EXTRACTION OF METHANE GAS DURING BROWN COAL MINING AND POSSIBILITY OF ITS USAGE

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DOI: 10.17973/MMSJ.2022_03_2022003

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Coal mining is still proceeding in some countries today, although EU countries have agreed to move to a carbon-neutral economy by 2050.
Mine gases were developed during coalification. The quantity of gas inside the coal deposits depends on the: level of coalification, quantity of colliery tip and on conditions, which have contributed to the keeping of gas inside the coal deposits. Mine gases are endangering mining operation hence it is necessary to assure their dilution or extraction. We can use the extracted mine gas in different ways from supplies to the system of natural gas up to using it in different appliances.
This article deals with the formation, acquisition and extraction of mine gas locally during mining operation.
This technology increases the safety of the mining area. It contributes to the reduction of CH_4 emissions and uses them for energy purposes.

KEYWORDS

coal deposits, extracted mine gas, degassing station, gaseousity of CH_4, cogeneration

1 INTRODUCTION

Coal domination in electricity generation is based on coal abundant and widely dispersed resources compared with oil and gas that is also a matter of energy security and minimizes the risk of energy supply disruption. Coal deposits occur in about 70 countries. At present extraction level, the proven coal reserves are estimated to last over 190 years [Twardowska 2006].

Coal seam gas (CSG) is becoming an increasingly important source of energy around the world. Many countries such as United States, Canada, Australia and China are investing in the CSG industry. A rise in the cost of conventional natural gas and many other energy resources, along with a decline in these conventional resources and issues such as climate change have encouraged a global interest in alternative sources of energy like CSG. The estimated quantity of CSG worldwide is around 1.4×1014 m^3, it is clear that coal seam gas is a significant source of energy [Hamawand 2013].

The analysis in References [Marcos-Martinez 2019, Tausova 2021] can inform social license and regulatory decisions related to the CSG industry that impact competing social priorities such as energy and water security, economic growth and environmental health.

Mining gases are part of the air of mining works, they are threatening mining operation and therefore it is necessary to ensure their dilution or degassing. Degassed mining gas can be used in different ways, from the process of the supply to the natural gas network to on-site use in appliances, e.g. cogeneration units.

The article deals precisely with the formation, acquisition and use of mining gas on site during mining operation.

Mining gases have evolved in the coalification process are preserved:

- primarily in the coal seams, in which they have formed, these are gases in the coal mass closed, according to the sorption theory, those are gases absorbed and adsorbed,
- secondary in seams and accompanying rocks, these are gases that fill all cracks, fractures and layered areas in both coal and accompanying rocks.

The amount of gas in the coal deposits depends on:

- from the degree of coal mass coalification, with the degree of coalification the sorbent capacity of coal increases.
- on the amount of coal mass in the deposit, the greater the amount of coal mass, the more gas is produced in a productive coal deposit.
- on the conditions which have contributed to its maintenance in the certain environment include: geological development of the area, tectonic and hydrogeological deposit ratios, porousness and permeability of coal and accompanying rocks.

The literature [Zhang 2016] states that coal permeability decreases with increasing gas pressure and applied vertical load. Mining activities disturb the rock environment, change the equilibrium state, release and exhalations into the mining air.

2 CURRENT STATE OF THE SOLVED PROBLEM OF METHANE GAS EXTRACTION IN LIGNITE MINING

2.1 *Geology of coal deposits in Slovakia*

Lignite resources are estimated at just over one billion tonnes. Exploitable lignite reserves, including brown coal, are calculated at 135 million tonnes. There is an insignificant hard coal deposit in the eastern part of Slovakia, which is not exploitable. In 2018, 1.5 million tonnes of lignite were produced. Lignite is extracted by one company at three underground mines located in the central and western parts of Slovakia. More than 90% of the total lignite production was used for electricity generation and district heating [Euracoal 2021].

The Cigel, Handlova and Novaky coal deposits are located in the Horna Nitra Basin.

The filling of the Horna Nitra basin (Fig. 1) in the area of Cigel, Handlova and Novaky coal deposits consist of layers:

• the Kamenske - footwall tuffites,
• the Novaky,e.g.handlova productive layers with coal seams,
• the Kos hanging wall clays,
• the Lehota- defritic-volcanic formation.

