Degradation of micropollutant by hydrocavitation/ozone

Amit Kumar[1*], Ysabel Huaccallo-Aguilar[1], Sebastian Felix Reinecke[1], Markus Meier[2], Uwe Hampel[1,3]

[1]CLEWATEC, Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany

[2]AIR LIQUIDE Forschung und Entwicklung GmbH, Gwinnerstraße 27-33, 60388 Frankfurt, Germany

[3]Chair of Imaging Techniques in Energy and Process Engineering, Technische Universität Dresden, 01062 Dresden, Germany

18 HELMHOLTZ CENTRES

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

JÜLICH
FORSCHUNGSZENTRUM

GSI

+ Helmholtz Institutes
Jena and Mainz

KIT
Karlsruher Institut für Technologie

DESY
Hamburg and Zeuthen

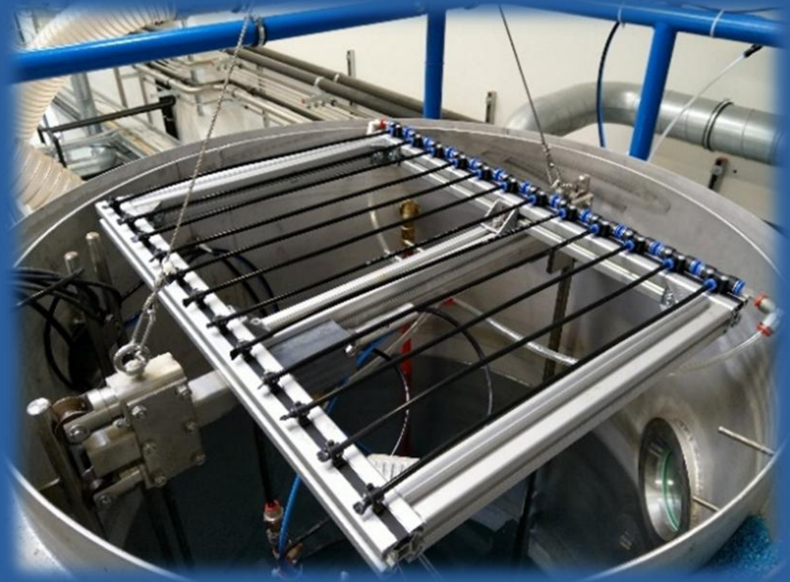
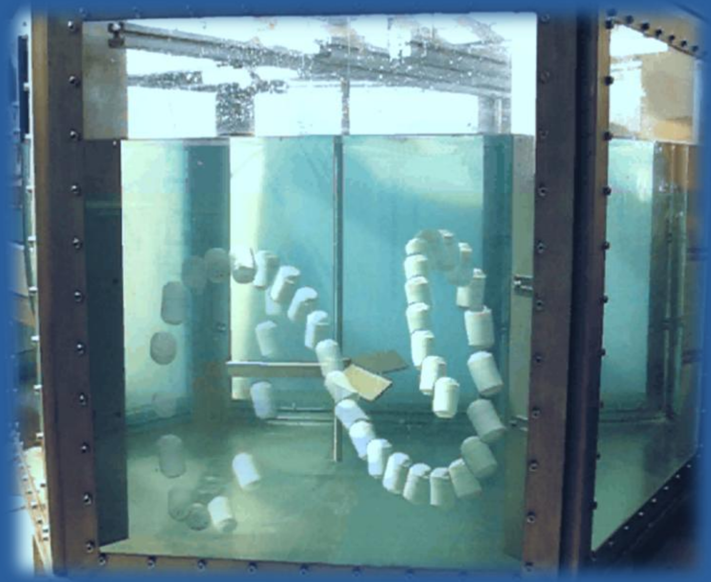
HZB Helmholtz Zentrum Berlin

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

DRESDEN concept
SCIENCE AND INNOVATION CAMPUS

HZDR

The Clean Water Technology Lab CLEWATEC – Helmholtz Innovation Lab

CLEWATEC
Competence Center for Clean Water Technology
at HZDR

A Helmholtz Innovation Lab

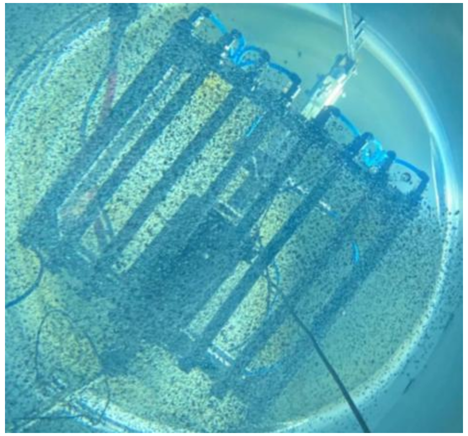
Group of Efficient Wastewater Treatment

The Helmholtz Innovation Lab **CLEWATEC** is an interface between research and industry,
Connecting the resources and actors necessary for water innovation

DRESDEN concept
SCIENCE AND INNOVATION CAMPUS

HZDR

The Clean Water Technology Lab CLEWATEC – Helmholtz Innovation Lab

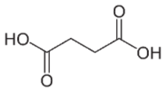


Advanced oxidation process (AOP)

