Electrochemical Technologies in Wastewater Treatment

Guohua CHEN

Department of Chemical and Biomolecular Engineering
The Hong Kong University of Science and Technology
Eco Asia Conference (29 / 10 / 2008)

Water Pollution Impacts

Wastewater Treatment Techniques

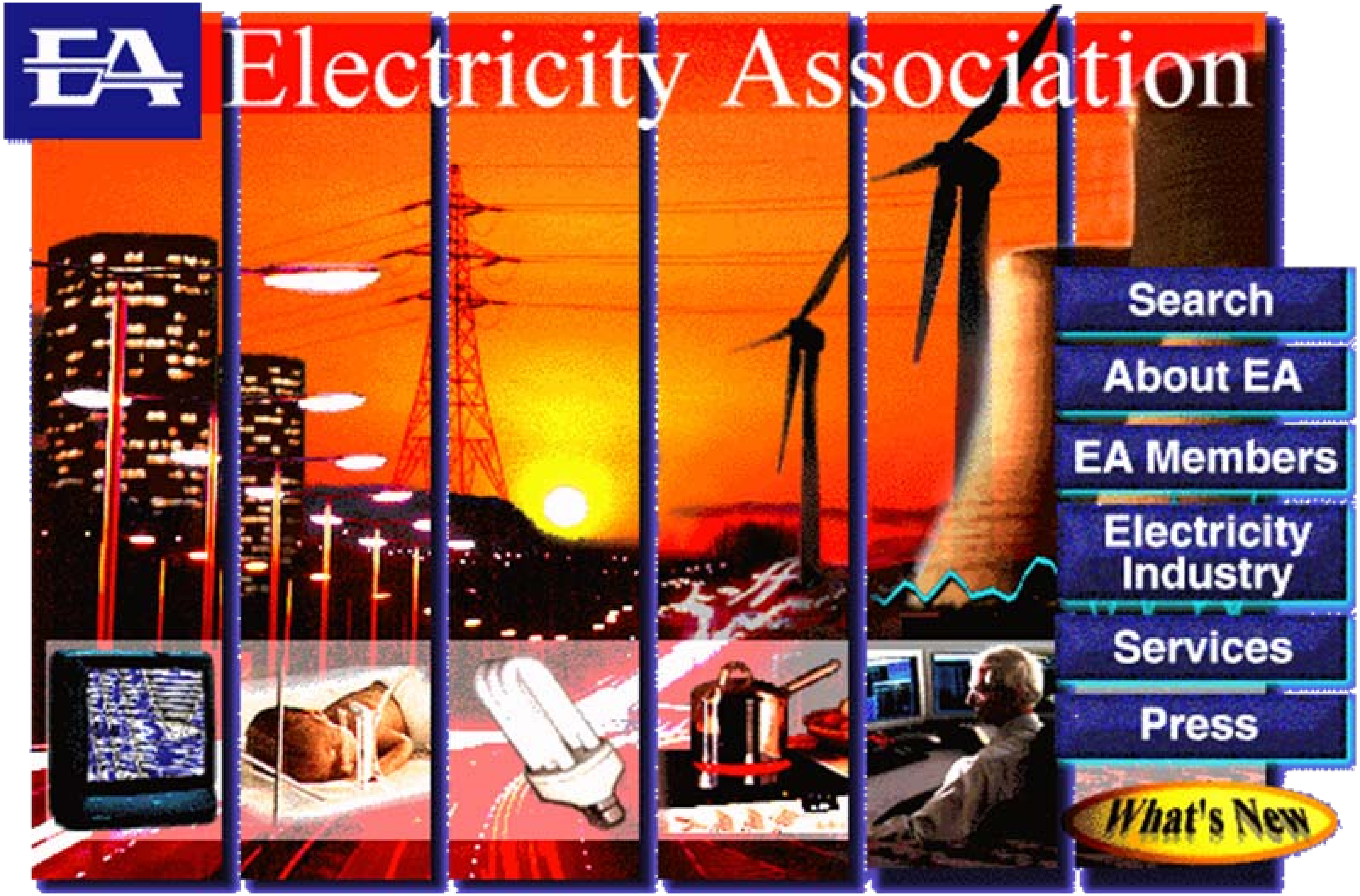
Coagulation
Sedimentation
Flotation
Filtration

