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Plasma supported deodorization - research and practical verification

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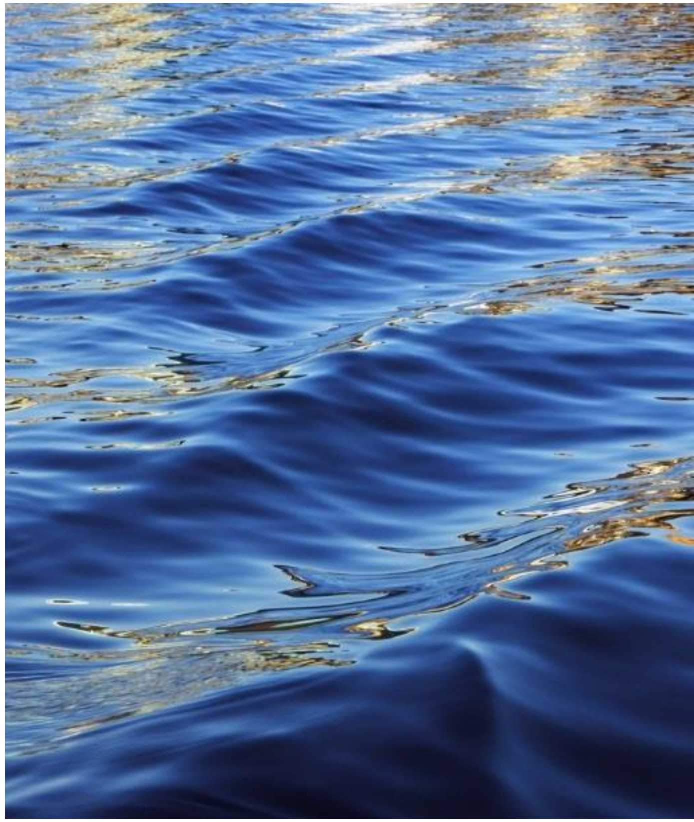
STEP project workshop



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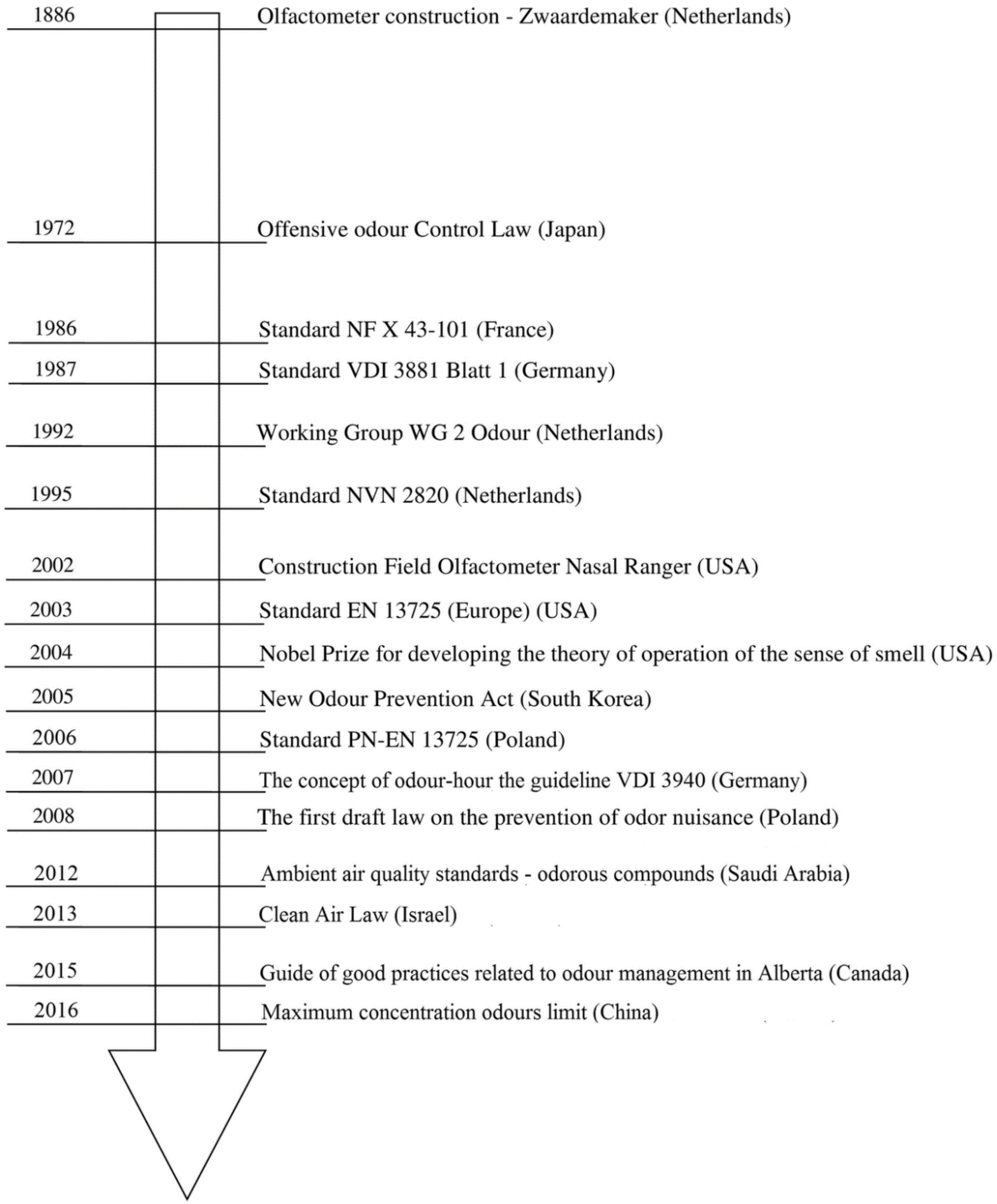
Air quality – background of the research



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

Wydział Elektryczny

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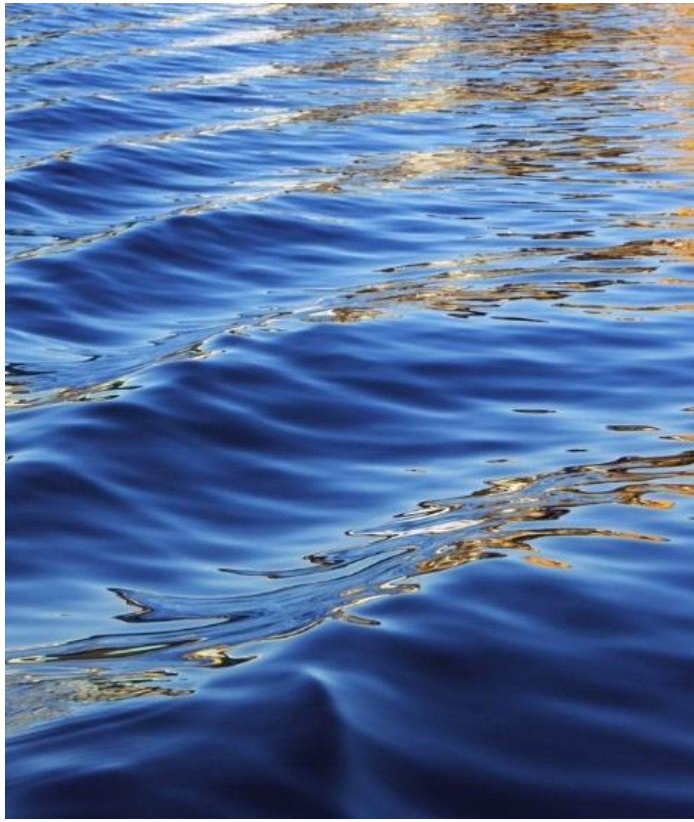
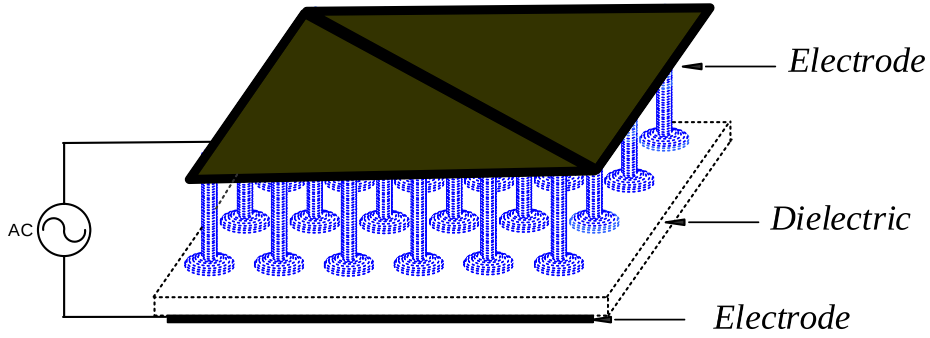
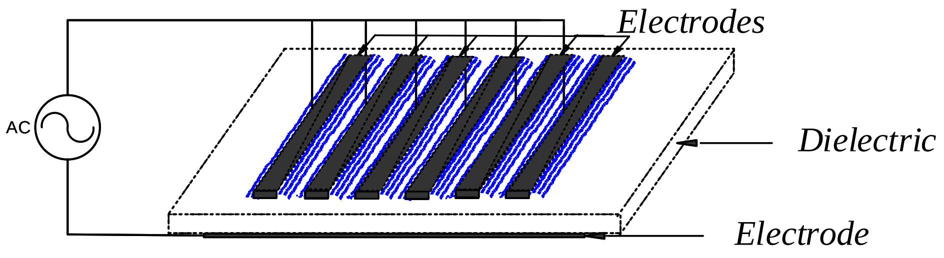
I. Plasma reactor types and treatment methods



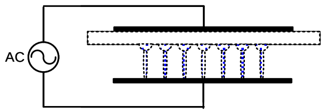
Discharge (reactor) types

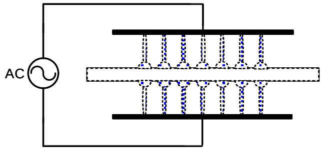


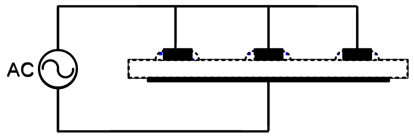
Volume barrier discharge (VD)

