Restructuring substantial increase in natural gas reserves by coalbed methane (CBM) recovery

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Abstract. Coal deposits, especially hard coal deposits, contain in their structure large amounts of methane, which during exploitation is diluted through industrial ventilation and degassing technologies down to non-hazardous concentrations, reducing the major risk factor for the safety of workers and resources minerals. The amount of methane released and exhausted into the atmosphere by the degassing and ventilation stations of the mining units, in addition to being wasted instead of being used, is also a factor of environmental pollution, as a potential greenhouse gas (GHG). The environmental issues and the climate crisis faced by humanity compel the establishment of an Action Program on the methane issue, which includes the capture, recovery and exploitation of gas from active coal mines, or from virgin strata, from unexploited mining fields, with the help of currently available technologies and practices, which represent the chance to obtain clean energy and substantial climate benefits, in the short and long term. The solution to the use of methane gas from coal at active mining operations in Jiu a Valley - Romania, by burning it to obtain the thermal agent, brought important economic benefits by reducing energy costs and environmental protection by reducing methane emissions in the atmosphere. The present paper proposes an analysis of the benefits obtained as well as the development possibilities of methane usage for obtaining a clean fuel.

1 Introduction

Coalbed methane gas can be considered a secondary resource, being associated with a main coal deposit. In Romanian legislation, (petroleum law no. 238/2004), it is considered as a primary resource and, accordingly, methane gas exploitation operations associated with coal deposits are directly concessioned to the owner of the mining activity.

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The related exploitation technologies are unconventional, in relation to exploitation of traditional gas deposits, a by-product is recovered, which would otherwise be lost, environmental pollution is avoided/reduced, and contributions are brought to reducing known risks in the exploitation of coal.

That is why, both by implications and by specific methods, it is a current theme, and an engineering challenge foreseen at international level in the Action Program for environmental problems facing humanity, offered by the Global Methane Initiative and the ad-hoc group within the UN, established on the issue of methane.[1]

The engineering practice that includes capture, recovery and exploitation of methane gas from coal mines, active or in the process of being closed, is also applied to the mines of Jiu Valley (Livezeni, Vulcan and Lupeni).[2]

2 INSEMEX research highlights in the field of methane degassing and recovery

A first action undertaken, started in 1954, was the classification of mines in the Jiu Valley Carboniferous Basin, according to the regime of methane releases. The action was completed in 1959, the year in which all the mines in operation in Romania were registered. On this occasion, the classification methodology was also developed, being included in the legislation in force. This activity still has a permanent character with a well-established periodicity and work methodology.

For example, measurements and determinations carried out in 1959 showed that the absolute flow of methane releases at the level of the mines in the basin had a total value of 4,400,547 m³/month (methane discharged into the atmosphere through the main ventilation stations). The centralized situation referring to methane quantities discharged from mining operations for the year 2022, in the Jiu Valley, shows that the volume of methane was 4,297,854 m³/year, excluding the degassing stations whose volume of utilized methane was 570,916 m³/year.

The first central degassing station was put into operation at the Lupeni mine in 1969. Completion of this installation was conditioned by the fact that the mining activities in layer 13, blocks III-A, IV and VI, could no longer be carried out due to releases and accumulation of methane in large quantities and at dangerous concentrations.

The objectives of the paper were: improvement of degassing methods and techniques; improving working conditions and increasing safety and health at work when extracting coal by reducing the amount of methane; increasing the degree of methane recovery and capitalizing on own energy resources; reducing the ecological impact by reducing the greenhouse effect.

The principle of degassing consists in capturing and draining a significant part of the amount of methane of the coal layers (the base layer or unexploitable layers), from sterile rocks or unexploited areas and evacuation to the surface through sealed pipes, under the depression created by vacuum pumps (central degassing) or in a contaminated air current, in which dilution below the limits allowed by norms is possible, by means of high-capacity ejectors (local degassing).

