Sterilizasyon Teknolojisinde Yeni Bir Fiziksel Sınır

Patentli (No: TR2019 17785 B) Hidronyum İyonizasyonu ve Uzun Lümen Sterilizasyonunun Fiziksel Kimyasal Modeli Analizi

Hygcen akredite Laboratuvarları Destekli Teknik Rapor

Bischofshofen 2020-09-29

Hasan Tahsin ÖZBEK • Bülent DEVECİ • Yüksel ERGÜN

White Paper - **02.03.2026**

ÖZET

Minimal invaziv cerrahi ve fleksibl endoskopi sistemlerinin yaygınlaşması, sterilizasyon süreçlerinde geometrik limit problemini ortaya çıkarmıştır. Özellikle:

- Ø1–2 mm çap
- 1–15+ metre uzunluk
- Kompleks iç yüzey yapıları difüzyon temelli düşük sıcaklıklı sterilizasyon yöntemlerinin fiziksel sınırlarını belirlemektedir.

Bu çalışma, H_2O_2–O_3–DBD plazma kombinasyonuna dayalı hidronyum (H_3O^+) ve peroksizon (H_2O_4) oluşumu üzerinden:

- Reaktif üretim kinetiği
- Plazma ortam parametreleri
- Lümen içi taşınım mekanizmaları
- Biyolojik validasyon
- Materyal etkileşimi
- Kalıntı ve toksikoloji başlıklarını bütünleşik olarak tanımlar.

Temel yaklaşım:

Sterilizasyon, pasif difüzyon değil; elektrik alan destekli reaktif taşınım ve faz kontrollü kimyasal üretim problemidir.

KEYLER
Peroksizon, DBD Plazma, Reaktif Taşınım, Difüzyon, Kinetik, İyonizasyon, Validasyon, Toksikoloji

1. GİRİŞ VE PROBLEM TANIMI

Fleksibl endoskoplar ve robotik cerrahi enstrümanları:

- Çok katmanlı yapı
- Heterojen yüzey enerjisi
- Uzun ve dar lümen geometri

nedeniyle klasik sterilizasyon modelleri için sınır durum oluşturur.

Difüzyon temelli gaz penetrasyonu:

- Mesafe ile eksponansiyel azalır
- Yüzey etkileşimleri ile enerji kaybeder
- Faz değişimi ile kesintiye uğrar

Bu durum özellikle uzun lümenlerde sterilite sürekliliğini sınırlar.

2. MEVCUT TEKNOLOJİLERİN FİZİKSEL LİMİTLERİ

2.1 Difüzyon Sınırlaması

Lümen boyunca konsantrasyon:

$$C(x) = C_0 e^{-kx}$$

- k: yüzey etkileşim katsayısı
- x: lümen uzunluğu

Sonuç:

- x arttıkça C(x) hızla azalır
- Belirli bir uzunluktan sonra etkisiz hale gelir

2.2 Yoğunlaşma (Condensation)

Gaz fazındaki H_2O_2:

- Duvar çarpışmaları ile enerji kaybeder
- Lokal sıcaklık/parsiyel basınç koşullarında sıvı faza geçer

Sonuç:

- Film oluşumu
- Akış kesilmesi
- İleri penetrasyonun durması

2.3 Gaz Tükenmesi (Depletion)

- Reaktifler lümen boyunca tüketilir
- Son noktalarda aktif tür konsantrasyonu düşer

2.4 Plazma Sistem Limitleri

- Radikaller kısa ömürlü
- Lokal üretim → lokal etki
- Lümen boyunca sürdürülemez

2.5 Ozon Sistem Limitleri

- Yüksek oksidatif agresyon
- Kontrol zorluğu
- Materyal hasarı riski

Genel Sonuç

Aynı anda:

- Uzun penetrasyon
- Düşük sıcaklık
- Düşük hasar
- Düşük kalıntı sağlayan sistem bulunmamaktadır.