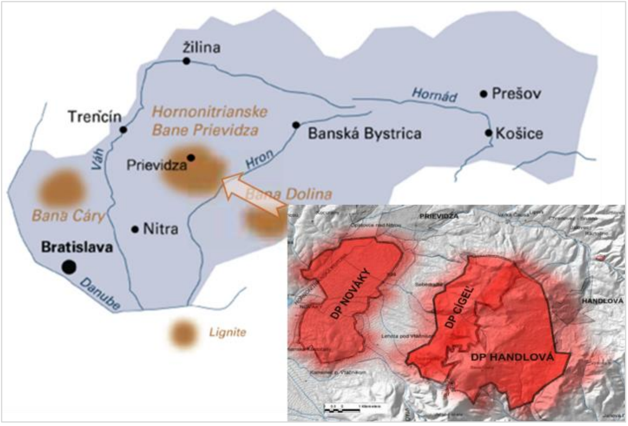

Figure 1. Lignite deposits in Slovakia (Adapted from [Euracoal 2021, Zelenak 2021]

- ***The Kamenske - footwall tuffites***

The Kamenske geological formation is set aside as geological formation of epiclastic volcanic conglomerates and sandstones with non-volcanic material in the footwall of coal seams. In commonly used terminology referred to as a complex of footwall tuffites. The thickness of the layer is highly variable, reaching a maximum of about 350 m.

- ***The Novaky, e.g. Handlova productive layers with coal seams***

Novaky and Handlova geological formations are formed at the bottom by sandy clay and tuffaceous sediments, which gradually pass into brown, dark grey to black coal clays with coal seams.

The thickness of the entire productive complex of geological formation reaches up to 50 m. The most important coal seam is the so-called main seam of the Novaky coal deposit, which is developed practically throughout the deposit.

It reaches a thickness of 8-10 m and a calorific value of 11.5 MJ/kg. The most important coal seam of the Handlova coal deposit is the so-called joint seam, the thickness of which is 7-11 m and the calorific value of 13.7 MJ/kg. The degree of coalification of the seams corresponds to the spread of lignite hemyphase to orthophase. From the petrographic point of view, these are lignite humits represented by detritus and xylitol, Table 1.

Coal deposit	Novaky	Handlova
The thickness (m)	8-10	7-11
Calorific value (MJ/kg)	11.5	13.7

Table 1. Novaky and Handlova the most important coal seams (Fazekaš, 2009)

- ***The Kos hanging wall clays***

The Kos geological formation is located in the hanging wall of Novaky formation, and it consists of clays and marl clays. The marl of the geological formation is variable. The thickness of the geological formation varies from 0 –300 m.

- ***The Lehota- defritic-volcanic formation***

The Lehota geological formation lies above the Kos and consists of gravel, sands, sandy clays and clays with Mesozoic and carbonate material. In commonly used terminology it is referred to as a detritical-volcanic formation [Fazekas 2009, Zelenak 2003].

3 MATERIALS AND METHODS

3.1 *Bearing degasification*

Monitoring of the amount of methane concentration and related other degassing procedures of mining premises takes place in degassing stations [Act No. 51/1988].

Water-ring pump is used as a source of vacuum. Other elements of the station are related to the regulation of vacuum and flow volume, measurement of station parameters and sucked gas and extraction of water from degassed gas

Degassed gas may be used as fuel in the cogeneration unit. It thus allows combined production of heat and electricity in one installation, with fuel efficiency.

The system of degassing of mining premises is set up in a brown coal mine for the purpose of ensuring the safety of operation.

From the point of view of fulfilling the function of degassing and its localization in the mining environment, we divide the degassing into:

a) *Degassing from the surface;*
b) *Mining degassing.*

Mining degassing is divided according to the location of the degassing station:

c) *Surface (at central degassing),*
d) *Underground (in the detection of local),*
e) *Temporary on the surface.*

a) Degassing from the surface

When degassing from the surface, wells are drilled into the gas deposit, which drains the gas through its own overpressure in the deposit. This gas is directly or through a compression station connected to a consumer pipeline. In this way, future mining fields are degassed in the long run. Gas is rationally used in industry and there are significantly smaller problems with the gassing of workplaces.

b) Mining degassing

In mining the degassing means forced extraction of methane from mining works through pumps, while wells are led from mining works.

c) Surface (at central degassing)

Central mining degassing is a way of extracting gas from mountains and other sources, in which the degassing station is on the surface near the air shaft and all gas pipelines result centrally into a single degassing station. At the same time, these stations are pushing the degassed gas to the consumer.

d) Underground (in the detection of local)

Local degassing stations are located directly in the mine upstairs near the air shaft. They are set up to reduce the methane content of the mountain range only in a small part of the mine field, weighed on those mines where there haven't been problems with excessive gas releases until now.