Efficient aeration systems

Process characterization

Energy water sector coupling



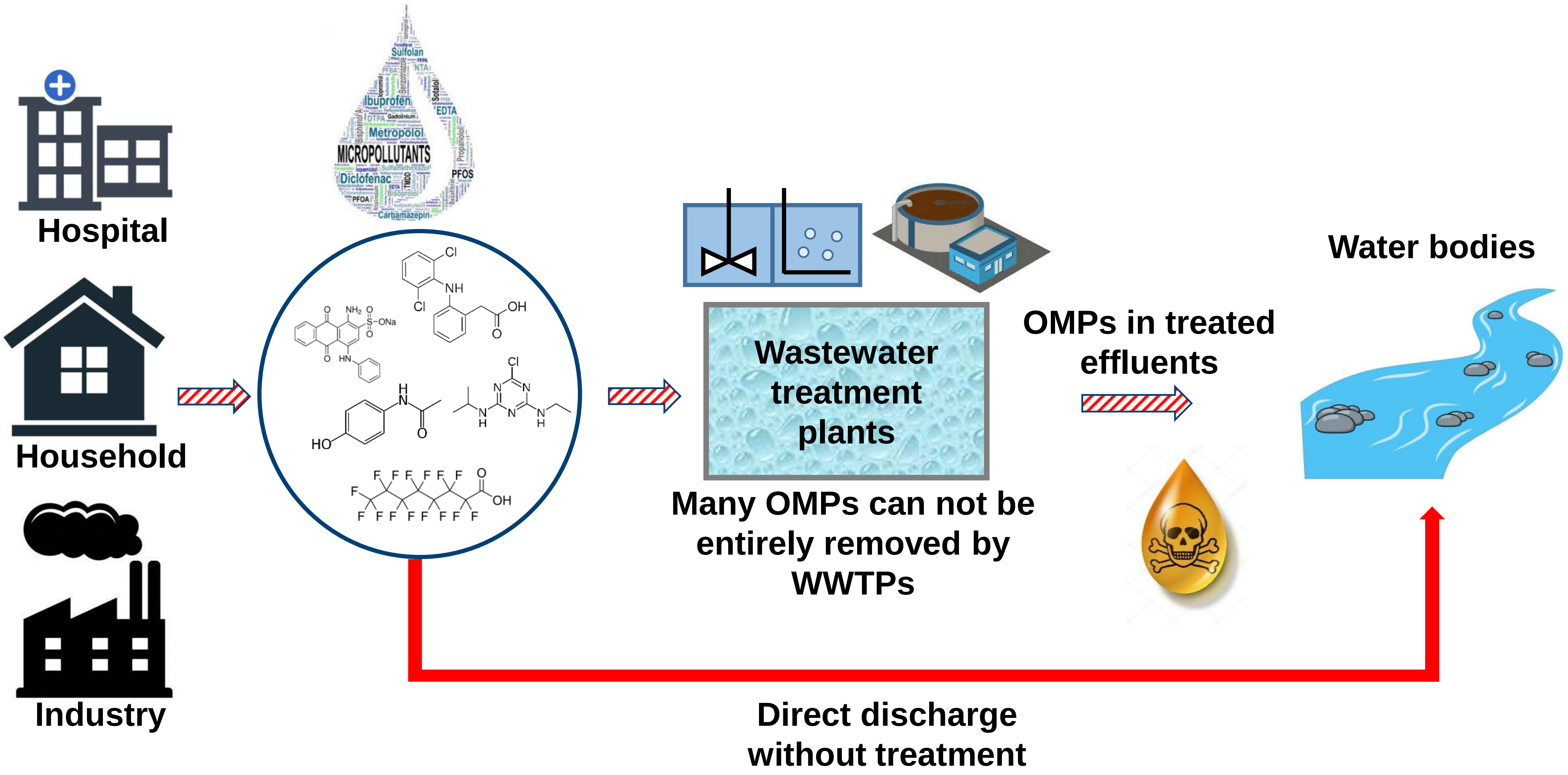
PFOS

CLEWATEC
Competence Center for Clean Water Technology
at HZDR

DRESDEN concept
SCIENCE AND INNOVATION CAMPUS

HZDR

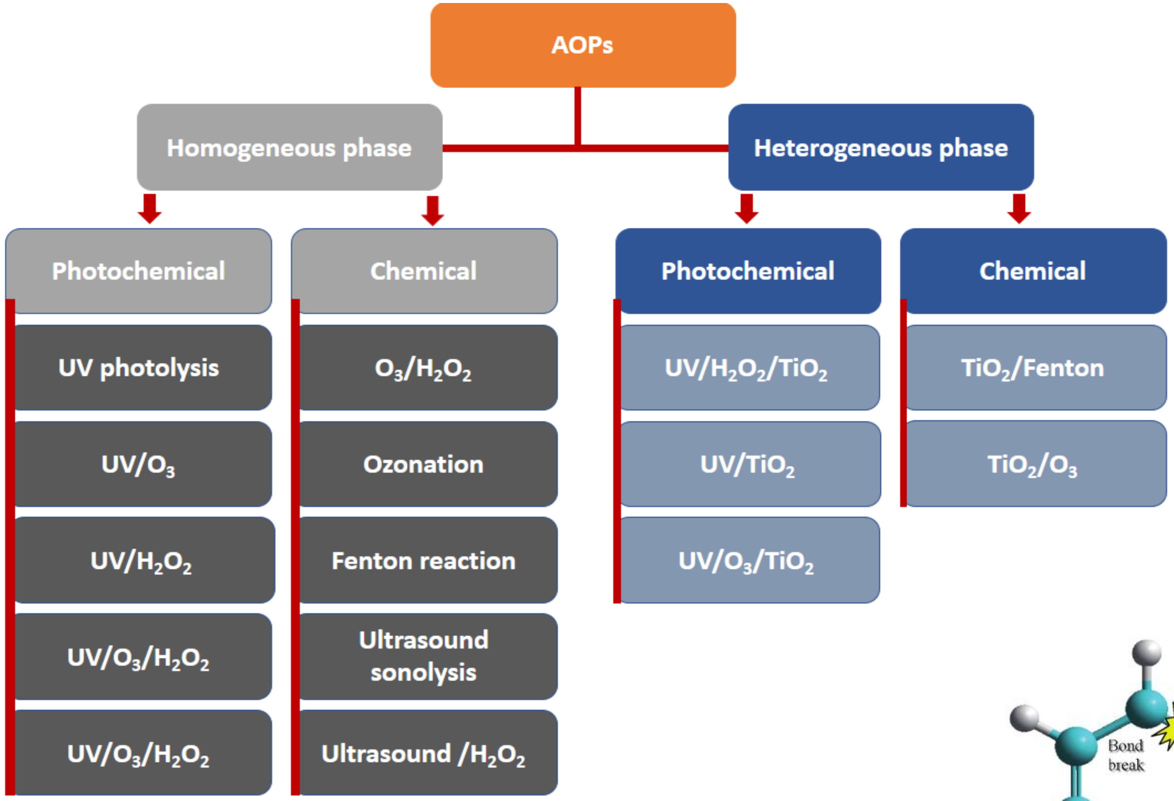
Organic micropollutants (OMPs)



Kumar et al.