3. HİBRİT REAKTİF SİSTEM TANIMI

3.1 Sistem Bileşenleri

- H_2O_2: Prekürsör
- O_3: Oksidatif sürücü
- DBD plazma: Enerji kaynağı ve kontrol

3.2 Reaktif Türler

- H_3O^+: İyonik taşıyıcı
- H_2O_4: Stabil oksidan
- $OH\cdot$: Yüksek reaktif radikal

3.3 Temel Taşınım Mekanizması

Klasik: $J = -D\nabla C$

Hibrit: $J = -D\nabla C + \mu CE$

- D: Difüzyon katsayısı
- μCE: Elektrik alan kaynaklı drift

4. PLAZMA FİZİĞİ

4.1 Operasyon Aralığı

- Basınç: 0.1 – 0.4 Pa
- Voltaj: ~6 kV
- Akım: ~20 mA
- Frekans: 50–100 Hz

4.2 Plazma Parametreleri

- Elektron yoğunluğu: $n_e \approx 10^{13} - 10^{15}\, m^{-3}$
- Elektron sıcaklığı: $T_e \approx 1\text{–}3 eV$

4.3 Debye Uzunluğu

$$\lambda_D = \sqrt{\frac{\varepsilon_0 k T_e}{n_e e^2}}$$

$\approx 10^{-4} – 10^{-3}$ m

Sonuç:

- λD < lümen çapı
- Plazma hacimsel olarak kararlı
- İyonlar duvara çökmek yerine hacimde kalır

5. REAKSİYON KİNETİĞİ

5.1 Temel Reaksiyonlar

$$O_3 + e^- \rightarrow O_2 + O\cdot$$

$$H_2O_2 + e^- \rightarrow 2OH\cdot$$

$$OH\cdot + H_2O \rightarrow H_3O^+$$

$$HO_2\cdot + HO_2\cdot \rightarrow H_2O_4$$

5.2 Diferansiyel Kinetik Model

$$\frac{d[OH]}{dt} = k_1[H_2O_2] + k_2[O_3] - k_3[OH]^2$$

$$\frac{d[H_3O^+]}{dt} = k_4[OH][H_2O] - k_5[recombination]$$

5.3 Faz Yönetimi

- Plasma ON: Radikal üretimi
- Plasma OFF: Stabil tür oluşumu

Bu yapı:
- Reaktif üretim kontrolü
- Radikal baskılama
- Stabil oksidan üretimi sağlar.