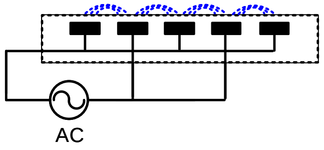


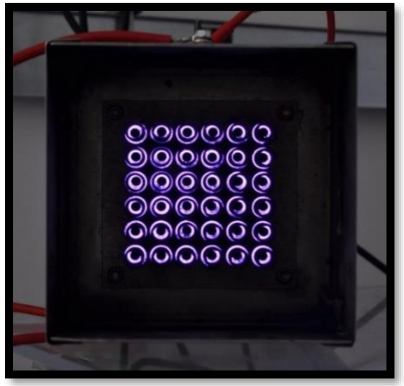
Surface barrier discharge (SD)

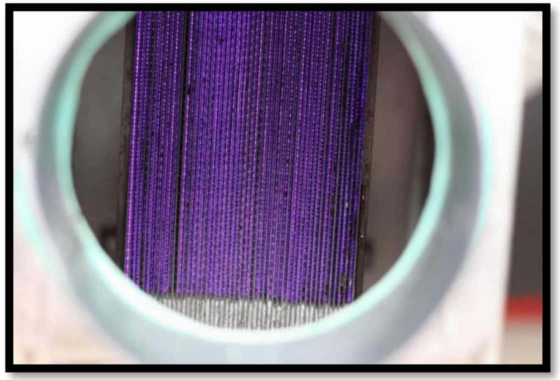


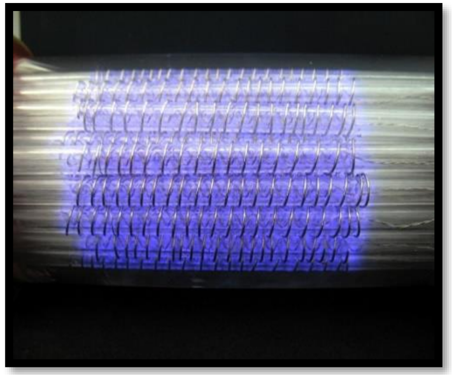




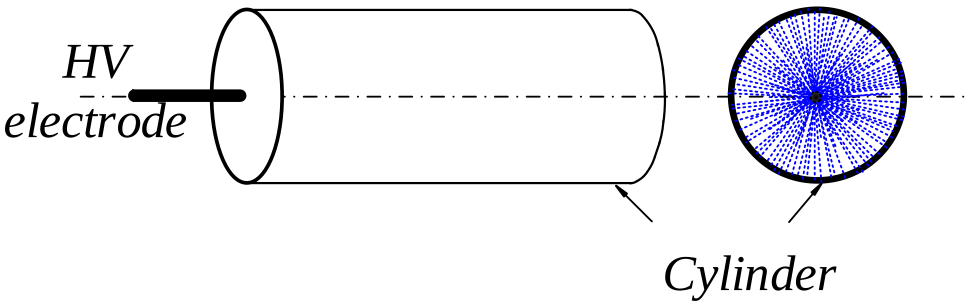


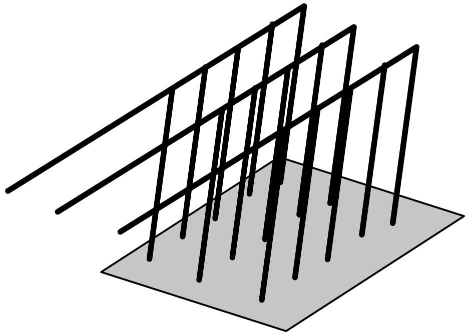


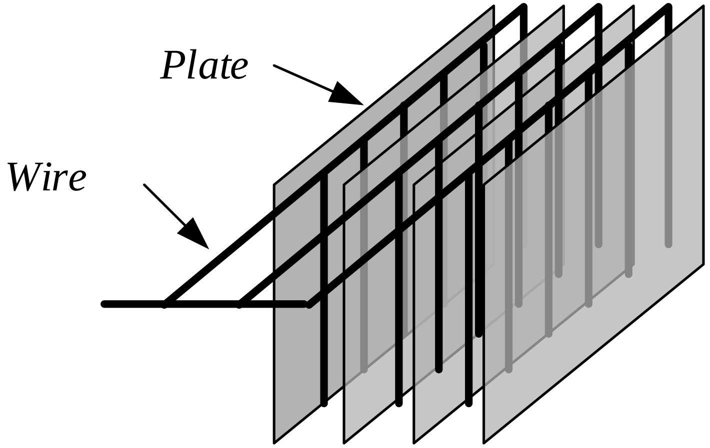


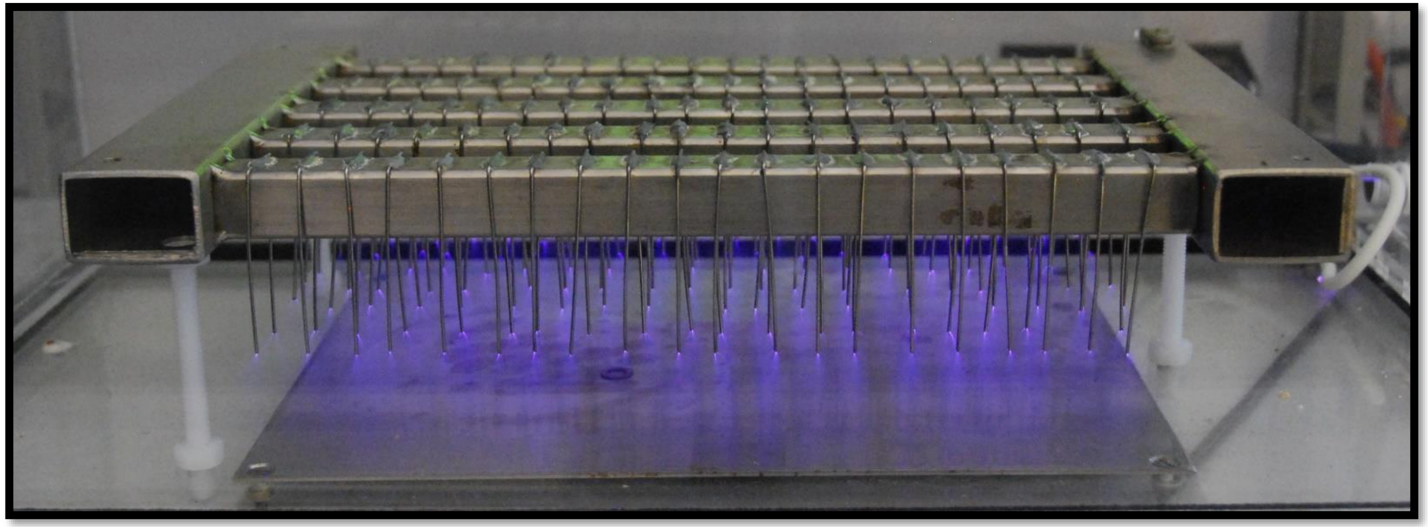


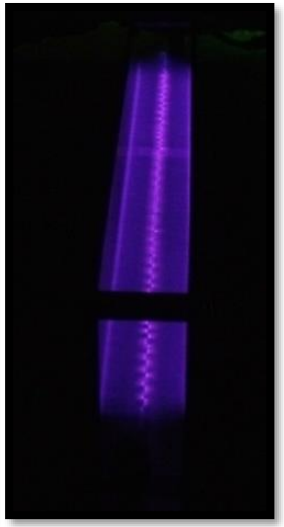
Discharge (reactor) types

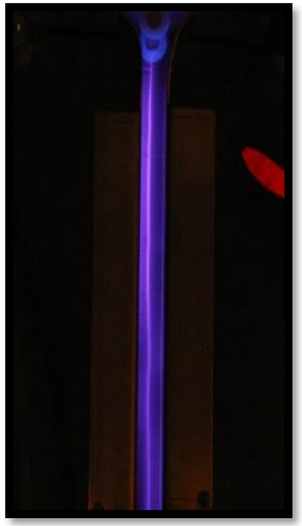












Electron Energy

Average Electron Energy: 5-15eV

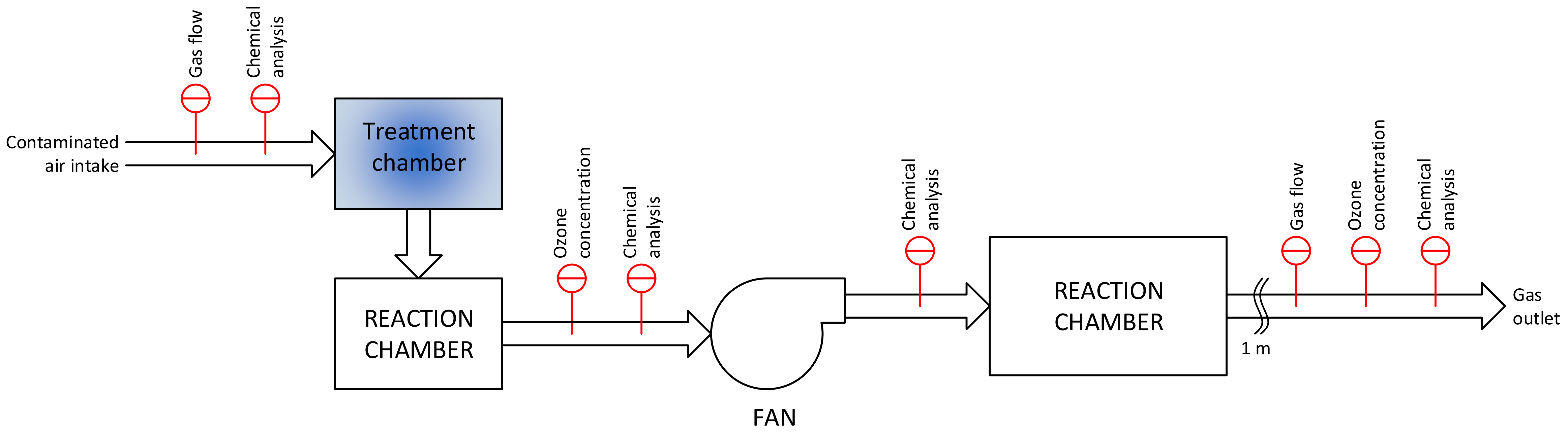
A. S. Gibson, J. A. Riousset, i V. P. Pasko, „Minimum Breakdown Voltages for Corona Discharge in Cylindrical and Spherical Geometries”, nr 1.