These mines do not have a central degassing set up, because it would be inefficient for the entire mine field. Although the degassing station is set up upstairs, the gas outlet from the discharge side of the degassing station is guided by air shaft and then into the atmosphere. In this case, the exhaust pipes must lead to at least 3 m above the tallest building

e) Temporary on the surface

Very often, a temporary degassing station located on the surface is used when excavating new shafts on the surface. In this case, this station serves to take the gas from the mountain range outside the bottom of the extraction. The pump with electric motor is separated from the surveillance room, where there are control and measuring instruments. The detection station has a separate circulation of water brought out to the cooling micro tower with a concrete sleeve. Poor degassed gas is released into the atmosphere.

3.2 Degassing station

The degassing station consists of equipment complex used to create vacuum in the mine pipeline at such height that would overcome resistance to the movement of gas from the degassed well to the degassed station, creating the necessary vacuum in the well, which would cause the gas to flow from the mountain to the borehole. Vacuum means the pressure difference between the degassing station and the bottom of the well, where at no point in the pipeline the pressure can be higher than atmospheric pressure.

In the area of degassing, the detection station performs similar functions as the main mining fan. The requirements for continuous operation, reliability, must be similar to those of the main mining fan.

This also applies to the backup of operating pumps and their performance, power supply. Independently of the basic functions, the detection station often performs the function of compressor in the supply of gas to the public gas network.

The degassing station is a building made of non-combustible material, situated near the air shaft. As a rule, it is single-floored with basement. The dimensions of the building are designed according to the number of gas mixture pumps. In the basement there are pipes and cable wiring, pumps for running water and ventilation equipment in the building.

The ground floor is divided by a gas-permeable partition into two parts. In the space with the risk of explosion, water-ring pumps are located, including electric motors in a non-explosion design. The building of the degassing station should be located at a distance of at least 20 m from the nearest buildings. It must be fenced with a fence and a lockable gate.

Only personnel in charge of the plant are allowed to enter the building of the degassing station. A sufficient number of lightning rods (in accordance with the relevant standard according to the size of the object) shall be placed on the roof of the deactivation station to protect the entire area from possible lightning strikes.

In the control part of the degassing station are situated measuring and registration devices, a room for operation, social and hygienic equipment.

Since the measuring and recording devices are not in a non-combustible or spark-safe version, this part must be so furnished that the methane content does not exceed 0.25 %. To do this, there shall be continuous analysers in the room which, when this limit is reached, visually and acoustically alert the operator about the condition.

In order to monitor and thus influence the operation of the detection station and for reasons of safety of work, the following devices are placed in the control part:

• ring manometers, registration for measuring the quantity of gas mixture on the suction and discharge sides,
• recorder manucumeters with a U-manometer connected in parallel for the measurement of vacuum in the suction,
• recording manometer with a U-manometer connected in parallel to measure the pressure in the pipes behind the pumps
• point temperature recorder for measuring the temperature of the gas mixture behind the pumps,
• infra-analyser for measuring the methane content of the degassed mixture, ring manometers registered for measuring the quantity of gas mixture supplied to the consumer's network, recording manometers with parallel U-manometers for measuring the pressure of the gas mixture supplied.

In addition to the following devices monitored in the control part, other instruments shall be located at the measuring point:
• tubular U-mercury manometers, to measure ball cap resistance,
• manucumetres, for measuring vacuum intake of vacuum pumps
• manometers for pressure measurement, for measuring the water pressure on the supply to the vacuum pumps, for measuring the pressure of cold operating water at pump displacement or from the distribution, for water pressure on the cooled water filters and for measuring the pressure of the heated water discharged to the cooling tower,
• status marks to measure the level of the centrifugal separators,
• resistance status markers in the tank of warmed water,
• non-exploding manometers for measuring the water pressure on the supply to the outlet blockages,
• non-exploding capillary thermometers for measuring water temperature in centrifugal separators,
• glass thermometers for measuring the temperature of the gas mixture behind the pumps, the temperature of the cold water transported to the pumps and the temperature of the water pumped to the cooling tower.

