Electrochemical Carbon Nanotube Filters for Water and Wastewater Treatment

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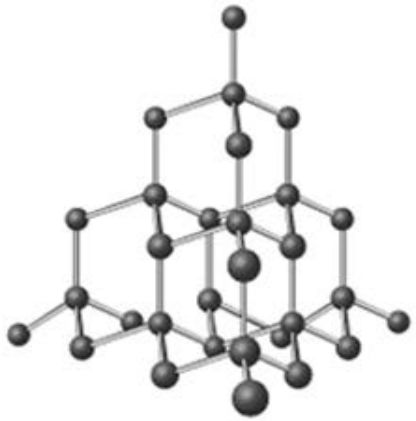
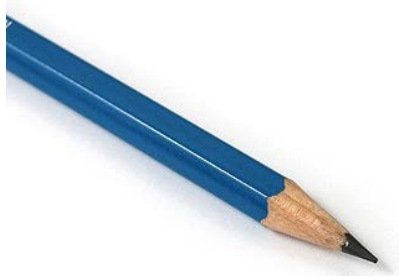
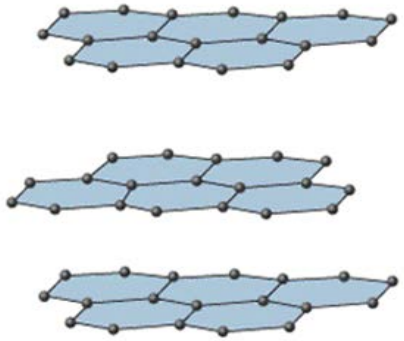
Carbon-based materials

