INTERNATIONAL OZONE ASSOCIATION

Europe Africa Asia Australasia Group

INTERNATIONAL CONFERENCE

EA3G2022
28 - 30 November 2022
Toulouse, France

Ozone and Advanced Oxidation

Science, technologies and applications for a better world

PROGRAMME

BOOK OF ABSTRACTS

General Sponsor

Resourcing the world VEOLIA

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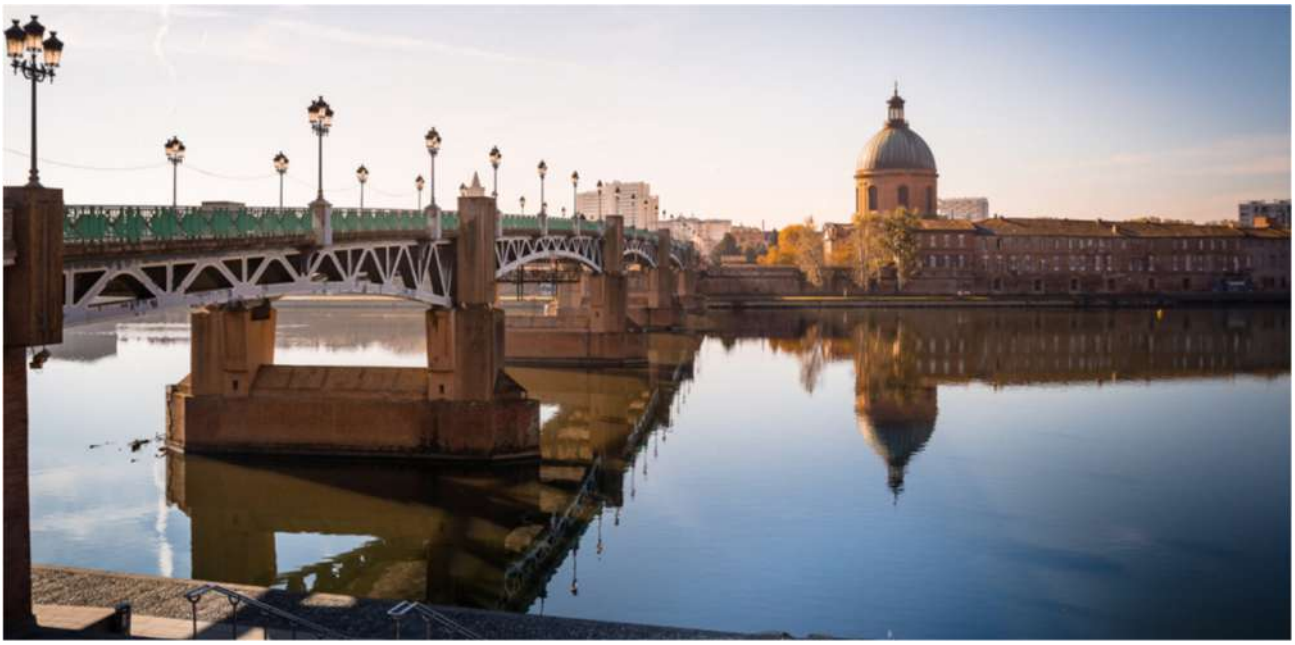

CONTENTS

WELCOME ADDRESS

The European African Asian Australasian Group of the International Ozone Association presents its EA3G2022 International Conference & Exhibition on Ozone and Advanced Oxidation – Science, Technologies and Applications for a Better Word.

This event was organised to be held in Toulouse thanks to the collaboration with INSA, National Institute of Applied Science,Toulouse, France.

EA3G2022 renews with a long series of successful conferences which were organised to provide an international forum for all concerned including fundamental, engineering and applied aspects of oxidation techniques involving ozone and advanced oxidation systems.

Population growth associated with increases in urbanization, in consumption, in industrialization, in pollution emissions already lead to shortages of water, food, raw materials and globally to climate change. However, climate and earth-resilient development is still possible by devoting greater efforts to certain key sectors: reduction of emissions to air, better resources management and preservation of the natural ecosystems. This involves particularly the implementation of advanced technologies.

EA3G2022 conference thus aims to present an overview of the current state of knowledge and latest advances regarding the use of Ozone and Advanced Oxidation to provide solutions face to these challenges.

We would like to express our gratitude and thanks to all of you who contributed to make this event possible: INSA Toulouse staff under the leadership of M. Pic Service de l'Eau, keynote speakers, authors, exhibitors, sponsors, Association' members, chairpersons and members of the Committees.

We wish you a very enjoyable and fruitful Conference.

On behalf of the IOA-EA$_3$G Organising Committee

Sylvie Baig,
IOA-EA$_3$G President

> The Organizer IOA-EA$_3$G

The International Ozone Association is a non-profit organization dedicated to the development of educational and scientific activities to respond at the best to the needs of industry and research community in the field of ozone and derived oxidants. Since its foundation in 1973, the IOA is at the forefront in connecting professionals around the globe involved and interested in ozone-related issues including scientists, researchers, engineers, system designers, technologists, equipment manufacturers, consultants, users and members of governmental agencies.

Typical topics covered in the activities program are ozone generation, secondary oxidant generation, gas mass transfer, chemical reactions of ozone in gas and liquid phases, engineering aspects, water treatment for disinfection and pollutants removal, oxidation for food processing, for pulp bleaching, for products manufacture and conditioning, development of analytical procedures and materials, development of equipments for ozone use, development and applications of advanced oxidation processes, safety and health effects.

The EA$_3$G group of IOA manages IOA membership in Europe, Africa, Asia and Australasia.

www.ioa-ea3g.org

COMMITTEES

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Dr. Sylvie Baig | Head of Scientific Innovation, Suez, France
Pr. Stephan Brosillon | Department Manager, Polytech Montpellier, France
Pr. Santiago Esplugas | Department Manager, University of Barcelona, Spain
Dr. Jean-Stéphane Pic | Assistant Professor, INSA Toulouse, France
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Pr. Chedly Tizaoui | Professor, Swansea University, UK
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Dr. Jean-Stéphane Pic | Assistant Professor, INSA Toulouse, France
Dr. Frédéric Violleau | Research Director, Ecole d'Ingénieurs de Purpan, France

SPECIAL ACKNOWLEDGEMENTS AND CONTRIBUTIONS

The success in the organization of this event results from the strong and faithful involvement of many individuals, from the support of exhibiting companies, from the generous contribution of the sponsors and from the partnership with INSA Toulouse.

The Organizers would like herewith to acknowledge the support given by the following partners:

www.insa-toulouse.fr

INSA Toulouse
Organization partner and conference host
National Institute of Applied Science

Soutenu par

www.ademe.fr
https://transitions2050.ademe.fr/

ADEME
Institutional Support
Environmental and Energy Management Agency

www.eau-grandsudouest.fr

Agence de l'Eau – Comité de Bassin Adour-Garonne
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www.watertechnologies.fr

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EXHIBITION

www.alphatech-ozone.fr

ALPHATECH Ozone System

Alphatech Ozone System has specialized since 2009 in the design, manufacture and commissioning of systems to treat air, surfaces and water with ozone.

System development for disinfection by air, treatment of cooking water, process water, disinfection tunnel.

https://arrowlake.se

ARROW LAKE

Arrow Lake - Much more than robust ozone technology.

Arrow Lake was founded in 2016 with a clear mission - to design and manufacture robust, industry-proofed ozone technology and decrease dependency on harmful yet, widely accepted water and air treatment practices. The company is located in Malmö, Sweden, where we manufacture our ozone technology and perform application tests.

However, what makes Arrow Lake truly unique is our team of passionate and dedicated experts covering all from Research and product development to applied ozone solutions. The team brings decades of outstanding, hands-on expertise from numerous industries, enthusiasm, and curiosity to look for new ways.

The result of the unique Arrow Lake culture is our Water Quality Management System FLO_3W® – an intelligent, demand-oriented system providing complete control of the process, and reliability in its efficacy, despite changing water quality parameters during the production cycle.

www.bmt-berlin.de

BMT MESSTECHNIK GmbH

For more than 35 years **BMT Messtechnik GmbH** has been specialized in photometric measurement of ozone in air, oxygen, and water. BMT is the technology leader in the measurement of ozone and we are committed to providing measuring devices with the highest accuracy, durability and longevity on the market. We offer an extensive range of devices to guarantee a solution to every conceivable problem. BMT is also providing small and advanced air cooled ozone generators for ozone experiments and for small scale ozone systems. Our ozone instruments are used worldwide in many kinds of ozone applications such as: semiconductor, pharmaceutical, ballast water treatment, medical, and chemical. For ozone treatment of water and waste water BMT offers complete solutions for all points of ozone measurement in a plant.

www.purpan.fr

Ecole d'Ingénieurs de PURPAN

Ecole d'Ingénieurs de PURPAN is engineering school in life sciences. Its Research, Development and Consulting activity is focus on service to industrial and socio-economic partners. In this context, PURPAN has developed a research platform for the development of alternative solutions to chemical products using Oxidative Technologies for Agriculture and Agri-Food (TOAST platform). This platform is equipped with storage rooms, culture chambers and an experimental room to evaluate the performance of oxidative technologies (O_3, UV, O_3/UV, EW ...) for the preservation and disinfection of foodstuffs, the disinfection of agri-food processes, the protection of plants, the modification of the technological qualities of agricultural raw materials, the realization of a green chemistry reaction ....

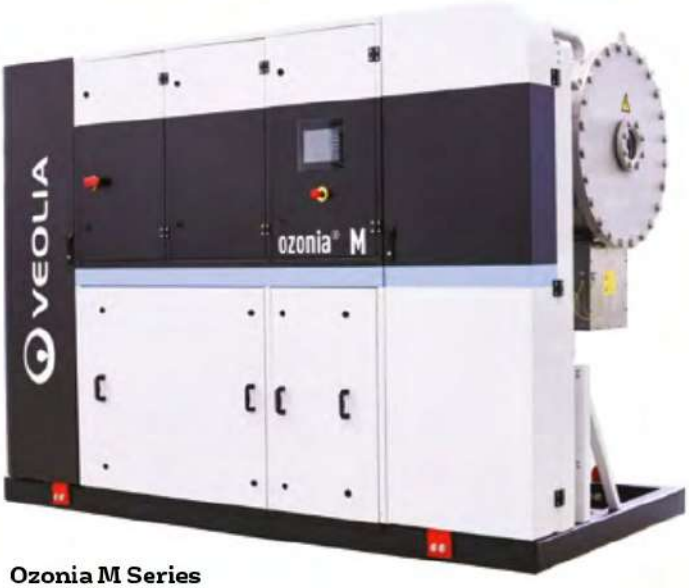
The TOAST platform team from the PURPAN is at your disposal for your research and development projects!

