter content 34%;
   - young age of coal – Early and Middle Jurassic period (according to contemporary research, the kinetic parameters of coal gasification for younger group of brown coals is much better than for Carboniferous coals)
   - advantageous stratification of overlaying beds (Fig. 1.) including the presence of:
     – two layers of claystone beds (strata) directly above the seam,
     – approximately 40 m thick sandstone layer,
     – tight quaternary overburden,
     – lack of aquifer horizons,

b) the UCG establishment is located in an uninhabited area (the nearest human settlements are located approximately 30 km away), and the region of the experiment is partly dedicated to agro-forestry,

c) other legal considerations related to zoning and use of the environment, particularly, in terms of the experiment and the possible exploitation of the seam with the use of UCG method.

Serious consideration of the underground coal gasification method requires a thorough analysis of conditions and opportunities for application of this technology in Poland. The Polish coal mining operation already averages at more than 700 m in depth and is growing by several meters per year, which results in escalation of hazards and rapidly rising costs of unit production. The experience of Polish and international mining industry shows that operating at depths exceeding 1000 m with the use of conventional methods is difficult, dangerous and very expensive. On the other hand, it is also known that the shaftless (borehole) method of underground gasification is characterized by more favorable financial results compared to the shaft method. The study carried out in the "Development of coal gasification technology for highly efficient production of fuels and electricity" project shows that ensuring continuous operation of a 20 MW CHP system would require the simultaneous operation of at least 6 production wells. Therefore, it is difficult to imagine a syngas producing UCG plant as a quantitative alternative to the conventional extraction of an ordinary mine, whose annual production of 3 million tons can power a 1000 MW unit of a coal-fired power plant. According to these data, obtaining such power would require the simultaneous operation of approximately 300 UCG production wells.

In this situation, the AGH research team proposes a compromise solution - the hybrid technology of obtaining primary energy carriers from coal seams located at great depths, as a complementary element of conventional extraction. The complexity and hybrid nature of the proposed method lies in the fact that operating mines, which are currently approaching levels deeper than 1000 meters, may continue their operations following the implementation of the simultaneous methane drainage and coal gasification technology using the same underground infrastructure.

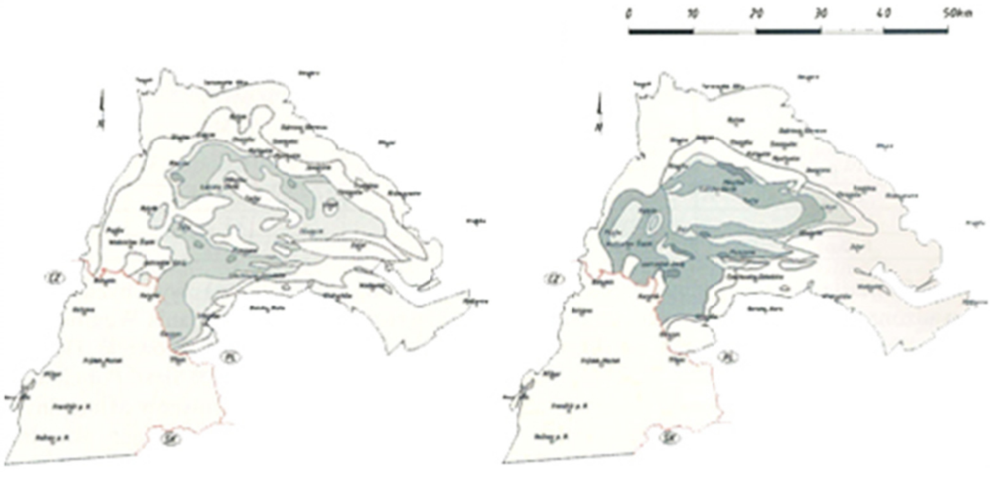
In this context, it is necessary to take into consideration the following aspects:

a) resource base at depths in the range of 1000 to 1500 m,
b) mining and geological conditions at these depths,
c) the level of natural hazards in specific mines at depths greater than 1000 m
d) organization of work in the mine with regard to the implementation of the hybrid technology allowing for economically efficient and technically optimal exploitation of seams inaccessible to conventional mining operations.

3. Potential hard coal resources at depths greater than 1000 m

The Upper Silesian Coal Basin in Poland is known as a region extremely rich in coal, which has been developed by the mining industry for centuries. All except one currently active coal mines are located in the Upper Silesian Coal Basin. Currently exploited deposits occupy about 1106 km^2, representing approximately 20% of the total Upper Silesian Coal Basin area, which reaches around 5600 km^2 within the Polish borders (Szuflicki et al., 2013).