Advanced oxidation processes (AOPs)

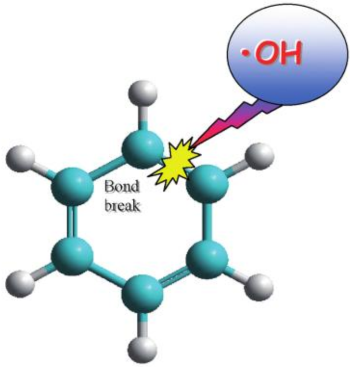
WWTPs ⇒ **Advanced treatment**



Processes	Reactions
H_2O_2 – Fenton	$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + \mathbf{HO\bullet} + OH^-$
UV/TiO_2	$TiO_2 + hv \rightarrow e^- + h^+$ $h^+ + H_2O \rightarrow H^+ + \mathbf{HO\bullet}$
O_3/H_2O_2	$2O_3 + H_2O_2 \rightarrow 2\mathbf{HO\bullet} + 3O_2$
UV/H_2O_2	$H_2O_2 + UV \rightarrow 2\mathbf{HO\bullet}$
UV/H_2O_2/O_3	$2O_3 + UV + H_2O_2 \rightarrow 2\mathbf{HO\bullet} + 3O_2$
Ultrasound/UV/O_3	Ultrasound + UV + $O_3 \rightarrow \mathbf{HO\bullet}$

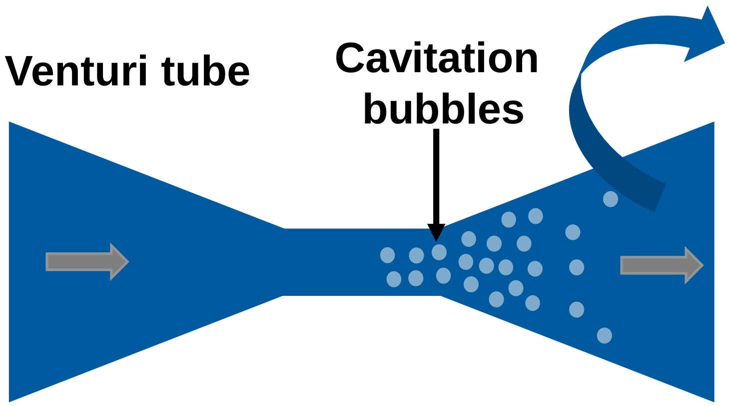
Degradation rate **$k \approx 0.1\text{-}10 \times 10^9\ M^{-1}s^{-1}$**
(for most organic pollutants)