6. LÜMEN İÇİ TAŞINIM

6.1 Coulomb İtki

- Aynı yüklü iyonlar birbirini iter
- Merkezde yoğunlaşma oluşur

6.2 Akış Karakteri

- Duvar etkileşimi azalır
- Enerji kaybı düşer
- Jet benzeri akış oluşur

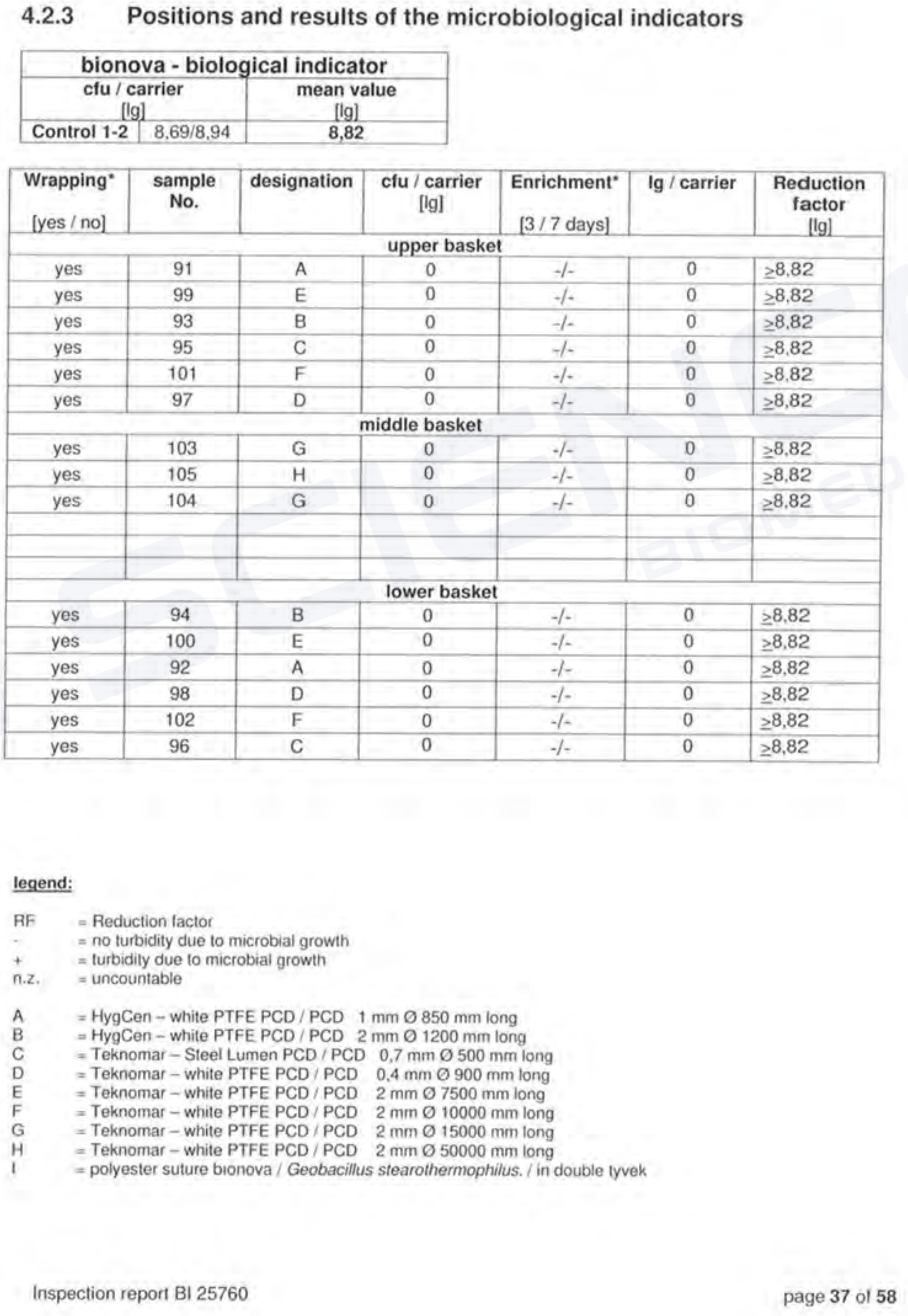
6.3 Sonuç

- Konsantrasyon kaybı minimize edilir
- Uzun mesafe taşınım mümkün hale gelir

7. VALİDASYON

7.1 Test Konfigürasyonu

- Lümen: 2 mm / 15 m
- Yük: full load
- BI: 10^6 Geobacillus stearothermophilus
- Tek Döngü: 35dk



4.2.3 Positions and results of the microbiological indicators

bionova - biological indicator		
cfu / carrier [lg]		mean value [lg]
Control 1-2	8,69/8,94	8,82

Wrapping* [yes / no]	sample No.	designation	cfu / carrier [lg]	Enrichment* [3 / 7 days]	lg / carrier	Reduction factor [lg]
			upper basket			
yes	91	A	0	-/-	0	≥8,82
yes	99	E	0	-/-	0	≥8,82
yes	93	B	0	-/-	0	≥8,82
yes	95	C	0	-/-	0	≥8,82
yes	101	F	0	-/-	0	≥8,82
yes	97	D	0	-/-	0	≥8,82
			middle basket			
yes	103	G	0	-/-	0	≥8,82
yes	105	H	0	-/-	0	≥8,82
yes	104	G	0	-/-	0	≥8,82
			lower basket			
yes	94	B	0	-/-	0	≥8,82
yes	100	E	0	-/-	0	≥8,82
yes	92	A	0	-/-	0	≥8,82
yes	98	D	0	-/-	0	≥8,82
yes	102	F	0	-/-	0	≥8,82
yes	96	C	0	-/-	0	≥8,82

legend:

RF = Reduction factor
\- = no turbidity due to microbial growth
\+ = turbidity due to microbial growth
n.z. = uncountable

A = HygCen – white PTFE PCD / PCD 1 mm Ø 850 mm long
B = HygCen – white PTFE PCD / PCD 2 mm Ø 1200 mm long
C = Teknomar – Steel Lumen PCD / PCD 0,7 mm Ø 500 mm long
D = Teknomar – white PTFE PCD / PCD 0,4 mm Ø 900 mm long
E = Teknomar – white PTFE PCD / PCD 2 mm Ø 7500 mm long
F = Teknomar – white PTFE PCD / PCD 2 mm Ø 10000 mm long
G = Teknomar – white PTFE PCD / PCD 2 mm Ø 15000 mm long
H = Teknomar – white PTFE PCD / PCD 2 mm Ø 50000 mm long
I = polyester suture bionova / *Geobacillus stearothermophilus.* / in double tyvek

