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QATAR SUSTAINABLE WATER AND ENERGY UTILIZATION INITIATIVE

Electrochemical inactivation of L. pneumophila using Boron Doped Diamond anodes

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Outline

- ❑ **Bacterial Waterborne Pathogens: Legionella**
  - ✓ Health Effects
  - ✓ Exposure
  - ✓ Treatment
- ❑ **Electrochemical disinfection**
  - ✓ What happens in an electrolytic cell
  - ✓ Direct Electrochemical oxidation
  - ✓ Indirect electrochemical oxidation
- ❑ **Inactivation of L. pneumophila using BDD anodes**
  - ✓ Experimental set up and analytical methods
  - ✓ Production of Oxidants on BDD
  - ✓ Influence of experimental parameters on bactericidal action
- ❑ **Conclusion**

Bacterial Waterborne Pathogens

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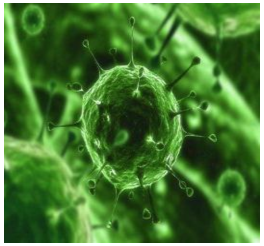
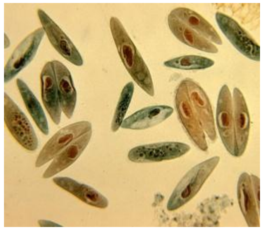
- There are three main types of microorganisms in drinking water: bacteria, viruses, and protozoa.
- These can exist naturally or can occur as a result of contamination from human or animal waste.
- Some of these are capable of causing illness in humans.
- Microbiological quality is determined by testing drinking water for *Escherichia coli.*
- The main goal of drinking water treatment is to remove or kill these organisms to reduce the risk of illness.
- Total coliform bacteria are easily destroyed during disinfection.

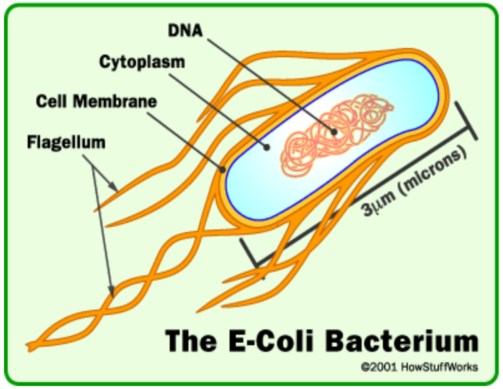
bacteria



viruses



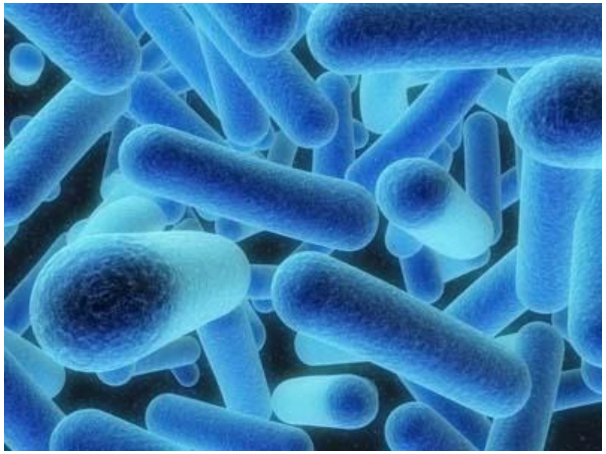
protozoa



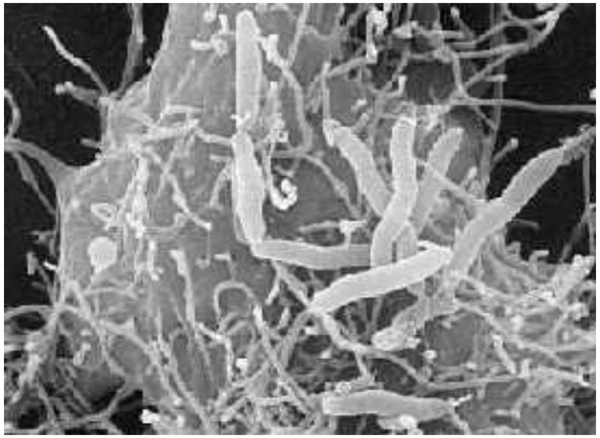
Escherichia Coli **bacteria**

Natural waterborne bacteria

- There are naturally occurring waterborne bacteria, such as *Legionella* spp. and *Aeromonas hydrophila*, with the potential to cause illnesses.
- The absence of *E. coli* does not necessarily indicate the absence of these organisms, and for many of these pathogens, no suitable microbiological indicators are currently known.
- Remove or inactivate pathogens is the best way to microorganisms in drinking water including filtration and disinfection with adequate residual.
- Filtration systems should be designed and operated to reduce turbidity levels.
- It is important to note that all chemical disinfectants (e.g., chlorine, ozone) used in drinking water can be expected to form disinfection by-products, which may affect human health.



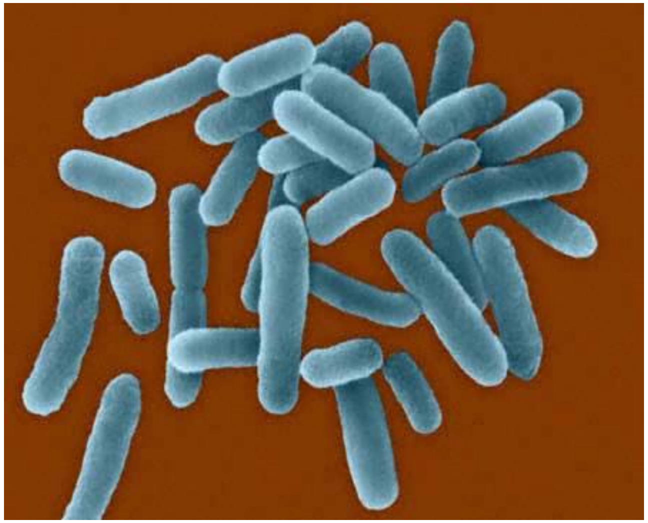
Legionella spp.