Ozonia*
ozone systems

Veolia now delivers oxidation, purification, and disinfection equipment from our **Ozonia** ozone and Aquaray* UV businesses. Our company's roots remain in Switzerland, where the **Ozonia** teams have been **pioneering world leading technologies** and pushing the boundaries of the ozone industry for over 40 years. Veolia has thousands of **Ozonia** ozone installations, including some of the world's largest oxidation systems.

With three R&D centers and four manufacturing facilities in North America, Europe and China, **Veolia can deliver** to any customers specifications.

Trust Veolia to deliver the highest quality **ozone technology solutions** to meet even the most difficult treatment challenges.



Ozonia M Series
Ozone System

Key Benefits of the Ozonia M Series:

SmartO3 Technology

New advanced features make operations and maintenance faster, easier, and less costly:

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Wider pressure range up to 3.0 bar

Higher ozone gas pressure allows optimization of the surrounding systems and infrastructure

Reliable performance in harsh environments

Reinforced system protection from ambient conditions up to IP65

Visit our website for information on our full range of solutions.

GENERAL INFORMATION

> Language

The official language will be English.

> Conference venue

INSA Toulouse
National Institute of Applied Science
135 Avenue de Rangueil
31400 TOULOUSE (France)
Tél. : 33 (0)5 61 55 95 13 - Fax : 33 (0)5 61 55 95 00
www.insa-toulouse.fr

> Registration categories

There are 8 categories of registration with associated fees as follows:

- IOA Member - Full registration
- Non-member - Full registration
- Member Student - Full registration
- Non-member Student - Full registration
- One-day registration – Member, 28 or 29 November
- One-day registration - non-Member, 28 or 29 November
- Conference dinner
- Technical Tour

The full registration fee covers scientific sessions, electronic proceedings, abstracts book, lunches and refreshments. A special discount rate is available for IOA members. Valid student ID is required for student registration. Additional registration is required for the Conference dinner and technical tour. These two options are opened to guest.

> Welcoming desk

It will be opened during the conference as follow:

- Monday, November 28 07:30 - 18:00
- Tuesday, November 29 08:30 - 18:00
- Wednesday, November 30 08:30 - 12:00

> Badges

The wearing of a badge is compulsory during the conference. They are necessary to access all scientific sessions, exhibition and lunch room.

> Coffee breaks & Lunch

Complimentary coffee and drinks will be available at the scheduled break times.
Each day, lunch will be offered in the same building as the conference.

> Liability and insurance

Registration for the Conference implies that the delegate agrees that neither the Organizers assume any liability whatsoever. Delegates are requested to make their own arrangements for medical, travel and personal insurance.

> Disclaimer

The Organizers may at any time, with or without giving notice, in their absolute discretion and without giving any reason, change the Conference programme and withdraw any invitation to attend. In any case, neither the organizers nor any of their officers employees, agents, members or representatives shall be liable for any loss, liability, damage or expense suffered or incurred by any person, nor will they return any money paid to them in connection with the Conference unless they are satisfied not only that the money in question remains under their control, but also that the person who paid it has been unfairly prejudiced (as to which the decision shall be in their sole and unfettered discretion, and when announced, final and conclusive).

GENERAL PROGRAMME

The conference will include:

- 2,5-day scientific and technical sessions including keynote lectures, oral presentations and posters session
- Welcome addresses and conference introduction
  - Bertrand Raquet, Director of INSA Toulouse
  - Sylvie Baig, IOA-EA$_3$G President
  - Michel Roustan, IOA-EA$_3$G Vice-President
- Keynote lectures: climate change and water management, opportunities
  - Valérie Quiniou-Ramus, Prospective and Research Executive Director (DEPR), ADEME
  - Bernard Legube, Chair of the Scientific Committee, Agence de l'Eau Adour Garonne
- 2,5-day exhibition of ozone related products and services,
- Half-day technical visit of full-scale applications,
- Conference dinner and Awards ceremony for delegates and their guests.

Monday 28 November		
7h30-9h00	Registration	
9h00-9h30	Welcome and opening session	
10h00-10h30	Keynote lectures	
10h30-11h00	Coffee break, poster exhibition	
11h00-13h00	Session 1. Fundamentals & engineering aspects	Exhibition
13h00-14h30	Lunch	
14h30-16h00	Session 2. Poster introductions & Exhibition	
16h00-16h30	Coffee break, poster session and exhibition	
16h30-19h00	Session 3. Agri-food applications	
19h00-21h00	Music Show by INSA Students / Cocktail	
Tuesday 29 November		
8h30-10h30	Session 4. Advance Oxidation Processes	
10h30-11h00	Coffee break, poster exhibition	
11h00-12h30	Session 5. Workshop Post Covid-19	Exhibition
12h30-14h30	Lunch	
14h30-16h30	Session 6. Micropollutants	
16h30-17h00	Coffee break, poster session and exhibition	
17h00-18h00	Session 7. Workshop PFAS	
20h00	Conference Dinner - Restaurant boat L'Occitania	
Wednesday 30 November		
8h30h10h20	Session 8. Full scale studies – Part 1	
10h00-10h30	Coffee break, poster session and exhibition	Exhibition
10h30-11h30	Session 9. Full scale studies – Part 2	
11h30-12h00	Closing session and Award Ceremony	
12h00-13h00	Lunch	
13h00-18h00	Technical visit / Rabastens: Drinking water plant & Wine cellar	

> Publications and scientific awards

To encourage young researchers, the Programme Committee will select and award a prize to the best paper presented by a Doctorate Student during the Conference.
All accepted papers will be printed in the conference proceedings that will be handed out to participants at registration. After the conference, the editors of the Ozone: Science & Engineering Journal will make the final selection among the papers presented for possible publication in this IOA peer-reviewed journal.

> Conference dinner - Tuesday 29, 20h00

A conference dinner is proposed to delegates on Tuesday 29 November at the Restaurant boat: L'Occitania.
We will offer you an original moment that will mark your spirits. We invite you to embark for a few hours of relaxation and gastronomy along the water.

> Technical visit / Rabastens: Drinking water plant & Wine cellar – Wednesday 30 afternoon

By kind permission of the operator, the Syndicat d'Alimentation en Eau Potable du Gaillacois (Gaillacois Drinking Water Supply Syndicate), the tour will feature the Drinking Water Plant located at Rabastens, halfway between Toulouse and Albi, between Montauban and Castres, prestigious cities of tourism in the Haut-Languedoc area.

The opportunity to discover also in this middle valley of the Tarn river a pleasant environment and the riches of the past: old half-timbered houses, aristocratic hotels, medieval churches, ramparts, museums, castles…

The tour will in addition include a stop for visit and tasting at the Cellar Vinovalie specialized in the design of wines with accessible and gourmet profiles.

The Syndicat d'Alimentation en Eau Potable du Gaillacois supplies drinking water to nearly 50 000 people spread over the 58 member municipalities. It also serves agri-food establishments (wine cellars in particular) and contributes to fire protection by putting its network at the service of municipalities. Il operates two Drinking Water Plants of similar production capacities. Both of them are fed from the Tarn river.

The new plant located in Rabastens can produces 900 m^3/h. The quality of the water is very good because the treatment process is modern and very complete: preozonation, coagulation, flocculation, sand filtration, ozonation, activated carbon filtration and final chlorination.

The tour will depart from and return to the Conference venue.
Special registration will be required. The fee will include bus transfer.
Visitors will have to provide copy of ID card or passport one month prior to visit.
Wearing of trousers and closed-in walking shoes is recommended.
The organisers reserve the right to cancel or limit attendance at any tour with monies refunded subject to minimum and maximum registration numbers.

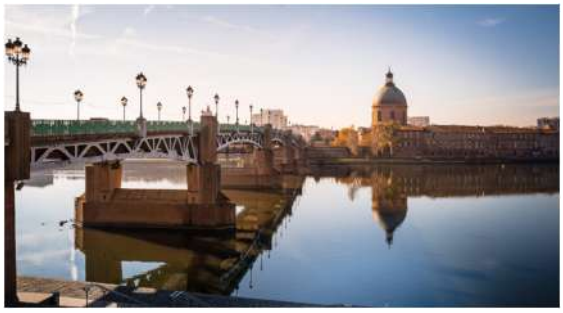
> Enjoy your stay in Toulouse, the "Ville Rose"

Ideally situated in the heart of Southern France, between the Mediterranean and the Atlantic Ocean, the cosmopolitan and enthusiastic Ville Rose joyously mixes heritage and lifestyle, great cultural events and festival pleasures. Toulouse is an absolute must for everyone wanting to explore France. At once both modern and proud of the legacy of its past, open and radiant, you are bound to be seduced by the incomparable Toulousain lifestyle, coupled with the wealth of its cultural heritage.

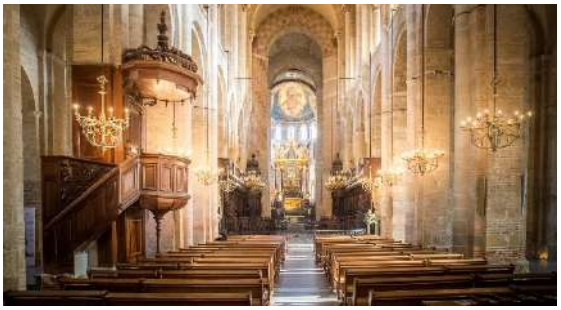
Your stay in Toulouse will certainly be a time of great pleasure. Its 2000-year-old history shows itself in an architecture of brick and tiles that is typical of the cities, villages and farms of the Midi-Pyrenees region. Reflections of the golden light on the brick of Toulouse have earned it the name of the "Ville Rose" and confer an atmosphere on the city that is at once gentle and warm.

Toulouse, France's fourth biggest city, is bubbling over with life. There's nothing like a stroll around the historic centre, walking alongside the Garonne and the Canal du Midi, or stopping in one of the many cafés whose terraces spill out onto the streets. All over the city, the ambience is friendly, tinged with the well-meaning familiarity that is particular to the people of Southern France.