Inspection report BI 25760

page 37 of 58

7.2 Sonuçlar

- %100 inaktivasyon
- SAL = 10^{-6}

7.3 İstatistik

- Tekrar sayısı ≥ 3
- Half-cycle doğrulama mevcut

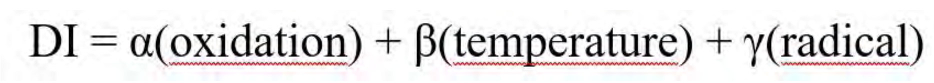
8. MATERYAL UYUMLULUĞU

Test edilen:
- 316L
- PEEK
- Silikon

8.1 Gözlemler

- Mikro-pitting yok
- Pasivasyon korunmuş
- Çatlak oluşumu yok

8.2 Damage Index



$$DI = \alpha(\text{oxidation}) + \beta(\text{temperature}) + \gamma(\text{radical})$$

düşük DI

9. YÜZEY ANALİZİ (SEM)

- Yüzey topografyası değişmemiş
- Mikroyapı stabil

10. KİMYASAL KALINTI (FTIR)

- LOD: 0.01 mg/m²
- ölçüm: < LOD

10.1 Dönüşüm Mekanizması

- H_2O_2: H_2O
- O_3: O_2

11. KONTROL ALGORİTMASI

Girdi Parametreleri
- Basınç
- Nem
- Gaz oranı
- Plazma duty

Hedef
Max:
- H_3O^+
- H_2O_4

Min:
- Radikal
- Kalıntı

Döngü Yapısı

1. H_2O_2 yükleme
2. O_3 enjeksiyon
3. Plasma ON
4. Plasma OFF
5. Geri besleme

12. REKABET ANALİZİ

Parametre	Difüzyon Sistemleri	Hibrit Sistem
Taşınım	Difüzyon	Drift + difüzyon
Lümen	~1 m	15 m
Nem	Problem	Reaktif
Kontrol	Sınırlı	Aktif

13. EKONOMİK ETKİ

- Cihaz ömrü artışı
- Sarf maliyeti azalması
- Bakım ihtiyacı düşüşü

14. REGÜLASYON UYUMU

- MDR 2017/745
- ISO 14937
- ISO 11138
- ISO 10993

15. TOKSİKOLOJİ VE EMİSYON

- Kalıntı: tespit edilemez
- Emisyon: O_2 + H_2O
- Toksisite: non-toxic

16. SONUÇ

Bu çalışma:

- Sterilizasyonun difüzyon modeli ile sınırlı olmadığını
- Elektrik alan destekli reaktif taşınımın kritik olduğunu
- Uzun lümen sterilizasyonunun fiziksel olarak mümkün olduğunu tanımlar.

H_3O^+ ve H_2O_4 temelli hibrit yaklaşım:

- Kontrollü kimya üretimi
- Düşük hasar
- Düşük kalıntı
- Uzun mesafe penetrasyonu özelliklerini birlikte sağlar.

KAYNAKÇA

Bu Daniela Trogolo, J. Samuel Arey, Peter R. Tentscher. Gas-Phase Ozone Reactions with a Structurally Diverse Set of Molecules: Barrier Heights and Reaction Energies Evaluated by Coupled Cluster and Density Functional Theory Calculations. The Journal of Physical Chemistry A 2019, 123 (2) , 517-536. DOI: 10.1021/acs.jpca.8b10323.