An important device of the degassing station is to signal the decrease in the methane content of the transported mixture to 40; 35 and 30%. If the methane content is dropped to 35%, the supply of gas to the consumer must be stopped and the gas mixture is released into the atmosphere by the chimney. Continuous metanomers are located in the control part and in the machine part of the decay station.

3.3 Calculation of degassing station efficiency

In order to operate the degassing, in the rock environment we need:

• A degassing station which provides sufficient vacuum to suck the degassed mixture,
• The gas pipeline,
• Decay wells.

Its effectiveness is important in the operation of the degassing. We calculate it from the formula:

$$E_f = 100\frac{D_g}{E_x + D_g} \tag{1}$$

where:

E_f – the effectiveness, %,
D_g - amount of gas pumped by degassing, m^3/day,
E_x – amount of gas in mining winds dissuaded by ventilation, m^3/day.

The formula shows that the larger the volume of the degassed mixture, the higher the efficiency of the degassing. For each m^3 CH_4 that we exhale into the ventilated current, we must ensure 124 m^3 of wind to dilute the contents of CH_4 in the mining winds to 0.8% [Zelenak 2003].

3.4 Composition of mining gas

The present measurements have proved that during suction from existing degassed sources, CH_4 concentrations were between 32 up to 82%. In Table 2 the results of the measurement are on one of the degassed sources.

The concentration of methane during degassing of less rich sources is 6-11 % before treatment in the degassing station, with oxygen fluctuating between 10 to 14 %. A gas mixture with such parameters is explosive and is therefore adjusted to a methane value below 3 % before entering the vacuum source (by opening the circulation valve) or by mixing the gas mixture from a more substantial degassing source, the methane concentration at the output of the degassing system in this case is reaching values in the range of 27-45 %.

CH_4	CO_2	O_2	Flow	Vacuum	Displacement	CH_4^*
%	%	%	m^3/hour	kPa	kPa	
70	15	2.7	124	18	7	100

**Methan number*

Table 2. Results of measurements at the degassing source (Zelenák, 2003)

Taking into account the expected further processing of the methane mixture, a certain technological minimum of methane concentration (approx. 30 %) has to be observed because of its inexplosivenes. Increasing the energy value of the degassing gas is possible by means of membrane separation methods, which are well described in lit. [Bobak 2012, Isaac 2014, Sipek 2014, Kirchbachera 2018].

Pure methane is dangerous if it is mixed with air in volumetric concentrations of 5 to 15% [Varga 1999], which correspond to the flammability limits. According to Table 1, there is also an inert component of CO_2 in the degassing gas, which causes the flammability limits to shift. Modelling of the influence of inert components on the flammability limits of gas-air mixtures are described in more detail in [Kizek 2001].

4 RESULTS AND DISCUSSION

4.1 Presence of methane in coal deposits and their gaseousness

The presence of methane is in Handlova and Novaky coal deposits. Mining gases developed in the coal production process are less absorbed and adsorbed in coal mass. To a greater extent, they occur in seams and accompanying rocks. These are gases that fill cracks, breaks and layered areas in both coal and accompanying rocks.

The collector of methane accumulation is the maximum damaged part of the formation - interlayer, which, for example, on the Handlova deposits is represented by a base of tuffitic sandstones with a gradual transition to melaphyrical tuffites, where two to three seams with sufficient power of interlayer to melophyrical rocks are developed The collector of methane accumulation is the maximum damaged part of the formation - interlayer, which, for example, on the Handlova deposits is represented by a base of tuffitic sandstones with a gradual transition to melaphyrical tuffites, where two to three seams with sufficient power of interlayer to melophyrical rocks are developed.

The removal or discharge of large volumes of water from coal measures reduces in situ fluid pressure allowing natural gas to be released from the coal matrix. Increasing the connectivity of in situ fluids may lead to a reduction in resistivity of the targeted lithology. A correct assessment of such resistivity variations is of significant interest not only for the industry to optimize production and extraction well locations but also for the regulatory bodies, in which a desire for a reliable method for monitoring changes in subsurface fluid distribution allows sound risk assessment of potential environmental hazards [Rees 2016].

The relative gaseousness on deposits ranges from 2.0 to 7.0 m^3/t. Gas efficiency depends on how the safety of mining operations is handled.

As a rule, up to a relative gaseous value of 5 m^3/t, safety can be ensured in common ways, higher values require the extraction, so-called degassing of mining gas.