About 23% of the area, that is approximately 1291 km^2, is composed of prospective areas where seams are estimated to be found at depths ranging from 1000 to about 1300 m (Szuflicki



a) – at depths 1000-1250 m b) – at depths 1250-1500 m

Fig. 2. Occurrence of hard coal resources in the Upper Silesian Coal Basin at depths greater than 1000 m (Probierz et al, 2012)

et al., 2013). According to the annual PGI report, a significant part of the area, which has not yet been exploited, contains seams that remain at depths greater than 1000 m (Szuflicki et al., 2013).

According to Probierz et al., the prospective resources in the Upper Silesian Basin located within the depth interval of 1000-1250 m amount to approximately 8,060.6 million tons (including 4,276.5 million tons of power coal and 3,784.1 million tons of coking coal). Whereas about 17.4 million tons of coal (including 14.8 million tons of power coal and 2.6 million tons of coking coal) are found within the depth interval of 1250-1300 m. Figure 2 shows the areas with identified coal seams at depths greater than 1000 m (Probierz et al., 2012).

Detailed studies of individual seams are necessary to determine the technology required for the underground gasification of coal seams located at great depths. Research of the resource base in relation to a number of selected mines will be conducted as part of the project. Literature suggests that the resource base of the JSW S.A. company has already been a subject of fairly extensive research (Marcisz, 2010; Probierz & Marcisz, 2010).

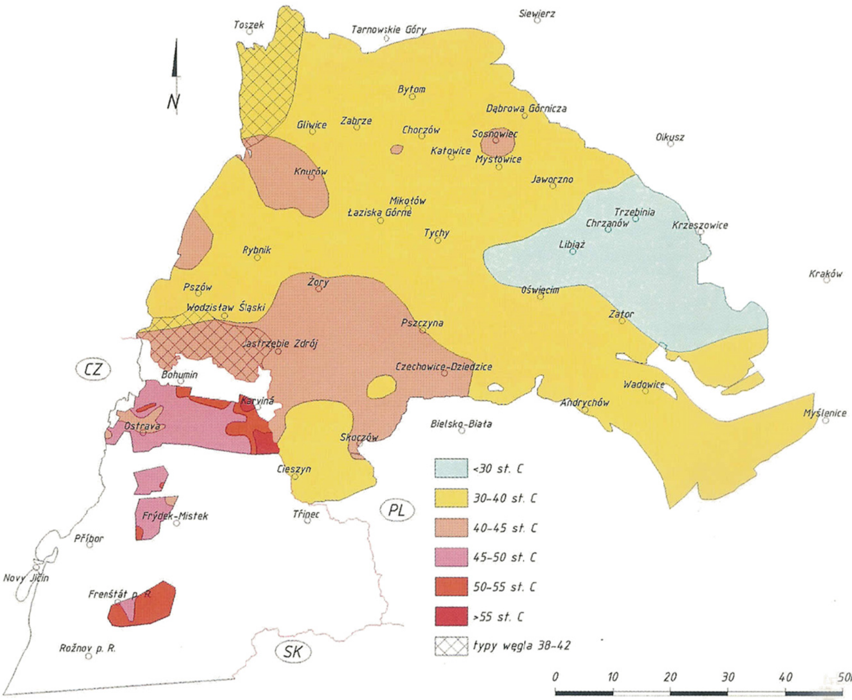


Fig. 3. Map of the regional temperature field in the area of the Upper Silesian Coal Basin in the Polish part at the depth of 750 m; in the Czech part at the depth of 1100 m. *Source:* (Probierz et al., 2012)

4. Natural hazards in coal seams at depths greater than 1000 m

It is well known that increasing depths are accompanied by a disproportionately quick intensification of natural hazards. Polish mines feature all possible natural hazards: climate, methane, rock bursts, fire, dust and water. These threats are usually rated with the highest risk categories, classes or grades. In most cases, threats occur simultaneously, creating the so-called combined hazard.

4.1. Climate hazard

Currently, the average depth of exploitation exceeds 700 m and increases by 8-10 m a year, which results in a very noticeable increase of *in situ* rock temperature. The problem of geothermal energy has been widely described in the works of Lewandowska and Probierz, among others (Lewandowska, 2001; Probierz & Lewandowska, 2004). In areas where preparatory and exploitation works are conducted, the temperature of rocks constituting walls and roadways is about 44 degrees C. This temperature is the result of natural *in situ* temperature distribution in the Upper Silesian Coal Basin, example of which is shown in Figure 3 (Probierz et al., 2012).

