Emisja metanu a koszt energii!
Biodegradacja metanu z powietrza wentylacyjnego w kopalni węgla kamiennego z wykorzystaniem bioreaktora KBT.

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Ekoinwentyka Ltd. and Compact Trickle Bed Bioreactors (CTBB)

- Air pollution treatment and own, innovative technology of air biopurification in CTBB.

- For all industry sectors with Volatile Organic Compounds (VOCs) and Odors (H_2S, NH_3) emission problem.

INTRODUCTION

● **Odor sources:** agricultural and industrial activities, animal farms, rendering plants, wastewater treatment plants, waste treatment or disposal facilities, paint shops, oil refineries, pulp and paper mills, mushroom farm, various chemical industries and copper – ore mine (KGHM S.A.) etc.

• ***VOCs and Odors are dangerous***

- impairment of the quality of the environment;
- interference with business activities
- Some odoros act as precursors of photochemical oxidation (formation of tropospheric ozone, occurrence of smog).
- harmful to health:
  - cause eye, nose, and throat irritation, damage to liver and kidney,
  - neurological damage

Methane (CH_4) - colorless and odorless gas, greenhouse gases GHG with a potency of 21–25 times more than carbon dioxide (CO2) in regard to its contribution to global warming

COP24 (2018) - aiming to achieve a reduction of GHG emissions

Industry MUST meet Strict Environmental Regulations

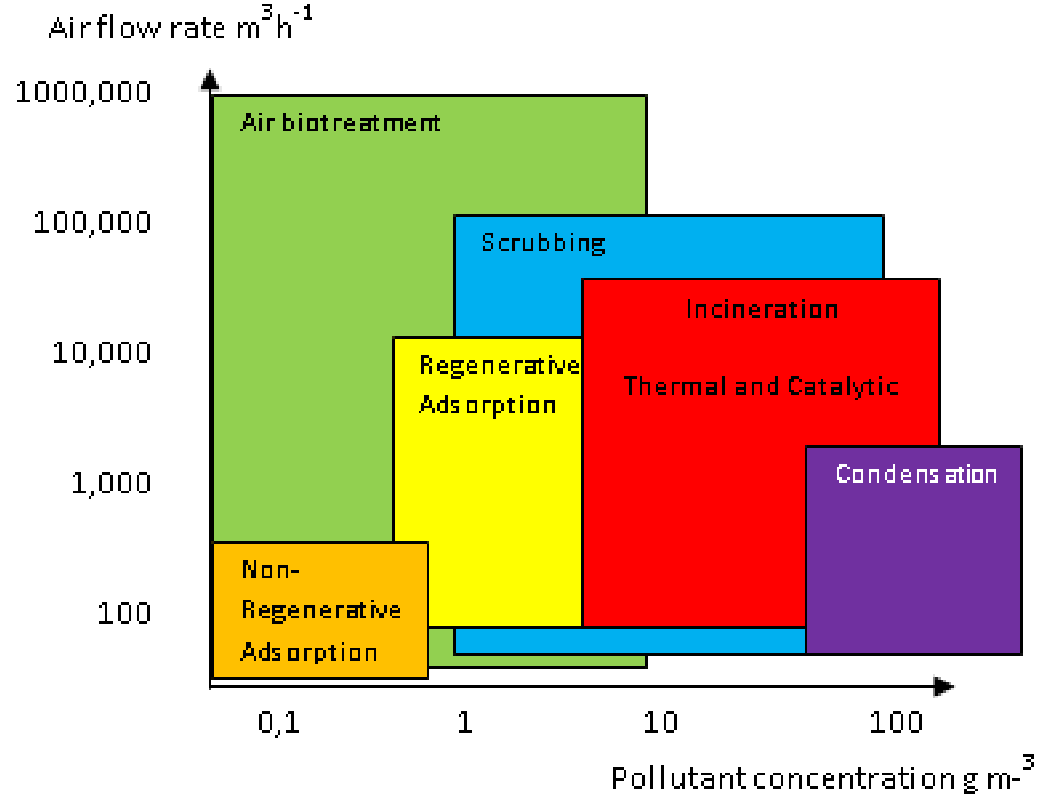
Big Penalties for Noncompliance

1. **Up to 500k EUR/ year Penalty**

If regulations are NOT met…

2. **Forced Plant Shutdown**

Comparison of existing technologies for VOCs and odors elimination.