1. Alexandra Fischbacher, Katja Löppenberg, Clemens von Sonntag, and Torsten C. Schmidt . A New Reaction Pathway for Bromite to Bromate in the Ozonation of Bromide. Environmental Science & Technology 2015, 49 (19) , 11714-11720. DOI: 10.1021/acs.est.5b02634.
2. Yi Yang, Jin Jiang,. inglin Lu, Jun Ma, and Yongze Liu . Production of Sulfate Radical and Hydroxyl Radical by Reaction of Ozone with Peroxymonosulfate: A Novel Advanced Oxidation Process. Environmental Science & Technology 2015, 49 (12) , 7330-7339. DOI: 10.1021/es506362e.
3. Janez Cerkovnik and Božo Plesničar . Recent Advances in the Chemistry of Hydrogen Trioxide (HOOOH). Chemical Reviews 2013, 113 (10) , 7930-7951. DOI: 10.1021/cr300512s.
4. Alexandra Fischbacher, Justus von Sonntag, Clemens von Sonntag, and Torsten C. Schmidt . The •OH Radical Yield in the H_2O_2 + O_3 (Peroxone) Reaction. Environmental Science & Technology 2013, 47 (17) , 9959-9964. DOI: 10.1021/es402305r.
5. Carlos Barrera-Díaz, Lina. A. Bernal-Martínez, Reyna Natividad, and Juan M. Peralta-Hernández . Synergy of Electrochemical/O_3 Process with Aluminum Electrodes in Industrial Wastewater Treatment. Industrial & Engineering Chemistry Research 2012, 51 (27) , 9335-9342. DOI: 10.1021/ie3004144.
6. Sergej Naumov and Clemens von Sonntag . Standard Gibbs Free Energies of Reactions of Ozone with Free Radicals in Aqueous Solution: Quantum-Chemical Calculations. Environmental Science & Technology 2011, 45 (21) , 9195-9204. DOI: 10.1021/es2018658.
7. J. Pablo Pocostales, Myint M. Sein, Wolfgang Knolle, Clemens von Sonntag, and Torsten C. Schmidt. Degradation of Ozone-Refractory Organic Phosphates in Wastewater by Ozone and Ozone/Hydrogen Peroxide (Peroxone): The Role of Ozone Consumption by Dissolved Organic Matter. Environmental Science & Technology 2010, 44 (21) , 8248-8253. DOI: 10.1021/es1018288.
8. Helena Jablonowski, Joao Santos Sousa, Klaus-Dieter Weltmann, Kristian Wende, Stephan Reuter. Quantification of the ozone and singlet delta oxygen produced in gas and liquid phases by a non-thermal atmospheric plasma with relevance for medical treatment. Scientific Reports 2018, 8 (1) DOI: 10.1038/s41598-018-30483-w.
9. Yalei Ding, Jiejie Wang, Shanshan. u, Kun-Yi Andrew Lin, Shaoping Tong. Oxygen vacancy of CeO_2 improved efficiency of H_2O_2/O_3 for the degradation of acetic acid in acidic solutions. Separation and Purification Technology 2018, 207, 92-98. DOI: 10.1016/j.seppur.2018.06.027.

10. Donggwan Lee, Jae-Cheol Lee, Joo-Youn Nam, Hyun-Woo Kim. Degradation of sulfonamide antibiotics and their intermediates toxicity in an aeration-assisted non-thermal plasma while treating strong wastewater. Chemosphere 2018, 209, 901-907. DOI: 10.1016/j.chemosphere.2018.06.125.

11. David B. Miklos, Christian Remy, Martin Jekel, Karl G. Linden, Jörg E. Drewes, Uwe Hübner. Evaluation of advanced oxidation processes for water and wastewater treatment – A critical review. Water Research 2018, 139, 118-131. DOI: 10.1016/j.watres.2018.03.042.

12. Pierre-François Biard, Thom Thi Dang, Jenny Bocanegra, Annabelle Couvert. Intensification of the O 3 /H 2 O 2 advanced oxidation process using a continuous tubular reactor filled with static mixers: Proof of concept. Chemical Engineering Journal 2018, 344, 574-582. DOI: 10.1016/j.cej.2018.03.112.

13. Emmanuel Mousset, Nihal Oturan, Mehmet A. Oturan. An unprecedented route of OH radical reactivity evidenced by an electrocatalytical process: Ipso-substitution with perhalogenocarbon compounds. Applied Catalysis B: Environmental 2018, 226, 135-146. DOI: 10.1016/j.apcatb.2017.12.028.

14. J.F. Pérez, S. Sabatino, A. Galia, M.A. Rodrigo, J. Llanos, C. Sáez, O. Scialdone. Effect of air pressure on the electro-Fenton process at carbon felt electrodes. Electrochimica Acta 2018, 273, 447-453. DOI: 10.1016/j.electacta.2018.04.031.

