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Enhanced operation of capacitive deionization using a novel biochar integrated flow-electrode

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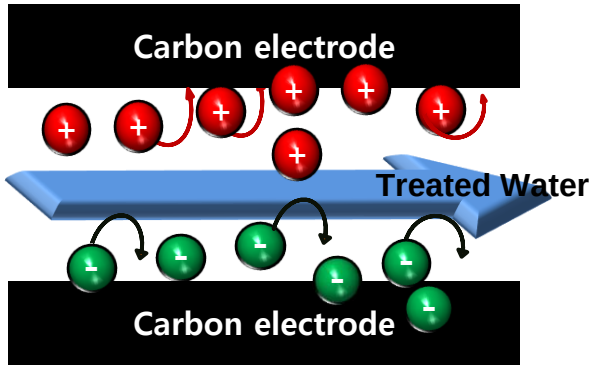
SIWW 2022

April 17-21, 2022 / Singapore

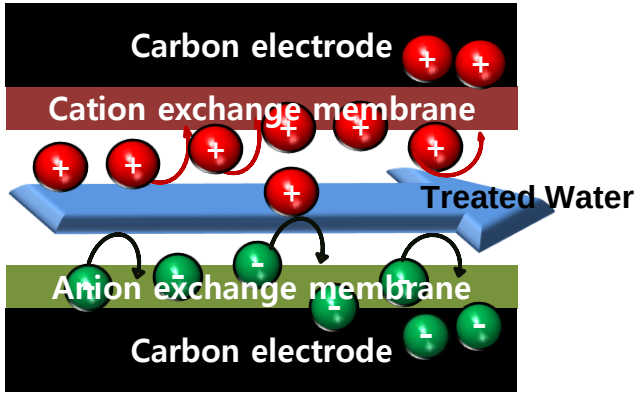
Contents

Electro-driven desalination process

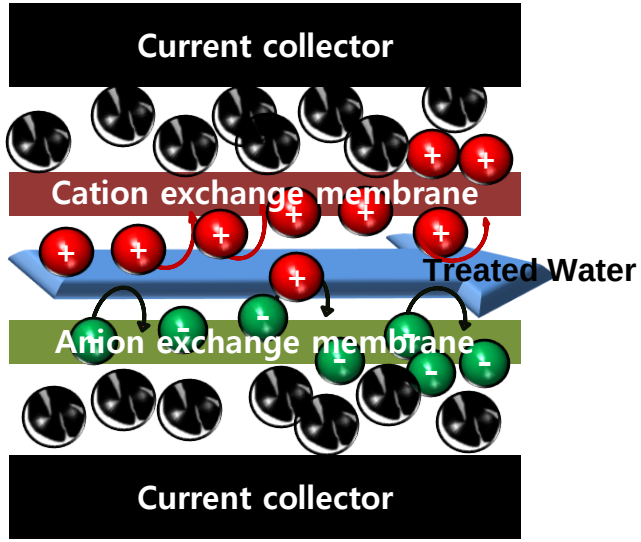
(a) CDI



(b) MCDI



(c) FCDI



Conventional CDI

- **Solid-type** flow electrode
- **Semi-continuous process**
- **No ion-exchange membrane**

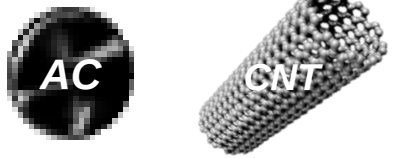
Flow-electrode CDI

- **Liquid-type** flow electrode
- **Sustainable continuous process**
- Higher deionization performance
- Lower energy consumption

Research on FCDI system

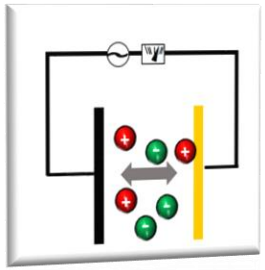
1. Flow-electrode

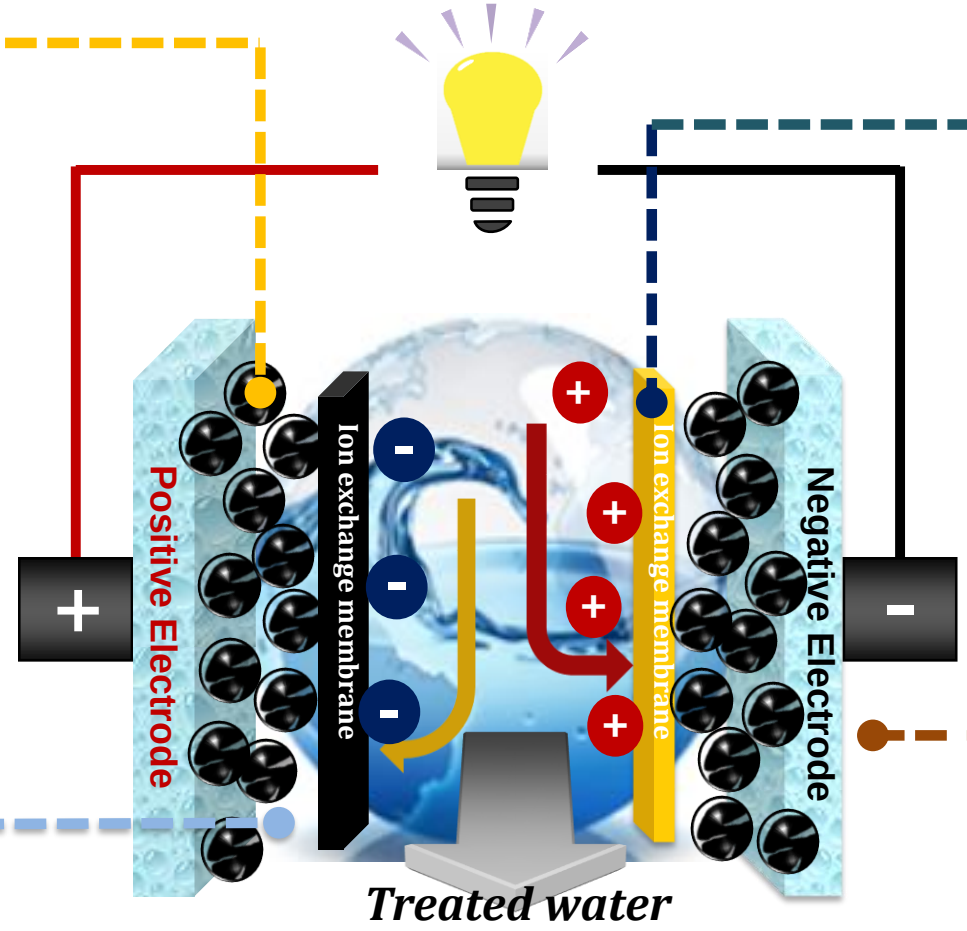
- Electrode materials
- Loading conditions