diamond

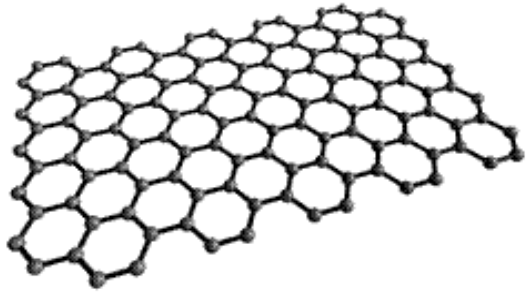


graphite

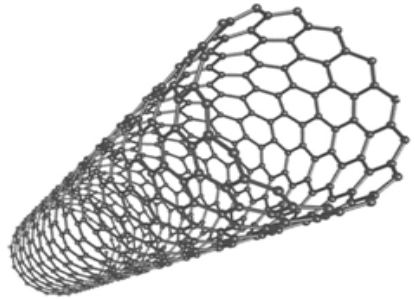




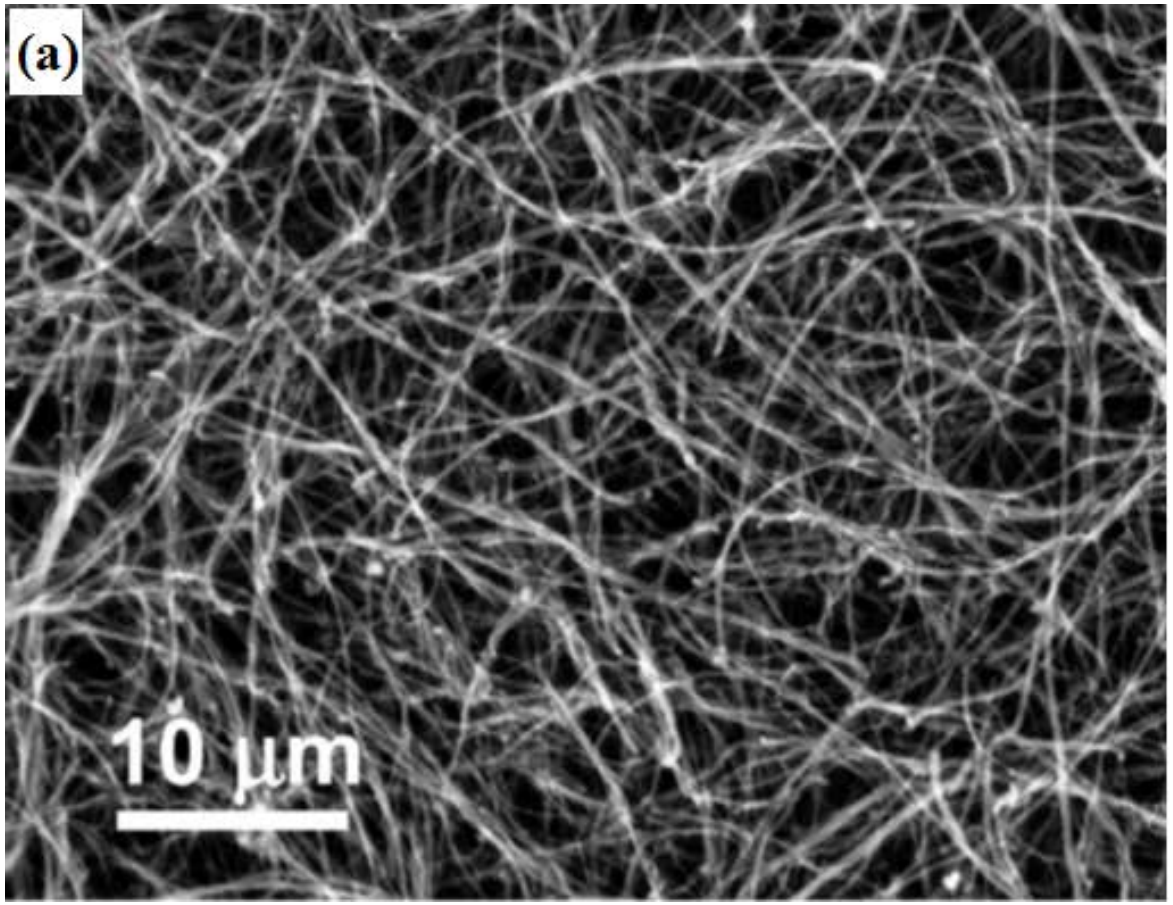
graphene

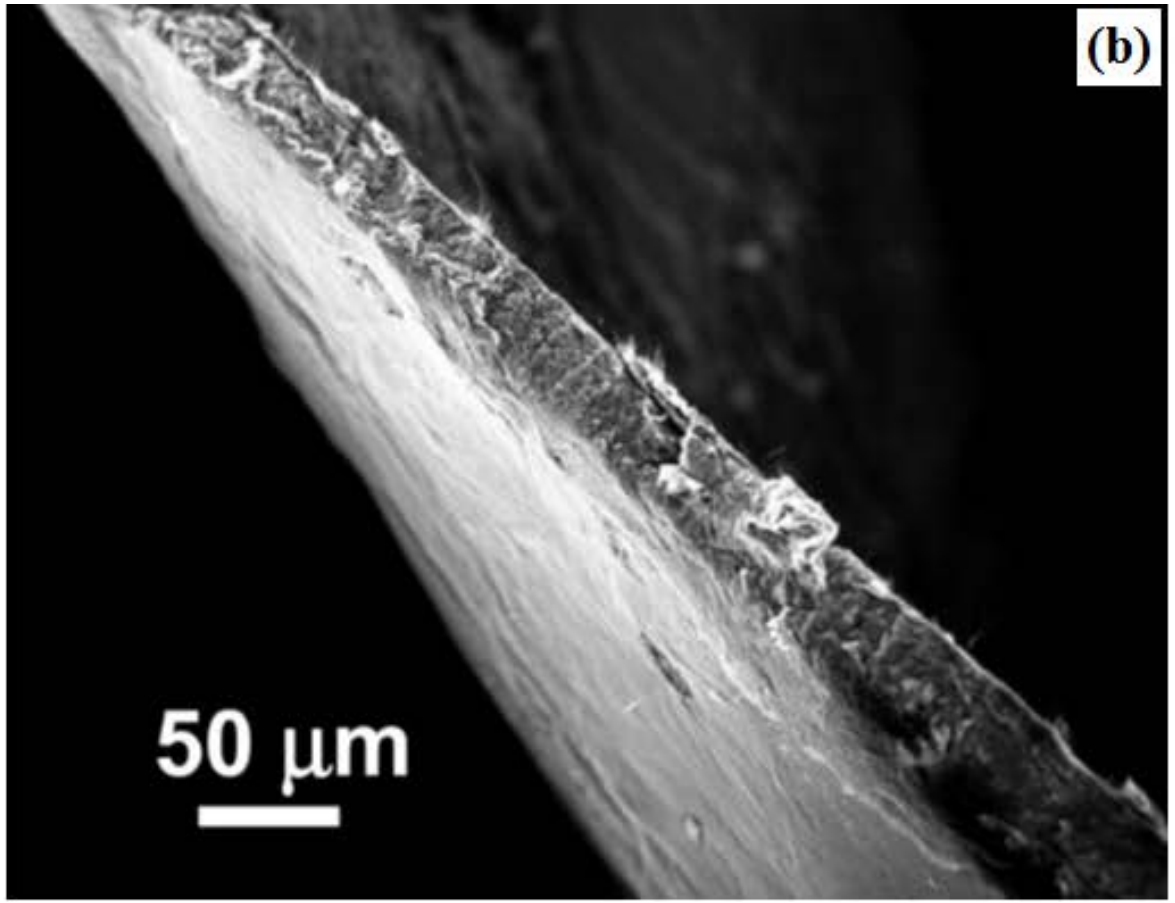


carbon nanotube



SEM characterization of CNT filter

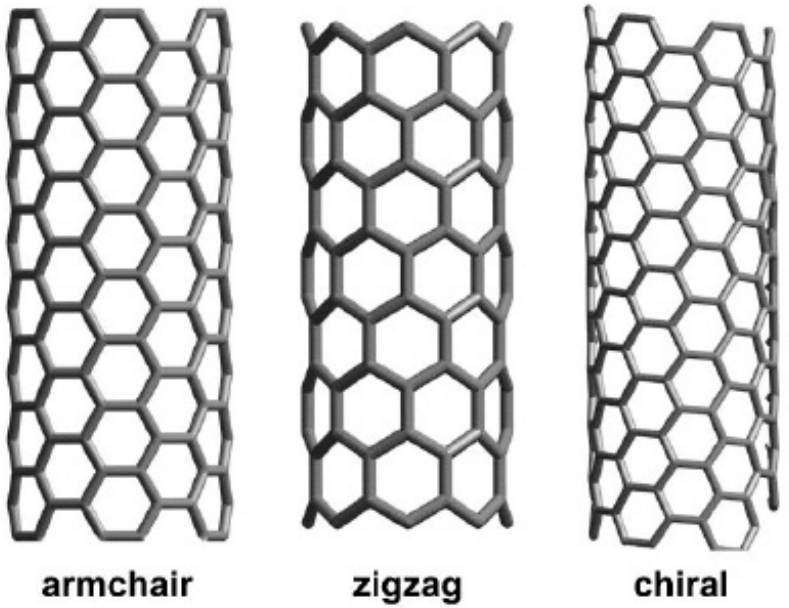




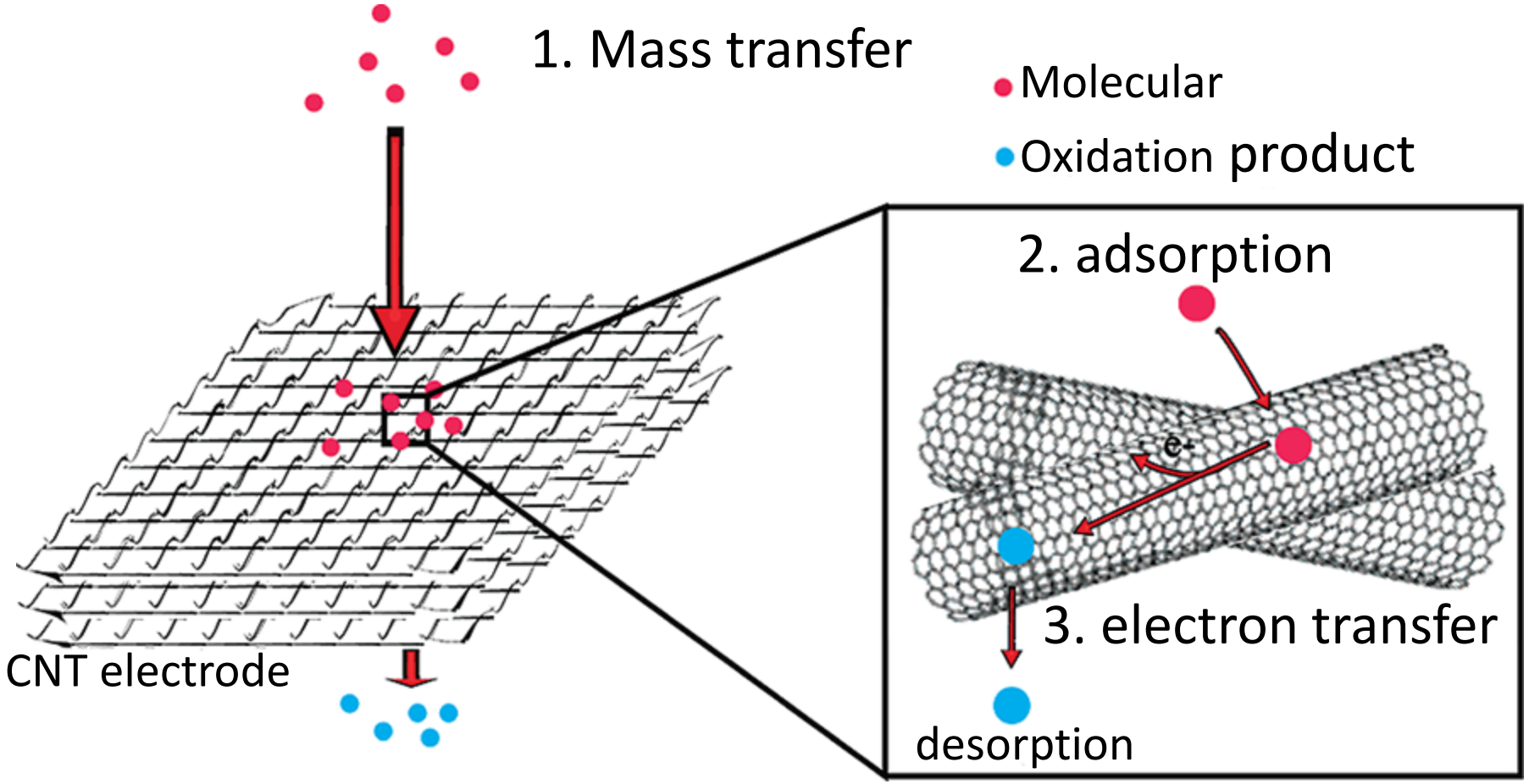
average pore size = 15 nm
an average height = 41 µm

Advantages of CNT filters

- Large specific surface area
- Electrically conductive
- Mechanical stable
- Antibacterial



Working principle of CNT filters



Technologies to remove trace level contaminants

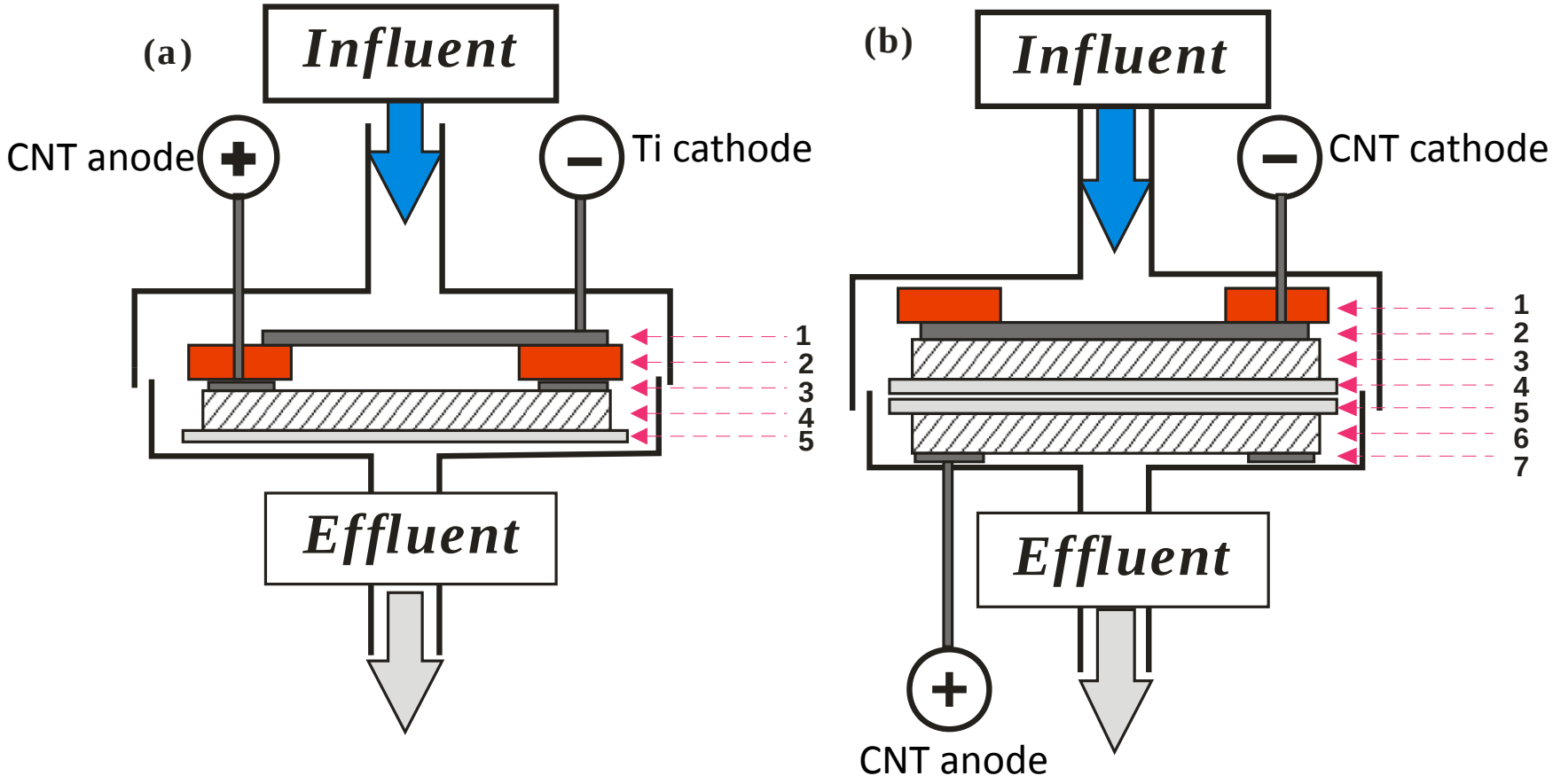
- Physical adsorption
  - *Activated Carbon*
- Advanced oxidation processes (AOPs)
  - *UV + H_2O_2; ozonation; chlorination*
- Proposed technology
  - *Carbon nanotube (CNT) electrochemical filter*