Toulouse is also a major shopping destination. All the major internationally-renowned brands in fashion, design, leather goods and jewellery are represented in Toulouse. The city neighbourhoods also live by the rhythm of the open-air and covered markets. Here you'll find local products from the Midi-Pyrenees, which is one of the South-West's most important gastronomic regions – producing wine, foie gras, cheeses, charcuterie, and of course cassoulet – the Toulousain dish par excellence.



www.toulouse-tourisme.com



SCIENTIFIC AND TECHNICAL PROGRAMME

Monday 28 November

7h30-9h00	**Registration**
9h00-10h30	**Opening session**
	Welcome addresses and conference introduction Bertrand Raquet, Director of INSA Toulouse Sylvie Baig, IOA-EA$_3$G President Michel Roustan, IOA-EA$_3$G Vice-President **Keynote lectures: climate change and water management, opportunities** Valérie Quiniou-Ramus, Prospective and Research Executive Director (DEPR), ADEME (France) **Effects of climate change on the water resources of the Adour-Garonne hydrographical basin - The role of scientists** By Bernard Legube, Chair of the Scientific Committee, Agence de l'Eau Adour Garonne (France)
10h30-11h00	**Coffee break, poster exhibition**
11h00-13h00	**Session 1. Fundamentals & engineering aspects /** Chair: Em Pr. Michel Roustan
11h00-11h20	**1.1. Evaluation of the reactivity of ozone and hydroxyl radical with several bisphenol analogues by competition kinetics** O. Porcar-Santos, A. Cruz-Alcalde, C. Sans (Spain)
11h20-11h40	**1.2. Comparative study of chlorination and ozonation of fluorinated pesticides in water: Kinetics, transformation products and toxicity assessment** R.B.M. Diakabou Oby, H. Carreyre, J.M. Ouamba, S. Thibaudeau, H. Gallard (France, Congo)
11h40-12h00	**1.3. Ozone diffusion through hollow fiber membrane contactor** A. Schmitt, J. Mendret, S. Brosillon (France)
12h00-12h20	**1.4. Advanced oxidation with dissolved ozone and hydrodynamic cavitation for micropollutant removal** N. Matzke, M. Kolkmann, J. Mante, M. Meier, S. F. Reinecke, Uwe Hampel (Germany, France)
12h20-12h40	**1.5. Reduced-Order Modelling Approach Based on Computational Fluid Dynamics to Predict Gas Hold-up in Micro/Meso Structured Static Mixers** P. H. Marrocos, I. S. Fernandes, M. M. Pituco, R. J. Santos, V. J. P. Vilar (Portugal)
12h40-13h00	**1.6. Towards establishing standard ozonation batch test method through combining lab experiments and CFD-Amozone modelling** M. Yang, G. Bellandi, R. Muoio, K. Guerrero, A. B. Sanchez, A. Börgers, R. Schemen, P. Van Dijk, P. Vlasschaert, U. Rehman, A. Wieland, J. Türk, W. Audenaert (Belgium, The Netherlands)
13h00-14h30	**Lunch**
14h30-16h00	**Session 2. Poster introductions & Exhibition /** Chair: Pr. Stephan Brosillon
Advanced Oxidation Processes and Combinations	
	2.1. Insights into the catalytic ozonation over manganese oxide composite: Cooperative structure, degradation performance, and synergistic mechanisms Jing Liu, Xiangjuan Yuan, Carmen Sans (Spain, China)
	2.2. Removal of aqueous Nitrobenzene by Photoctalytic-ozonation process on Activated carbon under solar radiation: Catalyst characterization and kinetic study A. Meriem, G. Monia, F. J.Rivas Toledo, A. Ouederni (Tunisia, Spain)
	2.3. Resistance of polymeric ultrafiltration membranes exposed to ozone produced by diamond electrodes J. Gäbler, S. Glass, V. Filiz, F. Neumann (Germany)
	2.4. Electrochemical production of persulfate with boron-doped diamond electrodes M. P. Castro, M. A. Montiel, I. F. Mena, M. A. Rodrigo, J. Gäbler, M. Höfer, M. Armgardt, L. Schäfer (Spain, Germany)
	2.5. Assessing the role of ozone and granular activated carbon processes in the UK water industry: past, present and future L. Bertolaso, M. Chipps, D. Moran, B. Jefferson, P. Jarvis, I. Carra (UK)

Exhibition

Exhibition

14h30-16h00	**Session 2. Poster introductions & Exhibition (cont'd)**	
Agri-food applications		
	2.6. Novel materials with antimicrobial and antifungal properties obtained by ozonation of cyclodextrins: from synthesis to practical applications E. Haddad, M. Pagès, Y. Coppel, R. Sanchez, F. Violleau, M.-H. Manero, R. Richard, J.-P. Torré (France)	
	2.7. Ozone: a tool for reducing melons and plums losses during storage L. Volmerange, M.Pages, C.Berger, V. Quintard, F. Violleau (France)	
Fundamentals and engineering aspects		
	2.8. Degradation of Three Anti-Cancer Drugs in Water: Determination of Kinetic Parameters S. Zimmermann, E. Borowska, S. Sohrabi, H. Horn (Germany)	
	2.9. Gas-liquid pressure drop of downward flows in NETmix static mixer: experimental validation of computational fluid dynamics model P. H. Marrocos, I. S. Fernandes, M. M. Pituco, R. J. Santos, V. J. P. Vilar (Portugal)	
	2.10. NETmix Technology as Ozone Gas Injection System: Assessment of the Gas-Liquid Mass Transfer M.M. Pituco, P.H. Marrocos, M.M. Dias, J.C.B Lopes, R.J. Santos, F.C. Moreira, V.J.P. Vilar (Portugal)	
	2.11. Enhancement of activated sludge system using micro nano bubbles for sustainable wastewater treatment M. Mohamed, M.Sakr, M.Kizhisseri, M. Maraqa, M. Hamouda (United Arab Emirates)	Exhibition
	2.12. Spraying ozonated water: mass transfer characterization from the atomizing liquid film to the cloud of droplets A. Canado, M. Tournois, C. Lemen, N. Dietrich, M. Pages-Homs, F. Violleau, G. Hébrard (France)	
	2.13. Design improvement of an ozonation tank by CFD with ozone kinetics H. Norouzi-Firouz, G. Bellandi, A. Claro Barreto, B. Antoine, O. Rogez, U. Rehman, S. Dassonneville, W. Audenaert (Belgium, France)	
	2.14. Comparative experimental study between surface and volume DBD ozone generators supplied by different voltage waveform shapes S. Nemmich, K. Nassour, N. Ramdani, Y. Brahami, A. Tilmatine (Algeria)	
	2.15. Experimental modeling of ozone decomposition in air using response surface methodology S. Nemmich, Y. Brahami, K. Nassour, N. Ramdani, Y. Bellebna, M.N. Brahami, A. Tilmatine (Algeria)	
	2.16. Effect of the irrigation with ozonated water on the root development of tomato N. Ramdani, M.M. Reguieg, S. Nemmich, K. Nassour, F. Boukhoulda, A. Tilmatine (Algeria)	
	Visit of poster exhibition	
16h00-16h30	**Coffee break, poster session and exhibition**	
16h30-19h00	**Session 3. Agri-food applications /** Chair: Dr. Frédéric Violleau	
16h30-16H50	**3.1. Wastewater Reuse for agriculture - Smart Control Concepts** A. Ried (Germany)	
16h50-17h10	**3.2. Ozonated water to treat downy and powdery mildews in agriculture** A. Canado, M. Pages-Homs, W. Remus-Borel, G. Hébrard, F. Violleau (France)	
17h10-17h30	**3.3. Ozone Gas Treatment: an alternative solution to preserve the sanitary quality of young grapevine plants** M. Pages, C. Berger, P.D. Tourette, F. Violleau (France)	Exhibition
17h30-17H50	**3.4. Quality and mite growth on pecorino cheese stored in ozonated ripening rooms** C. Carboni, C. Grasso, R. Forniti, M. Lembo, V. Eramo, R. Botondi (Italy)	
17h50-18h10	**3.5. A mobile tool for post-harvest treatment and preservation of bananas using ozone** C. Berger, M. Pages, L. Volmerange, P. Brat, O. Hubert, J. Grabulos, V. Bancal, A. Normand, A. Pugeaux, L. de Lapeyre de Bellaire, S. Gerbaud, F. Violleau (France)	
18h10-19h00	**Round table discussion on Regulatory aspects**	
19h00-21h00	**Music Show by INSA Students** **Cocktail**	

Tuesday 29 November

8h30-10h30	**Session 4. Advance Oxidation Processes /** Chair: Pr. Santiago Esplugas	Exhibition
8h30-8h50	**4.1. Photocatalytic degradation of Paracetamol using Olive stones Activated Carbon** D. Houda, G. Monia, F. J. Rivas Toledo, A. Ouederni (Tunisia, Spain)	
8h50-9h10	**4.2. Kinetic modelling assisted optimization of the peroxone (O_3/H_2O_2) water treatment process** M. Mortazavi, S. Garg, T.D. Waite (Australia)	
9h10-9h30	**4.3. Advanced Ozone Oxidation for efficient Sodium Dodecyl Sulfate Degradation** A.A.S. Gallab, C. Tizaoui (UK, Egypt)	
9h30-9h50	**4.4. Oxygen plasma modification of carbon felt electrodes for enhanced the electrochemical degradation of water organic pollutants** P. Jakobczyk, M. Pierpaoli, G. Skowierzak, I. Kaczmarzyk, M. Nadolska, A. Wcisło, R. Bogdanowicz, J. Ryl (Poland)	
9h50-10h10	**4.5. Microwave plasma-enhanced chemical vapor deposition-assisted synthesis of carbon nanoarchitectures for the advanced oxidation of water pollutants** M. Pierpaoli, P. Jakóbczyk, A. Łuczkiewicz, Sylwia Fudala-Książek, Robert Bogdanowicz (Poland)	
10h10-10h30	**Discussion on AOPs**	
10h30-11h00	**Coffee break, poster exhibition**	
11h00-12h30	**Session 5. Workshop Post Covid-19 /** Chair: Pr. Chedly Tizaoui General overview on how ozone contributed to the fight against COVID - Ozone contribution to the fight against COVID-19 (C. Tizaoui) - Impact of COVID-19 on society: New challenges in sanitisation (C. Carboni) Open discussion on: - attendees' experiences and research contributions to the COVID-19 topic	
12h30-14h30	**Lunch**	
14h30-16h30	**Session 6. Micropollutants /** Chair: Dr. Sylvie Baig	Exhibition
14h30-14h50	**6.1. Simultaneous Removal of Gemfibrozil and Ibuprofen in the Presence of Microcystis aeruginosa in Treated Sewage Effluent using Ozone and Ozone-Hydrogen Peroxide** J. Saththasivam, H. Farzaneh, G. Ponnusamy (Qatar)	
14h50-15h10	**6.2. Ozone diffusion by hollow fiber membrane contactor for pharmaceutical removal and bromate minimization** A. Schmitt, J. Mendret, S. Brosillon (France)	
15h10-15h30	**6.3. WWTP effluent treatment for reuse: Effective ways for pharmaceutical degradation by ozonation andA.j. optimization of O3/H2O2 advanced oxidation for bromate control** M. Spruijt, A.J. Martijn, R. Koolen, J.C. Kruithof (The Netherlands)	
15h30-15h50	**6.4. Bromate in Ozone Treatment - a new avenue** T. Puehmeier, I. Simões, J. Ryckeboer, R. Gyssels, A. Wieland, J. Mielcke, H. Stapel, M. Hoffmann, M. Rothe, B. Paolini (Germany, Switzerland)	
15h50-16h10	**6.5. A bromate-free solution to remove micropollutants** L. de Franceschi, B. Heiniger, A. Murillo, L. Dinkloh (Switzerland, Germany)	
16h10-16h30	**Discussion**	
16h30-17h00	**Coffee break, poster session and exhibition**	
17h00-18h00	**Session 7. Workshop PFAS /** Chair: Dr. Achim Ried	
	Treatment technologies & concepts to manage PFAS in the water cycle – a Review A. Ried (Germany)	
	Discussion on: Regulations Experience from delegates	
20h00	**Conference Dinner - Restaurant boat L'Occitania**	