The density of heat flow of rocks emitted to the ventilation air is equally significant. The map of the USCB is presented in Figure 3 (Probierz et al., 2012).

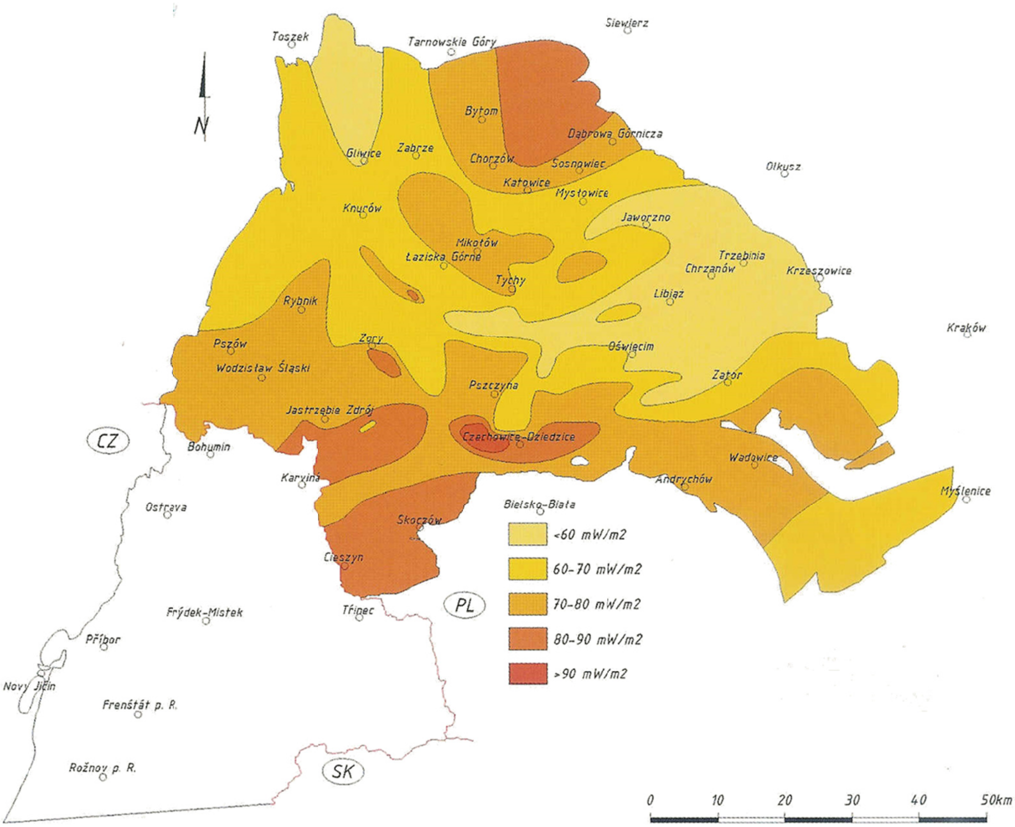


Fig. 4. Map of density of heat flow of rocks emitted to the ventilation air in the Upper Silesian Coal Basin.
Source: (Probierz et al., 2012)

In this situation, ventilation air temperature rapidly exceeds the acceptable level of 28 degrees C, often reaching values above 35 degrees. This entails reduction of work time to six hours and operations conducted in emergency rescue mode. Such conditions would completely undermine the logic behind mine operation and lead to an unimaginable increase in operating costs. Some aspects of air cooling system design in selected types of coolers used in conventional air-conditioning systems of underground mines are discussed in the work of Kuczery and Nowak, who, among other things, present the methodology of calculation of cooling capacity required for underground operation to estimate energy needs within certain inlet air parameters (Kuczery & Nowak, 2012).

At the same time it is worth noting that the increase in depth significantly improves quality of the coal. Given the already incurred costs of underground infrastructure, resigning from its exploitation appears to be completely unjustified.