⇒ **to remove particles**

Biological processes
Advanced oxidation
Adsorption
Membrane processes

⇒ **to remove organic compounds**

Electricity Is Not a Stranger



Electrochemical methods

Electrodeposition

Electrocoagulation

Electroflotation

Electrooxidation

Electrodisinfection

Electroreduction

$\Rightarrow$

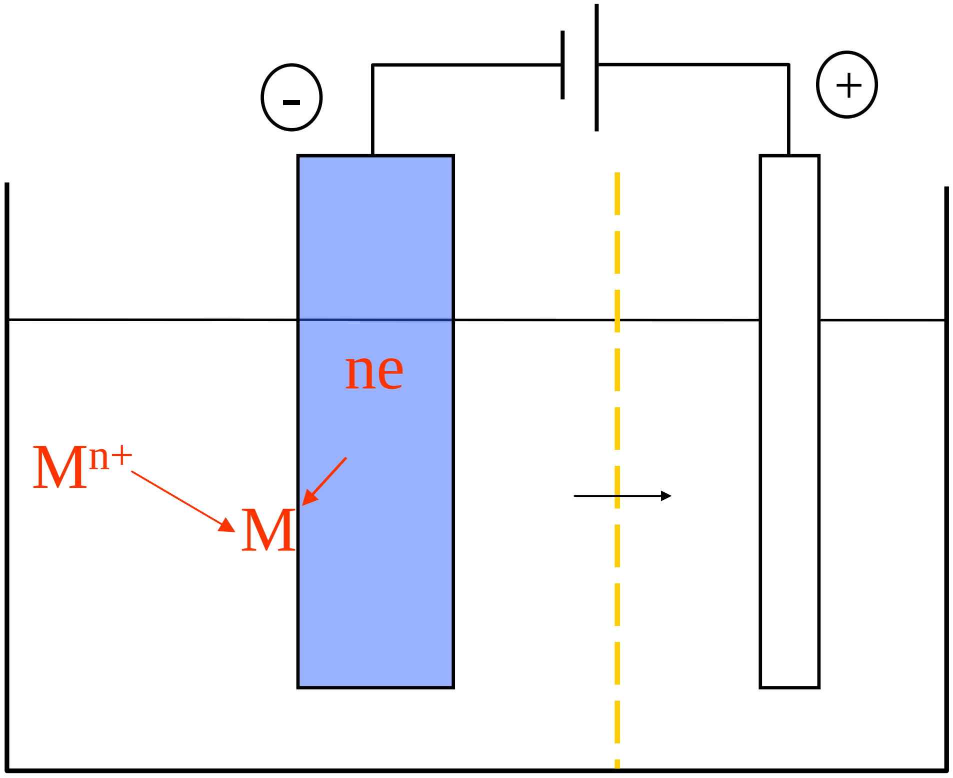
High efficiency

Easy operation

Compact facilities

Electrodeposition for heavy metal recovery

$$M^{n+} + ne \longrightarrow M$$



Electrocoagulation

- Generating coagulant electrically

$$Al - 3e \rightarrow Al^{3+}$$
$$Fe - 2e \rightarrow Fe^{2+}$$

- Sludge floated by hydrogen gas

$$2H_2O + 2e \rightarrow H_2 + 2OH^-$$

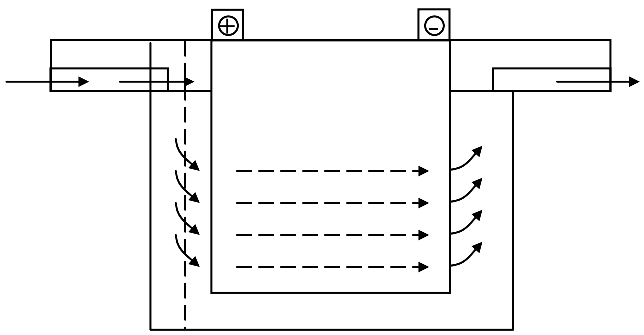
Applications of Electrocoagulation

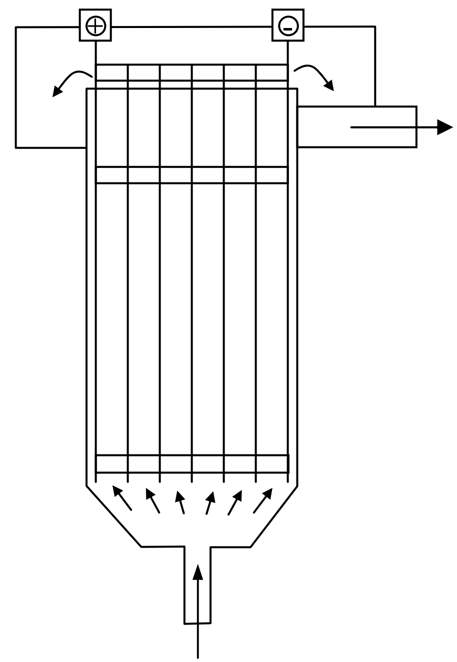
- Suspended solids
- Oil & grease

Facilities Required

- Al or Fe plates as electrodes
- DC power supply
- Pumping facility

Electrocoagulation units





(a) Horizontal flow

(b) Vertical flow

The aluminum demand and power consumption for removing pollutants from water					
Pollutant	Unit quantity	Preliminary purification		Purification	
		Al^{3+}, mg	E, W·h/m^3	Al^{3+}, mg	E, W·h/m^3
Turbidity	1 mg	0.04 – 0.06	5 - 10	0.15 – 0.2	20 - 40
Colour	1 unit	0.04 – 0.1	10 - 40	0.1 – 0.2	40 – 80
Silicates	1 mg/SiO_2	0.2 – 0.3	20 - 60	1 - 2	100 - 200
Irons	1 mg Fe	0.3 – 0.4	30 - 80	1 – 1.5	100 – 200
Oxygen	1 mg O_2	0.5 - 1	40 - 200	2 - 5	80 - 800
Algae	1000	0.006 – 0.025	5 -10	0.02 – 0.03	10 – 20
Bacteria	1000	0.01 – 0.04	5 - 20	0.15 – 0.2	40 - 80