2. Electrolyte

- Charge transport
- Electrical resistance



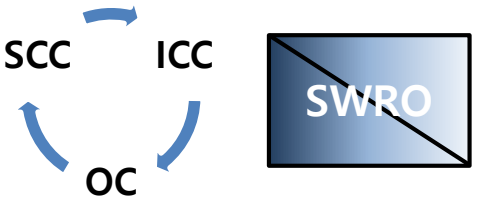


3. Ion-exchange membrane

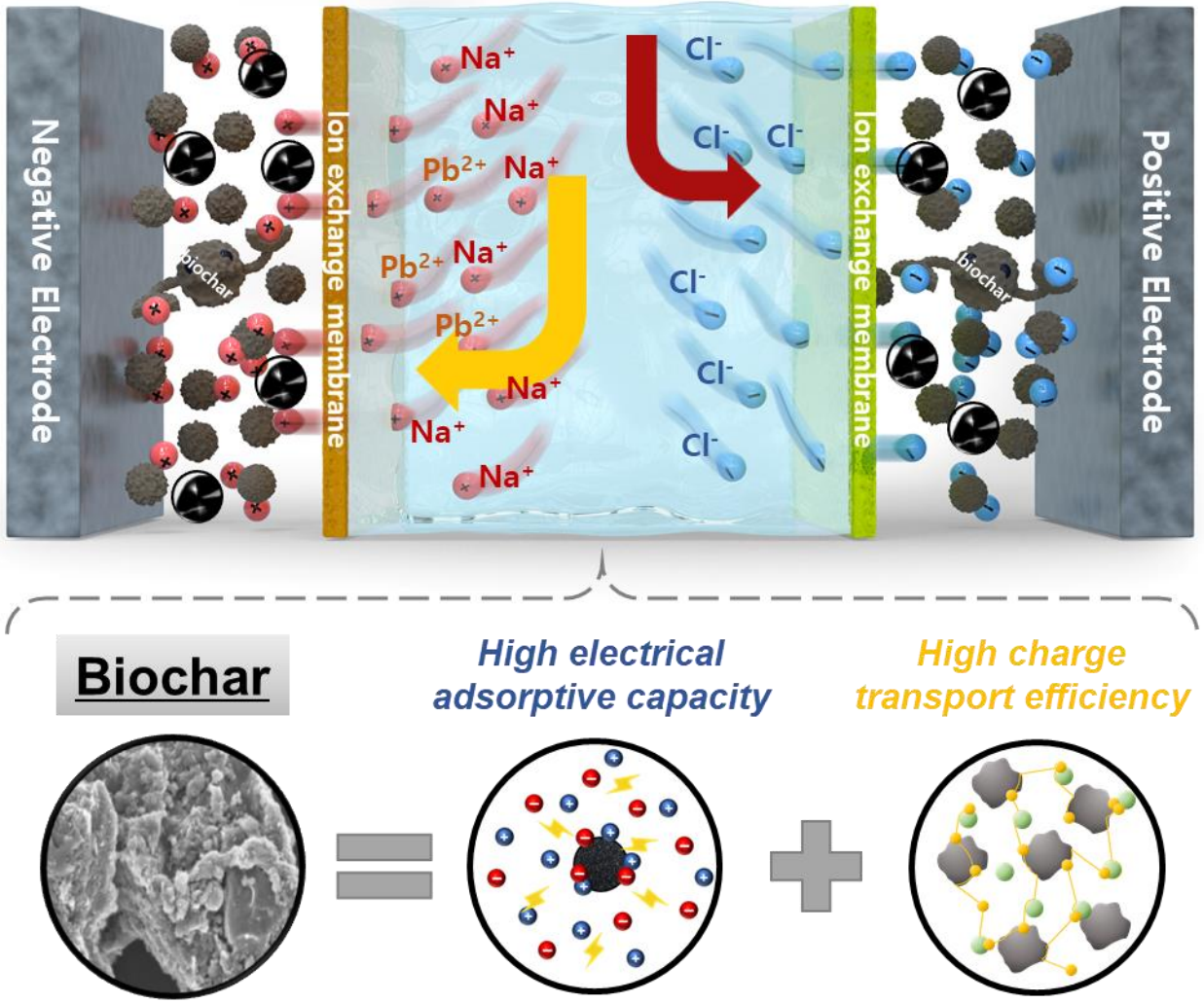
- Ion transport
- Electrical resistance

4. System operation

- Operation modes
- Process hybridization



Investigation of flow-electrode material



Flow-electrode material		
Adsorption capacity	Charge transport efficiency	Fluid dynamic

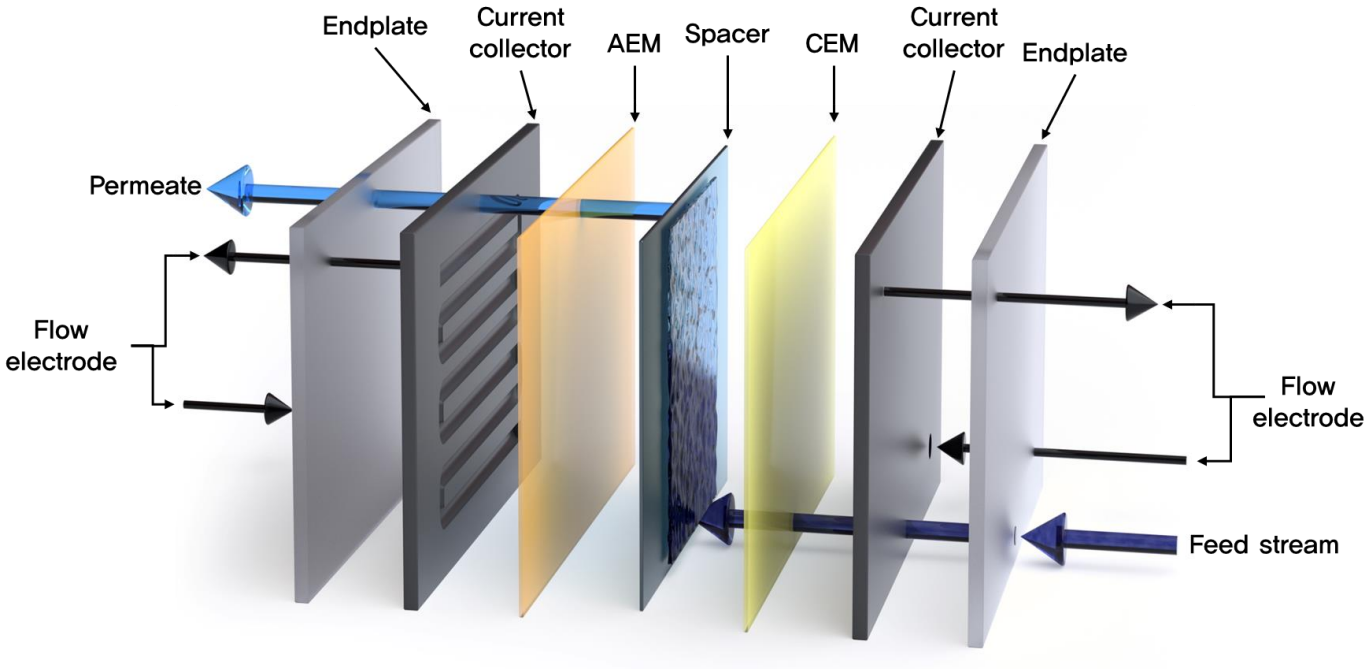
Integration of biochar as a novel flow-electrode material