Two types of CNT filters

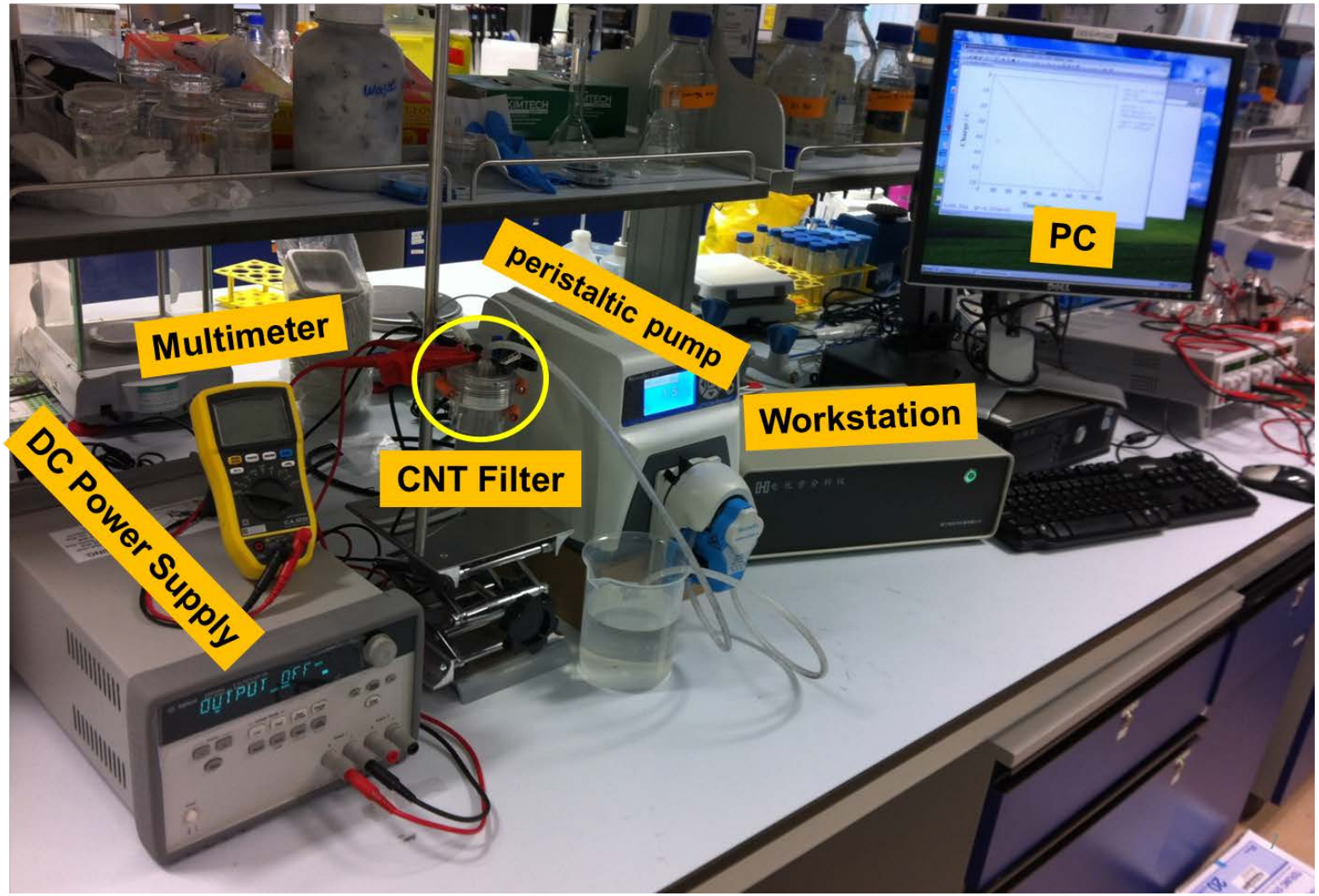
Anode: CNT
Cathode: Titanium

Anode: CNT
Cathode: CNT

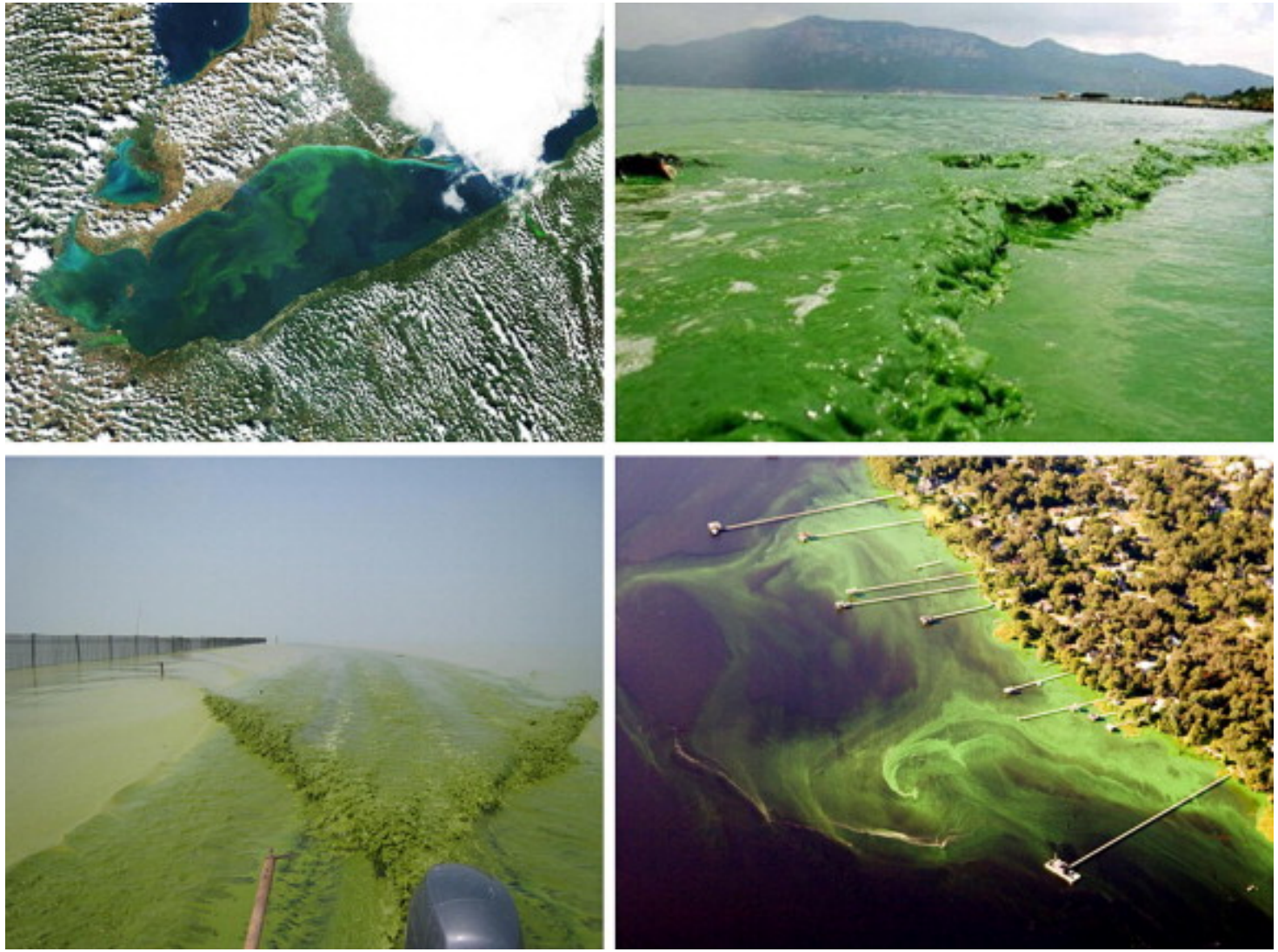
Schematics of CNT filters

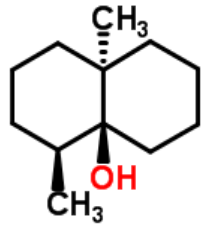


Electrochemical oxidation in a carbon nanotube (CNT) filtration system

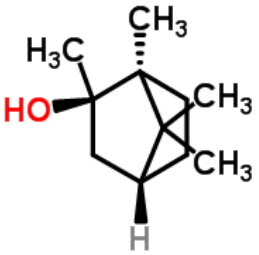


Off-flavor compounds, such as geosmin and 2-MIB, may cause taste and odor issues





geosmin

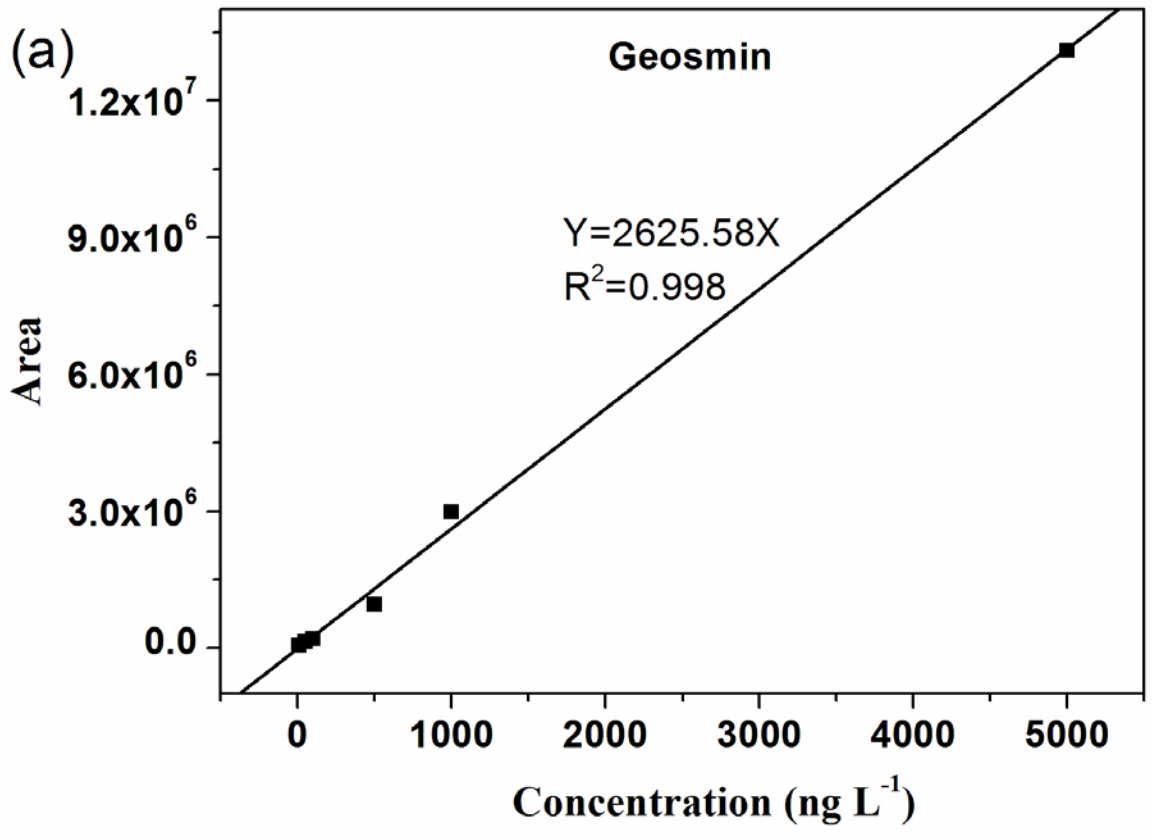


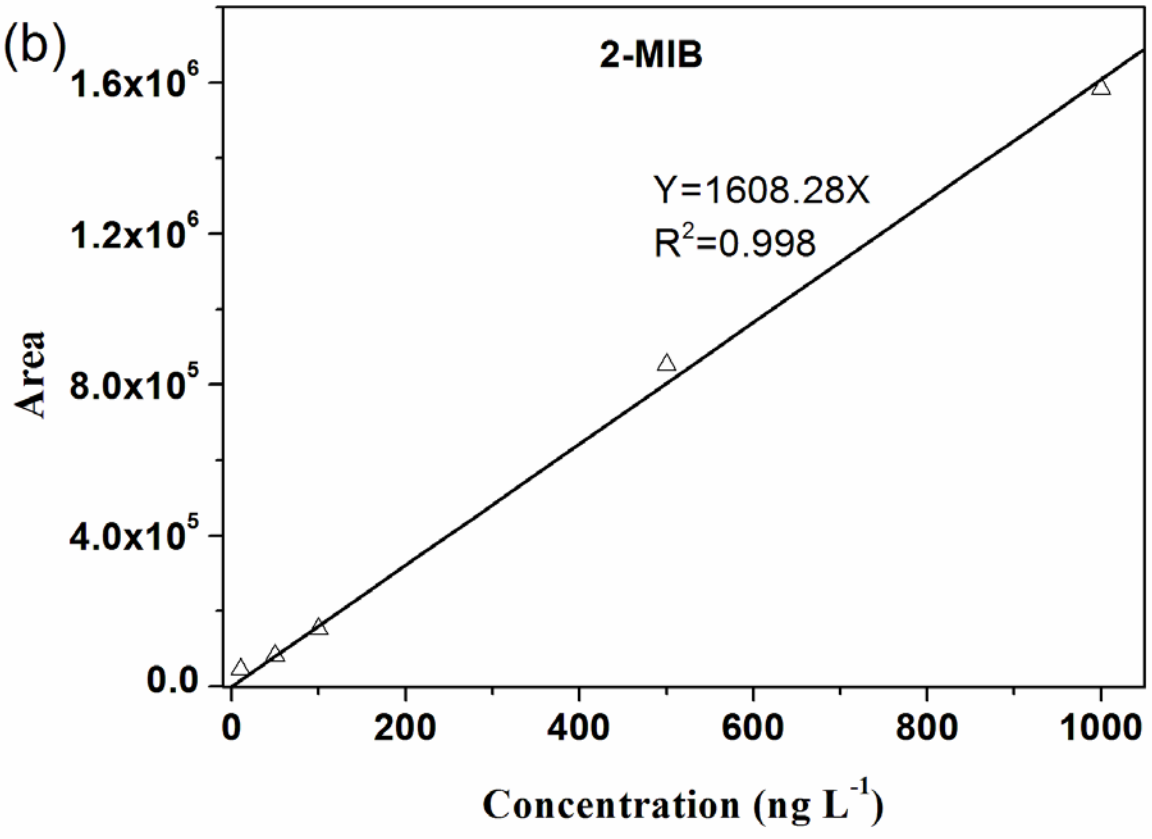