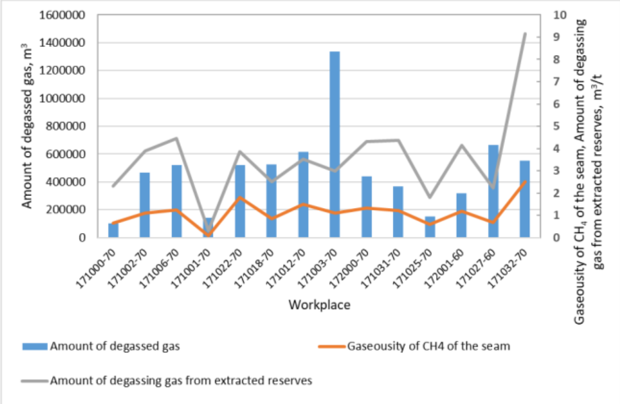

Figure 2. Dependence of degassed gas, gaseousity of CH_4 of the seam and amount of degassing gas from extracted reserves in dependence on the monitored workplaces (Adapted from [Fazekas 2009])

For the analysis of the degassing of mining sites, the obtained values from the brown coal-coal Horna Nitra mines during the reference period 2005-2007 were used. The results obtained are shown in the following illustrations.

Fig. 2 shows the amount of degassed gas from each workplace during the reference period. The figure also shows the gaseousness of methane from the seam as well as the amount of degassing gas from extracted reserves in the period considered, converted into a tonne of coal reserves extracted. By comparing workplaces, differences in the amount of degassed gas obtained can be observed.

The energy value of the gas obtained is recovered in the following Fig. 3. In this figure, the energy value is converted into pure methane, which we would obtain by separating the methane component from the degassed gas. From the methane content of the degassed gas, it can be observed that the lowest methane content is 27.32% and the maximum is 46.36% from the observed sites. By conversion to workplaces, the methane content of the degassed gas occurs on average 33.36%, which is already an interesting value from an energy point of view. The calorific value of the degassing gas also speaks more closely about the energy content. The average calorific value from the sites surveyed was 11.52 MJ/m^3 with a minimum value of 9.8 and a maximum of 16.64 MJ/m^3. Gaseous fuels are edible with such calorific value according to [Varga 1999] into a medium to very calorific group of gases. The calorific value of the decay gas has been converted only to the methane content of the degassing gas.

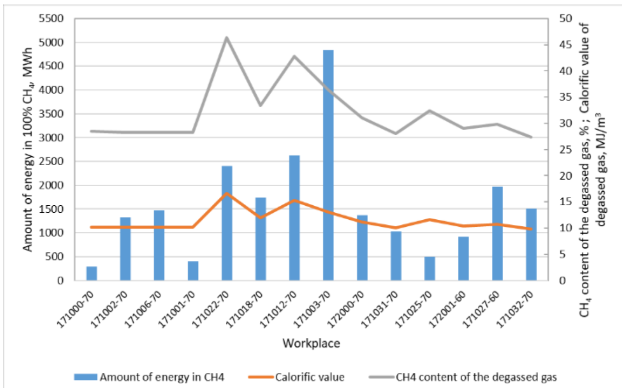

Figure 3. Amount of energy in 100% CH_4 in relation to the CH_4 content of the degassed gas and its calorific value in individual monitored workplaces (Adapted from [Fazekas 2009])

From Fig. 2 and Fig. 3 it can be concluded that there were workplaces with high gas richness in the monitored area, such as workplace 171003-70 as well as workplaces with low amounts of degassed gas (171000-70, 171001-70 and 171025-70). The detection equipment is set up mainly to ensure safety in the mining area and therefore such small quantities of degassed gas are also obtained.

The first issue of safety in the mining space can be solved by such degassing facilities. Another question arises directly with its energy value. How to use such gas? After cleaning such gas, the gas energy is usable directly in the cogeneration unit and the electricity obtained is usable for other purposes.

Another option is to use technologies for the separation of methane from gas, e.g. by means of membrane separators (this is mentioned below) and as pure methane to inject it into the gas distribution network or used for storage in CNG pressure facilities or LNG.

If we were to evaluate the deactivation gas from the point of view of pure methane, Fig. 3 shows the calculated amount of energy for each monitored workplace. The richest source of methane would again be the 171003-70 site, where increased amounts of methane in coal mining are expected to be released in the mining area. Over the period considered, 22362.35 MWh of energy could be obtained by separating pure methane from the degassed gas.