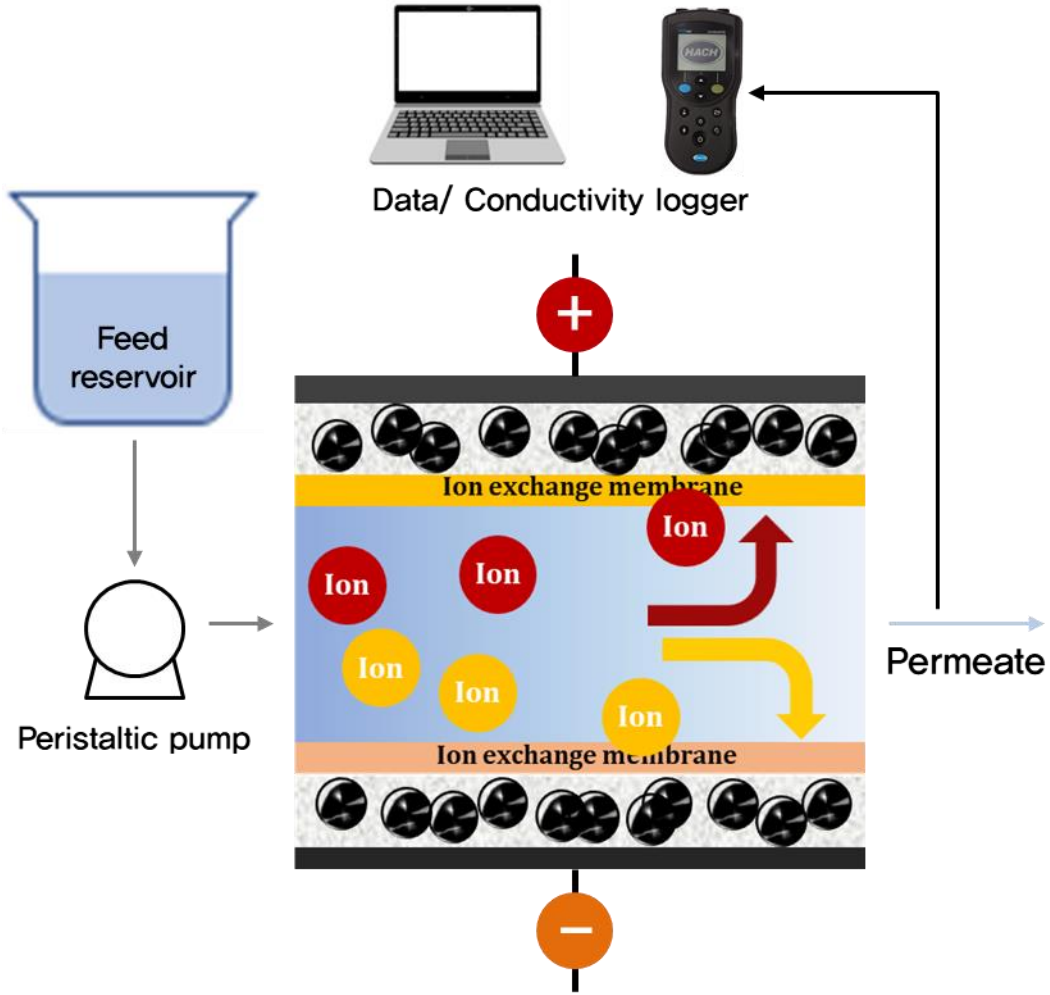
SIWW 2022

April 17-21, 2022 / Singapore

Contents

FCDI experimental method





FCDI operation

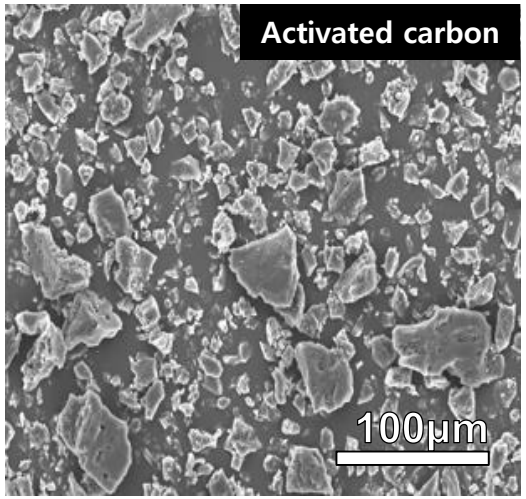
- Flow-electrode : biochar (700℃ pyrolyzed)
- Ion-exchange membrane : ASE/CSE (ASTOM Corp.)
- Operation voltage : 0.4 ~ 1.1 V
- Feed solution : 500ppm NaCl + 100ppm Lead

