Proceedings of the 4th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/85/20240697

The plausibility and ideal design of electrochemical disinfection for drinking water in hospitals susceptible to Legionella and E. coli contamination, compared to traditional methods

Junao Wu[1,6,†], Yi Yu[2,5,7,†], Haoyang Xu[3,8,†], Jiazhen Li[4,9,†]

[1]Hong Kong International School, Hong Kong, 00000, Hong Kong, China
[2]Letter & Science, University of Wisconsin-Madison, Madison, 53703, United States
[3]Nanjing Foreign Language School, Nanjing, 210008, China
[4]Energy engineering, Zhejiang University, Hangzhou, 310013, China
[5]Corresponding author

[6]250233@hkis.edu.HK
[7]Yu353@wwisc.edu
[8]xu.haoy@outlook.com
[9]2016410931@qq.com
[†]Junao Wu, Haoyang Xu, Jiazhen Li, and Yi Yu contributed equally to this work and should be considered co-first authors.

Abstract. Legionella and Escherichia coli (E. coli), bacteria lethal to humans, are widespread in drinking water. Traditional disinfection methods using chlorine gas, temperature control, and ultraviolet are widely applied today but have several drawbacks. In contrast, the electrochemical disinfection methods could address the problems. This study reviews the literature on electrochemical disinfection and compares traditional disinfection methods with electrochemical ones under evaluation of cost, E. coli contamination efficiency, and effect. Results show that titanium meshed electrodes are the most cost-efficient compared to more effective electrodes with significantly higher production costs. The application of the proposed electrochemical disinfection device gains a financial advantage over traditional methods, suggesting a promising future for the disinfection method. Meanwhile, investigations on the electrocoagulation method aim to disinfect the water to the drinking water level. Results show that the combination of electrocoagulation and the titanium meshed electrode device proves to have a better disinfection effect than individual methods and a lower cost than traditional methods. This research provides insight into the properties of biofilms, traditional disinfection methods, and different electrochemical disinfection methods. After reviewing the literature and evaluating various factors, we offer an ideal design for Legionella and E. coli-contaminated water disinfection devices with a promising future once applied.

Keywords: electrochemical disinfection, Legionella, Escherichia coli, drinking water, hospital

DOI: 10.54254/2755-2721/85/20240697

1. Introduction

Legionella first appeared in 1976, in a Philadelphia hotel hosting a meeting for veterans. In this largest-ever community-associated outbreak of Legionnaires' disease (LD) in the US, 182 individuals were affected, 29 of whom succumbed to the illness [1]. Despite over four decades since the identification of Legionella and its pervasiveness, the bacteria remain a significant threat to human health. The mortality rate of LD is about 10%, and, according to Public Health Ontario (PHO) (https://www.publichealthontario.ca), the projected number of cases in 2017 was 7000, which indicated an alarmingly large number of people suffering from the preventable disease. Escherichia coli (E. coli), a fecal coliform bacterium that causes severe, bloody diarrhea, has proved to be a fatal issue for less developed countries. Even in developed countries, inadequate systems can allow E. coli to proliferate and harm people. On August 8th, 2023, a second mysterious wave of E. coli infection occurred in Norway and affected half a dozen people. E. coli contamination of water treatment systems is a vital issue, claiming around 100 lives in the United States annually. Interested in improving inadequate water treatment systems to ensure that such preventable infections occur with less frequency, we focus on treating the drinking water in hospitals, as the immunocompromised are more easily infected and Legionella usually inhabits hospital waters.

Disinfection, a typical unit process applied in wastewater treatment, eliminates microorganisms. Chlorination, the process of adding chlorine or chlorine compounds into water to kill bacteria, is the dominant traditional disinfection method. However, safety concerns and efficiency drawbacks are addressed by recent research. Most disinfection by-products (DBP) formed during the process are toxic to citizens' health and need strict control. In addition, the occurrence of dark points where the chlorine level is too low, along with over-chlorination at other points, decreases the overall disinfection efficiency, increases operating costs, and poses threats to human health. Ultraviolet irradiation and O_3 oxidation, also common disinfection methods, leave no residue for secondary disinfection. Electrochemical disinfection, in comparison, has attracted attention due to its high efficiency, convenience in installation and operation, and environmental friendliness. Both direct oxidation and indirect oxidation function to inactivate pathogenic microorganisms (PMs) [2]. Nevertheless, in the condition of modern hospitals, more research needs to be done about the feasibility of the implementation of electrochemical disinfection devices.