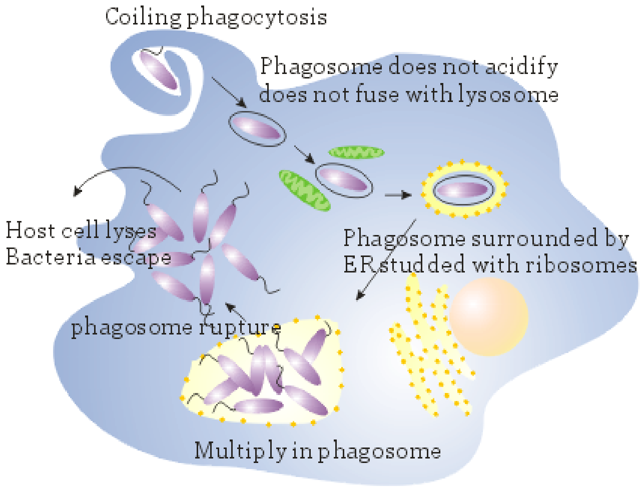


Aeromonas Hydrophila

Legionella pneumophila

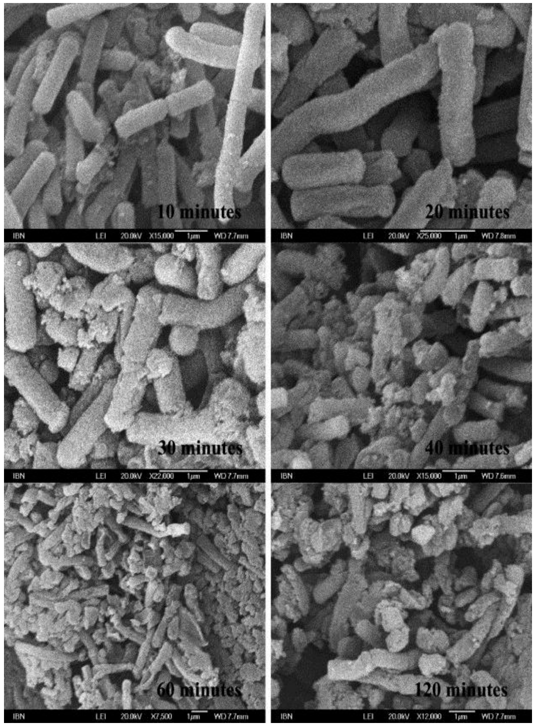
- Unlike most other common waterborne pathogens, *Legionella* species are naturally present in water environments,
- Ability to survive under varied water conditions, including temperatures from 0 to 63° C and a pH range of 5.0–8.5.
- There are two distinct illnesses caused by *Legionella*: Legionnaires' disease and Pontiac fever.
- Legionnaires' disease is a severe pneumonia that can be accompanied by extra-pulmonary manifestations, such as renal failure
- Systems that generate aerosols, such as cooling towers, whirlpool baths, and shower heads, are the more commonly implicated sources of infection.





Legionella pneumophila

- *Legionella* contamination is particularly troublesome in hospitals, where human populations can be exposed to aerosols containing hazardous *L. pneumophila*
- Once Legionella becomes established in a water system (i.e., in the biofilm), it is nearly impossible to eradicate it.
- Control of Legionella: Hyperchlorination, Chlorine dioxide, ozonation, ultraviolet (UV) light irradiation and copper-silver ionization.
- Production of trihalomethanes and other disinfection byproducts
- Long-term treatment might result in the development of Legionella resistance
- Electrochemical treatment of water has shown potential for the disinfection and improvement of physicochemical quality of drinking water



Bacterial membrane damage caused by disinfection

What happens inside an electrochemical cell during the electrolysis of a wastewater?

