



Direct corona treatment of industrial composting waste gases

Dr. Hab. Ing. Marcin Hołub

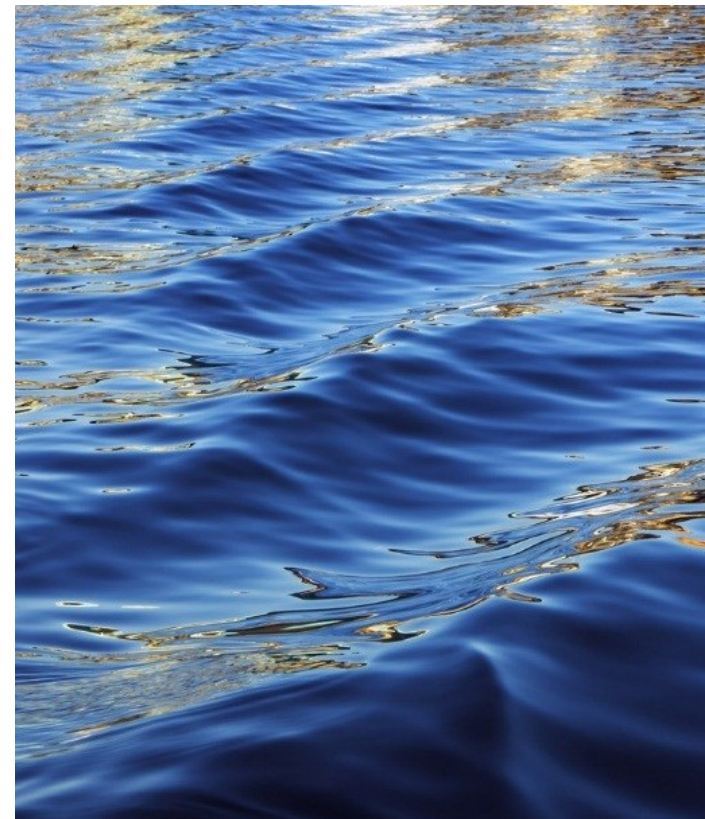
Professor of the West Pomeranian University of Technology, Szczecin

J. Kołek

New trends for plasma-based innovation for environment



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Air quality – background of the research

ZAGROŻENIA DLA ŚRODOWISKA NATURALNEGO

Jakie są najważniejsze problemy środowiska naturalnego w Polsce?



1886	Olfactometer construction - Zwaardemaker (Netherlands)
1972	Offensive odour Control Law (Japan)
1986	Standard NF X 43-101 (France)
1987	Standard VDI 3881 Blatt 1 (Germany)
1992	Working Group WG 2 Odour (Netherlands)
1995	Standard NVN 2820 (Netherlands)
2002	Construction Field Olfactometer Nasal Ranger (USA)
2003	Standard EN 13725 (Europe) (USA)
2004	Nobel Prize for developing the theory of operation of the sense of smell (USA)
2005	New Odour Prevention Act (South Korea)
2006	Standard PN-EN 13725 (Poland)
2007	The concept of odour-hour the guideline VDI 3940 (Germany)
2008	The first draft law on the prevention of odor nuisance (Poland)
2012	Ambient air quality standards - odorous compounds (Saudi Arabia)
2013	Clean Air Law (Israel)
2015	Guide of good practices related to odour management in Alberta (Canada)
2016	Maximum concentration odours limit (China)

Source: Wysocka, Izabela, Jacek Gębicki, and Jacek Namieśnik. "Technologies for deodorization of malodorous gases." Environmental Science and Pollution Research (2019): 1-26.

Contents:

Plasma reactor
types and
treatment
methods

Plasma – discharge reactors

Plasma – Direct, Indirect, Hybrid

Experiments
on a
composting
facility

Composting facility Goleniów WWTP

Plasma System and power supply

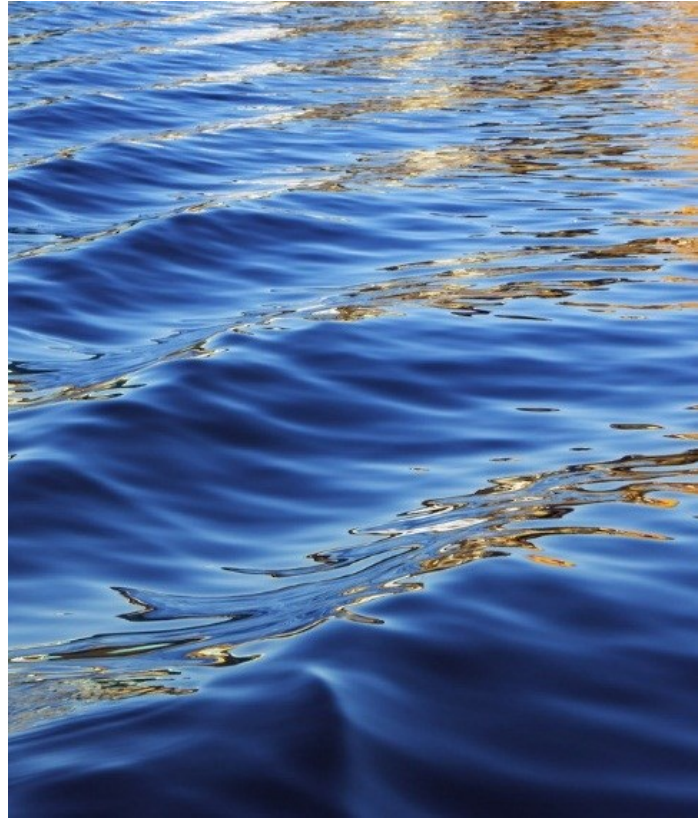
Results

Summary

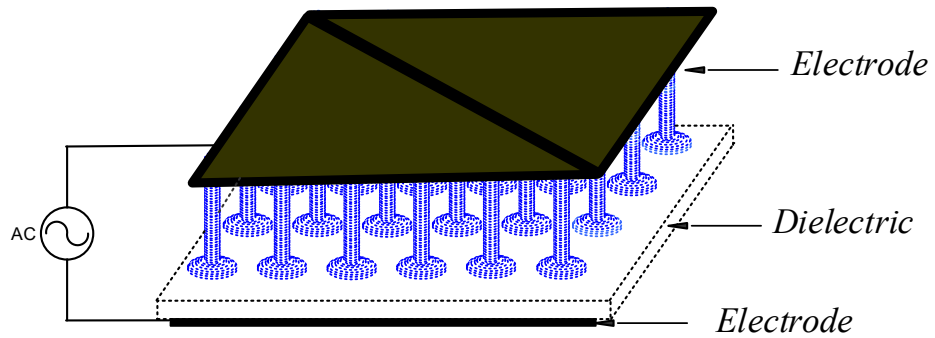




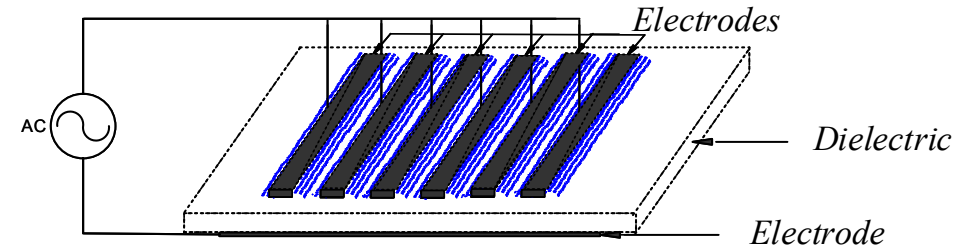
I. Plasma reactor types and treatment methods



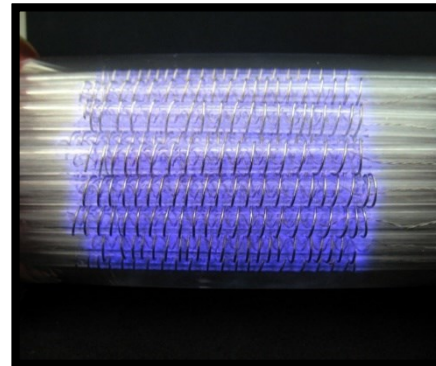
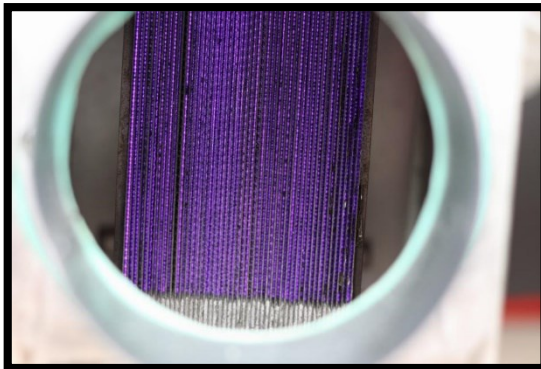
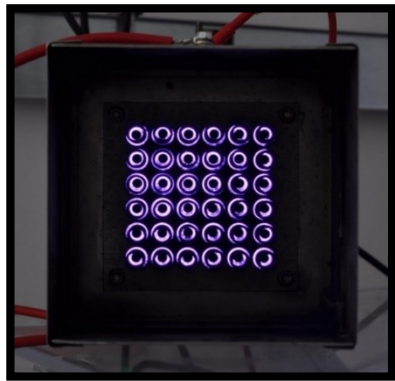
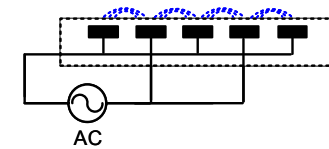
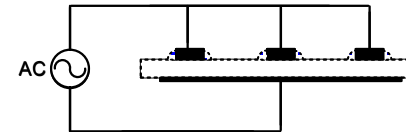
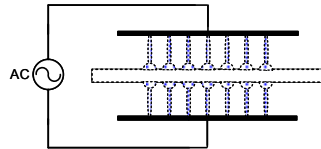
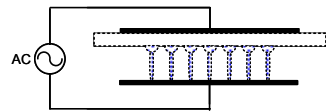
Discharge (reactor) types