Electroflotation

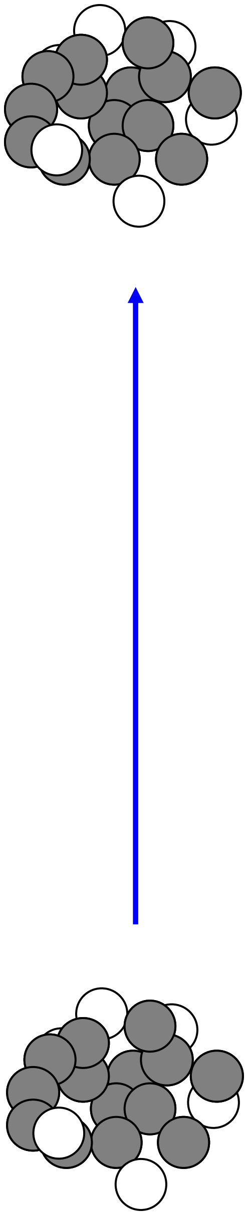
- Generating gas bubbles electrically

$$2H_2O - 4e \rightarrow O_2 + 4H^+$$

$$2H_2O + 2e \rightarrow H_2 + 2OH^-$$

- Gas bubbles attaching to flocs

- Floating to top of water surface



Economic parameters in treating oily effluents				
Treatment type	EF	DAF	IF	Settling
Bubble size, μm	1 - 30	50 - 100	0.5 – 2	
Specific electricity consumption, W/m^3	30 - 50	50 - 60	100 - 150	50 – 100
Air consumption, m^3/m^3 water		0.02 – 0.06	1	
Chemical conditioning	IC	OC + F	OC	IC + F
Treatment time, minutes	10 - 20	30 - 40	30 - 40	100 - 120
Sludge volume as % of treated water	0.05 – 0.1	0.3 – 0.4	3 - 5	7 - 10
Oil removal efficiency, %	99 – 99.5	85 - 95	60 - 80	50 – 70
SS removal efficiency, %	99 – 99.5	90 - 95	85 - 90	90 - 95

Challenges in O_2 Evolution Anodes

- Economical
- Stable
- Active

O_2 Evolution Anodes

- Pt (wire, mesh, plates)
- PbO_2
- Graphite
- DSA (TiO_2-RuO_2; IrO_2 with Ta_2O_5, ZrO_2 or CeO_2)
- DSA (Ti/IrO_2-Sb_2O_5-SnO_2)

Electrooxidation

Indirect electrooxidation

Cl_2 formation
H_2O_2 generation
O_3 generation
mediator, Ag^{2+}

Direct oxidation

OH radicals for complete mineralization

Formation Potential of Typical Chemical Reactants

Oxidants		Formation potential
H_2O/ •OH	(hydroxyl radical)	2.80
O_2/O_3	(ozone)	2.07
$SO_4^{2-}/S_2O_8^{2-}$	(peroxodisulfate)	2.01
MnO_2/MnO_4^{2-}	(permanganate ion)	1.77
H_2O/H_2O_2	(hydrogen peroxide)	1.77
Cl^-/ClO_2^-	(chlorine dioxide)	1.57
Ag^+/Ag^{2+}	(silver (II) ion)	1.50
Cl^-/Cl_2	(chlorine)	1.36
$Cr^{3+}/Cr_2O_7^{2-}$	(dichromate)	1.23
H_2O/O_2	(oxygen)	1.23