TABLE I
CHEMICAL COMPOUNDS AMENABLE TO TREATMENT BY AIR IONIZATION

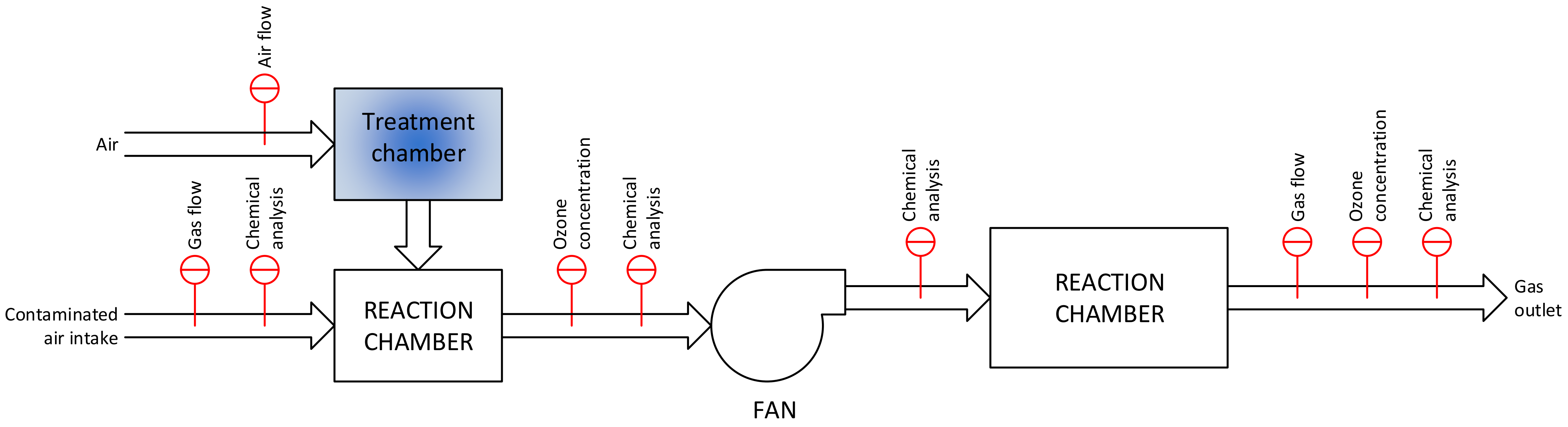
	Chemical	Formula	IE, eV
1.	Phenanthrene	$C_{14}H_{10}$	7.89
2.	Pinene, α-	C_8H_{19}	8.07
3.	Naphthalene	$C_{10}H_8$	8.14
4.	Trimethylbenzene, 1,2,4-	C_9H_{12}	8.27
5.	Limonene (1-Pentene)	$C_{10}H_{16}$	8.3
6.	Xylene, p-	C_8H_{10}	8.44
7.	Styrene	C_8H_8	8.46
8.	Xylene, o-, m-	C_8H_{10}	8.55
9.	Ethyl Benzene	C_8H_{10}	8.77
10.	Toluene	C_7H_8	8.83
11.	Cyclohexene	C_6H_{10}	8.95
12.	Chlorobenzene	C_6H_5Cl	9.07
13.	Benzene	C_6H_6	9.24
14.	Nitric Oxide	NO	9.26
15.	Tetrachloroethylene	C_2Cl_4	9.33
16.	Trichloroethylene	C_2HCl_3	9.46
17.	Methyl Ethyl Ketone	C_3H_8O	9.52
18.	Nitrogen Dioxide	NO_2	9.59
19.	Dichloroethylene, trans-1,2-	$C_2H_2Cl_2$	9.64
20.	Octane	C_8H_{18}	9.80
21.	Cyclohexane	C_6H_{12}	9.88
22.	Butyl Acetate, n-	$C_6H_{12}O_2$	9.92
23.	Heptane, n-	C_7H_{16}	9.93
24.	Ammonia	NH_3	10.07
25.	Hexane, n-	C_6H_{14}	10.13
26.	Acetaldehyde	CH_3CHO	10.23
27.	Methyl Acetate	$C_3H_6O_2$	10.25
28.	Pentane, n-	C_5H_{12}	10.28
29.	Hydrogen Sulfide	H_2S	10.46
30.	Ethyl Alcohol	C_2H_5OH	10.48
31.	Ethylene	C_2H_4	10.51
32.	Butane	C_4H_{10}	10.53
33.	Methyl Alcohol	CH_4O	10.84
34.	Formaldehyde	CH_2O	10.88
35.	Trichloroethane, 1,1,1-	$C_2H_3Cl_3$	11.0
36.	Trichloroethane, 1,1,2-	$C_2H_3Cl_3$	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_3Cl	11.26
41.	Methylene Chloride	CH_2Cl_2	11.33
42.	Tetrachloromethane	CCl_4	11.47
43.	Ethane	C_2H_6	11.52
44.	Nitric Acid	HNO_3	11.95
45.	CFC-113	$C_2Cl_3F_3$	11.99
46.	CFC-12	CCl_2F_2	12.0
47.	Oxygen	O_2	12.07
48.	Methyl Cyanide	C_2H_3N	12.20
49.	Sulfur Dioxide	O_2S	12.35
50.	Sulfuric Acid	H_2O_4S	12.40
51.	Ozone	O_3	12.53
52.	Methane	CH_4	12.61
53.	Water	H_2O	12.62
54.	Hydrogen Chloride	HCl	12.74
55.	Nitrous Oxide	N_2O	12.89
56.	Hexafluoroethane	C_2F_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



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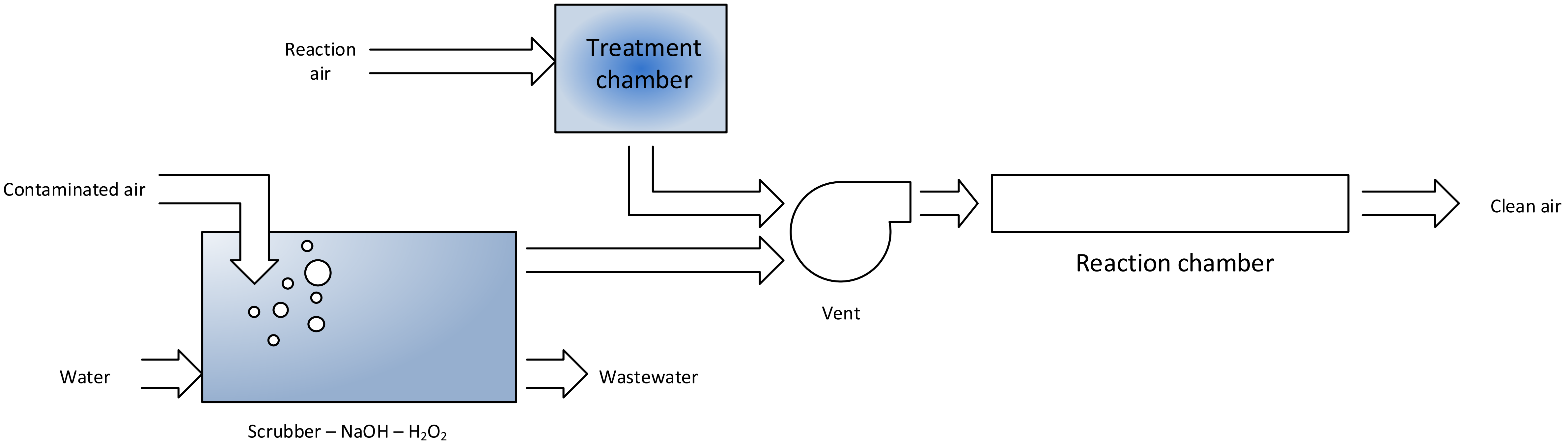
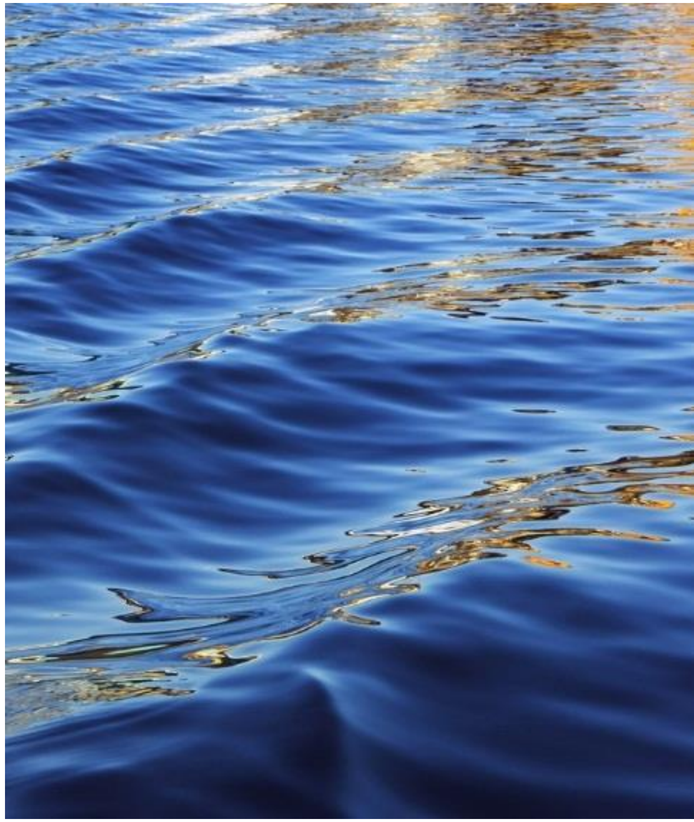
System construction - hybrid