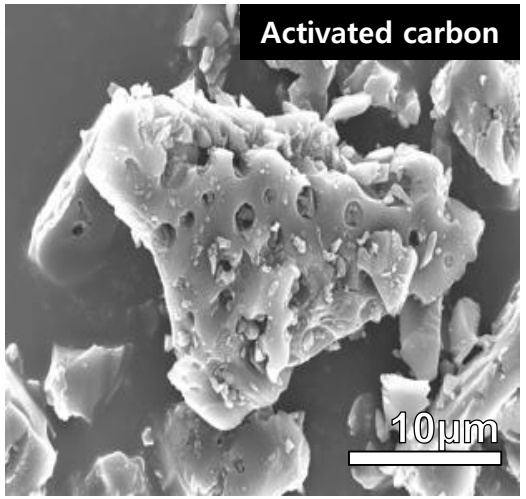
SIWW 2022

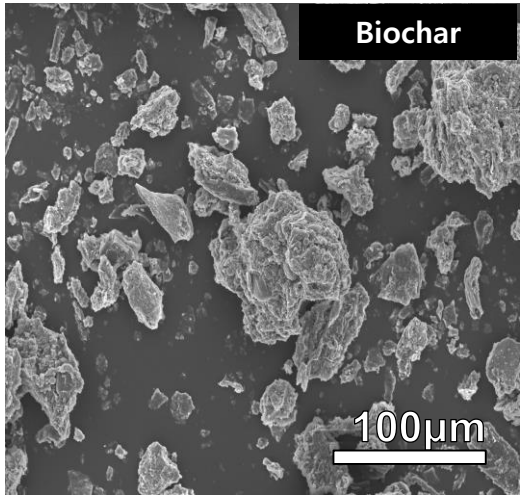
April 17-21, 2022 / Singapore

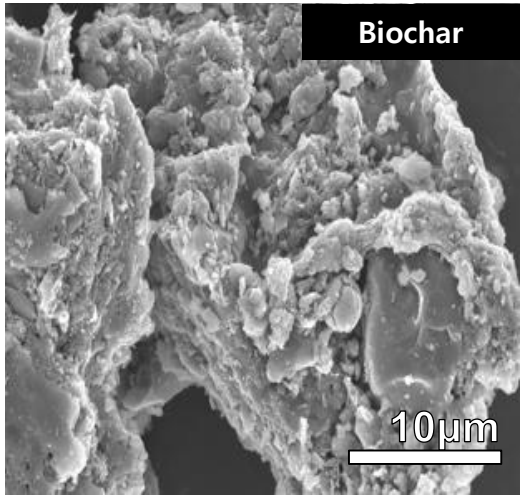
Contents

Electrode characterization – SEM/EDS



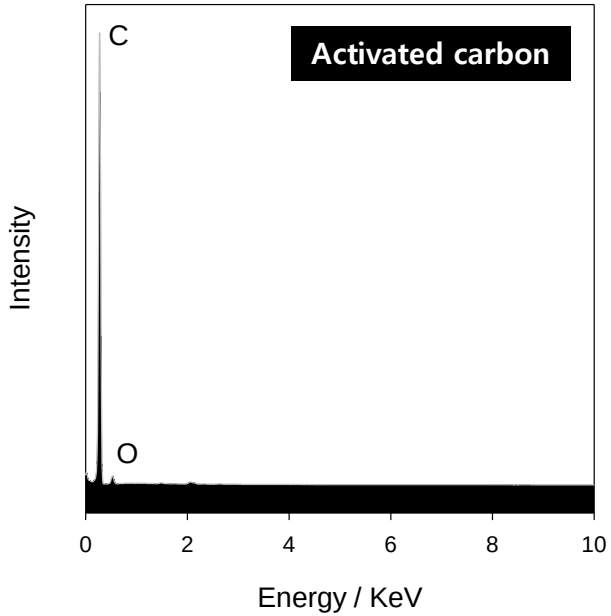


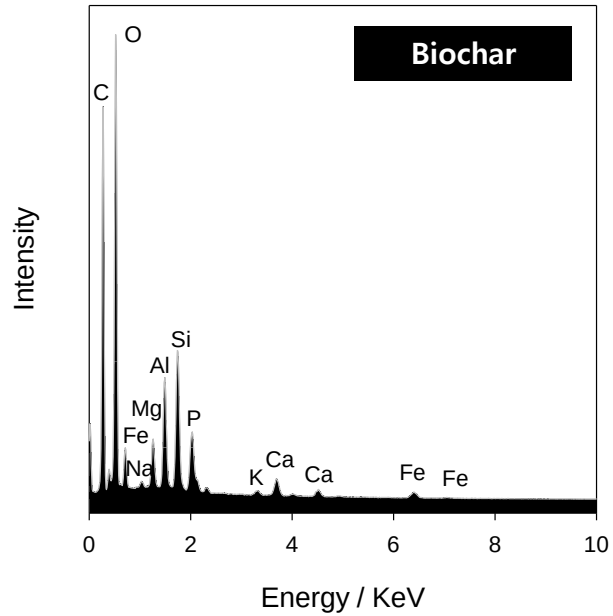




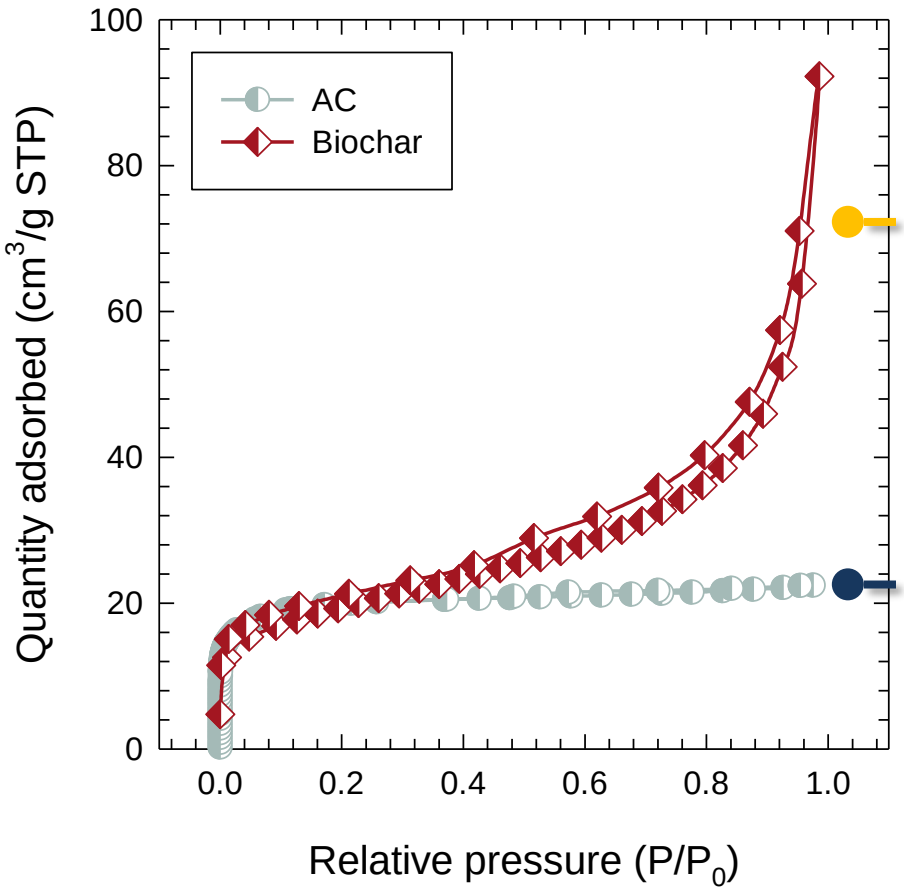
	Particle size		SA_{BET} (g^{-1})	V_P ($cm^3\ g^{-1}$)	V_{MP} ($cm^3\ g^{-1}$)	S_P (Å)
	Width (μm)	Length (μm)				
Activated carbon	15.57	17.6	1764.20	0.808	0.614	18.33
Biochar	28.12	26.26	67.64	0.131	0.081	114.63

SA_{BET}: BET surface area; V_P: total volume of pores; V_{MP}: volume of micropores; S_P: average pore size