Basic Requirements of Electrodes

- **Good activity**
- **High stability**
- **Low cost**

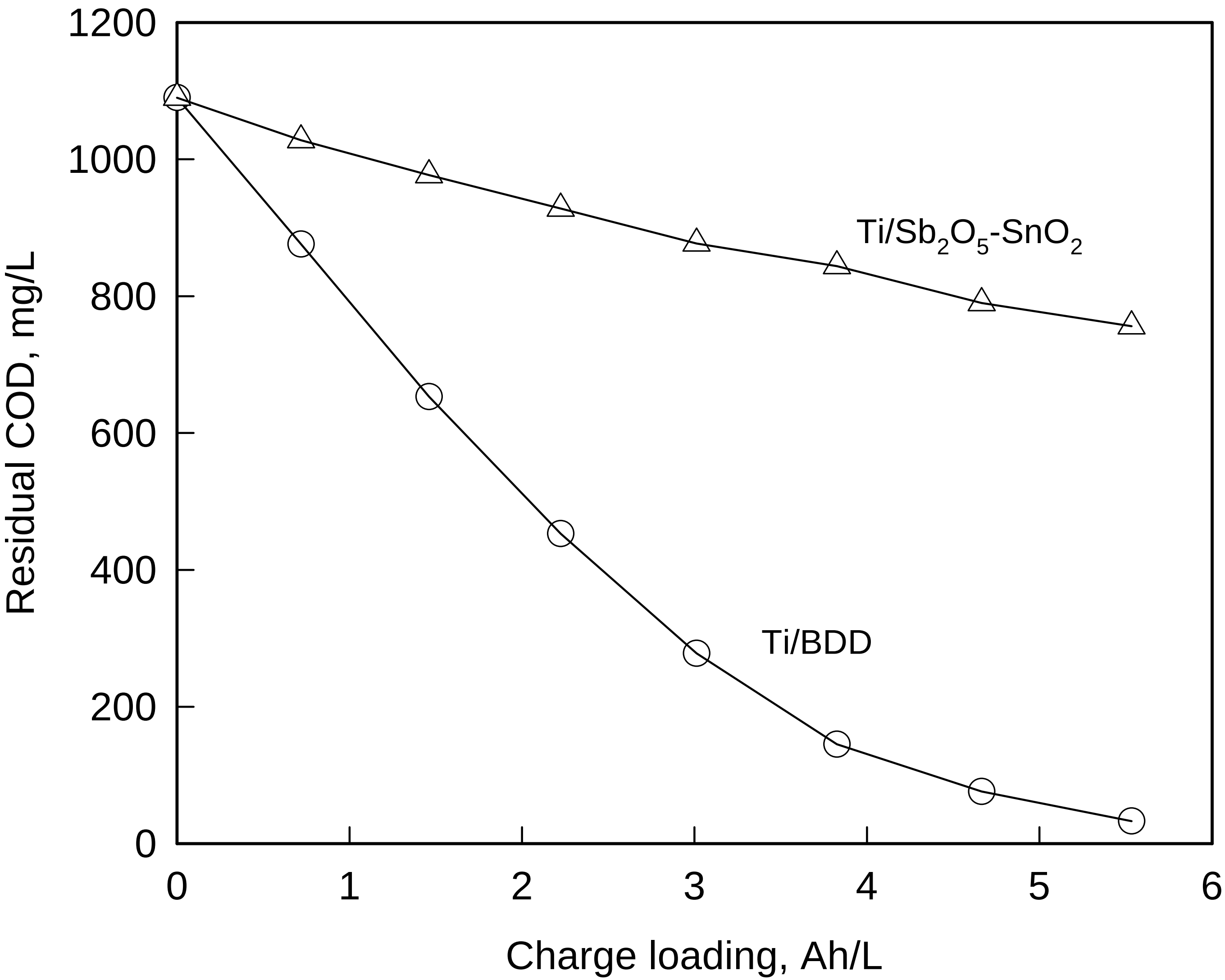
Potential of Oxygen Evolution of Anodes

Anode	Value, V	Over-potential, V
Pt	1.3 –1.6	0.1 – 0.3
IrO_2	1.6	0.4
Graphite	1.7	0.5
PbO_2	1.9	0.7
SnO_2	1.9	0.7
Pb-Sn	2.5	1.3