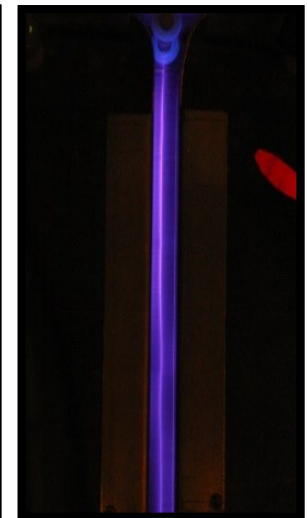
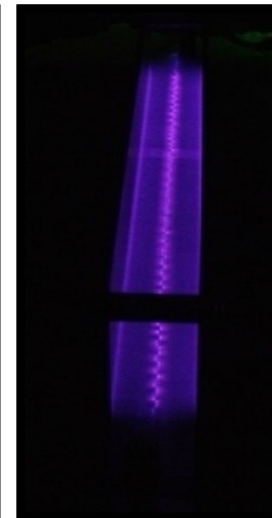
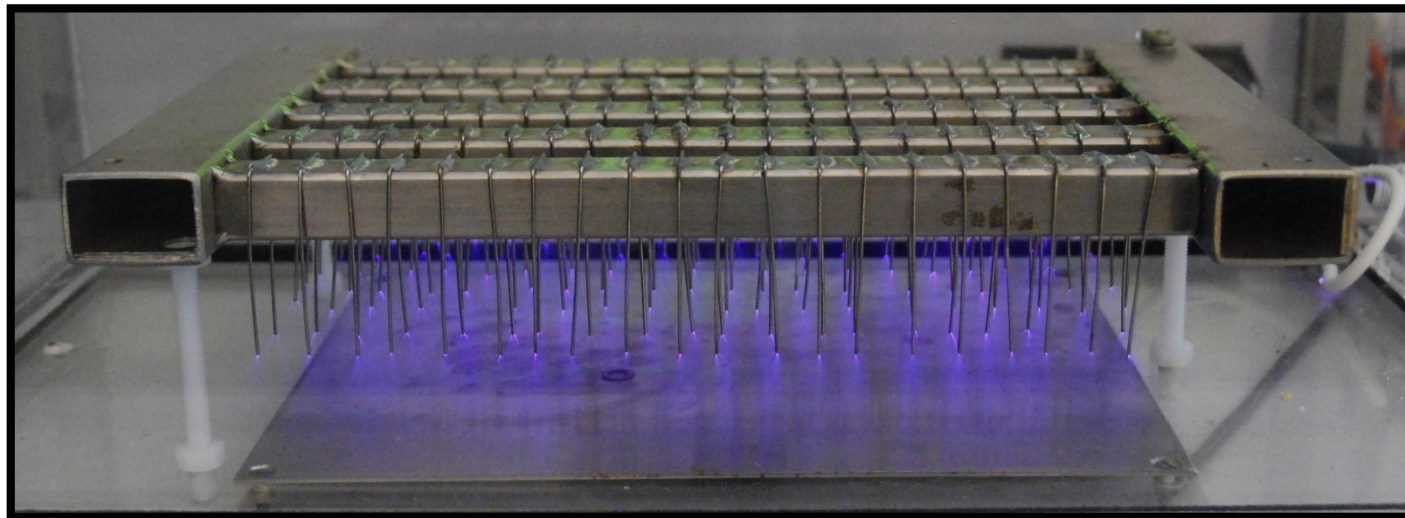
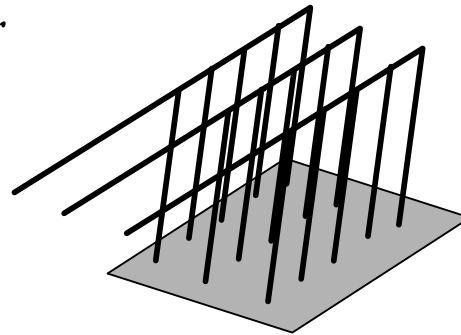
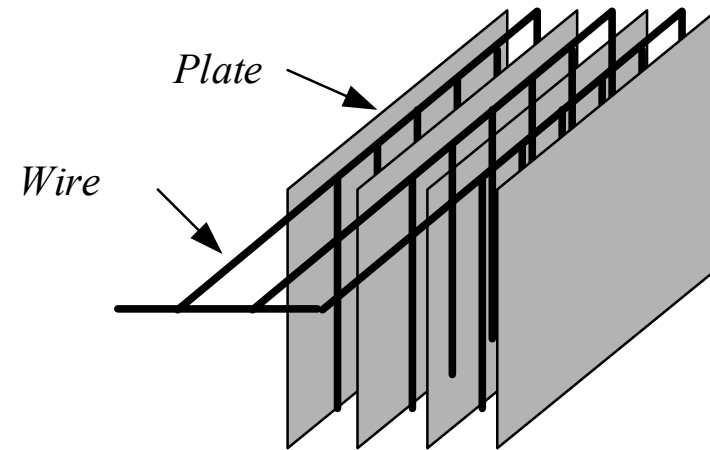
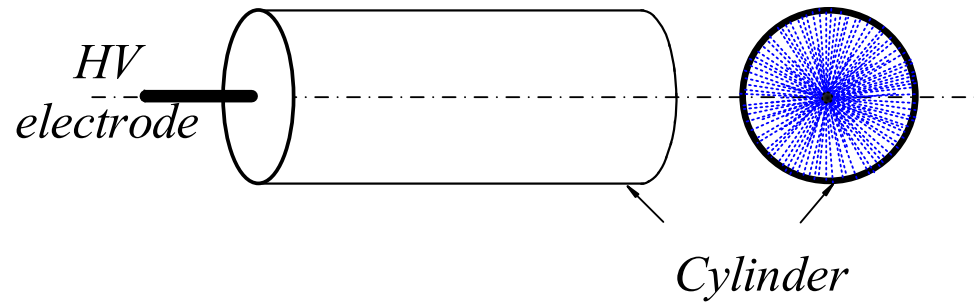
Volume barrier discharge (VD)



Surface barrier discharge (SD)



Discharge (reactor) types



Electron Energy

Average Electron Energy: 5-15eV

A. S. Gibson, J. A. Riouset, i V. P. Pasko,
„Minimum Breakdown Voltages for
Corona Discharge in Cylindrical and
Spherical Geometries”, nr 1.

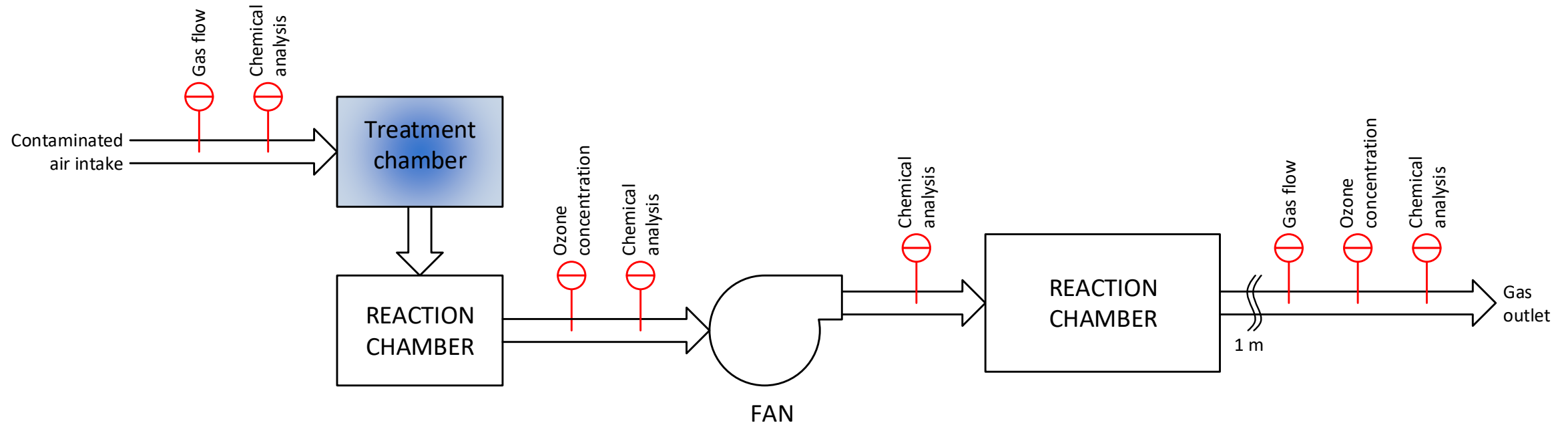
TABLE I CHEMICAL COMPOUNDS AMENABLE TO TREATMENT BY AIR IONIZATION			
	Chemical	Formula	IE, eV
1.	Phenanthrene	C ₁₄ H ₁₀	7.89
2.	Pinene, α-	C ₈ H ₁₉	8.07
3.	Naphthalene	C ₁₀ H ₈	8.14
4.	Trimethylbenzene, 1,2,4-	C ₉ H ₁₂	8.27
5.	Limonene (1-Pentene)	C ₁₀ H ₁₆	8.3
6.	Xylene, p-	C ₈ H ₁₀	8.44
7.	Styrene	C ₈ H ₈	8.46
8.	Xylene, o-, m-	C ₈ H ₁₀	8.55
9.	Ethyl Benzene	C ₈ H ₁₀	8.77
10.	Toluene	C ₇ H ₈	8.83
11.	Cyclohexene	C ₆ H ₁₀	8.95
12.	Chlorobenzene	C ₆ H ₅ Cl	9.07
13.	Benzene	C ₆ H ₆	9.24
14.	Nitric Oxide	NO	9.26
15.	Tetrachloroethylene	C ₂ Cl ₄	9.33
16.	Trichloroethylene	C ₂ HCl ₃	9.46
17.	Methyl Ethyl Ketone	C ₃ H ₈ O	9.52
18.	Nitrogen Dioxide	NO ₂	9.59
19.	Dichloroethylene, trans-1,2-	C ₂ H ₂ Cl ₂	9.64
20.	Octane	C ₈ H ₁₈	9.80
21.	Cyclohexane	C ₆ H ₁₂	9.88
22.	Butyl Acetate, n-	C ₆ H ₁₂ O ₂	9.92
23.	Heptane, n-	C ₇ H ₁₆	9.93
24.	Ammonia	NH ₃	10.07
25.	Hexane, n-	C ₆ H ₁₄	10.13
26.	Acetaldehyde	CH ₃ CHO	10.23
27.	Methyl Acetate	C ₃ H ₆ O ₂	10.25
28.	Pentane, n-	C ₅ H ₁₂	10.28