This article aims to investigate the plausibility and ideal design of electrochemical disinfection for drinking water in hospitals prone to Legionella and E. coli contamination. This article analyzes and compares traditional methods with multiple electrochemical methods from different aspects. Specifically, the risk of pathogens to human health, the cost and efficiency of different electrode materials, and the electrocoagulation method are investigated.

2. Methods

To ensure a comprehensive review on electrochemical disinfection method for drinking water in places susceptible to Legionella and E. coli contamination, we searched PubMed (https://www.ncbi.nlm.nih.gov/pubmed) and Academic Search (https://web-p-ebscohost-com.ezproxy.library.wisc.edu/ehost/search/advanced?vid=0&sid=a1bd1413-7520-4a5a-ab57-0bd8ec6dd90c%40redis) through August 2023. We used the search terms electrochemical, disinfection, E. coli, legionella, BDD, oxidation, Electrocoagulation, hospital, chlorine gas, ozone, and UV light. The reference lists are also reviewed manually in the interested articles.

3. Results regarding biofilms

3.1. The hazards of chlorinated drinking water disinfection methods

Chlorination is one of the most commonly used methods of water disinfection, and chlorinated water released into the environment can potentially harm humans in several ways [3,4]. Chlorine is a strong oxidizing agent that causes skin and eye irritation, redness, and itching, and contact with chlorinated water can irritate the skin and eyes. Chlorination may contain disinfection byproducts such as

DOI: 10.54254/2755-2721/85/20240697

trihalomethanes and halo acetic acids and long-term exposure to these DBPs has been linked to an increased risk of certain health problems, including cancer, reproductive disorders, and developmental disorders. Ingestion or inhalation of chlorinated water can lead to respiratory problems, with chlorine released from chlorinated water, especially in warm conditions, and inhalation of chlorine gas can lead to respiratory distress, coughing, and difficulty breathing. Chlorinated water can also impact marine ecosystems and thus indirectly affect human health. The discharge of large quantities of chlorinated water into coastal waters can disrupt the balance of marine life, leading to changes in the food chain and potential contamination of seafood.

3.2. Current methods of disinfection and biofilms

Besides Chlorination, other traditional bacterial disinfection methods, such as ultraviolet light, electroionization, and ozone treatment, are widely utilized to ensure the purity of water entering healthcare systems [5]. However, these modalities present significant limitations due to their inability to maintain residual disinfection. Often the largest issue that hospitals face with water contamination lies with the biofilms forming inside the lining of building pipes.

These biofilms house pathogenic bacteria like Legionella and E. coli, making them more resistant to mechanical and biological destruction. Intensive measures, such as heat flushing and chlorination, are commonly implemented after detecting an outbreak when the system has already been compromised. Following disinfection procedures, microbial matrices often remain, providing a refuge for bacterial repopulation and perpetuating the cycle of contamination [6,7]. Microscopic investigations reveal a high density of bacteria within biofilms and cellular fragments adhered to pipe surfaces after electrochemical disinfection. Polymerase Chain Reaction (PCR) methods have identified these cellular remnants as Escherichia coli (E. coli), which are known to mechanically fasten to pipe walls via filamentous appendages, thereby enhancing the robustness of biofilms.

The most widespread mechanism of drinking water disinfection is chlorination. Despite its affordability and easy use, chlorination faces obstacles including potential microbial resistance from mycobacterium and weakness against post-disinfection changes in bacterial communities. The effectiveness of chlorination can also be further reduced by factors like dissolved organic carbon and ammonia presence [7,8].