According to the presented results from individual workplaces, it can be stated that gas from degassing with its energy value is usable in industry [Yeromin 2015, Lazic 2011] in heating furnaces or for the production of electricity in cogeneration units.

4.2 Use of the gas in the cogeneration unit

The measured concentrations of CH_4 in the gas mixture on coal deposits of Horna Nitra mines show such parameters that they can be used in driving engines which use natural gas as a fuel or they are adapted for the usage of mining gas.

The average value of the calorific value of the degassed mixture from the monitored workplaces is 11.52 MJ/m^3, which represents a medium calorific gas [STN EN 15502-2-2, 2015].

In cogeneration units it is possible to use gaseous fuel with lower energy value [Kostur 2015] than in the case of gasification of biomass with separated waste [Kocanova 2014] and therefore degassing gas is even with increased content of inert components usable in the process of cogeneration.

Installed cogeneration units using degassed gas as fuel allow joint production of heat and electricity in one apparatus. This can achieve up to 40 % fuel efficiency and thus get electricity and heat significantly cheaper Fig. 4.

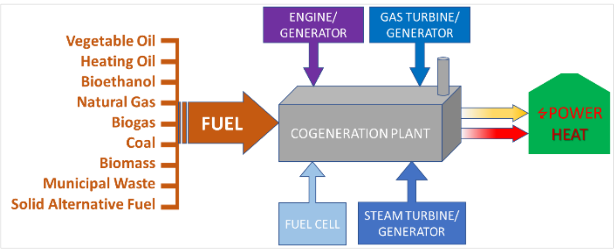

Figure 4. Energy saving in cogeneration unit (Adopted from [MDE 2021])

The cogeneration process is carried out in a cogeneration unit, where it includes a gas combustion engine that drives a three-phase generator. It generates electricity. Cooling the engine, oil and burned gases we can gain heat. In the case of cogeneration of mechanical energy and heat, the internal combustion engine directly drives the work equipment: in industry, these are often pumps, compressors or blowers [Variny 2019]. Such a source of mechanical energy can be an economically attractive replacement not only for an electric motor, but also for another power unit - such as a steam turbine, and thus contribute to reducing primary energy consumption and greenhouse gas emissions [Furda 2020, Variny 2020]. For the energy recovery of such poor gases, it is important to monitor their energy parameters as in [Travnicek 2020].

For the separation of the flammable component CH_4 and other components and water from the degassed gas, e.g. in the case of gas, it may be used for the separation of the flammable component of the CH_4 and other components and water from the degassed gas by using MemBrain technology.

In addition to membrane separation modules, MemBrain technology also includes technology for removing sulphate and water vapour from the mixture, which is pre-ranked by the separation process itself.

5 CONCLUSIONS

Mining gases, which are the output from the degassing of mining premises, are currently discharged into the air. Their economic and ecological appreciation can become an interesting source of alternative energy. The commissioning of a cogeneration unit can generate electricity and heat from mining gas, from an economic point of view, the economic benefits of this energy source and the period of return of the funds put into the purchase and commissioning of the technology are important. [Koraus 2021]. In particular, for the use of CH_4, it is necessary to have mapped existing degassed sources and know the parameters of the concentrations achieved in the gas mixture.

Coal seam degasification is an important practice for minable coal seams for two reasons; the first is its proven effectiveness in improving the safety of underground coal mines by reducing the risk of methane explosions through a reduction in coal gas content, and the second is the potential of utilizing produced methane as an unconventional energy source either as pipeline gas or to generate electricity at the mine site [Karacan 2011, Moore 2012].

The discharge of mining gases into the air is also subject to environmental control and air cleanliness, which is currently being given a great deal of attention. Slovakia, for example, committed to the Cooperative Programme for Monitoring and Evaluation of Remote Pollution Transmission in Europe- EMEP (Environment Monitoring and Evaluation Programme). It aims to monitor, model and evaluate the long-range transmission of pollutants in Europe [Malindzakova 2015].

The problem of degassing was intensively addressed in the 1990s. With the demands of reducing methane emissions, degassing is currently becoming a high-current energy and environmental topic.

ACKNOWLEDGMENTS

This article was supported by the state grant agency for supporting research work and co-financing the project KEGA 023TUKE-4/2021 and VEGA 1/0588/21.

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