Ebonex (Ti_4O_7)	2.2	1.0
Si/BDD	2.3	1.1
Ti/BDD	2.7 – 2.8	1.5 – 1.6

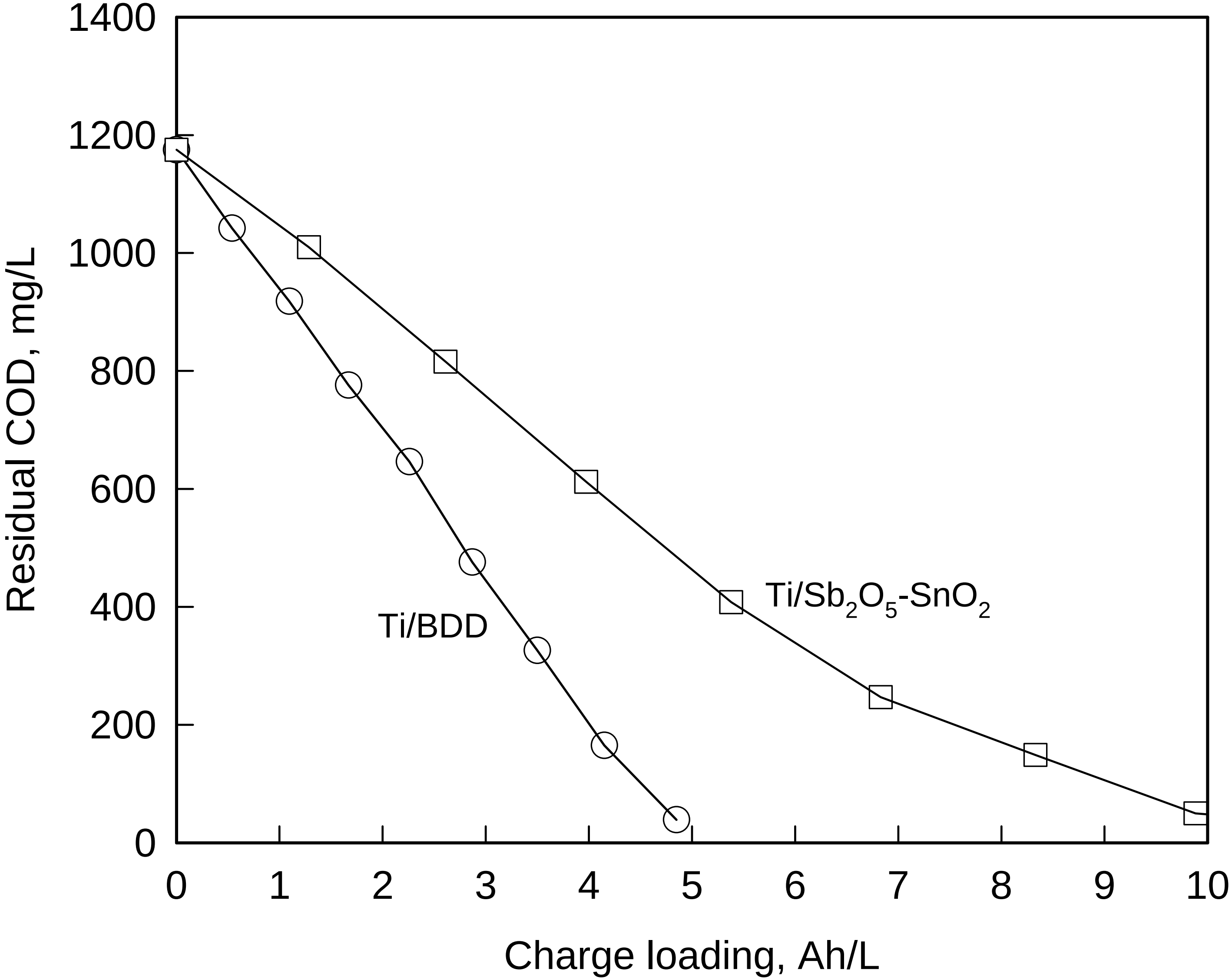
Analysis of Available Electrodes

- **Graphite:** unstable, ineffective, cheap
- **Pt, IrO_2:** too expensive, ineffective
- **PbO_2, SnO_2:** unstable, easy to make
- **B-diamond (BDD), effective, expensive**