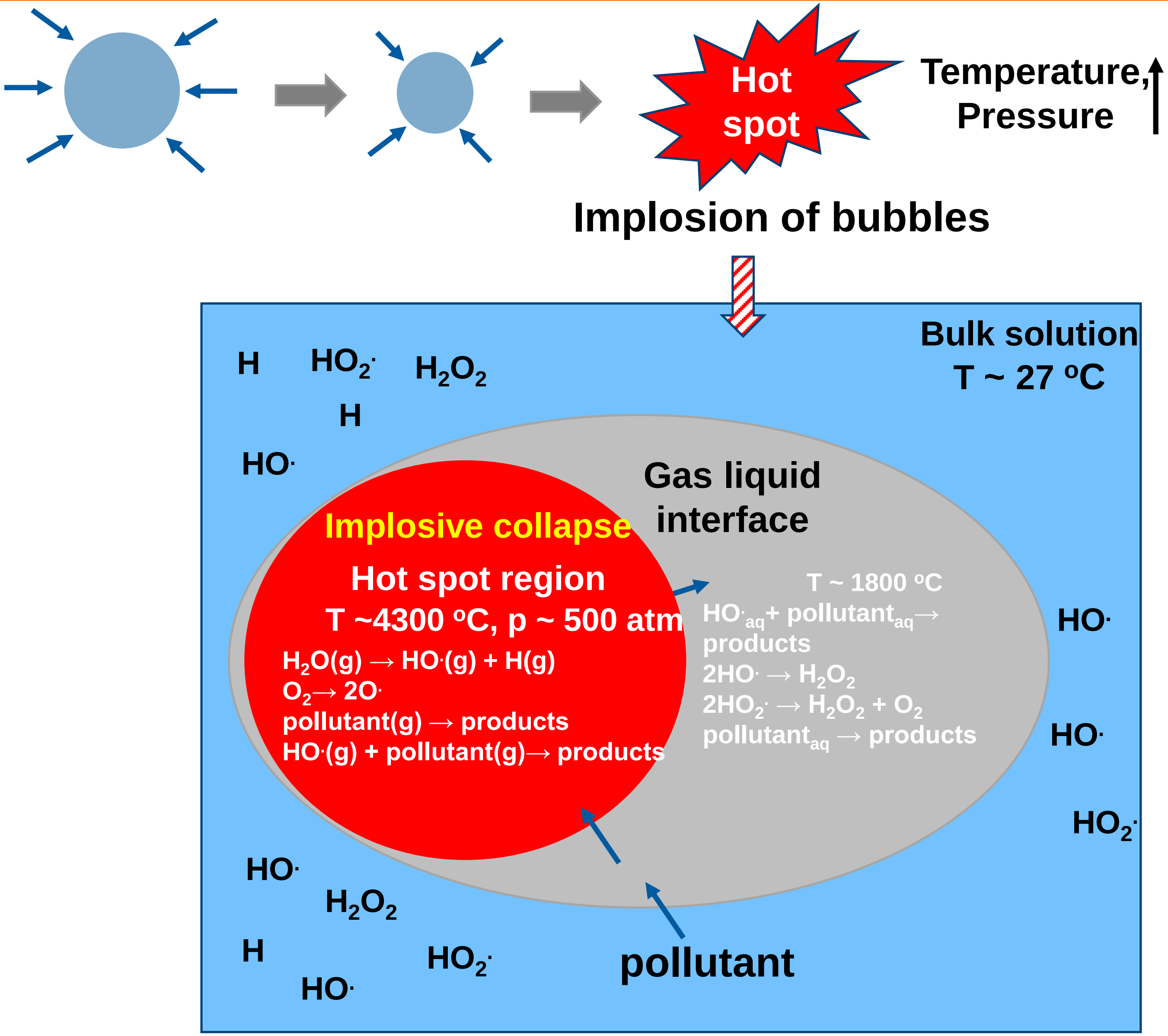
HO• + Pollutant → Products



Non-selective chemical oxidant

Hydrodynamic cavitation for wastewater treatment





Implosion of bubbles

⇓

HO· and other radicals

⇓

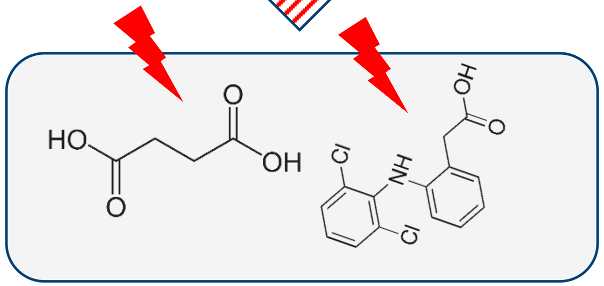
Degradation of pollutants

Gagol et al. 2018, https://doi.org/10.1016/j.cej.2018.01.049

Hydrodynamic cavitation (HC) combination with ozone (O_3)

Hydrodynamic cavitation + **Ozone** → HO· O HO· HO· O

More radicals



$$O_3 \rightarrow O\cdot + O_2$$

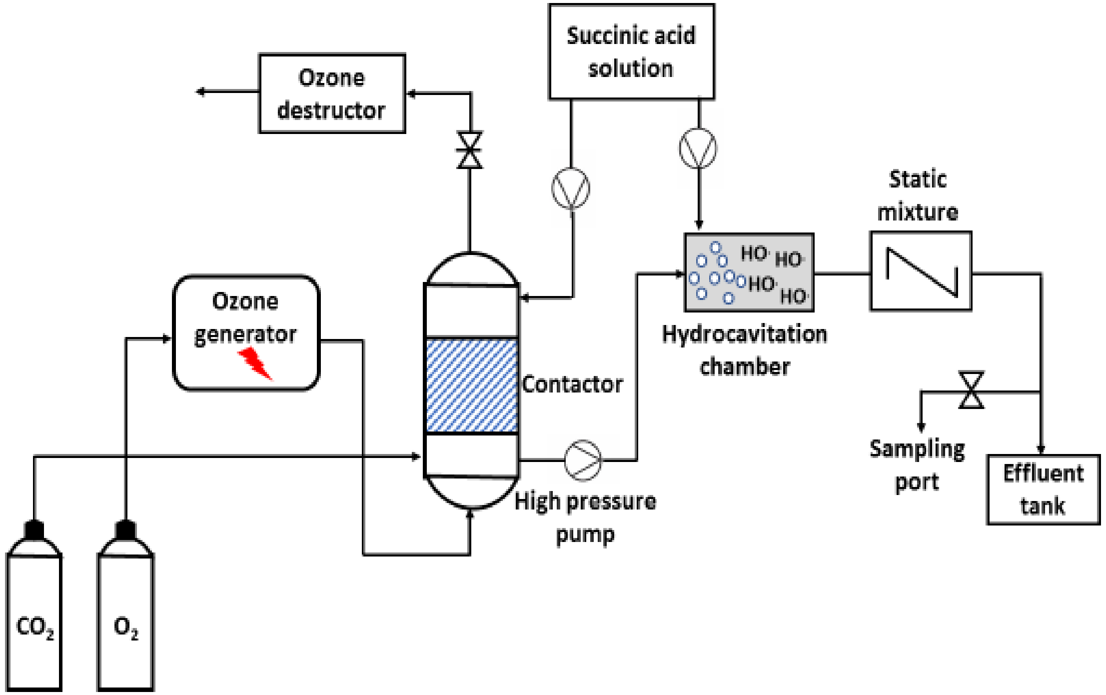
$$O\cdot + H_2O \rightarrow 2HO\cdot$$

At cavitation con..