II. Experiments on a composting facility

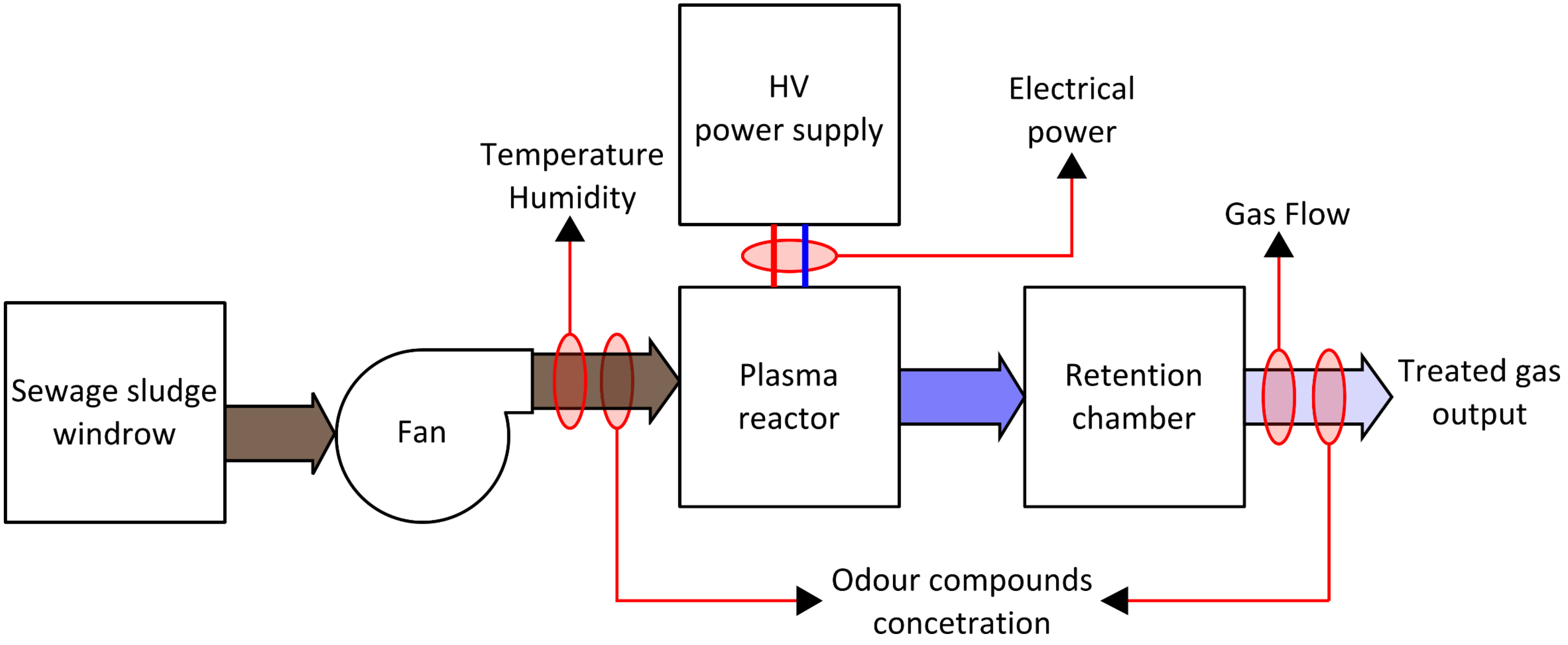
Science in industrial conditions



Plasma based deodorization – Composting facility

Sludge to compost production facility in Goleniów:

Plasma odour control system – pilot plant in Goleniów



Sewage sludge composting house

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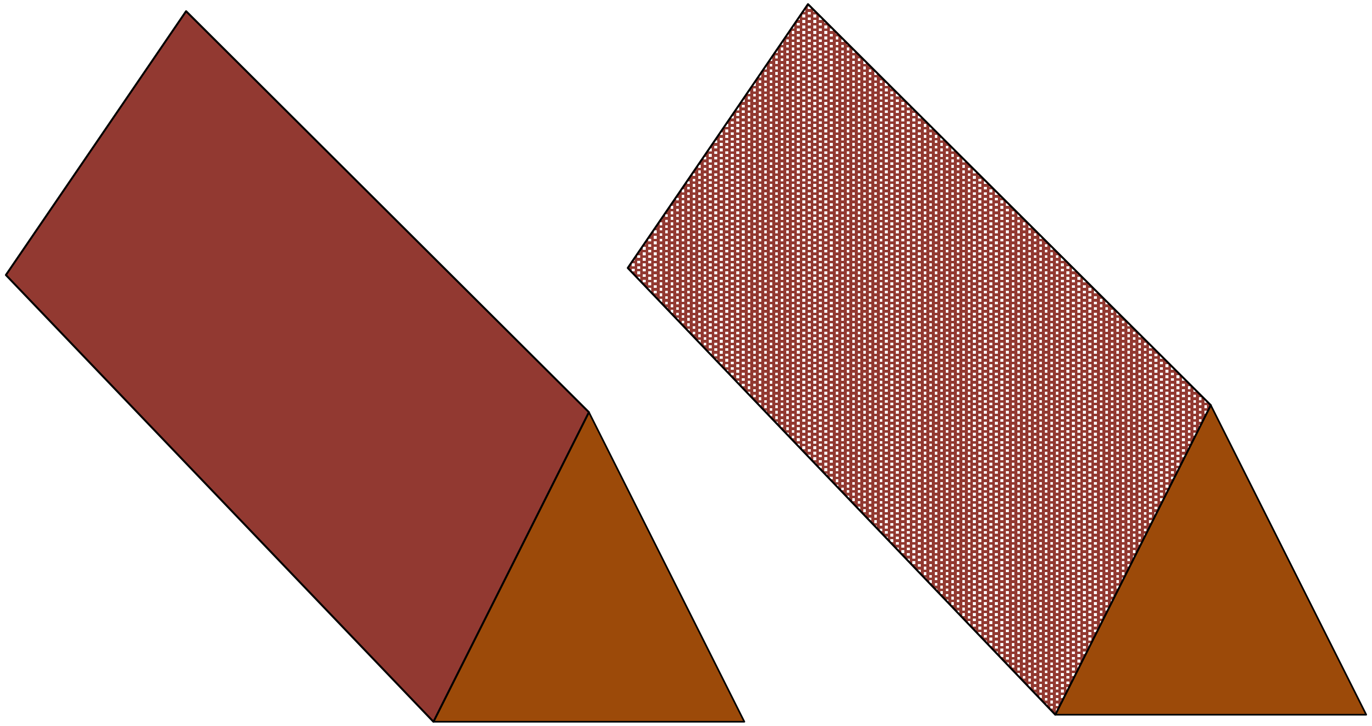
Goleniowskie Wodociągi i Kanalizacja

Measurement process

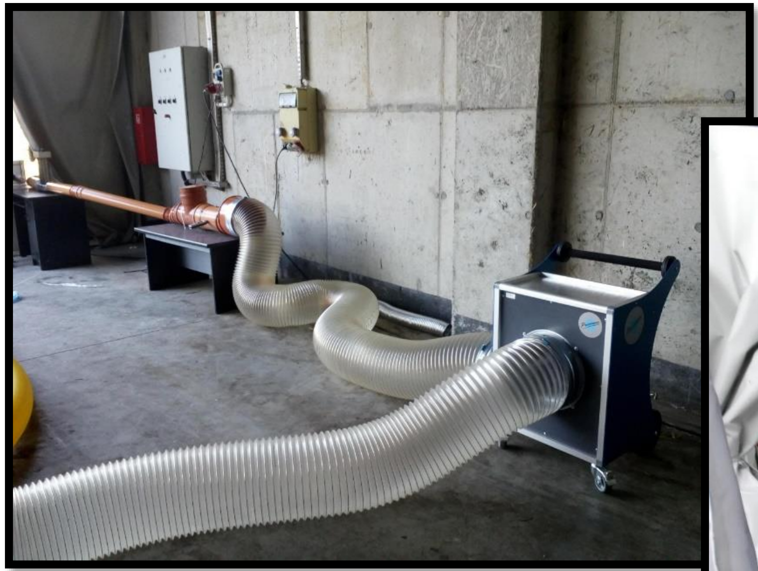
Windrow I
(composition I)

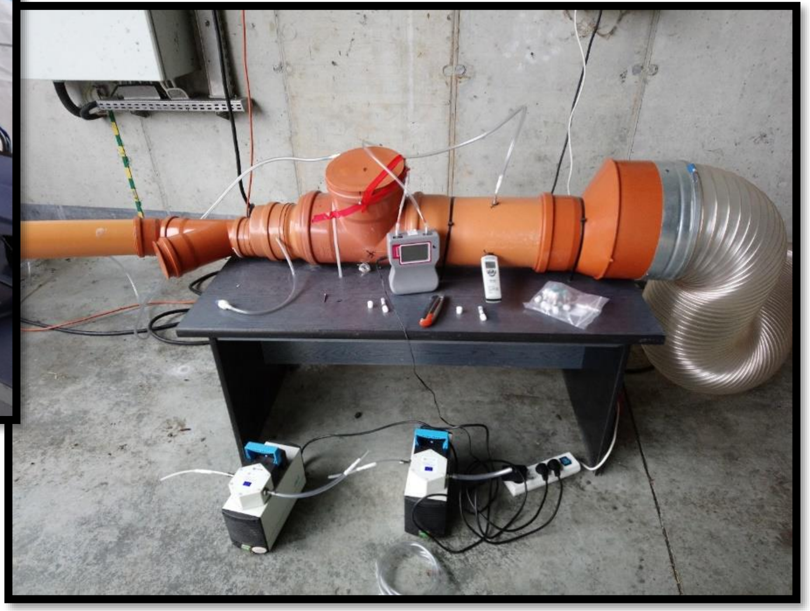
Windrow II
(composition II)