Suitability of various air pollution control technologies. (after Deshusses, M.A., 2003/04)

Feature	OUR SOLUTION (Biopurification)	Current Alternatives
Risk for Explosion	✓ SOLVED	X HIGH RISK
Emission charges (NOX, CO2)	✓ SOLVED	X EXPENSIVE
ENERGY INTENSIVE	✓ 30 ^{0}C	400 – 800 ^{0}C (e.g.Combustion)
EXPENSIVE COMPONENTS	✓ ECONOMIC SOLUTION (microorganism)	Platinum Pt Active Carbon
Industrial Waste by Products	✓ SOLVED	X HIGH RISK
control of all process parameters	✓ SOLVED	X NO (old biofilters)
Acidification & oxidation of bed	✓ SOLVED	X NO (old biofilters)

Purpose and scope of research – work

CH_4:

- *In 2018, the coal sector in Poland was responsible for 33.8% of the country's total methane emissions*
- *Penalty Costs were estimated at 5,500-27,000 PLN (around 1200 – 6300 EUR) per ton of CH_4 emissions*
- *Emissions from ventilation shafts: **„Nowadays" technologie** (i.e. Ventilation Air Methane Oxidiser (VAMO)), which captures methane from the shafts and destroys it by oxidizing it to carbon dioxide.*

The investment cost *is approximately* ***PLN 60 million*** ***per 0.5 million m³/h****.*

Operating costs *are approximately PLN 1,000 per ton of methane emissions, which, given total methane emissions from thermal coal mining of 200,000 tons of CH_4, translates to approximately* ***PLN 200 million annually****.*

Acc. Metan zabija górników. Może też zadać ostateczny cios polskiemu górnictwu - WysokieNapiecie.pl

Purpose and scope of research – work.

- **Selected experimental results of an on-going project conducted by Ekoinwentyka Ltd.**

- **<u>Scope and Aims:</u>**

- investigate the best conditions for methane biodegradation in a biofiltration system treating ventilation air in a coal mine
- to design, test and apply a compact trickle-bed bioreactor (CTBB), fed continuously with mineral salt solution, to the biodegradation of methane and VOC mixture
- purification of methan and VOCs contained in the VENTILATION air in a real condition of COAL MINE INDUSTRY.

- **<u>Aims:</u>**

- to determine the ranges of parameters of CTBB reactor operation at which the tested microorganisms are most effective.
- Possible consequences of a fatal pollutant overload and the time required for regenerating the microorganisms and returning to stable process conditions.
- Creation of a database for technology upscaling to a selected industry (COAL MINE)

Methods - Presentation of equipment

Fig. 1 COAL MINE INDUSTRY: CTBB was implemented for the biodegradation of METHANE AND VOCs contained in the air