3.3. The problems of Legionella contamination

Legionella contamination remains a threat to human health decades after its first occurrence, appearing undiagnosed in alarming numbers, with an estimated mortality rate of about 10% [9]. A study conducted in the summer of 2018 showed that 28% of the pneumonia cases at Humber River Hospital in North York (Toronto) were Legionnaires' disease; new methods are needed to further safeguard immunosuppressed individuals from Legionella in healthcare facilities [9].

Legionella's inherent resilience in aquatic environments is substantially amplified due to the bacterium's ability to infiltrate and exploit free-living amoebae, such as Acanthamoeba, as hosts for protection. Not only does this endosymbiotic relationship improve the pathogenicity and virulence of both organisms, but it also remarkably enhances Legionella's capability to invade human epithelial cells [10]. Amoebae hosts provide Legionella with increased resistance to environmental stressors. Specifically, even high concentrations of conventional disinfectants like chlorine, typically lethal to many bacteria, and elevated heat levels fail to eliminate the Legionella encased within amoebae. This heightened resilience represents a major obstacle to conventional water treatment strategies, necessitating novel and more effective solutions.

4. Results regarding disinfection methods

4.1. Basic principles of electrochemical disinfection

One of the most crucial factors in determining the kind and quantity of electrogenerated oxidants is the choice of electrode material. Different types of electrodes should be applied depending on the electrolyte

DOI: 10.54254/2755-2721/85/20240697

and the quality indicators of wastewater. As a result, we reviewed the literature to look for detailed descriptions of different electrode materials. Specifically, active anodes are efficient and commonly used in chloride-containing water as they produce reactive chlorine species (RCS) disinfectants. Investigations have demonstrated that active electrodes, such as dimensional stable anode (DSA) and metal electrodes, might swiftly inactivate PMs in the presence of Cl^- due to the active anode's low chlorine evolution potential and the creation of a significant amount of RCS on the surface. For example, Ti/RuO_2 anode achieved 6 log units of E. coli inactivation in 210 min [11]. In contrast, active anodes do not work as efficiently in non-chlorine water [2]. For instance, Jeong's group found that Pt anode in inert electrolyte displayed a low efficiency in treating E. coli, as the accumulation of •OH is limited by PtOx produced during the reaction [12]. Non-active anodes are commonly employed in water that doesn't contain chlorides because they can generate reactive oxygen species (ROS) disinfectants. More physically adsorbed M(•OH) can be generated on the non-active electrode surface, which benefits the disinfection process. Boron-doped diamond (BDD), with oxygen evolution overpotential and exceptional corrosion resistance, is reported to produce a large amount of BDD(•OH). As a result, the BDD anode (8 cm^2) completely inactivated E. coli in non-chorine water within 30 min [13]. However, the high costs of the commercially available electrodes mentioned above hindered the mass production and application of these materials. To cope with the problem, transition metal oxides modified DSA, including Sb doped $Sn_{80\%}$–$W_{20\%}$ oxide anode (E. coli removal of 7.4 log units in 1 min) [14], greatly improves the disinfection efficiency by producing more of ROS and RCS, and lowers the material cost. In addition, indirect cathodic oxidation mainly includes the generation of H_2O_2. Cheap carbon-based materials, such as modified reticulated vitreous carbon (RVC) (E. coli removal of 6 log units in 210 min), can replace expensive traditional stainless steel or metal material cathodes to generate a greater amount of hydrogen peroxide.

As shown in Table 1, the current and disinfection rates for different electrodes are shown. All the current densities are in the scale of milliamps and inactivation rate in minutes and log units, except for the titanium and Ag-CNT/ceramic membrane electrode where only voltage and log units were found.