After 1969, central degassing was also implemented at the mining operations: Paroseni (1977), Livezeni (1988) and Vulcan (2006). Because of the large quantities of methane discharged into the underground atmosphere, as a result of both the continuous increase in production and limitations set by ventilation systems, INCD-INSEMEX, through the research carried out, developed appropriate technologies for degassing coal horizons and criteria for the implementation of degassing, respectively degassing framework methods, depending on the type of mining works, exploitation method, thickness and inclination of coal layers (fig.1).[3]
The Romanian Evaluations carried out by INCD-INSEMEX during peak periods of mining operations, showed the following amounts of methane extracted by the central degassing installations: Lupeni mine - approx. 160,000,000 N m$^3$; Paroseni mine approx. 30,000,000 N m$^3$; Livezeni mine approx. 25,000,000 N m$^3$; Vulcan mine - approx. 1,190,000 N m$^3$. [4]

At the Lupeni mine, the problem of exploiting extracted methane has been solved since 1974. This was achieved by burning the methane, for heating water in the mine’s bathrooms, heating the air entering the mine in the cold season (shafts Stefan and no. 12), heating the furnaces for processing through forging as well as heating the rooms of the degassing station from the Central ascensional.

In the warm seasons, the consumption of methane gas was between 2.9 and 4.3 m$^3$/min, while in the winter it reached values of 7.6 and 9.4 m$^3$/min. There were also situations when the consumption needs exceeded the quantity of methane obtained through its own degassing station. [5]

The problem of exploiting the methane extracted at the Vulcan mine was solved in the summer of 2007, by using it to heat water at its own thermal point.

After 1970 INCD-INSEMEX built several local degassing installations, which successfully completed the central degassing system and which are currently used at the level of mining units in operation (fig.2).

Fig. 1. Central degassing station (Central degassing methods)

Fig. 2. Local degassing installation

Legend: 1- degassing ejector; 2 - flame arrester; 3 – Royal- Duth device; 4 - Water- detrius-gas separator; 5 - faucet with drawer; 6 – air flow supplementation section in the dilution chamber; 7- iscaharge section; 8 - gas deflector; 9 - gas dilution chamber; 10 - Wire mesh to even out the air flow.
Research carried out by INCD-INSEMEX also extended to the level of geological research drills made from the surface towards the coal horizons, which presented manifestations of methane, establishing on this occasion, the probes' radius of action and their specific parameters (initial pressure and gas quality). [6]

In the course of 2002, in collaboration with SCTGN Medias, the documentation "Technical possibilities for capitalising methane gas from the central degassing stations and the main air exhaust streams from the Lupeni mine" was developed, completed with the technical-economic evaluation of the possible solutions to be applied.

In 2006, INCD-INSEMEX prepared the "Pre-feasibility study regarding the extraction and use of methane stored in the coal seams of Jiu Valley", a work completed with the establishment of an optimal solution for a pilot station for capitalisation of methane from coal seams unaffected by exploitation (virgin).

During 2005 - 2006 INCD-INSEMEX Petrosani collaborated on the project "Research on parameters characteristic of dynamic phenomena at the coal mines in Jiu valley and the development of safety measures" coordinated by IPROMIN¬ SA Bucharest, which highlighted, through measurements carried out underground, the tendency of extracted methane to increase in quantity as the exploitation depth increases.

During 2005-2006 within the Sectoral Research Program, INCD-INSEMEX Petrosani carried out the project "Reducing methane emissions at the main ventilation stations at the mines in Jiu Valley by improving methods of its recovery and capitalisation from the coal seams", work materialised in: improving the degassing of coal layers and surrounding barren rocks both for degassing methods with holes drilled from underground works, executed simultaneously with the preparation of new mining fields, as well as in drillings executed from the surface, in case the exploitation depth is shallow; novelty elements for the mining method with a coal bank undermined behind the front line compared to the mining method with frontal cuttings.