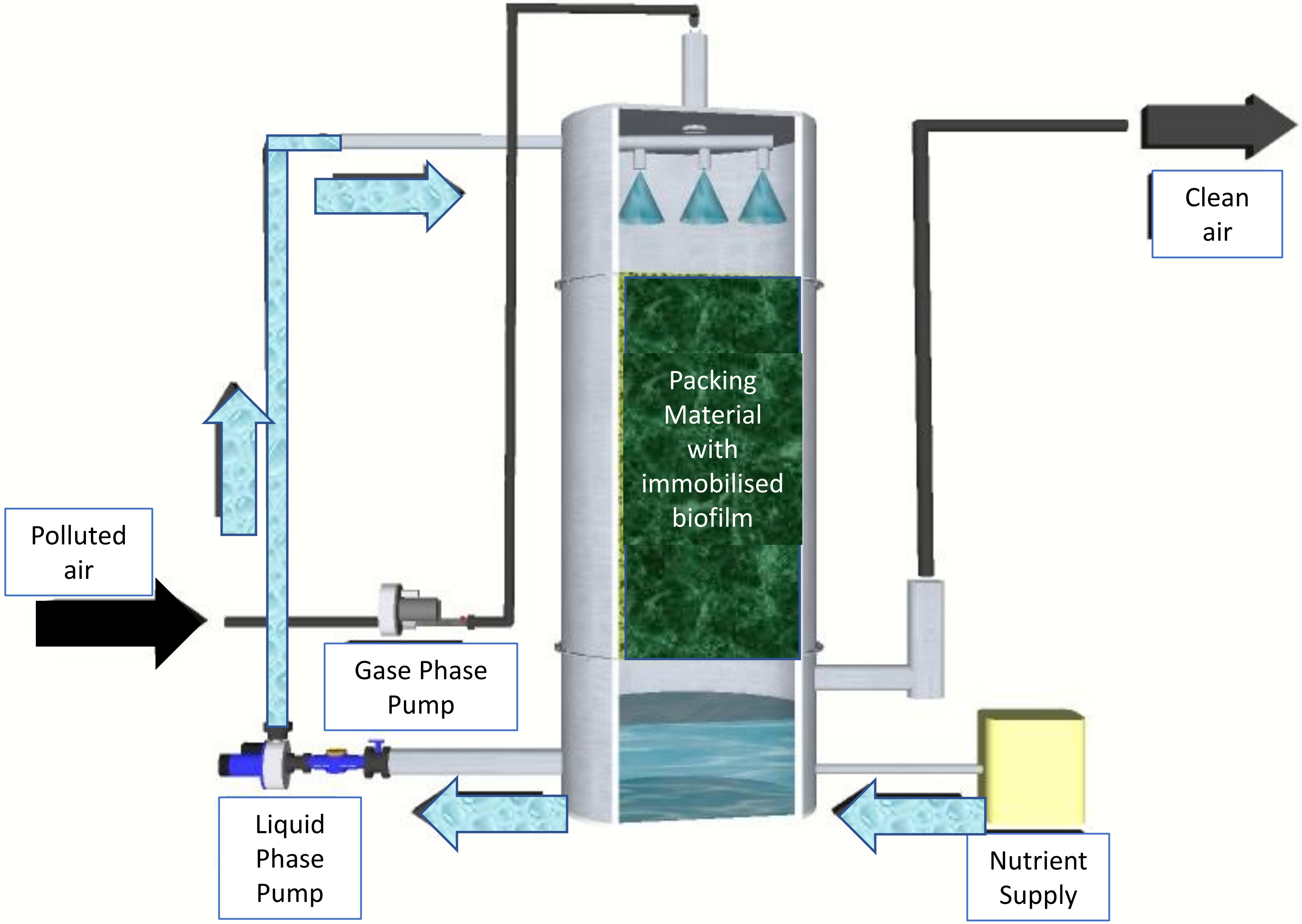


Fig. 2. CTBB diagram

Result and discussion

Nomenclature:

Measured:

$C_{g\ in}$, $C_{g\ out}$ – CH_4, VOC concentration at inlet and outlet

t_g - average gas residence time $t_g = V_r / V_g$

(V_r – empty bed volumeof the CTBB, V_g – gas phase flowrate)

pH - pH of the solution

Calculated:

Specific CH_4, VOC load L=$Ms = C_{gin} / t_g$

Specific elimination capacity $EC = (C_{gin} – C_{gout})/ t_g$

CH4, VOC, conversion degree RE=$K = [(C_{gin} – C_{gout})/ C_{gin}]·100\%$

Result and discussion

MICROORGANISM:

Ekoinwentyka Ltd. developed the bacterial consortium. The main microorganisms identified in the obtained inoculum were ***Pseudomonas fluorescens and Acidithiobacillus sp. P. fluorescens*** *(methanotrophic bacteria, also known as methane oxidizing bacteria or methanotrophs).*

These microorganisms oxidize methane successively to methanol, formaldehyde, formate and finally carbon dioxide:

$CH_4 \rightarrow CH_3OH \rightarrow HCHO \rightarrow HCOOH \rightarrow CO_2$

Tested process parameters

$T = 303 \pm 5$ K (~30 °C),

pH = 5.5 to 7.5,

Vg = 2–30 m^3/h.

VOC, CH4 Cg = 700- 3230 mg/m^3

Pollutant concentrations fluctuated randomly depending on the amounts of methane, NH_3, H_2S and VOCs emitted in the gas from the coal mining field.