15. Guilherme Garcia Bessegato, João Carlos de Souza, Juliano Carvalho Cardoso, Maria Valnice Boldrin Zanoni. Assessment of several advanced oxidation processes applied in the treatment of environmental concern constituents from a real hair dye wastewater. Journal of Environmental Chemical Engineering 2018, 6 (2) , 2794-2802. DOI: 10.1016/j.jece.2018.04.041.

16. A. Privat-Maldonado, Y. Gorbanev, D. O'Connell, R. Vann, V. Chechik, M. W. van der Woude. Nontarget Biomolecules Alter Macromolecular Changes Induced by Bactericidal Low–Temperature Plasma. IEEE Transactions on Radiation and Plasma Medical Sciences 2018, 2 (2) , 121-128. DOI: 10.1109/TRPMS.2017.2761405.

17. Mika Sillanpää, Mohamed Chaker Ncibi, Anu Matilainen. Advanced oxidation processes for the removal of natural organic matter from drinking water sources: A comprehensive review. Journal of Environmental Management 2018, 208, 56-76. DOI: 10.1016/j.jenvman.2017.12.009.

18. B.W. Darvell. More Chemistry. 2018,,, 771-789. DOI: 10.1016/B978-0-08-101035-8.50030-4.

19. Erika Reisz, Clemens von Sonntag, Agnes Tekle-Röttering, Sergej Naumov, Winfried Schmidt, Torsten C. Schmidt. Reaction of 2-propanol with ozone in aqueous media. Water Research 2018, 128, 171-182. DOI: 10.1016/j.watres.2017.10.035.

20. João F. Gomes, Inês Leal, Katarzyna Bednarczyk, Marta Gmurek, Marek Stelmachowski, Magdalena Diak, M. Emília Quinta-Ferreira, Raquel Costa, Rosa M. Quinta-Ferreira, Rui C. Martins. Photocatalytic ozonation using doped TiO 2 catalysts for the removal of parabens in water. Science of The Total Environment 2017, 609, 329-340. DOI: 10.1016/j.scitotenv.2017.07.180.

21. Pierre-François Biard, Thom Thi Dang, Annabelle Couvert. Determination by reactive absorption of the rate constant of the ozone reaction with the hydroperoxide anion. Chemical Engineering Research and Design 2017, 127, 62-71. DOI: 10.1016/j.cherd.2017.09.004.

22. Ozge Turkay, Sibel Barışçı, Mika Sillanpää. E-peroxone process for the treatment of laundry wastewater: A case study. Journal of Environmental Chemical Engineering 2017, 5 (5) , 4282-4290. DOI: 10.1016/j.jece.2017.08.012.

23. Minhwan Kwon, Homin Kye, Youmi Jung, Yeojoon Yoon, Joon-Wun Kang. Performance characterization and kinetic modeling of ozonation using a new method: R OH,O3 concept. Water Research 2017, 122, 172-182. DOI: 10.1016/j.watres.2017.05.062.

24. Ligy Philip, Bhallamudi Murty, Channarong Puchongkawarin, Miao Guo, Nilay Shah, David Stuckey, Benoit Chachuat, Yannic Vaupel, Sarojini Tiwari, Chitta Behera, Babji Srinivasan, Chedly Tizaoui, Olajumoke Odejimi, Ayman Abdelaziz. 3 Wastewater Treatment. 2017,,, 115-180. DOI: 10.1201/9781315153209-4.

25. Songjie Wu, Qian Zhang, Ruonan Ma, Shuang Yu, Kaile Wang, Jue Zhang, Jing Fang. Reactive radical-driven bacterial inactivation by hydrogen-peroxide-enhanced plasma-activated-water. The European Physical Journal Special Topics 2017, 226 (13) , 2887-2899. DOI: 10.1140/epjst/e2016-60330-y.

26. Julia Patzsch, Jonathan Z. Bloh. Improved photocatalytic ozone abatement over transition metal-grafted titanium dioxide. Catalysis Today 2017, DOI: 10.1016/j.cattod.2017.07.010.