In order to carry out the exploitation of coal in safe conditions, it is necessary to avoid the possibility of occurrence of an explosive atmosphere of methane + coal dust + air in the underground atmosphere.[7,8]

Thus, large quantities of methane released in the mining process are diluted with large amounts of air to concentrations below 1% vol. Air with a methane content of less than 1% vol. is discharged into the atmosphere. In the case of the Paroseni mine (currently closed), the amount of methane released into the atmosphere was about 12 m³/min. The air-methane mixture (VAM) in this concentration could have been used to supply air to the burners at the Paroseni thermal power plant. Considering the large greenhouse effect of methane, this project suggested modern, viable solutions for capitalizing on this considerable amount of methane at low concentrations in the air stream.[9]

Such projects are by definition projects of high complexity, and the complex project of methane gas production and capitalisation in the Jiu Valley coalfield can be carried out by technical teams, made up of CEH Hunedoara representatives and INSEMEX Petrosani researchers, focused on evaluation and enlargement of the amount of gas extracted by mining units, specialists who make the technical equipment for the use of mine gas, as well as consultants on the issue of the use and capitalisation of carbon credits (green certificate).

Considering the energy crisis triggered in 2022, the current gas crisis at European level, caused by the Russian-Ukrainian conflict, the potential capitalisation of methane from coal seams contributes to an increase in the national gas reserve and an increase in the safety and energetic independence coefficient of the country.
3 Classification of coalbed methane gas and drainage-capture technologies

Depending on the origin (as far as the overlap of the degassing process with that of coal mining is concerned) and the method of extracting methane gas associated with coal deposits, it can be classified into (fig. 3): [9]

**Fig. 3.** Coal methane classification scheme

*Methane gas from virgin deposits (VCBM+ECBM)* – is extracted from coal layers and sterile rocks surrounding them through surface drilling, before opening the deposit and its exploitation, or in the case of those layers or portions of layers which are not exploitable for technical and economic reasons. In general, methane concentrations exceed 60%, but obtaining satisfactory results is determined by concentration and pressure of the methane gas as well as methane permeability of the layer and the surrounding barren rocks. The ECBM variant extracts methane from unexploited or virgin coal seams through holes drilled from the surface by injecting carbon dioxide (CO2) and/or nitrogen (N2).

*Methane gas from active mines (CMM)* – is extracted through drillings executed from underground in the coal layer simultaneously with the execution of mining works for the preparation of new abating fields, through drillings executed from adjacent mining works to the exploited areas, or through drillings executed from the surface, if the exploitation depth is reduced. In this case, two options are considered: pre-extraction and post-extraction. Extraction of methane before the exploitation process through underground holes (for reasons of safety of human and mineral resources) – pre-extraction. Extraction of methane after the end of the exploitation process from vertical wells on the surface, or inclined or horizontal boreholes from underground gas drainage galleries, or by other methods of capturing gas from the exploited spaces, including drainage of isolated areas of a mine (for safety reasons) - post extraction.

*Methane gas from the general ventilation current (VAM)* - used because of releases that are continuously produced from the massif of barren rocks and coal, along the route of underground mining works and from active workplaces. Due to the large volumes of
circulated air, the concentration of methane gas is generally below 0.6%, the technologies for exploiting the air-methane mixture for energy purposes being in continuous development.

*Methane gas from abandoned mines (AMM)* – is extracted through surface drilling or through abandoned pipes in the main opening works, works which after closing turn into methane gas accumulation tanks. In this case, the extraction solution adopted is determined by the closing solution.

Technologies for capturing and draining methane from coal seams can be divided into two large groups, namely: technologies for capturing and draining methane from the coal seam before and during mining of the coal seam and technologies for capturing and draining methane from the mined space during exploitation or in the post-extraction period. Their application depends on a number of factors and characteristics of the coal and methane-bearing waste rock, permeability and desorption rate, porosity, moisture content, coal seams’ angle of inclination and depth. [10]

Technologies for capturing/draining coal seam gas before or during mining include:
- vertical drilling from the surface to the coal layer or layers;
- directed drilling from the surface to the coal layer or layers;
- long or short drillings executed from underground in the coal layer;
- directional drillings super-adjacent to the layer in operation.