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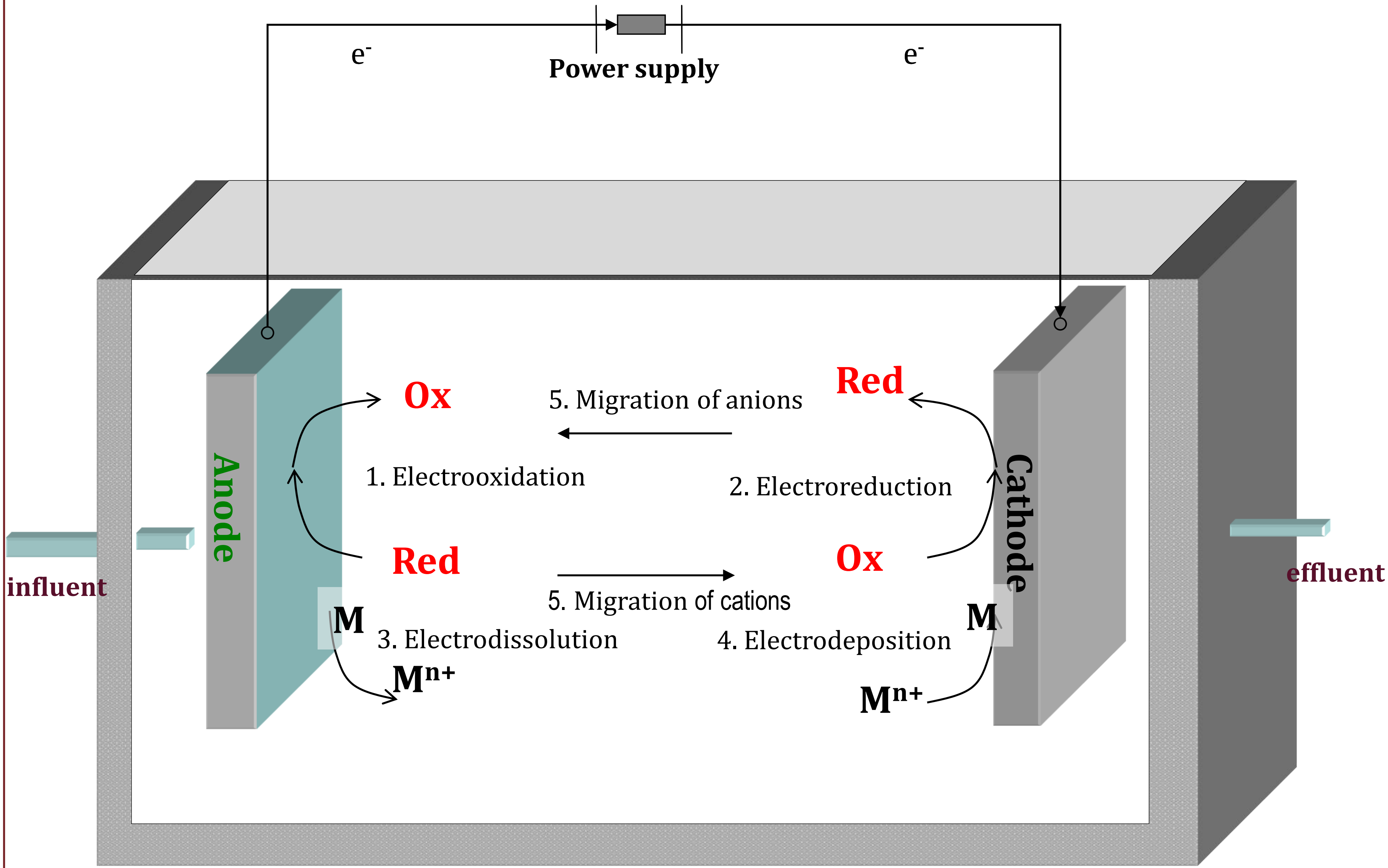
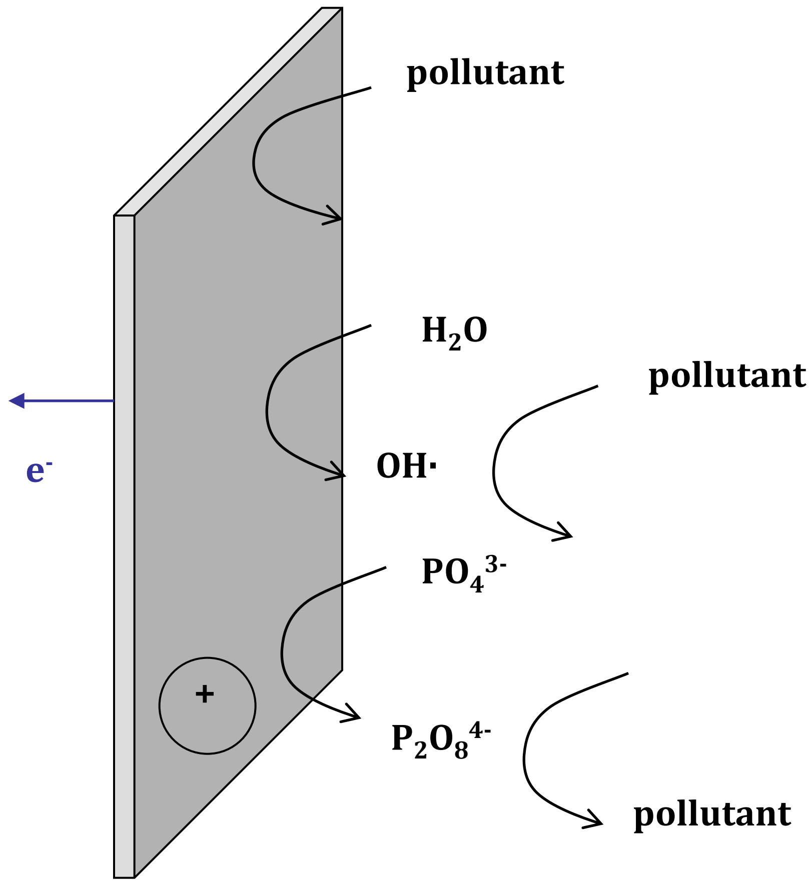


Electrochemical oxidation : use of an electrolytic cell to oxidize the pollutants contained in a wastewater



1. Direct electrolysis

Oxidation of the pollutant on the electrode surface

2. Advanced oxidation processes

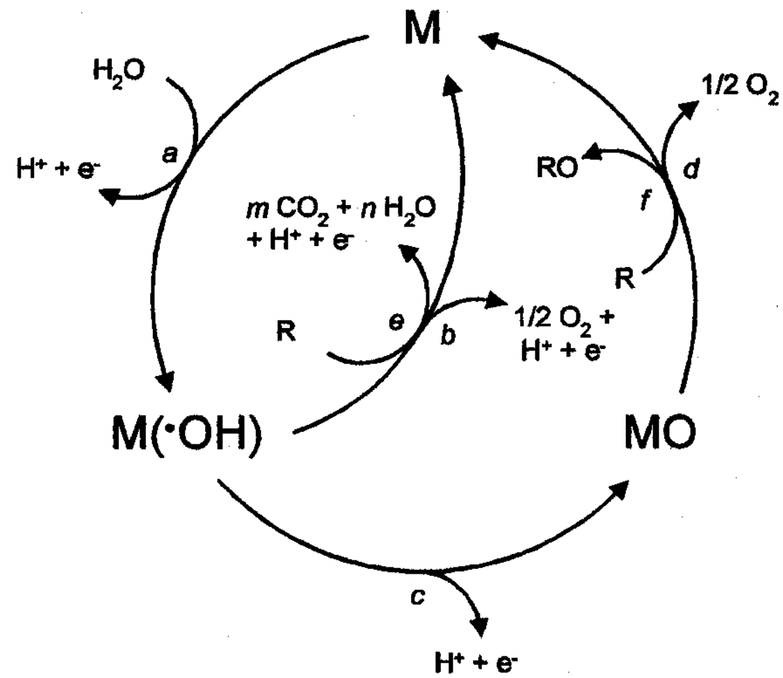
With some anode materials it is possible the generation of OH·