29.	Hydrogen Sulfide	H ₂ S	10.46
30.	Ethyl Alcohol	C ₂ H ₅ OH	10.48
31.	Ethylene	C ₂ H ₄	10.51
32.	Butane	C ₄ H ₁₀	10.53
33.	Methyl Alcohol	CH ₄ O	10.84
34.	Formaldehyde	CH ₂ O	10.88
35.	Trichloroethane, 1,1,1-	C ₂ H ₃ Cl ₃	11.0
36.	Trichloroethane, 1,1,2-	C ₂ H ₃ Cl ₃	11.0
37.	Carbonyl Sulfide	COS	11.18
38.	Phosgene	COCl ₂	11.2
39.	Halon FC 12-B	CClBrF ₂	11.21
40.	Methyl Chloride	CH ₃ Cl	11.26
41.	Methylene Chloride	CH ₂ Cl ₂	11.33
42.	Tetrachloromethane	CCl ₄	11.47
43.	Ethane	C ₂ H ₆	11.52
44.	Nitric Acid	HNO ₃	11.95
45.	CFC-113	C ₂ Cl ₃ F ₃	11.99
46.	CFC-12	CCl ₂ F ₂	12.0
47.	Oxygen	O ₂	12.07
48.	Methyl Cyanide	C ₂ H ₃ N	12.20
49.	Sulfur Dioxide	O ₂ S	12.35
50.	Sulfuric Acid	H ₂ O ₄ S	12.40
51.	Ozone	O ₃	12.53
52.	Methane	CH ₄	12.61
53.	Water	H ₂ O	12.62
54.	Hydrogen Chloride	HCl	12.74
55.	Nitrous Oxide	N ₂ O	12.89
56.	Hexafluoroethane	C ₂ F ₆	13.6
57.	Hydrogen Cyanide	HCN	13.60
58.	Carbon Dioxide	CO ₂	13.78
59.	Carbon Monoxide	CO	14.01
60.	Nitrogen	N ₂	15.58

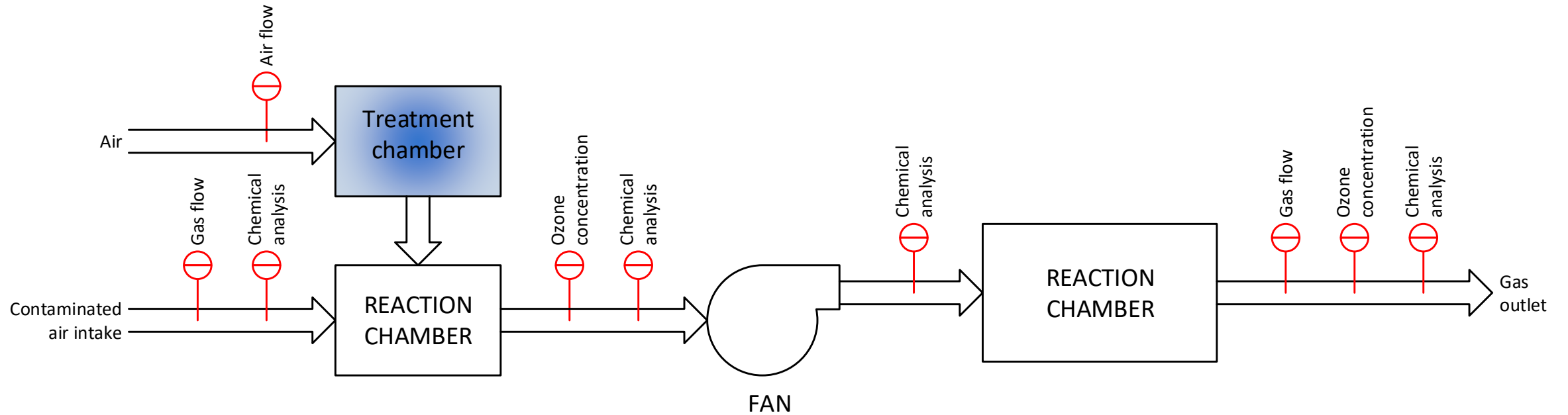
S. L. Daniels, „«On the ionization of air for removal of noxious effluvia» (air ionization of indoor environments for control of volatile and particulate contaminants with nonthermal plasmas generated by dielectric-barrier discharge)”, *IEEE Trans. Plasma Sci.*, t. 30, nr 4 I, ss. 1471–1481, 2002.



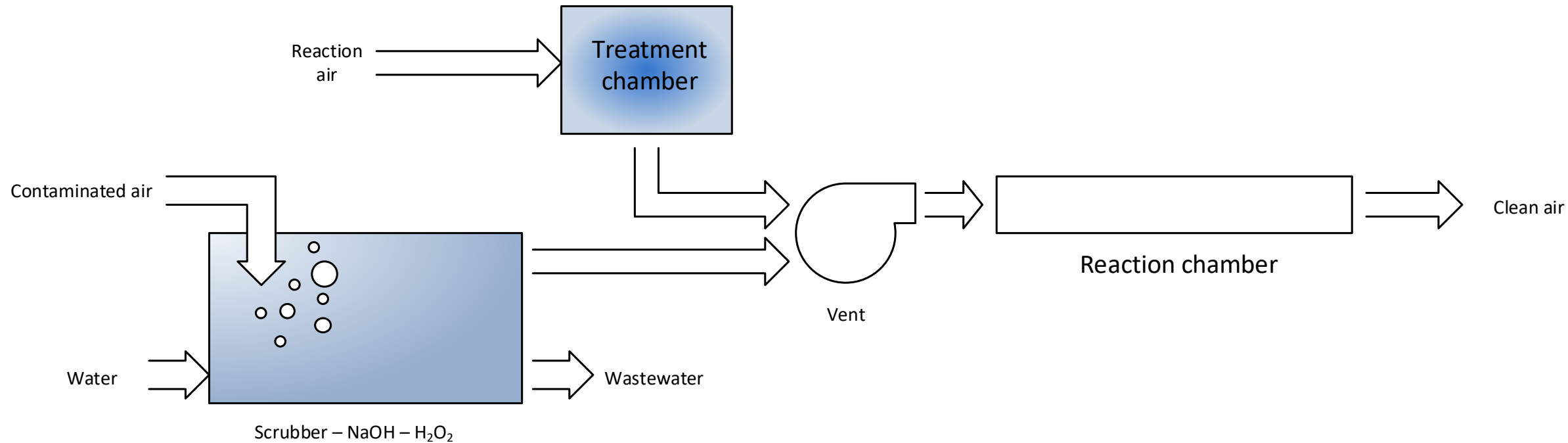
System construction - direct



System construction - indirect



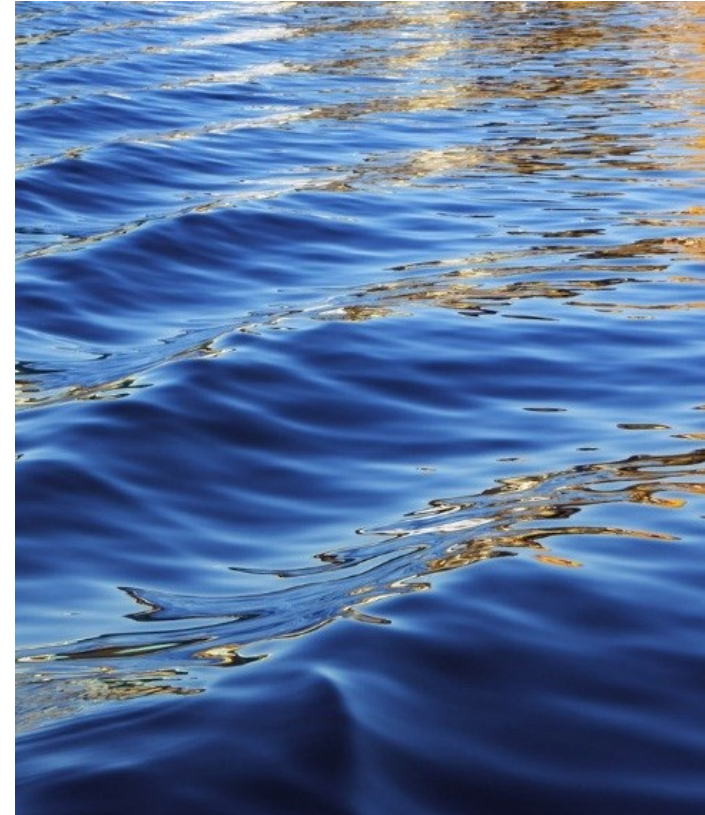
System construction - hybrid





II. Experiments on a composting facility

Science in industrial conditions



Plasma based deodorization – Composting facility

Sludge to compost production facility in Goleniów:

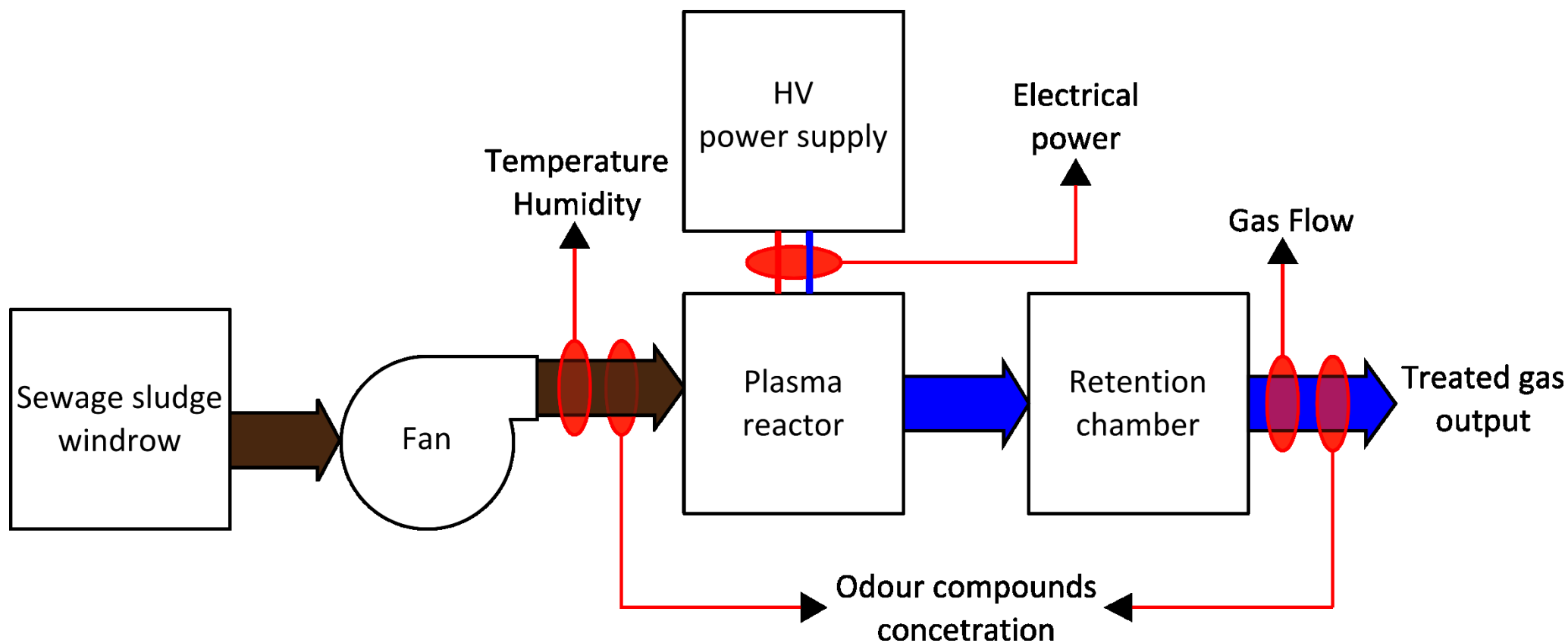


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Goleniowskie
Wodociągi
i Kanalizacja

Plasma odour control system – pilot plant in Goleniów



Sewage sludge composting house

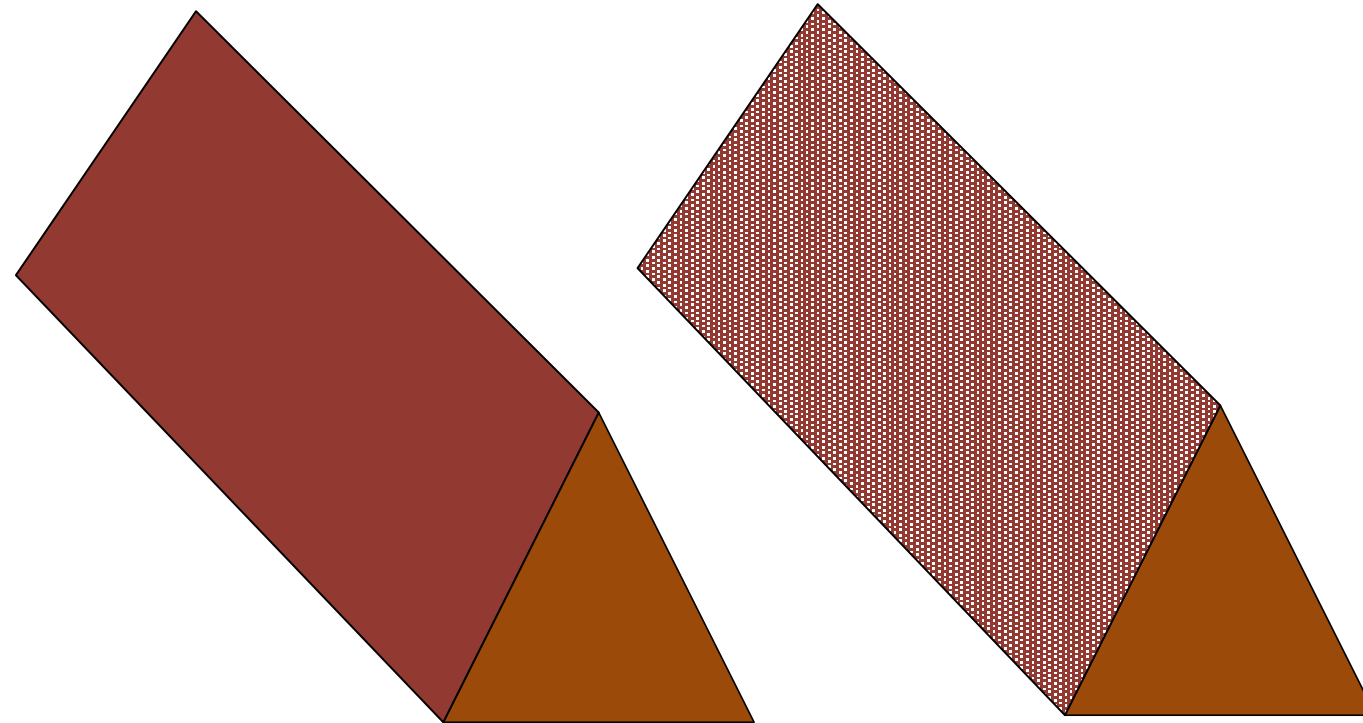


Measurement process

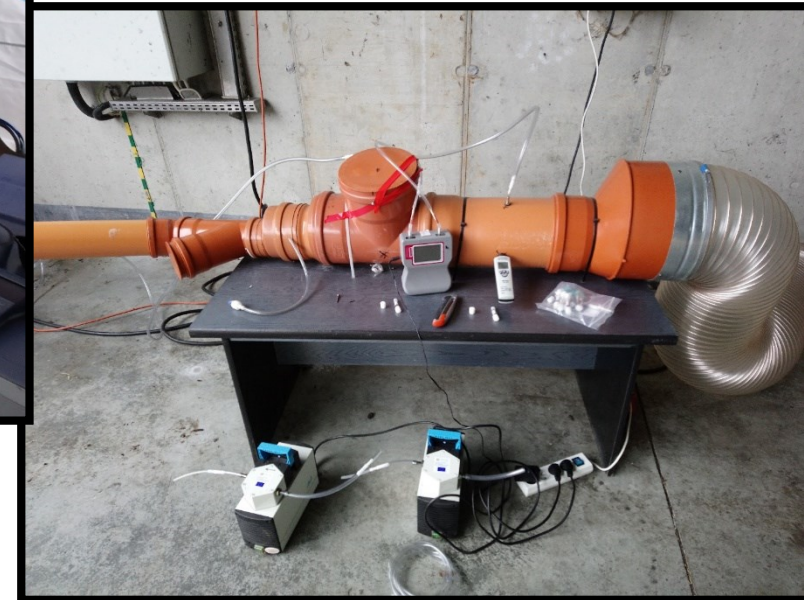
Windrow I
(composition I)

Windrow II
(composition II)

Phase 1: first three weeks (intense composting)
Phase 2: two months and three months after start
(less intense composting)



Sewage sludge composting house



Problems: flow control, humidity (99%)



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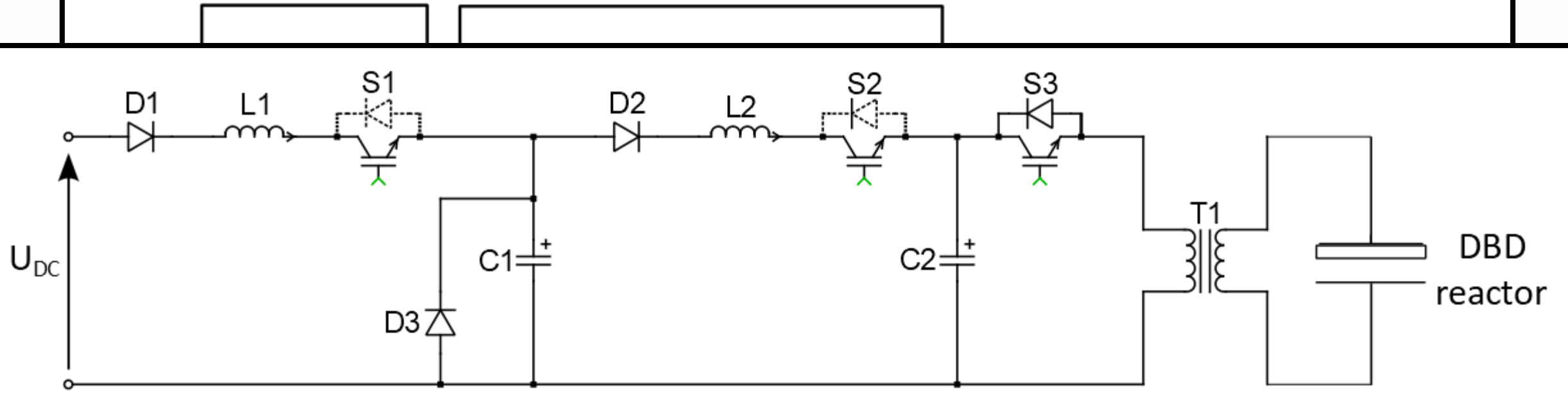