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



Sewage sludge composting house

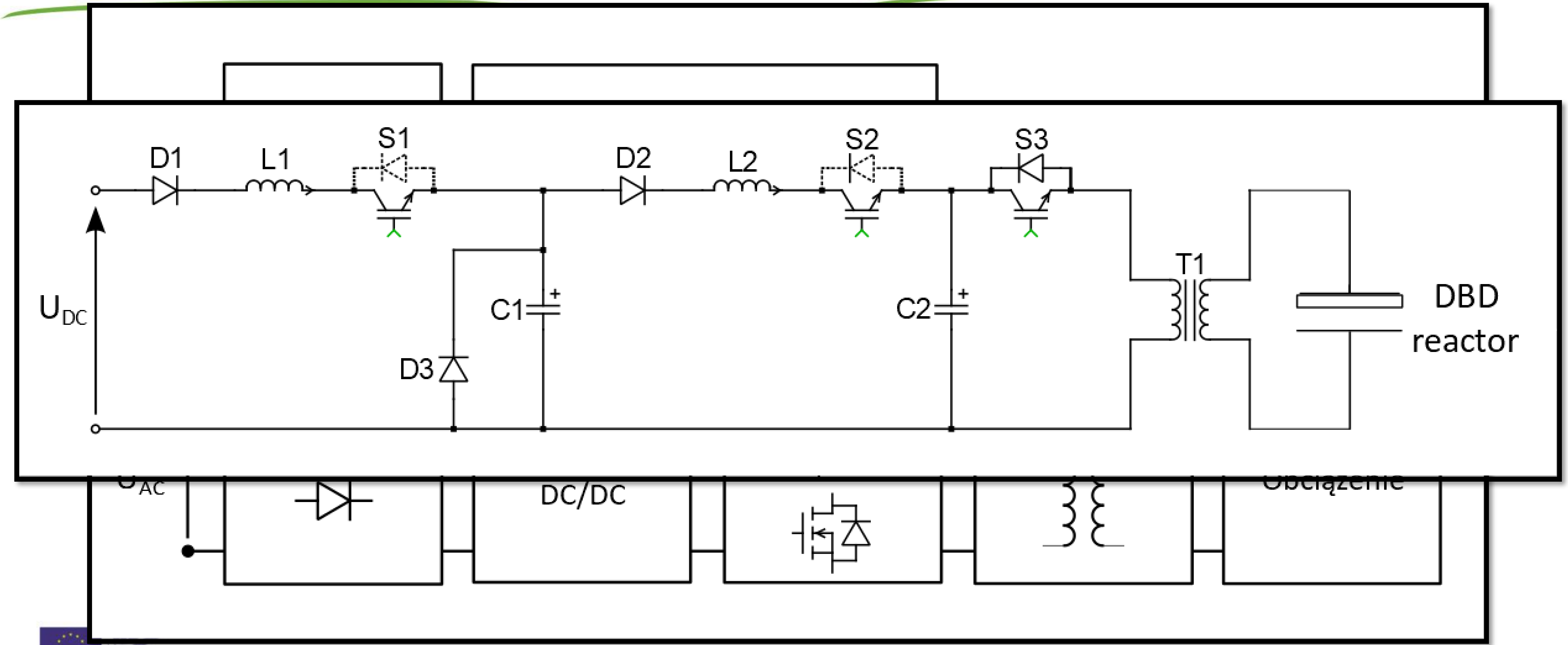


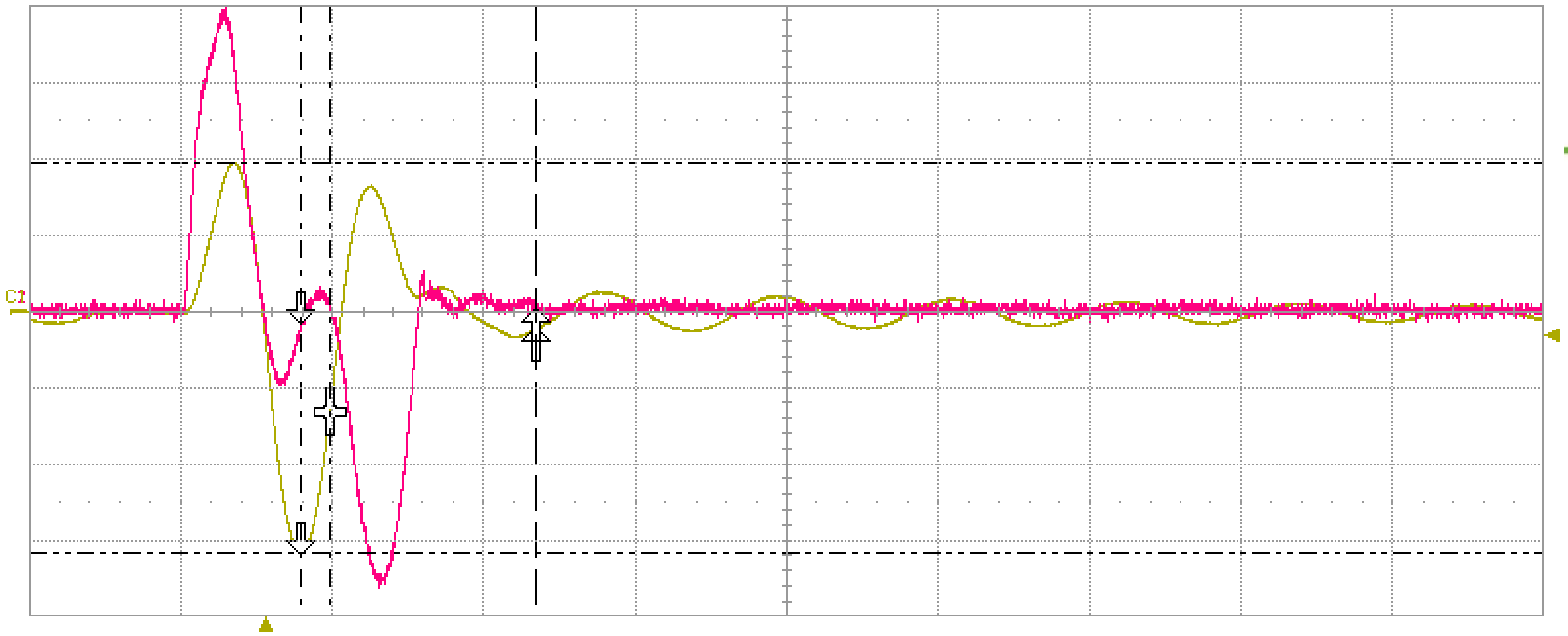


Problems: flow control, humidity (99%)

Non-Thermal plasma Reactor and HV electrodes

HV supply schematics





Measure	P1:pkpk(C1)	P2:ampl(C1)	P3:max(C1)	P4:lvl@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 µVs
num	215	215	215	215	215	215
status	✔		✔	✔	✔	✔

C1 A BwL DC1M
10.0 kV/div
0 V offset
228 #
↓ -32.193 kV
↑ -2.450 kV

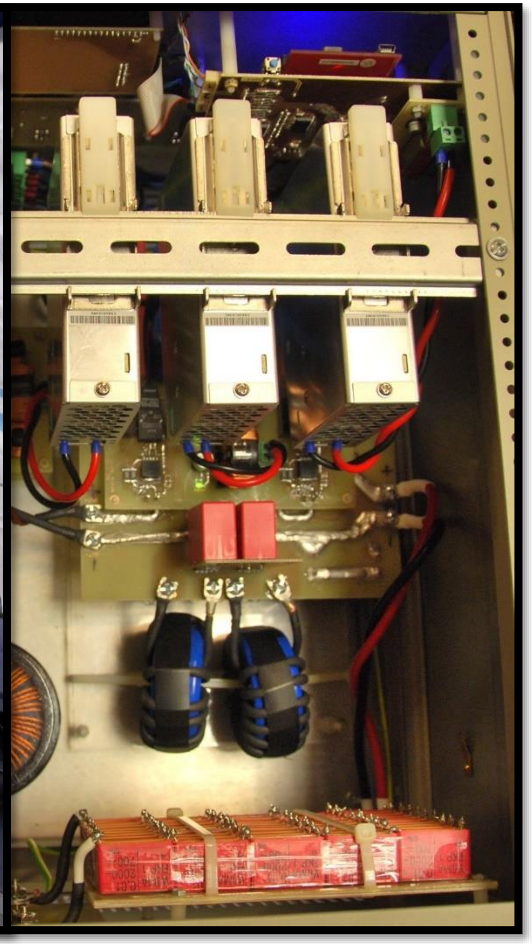
C2 INV DC1M
20.0 V/div
0.00 V offset
↓ -2.65 V
↑ 0.00 V

Timebase -17.2 µs
5.00 µs/div
5.00 kS 100 MS/s

Trigger C1
Auto -3.3 kV
Edge Negative

X1= 1.18 µs ΔX= 7.77 µs
X2= 8.95 µs 1/ΔX= 128.7 kHz

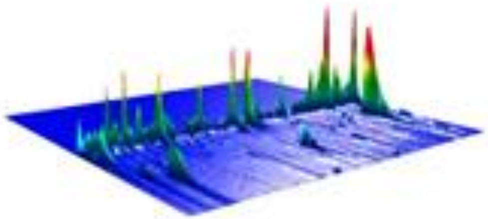
High Voltage power supply

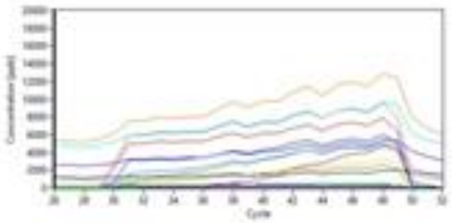


Measurement equipment and methodology

- Ammonia and Hydrogen sulfide

- Full analysis of the composition
  - two-dimensional gas chromatography
  - mass spectrometry





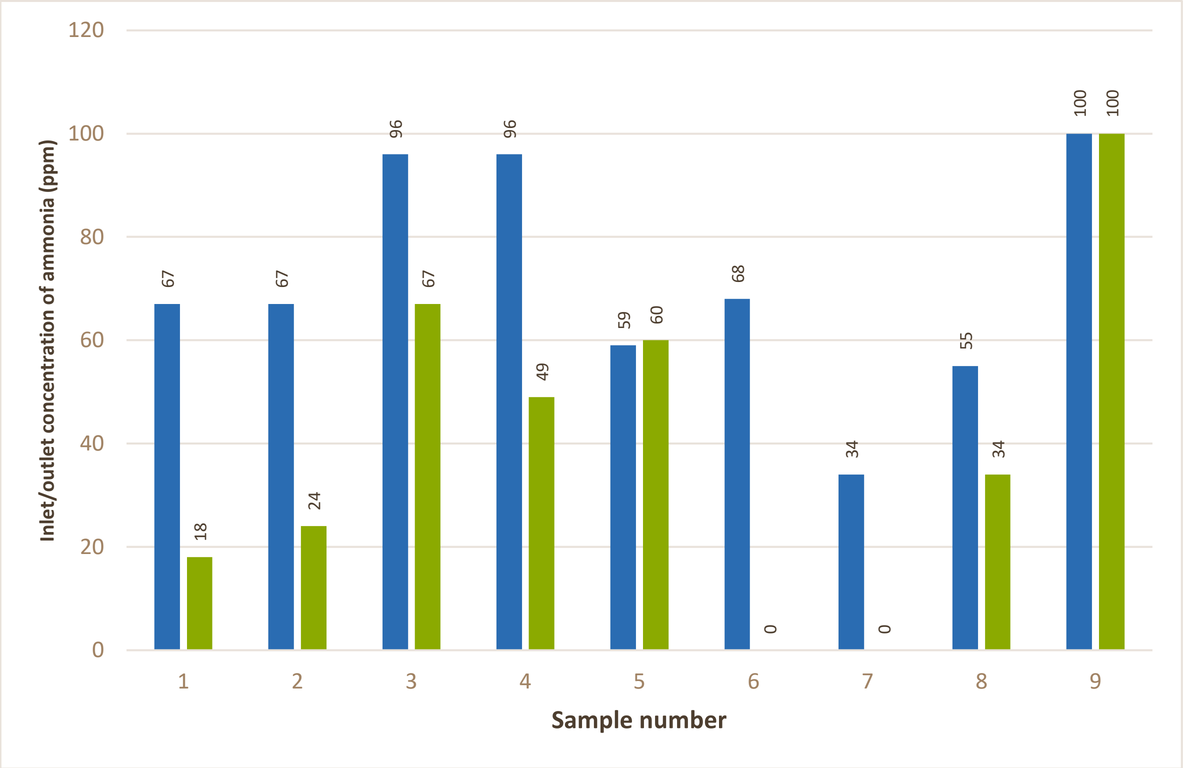
- Around 1000 different chemical compunds detected
- 126 compounds identified with over 80% probability
- 10 identified quantitatively and measured

