Fundusze Europejskie Inteligentny Rozwój

Rzeczpospolita Polska

Narodowe Centrum Badań i Rozwoju

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Porównanie emisji, zużycia energii i wody pomiędzy bioreaktorami KBT a technologiami klasycznymi w procesie oczyszczania gazów z LZO i odorów: studium przypadku.

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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.

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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.

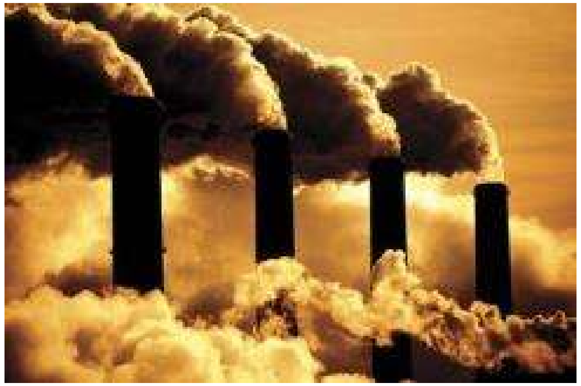
• ***VOCs and Odors are dangerous***

- 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

● **Odor abatement regulations: Industrial Emissions Directive (IED) 2010/75/EU of the European Parliament**

Industry MUST meet Strict Environmental Regulations

Big Penalties for Noncompliance

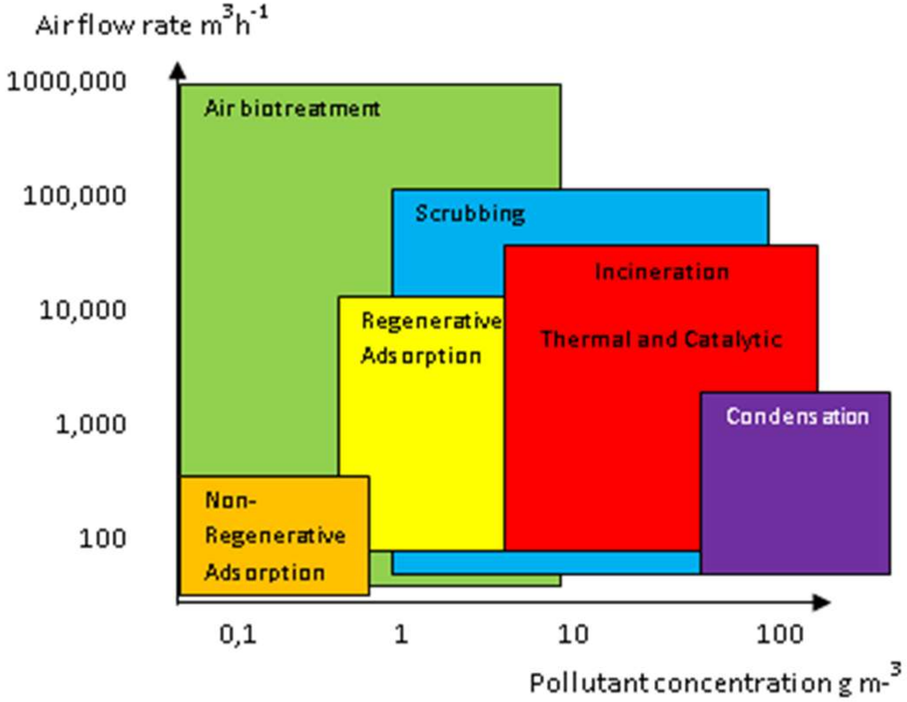


1. **Up to 500k EUR/ year Penalty**

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 °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.