Effective degradation of micropollutants

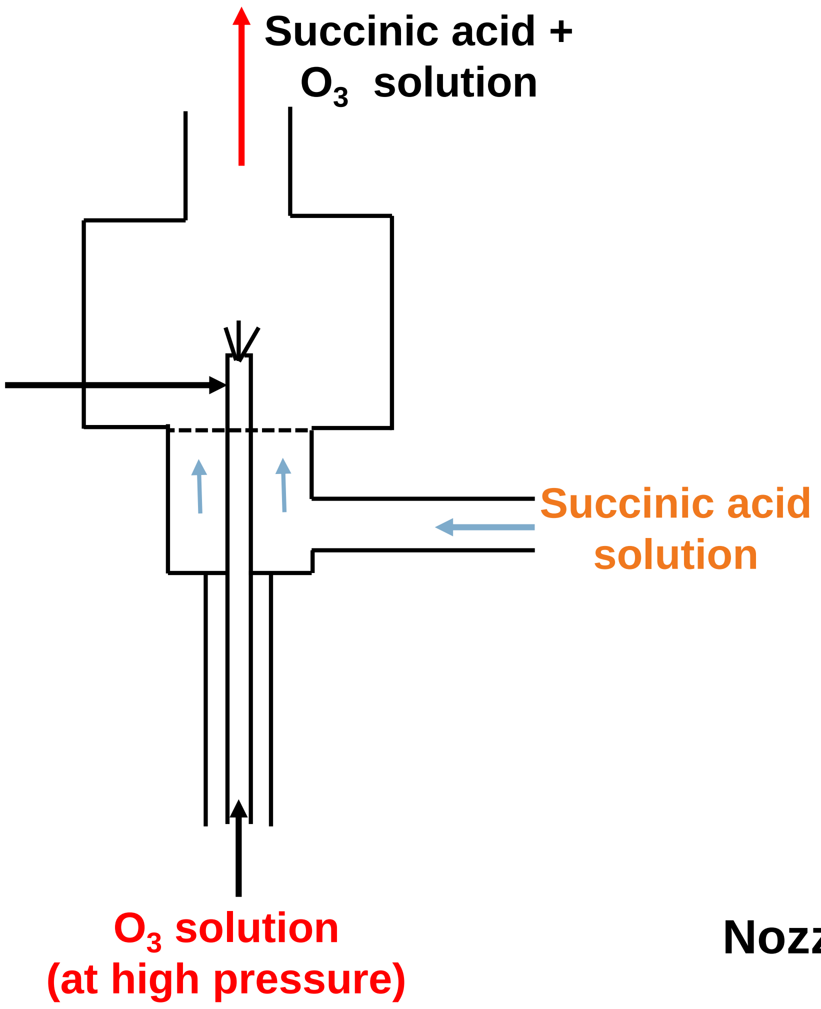
Gagol et al. 2018, https://doi.org/10.1016/j.cej.2018.01.049

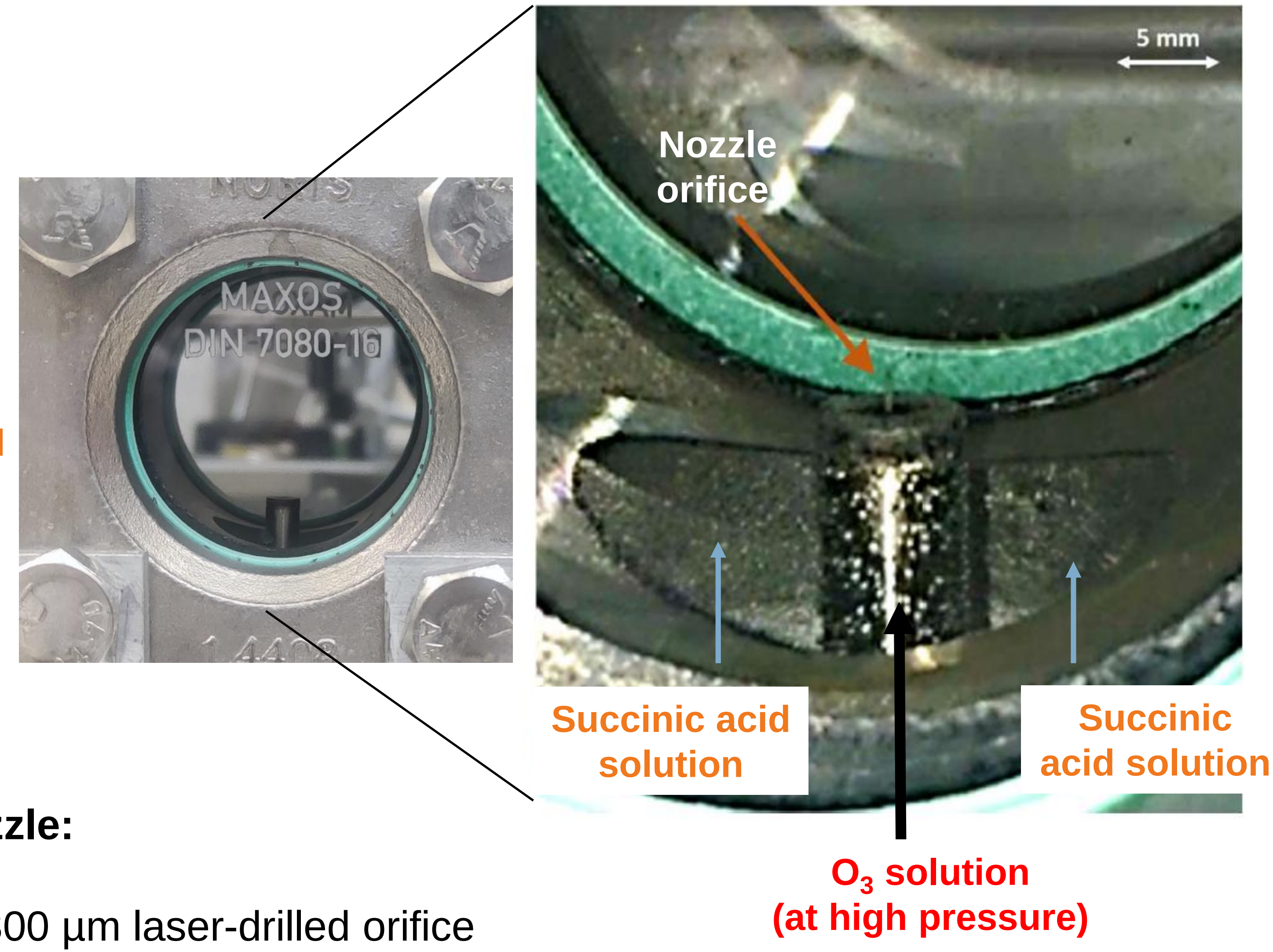
HC + O_3 experimental setup



Technical specifications	
O_3 contactor volume	5 L
O_3 reservoir pressure	≤ 10 bar
Nozzle upstream pressure	2 – 50 bar
O_3-Generator	≤ 8 g/h
Process water flow	10 – 100 L/h
Residence time in HC-Chamber	~30 seconds

HC reaction chamber





Nozzle:

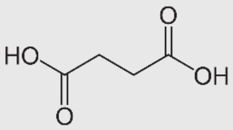
- 300 µm laser-drilled orifice
- 6 mm OD and 4 mm ID steel pipe
- Injection in co-current flow