Table 1. Cost of electrode material

Anode	Cathode	PMs	Current Density	Inactivation rate	Ref.
BiO_x/TiO_2	SS (90.45 cm^2)	*E. coli*	1.2 mA/cm^2	30 min: > 5 log units	[15]
Sb-$Sn_{80\%}$-$W_{20\%}$	SS (80 cm^2)	*E. coli*	6 mA/cm^2	1 min: 7.4 log units	[14]
Ti/RuO_2	Modified RVC	*E. coli*	0.8 mA/cm^2	210 min: 6 log units	[11]
BDD (8 cm^2)	Ti (8 cm^2)	*E. coli*	4.2 mA/cm^2	30 min: completely inactivated	[13]
BDD (3 cm^2)	SS (3cm^2)	*E. coli*	33.3 mA/cm^2	60 min: > 5 log units	[16]
Pt (5 cm^2)	Graphite rod	*E. coli*	100 mA/cm^2	180 min: 90%	[12]
Ti	Ag-CNT/ceramic membrane	*E. coli*	Not mentioned (voltage: 2.0 V)	6 log units	[17]
Platinized titanium mesh electrodes	Platinized titanium mesh electrodes	*E. coli*	10 mA/cm^2	60 min: 5 log units	[18]

In Table 2, the price of each electrode material is listed. Stainless steel, Titanium, Bismuth oxide, Tin, and Tungsten oxide are listed in price per kilogram. The RVC glass carbon rod and BDD electrode, as commercially available products, have prices listed separately in units of millimeters and cubic centimeters.

DOI: 10.54254/2755-2721/85/20240697

Table 2. Current density and Inactivation rate of each electrode

Anode	Cathode	Cost	Ref.
BiO_x/TiO_2	SS (90.45 cm^2)	Stainless steel \$1.41/kg Ti \$2.75/kg BiOx \$499.5/kg	[15]
$Sb\text{-}Sn_{80\%}\text{-}W_{20\%}$	SS (80 cm^2)	Tungsten-oxide \$35-40/kg Tin \$2.75/kg	[14]
Ti/RuO_2	Modified RVC	RVC glass carbon rod \$10/mm Ti \$2.75/kg	[11]
BDD (8 cm^2)	Ti (8 cm^2)	BDD \$352.7/cm^3 Ti \$2.75/kg	[13]
BDD (3 cm^2)	SS (3cm^2)	BDD \$352.7/cm^3 Stainless steel \$1.41/kg	[16]
Platinized titanium mesh electrodes	Platinized titanium mesh electrodes	Ti \$2.75/kg Pt \$29,236/kg (tiny amount per electrode)	[18]

4.2. Basic principles of electrocoagulation

Electrochemical indirect oxidation has several drawbacks: chlorine generation produces disinfection by-products, with which potential health and environmental risks are associated; the effectiveness of hydrogen peroxide generation depends on the type and concentration of the active substance produced, and the effectiveness is compromised in the case of residual disinfection; the cost of the ozone generation process is more expensive than other methods [19]. Therefore, we introduce electrocoagulation.

Electrocoagulation works by passing an electric current through a series of electrodes in water [20], causing metal ions to be released into the water, which in turn causes the impurities in the water to clump together and form larger particles. These larger particles can then be filtered out. The anodic dissolution produces in-situ coagulants (metallic ions) with the generation of hydroxyl ions and hydrogen gas at the cathode. These in-situ coagulants are responsible for the generation of the floc surrounded by the metal hydroxides, which act as an excellent adsorbent. The hydrogen gas produced at the cathode assists in bringing the floc to the water surface by sweep flotation.

The mechanism involves four major steps [20]: (i) The anode material is connected to the power supply, metal cations are generated in the system, while the cathode hydrolyzes produce hydroxyl ions; (ii) The generated hydroxyl ions interact with metal cations, forming the colloids; (iii) The generated colloids react with pollutants to neutralize their charges and adsorb onto the colloids; (iv) Part of the colloid settles to the bottom and then is filtered out, and part of the colloid is carried to the water surface by sweep flotation with gas generated by the cathode.

4.3. Electrochemical disinfection and bacterial membranes

Electrochemical disinfection is a potent method for the elimination of gram-negative bacteria, utilizing both direct and indirect oxidation processes [14]. The process begins when an electrical current is applied to two electrodes. Direct oxidation occurs at the anode surface, leading to immediate microbial cell deaths. This action occurs as the electrical process extracts electrons from the bacterial cell membrane, thereby killing the bacteria [21].