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	$C_4H_{10}O_2$	May damage fertility and the unborn child
Toulene	$C_6H_5CH_3$	Headache, Diziness
Pentatane	C_5H_{12}	Drowsiness, diziness
Methanethiol	CH_4S	Very toxic
2-methylbutanal	$C_5H_{10}O$	Toxic while inhaled
Benzaldehyde	C_6H_5CHO	
Benzene	C_6H_6	cancirogen
Dichloromethane	CH_2Cl_2	Organs damage through repeated exposure

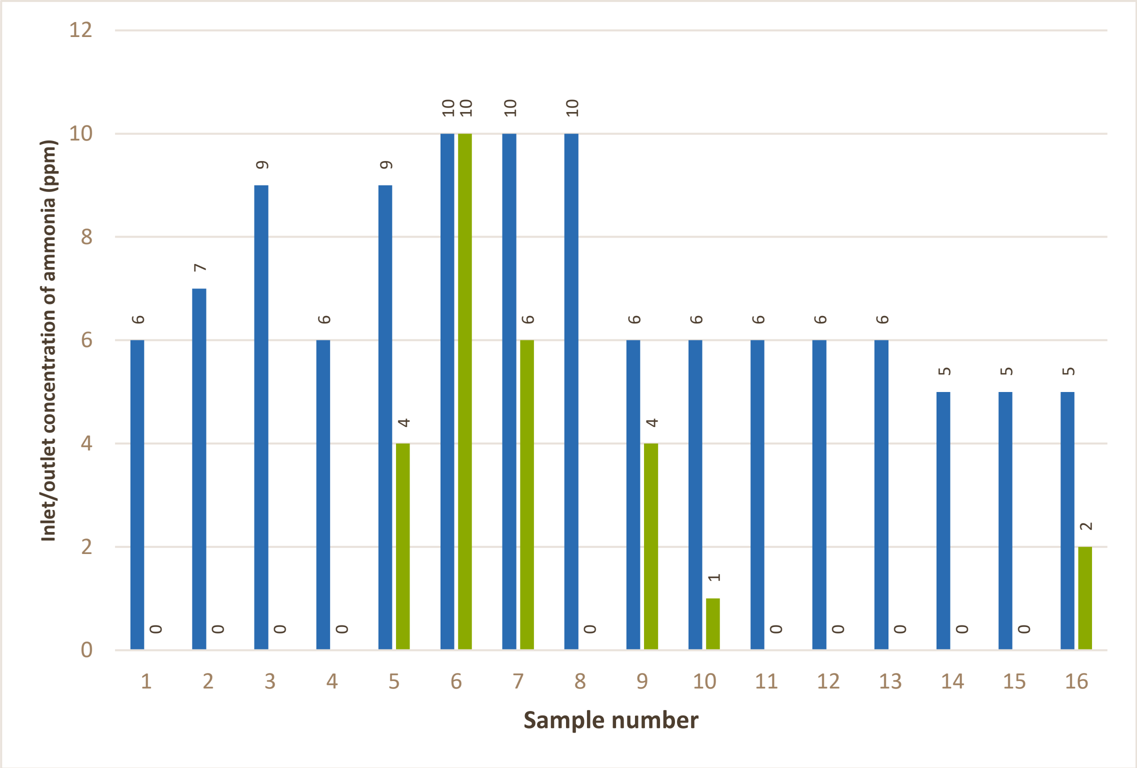
Ammonia reduction

1st composting phase



Average removal efficiency: 50%

2nd composting phase

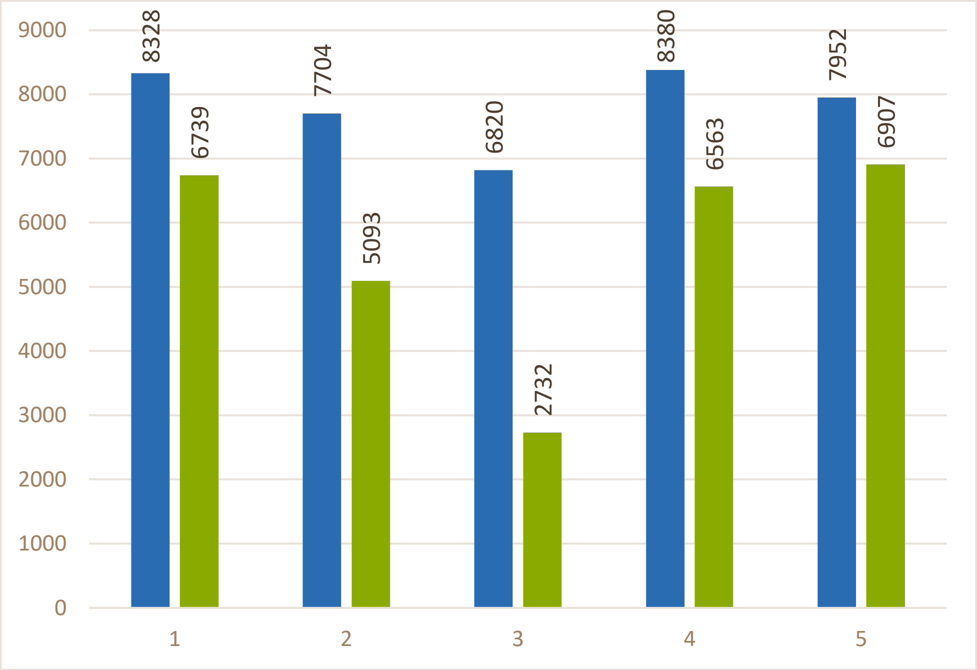


Average removal efficiency: 80%

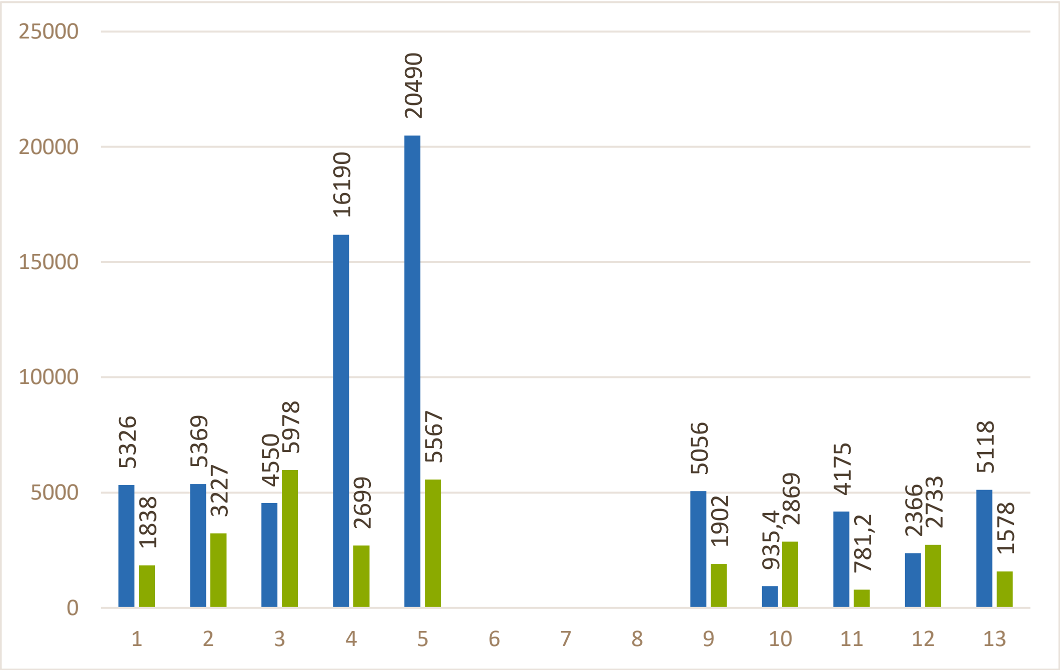
Flowrate: 0,8 m^3/h, Energy density: about 1,2 Wh/Nm^3