4.2. Methane hazard

In the case of methane presence in mines we are dealing with a kind of paradox. Although methane is an excellent fuel, its occurrence and release from coal massifs during exploitation is a big threat to the mining operation. Depending on the geological conditions, at a certain geological time (300 million years) methane could be released and escape into the atmosphere through leaky rock mass, creating the so-called degassed zone reaching up to 1000 meters. With increasing depth, the methane levels of coal-bearing formations covered by a tight overburden quickly escalate. This is reflected in the number of Polish coal mines operating in methane hazard conditions. Currently only 4 out of 31 coal mines are classified as methane-free. In 2012, 851.5 million m^3 of methane was released in Polish mines (the average of 1623.9 m^3 CH_4 per minute). Research into a potential economic use of coal bed methane is currently being carried out (Krzystolik & Skiba, 2009; Nawrat, 2013). This includes both high-concentration gas acquired in the process of methane removal as well as low-concentration methane originating from the ventilation air (Nawrat, 2013).

Methane level, i.e. the total amount of methane per ton of pure coal substance, increases with depth. Following the increasing depth of mining operations, it has already risen from 7.3 m^3/ton to 11 m^3/ton in the past 10 years. The increase in methane levels of coal seams and mines is discussed in detail in the works of Probierz and Szlązak, among others (Probierz et al., 2012; Szlązak N., 2008). The increase of methane hazard is illustrated by graphs presented in Figure 5 (Kotas, 1994; Lewandowska, 2001).

Although the above brief analysis suggests that the maximum methane level occurs at the depth interval between 950 and 1050 m, methane hazard in the seams located below 1000 m will be significantly higher than it was before. In view of the recent mining disasters in Poland and the world which occurred as a result of methane hazard, the descent of conventional operations to depths greater than 1000 m will be burdened with an extremely high risk and generate very high costs.

4.3. Danger of coal and gas outburst or rock bursts

Methane itself is a very big threat. However, combined with high pressure, which also increases with depth, it may become a direct cause of gas and rock outbursts. The increase in

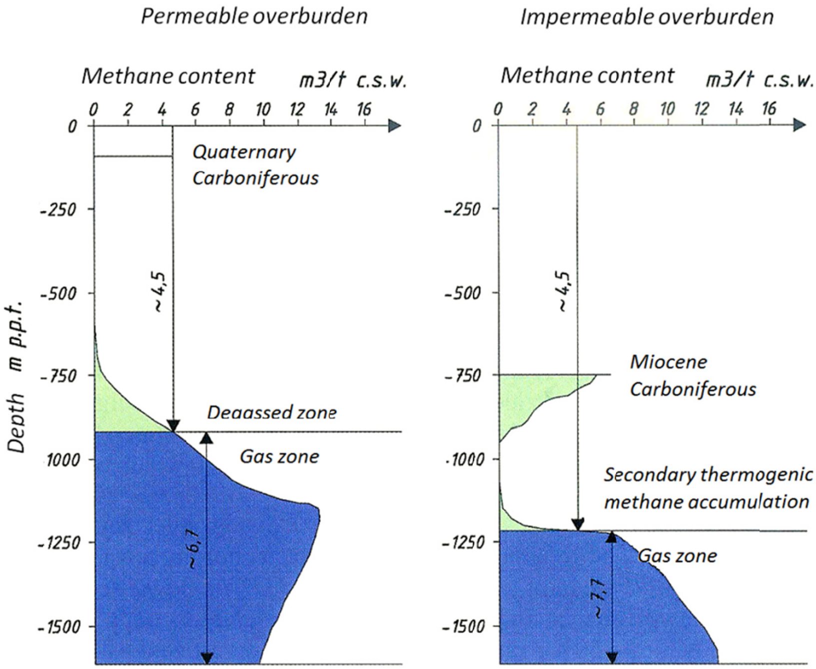


Fig. 5. Distribution of gas-bearing in the deposits of the Upper Silesian Coal Basin according to (Kotas, 1994)

gas-bearing (methane level) of deposits combined with reduced compression and gas permeability of the coal as well as increased rock pressure and the occurrence of numerous geological disturbances contributes to the escalation of this hazard.

With rapidly declining coal production, from 192 million tons in 1980 to 75.5 in 2011, the total number of tremors recorded in Polish underground mines is nearly 40,000, including 301 cases of resinous rock bursts which cost many miners their lives (Probierz et al., 2012).

4.4. Summary

As can be seen from the above analysis of current situation and historical data, these four natural hazards i.e.: climate, methane, gas outbursts and rock bursts are demonstrating a growing trend. The entire progressive mining community is looking for methods of minimizing the risks to the health or life of the miners by as much as possible. Development works on unmanned production systems are currently very common. Unmanned wall ploughs controlled from the surface have been successfully implemented by the Germans in the RAG Anthrazit Ibbenbüren GmbH mine. It is therefore advisable to consider non-conventional methods of operation with reference to coal seams located at great depths, i.e. below the ones exceeding 1000 m.