Simultaneously, secondary oxidation occurs in the solution: organic pollutants react on the anode, generating bulk oxidation species such as hydroxyl radicals, chlorine, and hypochlorous acid, which then act on free-floating bacteria, oxidizing their membranes and eliminating them [22]. This oxidation process is particularly effective against gram-negative bacteria such as Legionella and E. coli because the generated oxidants attack the bacteria's outermost peptidoglycan layer and phospholipid bilayer, disrupting the cell structure integrity [2].

DOI: 10.54254/2755-2721/85/20240697

On the surface of the cathode, hydrogen peroxide (H_2O_2) is produced, which also performs indirect oxidation. H_2O_2 can permeate the microbial cell membrane, reacting with free ferric ions or iron-sulfur clusters, leading to DNA damage and increased membrane permeability, thereby affecting bacterial viability [11]. Still, one of the most potent residual disinfectants is chlorine. Its action includes destroying the cell membrane, degrading cytoplasmic proteins, and maintaining a persistent presence in the water to act on free-floating Legionella and E. coli post-treatment; whereas hydroxyl radicals degrade quickly and are less effective than residual disinfectants [8].

5. Discussion

According to our results in Table 1 and Table 2, we choose the platinized titanium mesh electrodes as the currently most appropriate electrode materials to apply in real life after evaluation from aspects of cost, efficiency, and safety. The platinized titanium has an exceptionally low material cost of $0.0378 per electrode. Admittedly, the processing fee cannot be neglected, but the total cost is still significantly lower than that of any other electrode material. The inactivation rate of platinized titanium is not the best. However, as the latter process of electrocoagulation further disinfects the water, the provided disinfection result is satisfactory. While BDD and other metal anodes are slightly more effective in wastewater disinfection, their high material cost prevents the devices from being implemented in hospitals. This electrode is cost-efficient compared to the traditional method. The cost of healthcare and lost working days due to Legionnaires' disease in the UK is about £100M per year. Meanwhile, around £140M is used to monitor Legionella in the Domestic Hot Water (DHW) system in the UK [18]. According to the data from the UK Health Security Agency by July 17th, 2023, the average monthly number of cases of E. coli bacteremia is 3281.69. E. coli and Legionella are still a big issue in healthcare centers and while traditional methods cost a lot. If our proposed electrochemical method can be applied in healthcare centers, based on the electrode price and the energy consumption, the average cost for preventing E. coli and Legionella is £0.3106M per year, lower than the current cost of £140M per year.

Electrocoagulation is a water treatment process that utilizes electric current to remove pollutants from water. When an electric current is applied, metal ions are released from the electrode, forming metal hydroxide precipitates. When electrocoagulation is used following electrochemical oxidation, these precipitates can adsorb and neutralize various pollutants, including killed bacterial cells, disinfection by-products, and residual bacteria. Then, the precipitate can be separated from the water through precipitation or flotation. The coupling method of electrocoagulation and electrochemical oxidation further purifies water. Not only will the bacteria in the pipeline not be able to accelerate their reproduction and growth by consuming the dead bacteria, but these bacteria will also be killed by residual disinfection [23]. Disinfection by-products and precursors that generate disinfection by-products are also removed during the electrocoagulation process. Therefore, the coupling method of electrocoagulation and electrochemical oxidation can ensure the safety of hospital water use.

Overall, electrochemical disinfection presents a promising method for water treatment due to its capacity to generate chemical oxidants in situ via redox reactions on the electrode surface, eliminating the need for hazardous material transport and storage and making it scalable for various treatment contexts [22]. Electrochemical disinfection is a good possibility for healthcare facilities in particular because chlorine residuals from secondary oxidation would flow consistently through the pipes, greatly decreasing the chances of biofilm formation and partially decreasing amoeba survival.

6. Conclusion

This study investigates the plausibility of electrochemical disinfection methods in treating drinking water in hospitals. Electrochemical coagulation and disinfection are two processes that have the potential to substitute traditional disinfection methods when combined as they enhance the efficiency of each other and can target biofilms and free-living amoeba better than traditional methods, thereby controlling outbreaks of Legionella and E. Coli with more consistency. Analysis of Cost and electrode efficiency determines the possibility of substituting electrochemical disinfection methods for traditional methods. Further investigations into how flow rate impacts anode and cathode oxidation efficiency must be

DOI: 10.54254/2755-2721/85/20240697

explored, along with cost and efficiency analysis of the proposed combined methods (electrochemical disinfection and coagulation).