3. Chemical oxidation

On the electrode surface several oxidants can be formed from the salts contained in the salt

Active electrodes

Pt
Stainless steel
DSA

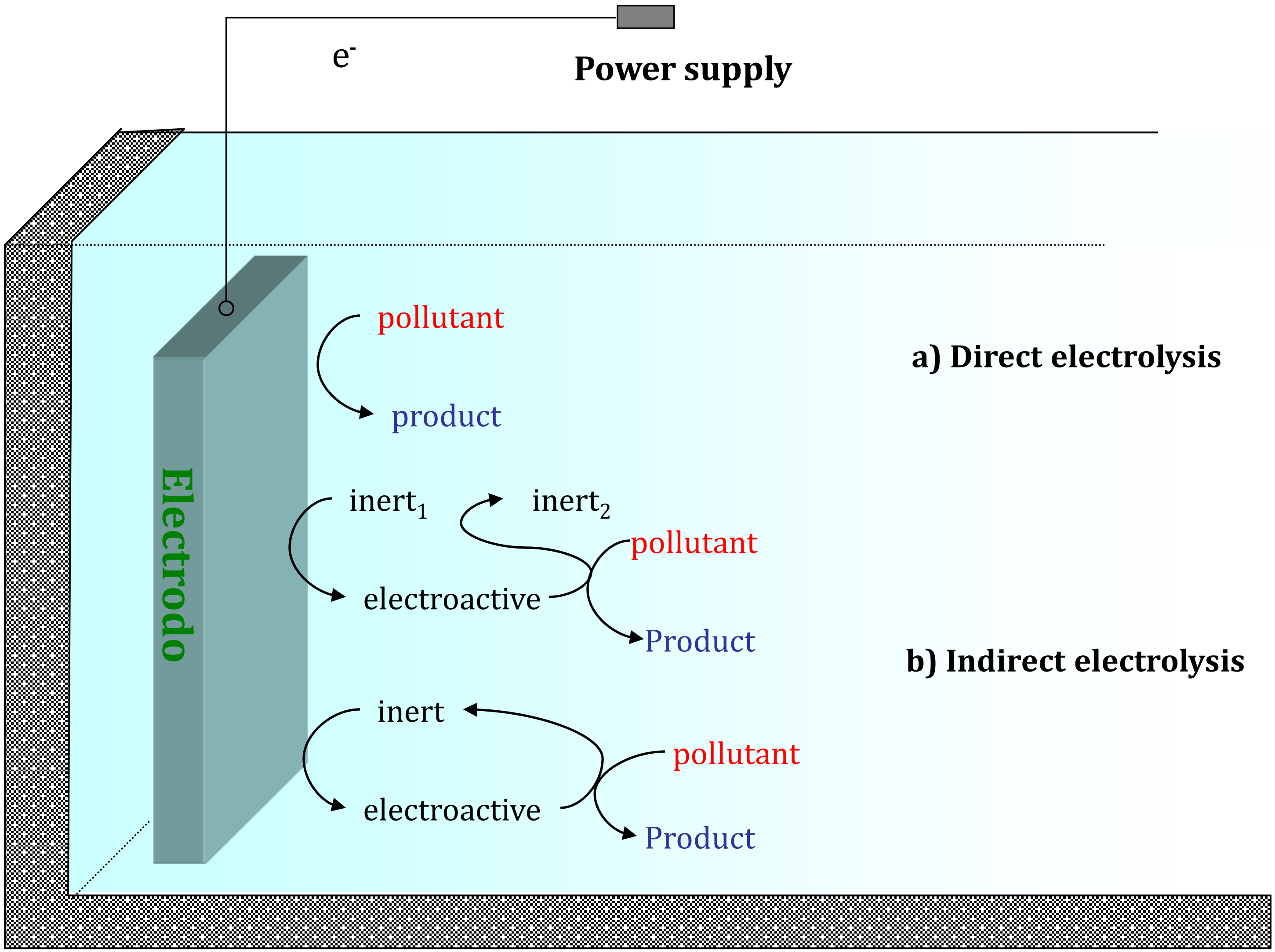


Non-active electrodes

Ti/SnO_2
$Ti/\ PbO_2$
Doped diamond

Drawbacks of non-active electrodes:
Conductive diamond: large price >6000 Euros/m^2
PbO_2/SnO_2: Dissolution of toxic species

Indirect electrochemical oxidation processes



Reversible oxidant

The oxidant can be reduced in the cathode. A divided cell may be considered

Ag(I) / Ag(II)

Co(II) / Co(III)

Ce(III) / Ce (IV)

Fe(II) / Fe (III)

SO_4^{2-} / $S_2O_8^{2-}$

PO_4^{3-} / $S_2O_8^{4-}$

Cl_2

These oxidants are generated from anions typically present in a wastewater

Irreversible (killers)

The oxidant is not reduced on the cathode. Non-divided cells are used for their production

