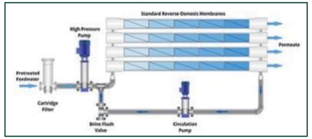
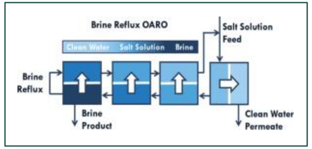
Advanced industrial wastewater Reuse and Resource Recovery Technology
: Summary

Expansion technical applications area to brine and energy reduction and resource recovery for efficient and economical reuse of advanced industrial wastewater

① High Recovery Desalination Technology

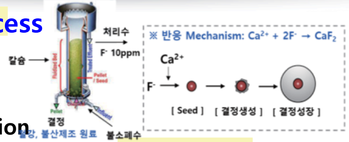




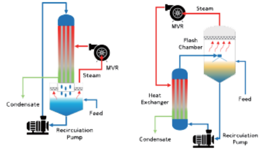
- Semi-batch RO (e.g. CCRO)
- Ultra high pressure RO (UHPRO)
- Osmotically-assisted RO (OARO)
- Electrodialysis (ED)
- Capacitive deionization (CDI)
- Membrane distillation (MD)

② Resource Recovery Technology

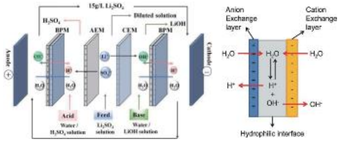
- Crystallization Process



- Evaporation/Concentration +Crystallization.

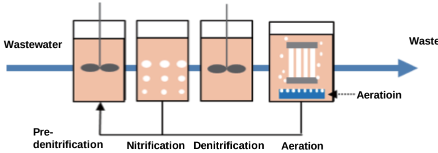


- BPED Process

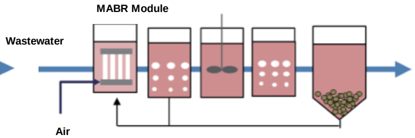


③ Energy saving Technology

- MBR Process

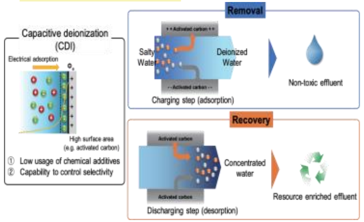


- MABR Process

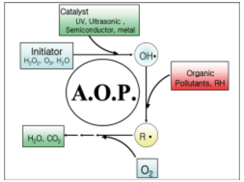


④ High-Purity Industrial Water Production Technology

- CDI Process



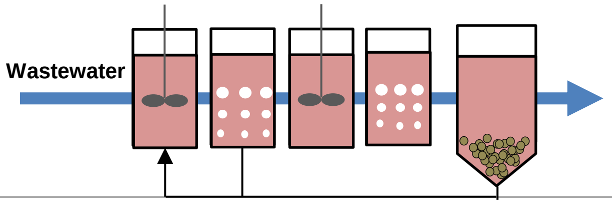
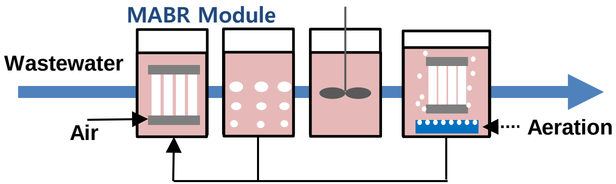
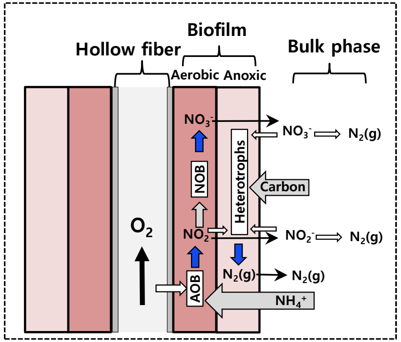
- Advanced Oxidation Process (Electrochemical Oxidation,UV, etc.)