2-methylisoborneol (MIB)

Method development - SPME/GC/MS

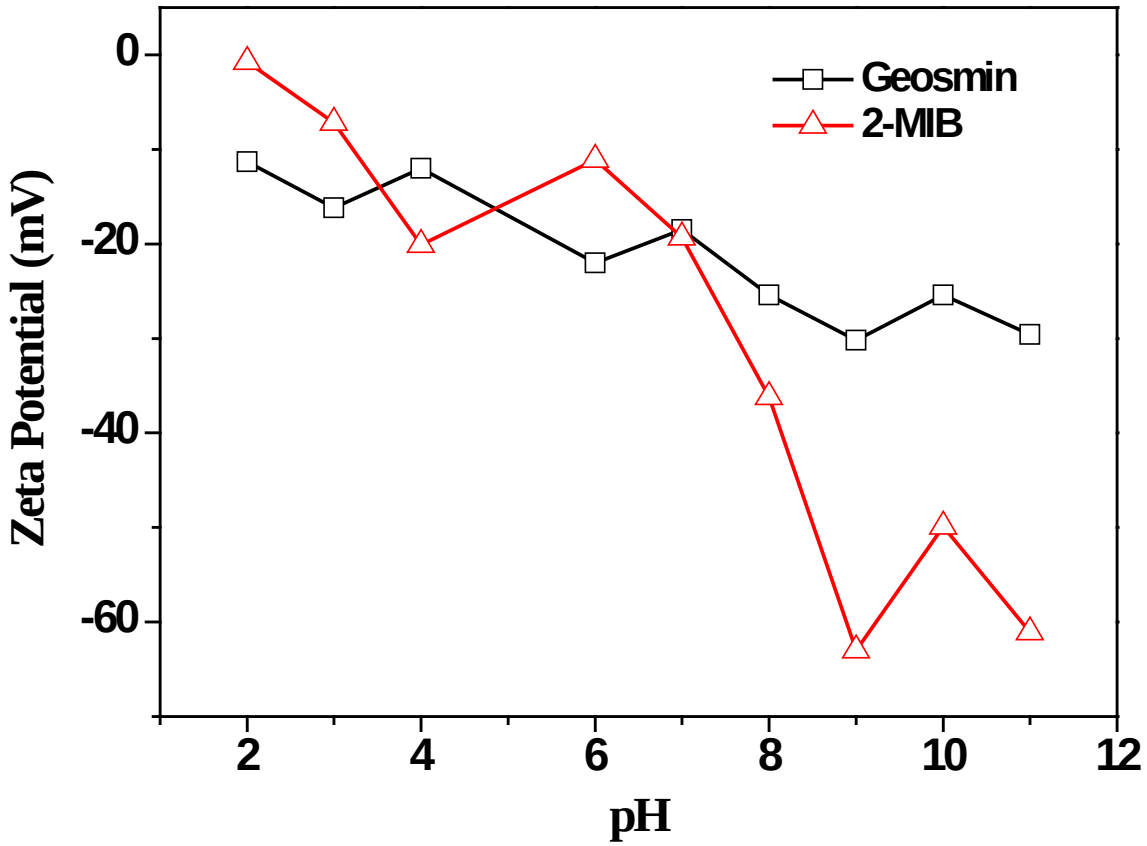
SPME	GC	MS
Cycle: SPME Syringe: Fiber	Column Oven Temp: 60 ^{0}C	Ion Source Temp: 230 ^{0}C
Pre Inc Time: 5min Incubator Temp: 60 ^{0}C Extract Time: 20 min	Injection Temp: 250 ^{0}C	Interface Temp: 250 ^{0}C
Agi Speed: 500 rpm Agi on Time: 5s Agi off time: 2s	Injection Mode: Splitless	Solvent Cut Time: 2 min
Desorption Time: 2min Fiber Bakeout:20 min	Sampling Time: 1 min	Threshold: 100