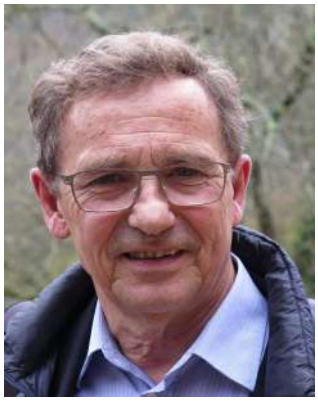
Wednesday 30 November

8h30h10h20	**Session 8. Full scale studies – Part 1 /** Chair: Dr. Jean-Pierre Duguet	Exhibition
8h30-8h50	**8.1. Prediction of ozone dosing in Full-scale Drinking Water Treatment Plant using Deep learning** M. Djeddou, A. Hellal, I. Loukam, A.I. Hameed (Algeria, Norway)	
8h50-9h10	**8.2. Ozone strong water dosing as optimized ozonation process for micropollutants reduction in wastewater treatment plants** K. Guerrero-Granados, J. Mante, M. Joy, M. Meier, A. Boergers, J. Tuerk (Germany, France)	
9h10-9h30	**8.3. Assessment of biological post-treatment procedures for degradation of transformation products from wastewater ozonation** J. Tuerk, A. Boergers, K. Guerrero-Granados, R. Cunha (Germany)	
9h30-9h50	**8.4. Multiple point ozonation for micropollutants removal from wastewater: a full-scale demonstration from Denmark** R. Mailler, T. Faraji, N. Jensen, F. Fenoglio, A. Gonzalez Ospina, S. Baig (France, Denmark)	
10h00-10h30	**Coffee break, poster session and exhibition**	Exhibition
10h30-11h30	**Session 9. Full scale studies – Part 2 /** Chair: Dr. Jean-Stéphane Pic	
10h30-10h50	**9.1. The Wervershoof WWTP case: towards real-time prediction of micropollutant removal and bromate formation with a digital twin for ozonation** R. Muoio, G. Bellandi, M. Hoekstra, S. Duchi, M. Spruijt, J. Versteegh, U. Rehman, W. Audenaert (Belgium, The Netherlands)	
10h50-11h10	**9.2. Towards online digital twin of two full-scale ozonation plants for micropollutant removal: minimize piloting efforts and improve decision making in design phase** G. Bellandi, R. Muoio, R. Schemen, P. Van Dijk, S. Weijers, U. Rehman, W. Audenaert (Belgium, The Netherlands)	
11h10-11h30	**9.3. Successful prediction of ozonation performances for microcontaminants removal, disinfection and by-products formation in wastewaters** S. Baig, M. Roustan (France)	
11h30-12h00	**Closing session and Award Ceremony** Sylvie Baig, IOA-EA$_3$G President Michel Roustan, IOA-EA$_3$G Vice-President	
12h00-13h00	**Lunch**	
13h00-18h00	**Technical visit /** Chair: Dr. Joël Mallevialle **Rabastens: Drinking water plant & Wine cellar**	

KEY NOTE SPEAKERS

Valérie Quiniou-Ramus is the Executive Director for Prospective and Research at ADEME, the French Agency for Energy Transition since 2019. Her Direction focuses on the coordination of ADEME's prospective scenarios for carbon neutrality in 2050 for France, as well as the coordination of the European Finance ClimAct project, the coordination of research programmes, the evaluation of public policies etc.

Valérie Quiniou graduated as a French engineer and naval architect from the École Polytechnique and the National School of Advanced Techniques. She started her career as a naval architect and then became a met-ocean advisor in the Oil and Gas Industry. In 2016, she joined the Corporate Sustainable Development and Environment Division and then the Strategy Direction of the O&G Company Total, as Vice-President on Climate Change. Until 2018, she was in charge of coordinating the 2°c roadmap and calculating the carbon footprint of Total.



Prof. Bernard Legube is Doctor of the University of Poitiers in water chemistry (since 1983) and Officer of the Academic Palms (since 2006).

His current functions: Emeritus professor of Poitiers University (since 2015), Chairman of the Scientific Council of the Water Agency Adour-Garonne (since october 2013 after being a member of the board), President of the Consortium of 30 french institutions (universities, engineer schools and reserch centers) in charge of the creation of the Franco-Vietnamese USTH University in Hanoi (2014-2022).

His main research specialities: Ozonation and ozonation by-products - chlorination and chlorination by-products - Advanced Oxidation Processes - Physico-chemistry of water - Characterisation of natural organic matter - Disinfection - activated carbon adsorption - coagulation to remove organic materials - Membrane Processes and membrane fouling - Water resources quality and evolution.

His main teaching loads (current and past): Water physical-chemistry - Solid/liquid separation processes (coagulation, flocculation, sedimentation, flotation, filtration) - Disinfection processes and elimination of dissolved compounds (oxidation, ion exchange, adsorption, precipitation) - Drinking water treatment (treatment processes) - Effects of climate change on water resources.

ABSTRACTS OF PRESENTATIONS

Session 1. Fundamentals & engineering aspects

1.1. Evaluation of the reactivity of ozone and hydroxyl radical with several bisphenol analogues by competition kinetics

O. Porcar-Santos, A. Cruz-Alcalde, C. Sans (Spain)

Bisphenol A (BPA) has been one of the most studied endocrine-disrupting compounds over the last decades. Because of this disrupting behaviour, the use of BPA was restricted by legislation, leading to its replacement by other bisphenol analogues, such as, bisphenol F (BPF), bisphenol S (BPS), bisphenol AF (BPAF), bisphenol E (BPE), bisphenol C (BPC) and bisphenol B (BPB), among others. In this work, the reactivity of these bisphenol A substitutes with ozone (O_3) and hydroxyl radical (·OH) was evaluated through competition kinetics. Results from the ozonation kinetic experiments revealed higher reactivity of all the compounds with O_3 at strong basic pH conditions (k_{app} ~ 10^9 M^{-1} s^{-1}). Contrarily, lower reactivity was observed at strong acidic conditions (k_{app} ~ 10^0 - 10^5 M^{-1} s^{-1}). Moreover, reactivity of ·OH with these bisphenols was also assessed, resulting in values of the second order rate constant around 10^9 - 10^{10} M^{-1} s^{-1}. The obtained results prove the viability of O_3 and ·OH for the removal of bisphenol A substitutes at the pHs found in most water and wastewaters.

1.2. Comparative study of chlorination and ozonation of fluorinated pesticides in water: Kinetics, transformation products and toxicity assessment

R.B.M. Diakabou Oby, H. Carreyre, J.M. Ouamba, S. Thibaudeau, H. Gallard (France, Congo)

In this work, the kinetic and mechanistic aspects of the chlorination and ozonation reactions of the fluorinated sulfonylurea herbicide trifloxysulfuron (TFS) were studied in order to elucidate their behaviour during water disinfection by chlorine and ozone. Trifloxysulfuron reacts efficiently with chlorine and ozone with second order rate constants equal to 33.60 and 3.57×104 M-1.s-1, respectively. The chlorination and ozonation reactions of TFS each led to five transformation products, including a fluorinated metabolite (3-(2,2,2-trifluoroethoxy)pyridine-2-sulfonamide) common to both oxidation processes. The latter was stable during chlorination and ozonation and was predicted by in silico QSAR methods to be more toxic to rats (a proxy of human toxicity) than its parent compound TFS.

1.3. Ozone diffusion through hollow fiber membrane contactor

A. Schmitt, J. Mendret, S. Brosillon (France)

Ozonation was carried out using a polytetrafluoroethylene (PTFE) hollow fiber membrane contactor. The objective was to conduct an extensive characterization of the ozone transfer in an in/out configuration. The overall mass transfer coefficient KLa was determined and was higher than in bubble columns. The transfer resistance due to the membrane was estimated to be lower than 1%. The impact of the presence of a reaction in the water was also evaluated using an organic dye (Acid Orange 7). The Hatta number and the acceleration factor were calculated, corresponding to a reaction that took place partially in the liquid film and in the liquid bulk. Finally, the impact of ozone on membrane material over time was evaluated.

1.4. Advanced oxidation with dissolved ozone and hydrodynamic cavitation for micropollutant removal

N. Matzke, M. Kolkmann, J. Mante, M. Meier, S. F. Reinecke, Uwe Hampel (Germany, France)

Hydrodynamic cavitation supported by dissolved ozone is being used as advanced oxidation process (AOP) for the removal of micropollutants from wastewater. In this first lab-scale study the generation of hydroxyl radicals (OH·) is tested with a hydrodynamic cavitation reactor consisting of an ozone contactor and subsequent pressure increased nozzle injection into the hydrodynamic cavitation chamber. Parameters ozone dosage and nozzle inlet pressure are varied and compared. Results show increased removal efficiencies with higher nozzle upstream pressure and low ozone dosage.