Advanced industrial wastewater Reuse and Resource Recovery Technology

: ① Wastewater Recycling : Energy Reduction technology MABR Process

☐ **MABR**(membrane aerated biofilm reactor) **Process**

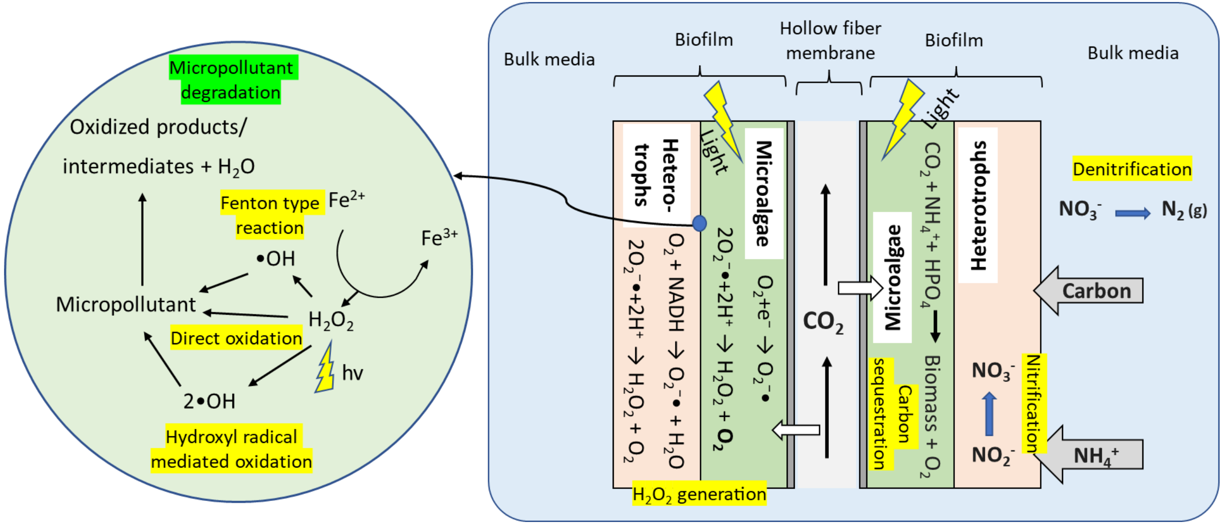
구분	As is	To be
Process	**Bardenpho + Clarifier**	**Bardenpho + MABR + MBR**
Concept		
Advantages	·Specialized for nitrogen removal compared to other biological processes	· utilizing existing facilities (Installation MABR module in existing pre-denitrification tank) · Increasing Removal Efficiency by up to 30%
Note	· Multiple case studies.	·Commercialized in 2016, applying in two overseas locations → Research on applicability to advanced industrial wastewater is underway.
MABR Mechanism	**-. Biofilm Inside: Nitrification, Denitrification, Anammox reaction** **-. Bulk phase: Denitrification** 	■ Chung(2024) Enhanced nitrogen removal from high-strength ammonia containing wastewater using a membrane aerated bioreactor (MABR). Membrane and Water Treatment, 15(2), 59-66. ■ Chung(2025) An innovative MABR-MBR integrated A2/O2 system for treating high- ammoniacal nitrogen containing wastewater, Journal of Membrane Science, Under Review

Advanced industrial wastewater Reuse and Resource Recovery Technology

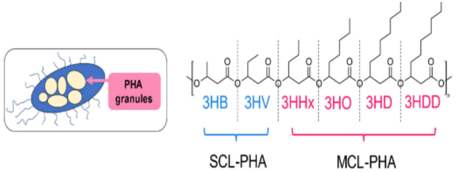
: ② Wastewater Recycling : Energy Reduction technology MABR Process

☐ **MABR**(membrane aerated biofilm reactor) **Process**

: A study on microalge-bacterial biofilm based MABR for simultaneous CO_2 sequestration, emerging pollutants and resource recovery following wastewater treatment



Polyhydroxyalkanoate (PHA)



- Application areas of PHA

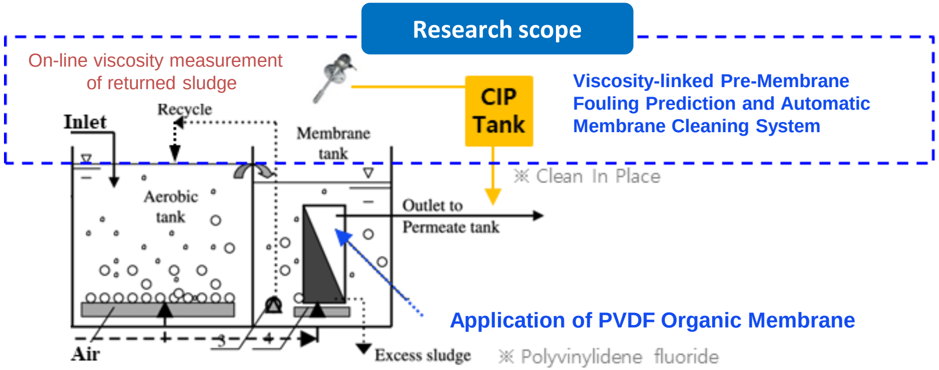
Food packaging | Agriculture | Drug delivery | implant

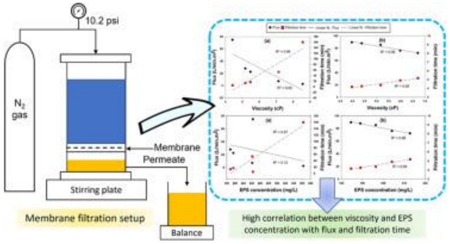
Advanced industrial wastewater Reuse and Resource Recovery Technology

: ③ Wastewater reuse technology : MBR or Development Pre-Membrane Fouling Prediction Technology

☐ **MBR**(membrane bioreactor) **Process**

: Chung(2024) Predicting membrane fouling in membrane bioreactor systems using viscosity. Journal of Environmental Management, 370