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

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

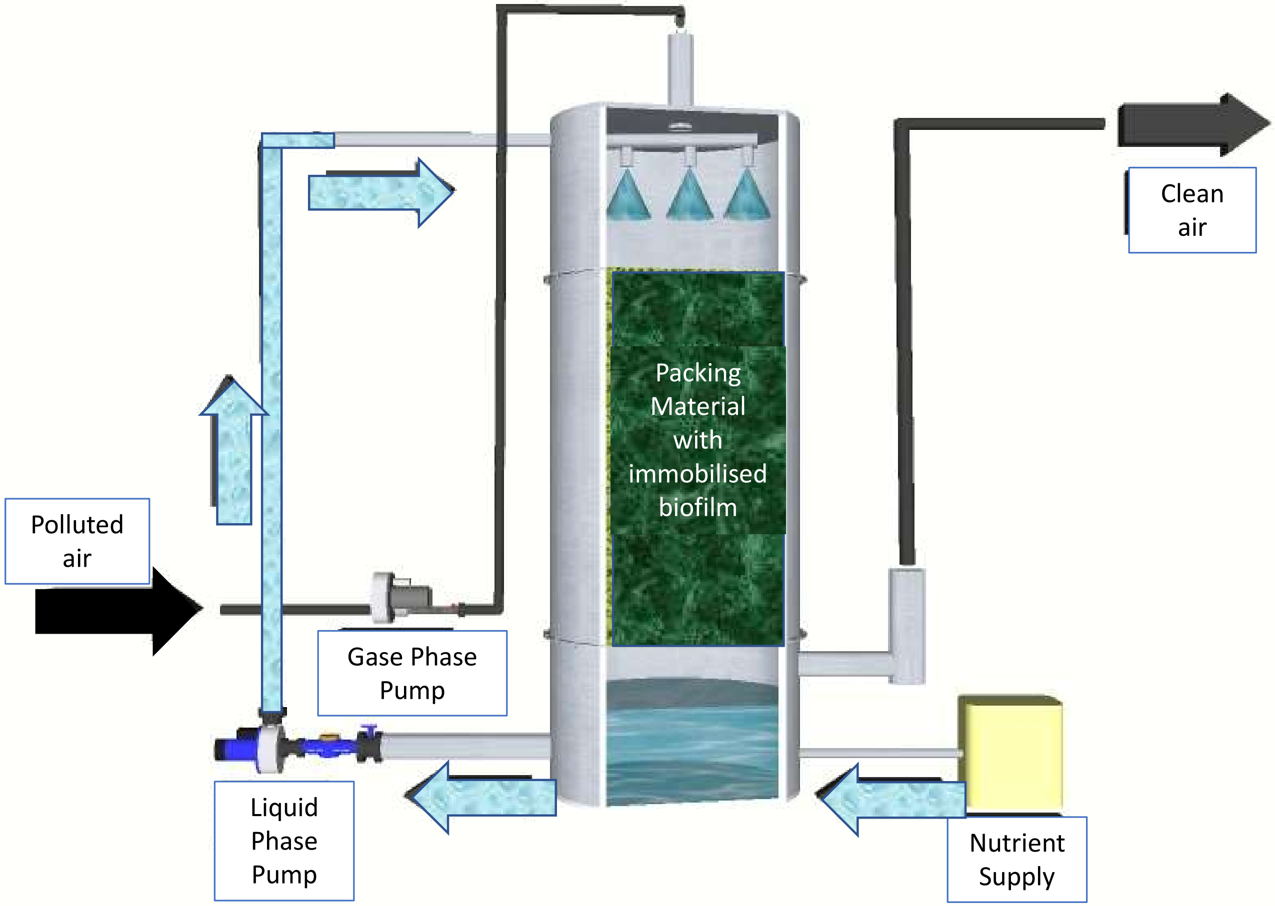
- This study used the operational data of an industrial-scale compact trickle bed bioreactor (CTBB) installed in the automotive painting industry by Ekoinwentyka Ltd. for biodegradation of (VOCs).
- The comprehensive data utilized in the present study encompassed critical process variables, including flow rates, water consumption, temperature profiles, and energy consumption. All these data were collected from the same industry, ensuring a robust and representative basis for our analysis.

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

- (i) to compare the energy consumption, water consumption, and emissions generation of CTBB with those of traditional technologies, namely direct combustion and catalytic combustion,
- (ii) to identify possible green energy alternatives for those technologies and assess their environmental impact,
- (iii) to assess through various parameters which green energy solution is the most feasible and sustainable for the studied technologies.