1.5. Reduced-Order Modelling Approach Based on Computational Fluid Dynamics to Predict Gas Hold-up in Micro/Meso Structured Static Mixers

P. H. Marrocos, I. S. Fernandes, M. M. Pituco, R. J. Santos, V. J. P. Vilar (Portugal)

The micro/meso structured static mixer NETmix extends the benefits of commercial static mixers for gas/liquid mixing by providing an operation with smaller pressure drops. This work proposes a methodology to quantify mass transfer parameters regarding the gas-liquid mixing phenomenon in the NETmix, based on the measurement of the gas hold-up as a function of gas and liquid volumetric flowrate through a reduced-order modelling approach based on computational fluid dynamics (CFD). It was observed that all predicted values of gas hold-up through the proposed model did not exceed a 10% error in relation to the CFD values, whereas the drift flux model had only 31% of its predictions within this 10% range.

1.6. Towards establishing standard ozonation batch test method through combining lab experiments and CFD-Amozone modelling

M. Yang, G. Bellandi, R. Muoio, K. Guerrero, A. B. Sanchez, A. Börgers, R. Schemen, P. Van Dijk, P. Vlasschaert, U. Rehman, A. Wieland, J. Türk, W. Audenaert (Belgium, The Netherlands)

Ozonation and its combination with other advanced oxidation processes is an effective solution to remove micropollutants and pathogens in many areas of the water treatment sector. Batch ozonation experiments are widely used to evaluate the ozone demand of a given water matrix and to assess the suitability of ozone technology. However, to date, the lack of sufficient standardization in this methodology can mislead the decision to build an ozone installation due to a certain bromate formation. The variability in bromate results among different laboratories is caused by the error propagation from the application of different methodologies of ozone injection and the analytical method chosen to quantify the bromate formed. This work shows a few of the most important aspects of this methodology waiting for standardization and their impact on the final bromate.

Session 2. Poster introductions & Exhibition

2.1. Insights into the catalytic ozonation over manganese oxide composite: Cooperative structure, degradation performance, and synergistic mechanisms
Jing Liu, Xiangjuan Yuan, Carmen Sans (Spain, China)

In the study, four types of MnO_2 with different crystal structures were synthesized via hydrothermal method, which exhibited excellent catalytic ozonation performance towards pollutant degradation in the aqueous solution. The different crystallographic structure of MnO_2 would lead to the different activity, which was also related to the specific surface area, pore volume, the presence of multivalent Mn ions, and the electrons transmission of catalyst. This work presents a new insight for water decontamination.

2.2. Removal of aqueous Nitrobenzene by Photoctalytic-ozonation process on Activated carbon under solar radiation: Catalyst characterization and kinetic study
A. Meriem, G. Monia, F. J.Rivas Toledo, A. Ouederni (Tunisia, Spain)

Nitrobenzene is considered highly toxic, it is resistant to oxidation by biological treatment due to its carcinogenesis and mutagenesis and it is considered as hardly biodegradable compound and inhibitor for activated sludge. Conventional technologies such as adsorption are used to the removal of organic compounds. Although these methods are effective, there are some difficulties in using these processes: high cost, formation of hazardous byproducts and applicability to only a limited concentration. Recently, advanced oxidation process (AOPs) have received much attention in water treatment due to their high oxidation. They are based on the generation of highly reactive and oxidizing hydroxyl radicals. In this study, the activated carbon based on walnut shell and olive stones were prepared. Activated carbon used as a catalyst was characterized and showed a great surface area of BET. The system O3/AC/Daylight significantly improves Nitrobenzene degradation and mineralization rate abatement if compared to runs conducted in the absence of radiation and/ or activated carbon.

2.3. Resistance of polymeric ultrafiltration membranes exposed to ozone produced by diamond electrodes
J. Gäbler, S. Glass, V. Filiz, F. Neumann (Germany)

Membranes can retain many pollutants and thus become more and more important for water cleaning and desalination, liquid phase separation. If biofouling occurs, flushing or backwash with ozonated water can be an efficient method to reduce the organic blocking. However, polymeric membranes might not withstand the oxidation load of the ozone. Therefore we report about stability tests of newly developed, polymeric high-performance membranes against ozonated water with the help of a special test rig.

2.4. Electrochemical production of persulfate with boron-doped diamond electrodes
M. P. Castro, M. A. Montiel, I. F. Mena, M. A. Rodrigo, J. Gäbler, M. Höfer, M. Armgardt, L. Schäfer (Spain, Germany)

Contaminants of emerging concern (CEC) hinder the reuse of treated wastewater e.g. for irrigation. Electrooxidation with conductive diamond electrodes is an energy-efficient method to reduce CECs. Strong oxygen species like hydroxyl radicals can be generated with the diamond electrodes. In the SERPIC project, the hydroxyl radicals are used to generate the powerful oxidant persulfate from a sulfate solution, which is able to degrade CECs. Results are shown about the efficiency of persulfate production in an electrochemical cell with a boron-doped diamond (BDD) anode.

2.5. Assessing the role of ozone and granular activated carbon processes in the UK water industry: past, present and future
L. Bertolaso, M. Chipps, D. Moran, B. Jefferson, P. Jarvis, I. Carra (UK)

In the 1990s, ozone and granular activated carbon (GAC) processes have been implemented to many of the surface water works in the UK. Ozone reacts with various organic and inorganic compounds through oxidation and is known for being highly selective. GAC is a filtration media commonly employed for its adsorption properties to remove organic-based contaminants. Today, the processes are reaching the end of their design lifespan and it is becoming crucial to determine whether these remain the most appropriate treatment solution going forward. Indeed, rising challenges need to be considered, such as climate change, anthropogenic activities and population growth, as these lead to shifts in water quality and the need of exploiting more challenging water sources.

2.6. Novel materials with antimicrobial and antifungal properties obtained by ozonation of cyclodextrins: from synthesis to practical applications
E. Haddad, M. Pagès, Y. Coppel, R. Sanchez, F. Violleau, M.-H. Manero, R. Richard, J.-P. Torré (France)

The degradation of our environment has been becoming a growing concern with the increase of industrialization and ever-increasing commercialization of chemical substances. Therefore, innovative researches have been involved for several years to develop eco-friendly products in substitution to usual pesticides and crop protection chemicals. In this study, a novel oxidative material was produced directly by gas-solid reaction between ozone (O_3) and cyclic polysaccharides 2-hydroxypropyl-β-cyclodextrin, (2-HP-β-CD). The influence of the main process parameters was studied by using a Design Of Experiment (DOE) strategy to both optimize the oxidizing power of the final product and assess the effect of the main synthesis process parameters on the material properties. In order to test the proficiency of the final product, microbiological and fruit preservation tests were also conducted. In the light of the results obtained, regarding the potential use of these materials in practical applications may be interesting.

2.7. Ozone: a tool for reducing melons and plums losses during storage
L. Volmerange, M.Pages, C.Berger, V. Quintard, F. Violleau (France)

Industrials and fruit growers are often facing huge losses during storage that can affect the profitability of their companies and be responsible of food waste. They are therefore looking for solutions to tackle this problem and limit the apparition of defaults such as mold. In this study, the effect of ozone on melons and plums preservation was investigated. Those fruits were stored during several days under various storage conditions and ozone concentrations. A reduction of both the fungal and bacterial flora has been highlighted in many cases on both species while the physicochemical properties of the fruits have not been affected. Those results are suggesting that ozone could be a promising tool for a better conservation.

2.8. Degradation of Three Anti-Cancer Drugs in Water: Determination of Kinetic Parameters
S. Zimmermann, E. Borowska, S. Sohrabi, H. Horn (Germany)

Bicalutamide, Capecitabine and Irinotecan are three widely used anti-cancer drugs that have been detected in waste water or surface waters and are considered potentially harmful to the environment (Azuma, 2015; Chatzimpaloglou, 2021). Advanced treatment steps in waste water treatment plants (WWTPs) might be able to reduce the concentration of these substances in the WWTP effluent. The degradation of these pharmaceuticals was investigated by using two different processes, i.e. UV-photolysis and ozonation. The kinetic parameters of the degradation reactions were determined.

2.9. Gas-liquid pressure drop of downward flows in NETmix static mixer: experimental validation of computational fluid dynamics model

P. H. Marrocos, I. S. Fernandes, M. M. Pituco, R. J. Santos, V. J. P. Vilar (Portugal)

Several benefits associated with a novel static mixer, the NETmix, such as a high mixing performance, have drawn attention to its application in ozonation, specifically to dissolve ozone in water. As such, computational fluid dynamics (CFD) tools can be used to further comprehend the mixing properties and capabilities of the NETmix in a gas-liquid flow. Therefore, this work validates a CFD model to represent a downwards gas-liquid flow in a NETmix by experimentally measuring the two-phase pressure drop associated with the flow at various gas and liquid volumetric flowrates, and comparing it with the respective values determined by simulations. The results show a good agreement between experiments and simulation.

2.10. NETmix Technology as Ozone Gas Injection System: Assessment of the Gas-Liquid Mass Transfer

M.M. Pituco, P.H. Marrocos, M.M. Dias, J.C.B Lopes, R.J. Santos, F.C. Moreira, V.J.P. Vilar (Portugal)

This work proposes a novel mixing concept based on the NETmix technology for continuous ozone dissolution in water. The NETmix is a micro/meso-structured static mixer consisting of a network of unit cells comprising mixing cylindrical chambers interconnected by prismatic channels. The gas-liquid mass transfer was evaluated using ozone and air gas streams by the determination of the mass transfer coefficients for ozone and oxygen. It was observed that the exclusive geometry of the NETmix improved the mass transfer rate when compared to other conventional and advanced mixing equipment while maintaining a high-energy utilization efficiency.

2.11. Enhancement of activated sludge system using micro nano bubbles for sustainable wastewater treatment

M. Mohamed, M.Sakr, M.Kizhisseri, M. Maraqa, M. Hamouda (United Arab Emirates)

Wastewater treatment became a mandatory choice for many countries. Among the successfully applied processes is the activated sludge system. Typically, aeration in activated sludge systems is achieved either by surface fans or by bottom diffusers. However, there is a need to improve the utilization of pumped air in the aeration tanks. The use of micro-nano air bubbles (MNBs) will be studied as a replacement for conventional macro air bubbles. MNBs have a higher surface area/volume ratio as compared to macro air bubbles and they tend to reside longer before they burst on the liquid surface. Laboratory experiments were carried out to characterize MNBs size and size distribution. Experiments on the treatment of domestic wastewater will involve the construction of an identical pilot-scale activated sludge prototype. The performance of the system will be compared in terms of BOD and COD degradation, biomass generation, and the extent of nitrification. Based on the results, sustainability of using air MNBs in activated sludge systems will be assessed.