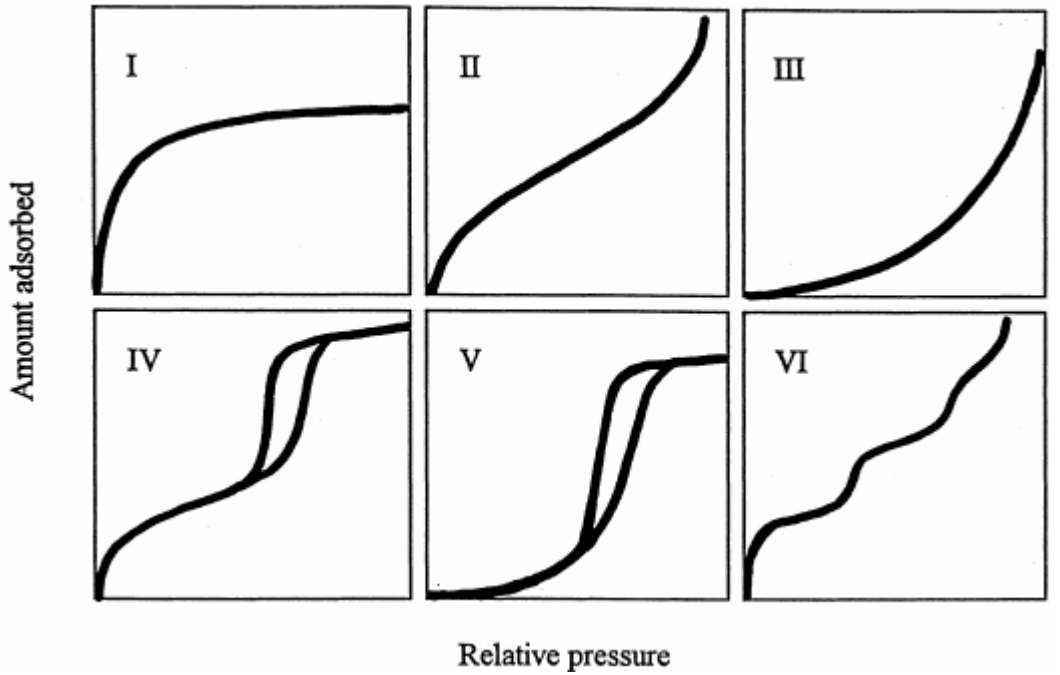


Electrode characterization – adsorption isotherm



Macroporous biochar

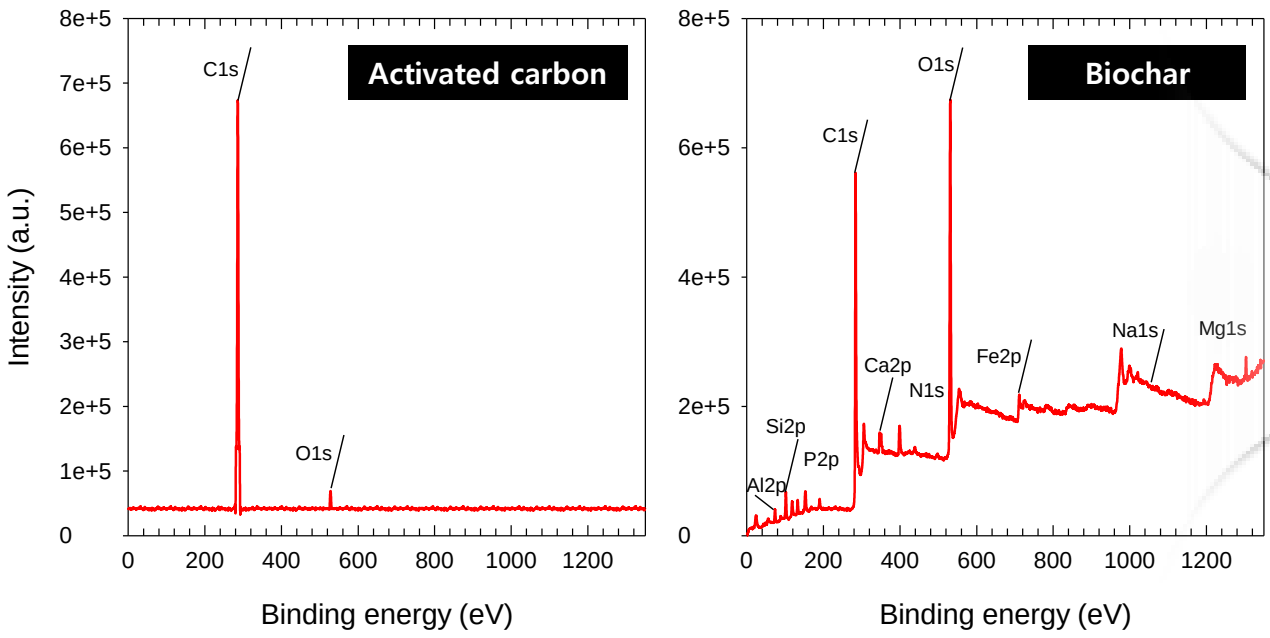
Microporous AC



IUPAC adsorption isotherm classification

Microporous	Macroporous	Mesoporous
Type I	Type II, III, VI	Type IV, V

Electrode characterization – XPS

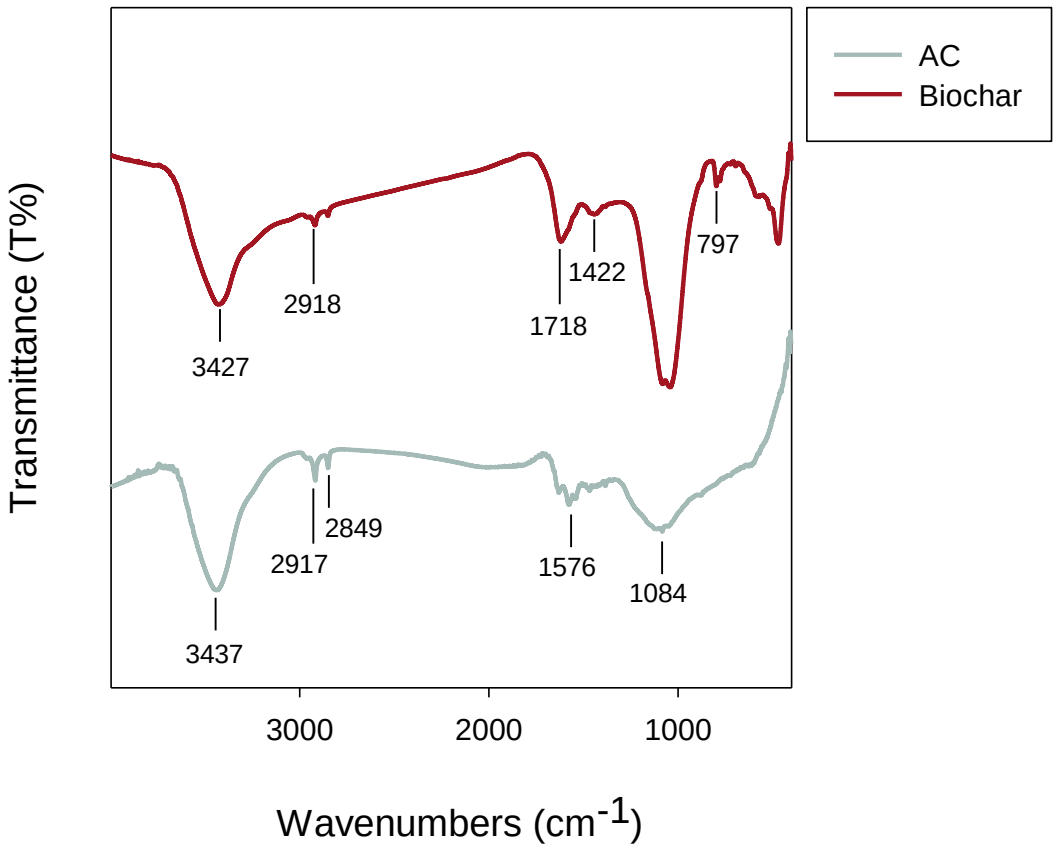


Heavy presence of functional groups on biochar

→ Affinity for heavy metal adsorption

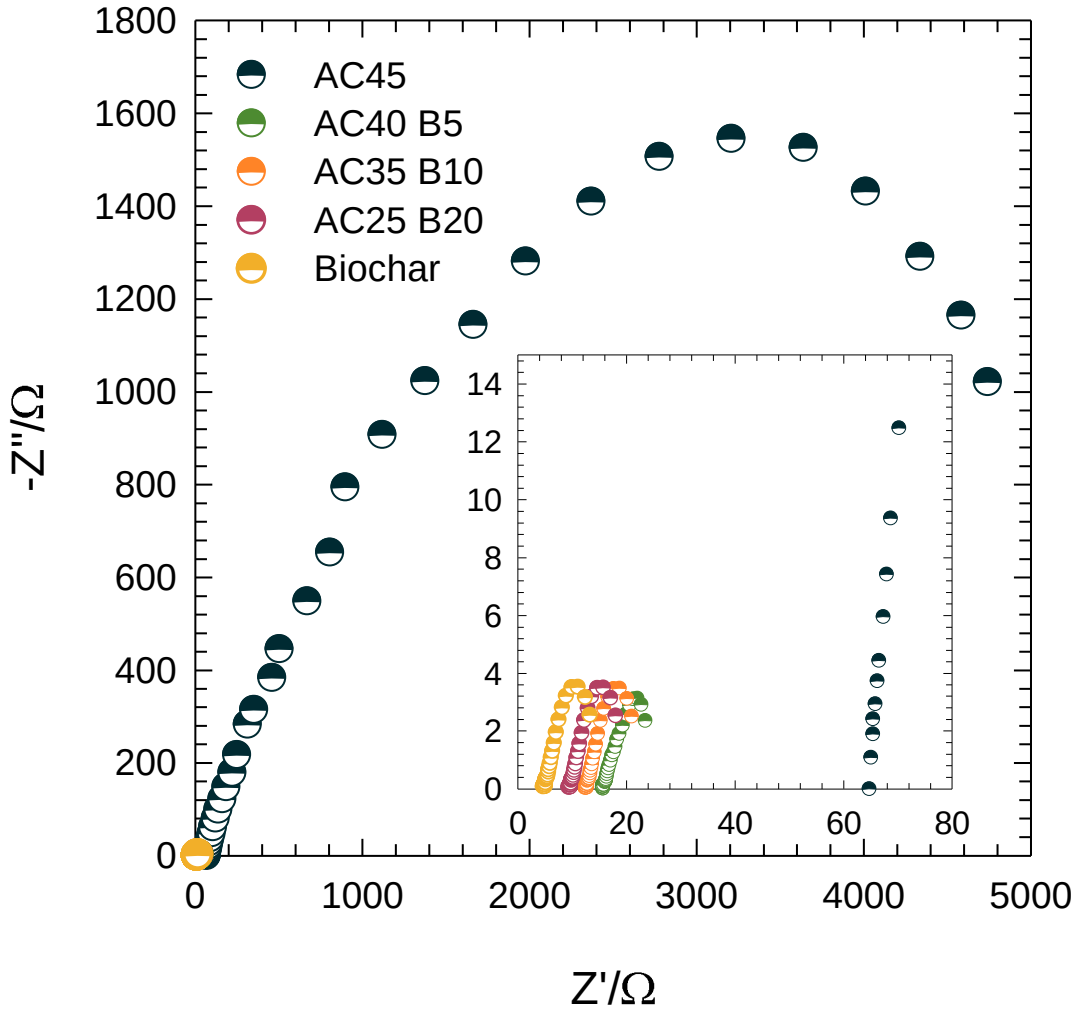
	Functional group	Binding energy (eV)	Composition ratio (%)
Carbon	C-C aromatic	284.7	63.63
	C-O-C esters	285.7	20.33
	C=O carbonyl	286.9	8.91
	O-C=O carboxyl	289.0	7.13
Oxygen	C=O carbonyl	531.8	50.83
	C-O alcohol/ether	532.9	23.59
	O-C=O carboxyl	534.0	25.58
Nitrogen	Pyridinic-N	398.7	48.13
	Pyrrole-N	400.6	44.08
	N-O	402.1	7.79

Electrode characterization – FTIR



Wavenumber (cm^{-1})	Compound class	Functional group	Electrode material	
			Activated carbon	Biochar
3550-3200	Alcohols	O-H stretching	3437	3427
3000-2840	Alkane	C-H stretching	2917/2849	2918
1720-1709	Carboxylic acid	C=O stretching	-	1718
1650-1566	Cyclic alkene	C=C stretching	1576	-
1440-1385	Carboxylic acid	O-H bending	-	1422
1085-1050	Primary alcohol	C-O stretching	1084	-
840-790	Alkane	C=C bending	-	797