Experimental conditions

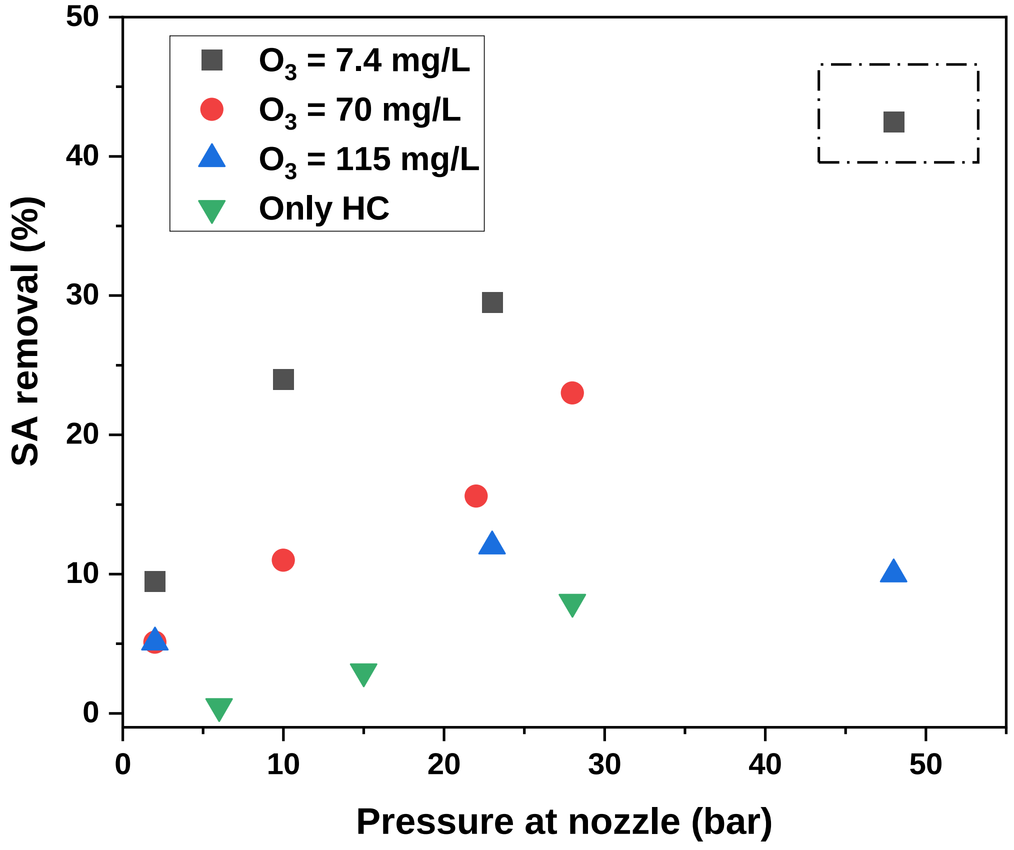
	P_{nozzle} (bar)	O_3 dosage (mg/L)	Q_{nozzle} (l/h)	Q_{feed} (l/h)	O_3 dosage ($\cdot 10^{-3}$ mg O_3/mg pollutant)
HC + OSW	2	**115**	3	17.9	163.3
	23	**115**	14	17.9	488.9
	48	**115**	15	17.9	518.5
	2	**70**	3	17.6	102.3
	10	**70**	9	17.6	237.7
	22	**70**	13.2	17.6	301.2
	28	**70**	15	17.6	323.3
HC + O_3	2	**7.4**	2.7	18.2	8.4
	10	**7.4**	6	18.2	16.2
	23	**7.4**	9	18.2	22.6
	48	**7.4**	15	18.2	29.5
Only HC	6	**0.0**	3.6	18.2	0.0
	15	**0.0**	2.7	18.2	0.0
	28	**0.0**	1.8	18.2	0.0

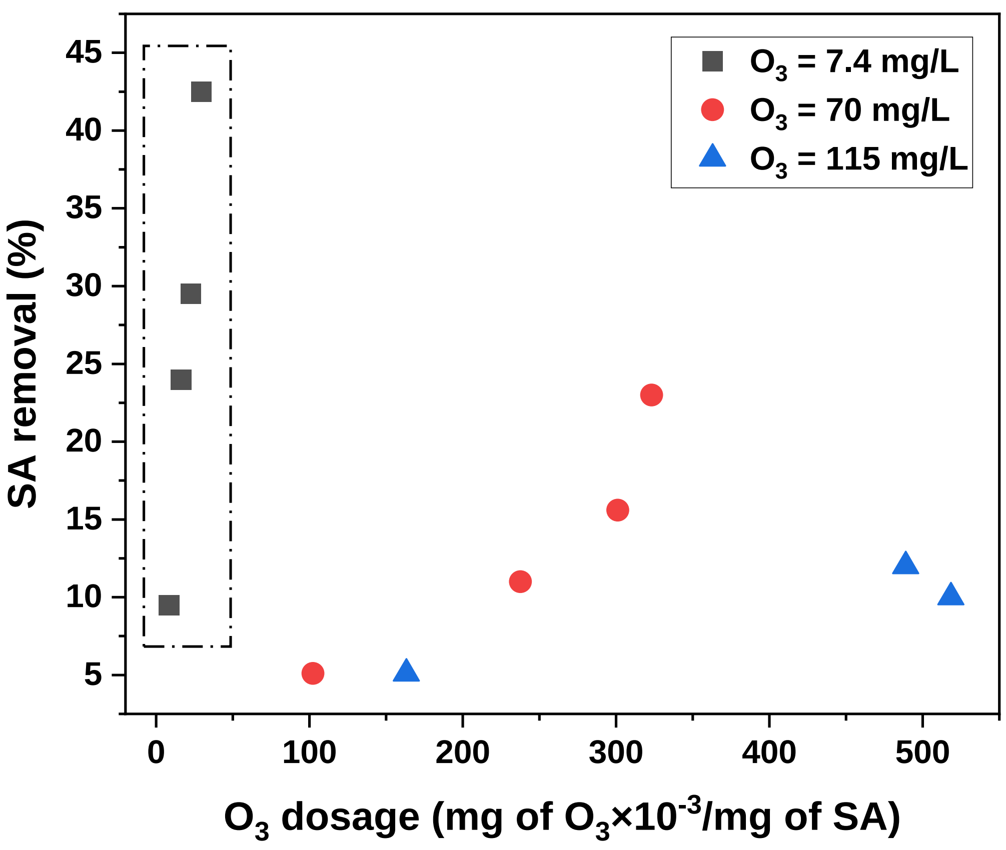
Succinic acid (SA) as persistant pollutant