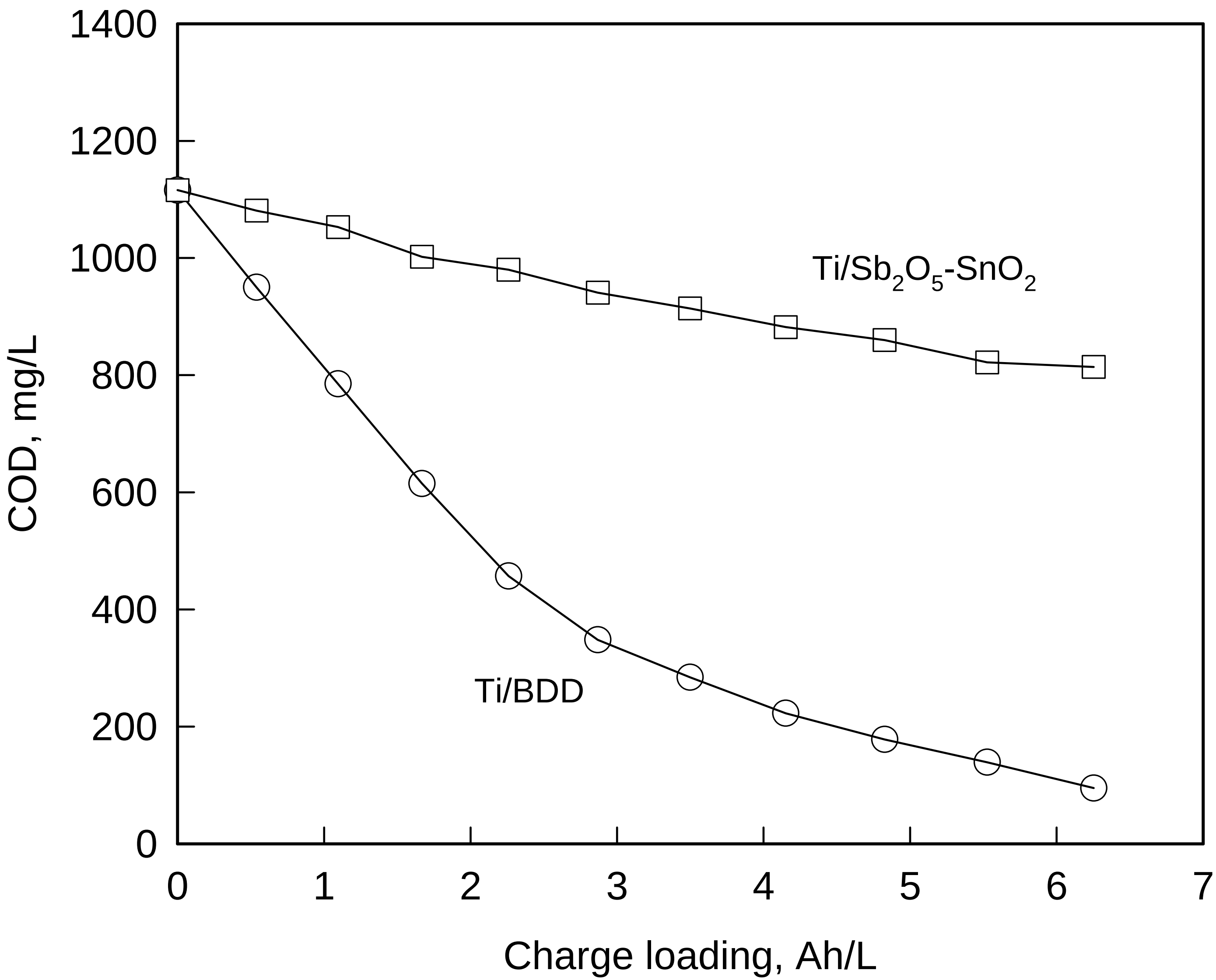
Oxidation of acetic acid



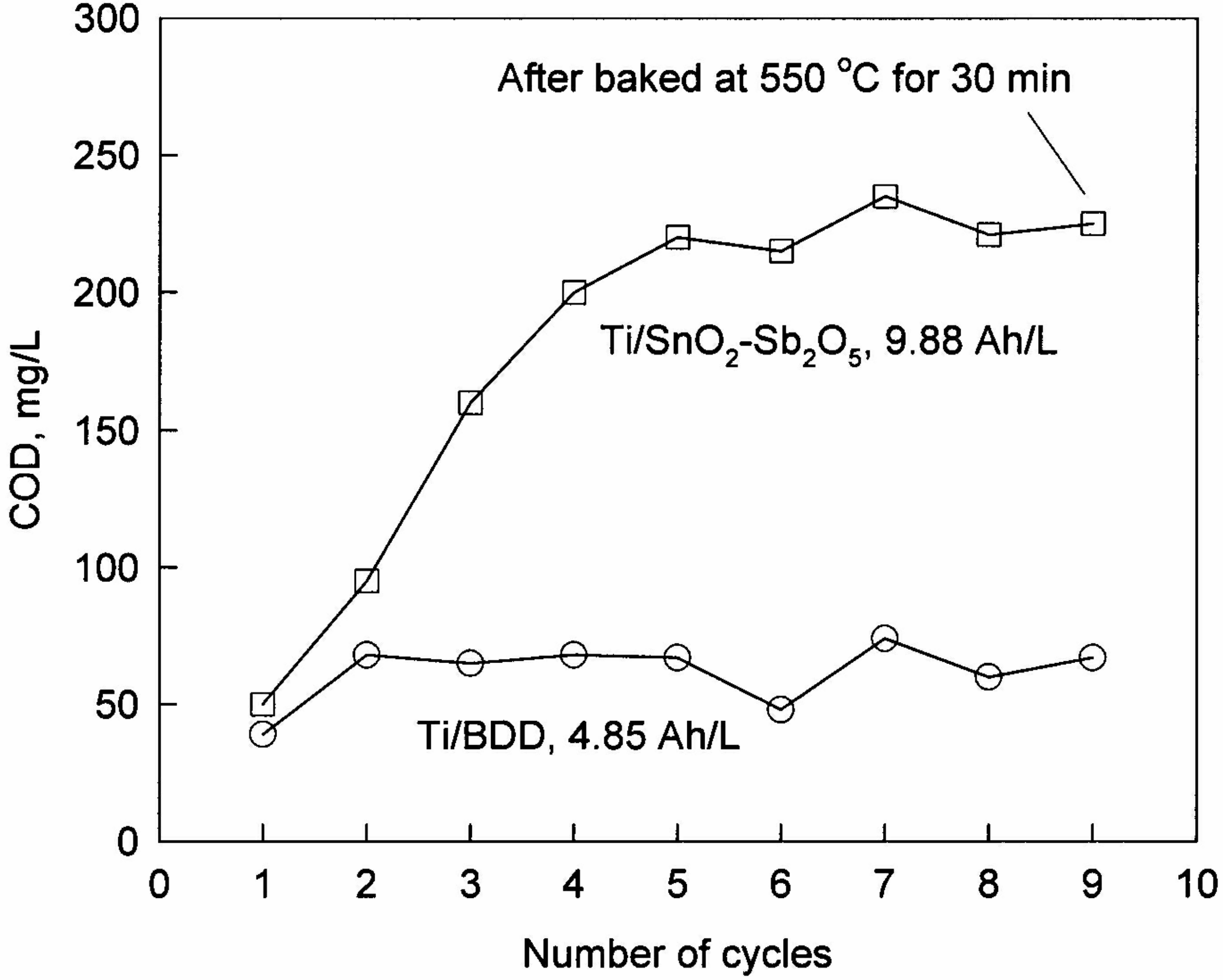
Oxidation of phenol



Oxidation of orange II



Reproducibility comparison,
500 mg/l phenol at 100 A/m^2, 30 ^oC.