5. Integrated shaft-drilling hybrid method of obtaining primary energy carriers from hard coal deposits located at great depths

An important goal of the strategic project entitled **"Development of coal gasification technology for highly efficient production of fuels and electricity"**, announced by the National Centre for Research and Development, carried out at AGH, GIG, IChPW and Silesian University of Technology, under which research of the underground coal gasification (UCG) technology is being conducted, is to develop a technology competitive to the conventional exploitation methods or complementary to the method of acquiring energy resources through the gasification of coal.

So far, the results of UCG research have indicated that this method, developed over 100 years ago, cannot replace traditional methods of fuel extraction and disposal in professional power plants. In has been reported that 95% of coal accumulated in the Earth's crust and water areas is unavailable to conventional mining technologies (Kapusta, 2013). In Chapter 4, it has been demonstrated that large deposits of coal located at depths greater than 1000 m will not be easy to extract using conventional methods, provided they will be extracted at all due to the intensification of natural hazards generating high operating costs. The work of Małkowski et al has demonstrated significant changes in the mechanical properties of rocks surrounding the georeactor, which further complicates the process of forecasting the stability of post-reaction cavities following underground coal gasification (Małkowski at al., 2013).

So far, the inventions in the field of *in situ* underground coal gasification have been as follows:

1. Shaftless method, which requires vertical or sloped boreholes drilled in the surface area leading into the coal seam, then a curved-directional (lateral) borehole drilled into the seam and gasifying media administered via embedded injection pipelines. In this system, the gasification products are extracted through openings extending from the end of the injection wells on the surface. The most advanced version of this type of georeactor is used by the Australian Linc Energy company, as shown in Figure 6 (Czaja at al., 2013).
2. Shaft method, which utilizes the existing mining infrastructure with additional boreholes, through which gasifying media are injected, drilled into the seam. The synthesis gas – a product of gasification – is extracted to a pipeline and transported onto the surface using the existing shaft. The analysis of the literature and patented methods so far has not shown any examples of underground structures which could serve as a model of underground mining with the use of coal gasification. Similarly, there is currently no algorithm for the preparation and exploitation works.

For coal deposits located at depths greater than 1000 m, drilling vertical boreholes from the surface to the seam for each individual georeactor will be very costly, undermining competitiveness of the process compared to the conventional method of mining coal. Estimating the cost of a vertical borehole drilled from the surface to a depth of 1000 m at about 2 million PLN and assuming that the wells would need to be drilled at a distance of several meters away from each other, the costs of gasification will be very high.

The hybrid technology for the exploitation of primary energy carriers assumes:

1. Mining operations on seams located at depth, the following aspects up to 1000 m using conventional methods.

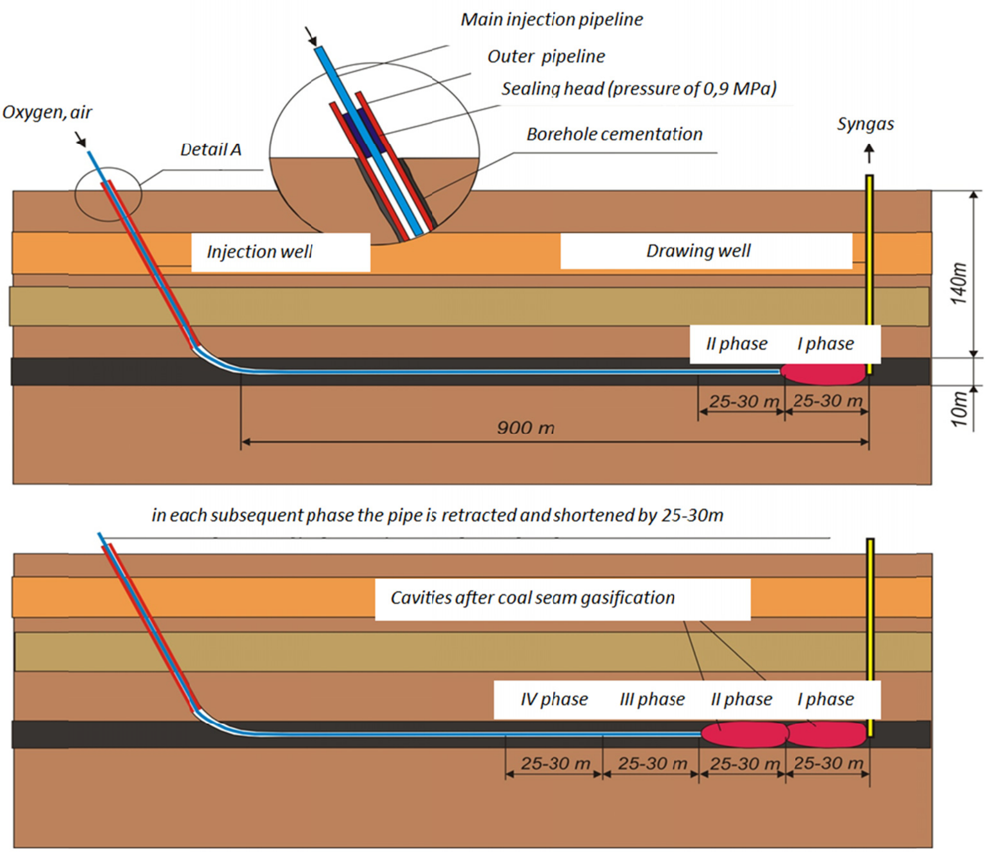


Fig. 6. Shaftless method of underground coal gasification in a Linc Energy V generation georeactor – Chinchilla, Australia (Czaja at al., 2013)

2. Due to the intensification of natural hazards at depths greater than 1000 m, e.g.:
   - increased rock mass pressure and associated difficulties in movement,
   - significant increase in methane levels of seams located at large depths leading to increased hazard,
   - rapid increase of climate hazard at great depths (*in situ* temperature may exceed 50 degrees Celsius), compelling the use of highly energy-intensive and expensive to operate air conditioning systems,
   - increased risk of rock bursts,

   we propose the construction of an underground system of workings and drilling pathways to enable:
   a) in the first phase – maximum extraction of methane released from the seam,
   b) in the second phase – gasification of carbonaceous material in seams located below the conventional level of 1000 m, on which underground gas mine workings will be built
   c) in the third phase – filling post-reaction cavities with fine-grained mineral waste administered wet.

The basic condition of the project is a specific system and design of the workings, allowing for temporary presence of people inside the georeactor area during gasification.

The schematic structure of such underground mine workings in an unconventional methane and syngas mine is shown in Figure 7.