Acknowledgment

Junao Wu, Haoyang Xu, Jiazhen Li, and Yi Yu contributed equally to this work and should be considered co-first authors.

References

[1] Fraser, D. W., Tsai, T. R., Orenstein, W., Parkin, W. E., Beecham, H. J., Sharrar, R. G., Harris, J., Mallison, G. F., Martin, S. M., McDade, J. E., Shepard, C. C., & Brachman, P. S. (1977). Legionnaires' disease: description of an epidemic of pneumonia. The New England journal of medicine, 297(22), 1189–1197. https://doi.org/10.1056/NEJM197712012972201

[2] Lu, S., & Zhang, G. (2022). Recent advances on inactivation of waterborne pathogenic microorganisms by (photo) electrochemical oxidation processes: Design and application strategies. *Journal of Hazardous Materials, 431*, 128619. Retrieved from https://www.sciencedirect.com/science/article/pii/S0304389422004071. doi:https://doi.org/10.1016/j.jhazmat.2022.128619

[3] Martínez-Huitle, C. A., & Brillas, E. (2008). Electrochemical alternatives for drinking water disinfection. Angewandte Chemie (International ed. in English), 47(11), 1998–2005. https://doi.org/10.1002/anie.200703621

[4] Shah, A. D., & Mitch, W. A. (2012). Halonitroalkanes, halonitriles, haloamides, and N-nitrosamines: a critical review of nitrogenous disinfection byproduct formation pathways. Environmental science & technology, 46(1), 119–131. https://doi.org/10.1021/es203312s

[5] Stout, J., Yu, V. L., Vickers, R. M., Zuravleff, J., Best, M., Brown, A., Yee, R. B., & Wadowsky, R. (1982). Ubiquitousness of Legionella pneumophila in the water supply of a hospital with endemic Legionnaires' disease. The New England journal of medicine, 306(8), 466–468. https://doi.org/10.1056/NEJM198202253060807

[6] Delaedt, Y., Daneels, A., Declerck, P., Behets, J., Ryckeboer, J., Peters, E., & Ollevier, F. (2008). The impact of electrochemical disinfection on Escherichia coli and Legionella pneumophila in ta

[7] Moore, G., & Walker, J. (2014). Presence and Control of Legionella pneumophila and Pseudomonas aeruginosa Biofilms in Hospital Water Systems. In Biofilms in Infection Prevention and Control: A Healthcare Handbook (pp. 311-337). Elsevier Inc.. https://doi.org/10.1016/B978-0-12-397043-5.00017-7

[8] Pang, Y. C., Xi, J. Y., Xu, Y., Huo, Z. Y., & Hu, H. Y. (2016). Shifts of live bacterial community in secondary effluent by chlorine disinfection revealed by Miseq high-throughput sequencing combined with propidium monoazide treatment. *Appl Microbiol Biotechnol*, *100*(14), 6435-6446.

[9] Spiegelman J, Pedutem T, Francisco MJ. Legionnaires' Disease Cases at a Large Community Hospital-Common and Underdiagnosed. Int J Environ Res Public Health. 2020 Jan 3;17(1):332. doi: 10.3390/ijerph17010332. PMID: 31947755; PMCID: PMC6982084.