Goleniowskie
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i Kanalizacja

Non-Thermal plasma Reactor and HV electrodes



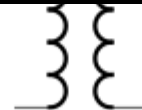
HV supply schematics



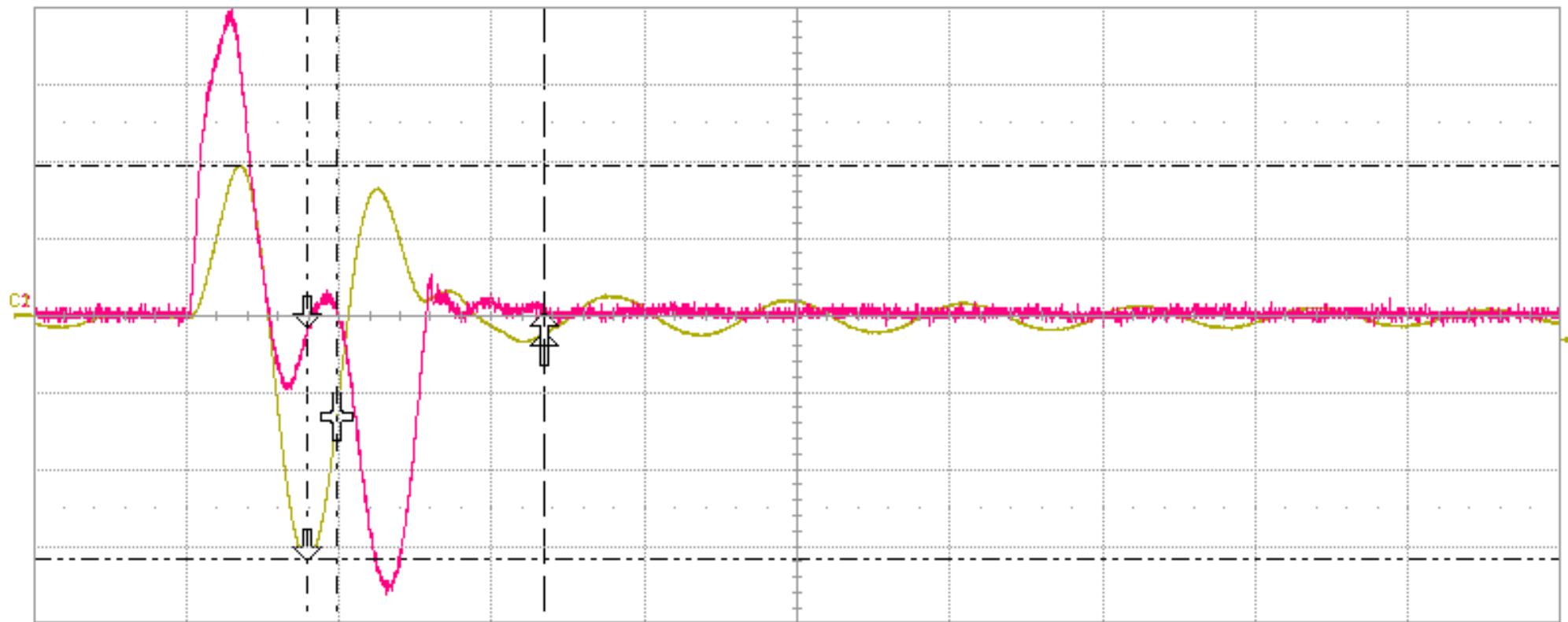
AC



DC/DC



Obciążenie



Measure	P1:pkpk(C1)	P2:ampl(C1)	P3:max(C1)	P4: M@x(C1)	P5:sdev(C1)	P6:area(C1)
value	51.1 kV	51.06 kV	19.45 kV	-13.29 kV	6.471 kV	-13.90710 mVs
mean	52.609 kV	52.5111 kV	20.0830 kV	-13.7436 kV	6.65271 kV	-13.0474553 mVs
min	49.7 kV	32.31 kV	18.90 kV	-14.01 kV	6.309 kV	-14.66748 mVs
max	54.4 kV	54.36 kV	20.77 kV	-12.98 kV	6.733 kV	-12.54023 mVs
sdev	955 V	1.6780 kV	397.6 V	258.7 V	114.67 V	536.9309 μ Vs
num	215	215	215	215	215	215
status	✓	✗	✓	✓	✓	✓

C1	A BwL DC1M	C2	INV DC1M
10.0 kV/div	20.0 V/div		
0 V offset	0.00 V offset		
228 #			
↓ -32.193 kV	↓ -2.65 V		
↑ -2.450 kV	↑ 0.00 V		

Timebase	-17.2 μ s	Trigger	C1
5.00 μ s/div	Auto	-3.3 kV	
5.00 kS 100 MS/s	Edge	Negative	
X1= 1.18 μ s	Δ X= 7.77 μ s		
X2= 8.95 μ s	1/ Δ X= 128.7 kHz		

High Voltage power supply



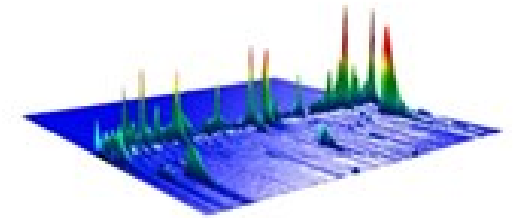
Measurement equipment and methodology

- Ammonia and Hydrogen sulfide

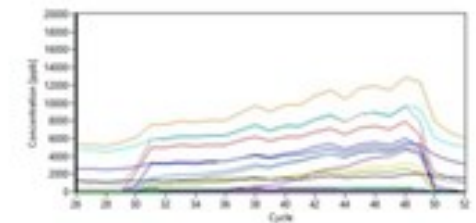


- Full analysis of the composition

- two-dimensional gas chromatography



- mass spectrometry



- Around 1000 different chemical compounds detected
- 126 compounds identified with over 80% probability
- 10 identified quantitatively and measured



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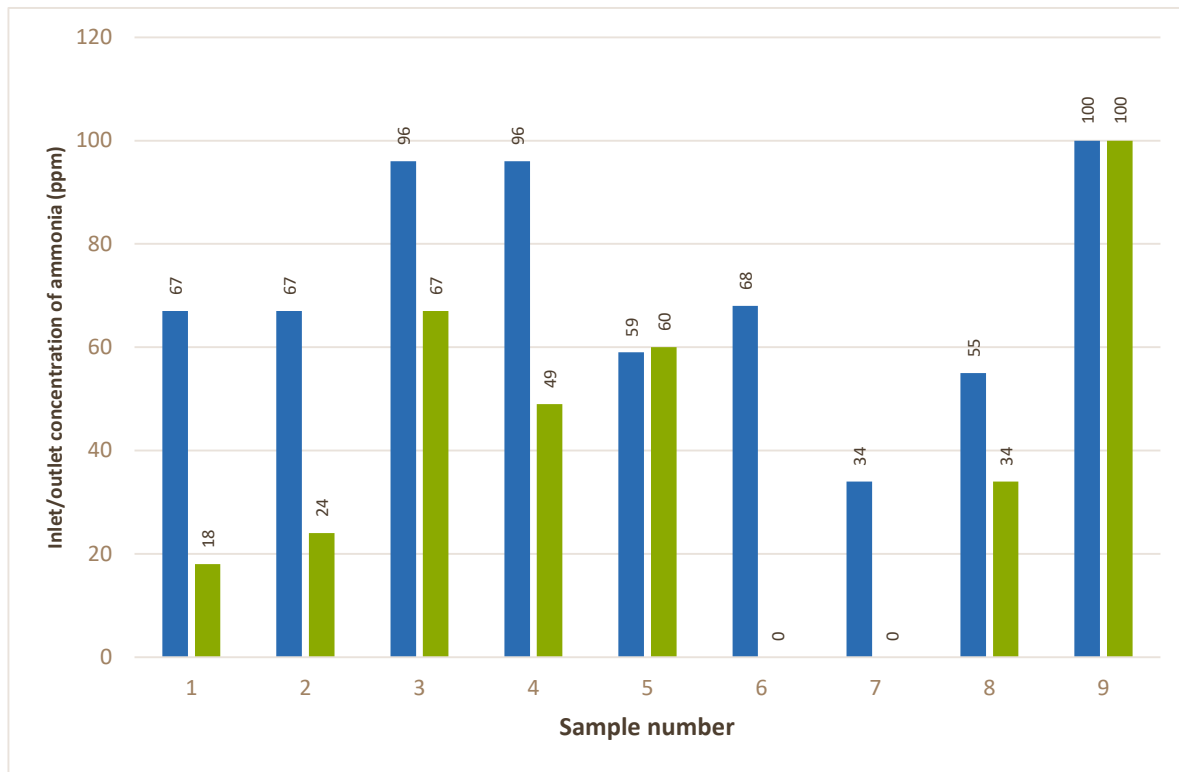
Goleniowskie
Wodociągi
i Kanalizacja