Electrode characterization – EIS



Electrochemical property

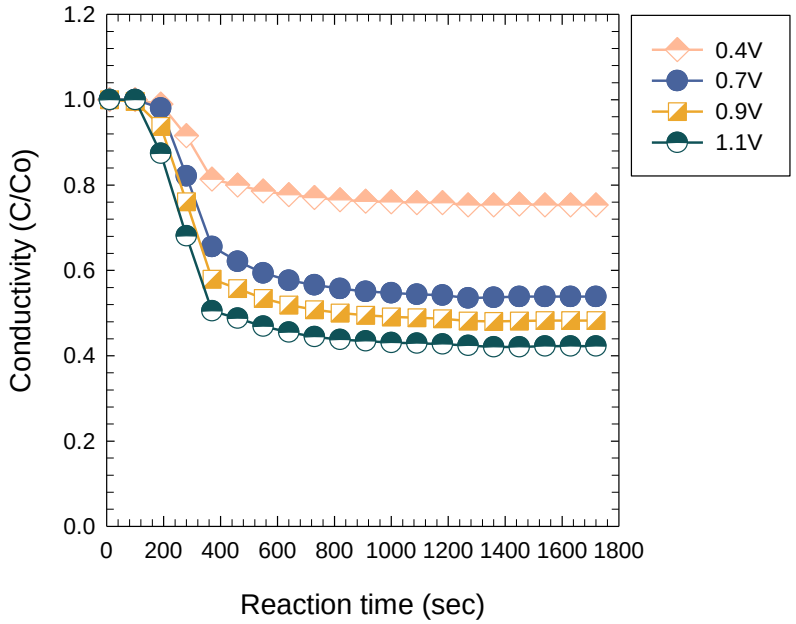
- Higher solution resistance (R_s), and charge transfer resistance (R_{ct}) for activated carbon
- **Charge efficiency :** Biochar > Activated carbon

- **Activated carbon :** lack of delocalized electrons for high conductance
- **Biochar :** oxygen-rich surface functionality & high ion-exchange capacity

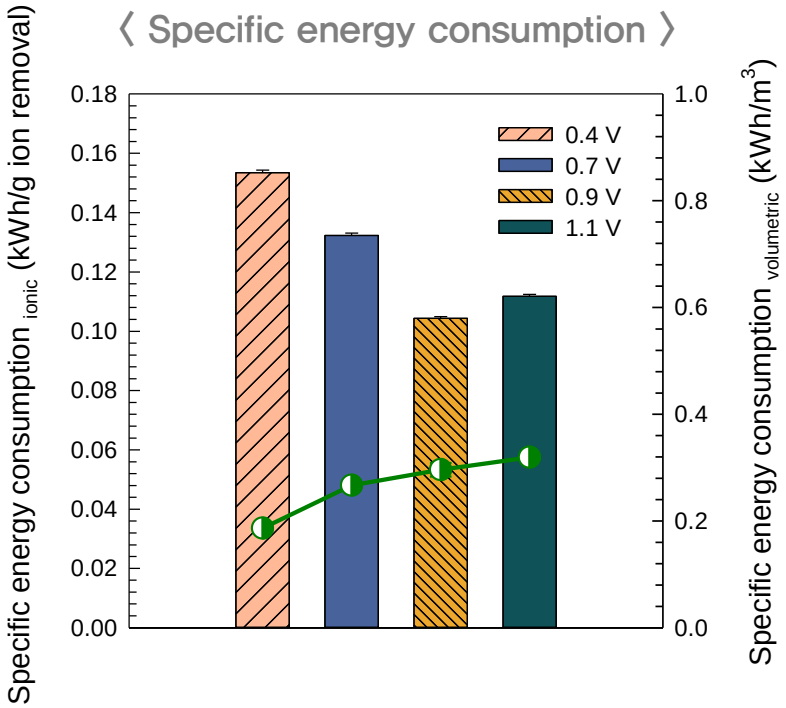
- Reduction in R_{ct} by 1/7
- Superior performance for biochar as flow-electrode

FCDI parameter optimization – applied voltage

〈 Ion removal performance 〉



〈 Specific energy consumption 〉

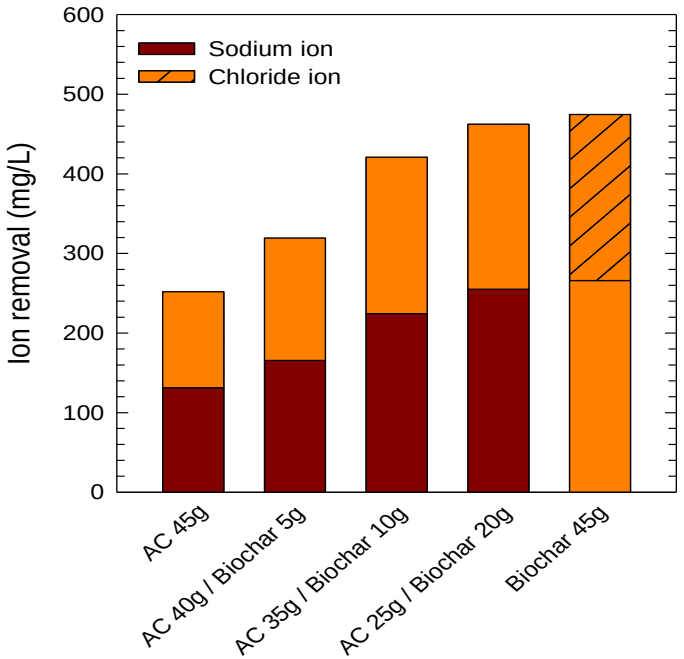


FCDI optimization

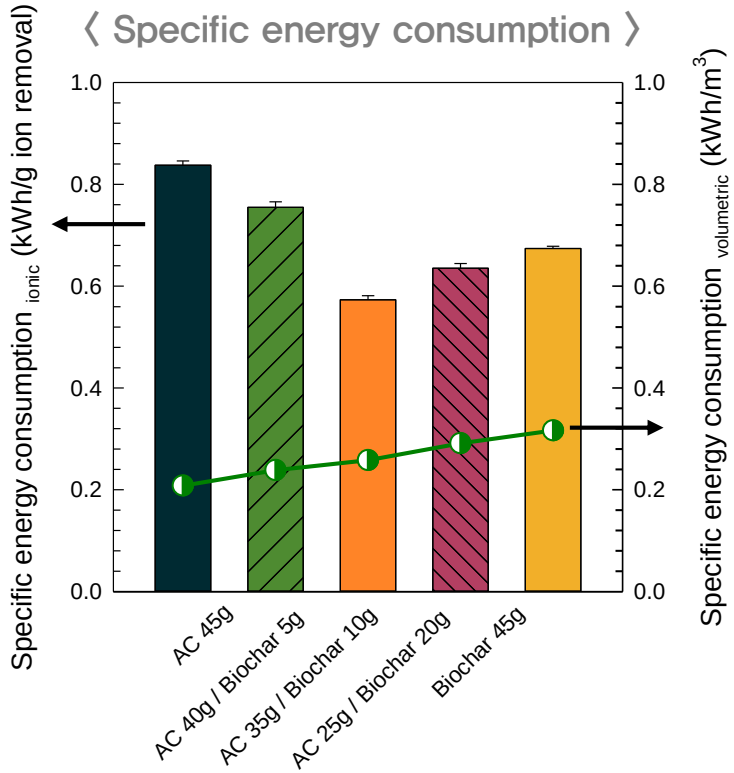
- Optimization based on applied voltage
- Evaluation via ion removal efficiency & specific energy consumption
- Optimal condition → Applied voltage 0.9 V