Method development – calibration curves



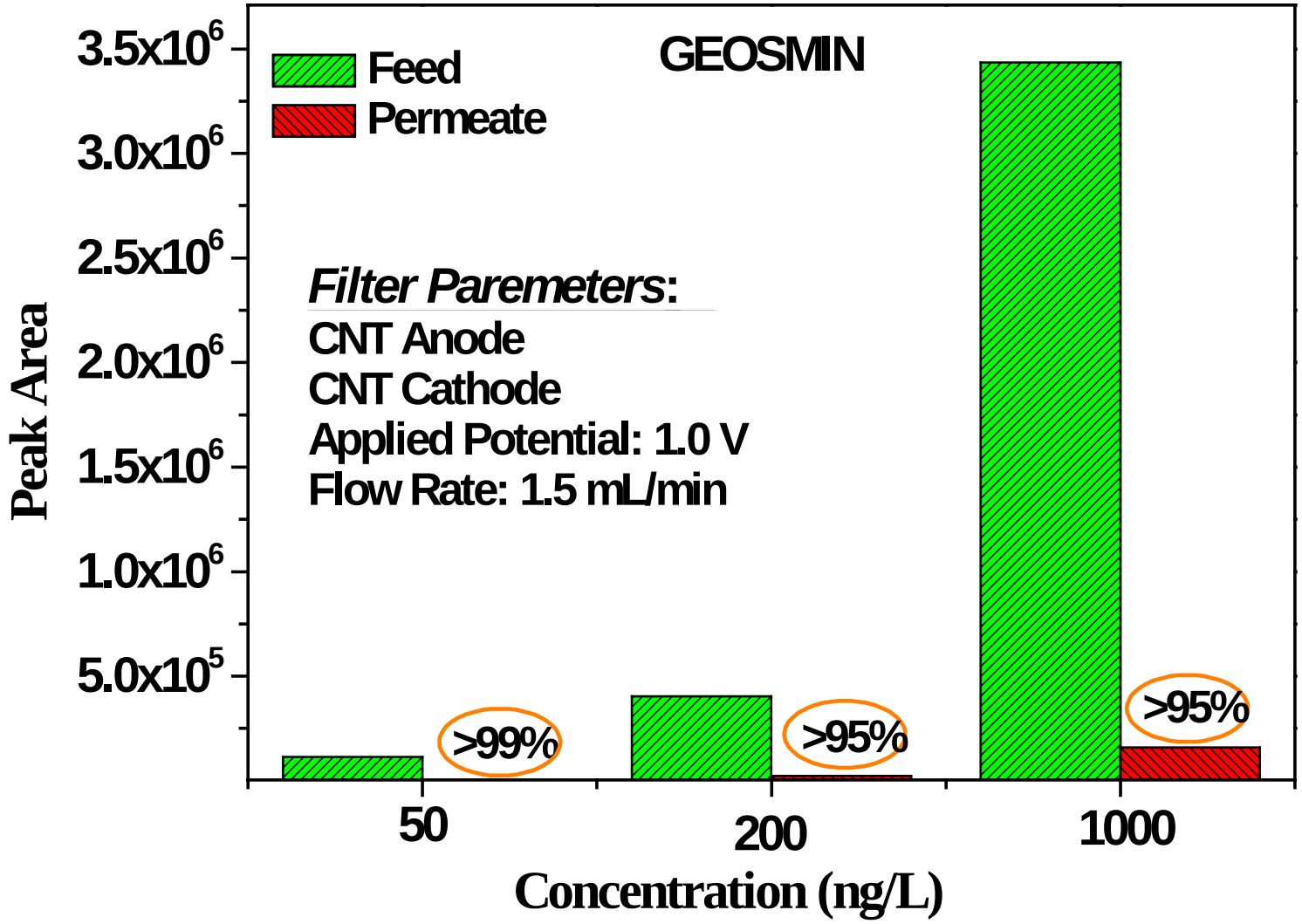


Experimental Results – Zeta potential

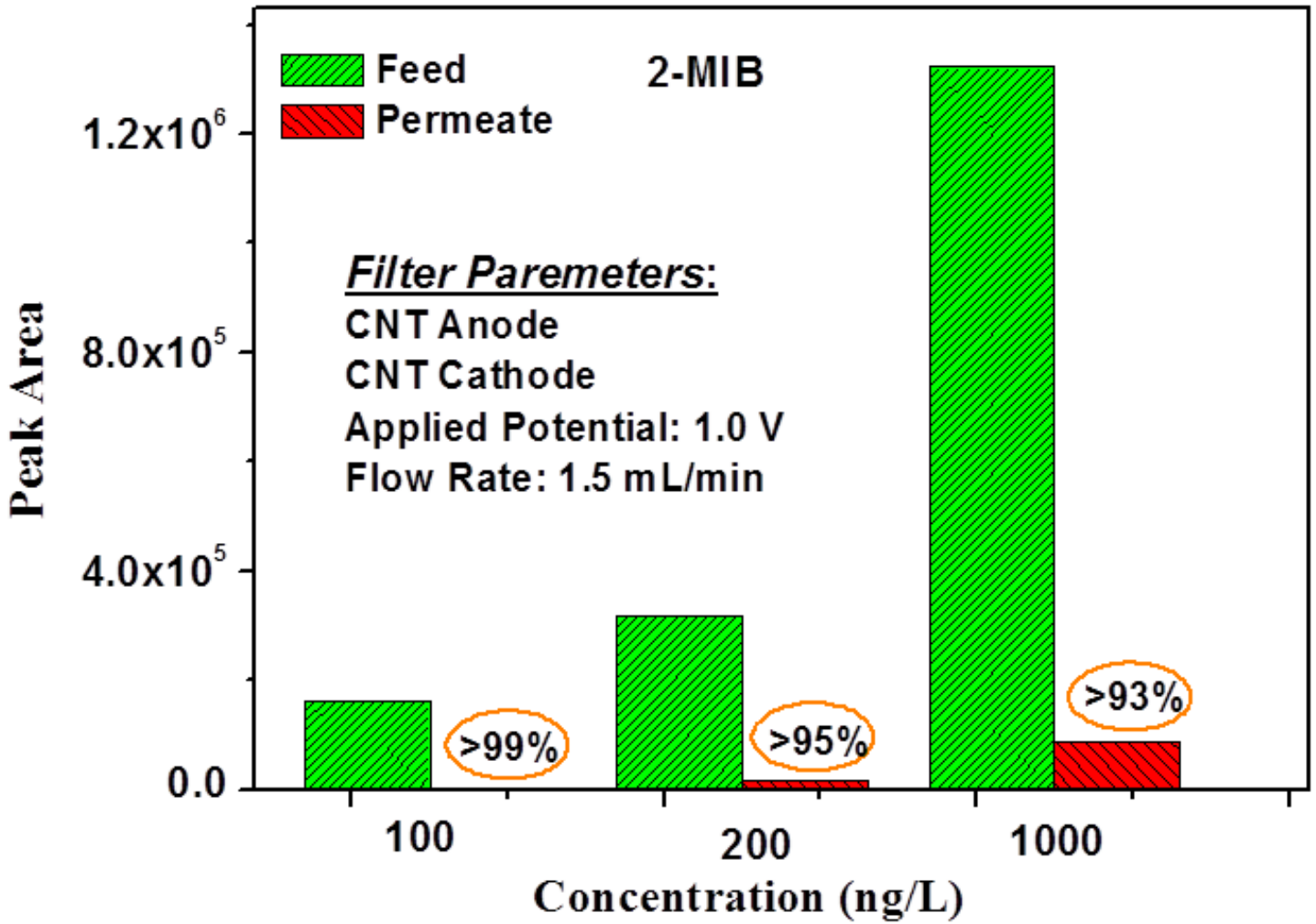


The off-flavor compounds are negatively charged at all pH Range

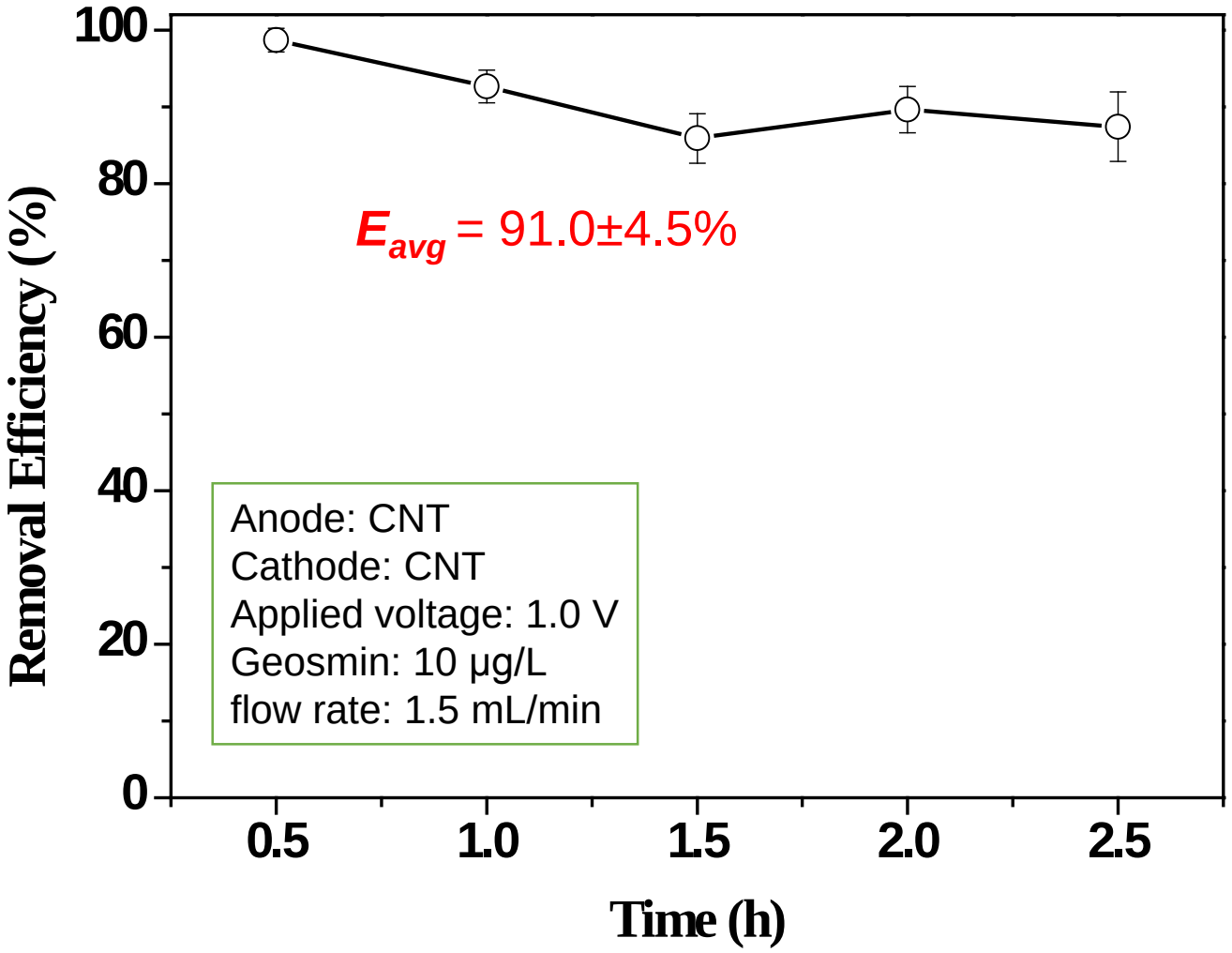
Geosmin, a taste & odor compound, was efficiently removed (>90%) by the CNT filter