Heksane reduction

1st composting phase



2nd composting phase



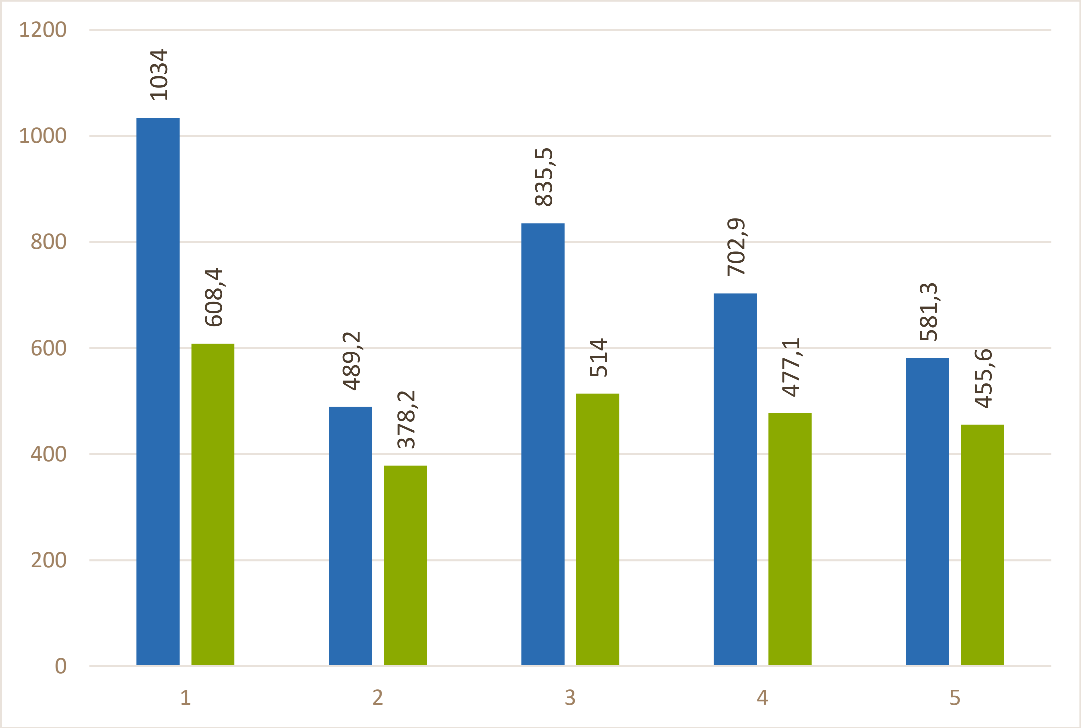
Average removal efficiency: 30%

Average removal efficiency: 22%

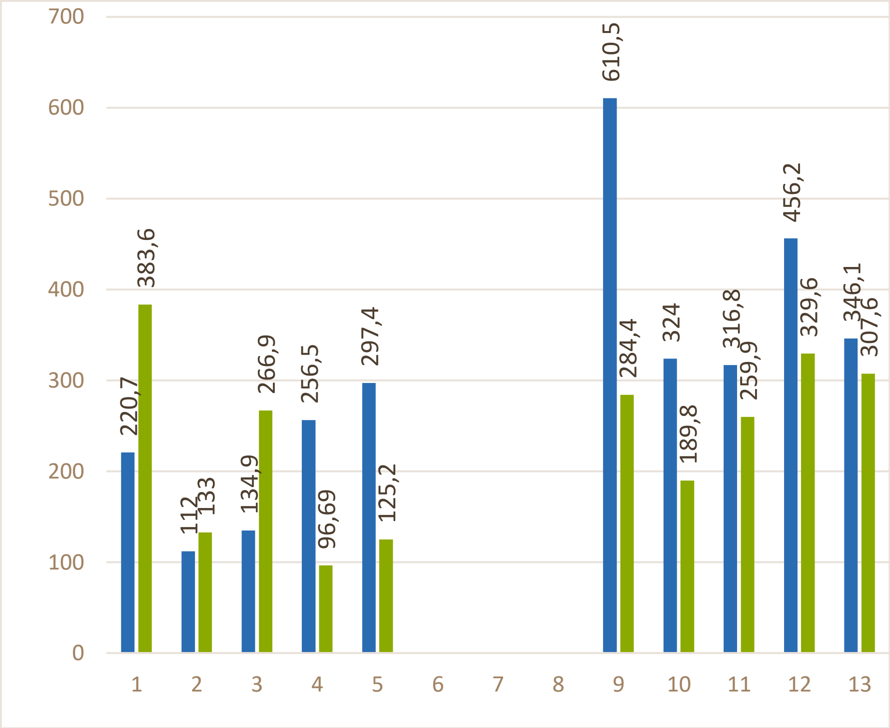
Flowrate: 0,8 m^3/h, Energy density: about 1,2 Wh/Nm^3

Toulene reduction

1st composting phase



2nd composting phase



Average removal efficiency: 31%

Average removal efficiency: 8%

Flowrate: 0,8 m^3/h, Energy density: about 1,2 Wh/Nm^3

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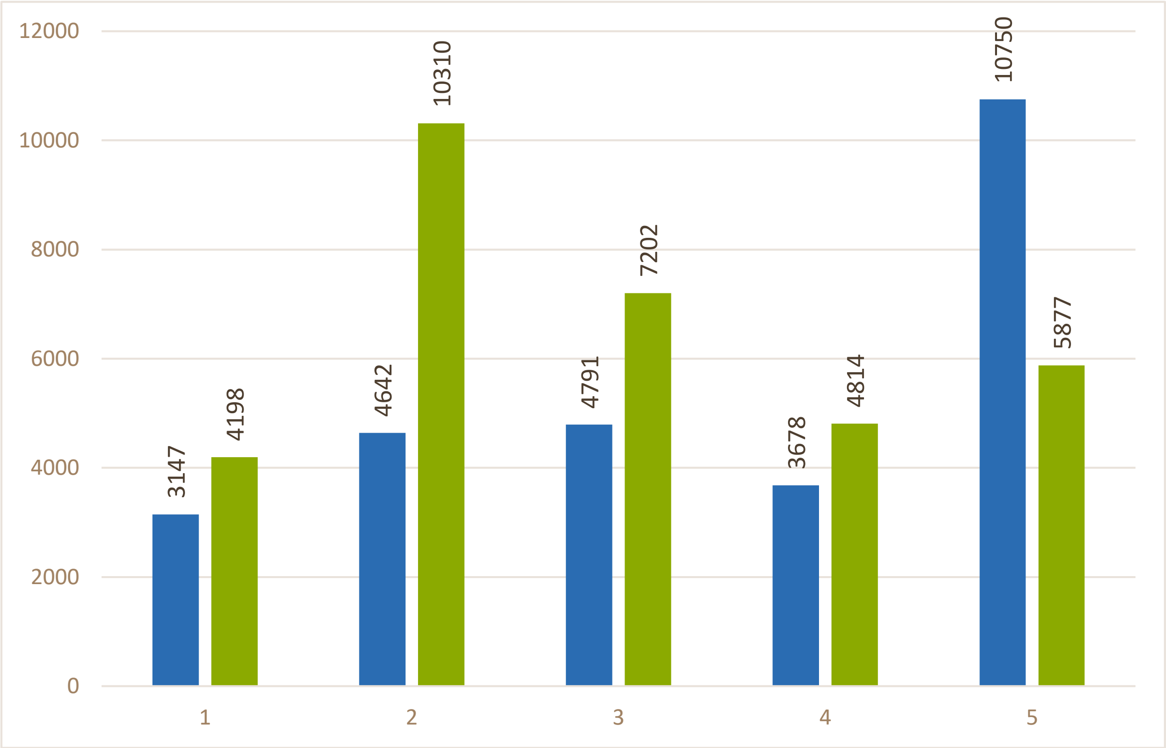
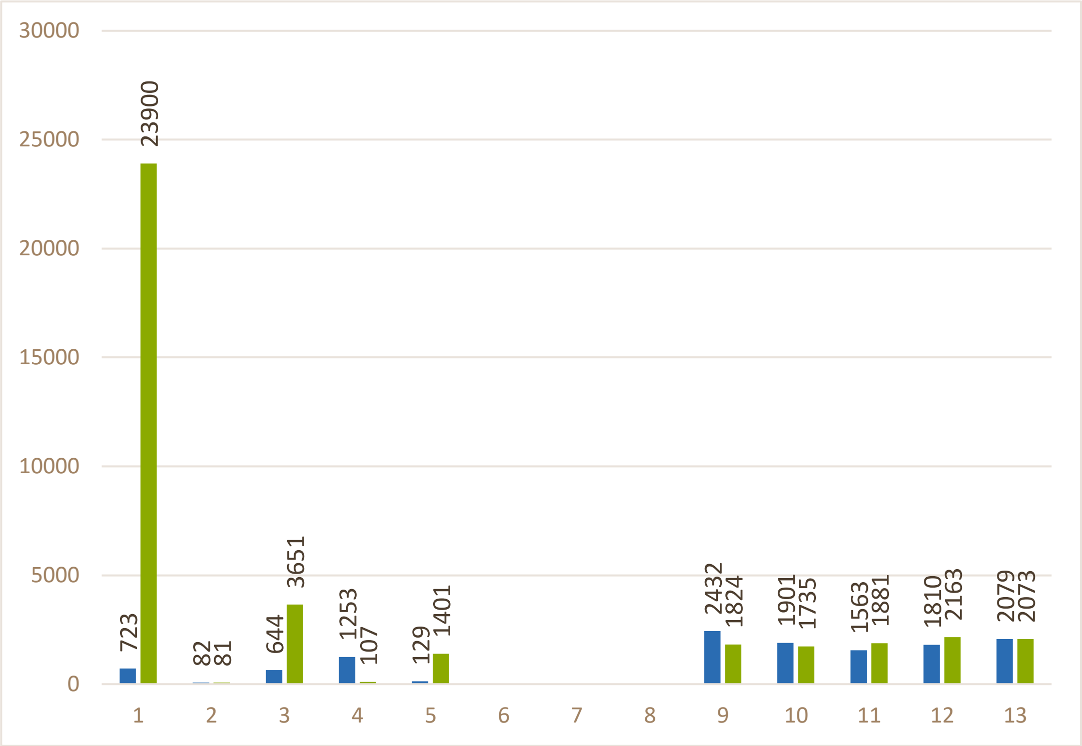
Benzene reduction/production?