O_3

H_2O_2

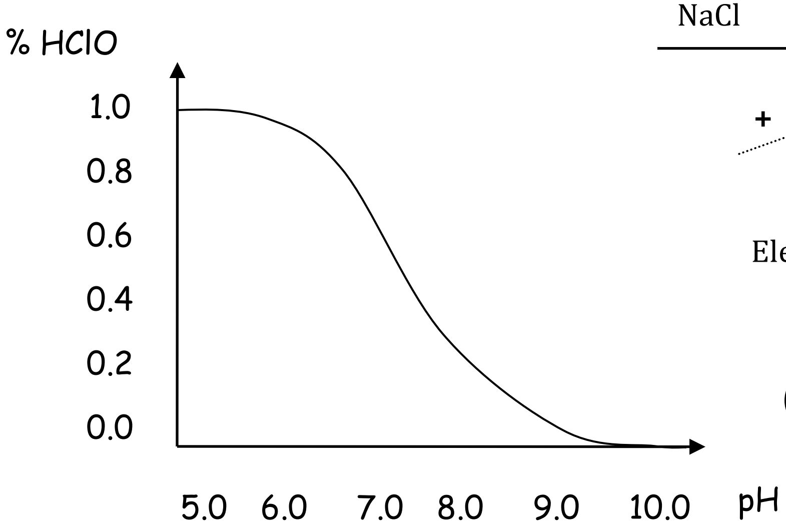
They can be formed by a cathodic process.

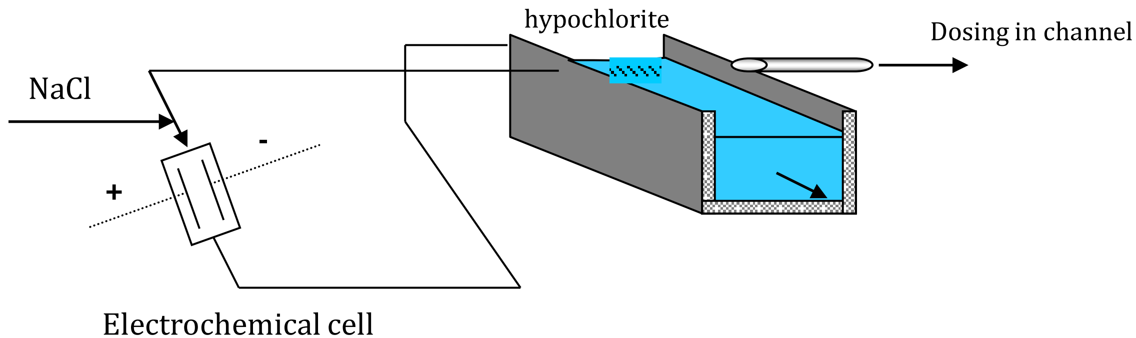
Electro-chlorination

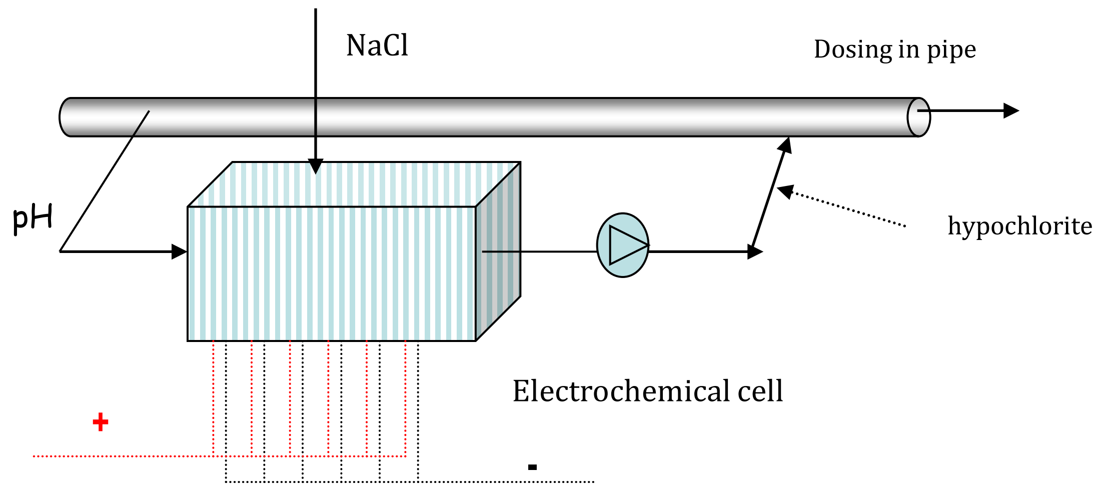
- ✓Chloride salts are frequently present in industrial wastewaters.
- ✓The chlorine speciation depends on the pH
- ✓It can lead to the formation of organo-chlorinated compounds