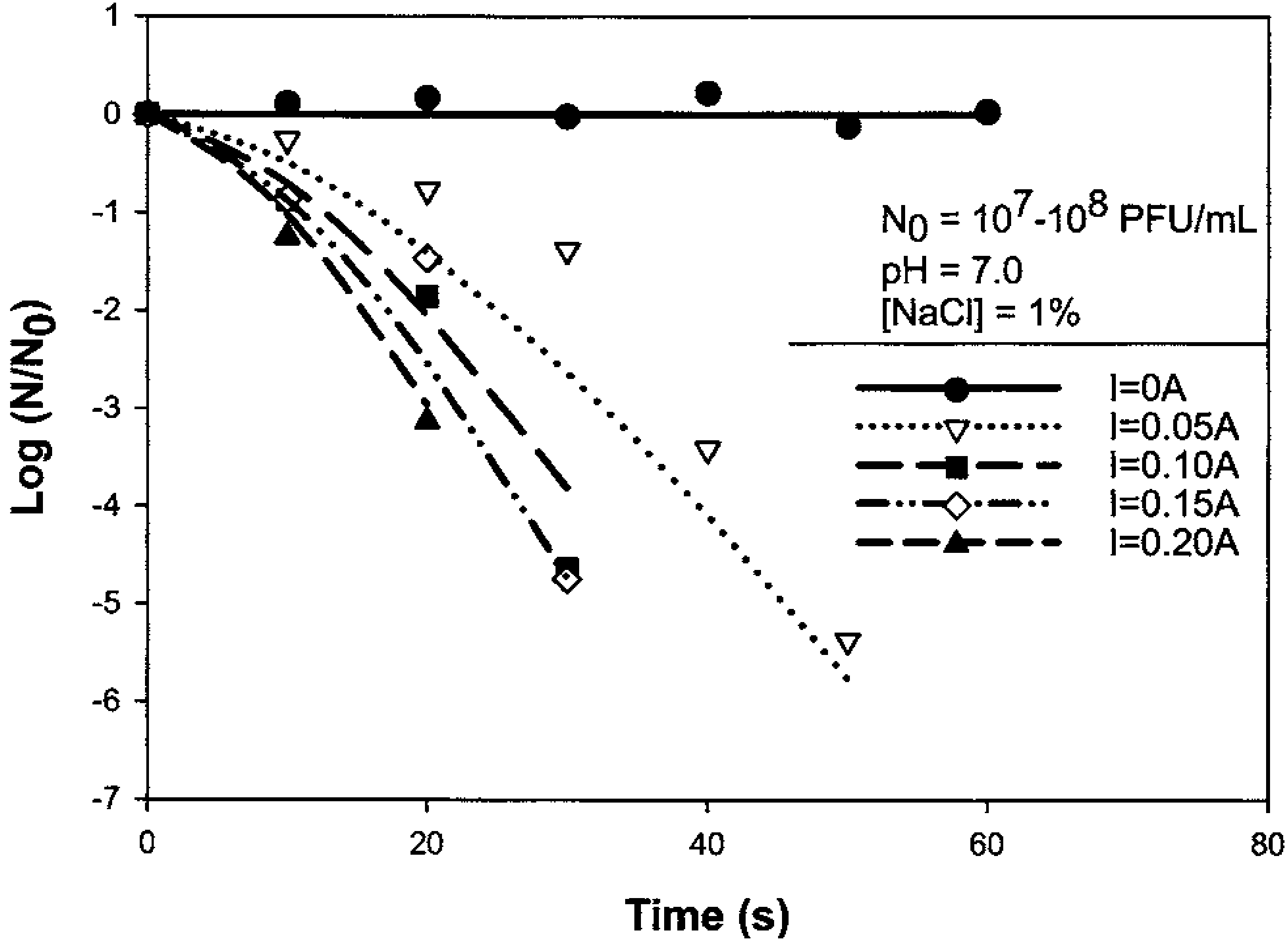
Electrodisinfection

- Generating chlorine electrically

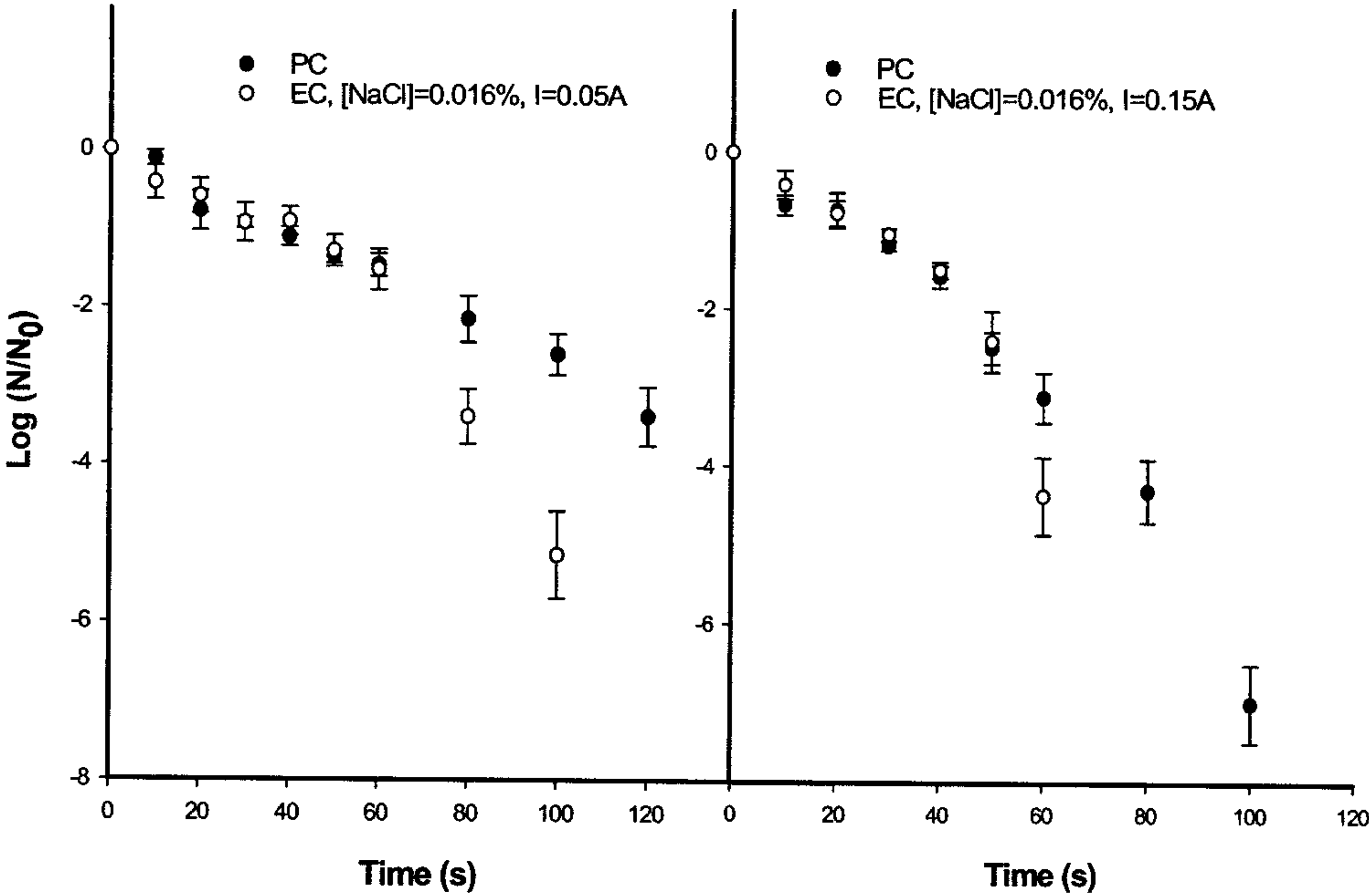
$$2Cl^- - 2e \rightarrow Cl_2 \qquad \text{(anode)}$$

$$2H_2O + 2e \rightarrow H_2 + 2OH^- \qquad \text{(cathode)}$$

- Generating OH radicals electrically (similar to electrooxidation)



Log-kill of bacteriophage MS2 versus time at different currents at salt content 1% NaCl by mass



Comparison between the log-kill of bacteriophage MS2 in the EC and PC systems at currents of 0.05 and 0.15 A