2.12. Spraying ozonated water: mass transfer characterization from the atomizing liquid film to the cloud of droplets

A. Canado, M. Tournois, C. Lemen, N. Dietrich, M. Pages-Homs, F. Violleau, G. Hébrard (France)

The present work proposes a fully characterization of the mass transfer occurring in a spray. First, a global method that relies on the collection and the titration of the sprayed liquid along the spray is presented. Ozone desorption and dioxygen absorption rates are determined and found to be equal. Moreover, for both solutes, most of the mass transfer (≈70%) occurred in the atomizing liquid film that form the droplets at the direct exit of the nozzle. General correlations allowed to predict the desorption occurring in the already formed droplets, but not during their formation in the liquid film.

2.13. Design improvement of an ozonation tank by CFD with ozone kinetics

H. Norouzi-Firouz, G. Bellandi, A. Claro Barreto, B. Antoine, O. Rogez, U. Rehman, S. Dassonneville, W. Audenaert (Belgium, France)

Safe drinking water and proper disinfection credit, are the primary objectives when designing a new ozonation tank. Rules of thumb and safety factors have been largely used, however, often resulting in oversizing installations, ozone doses, and related OpEx and CapEx. In addition to this, the importance of hydrodynamics has often been neglected to make important assumptions on the plug-flow behaviour, or over-baffling a reactor. In this study, an alternative method using computational fluid dynamics (CFD) coupled with the AMOZONE kinetic model to combine ozonation reactions with 3D hydraulic simulations. This combination of advanced modelling tools allowed us to have a better insight into the process of comparing different designs and operational conditions. The optimal design of an ozone installation could be achieved without expensive piloting or risky onsite testing. The sole optimization of the inlet configuration resulted in lower bromate formation and better contact time, allowing important savings e.g. additional baffles.

2.14. Comparative experimental study between surface and volume DBD ozone generators supplied by different voltage waveform shapes

S. Nemmich, K. Nassour, N. Ramdani, Y. Brahami, A. Tilmatine (Algeria)

Although dielectric barrier discharge (DBD) has been widely considered and studied for ozone generation, few comparative studies have been performed between surface DBD (SDBD) and volume DBD (VDBD) ozone generators, considering the influence of the voltage waveform applied to the generator. The objective of this work is to conduct an experimental analysis using two cylindrical ozone generators of SDBD and VDBD types, to make a comparative study in terms of ozone concentration and energy efficiency. The study was performed by applying three voltage signals of different shapes delivered by a high voltage amplifier: sinusoidal, triangular and square signals. The obtained results, using voltages up to 8 kV and frequencies up to 1.1 kHz, showed that the efficiency of the ozone generators depends strongly on the type of the voltage waveform and the ozone generator configuration. It was shown that the maximum values of ozone concentration and energy efficiency were obtained with the volume DBD and a triangular voltage signal.

2.15. Experimental modeling of ozone decomposition in air using response surface methodology

S. Nemmich, Y. Brahami, K. Nassour, N. Ramdani, Y. Bellebna, M.N. Brahami, A. Tilmatine (Algeria)

A better understanding of the ozone decomposition kinetics in gaseous phase is necessary to ensure optimal conditions of the ozone concentration in many ozone applications such as food storage and ozone sterilization. Monitoring and controlling the ozone half-life time and the “concentration*time” product values for microbial reduction are important keys to consider. This paper is aimed to an experimental investigation carried out to analyse the evolution of the half-life of ozone in air as a function of air flow rate Q (0 to 300 m^3/h), temperature T (20 to 40 °C) and relative humidity RH (40 to 80%). The study was carried out inside a sealed stainless steel chamber of dimensions 50x50x50 cm^3, using an experimental procedure based on response surface modelling. The obtained results showed that the decomposition of ozone gas should be optimized to ensure a more stable decomposition, where optimal values of the analysed factors were Q= 0 m^3/h, T=20 °C and RH= 40%.

2.16. Effect of the irrigation with ozonated water on the root development of tomato
N. Ramdani, M.M. Reguieg, S. Nemmich, K. Nassour, F. Boukhoulda, A. Tilmatine (Algeria)

This work is aimed to analyze the effect of the irrigation with ozonated water and the soil organic fertilization on tomato growth and in particular its effect on the root development. An experimental study was carried out inside a greenhouse where tomato seeds were planted in pots of volume 2L. The irrigation was provided regularly twice a week with three different concentrations of dissolved ozone in water (1, 2 and 3 ppm). The obtained results showed that the productivity irrigated with ozonated water is almost twice as high, with a maximal outcome for an ozone concentration of 2 ppm. The use of ozonated water allowed better development of the root parts with much higher density and mass of the root stems. Moreover, it was verified that organic fertilization is not required in case of irrigation with ozonated water since almost the same productivity was obtained for fertilized and not-fertilized soil substrates.

Session 3. Agri-food applications

3.1. Wastewater Reuse for agriculture - Smart Control Concepts
A. Ried (Germany)

Because of climate change more and more regions worldwide does not have enough water available to fulfill the needs for agriculture. Therefor Germany set up a Government funded program to develop flexible and sustainable concepts for water reuse in 2019. The goal of one of the approved projects (FlexTreat) is the development and demonstration of processes to fulfill the requirements in innovative water management concepts in agriculture.
One Work package “Digital Green Tech” investigates in advanced monitoring and control concepts of the treatment train “Ozonation + Biological Filtration + UV”. This includes the development of a digital twin of the real plant and the use of neural networks (AI). In addition the outcomes from the Artificial Intelligence will be used to generate so called “Virtual Sensors” for information which can´t be measured on-line directly.
The project will run over 3 years till Jan 2024. The installation of the real pilot treatment train was accomplished in September 2021. Till September 2022 the project will deliver the first results of operation and digital twin.

3.2. Ozonated water to treat downy and powdery mildews in agriculture
A. Canado, M. Pages-Homs, W. Remus-Borel, G. Hébrard, F. Violleau (France)

Ozonated water (OW) has proved its biocide properties over a wide range of microorganisms and applications. These biocide properties and the low remanence of the ozone molecule makes the OW a promising candidate to substitute controversial phytosanitary products used in agriculture. The present study aims to prove that ozonated water can inhibit the development of three mildews pathogens: Plasmopara viticola, the downy mildew of the vine; Hyaloperonospora parasiticae, the downy mildew of the cabbage; and Oïdium neolycopersici, the powdery mildew of the tomato. Different levels of treatments have been applied: an “in vitro” treatment with high controlled conditions, an “in planta” treatment with moderated controlled conditions, and an “in situ” treatment mooking real treatments conditions by spraying. Note that, the efficiency of the ozonated water spraying has been improved by using a patented anti-desorption device based on recent studies. OW has been proved to be a promising alternative to treat those plant diseases.

3.3. Ozone Gas Treatment: an alternative solution to preserve the sanitary quality of young grapevine plants
M. Pages, C. Berger, P.D. Tourette, F. Violleau (France)

Grafted grapevine plants are affected by several pathogenic microorganisms which results in decrease in their vigour or even their death. In order to limit classical chemical treatments, ozone gas can be considered as an interesting alternative thanks to its oxidative powerful and low remanence. In this study, two different trials were conducted: long (25 days) or short (34 hours) storage time with two ozone doses. Visuals observations with fungi occurrence detection, assessment of growth recovery and microbiological analysis on rootstock and roots were performed. Application of ozone gas resulted in lower incidence and severity of fungi development in all the cases. Growth was normal or improved, number of leaves can be increased. Long storage gave better results results than short conservation. Ozone gas treatment can be considered as a promising alternative to preserve sanitary quality of young grapevine plants.

3.4. Quality and mite growth on pecorino cheese stored in ozonated ripening rooms
C. Carboni, C. Grasso, R. Forniti, M. Lembo, V. Eramo, R. Botondi (Italy)

Pecorino cheese frequently presents mites and molds on the crust area, which need to be removed before the product can be marketed to preserve the product quality. This research is aimed to study the effects of gaseous ozone to control microbiological and mite growth and the effects on product quality during ripening storage of pecorino cheese that was treated with gaseous ozone at 200 and 300 ppb for 8 hours per day (overnight) for 150 days in the storage rooms under controlled conditions (12 ºC and 85% R.H.). The results showed that ozone at 200 ppb enables the growth of mites to be fully contained for 25 days of treatment and reduced significantly bacteria, molds and yeasts count for 75 days of the treatment. Regarding the centesimal composition data of Pecorino cheese, no significant differences were shown between the control samples and ozone treatment at 200 ppb. Sensory analysis also shows no specific defects of the ozone-treated samples. However, treatments with ozone 300 ppb contained microbiological and mite growth but did not have the same positive impact on some aspects of overall quality.

3.5. A mobile tool for post-harvest treatment and preservation of bananas using ozone
C. Berger, M. Pages, L. Volmerange, P. Brat, O. Hubert, J. Grabulos, V. Bancal, A. Normand, A. Pugeaux, L. de Lapeyre de Bellaire, S. Gerbaud, F. Violleau (France)

Ozone is an interesting alternative to conventional plant protection products due to its oxidizing and antimicrobial properties, as well as its low persistence. It can be used for preserving fruits in an ozonated atmosphere and in post-harvest treatment. A laboratory was built in a container as part of the ATMOZFR project to study this subject on various fruits such as banana. It includes a cold room for treating fruits with gaseous ozone in a controlled or not atmosphere. A skid generates ozonated water for fruits post-harvest treatment. It also contains a module for treatment of conditioning station water and laboratory equipment. This tool is quasi autonomous because it only requires access to water and electricity. It is mobile and navigable in order to be as close to the needs as possible. This container was shipped to Ivory Coast and installed in a banana plantation (Compagnie Fruitière®) to conduct tests immediately after harvest. The aim is to investigate the use of ozone as a post-harvest treatment or during banana sea shipping to improve preservation and extend green life. The first results showed a 40% reduction in crown rot on artificially inoculated banana with Colletotrichum musae after 13 days in a controlled ozonated atmosphere. Up to 85% of efficacy was achieved when bathing the bananas in ozonated water.

Session 4. Advance Oxidation Processes

4.1. Photocatalytic degradation of Paracetamol using Olive stones Activated Carbon
D. Houda, G. Monia, F. J. Rivas Toledo, A. Ouederni (Tunisia, Spain)

Paracetamol is a toxic and poorly biodegradable contaminant, usually found in wastewater. This compound could be effectively eliminated using advanced treatment processes. This paper presents experimental results of photocatalysis process on depollution of water from Paracetamol. Two catalysts were compared:olive stone activated carbon and TiO_2 supported on AC. the degradation efficiency is 85.27 % in the case of AC catalyst and 76.17 % with the supported catalyst after 310 min. So, there is no remarkable difference between the two catalysts as the constant rate is 0.86 h-1 and 0.76 h-1 respectively. So that supporting TiO_2 on AC have not a remarkable effect on the photocatalytic degradation of Paracetamol.