Technologies intended to capture and drain methane from the exploited space during exploitation or in the post-extraction period, include:
- vertical drilling from the surface in the exploited space;
- boreholes super-adjacent to the exploited space;
- fan drills executed from the preparation works related to the bank, ahead of the front line.

A combined variant of all types of technological drilling is exemplified in fig.4: [11]

![Fig. 4. Combined scheme of methane capture boreholes](image)

**4 Lowering pollutant emissions and capitalisation of methane at the mines in Jiu Valley**

Methane emissions today cause 25% of global warming and, according to studies in the field, since 2007 there has been a significant increase in their volume. Greenhouse gases: carbon dioxide and methane, are present in the ventilation system of the mines in Jiu
Valley, being discharged into the atmosphere (fig. 3). Their warming potential for 100 years, presented in the specialized literature, are: carbon dioxide with a potential value of 1, methane with a potential value of 21 and responsible for 0.5°C of the warming that the Earth has experienced so far.

The latest international studies (IPCC's Fifth Assessment Report (AR5)) of environmental organizations show that methane is 84 times more potent than CO₂ over a 20-year period, respectively 28 times when considering a period of 100 years. The estimates recorded in the National Greenhouse Gas Emissions Inventory have so far been made at the "Tier 1" level, according to the recommendations of the Intergovernmental Panel on Climate Change (IPCC) made in 2006. [12]

Romania is the second largest emitter of methane in the EU (after Poland), being responsible for 85% of the methane emitted by abandoned coal mines in the EU, and if only half of it were captured and used, it could generate 75 million euros of electricity. [13]

At national level, the Working Group on the reduction of methane emissions in Romania - ENERGIE was established, whose EU Regulation draft on reduction of methane emissions in the energy sector and the impact of its provisions on Romania is under debate. The meetings of this Working Group also aim to reach a consensus at Government and private sector level regarding Romania's commitments, at community and international level, to reduce methane emissions. The national contributions of the member states participate in the acceleration of the EU’s objectives of reducing these emissions by at least 30%, until the year 2030. [14]

Analysis of the possibilities to reduce methane emissions generated by extractive industry showed that the only recommended action consists in promoting studies and researches for the establishment of new technologies or the improvement of the existing ones for methane recovery, during exploitation of coal layers or after exploitation. Methane emissions are at the centre of new efforts to slow down the pace of climate crisis and are a priority in strategic development actions. Through the implementation of the National Guide to Pollutant Emissions, prevention, reduction and integrated control of pollutant emissions emitted by industrial activities is expected leading to an increase in the degree of environmental protection.

The mine air evacuated through the aeration system as well as through degassing – has a value from 10 to 45 m³ CH₄ for each ton of coal extracted. By applying degassing to the mines in Jiu Valley, from the data in the documentary portfolio, taking into account the amount of methane discharged through the ventilation system from the main ventilation stations, INSEMEX Petrosani performed an analysis for the year 2022 for the four active mines within the Hunedoara Energy Complex. [15]

The Vulcan Mining exploitation has utilized the methane extracted through the central degassing station at its own plant to obtain the thermal agent necessary for workers' hygiene. During the year 2022, a volume of 438,758 m³ CH₄ was recovered at concentrations of 40-50% vol., at an average flow rate of 4 m³/min related to the operating hours of the station. When the flow of methane drops below the required one, the gas supply is called upon from suppliers in the national system. The volume of methane discharged through the fan station, reported in the same year, is 131,484 m³ CH₄. Thus, the methane in the layer is recovered and utilized to the extent of 73.1% of the total amount.