Measured, main odour compounds

Compound	Chemical Symbol	Hazards
Ammonia	NH_3	Toxic while inhaled
Hydrogen Sulfide	H_2S	Highly toxic
Hexane	C_6H_{14}	Toxic while inhaled, pulmonary oedema, pneumonitis, death
Dimethyl disulfide	CH_3SCH_3	Toxic while inhaled
1-Methoxy-2-propanol	$\text{C}_4\text{H}_{10}\text{O}_2$	May damage fertility and the unborn child
Toulene	$\text{C}_6\text{H}_5\text{CH}_3$	Headache, Diziness
Pentatane	C_5H_{12}	Drowsiness, diziness
Methanethiol	CH_4S	Very toxic
2-methylbutanal	$\text{C}_5\text{H}_{10}\text{O}$	Toxic while inhaled
Benzaldehyde	$\text{C}_6\text{H}_5\text{CHO}$	
Benzene	C_6H_6	cancirogen
Dichloromethane	CH_2Cl_2	Organs damage through repeated exposure

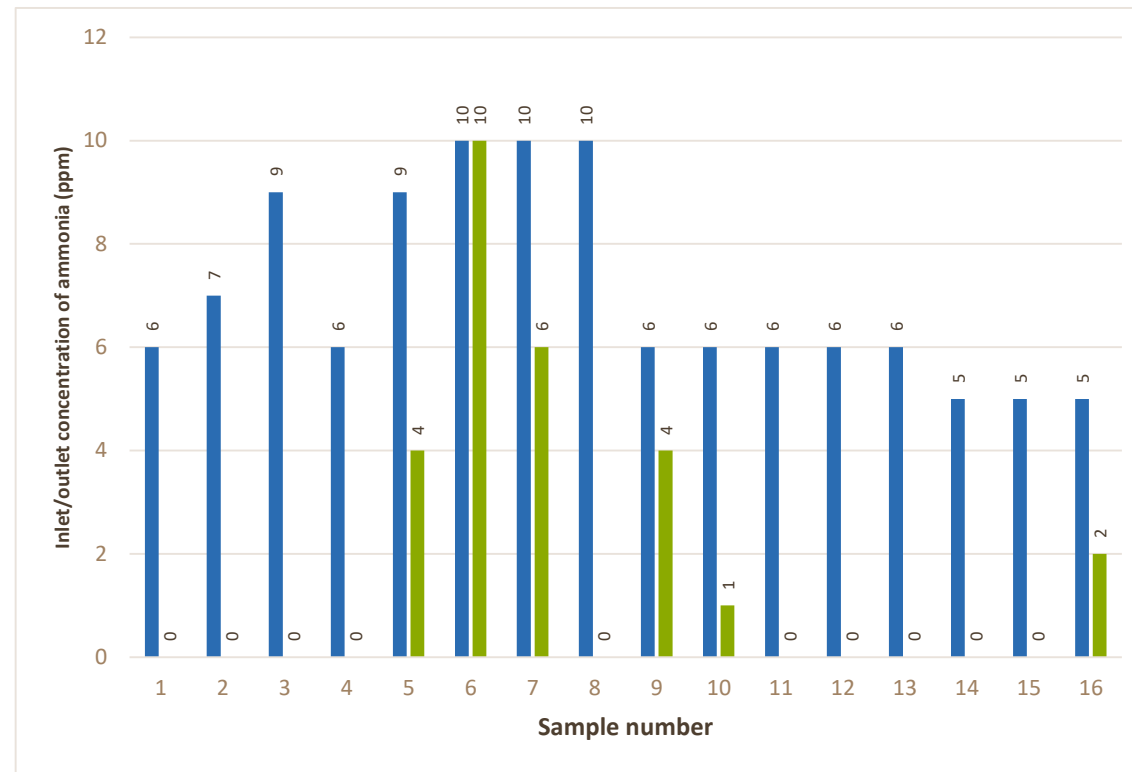
Ammonia reduction

1st composting phase