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Result and discussion

Table 1. Bio-oxidation of CH_4 in different reactors with different inoculum and packing materials (Vergara-Fernandez et. al., 2017)

Reactor	Inoculum	Packing	LCH_4 ($g\ m^{-3}\ h^{-1}$)	EC_{max} ($g\ m^{-3}\ h^{-1}$)	Void fraction	Specific area (m^{-1})	$EC_{sp.}$ ($g\ m^{-2}\ h^{-1}$)
Biotrickling filter (multiphase)	Methanotrophic consortium isolated from WWTP	Polyurethane foam with 10 % (v/v) of silicon oil as nonaqueous phase	157 131	22 51	0.97 0.97	600 600	0.037 0.085
Biofilter	Leachate from methanotrophic biofilter	Expanded clay rock—5 mm rock—2 mm	23	5.0 10.5 17.3	0.55 0.40 0.37	470 1250 1360	0.010 0.008 0.013
Biofilter	Not specified	Gravel (4–8 mm)	25	14.5	0.40	8500	0.002
Biofilter	Indigenous microorganisms from the packing material	Compost	29	27.5	Not specified	Not specified	Not specified
Biocover	Not specified	Manure compost/ sawdust (9:1)	9	5	0.41	Not specified	Not specified
Biotrickling filter	Lixiviate from biofilter treating CH_4	Clay spheres polypropylene spheres stones	62	10 8 21	0.40 0.90 0.44	310 280 470	0.032 0.029 0.047
Biotrickling filter with recirculation of gas	Methanotrophic consortium isolated from WWTP	Polyurethane foam in cubes of 1 cm^3	230	30	Not specified	1000	0.030
Biotrickling filter	Methanotrophs type I (*Methylomicrobium album*) and type II (*Methylocystis* sp.)	Polyethylene rings (1 cm ID, 1.2 cm OD, 1 cm height)	23	6.2	0.77	316	0.019

In our tests, the CTBB showed good methane elimination capacity EC, up to 147 g/m^{3}h, which is several times than EC values displayed in Table 1

These data were the basis for comparison to the performance of CTBB bioreactor designed by Ekoinwentyka Ltd. and used for pilot tests at coal mine to bioeliminate methane from mine shaft exhaust gases.

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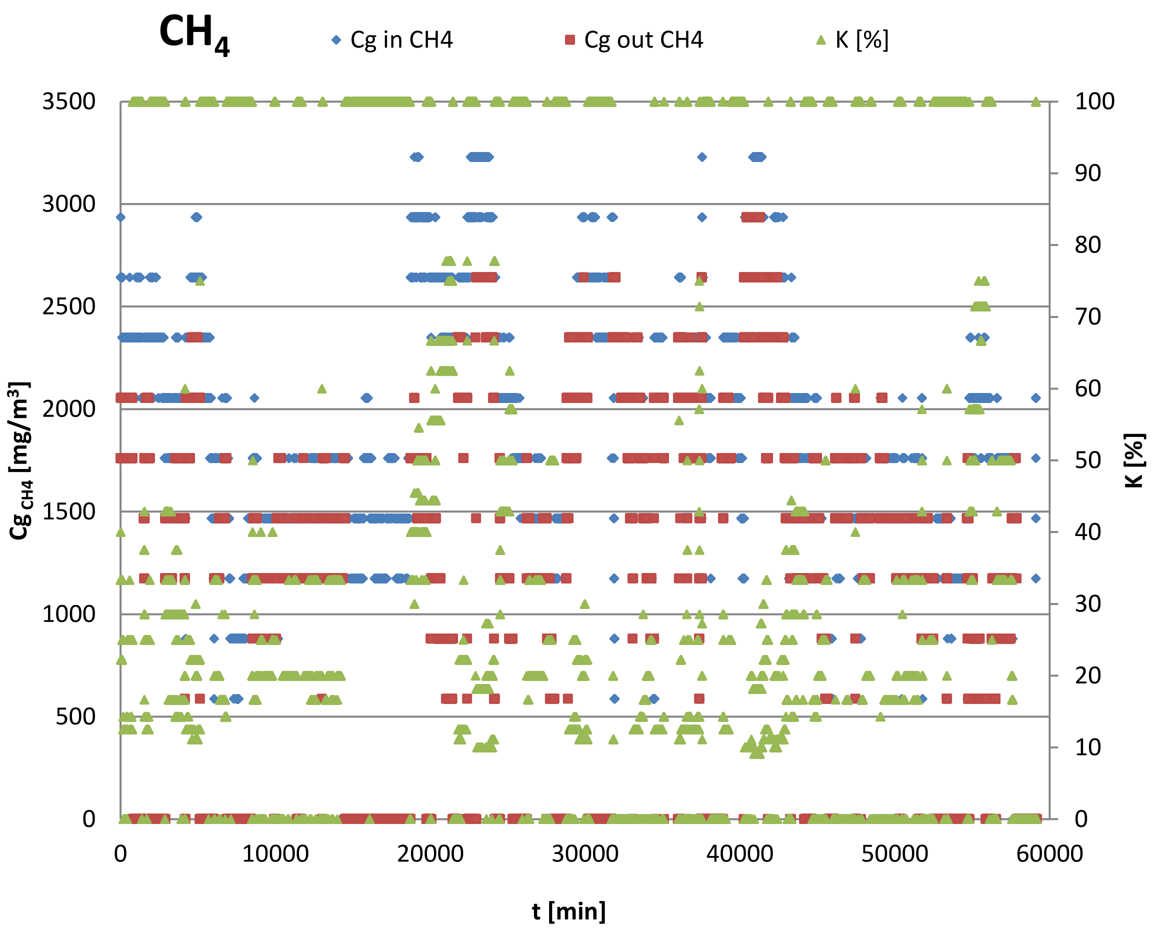