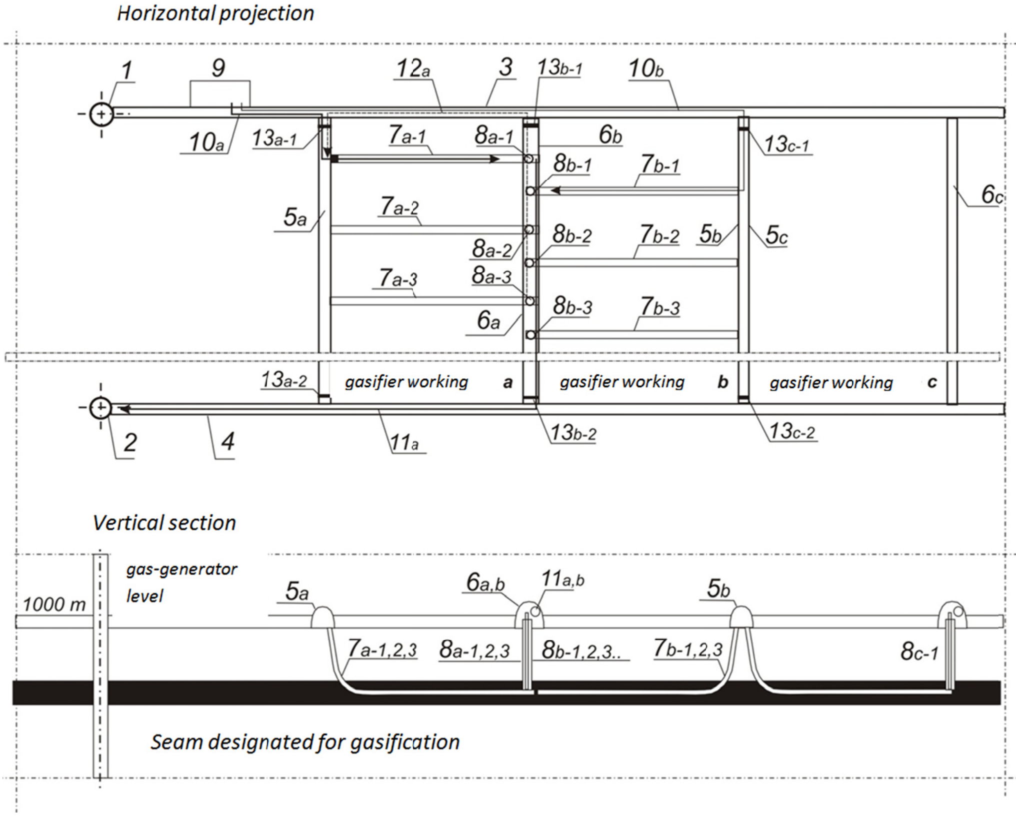


Fig. 7. Integrated shaft-drilling method of extracting primary energy carriers from hard coal beds. Idea of AGH-UST

Underground gas (methane and syngas) mine requires:

1. A minimum of two shafts (1 and 2) to maintain circulation of ventilation air, as well as to provide an inlet for the gasifying media and an outlet for the gas obtained in the process.
2. Two crosscuts or drifts: supplying the gasifying media 3 and extracting gasification products 4.
3. Depending on the size of the seam area where gasification is possible:
   a) several crosscuts or drifts 5a, b, c, from which the injection wells will be drilled entering the seam at a slightly inclined angle, then 7**a**-1, 2,3, **7b**-1, 2, 3, 7**c**-1, 2.3, etc.
   b) several crosscuts or drifts **6a**,b,c from which vertical boreholes (drawing wells) will be drilled, **8a**-1, 2, 3, **8b**-1, 2, 3, etc., connected with borehole 7**a**-1,2,3 etc. for receiving,

at first, methane – until its complete exhaustion from the seam, and then receiving and cooling the synthesis gas, which will be transported to the surface using pipeline 11a via shaft 2. Cooling-receiving wells may also be used to produce steam at a high temperature (3000°C-4000°C), which pipeline 12a can forward to the injection wells and pipes 7a-1, 2,3, 7b-1, 2.3, etc. as a gasifying agent .

The process of such organized exploitation of hard coal seams should be carried out according to the following general principles:

1. Geometry of the gasifier should be specified, depending on the geological structure, coal quality and thickness of the bed.
2. Georeactor workings 3,4,5,6, should be equipped with durable and airtight housing.
3. All georeactor workings 5a,b,c, 6a,b,c must be equipped with airtight dams with doors enabling separation from workings 3 and 4
4. All injection wells 7a-1,2,3, etc., and drawing wells 8a-1,2,3, etc. must be hermetically sealed relative to the housing of the working from which they are derived.
5. The entire underground mine system should also be equipped with medium allowing to quickly suspend the gasification process, such as nitrogen or water and dust mixture.

The process of primary energy carrier exploitation should be as follows:

1. In the first phase after drilling all the boreholes in the operational area **a**, they must be de-methanized using geometry dependent on the thickness of the seam via drawing wells 8a-1,2,3, etc., by applying a specific depression generated in the underground methane drainage stations located in working 4.
2. Upon termination of the methane flow, we should proceed to the gasification phase, provided that the process begins with the injection borehole 7a-1 and the drawing well 8a-1. Gasification can be simultaneously carried out in the following line, i.e. by the borehole 7a-3 and the well 8a-3.
3. Gasifying media should be administered through a special pipeline inserted into injection borehole 7a-1, 2,3, etc., in such a way that its end is located at the mouth of the drawing well 8a-1, 2,3.
4. After gasifying the entire volume of coal within the boreholes 7a-1 and 8a-1, we must allow the georeactor to cool, and then fill the cavity with wet waste (ash from power plants) using the borehole 7a-1.
5. After filling the two adjacent cavities 7a-1 and 7a-3, we can proceed to 7a-2, 7a-4, etc.
6. After exploitation of the first overlaying seam surrounding the borehole has been completed, we are ready to proceed onto deeper seams using the same working structure.

Previous trials of underground coal gasification did not provide complete information about the shape of the post-reaction cavities. They assume, that the cavities should have the shape of a cylinder (Figure 8a) with d_{kaw} diameter equal to the thickness of *m* bed – the distance between pairs of injection-drawing wells should reach the minimum of *a,* the value of which is dependent on:

$$a = d_{kaw} + d_f \tag{1}$$

where:

a — distance between gasifying wells, m,
d_{kaw} — diameter (or width) of the post-reaction cavity, m,
d_f — width of the post-exploitation pillar, m.