Average removal efficiency: 50%

2nd composting phase

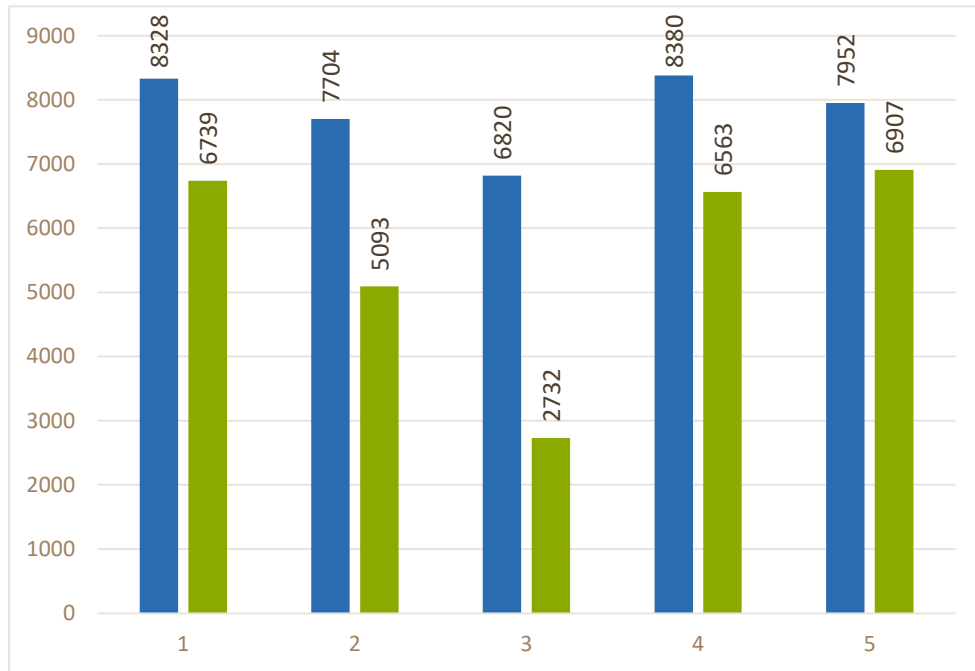


Average removal efficiency: 80%

Flowrate: 0,8 m³/h, Energy density: about 1,2 Wh/Nm³

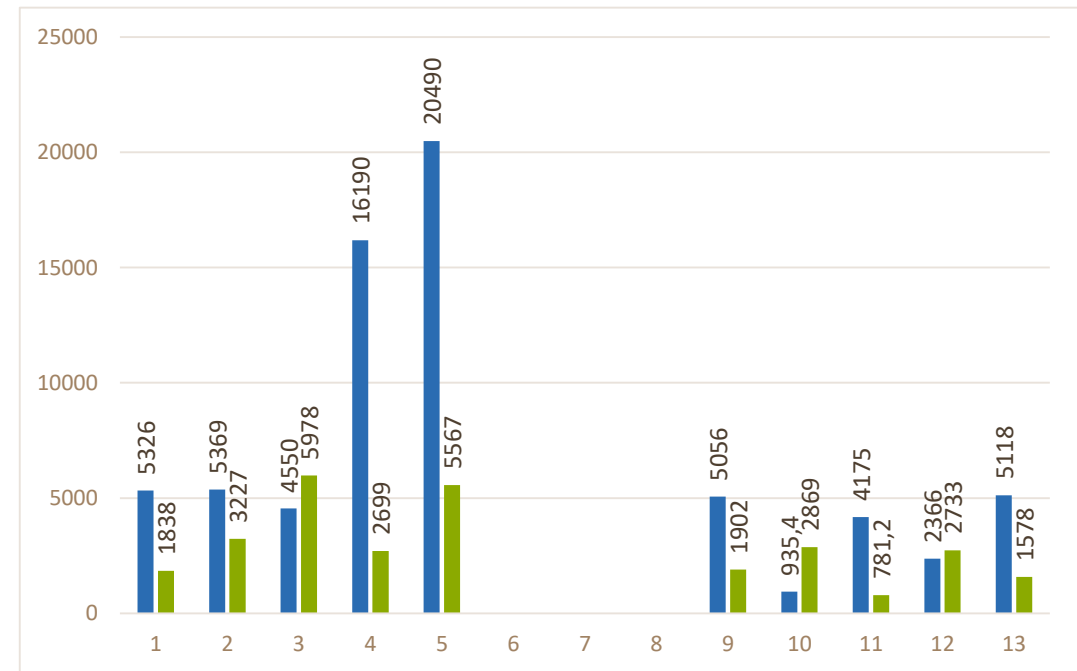
Heksane reduction

1st composting phase



Average removal efficiency: 30%

2nd composting phase

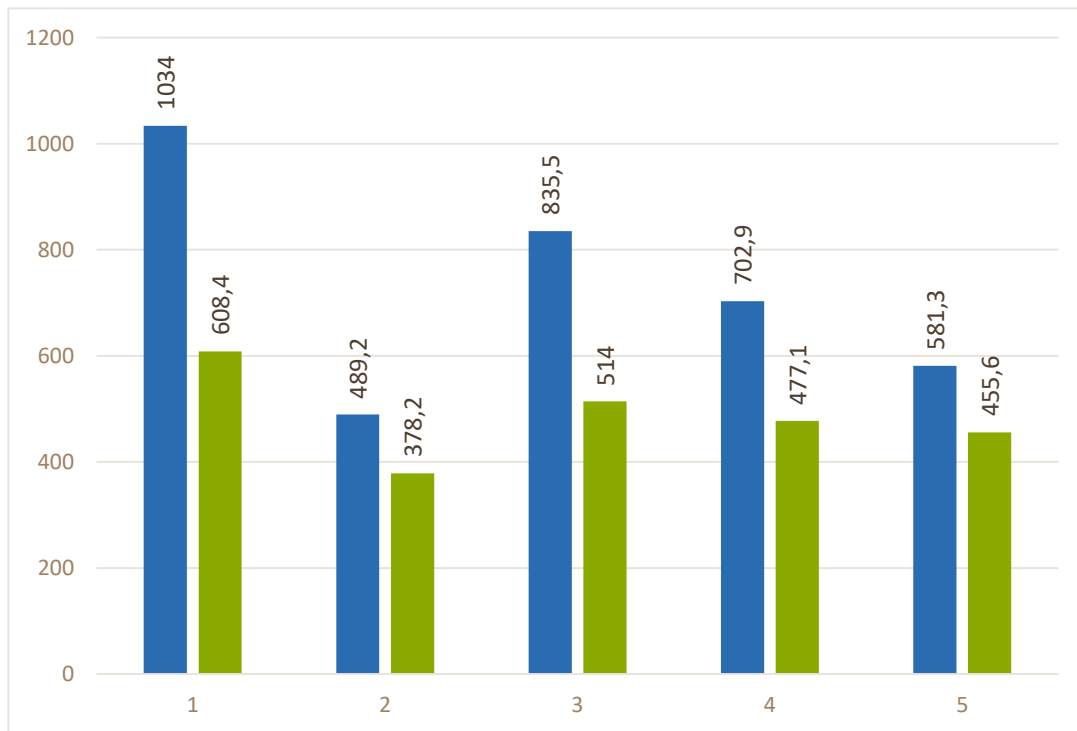


Average removal efficiency: 22%

Flowrate: 0,8 m³/h, Energy density: about 1,2 Wh/Nm³

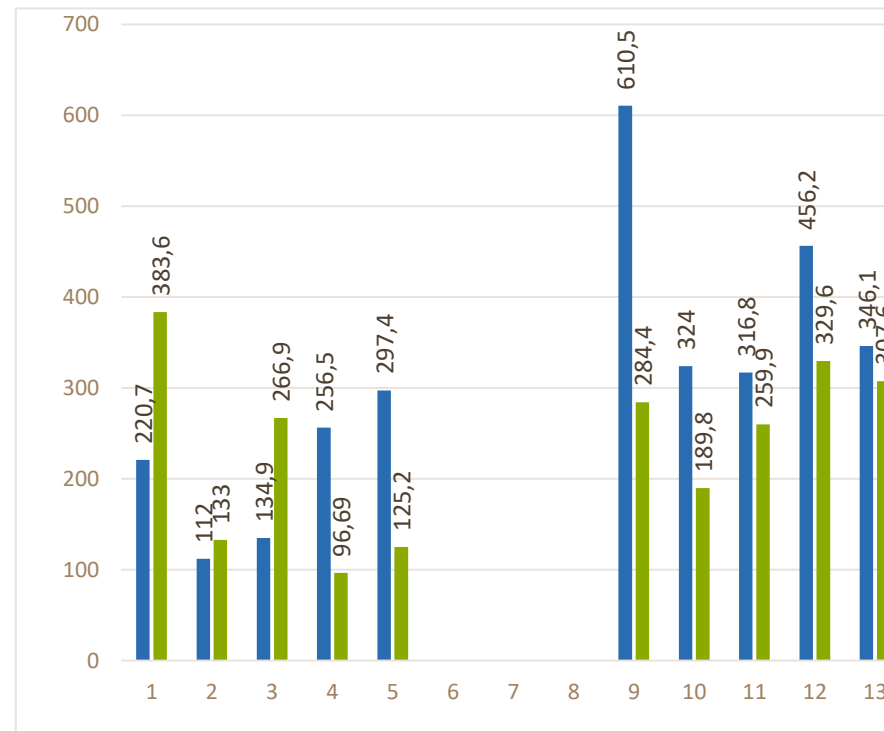
Toulene reduction

1st composting phase



Average removal efficiency: 31%

2nd composting phase

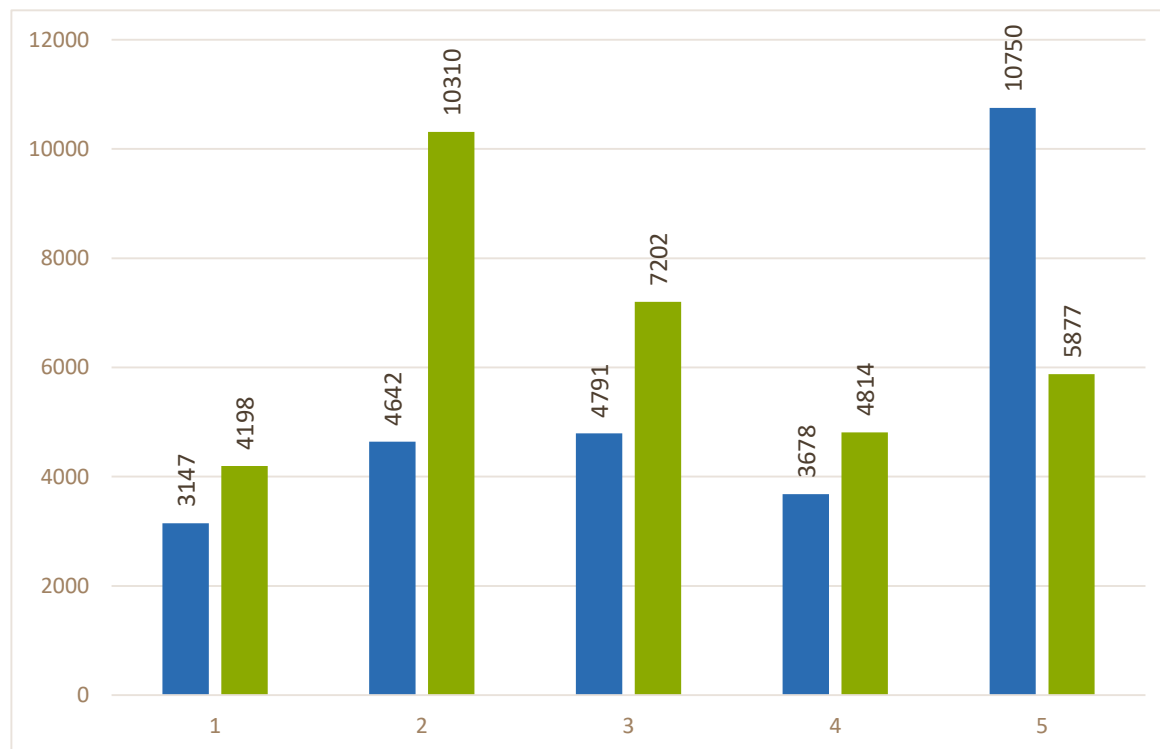


Average removal efficiency: 8%

Flowrate: 0,8 m³/h, Energy density: about 1,2 Wh/Nm³

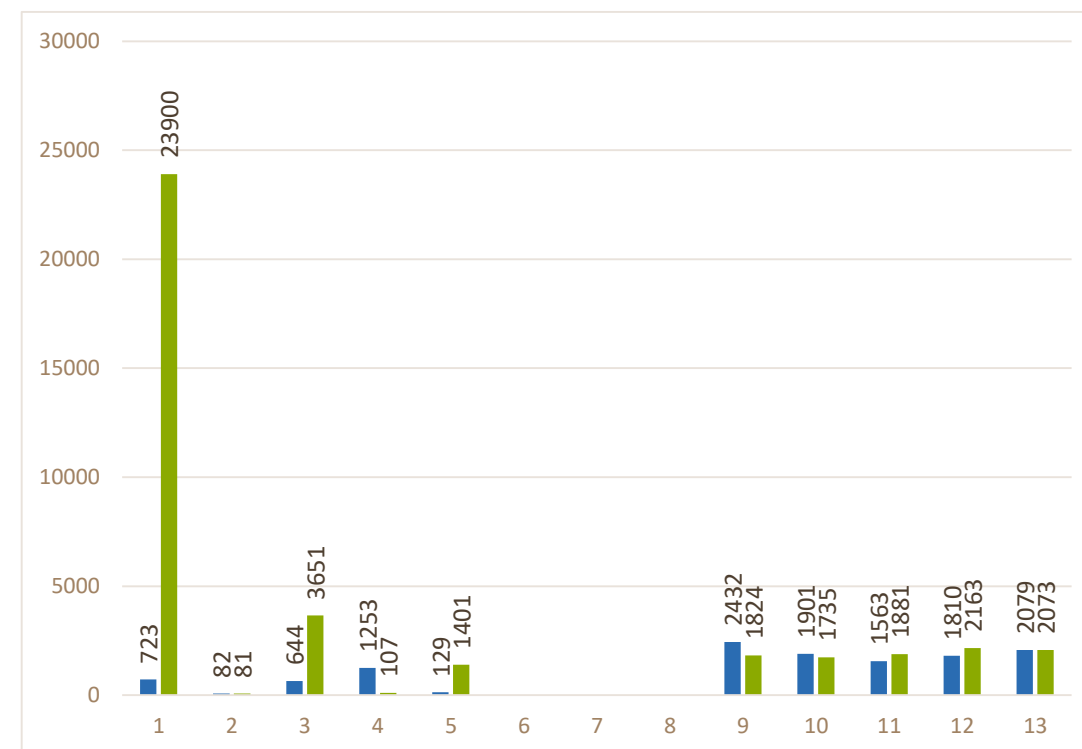
Benzene reduction/production?