27. Xinyang Li, Shaobin Sun,. u Zhang, Guicheng Liu, Clark Renjun Zheng, Jianzhong Zheng, Dayi Zhang, Hong Yao. Combined electro-catazone/electro-peroxone process for rapid and effective Rhodamine B degradation. Separation and Purification Technology 2017, 178, 189-192. DOI: 10.1016/j.seppur.2016.12.052.

28. Jingxin Yang, Ji Li, Wenyi Dong, Jun Ma, Jiayin Li. Influence of nitrite on the degradation of atrazine by ozonation. Journal of Chemical Technology & Biotechnology 2017, 92 (2) , 442-450. DOI: 10.1002/jctb.5031.

29. George Wafula Wanjala, Arnold Onyango, Calvin Onyango, Moses Makayoto. . African Journal of Biochemistry Research 2017,,, 79. DOI: 10.5897/AJBR2017.0967.

30. Glen Andrew de Vera, Wolfgang Gernjak, Howard Weinberg, Maria José Farré, Jurg Keller, Urs von Gunten. Kinetics and mechanisms of nitrate and ammonium formation during ozonation of dissolved organic nitrogen. Water Research 2017, 108, 451-461. DOI: 10.1016/j.watres.2016.10.021.

31. M. E. Zappi, R. Hernandez, D. Gang, R. Bajpai, C. H. Kuo, D. O. Hill. Treatment of groundwater contaminated with high levels of explosives using advanced oxidation processes. International Journal of Environmental Science and Technology 2016, 13 (12) , 2767-2778. DOI: 10.1007/s13762-016-1109-x.

32. Juhong Zhan, Yujue Wang, Huijiao Wang, Wenhua Shen,. uejun Pan, Jinlin Wang, Gang Yu. Electro-peroxone regeneration of phenol-saturated activated carbon fiber: The effects of irreversible adsorption and operational parameters. Carbon 2016, 109, 321-330. DOI: 10.1016/j.carbon.2016.08.034.

33. Jingxin Yang, Ji Li, Wenyi Dong, Jun Ma, Jie Cao, Tingting Li, Jiayin Li, Jia Gu, Pingxin Liu. Study on enhanced degradation of atrazine by ozonation in the presence of hydroxylamine. Journal of Hazardous Materials 2016, 316, 110-121. DOI: 10.1016/j.jhazmat.2016.04.078.

34. Xin Cheng, Hongguang Guo, Hongwei Liu, Yang Liu, Ying Yang, Yongli Zhang. Performance and Mechanism on Degradation of Estriol Using O 3 /PS Process. Ozone: Science & Engineering 2016, 38 (5) , 358-366. DOI: 10.1080/01919512.2016.1170589.

35. László Wojnárovits, Erzsébet Takács. Radiation Induced Degradation of Organic Pollutants in Waters and Wastewaters. Topics in Current Chemistry 2016, 374 (4) DOI: 10.1007/s41061-016-0050-2.

36. Jaedon Shin, Zahra Ramadhany Hidayat, Yunho Lee. Influence of Seasonal Variation of Water Temperature and Dissolved Organic Matter on Ozone and OH Radical Reaction Kinetics During Ozonation of a Lake Water. Ozone: Science & Engineering 2016, 38, 100-114. DOI: 10.1080/01919512.2015.1079120.

37. Yury Gorbanev, Deborah O'Connell, Victor Chechik. Non-Thermal Plasma in Contact with Water: The Origin of Species. Chemistry - A European Journal 2016, 22 (10) , 3496-3505. DOI: 10.1002/chem.201503771.

38. Arnold N. Onyango. Alternatives to the 'water oxidation pathway' of biological ozone formation. Journal of Chemical Biology 2016, 9, 1-8. DOI: 10.1007/s12154-015-0140-6.

39. Fei Qi, Wei Chu, Bingbing. u. Comparison of phenacetin degradation in aqueous solutions by catalytic ozonation with CuFe 2 O 4 and its precursor: Surface properties, intermediates and reaction mechanisms. Chemical Engineering Journal 2016, 284, 28-36. DOI: 10.1016/j.cej.2015.07.095.

40. Erika Reisz, Sergej Naumov, Winfried Schmidt, Clemens von Sonntag. Reaction of Ozone with Ag(I)—Mechanistic Considerations. Ozone: Science & Engineering 2015, 37, 393-404. DOI: 10.1080/01919512.2015.1041583.