FCDI parameter optimization – electrode composition

〈 Ion removal performance 〉



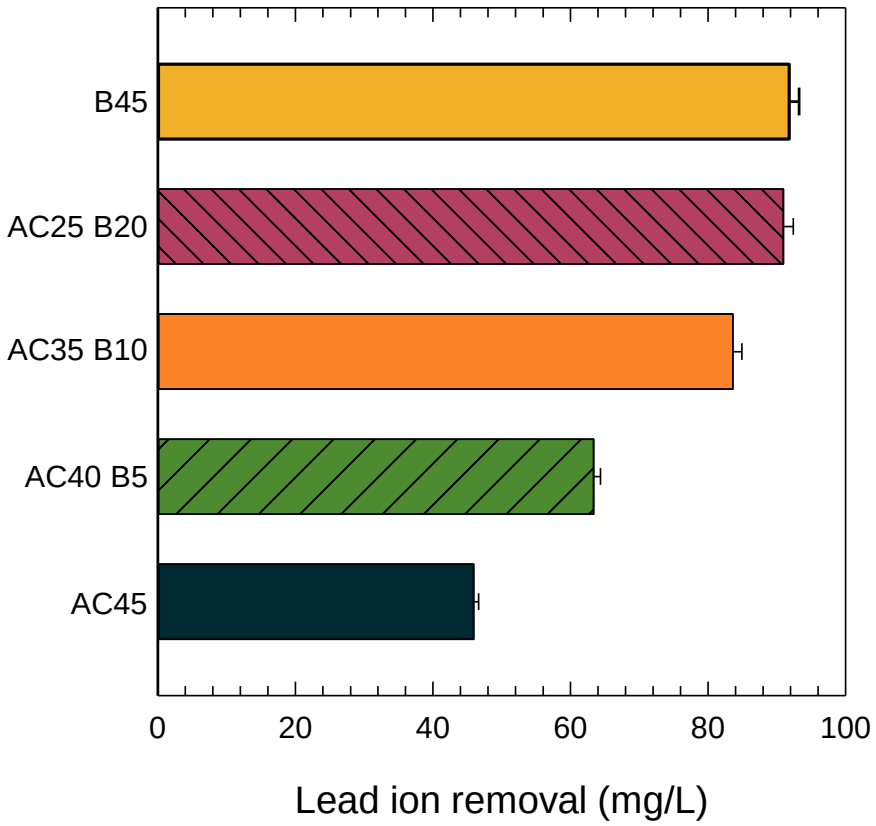
〈 Specific energy consumption 〉



FCDI optimization

- Optimization based on electrode composition : AC & Biochar
- Evaluation via ion removal efficiency & specific energy consumption
- Optimal condition → AC 35g + Biochar 10g

Biochar–FCDI application : lead removal



Lead removal

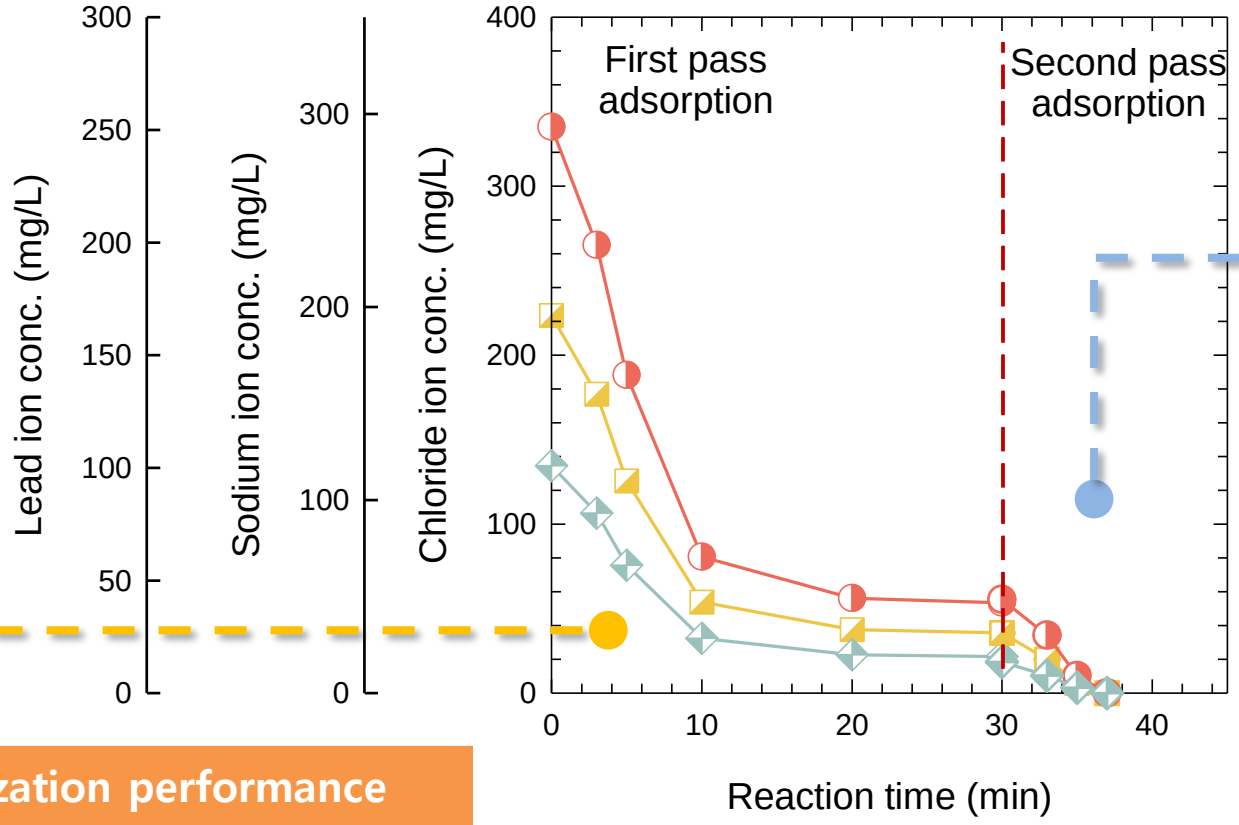
- Superior heavy metal adsorption : Biochar > Activated Carbon
- Improvements by 1.38 ~ 2.0 folds
- Applicability of biochar confirmed for heavy metal remediation

Low impedance

Presence of functional groups

Low zeta potential

Biochar–FCDI operation evaluation



Deionization performance

- Rapid initial deionization
- Average reduction of 85% with respect to initial concentrations

Permeate standard

- Second-pass FCDI operated to meet permeate concentration standards
- Complete desalination of lead-laden feed water within the second-pass system

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