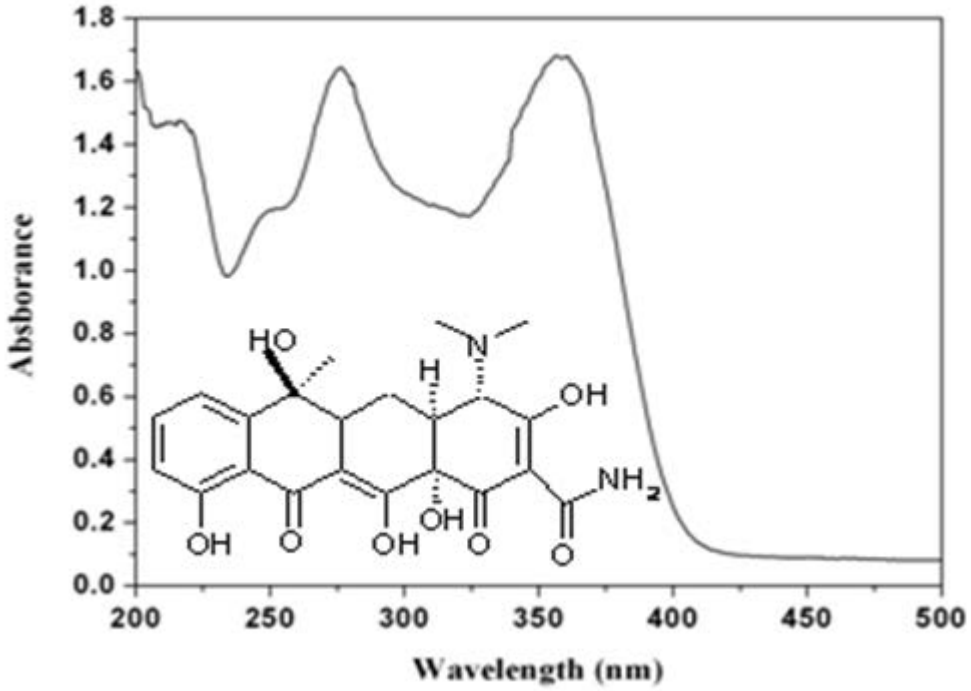
2-methylisoborneol, another taste & odor compound, was efficiently removed (>90%) by the CNT filter



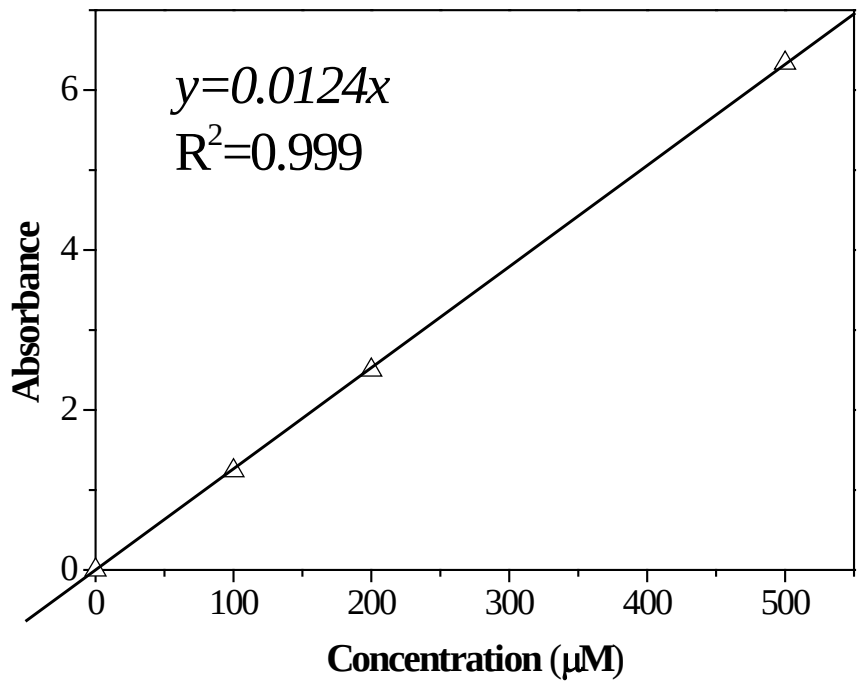
Removal efficiency of geosmin was still high after 2.5 hours of operation



Tetracycline – a typical pharmaceuticals and personal care products (PPCP)



(a) UV-vis absorption spectrum and chemical structure of tetracycline

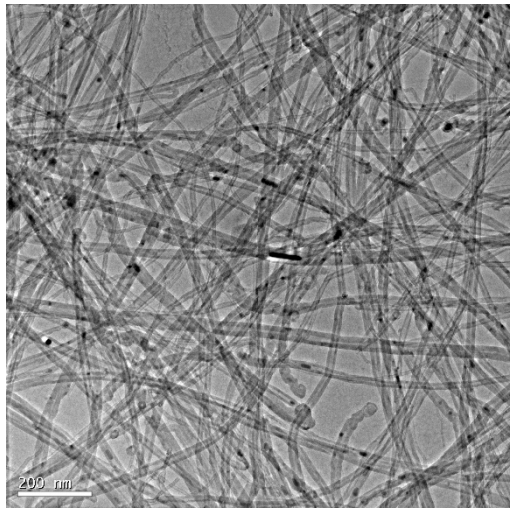


(b) Calibration curve of tetracycline solution.

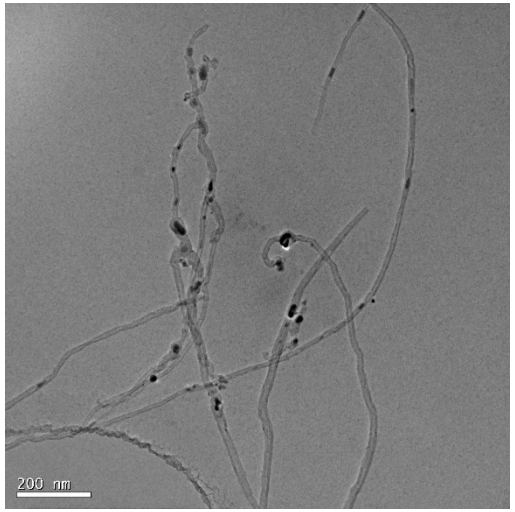
Characterization of CNT filters

	Dimension	BET (m^2/g)
C-CNT	<D>=**15 nm** <L> = 100 μm	88.50
J-CNT	<D>=**100 nm** <L> = 100 μm	30.29
M-CNT	<D>=**40 nm** <L> = 100 μm	34.57
U-CNT	<D>= 40 nm <L> =1 mm	55.76
XL-CNT	<D>=40 nm <L> =3 mm	55.86

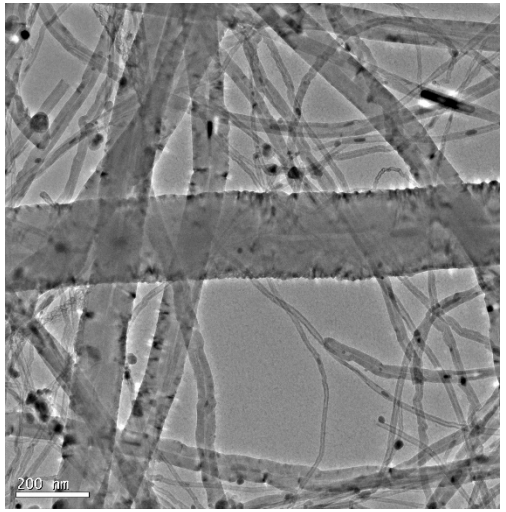
Characterization of CNT filters with TEM