Figure 3. Results of CH_4 concentration variability [mg/m³] and CTBB operation efficiency in the period 06.09.2024 to 21.10.2024.

Table 2. Statistical distribution of CH_4 concentration present in the inlet gas to the CTBB during the entire test period, including the period of interruptions in the gas supply to the CTBB

Range of CH_4 gas inlet mg/m³	% of CH_4	Range of Cg in CH_4 mg/m³	% of CH_4
>3000	2.31	2000-3000	42.19
>2000	44.50	od 1000 do 2000	51.98
>1000	96.48	od 500 do 1000	3.52
>500	100.00	od 0 do 500	0.00
>0	100.00		

Result and discussion

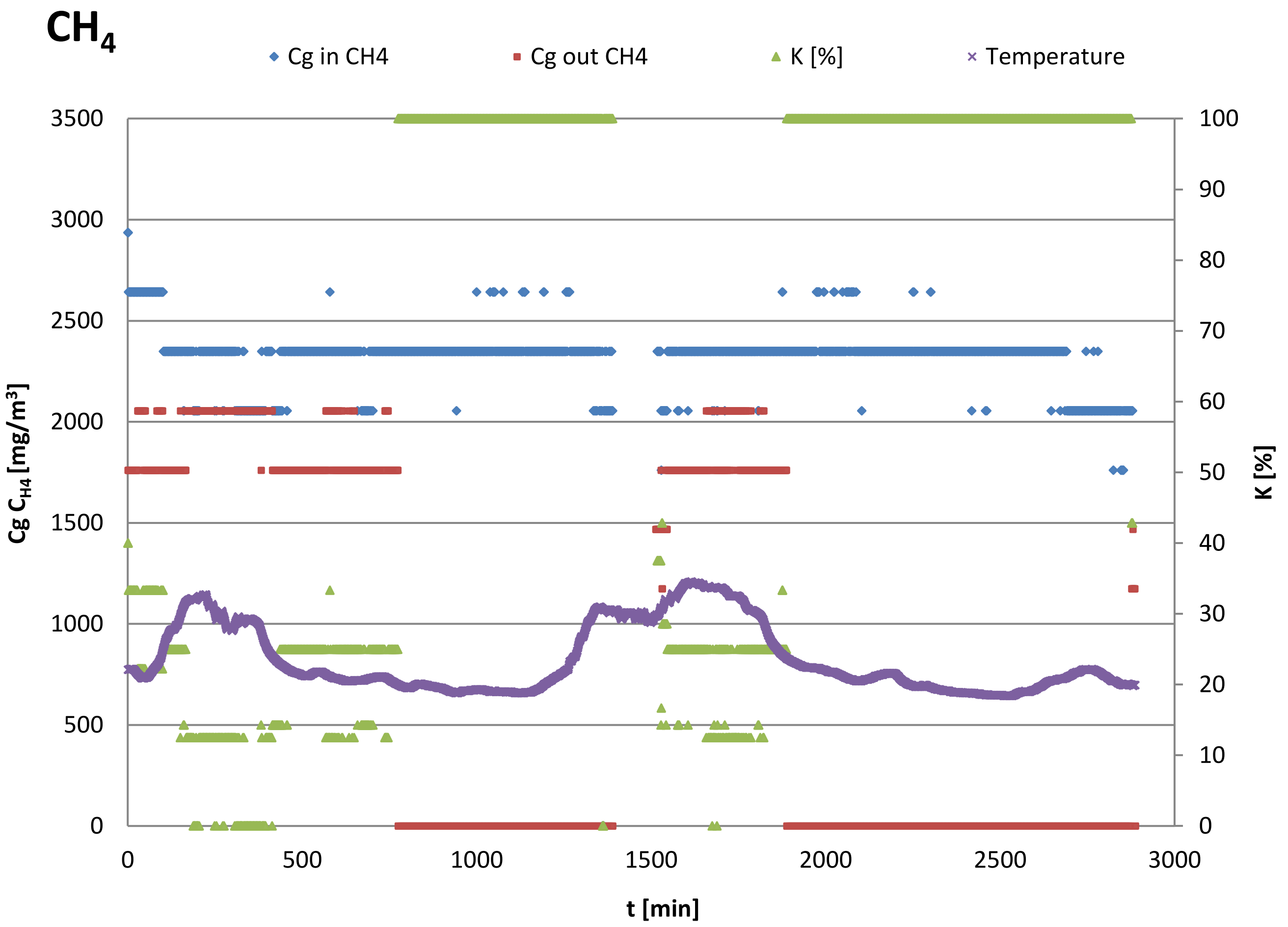

Fig. 4. Results of CH_4 concentration variability [mg/m^3] and CTBB operation efficiency in the period from 10/09/2024 to 12/09/2024.

Table 3. Statistical distribution of the average CH4 biodegradation efficiency depending on the CH4 concentration present in the inlet gas to the CTBB, over the entire test period.

Range of CH_4 inlet concentration [mg/m^3]	K [%]
0<Cg in<1000	70.44
1000<Cg in<1500	49.44
1500<Cg in<2000	46.93
2000<Cg in<2500	51.65
2500<Cg in<3000	44.08
3000<Cg in<3500	23.32