4.2. Kinetic modelling assisted optimization of the peroxone (O_3/H_2O_2) water treatment process
M. Mortazavi, S. Garg, T.D. Waite (Australia)

In this work, we investigated the performance of the peroxone (O_3/H_2O_2) process and optimized the process using a kinetic model. A range of parameters (H_2O_2 dosage, H_2O_2 dosing method ozone dosage, and the presence of humic acid) was investigated to evaluate the kinetic model and optimize the peroxone process to achieve high oxalate removal. Among the parameters investigated here, H_2O_2 dosing methods (i.e. single, multiple, and continuous injection(s)) have not been investigated widely by other researchers. And interestingly, peroxone process efficiency can be enhanced significantly by changing only the H_2O_2 dosing method while other parameters are kept constant. Optimizing the peroxone process help to decrease the treatment time, and O_3 and H_2O_2 concentrations which help to save on the capital costs. The model developed here is an excellent tool to predict oxalate oxidation by the peroxone process for various operating parameters and, to optimise the working conditions at full scale.

4.3. Advanced Ozone Oxidation for efficient Sodium Dodecyl Sulfate Degradation
A.A.S. Gallab, C. Tizaoui (UK, Egypt)

Sodium Dodecyl Sulfate (SDS) is a globally-utilized synthetic anionic surfactant. It is a primary ingredient in laundry, cleaning formulas, pharmaceutical and personal care products (PPCPs). Thus, it is normally expected to be found in greywater effluents, with a potential to contaminate surface and groundwater. SDS poses a moderate toxicity to human health and is hazardous to the environment. SDS as well as other PPCPs were detected in water supplies due to the incapability of municipal treatments to degrade them. The advanced ozone oxidation process (AOOP) is a powerful and promising technique that is used to decompose a wide range of PPCPs. This study evaluated the effect of ozone doses (from 3 to 50 mol O3/mol SDS) at pH values ranged from 3 to11 on the efficiency of AOOP to degrade SDS at initial concentration of 10 mg/L in one hour of reaction time. The degradation efficiencies of the process were tracked by LC-MS/MS and TOC analyses. The LC-MS/MS results indicated SDS degradation efficiency of 87% at O3/SDS ratio of 3 and pH11 while the TOC was reduced by 59.4% at ozone to SDS ratio of 50 and original pH (6.2). There was no change in the initial pH values of SDS solutions during ozonation at a low ratio of O3 to SDS. However, there was a significant change in pH, especially at higher pH values, during ozonation at high O3/SDS ratios.

4.4. Oxygen plasma modification of carbon felt electrodes for enhanced the electrochemical degradation of water organic pollutants
P. Jakobczyk, M. Pierpaoli, G. Skowierzak, I. Kaczmarzyk, M. Nadolska, A. Wcisło, R. Bogdanowicz, J. Ryl (Poland)

Oxygen plasma treatment surface modification is single-step, effective and low time-consuming, and does not require solvents (eco-friendly). Carbon felts are flexible and scalable, have high specific areas, and are highly conductive materials that fit the requirements of both anodes and cathodes in advanced electrocatalytic processes. Acetaminophen electrooxidation is a reference standard representing anti-inflammatory, organic pharmaceuticals. The modification of the porous anodes results in increased kinetics of acetaminophen degradation in aqueous environments.

4.5. Microwave plasma-enhanced chemical vapor deposition-assisted synthesis of carbon nanoarchitectures for the advanced oxidation of water pollutants
M. Pierpaoli, P. Jakóbczyk, A. Łuczkiewicz, Sylwia Fudala-Książek, Robert Bogdanowicz (Poland)

Microwave plasma-enhanced chemical vapor deposition (MPECVD) is an established technology for the bottom-up synthesis of boron-doped diamond (BDD) electrodes. Electrochemical oxidation (EO) is a reliable, scalable, and assessed advanced oxidation process (AOP) for the mineralization of various pollutants. A novel carbon nanoarchitectured electrode, synthesized by the MPECVD technique, is presented, tested and compared with a BDD electrode. The higher surface area of the nanoarchitectured electrode, jointly with the presence of sp2-C clusters, results in faster COD removal.

Session 5. Workshop Post Covid-19

General overview on how ozone contributed to the fight against COVID

- Ozone contribution to the fight against COVID-19 (C. Tizaoui)
- Impact of COVID-19 on society: New challenges in sanitisation (C. Carboni)

Open discussion on:

- attendees' experiences and research contributions to the COVID-19 topic

Session 6. Micropollutants

6.1. Simultaneous Removal of Gemfibrozil and Ibuprofen in the Presence of Microcystis aeruginosa in Treated Sewage Effluent using Ozone and Ozone-Hydrogen Peroxide
J. Saththasivam, H. Farzaneh, G. Ponnusamy (Qatar)

This study investigates the efficiency of ozone and ozone-hydrogen peroxide in removing ibuprofen and gemfibrozil in a treated sewage effluent contaminated with Microcystis aeruginosa (MA). The removal efficiency studies were conducted at various oxidant dosages. The experimental results indicated that the removal efficiency of ibuprofen and gemfibrozil dropped by 5 to 15% in the presence of MA at lower oxidant dosages. The studies also showed that there was no significant difference between ozone and ozone-hydrogen peroxide in terms of micropollutant removal efficiency where both technologies were able to remove over 80% removal of ibuprofen and gemfibrozil at oxidant/DOC of 1. Despite having similar removal efficiency, it must be emphasized that the contact time required for hydrogen peroxide was shorter when compared to conventional ozonation.

6.2. Ozone diffusion by hollow fiber membrane contactor for pharmaceutical removal and bromate minimization
A. Schmitt, J. Mendret, S. Brosillon (France)

This study focuses on the treatment by ozonation of organic pollutants present in wastewater. The originality of the work lies in the use of a PTFE membrane contactor to ensure the transfer of ozone gas. The production of bromates will be studied.

6.3. WWTP effluent treatment for reuse: Effective ways for pharmaceutical degradation by ozonation andA.j. optimization of O_3/H_2O_2 advanced oxidation for bromate control
M. Spruijt, A.J. Martijn, R. Koolen, J.C. Kruithof (The Netherlands)

Water authority HHNK, drinking water supply company PWN and PWNT are investing heavily in a collaborative research effort focusing on degradation of pharmaceuticals in WWTP effluent by ozonation. Pharmaceutical degradation as function of ozone dose was examined. Ozone based Advanced Oxidation Processes (AOP) (O_3/H_2O_2) experiments have been performed to limit bromate formation. The requirements for pharmaceutical control set by the Dutch government for discharge scenarios can be met by applying an ozone dose of 6.5 mg/L with no bromate formation. However, for reuse scenarios higher pharmaceutical degradation rates are desired and therefore elevated ozone dosages are needed, resulting in significant bromate formation. AOP (O_3/H_2O_2) can be used for high ozone regimes to achieve maximal pharmaceutical degradation with no bromate formation. Therefore, AOP (O_3/H_2O_2) can be used effectively as oxidation treatment step in an integrated treatment approach with O_3/H_2O_2 – inline coagulation – CMF for high quality reuse applications.

6.4. Bromate in Ozone Treatment - a new avenue
T. Puehmeier, I. Simões, J. Ryckeboer, R. Gyssels, A. Wieland, J. Mielcke, H. Stapel, M. Hoffmann, M. Rothe, B. Paolini (Germany, Switzerland)

Ozone is a highly effective oxidant and has a strong ability to inactivate a wide range of pathogens, including viruses. The treatment, incl. disinfection, of drinking water and wastewater with ozone is associated with the formation of disinfection by-products (DBP). Among the possible DBPs, bromate (BrO3-) is of increased concern because it is considered a potential carcinogenic to humans. The limit concentration established assumes, with the present risk calculations, that there might be some risk for human health. However, it is approved to consider technical and analytical feasibilities when implementing new limit concentrations. A lower limit concentration may have some impact on the use of ozone in disinfection or oxidation processes, which would trigger further sincere and undesirable consequences.

6.5. A bromate-free solution to remove micropollutants
L. de Franceschi, B. Heiniger, A. Murillo, L. Dinkloh (Switzerland, Germany)

Ozone is now well established as an efficient treatment solution for the removal of various organic wastewater constituents. Under certain conditions though, ozone treatment processes require critical evaluation and optimization due to the risk of by-product formation, particularly bromates. The present paper summarizes two years of laboratory scale studies and piloting performed in the framework of the removal of the undesirable organics so-called micropollutants in wastewater by direct injection of ozone into activated sludge. It also aims to summarize the latest findings and results of these experiments and provide an outlook of new treatment concepts with ozone.

Session 7. Workshop PFAS

Treatment technologies & concepts to manage PFAS in the water cycle – a Review
A. Ried (Germany)

The Public Demands PFAS Regulation.
PFAS chemicals have been used for decades in various industrial and consumer products, but over the years these chemicals have found their way into the environment and our drinking water. Studies showing possible health risks of these chemicals have been around since the 60s but these were kept secret from the public for decades. Now with the increasing awareness of these chemicals and their health risks, more and more citizens are demanding PFAS-free water, and some are going as far as raising lawsuits against utilities distributing PFAS contaminated water. This demand in the consumer end creates a need for water treatment plants to purchase solutions for PFAS treatment.

Discussion on:
- Regulations
- Experience from delegates

Session 8. Full scale studies – Part 1

8.1. Prediction of ozone dosing in Full-scale Drinking Water Treatment Plant using Deep learning
M. Djeddou, A. Hellal, I. Loukam, A.I. Hameed (Algeria, Norway)

Ozonation is a critical step in the drinking water purification process. The effectiveness of ozonation is closely proportional to the quality of the treated water. However, due to its nonlinear behavior, the ozone dosing process is a particularly difficult portion to regulate. Two deep learning models namely DNN model and CNN model were utilized in this work to predict the ozone dosing. The acquired findings look to be highly encouraging, and the methodologies appear to be promising. The DNN with 5 hidden layers model performs much better than the CNN model used for comparison in this study.