[10] Ji, W. T., Hsu, B. M., Chang, T. Y., Hsu, T. K., Kao, P. M., Huang, K. H., Tsai, S. F., Huang, Y. L., & Fan, C. W. (2014). Surveillance and evaluation of the infection risk of free-living amoebae and Legionella in different aquatic environments. *The Science of the total environment*, *499*, 212–219. https://doi.org/10.1016/j.scitotenv.2014.07.116

[11] Jin, Y., Shi, Y., Chen, R., Chen, X., Zheng, X., & Liu, Y. (2019). Electrochemical disinfection using a modified reticulated vitreous carbon cathode for drinking water treatment. *Chemosphere, 215*, 380-387. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/30336315

[12] Jeong, J., Kim, J. Y., Cho, M., Choi, W., & Yoon, J. (2007). Inactivation of Escherichia coli in the electrochemical disinfection process using a Pt anode. Chemosphere, 67(4), 652–659. https://doi.org/10.1016/j.chemosphere.2006.11.035

[13] Feng, W., McCarthy, D. T., Henry, R., Zhang, X., Zhang, K., & Deletic, A. (2018). Electrochemical oxidation for stormwater disinfection: How does real stormwater chemistry impact on pathogen removal and disinfection by-products level?. Chemosphere, 213, 226–234. https://doi.org/10.1016/j.chemosphere.2018.09.038

[14] Ghasemian, S., Asadishad, B., Omanovic, S., & Tufenkji, N. (2017). Electrochemical disinfection of bacteria-laden water using antimony-doped tin-tungsten-oxide electrodes. *Water Research, 126*, 299-307. Retrieved from https://www.sciencedirect.com/science/article/pii/S0043135417307844. doi:https://doi.org/10.1016/j.watres.2017.09.029

[15] Huang, X., Qu, Y., Cid, C. A., Finke, C., Hoffmann, M. R., Lim, K., & Jiang, S. C. (2016). Electrochemical disinfection of toilet wastewater using wastewater electrolysis cell. *Water Res, 92*, 164-172. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/26854604

[16] Bruguera-Casamada, C., Sirés, I., Prieto, M. J., Brillas, E., & Araujo, R. M. (2016). The ability of electrochemical oxidation with a BDD anode to inactivate Gram-negative and Gram-positive bacteria in low conductivity sulfate medium. Chemosphere, 163, 516–524. https://doi.org/10.1016/j.chemosphere.2016.08.042

[17] Fan, X., Liu, Y., Wang, X., Quan, X., & Chen, S. (2019). Improvement of Antifouling and Antimicrobial Abilities on Silver-Carbon Nanotube Based Membranes under Electrochemical Assistance. Environmental science & technology, 53(9), 5292–5300. https://doi.org/10.1021/acs.est.9b00313

[18] Cossali, G., Ratcliffe, M., Routledge, E., Karayiannis, T., & Fielder, J. (2013). The cost of Legionellosis and technical ways forward.

[19] Zhang, J., Yang, S., Cui C., Qiu S., & Deng F., (2021). Research Progress in Electrochemical Disinfection Process. Journal of Wuhan Institute of Technology,2021,43(05):473-480. 10.19843/j.cnki.CN42-1779/TQ. 202104019.

[20] Ghernaout, D., Aichouni, M., & Touahmia, M. (2019). Mechanistic Insight into Disinfection by Electrocoagulation - A Review. *Desalination and water treatment, 141*, 68-81. doi:10.5004/dwt.2019.23457

[21] Isidro, J., Brackemeyer, D., Sáez, C., Llanos, J., Lobato, J., Cañizares, P., . . . Rodrigo, M. A. (2019). Operating the CabECO® membrane electrolytic technology in continuous mode for the direct disinfection of highly fecal-polluted water. *Separation and Purification Technology, 208*, 110-115. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S1383586618307809?via%3Dihub. doi:10.1016/j.seppur.2018.04.070

[22] Wang, H., Masters, S., Edwards, M. A., Falkinham, J. O., III, & Pruden, A. (2014). Effect of Disinfectant, Water Age, and Pipe Materials on Bacterial and Eukaryotic Community Structure in Drinking Water Biofilm. *Environmental Science & Technology, 48*(3), 1426-1435. Retrieved from https://doi.org/10.1021/es402636u. doi:10.1021/es402636u

[23] Nidheesh, P. V., Scaria, J., Babu, D. S., & Kumar, M. S. (2021). An overview on combined electrocoagulation-degradation processes for the effective treatment of water and wastewater. Chemosphere, 263, 127907. https://doi.org/10.1016/j.chemosphere.2020.127907