1st composting phase



Average **production** efficiency: 38%

2nd composting phase



Average **production** efficiency: 150%

Flowrate: 0,8 m^3/h, Energy density: about 1,2 Wh/Nm^3

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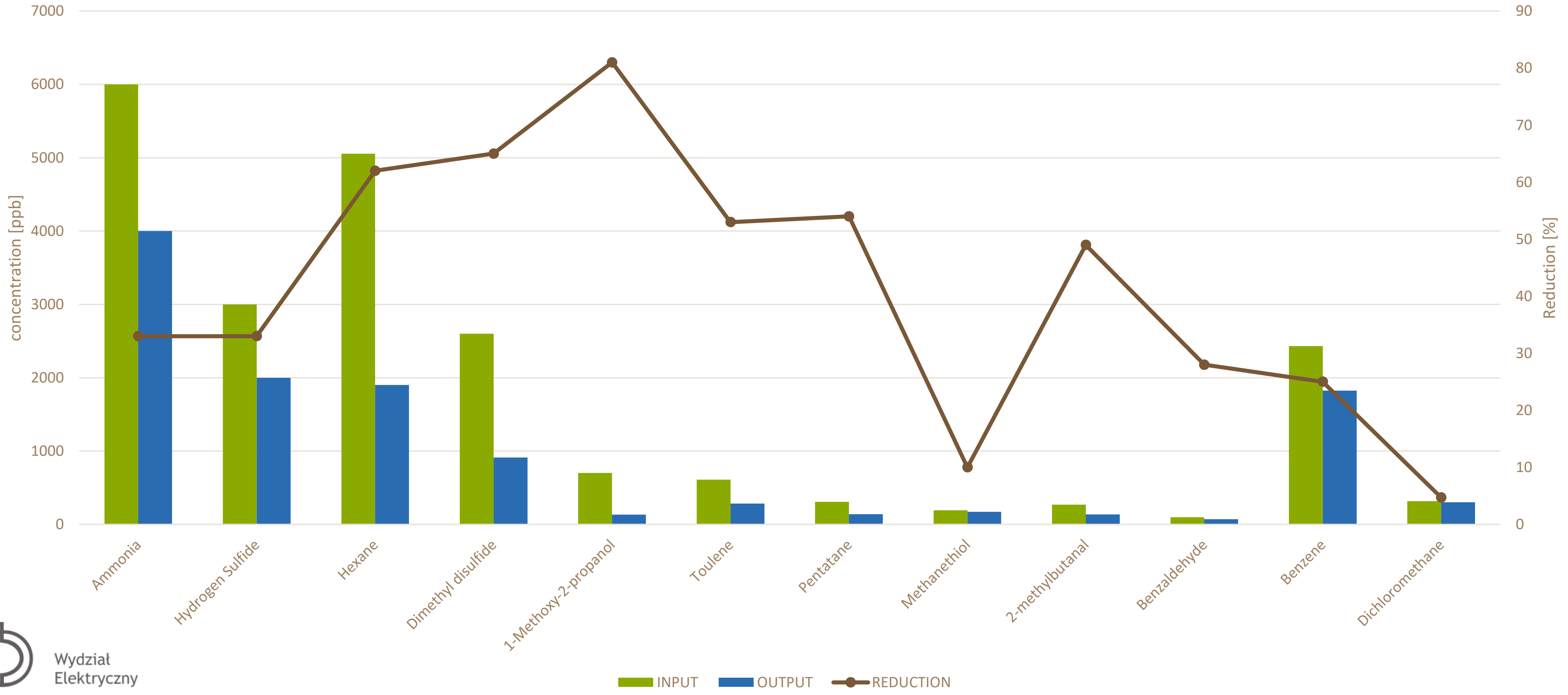
Average reduction: first phase: 25 % (of all compounds)
second phase: 40 % (of all reductive compounds)



(semi-industrial) reactor

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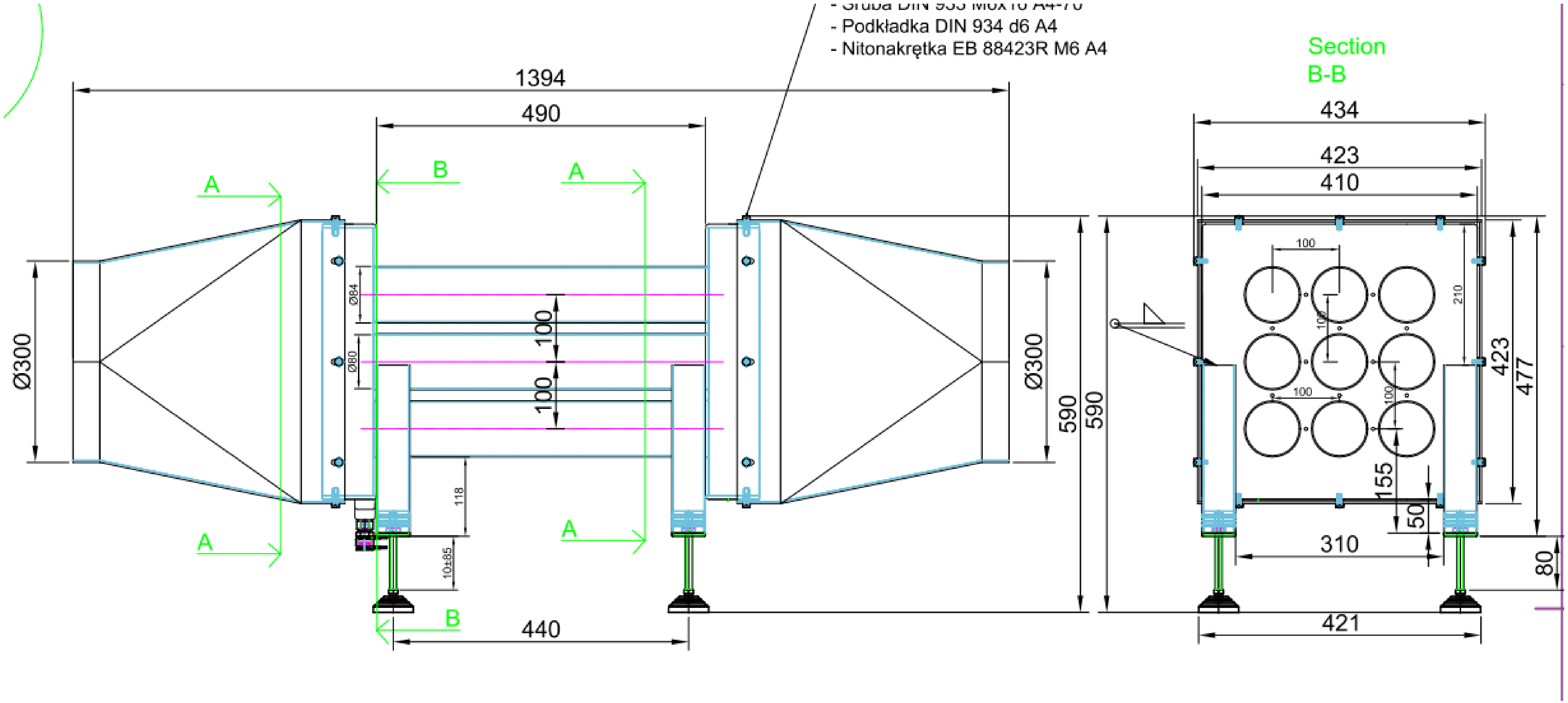
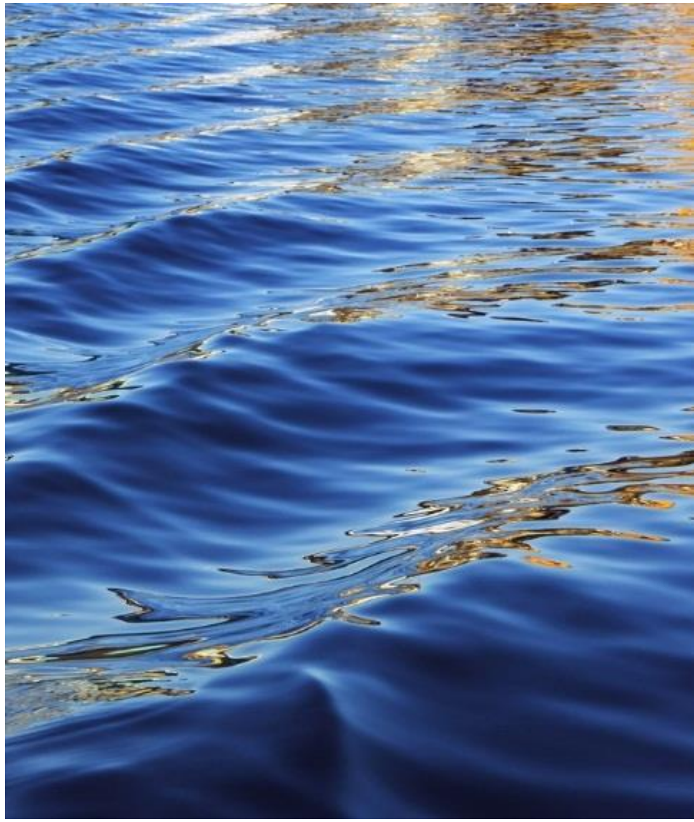


Flowrate: 5 m^3/h

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

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Thank You

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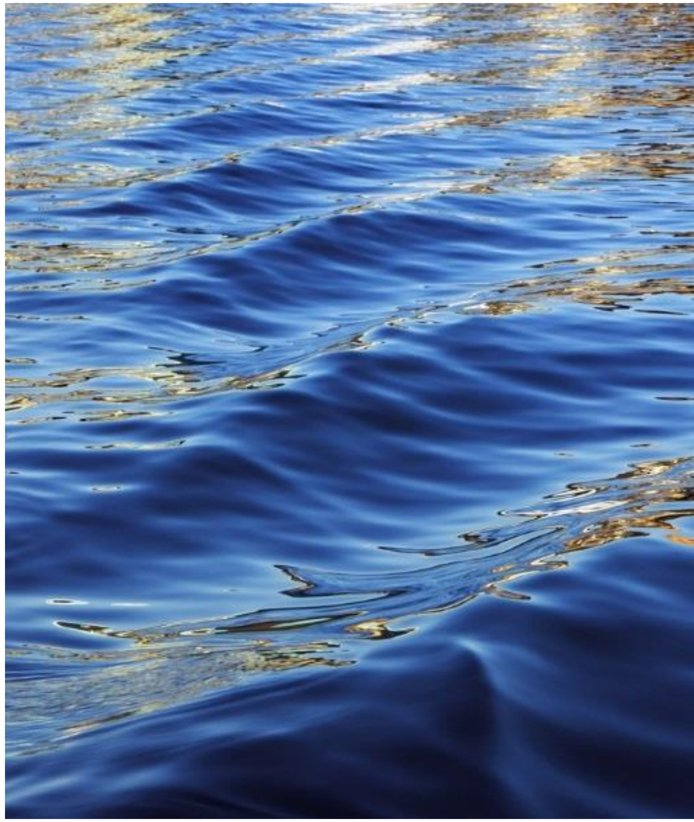

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