1st composting phase



Average **production** efficiency: 38%

2nd composting phase

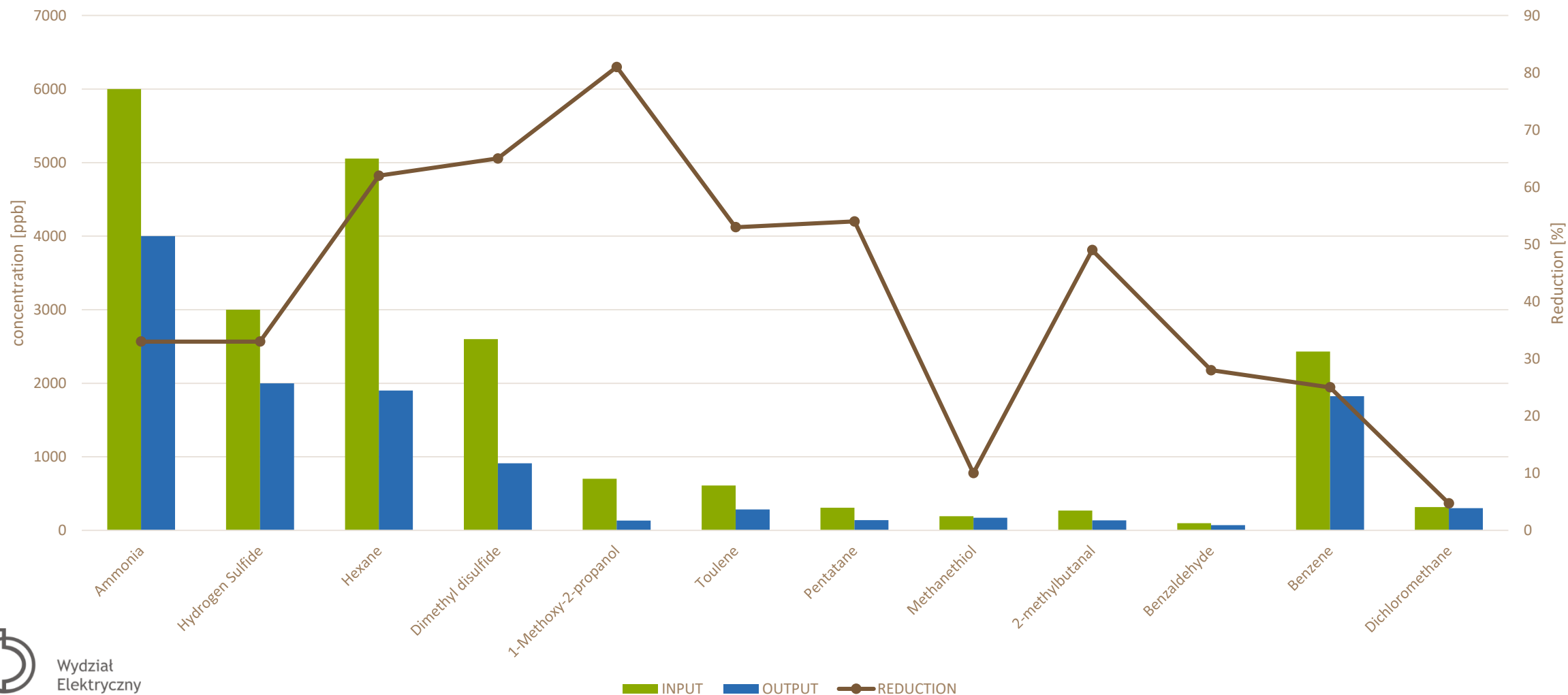


Average **production** efficiency: 150%

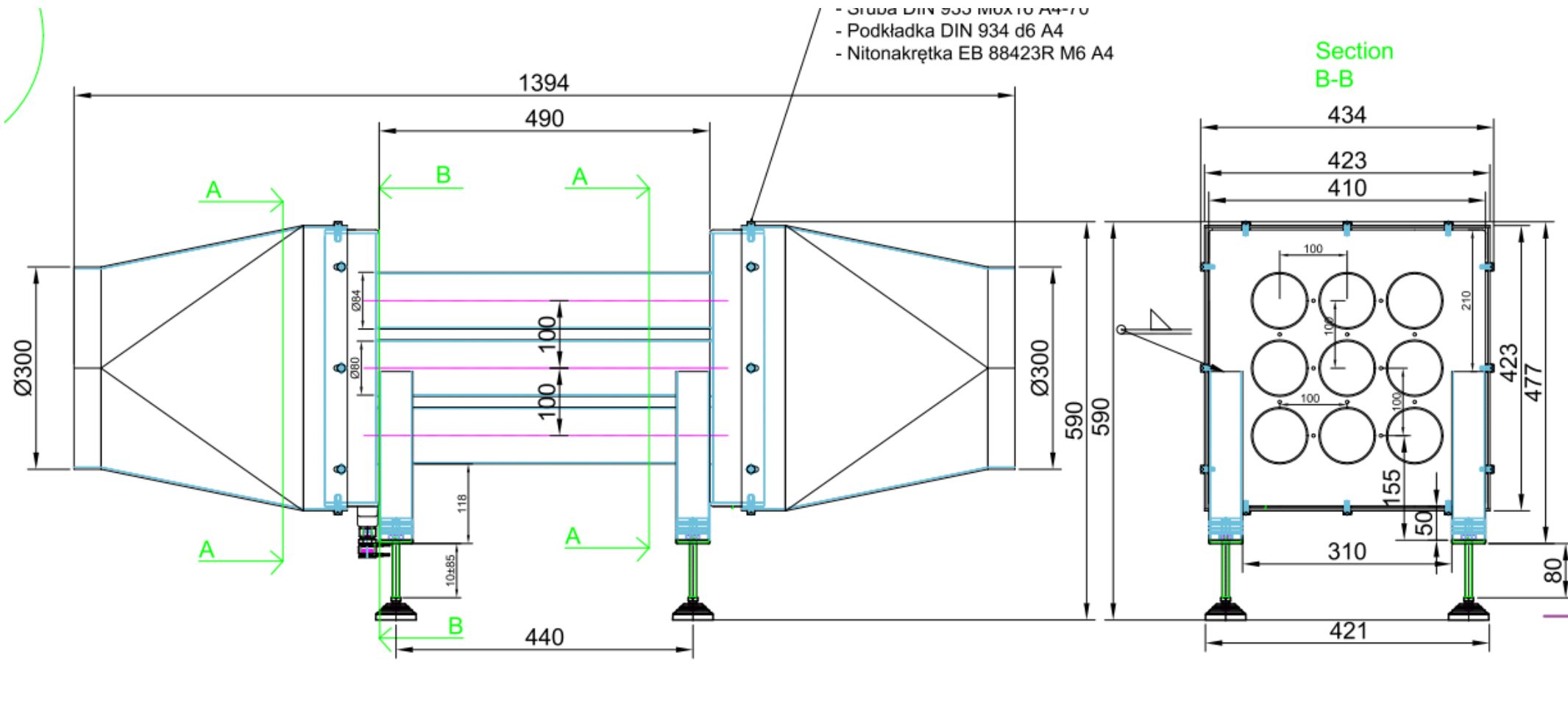
Flowrate: 0,8 m³/h, Energy density: about 1,2 Wh/Nm³



Average reduction: first phase: 25 % (of all compounds)
second phase: 40 % (of all reductive compounds)



(semi-industrial) reactor



Flowrate: 5 m³/h



III. Summary



Summary:

Plasma (ozone) treatment can be cost – effective air treatment solutions for low concentration of exhaust pollutants and for deodorization.

Non – thermal plasma systems offer a larger variety of reduction mechanisms. In industrial conditions often a hybrid treatment plant will offer best performance.

advantages of advanced oxidation technologies include

- Low operating and investment costs
- Waste – free processing
- Relatively small size of necessary equipment
- Low pressure drop in case of CD and ozone units
- Additional disinfection of treated gases.

Main disadvantages include

- Risk of corrosion of installation parts
- Presence of strongly oxidizing agents
- Possible ozone presence after treatment
- Efficient only for compounds which are susceptible to oxidation
- Possible synthesis of undesired by – products and sedimentation on reactor walls



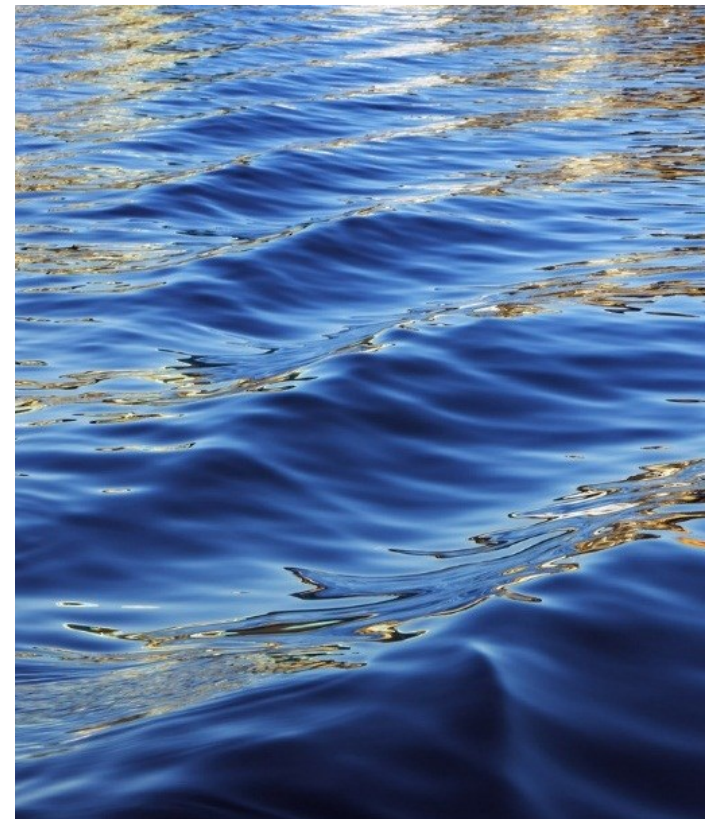
Thank You (Danke !)

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