In shaftless gasification, drilling deep boreholes into the seam has a very significant adverse effect on the cost of the entire process. Thus, one of the factors determines preferable thickness of the gasified seam as greater than 5 m.

However, if the boreholes are drilled from underground workings and their length required to reach the seam is between several dozen (e.g. 30 m) to a maximum of 200 m, their thickness may be reduced even to 3 m, provided good quality of coal in the gasified seams is ensured. In such case, the injection wells must be drilled at a distance of about 5 m from each other. It is also likely that the post-reaction cavity may have an elliptical cross-section, as shown in Figure 8b.

Such geometry of the gasifier workings would be more economically beneficial. A series of experiments will be required to develop methods of process control in order to maximize the possible volume of coal gasified using one pair of vertical boreholes.

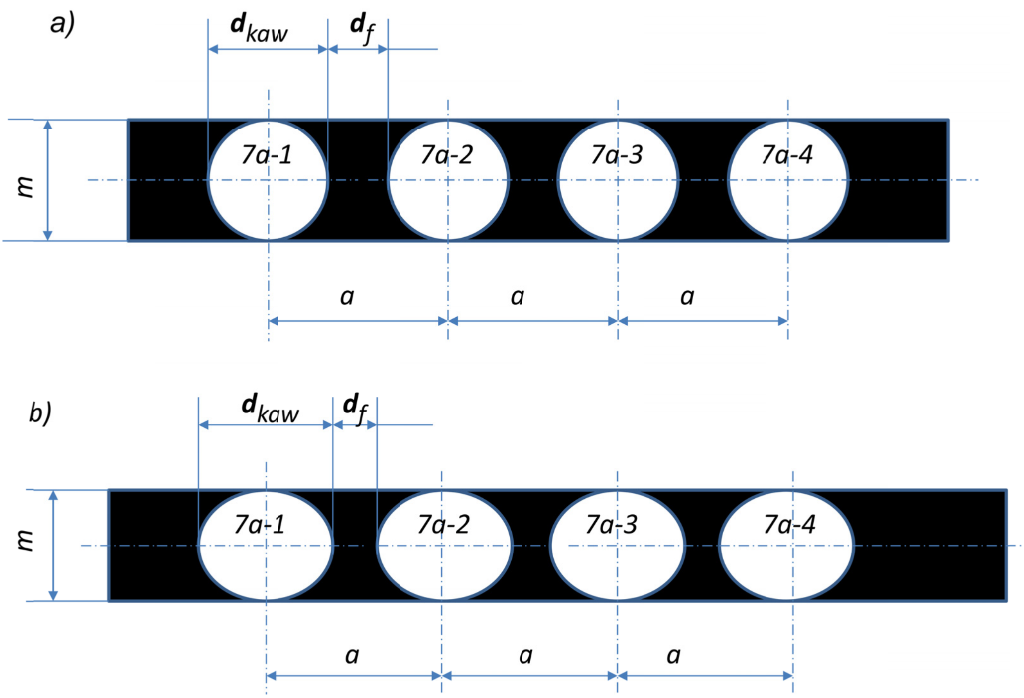


Fig. 8. Cross-section of the gasified seam and post-reaction cavities.
a) post-reaction cavities with a circular cross-section, b) post-reaction cavities with an elliptical cross-section

Key to symbols: m – thickness of gasified seam, d_{kaw} – diameter/width of post-reaction cavity, d_f – thickness of post-exploitation pillar, a – distance between injection wells

6. Summary

In the face of intensified natural hazards occurring at large depths, the presented concept of the hybrid shaft-drilling gasification method seems to be an alternative way of exploiting primary energy carriers from coal seams located at great depths.

The proposal requires a lot of further research, mainly with reference to numerous technical solutions in various sectors related to designing underground facilities.

In the mining sector, geometry of the gasifier workings of as well as the size and type of housing that meets the requirements of air tightness and resistance to elevated temperatures.

In the mechanical design sector, the entire infrastructure for the preparation and administration of gasifying media and installation used for the extraction of gas and its cooling with heat recovery for production of steam as the gasifying medium needs to be developed.

In the electrical sector, it is necessary to develop a hazard monitoring system and remote control of the entire process of gasification and syngas or methane emission.

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