Result and discussion

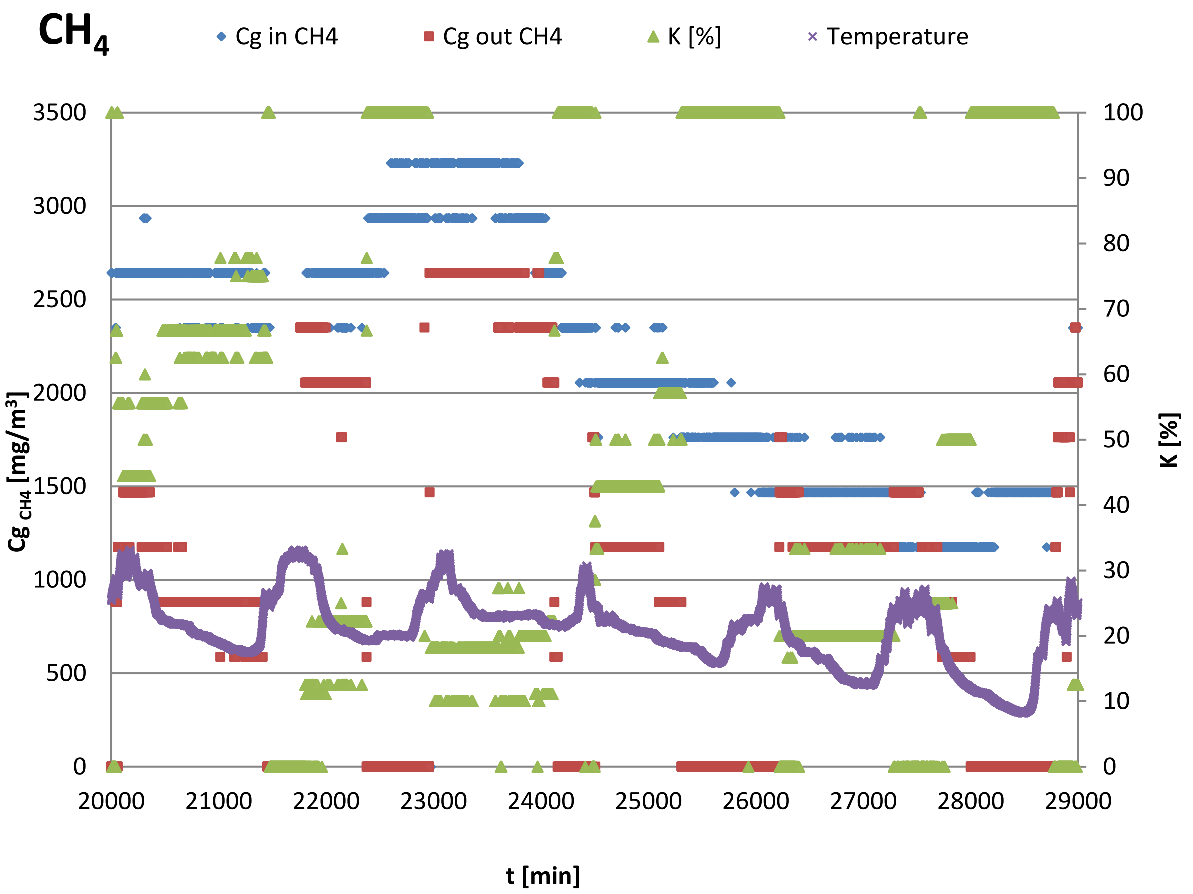

Fig.5. Results of CH4 concentration variability [mg/m³] and CTBB operation efficiency in the period from 24/09/2024 to 30/09/2024.

Table 4 presents the distribution of the efficiency of CH4 biodegradation in the CTBB reactor, depending on the temperature of the gases fed to the CTBB. The temperature of the gases fed to the CTBB was in the range from 8.2°C to 37°C.

Range of T [°C]	K [%]
0-10	74.9
10-15	67.8
15-20	55.21
20-25	53.19
25-30	62.21
30-37	74.2

while above the temperature T = 25°C it increases, reaching an average efficiency of K = 74.21% for the temperature range T = 30 - 37°C. The obtained results indicate that there are two levels limiting the biodegradation process - absorption and microorganism activity. The increase in CH4 biodegradation efficiency with a decrease in temperature <20°C is caused by the intensification of the absorption process of pollutants from the gas phase to the liquid phase. On the other hand, the increase in CH4 biodegradation efficiency with an increase in gas temperature >25°C is related to the increase in microorganism activity

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Result and discussion

Table 8. Measurement results obtained by CLPB on 18/10/2024

Cg in CH_4 [mg/m³]	Cg out CH_4 [mg/m³]	K [%]
1016.6	453.5	55.39
1319.6	900.2	31.78
1518.7	1352.5	10.94

independent research organization (Centralne Laboratorium Pomiarowo-Badawcze, CLPB)

It is worth noting that the CTBB pilot installation, in addition to CH4 biodegradation, eliminated other pollutants present in the mine exhaust air, reaching performance levels of:

- *Ethane – reduction rate of 51%,*
- *Ethylene – reduction rate of 33%,*
- *Propane – reduction rate of 56%,*
- *Acetylene – reduction rate of 71%,*
- *CO2 – reduction rate of 33%.*