The Lupeni Mining Exploitation, in 2022, utilized the methane extracted through the central degassing station, a volume of 132,158 m³ CH₄, with concentrations of 55-60% vol. and an average flow rate of 4 m³/min, at its own plant to obtain heating agent. The volume of methane discharged through the fan station, reported in the same year, is 1,413,912 m³ CH₄. Recovered and capitalised methane represents 8.55% of the total amount of methane. The mine is subject to the process of closing the mining activity.
The Livezeni Mining operation does not exploit the methane extracted through the degassing station, and has discharged into the atmosphere a volume of 450,550 m$^3$ CH$_4$ at a concentration of 35-40% vol. and an average flow rate of 1.3 m$^3$/min. A volume of 1,710,886 m$^3$ CH$_4$ is evacuated through the two fan stations.

The Lonea Mine, which is in the process of being closed, discharged a volume of 561,022 m$^3$ CH$_4$ through the fan station. It is not equipped with a central degassing station.

Among the existing and/or available options for using the methane resulting from the capture process, there is a wide spectrum of technologies that are required in the context of efficiency and environmental constraints. Depending on the concentration of methane in the mine gas, the following options can be considered for the commercial use of the mine gas;

- distribution of methane gas in the national high-pressure natural gas distribution system;
- distribution of methane gas for domestic and industrial consumers at low pressures;
- production of electricity by means of: generators, microturbines, etc.;
- supplying methane gas to a thermal power plant as fuel gas;
- compression of methane for the production of compressed natural gas;
- transformation of mine gas into liquefied natural gas;
- production of chemical substances based on methane gas;
- fuel for internal combustion engines;
- obtaining hydrogen H$_2$;
- use as fuel for heating industrial spaces, domestic hot water.

5 Conclusions

Started seven decades ago, the concern of INCD-INSEMEX Petrosani regarding the problem of methane from coal mines in Romania represents a distinct and continuous action in the research objectives of the institution. In the studies carried out at the beginning of the scientific activity of INCD-INSEMEX Petrosani in the Jiu Valley coal basin, only technical solutions to ensure the health and safety of underground workers and protection of the deposit were targeted, and not the energy potential of methane gas. Along the way, projects were outlined and put into practice to harness methane from coal seams as an alternative energy resource.

In order to ensure the health and safety at work of underground workers and safety of reserves of useful mineral substance open to exploitation, appropriate technologies for the degassing of coal layers and criteria for the application of degassing, respectively frame methods of degassing, have been developed, depending on the type of mining works, mining method, thickness and inclination of coal layers, creating central and local system degassing installations.

In the context of the current energy crisis triggered at international and national level, the potential capitalisation of methane from coal seams contributes to an increase in the national gas reserve and an increase in the country's energy safety and independence coefficient.

Depending on the origin (as far as the overlap of the degassing process with that of coal mining is concerned) and the method of extracting methane gas associated with coal deposits, the gas taxonomy includes 4 gas categories: methane gas from virgin deposits (VCBM+ECBM), active mine methane (CMM), general vent methane (VAM) and abandoned mine methane (AMM).

There are two groups of technologies for capturing and draining methane from coal seams: technologies for capturing and draining methane from the coal seam before and during coal seam mining and technologies for capturing and draining methane from the
mined space during mining or during post-extraction. Their use depends on a number of factors and characteristics of coal and barren methane-containing rocks.

Methane emissions are at the centre of new efforts to slow down the pace of the climate crisis and are a priority in strategic development actions. Analysis of the possibilities to reduce methane emissions generated by extractive industry showed that the only recommended action consists in promoting studies and researches for the establishment of new technologies or the improvement of the existing ones for methane recovery, during exploitation of coal layers or after exploitation.

In Jiu Valley, capture and capitalisation of methane gas from active mines is carried out at 2 mining operations, namely Vulcan and Lupeni, through degassing stations. During 2022 a total volume of 570,916 m³ CH₄ was capitalised representing 13.3% of a total volume of 4,297,854 m³ CH₄ (taking into account the ventilated air and unutilized degassing from the Livezeni mine and the ventilated air from the Lonea mine).

This work was carried out through the NUCLEU Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of MCID, project no. PN 23 32 02 03 - The superior valorisation for energy purposes of coal deposits under the conditions imposed by environmental strategies (VSMET).

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