$$2\,Cl^{-} \rightarrow Cl_2 + 2e^{-}$$

$$Cl_2 + H_2O \rightarrow HCl + HClO$$







Inactivation of L. pneumophila using BDD anodes

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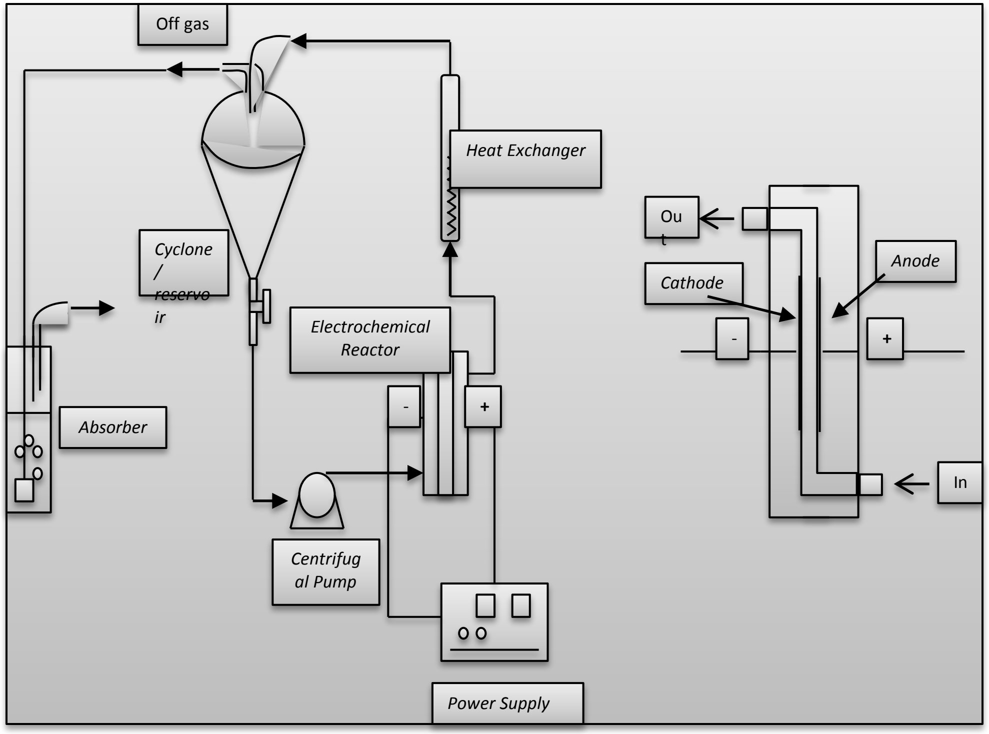
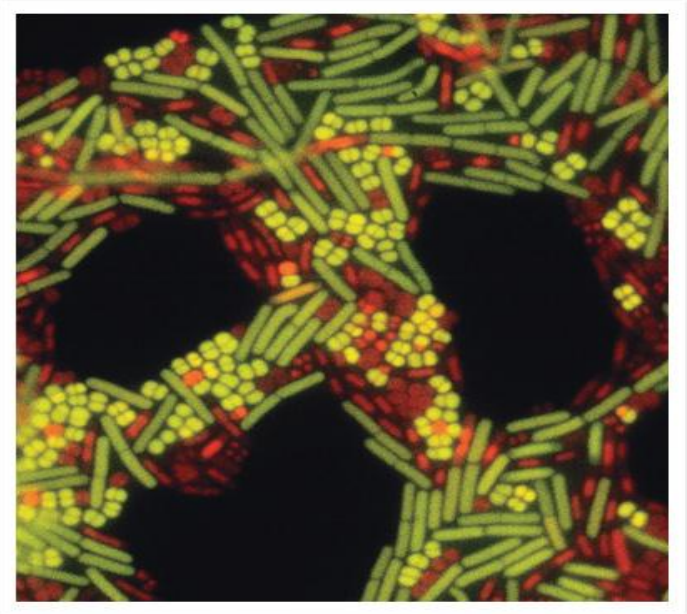


Experimental setup

- Single-compartment electrochemical flow cell
- Diamond-based material was used as anode and stainless steel as the cathode
- The electrolyte was stored in a glass container



Bacterial fluorescence

- The survival of L. pneumophila was detected by bacterial fluorescence staining and by colony forming
- Live bacteria with intact membrane are fluorescent green, whereas dead bacteria with damaged membranes were fluorescent red.