- High selectivity for oxidation by HO· **($k_{HO} = 10^{11} kO_3$)**

Chemical formula	Structure	Physical state	M.W. (g/mol)	Solubility in water (g/L)
$C_4H_6O_4$		Crystalline	118.09	83

Experimental results



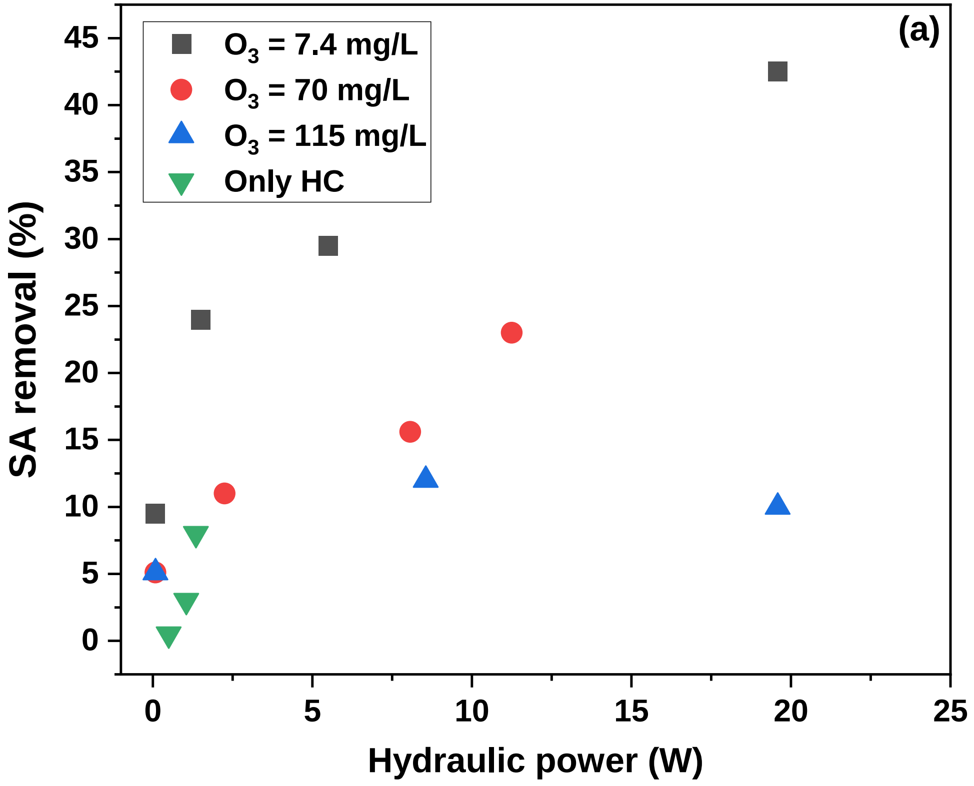


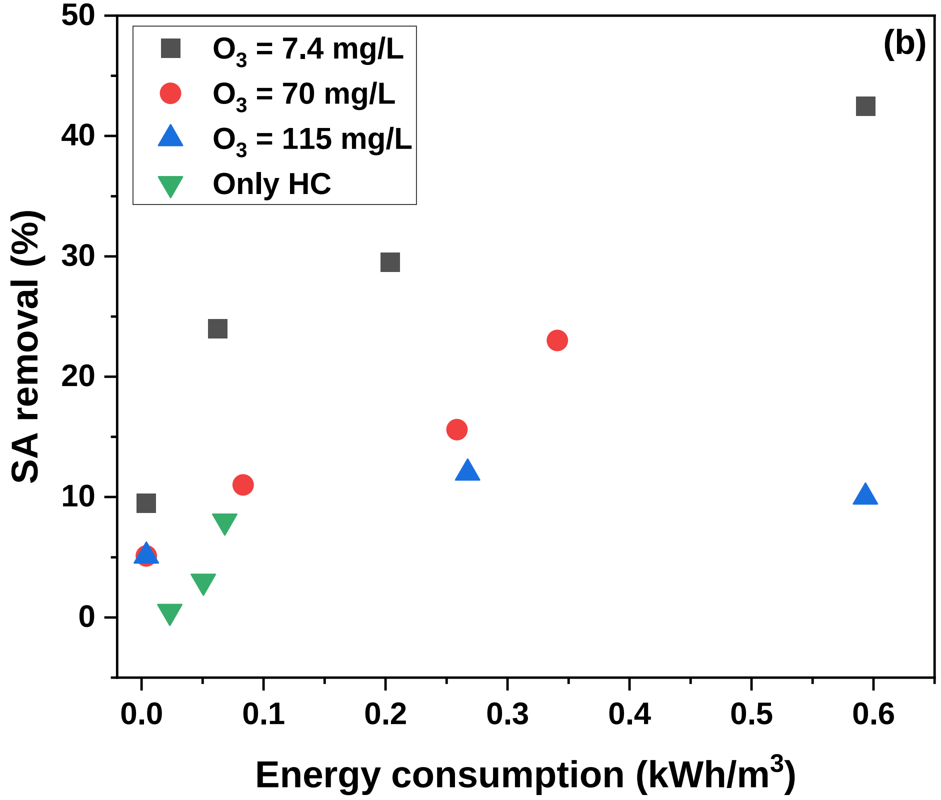
Higher removal at higher nozzle pressure and low ozone dosage