41. Huijiao Wang, Shi Yuan, Juhong Zhan, Yujue Wang, Gang Yu, Shubo Deng, Jun Huang, Bin Wang. Mechanisms of enhanced total organic carbon elimination from oxalic acid solutions by electro-peroxone process. Water Research 2015, 80, 20-29. DOI: 10.1016/j.watres.2015.05.024.

42. Jesús Ferre-Aracil, Salvador C. Cardona, Javier Navarro-Laboulais. Kinetic Study of Ozone Decay in Homogeneous Phosphate-Buffered Medium. Ozone: Science & Engineering 2015, 37, 330-342. DOI: 10.1080/01919512.2014.998756.

43. Fei Qi, Bingbing. u, Wei Chu. Heterogeneous catalytic ozonation of phenacetin in water using magnetic spinel ferrite as catalyst: Comparison of surface property and efficiency. Journal of Molecular Catalysis A: Chemical 2015, 396, 164-173. DOI: 10.1016/j.molcata.2014.10.001.

44. Erika Reisz, Alexandra Fischbacher, Sergej Naumov, Clemens von Sonntag, Torsten C. Schmidt. Hydride Transfer: A Dominating Reaction of Ozone with Tertiary Butanol and Formate Ion in Aqueous Solution. Ozone: Science & Engineering 2014, 36, 532-539. DOI: 10.1080/01919512.2014.891436.

45. Sergey L. Khursan. Peroxide intermediates of oxidation processes: Organic trioxides. 2014,,, 1-72. DOI: 10.1002/9780470682531.pat0874.

46. S. Reed Plimpton, Mark Gołkowski, Deborah G. Mitchell, Chad Austin, Sandra S. Eaton, Gareth R. Eaton, Czeslaw Gołkowski, Martin Voskuil. Remote delivery of hydroxyl radicals via secondary chemistry of a nonthermal plasma effluent. Biotechnology and Bioengineering 2013, 110 (10.1002/bit.v110.7) , 1936-1944. DOI: 10.1002/bit.24853.

47. Zdenko Machala, Barbora Tarabova, Karol Hensel, Eva Spetlikova, Libusa Sikurova, Petr Lukes. Formation of ROS and RNS in Water Electro-Sprayed through Transient Spark Discharge in Air and their Bactericidal Effects. Plasma Processes and Polymers 2013, 10 (10.1002/ppap.v10.7) , 649-659. DOI: 10.1002/ppap.201200113.

48. Josep M. Anglada, Miquel Torrent-Sucarrat, Manuel F. Ruiz-Lopez, Marilia Martins-Costa. Is the HO_4^- Anion a Key Species in the Aqueous-Phase Decomposition of Ozone?. Chemistry - A European Journal 2012, 18 (10.1002/chem.v18.42) , 13435-13445. DOI: 10.1002/chem.201201991.

49. Marek Golkowski, Czesław Golkowski, Jori Leszczynski, S. Reed Plimpton, Piotr Maslowski, Aleksandra Foltynowicz, Jun Ye, Bruce McCollister. Hydrogen-Peroxide-Enhanced Nonthermal Plasma Effluent for Biomedical Applications. IEEE Transactions on Plasma Science 2012, 40, 1984-1991. DOI: 10.1109/TPS.2012.2200910.

50. D. Gardoni, A. Vailati, R. Canziani. Decay of Ozone in Water: A Review. Ozone: Science & Engineering 2012, 34, 233-242. DOI: 10.1080/01919512.2012.686354.

51. Sergej Naumov, Clemens von Sonntag. The reaction of $•OH$ with O_2, the decay of $O_3•^-$ and the pKa of $HO_3•$ - interrelated questions in aqueous free-radical chemistry. Journal of Physical Organic Chemistry 2011, 24 (10.1002/poc.v24.7) , 600-602. DOI: 10.1002/poc.1812.

52. Rossano Amadelli, Luca Samiolo, Achille De Battisti, Alexander B. Velichenko. Electro-oxidation of Some Phenolic Compounds by Electrogenerated O_3 and by Direct Electrolysis at PbO_2 Anodes. Journal of The Electrochemical Society 2011, 158, P87. DOI: 10.1149/1.3589913.

53. Pentax, White Paper

54. ASP, White Paper

55. Olympus, White Paper