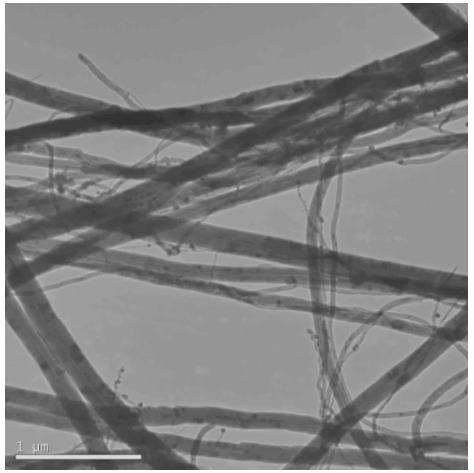
C-CNT



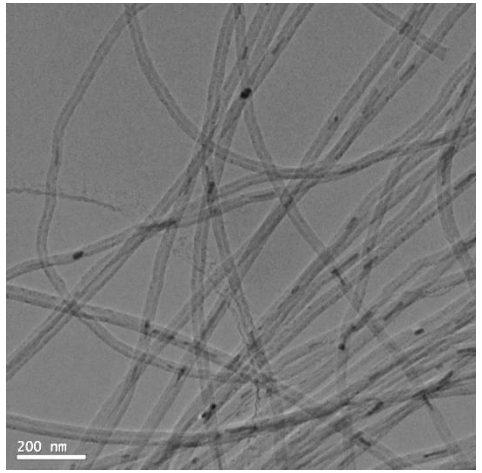
M-CNT



J-CNT

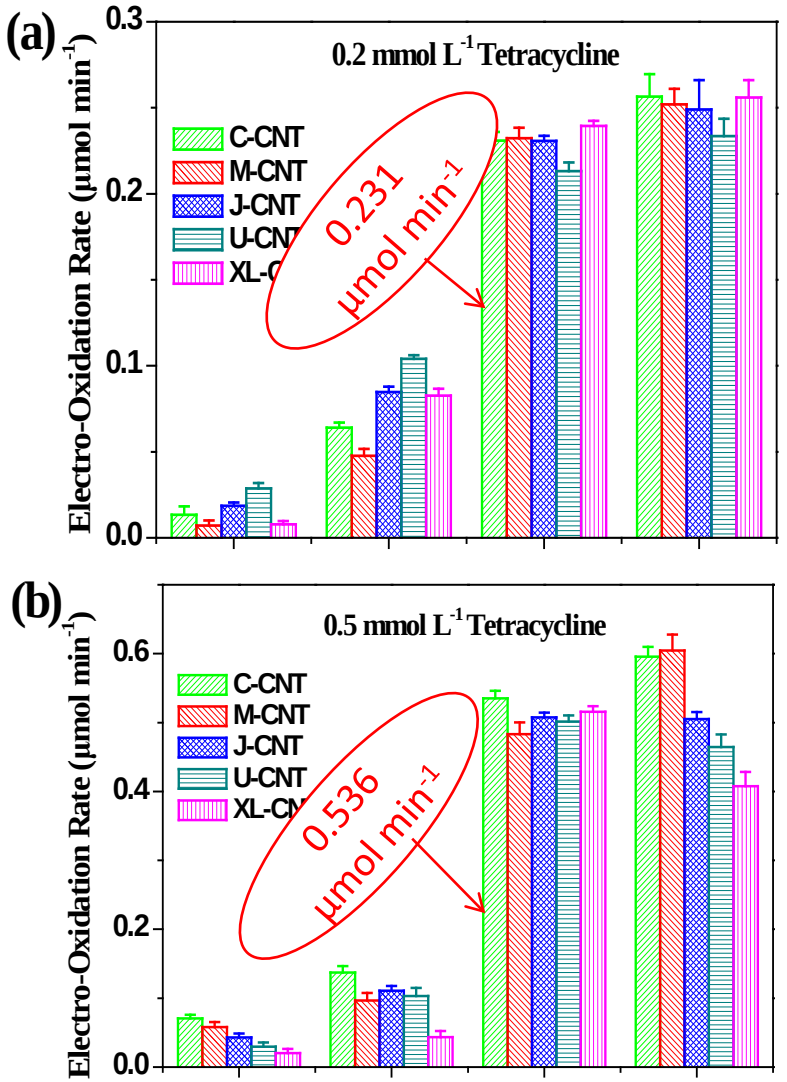


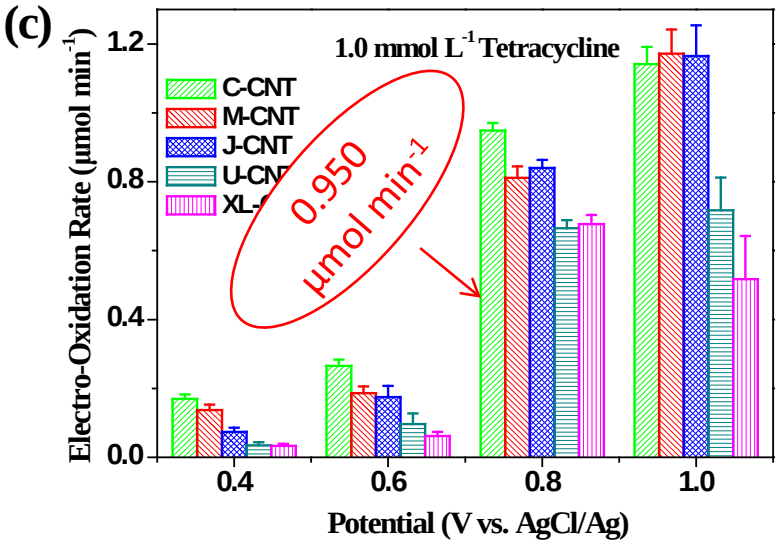
U-CNT



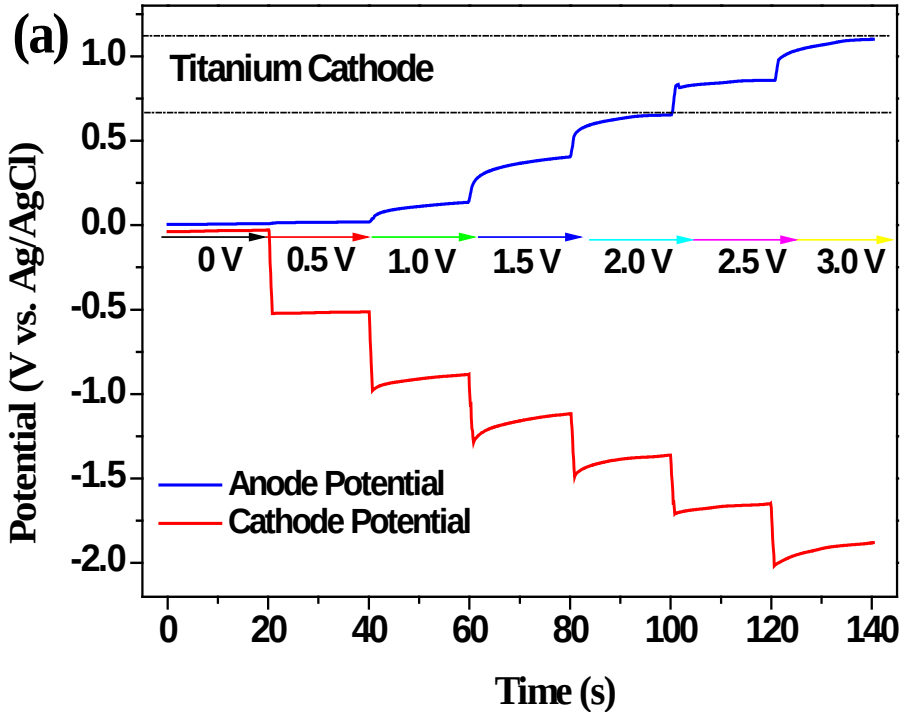
XL-CNT

The electro-oxidation rate of tetracycline was increased with potential

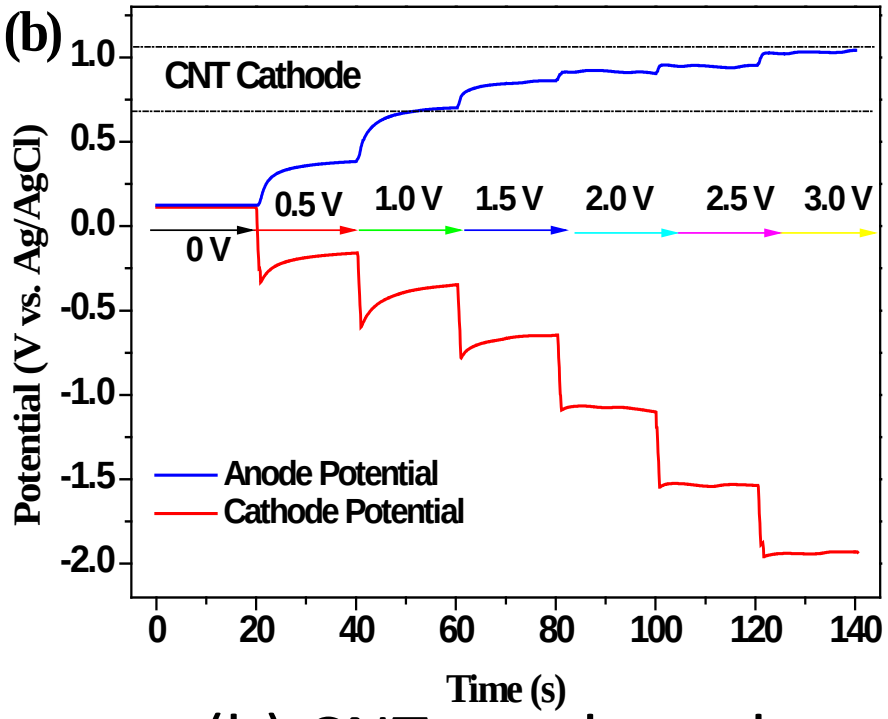




Effect of cathode materials: CNT cathode vs. Ti cathode

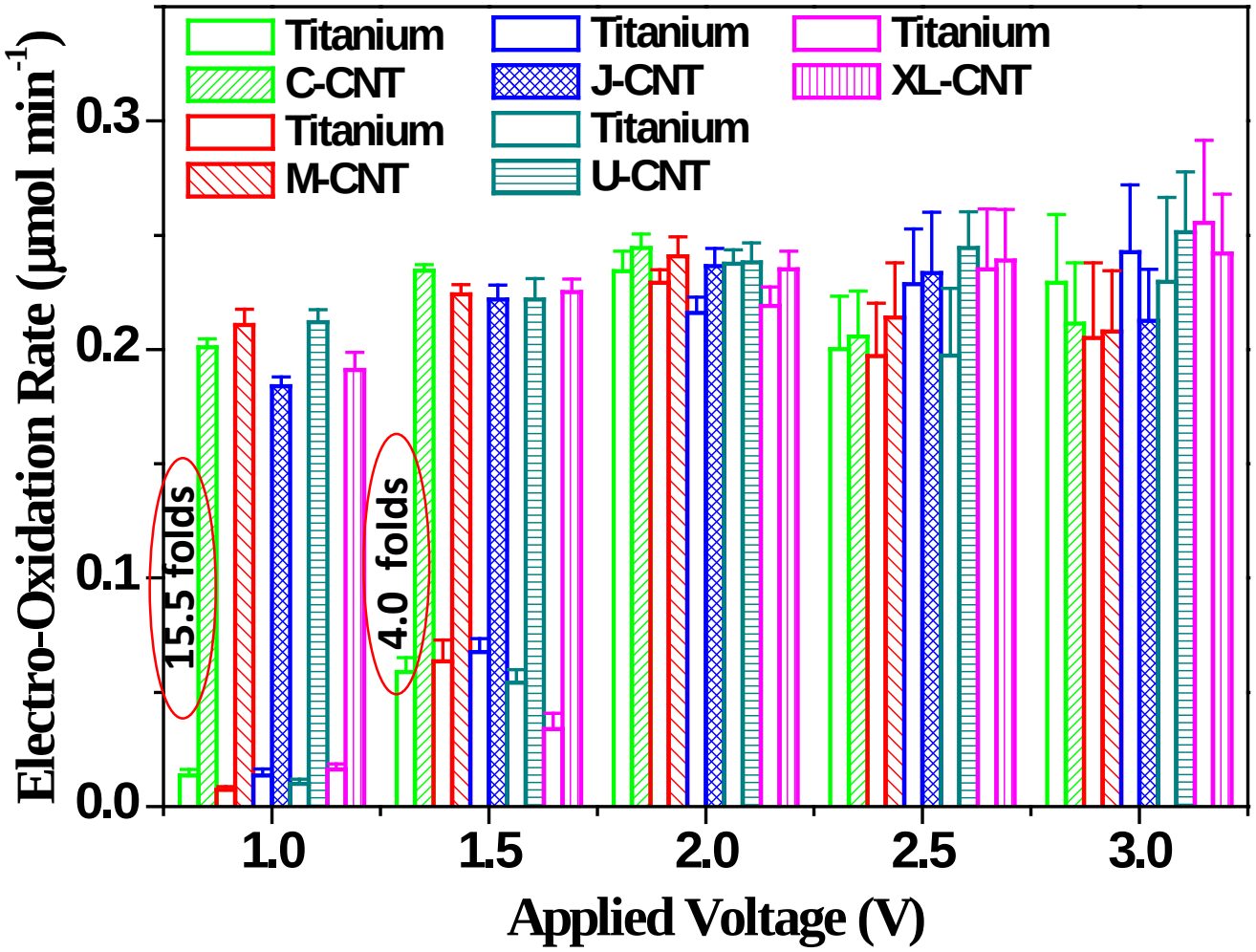


(a) CNT anode and titanium cathode

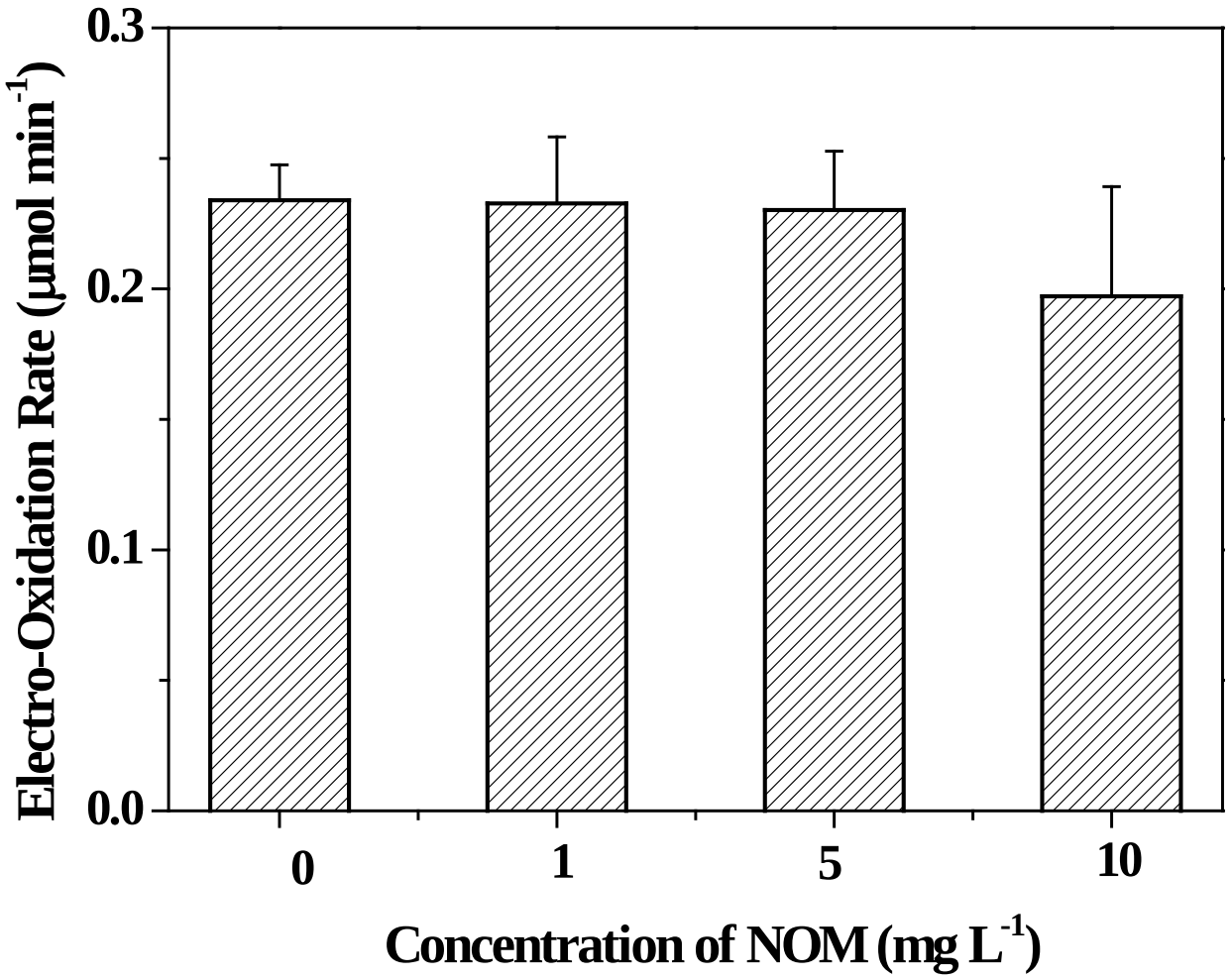


(b) CNT anode and CNT cathode

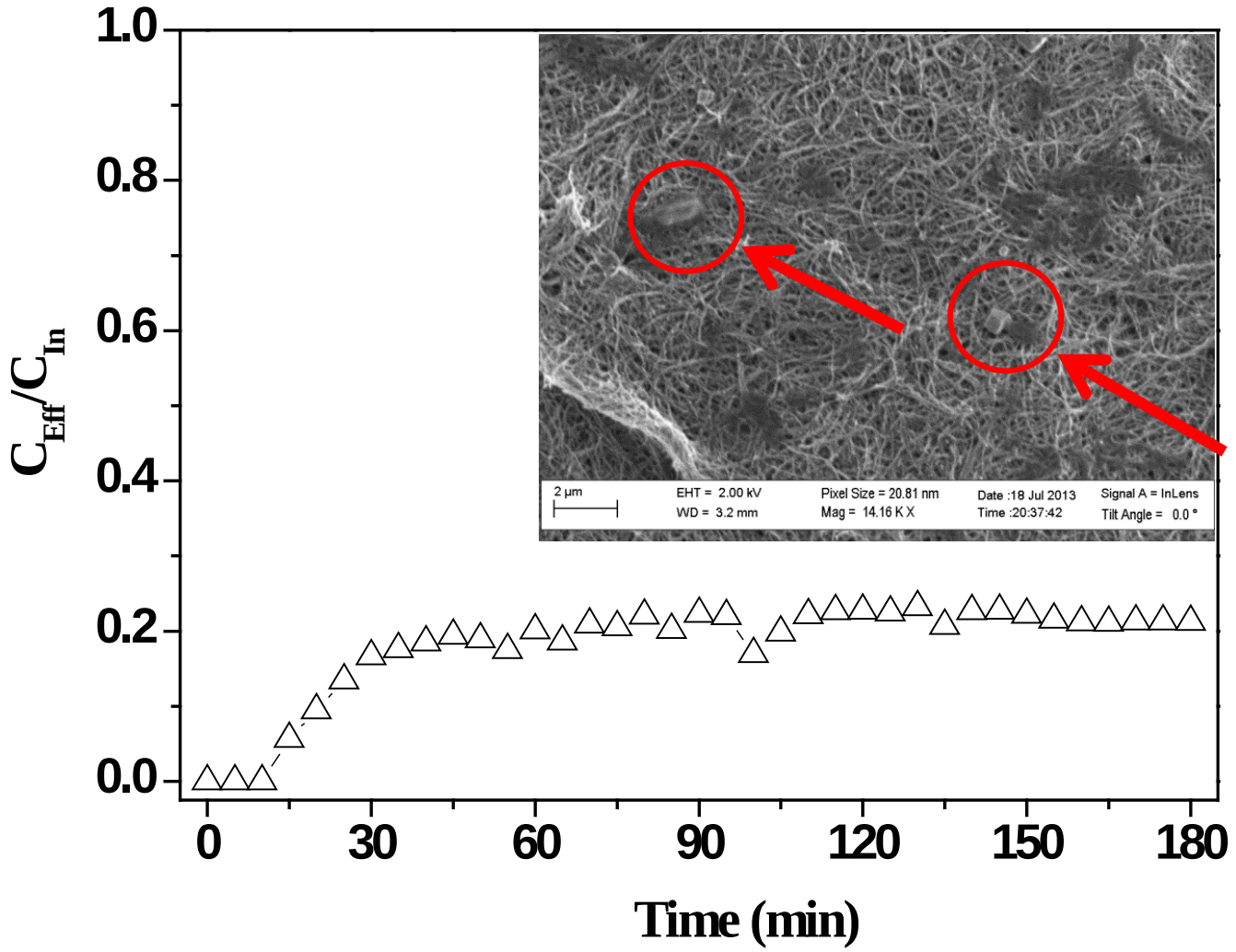
Effect of cathode materials on tetracycline removal



Low concentration of NOM has less effect on the electrooxidation of tetracycline.



The removal efficiency of tetracycline was maintained at ~90% within 3h.



Preliminary analysis on energy consumption for electrochemical filtration is promising

	Concentration (ng/L)	Water type	Condition (Voltage, current)	Energy consumption for electrochemical process (kWh/m^3)	Energy consumption for pumping (kWh/m^3)
2-MIB	100, 200, 1000	DI water	1V 1.0 mA	0.01	0.0042
Geosmin	50, 200, 1000	DI water	1V 1.0 mA 2V 5.0 mA	0.01 0.11	0.0042
2-MIB	1000, 10000, 20000	Tap water	1V 2.0 mA 2V 5.0 mA	0.02 0.11	0.0042
Geosmin	1000, 10000, 20,000	Tap water	1V 1.8 mA 2V 4.0 mA	0.02 0.09	0.0042
2-MIB	20,000	Reservoir water	1V 1.0 mA	0.01	0.0042
Geosmin	20,000	Reservoir water	1.5V 3.0 mA	0.05	0.0042
2-MIB	20,000	WRP effluent	1V 1.0 mA	0.01	0.0042
Geosmin	20,000	WRP effluent	1.5V 3.0 mA	0.05	0.0042

Summary

- Electrochemical treatment is a promising cost-effective technology to remove chemical contaminants, such as taste and odor compounds and PPCPs.

- A combination of electrooxidation and membrane filtration could further improve the efficiency of electrochemical systems to remove contaminants and further investigation is needed.

Acknowledgement

Team

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Questions?

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