DRESDEN concept SCIENCE AND INNOVATION CAMPUS

HZDR

Experimental results





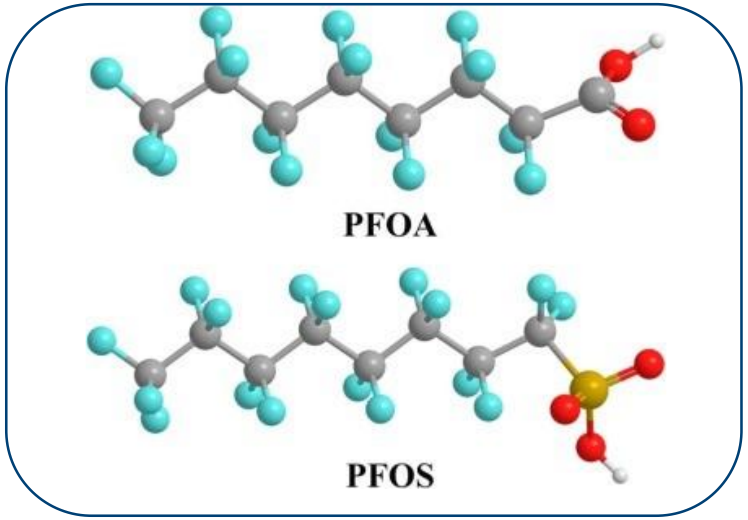
$$\text{Hydraulic power } (W) = (p_{\text{nozzle}} - p_{\text{chamber}}) \times Q_{nozzle}$$

Energy consumption < 1 kWh/m³ for 41 % removal of pollutant

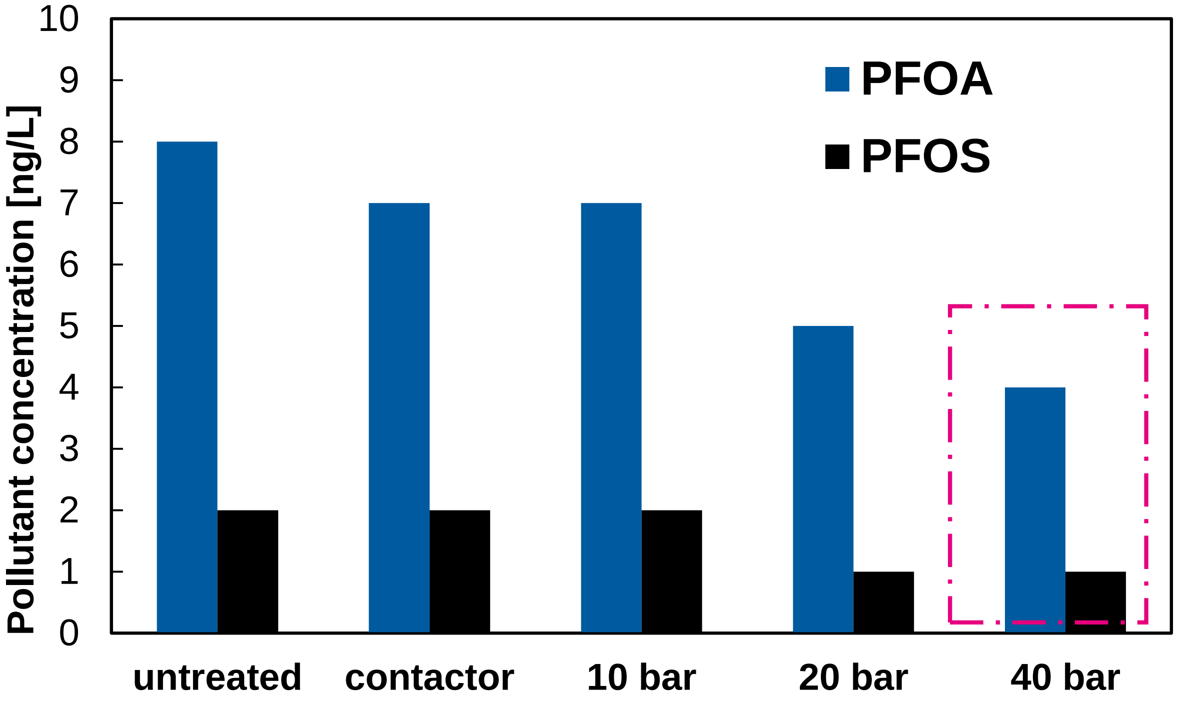
DRESDEN concept
SCIENCE AND INNOVATION CAMPUS

HZDR

WWTP effluent test: PFOS and PFOA treatment



- Perfluorooctanoic Acid (PFOA) and Perfluorooctyl Sulfonate (PFOS)
- **Forever chemicals**
- Stable due to C-F bond
- Less reactive with strong oxidants (HO·)



48 % removal at nozzle pressure of 40 bar

DRESDEN concept SCIENCE AND INNOVATION CAMPUS

HZDR

Summary and conclusions

- The current study demonstrated the utilization of **HC combined with O_3** for the elimination of emerging contaminants

- The combination treatment increased the pollutant degradation, which is a sign for increased amount of $HO^{\cdot}$ generation

- Several experimental parameters (nozzle pressure and O_3 dosages) were evaluated in the treatment, and their effect on pollutant removal was investigated

- **Lower O_3 dosages and higher nozzle pressure** were found to have a beneficial effect on pollution reduction (*40 % > reduction of succinic acid, PFOS, and PFOA*)

- Lower energy consumption ($1 < kWh/m^3$) was achieved as compared to published data (related to HC)

- The results indicated that HC + O_3 could be a promising and novel wastewater treatment solution

THANK YOU FOR YOUR ATTENTION

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

CLEWATEC

Competence Center for Clean Water Technology at HZDR

Air Liquide

ACKNOWLEDGEMENTS

This work is partly funded by the Initiative and Networking Fund of the Helmholtz Association in the frame of the Clean Water Technology Lab CLEWATEC- a Helmholtz Innovation Lab under the reference number HIL-A02

DRESDEN concept