Electrochemical production of oxidants on BDD anodes

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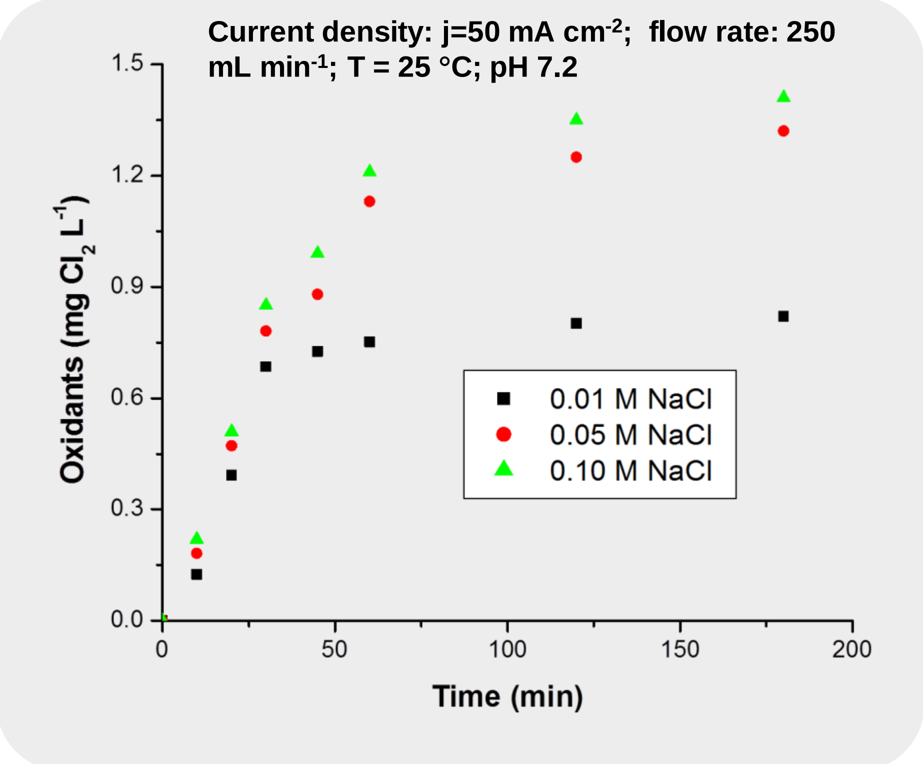
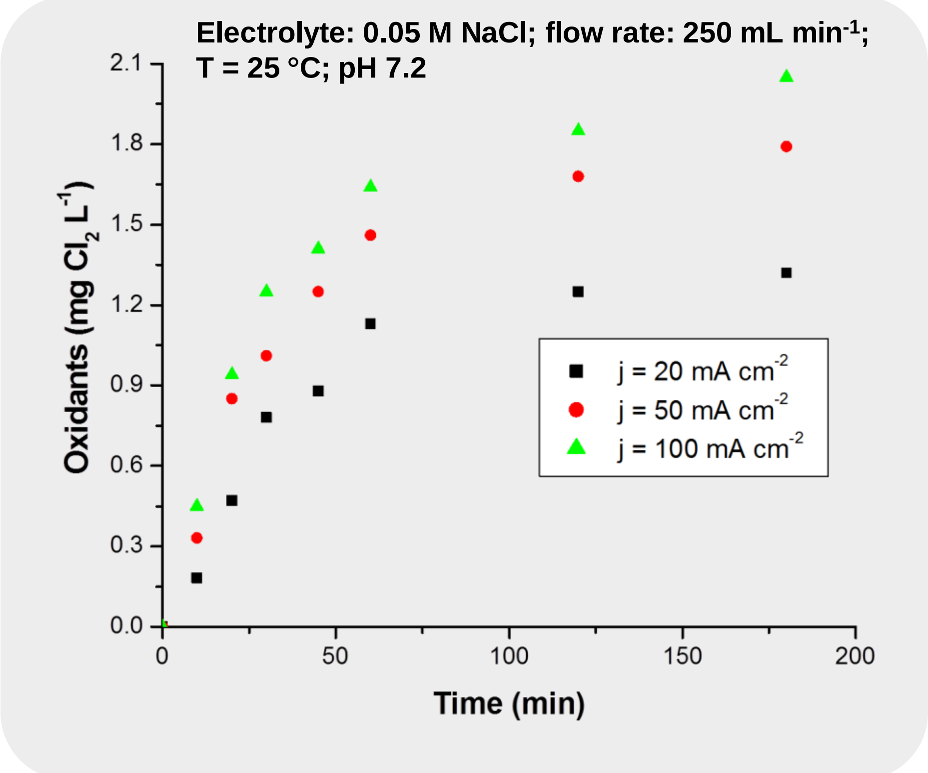
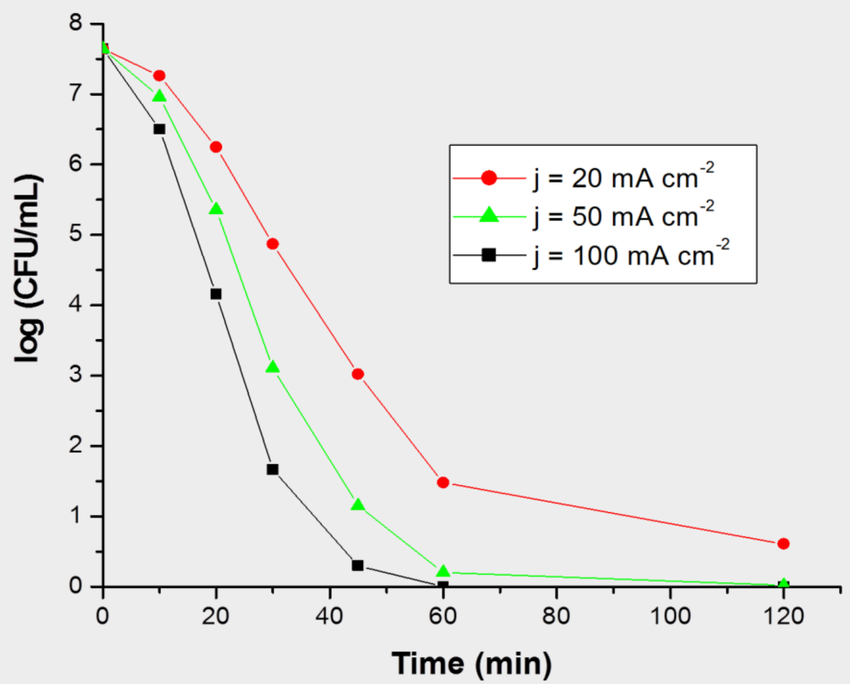




- Changes of oxidants concentration with time exhibits similar profiles
- The observed maxima for oxidants concentrations may be by the stability of oxidants and the mass transfer control
- Galvanostatic electrolysis produce sufficient amount of oxidants susceptible to inactivate waterborne pathogens in water

Electrochemical production of oxidants on BDD anodes: Influence of current density



Influence of current density on the bactericidal effect during electro-disinfection of Legionella-contaminated aqueous solutions. Experimental conditions: Electrolyte: 0.05 M NaCl; L. pneumophila bacterial density: 4.4 10^7 CFU mL^{-1}; flow rate: 250 mL min^{-1}; T = 25 °C; pH 7.2.

- ✓ The increase of the current density to 100 mA cm^{-2} achieves a complete inactivation of *Legionella* bacteria within 1 h.
- ✓ Partial bactericidal effects observed for low current densities revealed that the amount of oxidants produced was not enough to totally inactivate L. pneumophila bacterial cells.