Methods - Presentation of equipment

PAINTING INDUSTRY: CTBB was implemented for the biodegradation of VOCs contained in the air



CTBB diagram

Result and discussion

Nomenclature:

Measured and assumption:

- $C_{g\ in}$ = 300 mg/m^3 – VOC concentration at inlet
- V_g – 10 000 m^3/h gas phase flowrate,
- V_l – 30-90 m^3/h - liquid flowrate
- T_i *- 20 ℃ i 25 ℃ - initial temperature of gas (winter, summer)*
- T_0 *- 20 ℃, 400 ℃, 800 ℃ - operational temperatur of gas (CTBB, catalytic and direct cumbustion)*
- The natural-gas-fired boiler with a heat input <29,300 kW was considered as the main system for the energy production in the combustion processes, and the calculations were done through the United States Environmental Protection Agency (EPA)
- All CO_2 emission factors consider that 100 % of the fuel carbon content is oxidized to CO_2, as recommended by the Intergovernmental Panel on Climate Change (IPCC)

Result and discussion

Calculated:

Energy consumption [kJ/h] for each technology was calculated by considering the energy required to heat the incoming airflow rate Q [m3/h] from the initial Ti to the operational temperature To

$$Energy\ consumption = \text{Air density} \times \text{c} \times (T_0 - T_i) \times \text{Q}$$

$$\text{Methane requirement} = \frac{Energy\ consumption}{LHV \times Density \times Efficiency}$$

Where: LHV [kJ/kg] = lower heating value of methane, Density [kg/m^3]= density of methane, Efficiency [-] = efficiency of methane combustion.

$$\text{Emissions} = \text{Fuel} \times \text{HHV} \times \text{EF}_2$$

Where: Emissions = Mass of CO_2, CH_4, or N_2O emitted, Fuel = Mass or volume of fuel combusted, HHV = Fuel Higher Heating Value, EF_2 = Mass of CO_2, CH_4, or N_2O emission factor per energy unit

$$\text{Energy produced} = \text{VOC produced} \times \text{VOC heating value}$$

Energy produced [kJ/d] from VOC produced [kg/d] at known VOC heating value [kJ/kg]

Result and discussion - Energy consumption

Table 1. Comparison of the energy requirement and consumption of the three technologies: CTBB, catalytic combustion, and direct combustion, for air flow rate of 10,000 m^3/h and a 300 mg/m^3 VOC concentration at the inlet

Technology	Energy requirements [GJ/d]		Daily energy consumption [MWh/d]		Seasonal energy consumption [MWh]		Annual energy consumption [MWh]
	Winter	Summer	Winter	Summer	Winter	Summer	
CTBB	1.5	0.0	0.4	0.0	72.5	0.0	72.5
Catalytic combustion	110.3	107.0	30.6	29.7	5513.1	5350.1	10863.2
Direct combustion	226.3	221.1	62.8	61.4	11316.3	11056.9	22373.3

Result and discussion - Energy consumption

Technology	Energy required	Methane needed	
	MJ/d	kg/yr	m^3/yr
CTBB	715	7,000	10,600
Catalytic combustion (400 °C)	107,144	1,042,870	1,587,330
Combustion (800 °C)	220,668	2147840	3,269,160

Table 2. Comparison of methane needed for the three technologies according to their energy requirements at an air flow of 10,000 m^3/h

Comparison between methane and electricity consumption from an economic perspective – CTBB in Poland.

Item	Value	Unit
Energy required per year	72,541	kWh
Methane required per year	7000	kg
Annual cost of natural gas	33,153	PLN
	7450	EUR
Annual cost of electricity	56,945	PLN
	12,797	EUR

Table 3. Costs of methane and electricity for CTBB for airflow rate of 10,000 m^3/h

Result and discussion - Emissions generation

Generation of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) represented as CO2eq emissions

Technology	Emissions [t/yr.]					
	CO_2	NO_x	PM	SO_2	CO	VOC
CTBB	17	0.014	0.001	0.000	0.012	0.001
Catalytic combustion	2574	2.155	0.164	0.013	1.810	0.119
Direct combustion	5302	4.439	0.337	0.027	3.728	0.244

Table 4. Emissions of CO2, NOx, PM, SO2, CO, and VOC due to the use of methane as a fuel for the treatment of airflow of 10,000 m^3/h in CTBB, catalytic combustion, and direct combustion

Generation of nitrogen oxides (NOx), particulate matter (PM), sulfur dioxide (SO2), carbon monoxide (CO), and (VOC).