Electroreduction

- **Direct reduction on the surface of cathode**

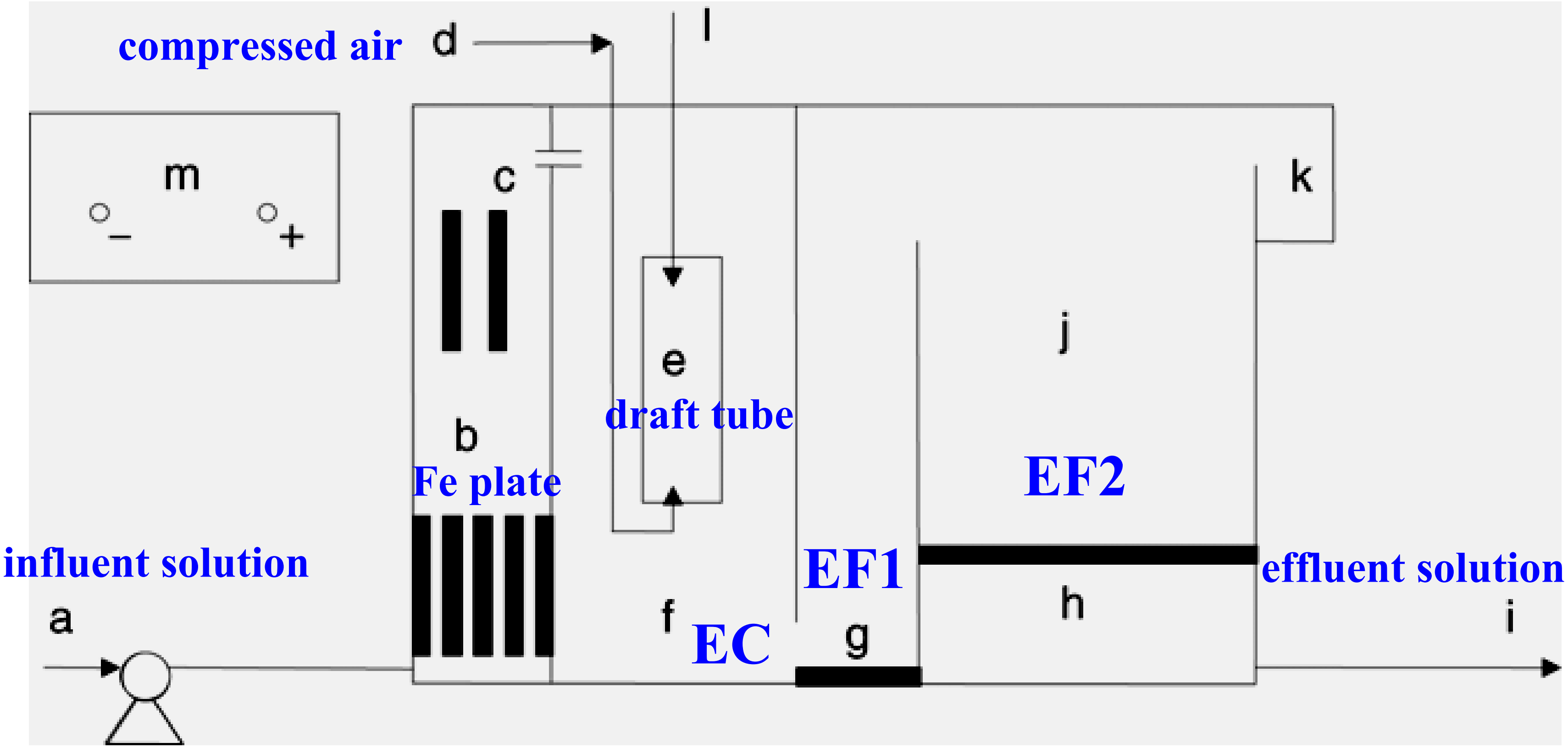
$$M^{n+} + ne \rightarrow M \qquad \text{(cathode)}$$

- **Mediated reduction by H_2 generated**

$$2H_2O + 2e \rightarrow H_2 + 2OH^- \qquad \text{(cathode)}$$

- **Mediated reduction by Fe^{2+} generated**

$$Fe - 2e \rightarrow Fe^{2+} \qquad \text{(anode)}$$



Anode(oxidation) :	$Fe \Leftrightarrow Fe^{2+}\ 2e^{-}$	(1)
Mediated reduction:	$Cr^{6+} + 3Fe^{2+} \Leftrightarrow Cr^{3+} + 3Fe^{3+}$	(2)
Cathode(reduction) :	$2H_2O + 2e^{-} \Leftrightarrow H_2 + 2OH^{-}$	(3)
Co-precipitation :	$Cr^{3+} + 3OH^{-} \Leftrightarrow Cr(OH)_3$	(4)
	$Fe^{3+} + 3OH^{-} \Leftrightarrow Fe(OH)_3$	(5)
	$Fe^{2+} + 2OH^{-} \Leftrightarrow Fe(OH)_2$	(6)

CONCLUSIONS

- Electrodeposition established
- Electrocoagulation works
- Electrocoagulation & electroflotation works better
- BDD is an excellent anode for electrooxidation
- Electrodisinfection outperforms pump chlorine system
- Electroreduction is finding more application

Acknowledgements

Professor Po Lock Yue
Professor Ping Gao
Professor Chii Shang

Dr. Xueming Chen
Mr. Feng Shen
Mr. Yuan Tian
Dr. Liang Guo
Miss Qian Fang
Mr. Johnston Ralston
Mr. Jiaqi Zheng

Financial Supports from ECF, RGC, DAG are appreciated


Thank you for your attention