In this context. the analyses performed by Ekoinwentyka on FID detectors indicated CH4 reduction values slightly lower (3-10%) than real ones due to the fact that as part of the CH4 reduction efficiency measurement, the said detectors indicated the elimination of VOCs (including ethane, ethylene, propane, acetylene, etc.). In estimating the future emission fees for CO2 emissions, the 3-10% margin can be seen as the added value of the tested CTBB technology (up to 33% CO2 reduction).

Conclusions

1. For the inlet gas temperature range of T = 0 – 10°C, the average CH_4 biopurification efficiency was K = 74.91%. It was observed that with the increase in gas temperature to T = 25°C, the biodegradation efficiency dropped to the level of average efficiency K = 53.20%, for the temperature range T = 20 - 25°C, while above the temperature T = 25°C it increased, reaching an average of K = 74.21% for the temperature range T = 30 - 37°C.
2. There are two factors limiting the biodegradation process – the rate of CH_4 absorption (Concentration of pollutant) and microorganism activity (temperature).
3. Conducting pilot-scale tests in real conditions at the coal mine facility create assumptions for upscaling and adapting the CTBB technology to a full industrial scale.
4. R&D research on the pilot installation (TRL VI) allowed for the identification of external factors (environmental, process parameter variability, administrative, etc.) which may affect the bio-purification process in CTBB under industrial conditions.
5. The research results served as a basis for assessing the installation's operation efficiency and allowed for the elimination of possible errors and the introduction of design changes allowing for the technological and economic optimization of the process

THANK YOU FOR YOUR ATTENTION!

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