Technology	CO_2 [t CO_2/yr]	NO_x [µg/m³ yr]	VOCs [mg/m³ yr]	SO_2 [µg/m³ yr]	CO [mg/m³ yr]	PM [µg/m³ yr]
CTBB	55	5,286	0.29	32	4	402
Catalytic combustion	2,648	253,067	13.92	1,518	213	19,233
Direct combustion	5,413	517,367	28.46	3,104	435	39,320

Table 5. Comparison of air emissions (CO2, NOx, VOCs, SO2, CO and PM) of each technology

Result and discussion - Alternative energy sources

Volatile organic compounds (VOCs) as alternative fuel.

- The heating value of VOCs for the specific composition used in this study was estimated to be approximately 33,000 kJ/kg.

	VOC concentration [mg/m^3]		
	300	600	1,000
VOC produced [kg/h]	3	6	10
Energy produced from VOC [MJ/d]	2,365	4,730	7,884

Table 6. Energy production from VOCs of different concentrations for air flow rate of 10,000 m^3/h

Result and discussion - Alternative energy sources – cost analysis

Price component	Electricity	Methane	Solar	Wind	Green hydrogen
Energy production [PLN/MWh]	785	200	335	295	506
Excise duty [PLN/MWh]	5	5	0	0	0
Total incl. VAT [PLN/MWh]	971	251	412	363	622

Table 7. Price of energy production, excise duty, and total price (including 23% VAT) for electricity, methane, solar energy, wind energy, and green hydrogen

Technology	Energy required per year [kWh]	Cost of energy per year [PLN]				
		Electricity	Methane	Solar	Wind	Green hydrogen
CTBB	73,325	71,165	18,418	30,213	26,606	45,606
Catalytic combustion	11,072,045	10,745,973	2,781,044	4,562,236	4,017,491	6,886,480
Direct combustion	22,804,013	22,132,435	5,727,846	9,396,393	8,274,436	14,183,412

Table 8. Annual cost of energy production necessary to heat 10,000 m^3/h of air in CTBB, catalytic combustion, and direct combustion reactor

Result and discussion - Environmental Impact Assessment - Health and Social Impact Assessment

Technology	Energy required per year [kWh]	Emissions generated per year [t CO_2eq]				
		Electricity	Methane	Solar	Wind	Green hydrogen
CTBB	73,325	46.928	3.252	0.624	0.122	0
Catalytic combustion	11,072,045	7,086.108	491.067	94.245	18.424	0
Direct combustion	22,804,013	14,594.568	1,011.404	194.108	37.946	0

Table 9.Yearly tCO2-equivalent emissions produced by each form of energy generation, for an airflow rate of 10,000 m3/h within a CTBB, catalytic combustion, and direct combustion reactors

Conclusions

1. **This research presents a comprehensive and in-depth analysis of three distinct technologies employed for the treatment of VOCs emissions: CTBB, direct combustion, and catalytic combustion.**

2. **Direct thermal combustion methods, including thermal and catalytic oxidation, exhibit 308 and 150 times higher energy demands, respectively, compared to CTBB, despite their lower water consumption, due to the need for elevated temperatures to facilitate efficient VOC removal.**

3. **Additionally, lower outflow concentrations of CO_2, PM, NO_x, SO_2, CO, and VOCs indicate the CTBB's superior environmental performance compared to catalytic and direct combustion systems.**

4. **This reduction lessens the environmental impact and reduces emission fees for industries.**

5. **Further research and development in this area are needed to enhance the capacity of CTBB to handle inlet VOC concentrations higher than 250 ppm. The research also emphasizes the significance of exploring green energy alternatives for enhanced sustainability. Among these alternatives, solar energy and green hydrogen emerge as promising and clean energy sources, offering potential economic and environmental advantages.**

THANK YOU FOR YOUR ATTENTION!

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Biotechnology makes a difference!