Electrochemical production of oxidants on BDD anodes: Influence of NaCl concentration

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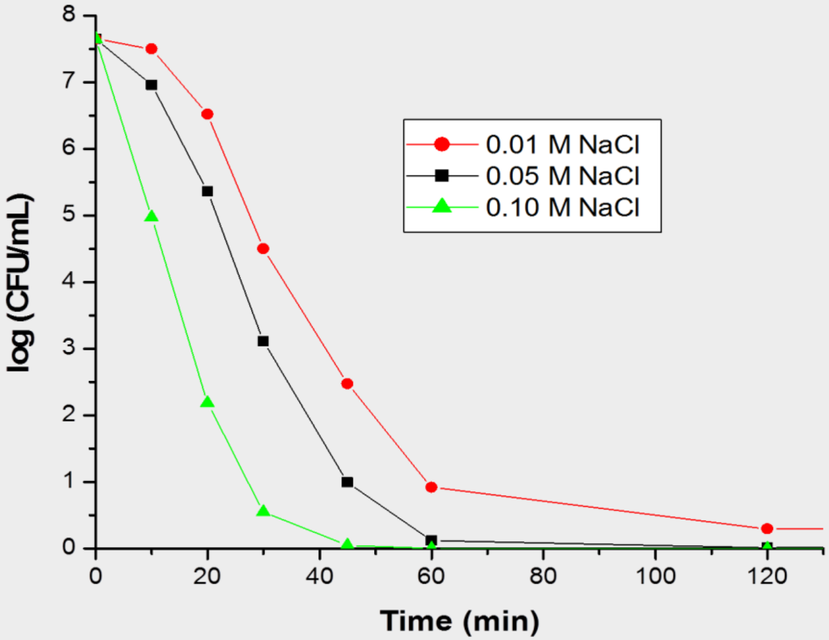

Influence of NaCl concentration on the bacterial death during BDD anodic oxidation of L. pneumophila. Experimental conditions: Current density: j=50 mA cm^{-2}; L. pneumophila bacterial density: 4.4 10^7 CFU mL^{-1}; flow rate: 250 mL min^{-1}; T = 25 °C; pH 7.2.

- ✓ The increase of NaCl concentration greatly enhanced the bactericidal efficiency of the electrochemical process
- ✓ The growth of L. pneumophila was completely inhibited in 0.1 M NaCl aqueous solution within 1 hr
- ✓ The role of Cl^- has been also verified through an experiment performed on bacteria contaminated water sample by adding 0.05 M $NaClO_4$

Electrochemical production of oxidants on BDD anodes: Influence of bacterial density

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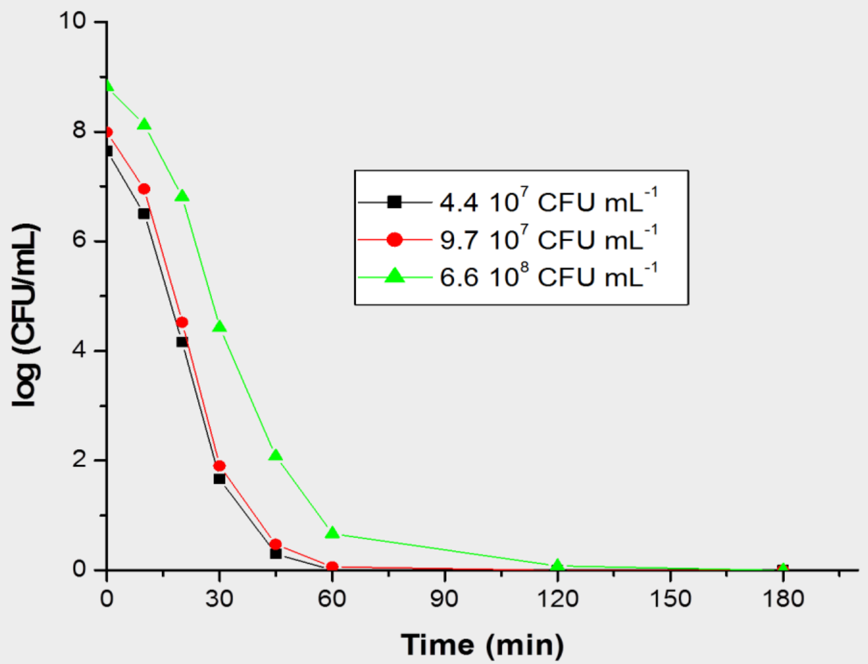

Influence of bacterial density on the bacterial survival during electro-disinfection of Legionella-contaminated aqueous solutions. Experimental conditions: Current density: j=50 mA cm^{-2}; Electrolyte: 0.05 M NaCl; flow rate: 250 mL min^{-1}; T = 25 °C; pH 7.2.

- ✓ Complete bacterial death has been achieved in all cases, but the required contact time increases with the increase of bacteria cells density
- ✓ This is is due to the continuous production of free chlorine and other oxidants during galvanostatic electrolysis

Electrochemical production of oxidants on BDD anodes: Influence of flow rate

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Influence of flow rate on bactericidal activity of galvanostatic electrolysis on BDD anodes. Experimental conditions: Current density: j=50 mA cm-2; Electrolyte: 0.05 M NaCl; pneumophila bacterial density: 4.4 107 CFU mL-1 T = 25 °C; pH 7.2.

Flow rate ($mL\ min^{-1}$)	Contact time (min)	Legionella ($CFU\ mL^{-1}$)
0	0	44,000,000
250	60	ND
500	60	ND
750	60	5,000,000
1250	60	18,000,000

- ✓ Complete bacterial death has been achieved only for flow rates of 250 and 500 $mL\ min^{-1}$
- ✓ The increase of the flow rate decreases the contact time between electrolyte and BDD anodes and between oxidants produced and microbial cells.

Conclusion

- Laboratory experiments have demonstrated that galvanostatic electrolysis using BDD anodes was capable to completely inactivate L. pneumophila bacteria in optimized conditions.
- The electrochemical disinfection efficiency depends on the dose of oxidants produced by electrochemical oxidation of the electrolyte, the stability of these oxidants, and contact time.
- The strong bactericidal action observed at the BDD anode material can be attributed to surface and bulk process: at the electrode/solution interface, high amounts of hydroxyl radicals as well as local acidic conditions can lead to cell death, whereas in the bulk of the solution, the disinfection can be attributed to the electro-generated oxidants.
- Further research will be done in order to obtain essential information for kinetic modeling development under field conditions.

Acknowledgement

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