8.2. Ozone strong water dosing as optimized ozonation process for micropollutants reduction in wastewater treatment plants
K. Guerrero-Granados, J. Mante, M. Joy, M. Meier, A. Boergers, J. Tuerk (Germany, France)

Growing concern over potential (eco)toxicological problems caused by micropollutants (MPs) in water has led to the development and application of adsorptive and oxidative advanced treatment technologies at European wastewater treatment plants (WWTPs). The direct dosage of gaseous ozone is the most common full-scale procedure to achieve an advanced oxidation process (AOP) due to the involved high reactive species. Several process parameters and set-ups may affect the efficiency of MPs removal and even cause or inhibit the formation of transformation products such as bromate (BrO_3^-). A new alternative ozone application procedure (dosage of ozone strong water – OSW) developed by Air Liquide was installed and operated in full-scale at the wastewater treatment plant of Duisburg-Vierlinden, Germany. The aim of the study was to analyze and compare the OSW injection with diffusers and pump injector systems in terms of required space and reaction time, ozone consumption, reactivity, and removal efficiency. A significant reduction of the time to achieve the maximum possible removal was determined for the OSW injection technology in case of all six MPs studied with maximum reaction times of 8 minutes. This could be attributed to the high removal efficiency of the immediate ozone reaction. Based on a theoretical reactor design, the reactor volume would be reduced by 73% of the installed volume for the standard injection mechanism.

8.3. Assessment of biological post-treatment procedures for degradation of transformation products from wastewater ozonation
J. Tuerk, A. Boergers, K. Guerrero-Granados, R. Cunha (Germany)

Persistent micropollutants (MPs), formation of transformation products (TPs) and consequent increase of toxicity after disinfection of wastewater by oxidation with O_3 rises the need for implementation of post-treatments. Biological post-treatment (BPT) is a promising solution as they appear to be cost-effective. In this study, moving bed biofilm reactors (MBBRs) are tested as BPT after a full-scale ozonation plant. The assessment of MPs showed z_{spec} dependent removal during ozonation, as expected. However, persistent MPs were not significantly reduced by BPT. Up to 22% of the TPs of ozonation were eliminated by BPT but the larger fraction remained unchanged. Biodegradation of N-Nitrosodimethylamine (NDMA) up to 50% was observed in a pilot MBBR. Endocrine-disrupting activity was below risk levels. AOC formation was observed during ozonation. An overall reduction of 76 ± 8% of the AOC levels after ozonation was obtained in the final effluent of the treatment plant but the impact of the MBBRs was not conclusive. If no NDMA is present, BPT in the studied wastewater treatment plant (WWTP) appear not to be necessary.

8.4. Multiple point ozonation for micropollutants removal from wastewater: a full-scale demonstration from Denmark
R. Mailler, T. Faraji, N. Jensen, F. Fenoglio, A. Gonzalez Ospina, S. Baig (France, Denmark)

Ozonation is currently the most used oxidation process for micropollutants (MPs) removal in wastewater treatment plants (WWTP). Ozone is a powerful oxidant reacting rapidly with dissolved organic matter and MPs which are usually not mineralized but rather transformed into smaller compounds called ozonation transformation products. A strategy to limit the presence of toxic ozonation by-products but also to optimize the treatment line is to reduce the ozone dose used in tertiary treatment and to inject ozone upstream or directly into the biological tank used for wastewater treatment. The multiple point ozonation process was studied and developed in the last years. This dosing strategy is particularly effective when the risk of forming toxic by-products is linked with the ozone dose applied during tertiary treatment, e.g., for bromates. Ozone injection could also have a positive impact on the biological process and sludge settleability. However, the optimal ozone doses for integrated and tertiary ozonation are not known. To answer this question, multiple point ozonation tests were carried out for 1 year. The full-scale tests performed at the Brædstrup WWTP plant in Denmark have shown that multiple point ozonation is an effective solution for removing MPs from wastewater. Removals higher than 85% were achieved for the two ozonation conditions tested. No ecotoxicity was measured for both conditions contrary to conventional treatment, which demonstrates that multiple point ozonation can also decrease the ecotoxicity of wastewater and that an ozonation post-treatment is not mandatory. Antibiotic resistant bacteria (ARB) and antibiotic resistant genes (ARG) were also removed which reduces risk of transferring these dangerous bacteria to the receiving bodies. Further tests should be carried out to optimize this process, especially the doses of ozone injected during the biological treatment and the tertiary ozonation.

Session 9. Full scale studies – Part 2

9.1. The Wervershoof WWTP case: towards real-time prediction of micropollutant removal and bromate formation with a digital twin for ozonation
R. Muoio, G. Bellandi, M. Hoekstra, S. Duchi, M. Spruijt, J. Versteegh, U. Rehman, W. Audenaert (Belgium, The Netherlands)

Ge(O)zond project is an advanced treatment project, combining the knowledge in drinking water production and wastewater treatment with today's power of digital twins aiming at the indirect reuse of wastewater treatment plant effluent. The project will implement AMOZONE as full-scale digital twin to 1) predict in real-time MPs removal, bromate formation, and other key variables, 2) assess the impact of upstream WWTP dynamics, 3) run in-parallel virtual piloting test, and 4) maximise process efficiency and performance.

9.2. Towards online digital twin of two full-scale ozonation plants for micropollutant removal: minimize piloting efforts and improve decision making in design phase
G. Bellandi, R. Muoio, R. Schemen, P. Van Dijk, S. Weijers, U. Rehman, W. Audenaert (Belgium, The Netherlands)

The AMOZONE kinetic ozonation model was applied to answer key questions for assessing the suitability of ozonation for the removal of micropollutants (MPs) from the effluent of two full-scale wastewater treatment plants (WWTPs). Different control strategies for MPs removal and bromate formation were tested. Results unravelled the complex dynamics behind O_3 and HO* reactions in these specific water matrices. The virtual full-scale experiments revealed the potential MPs removal, the extent of bromate production (average levels varied

between 1 and 3 µg/L), and the influence of the upstream WWTP dynamics. No onsite piloting or MPs analyses were needed, and innovative controls could be tested. These results are now aiding the preliminary design phase of these full-scale facilities which will also make use of computational fluid dynamics combined with the AMOZONE model.

9.3. Successful prediction of ozonation performances for microcontaminants removal, disinfection and by-products formation in wastewaters
S. Baig, M. Roustan (France)

The question of ozonation performances for wastewater disinfection with parallel removal of micropollutants and control of by-products release can be at best addressed by implementing a rigorous approach that covers: Kinetics of ozone reactions with micro-organisms, micropollutants and by-product precursors, coupling hydraulics and kinetics, combination of ozonation with downstream technologies both for the best performance of ozonation and for control of by-products. Examination of all these aspects leads to a global sound strategy to which one should refer to achieve an optimal treatment solution.

Closing session and Award Ceremony

Conference Conclusions
Special Prize of the Programme Committee

FURTHER CONTACT

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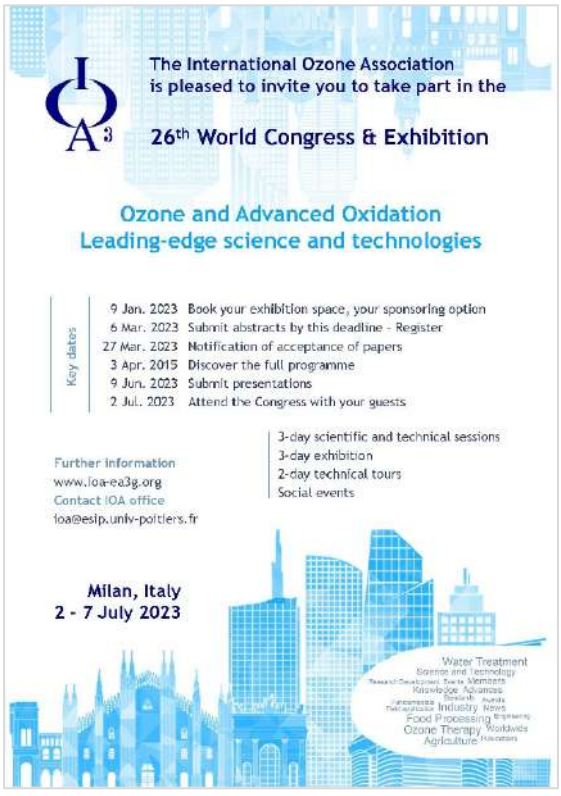

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- Association created in 1973
- Mission
  Answer the needs of the industry and research community in the fields of ozone and related oxygen oxidants
- Purpose
  - Education
  - Science

Any and all aspects of ozone and related advanced oxidation technologies

- Scope
  - Collection and dissemination of information
  - Promotion of research

Ozone and its applications

When effective oxidizing action is required

On

- Natural substances
- Manufactured products

- Mineral
- Inorganic
- Organic
- Biological

- Solid
- Liquid
- Gas

To achieve

- Disinfection
- Pollutants removal
  BOD, color, COD, VOCs, toxicity, micro-pollutants such as endocrine disruptors
- Conversion
- Purification
- Therapy

1785 First detected Van Marum
1840 Discovery Schönbein
1857 First generator Von Siemens
1897 1st Doctorate Researches on ozone Otto
1904 1st drinking water plant
1973 IOA
1973 First IOA World Congress
1979 First issue of Ozone: Science & Engineering

Numerous applications developed over more than a century

IOA Activities

- Publications
  - Ozone Science and Engineering Journal
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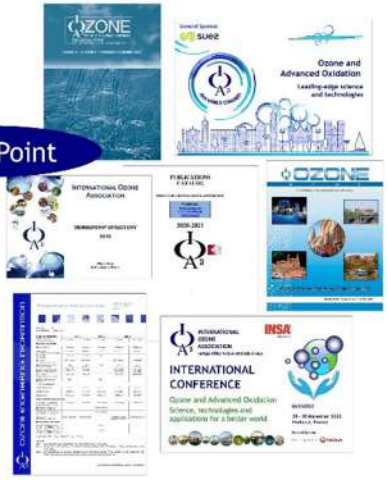
Focus Point



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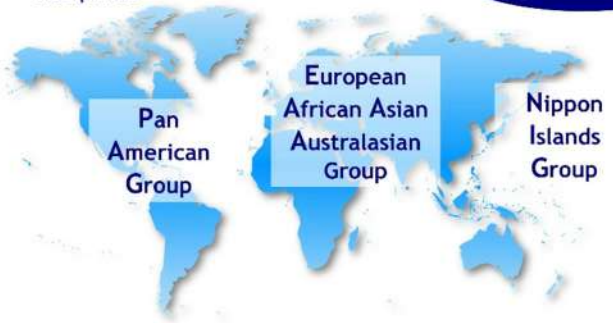

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