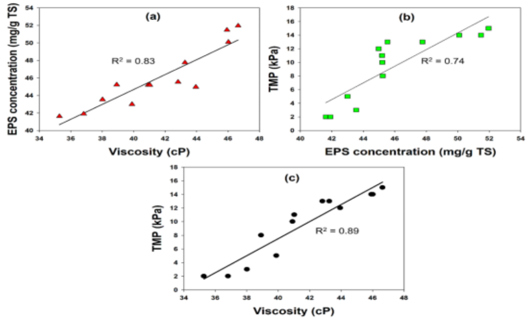
- **Direct Causes of Membrane Fouling**

➔ $\Delta P = J \times \mu \times R_t$

(ΔP: Transmembrane pressure, J: Flux, μ: Viscosity, Rt: Resistance)

- **Lab Test Results**

➔ **Derivation of the Correlation Formula Between Viscosity and Membrane Fouling Inducing Substances**



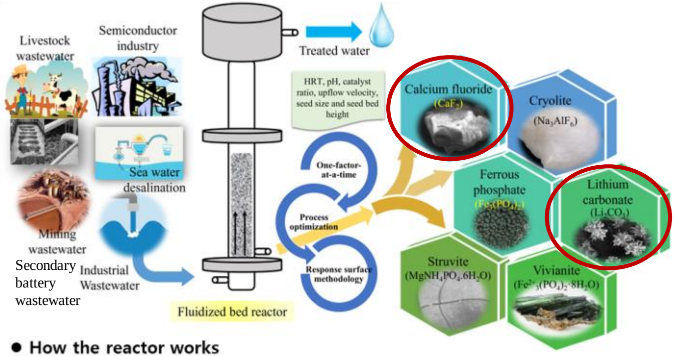
Advanced industrial wastewater Reuse and Resource Recovery Technology

: ④ Resource technology (Semiconductor, Second-Battery): Crystallizer Resource Recovery Process

Crystallizer for resource recovery

Overview

- Fluidized bed crystallization (FBC) is an advanced and efficient technology designed for the removal and recovery of pollutants, such as fluoride and phosphate, from industrial wastewater. This process converts valuable ions into their crystalline form by reacting them with appropriate chemicals to enable their separation from aqueous solutions.



How the reactor works

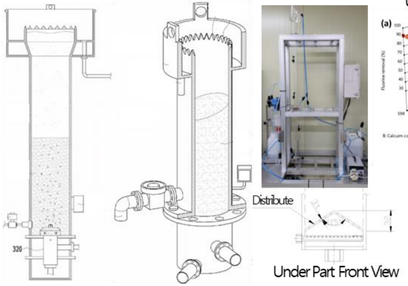
Reactor setup:
- Fill the fluidized bed reactor with silica seed materials.
- Ensure proper connection of inlet and outlet ports for influent and recirculation flow.

Operational parameters:
- Water Flow Rate: Maintain a consistent upflow velocity to ensure proper fluidization and uniform dispersion of silica seed particles.
- Reagent Dosing: Add the chemical agent in proportion to the concentration of reusable ions in the influent.
- pH Control: Adjust and maintain the pH to optimize crystallization on the silica seeds.
- Silica Seed Support: Ensure uniform distribution of silica seed materials to promote effective nucleation.
- Crystal Formation and Recovery: Monitor the growth of crystals on the silica seeds for uniformity. Once the crystals reach a sufficient size for reuse, discharge them from the reactor's bottom and recycle them as a resource.
- Treatment Monitoring: Analyze effluent samples for residual fluoride to assess treatment efficiency.

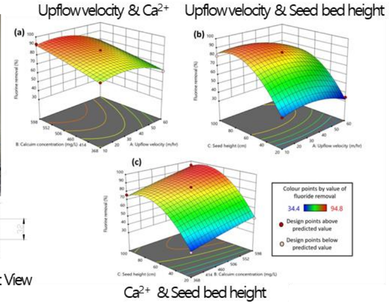
Study case: Crystallization system for CaF_2 resource recovery

※ F^- removal efficiency : 97% (F^- 300 ppm > 9.6 ppm), CaF_2 purity: 90%

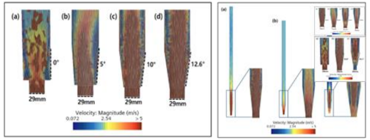
Design drawing of FBR reactor



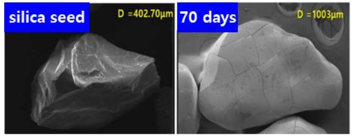
Optimal operating conditions (RSM)



Optimal design conditions (CFD)



SEM image of crystals



SCI paper

- Optimization of Calcium Fluoride Crystallization Process for Treatment of High-Concentration Fluoride-Containing Semiconductor Industry Wastewater, International Journal of Molecular Sciences (2024)
- Process Intensification for Enhanced Fluoride Removal and Recovery as Calcium Fluoride Using a Fluidized Bed Reactor, International Journal of Molecular Sciences (2024)
- Fluoride removal from wastewater and potential for resource recovery, Environmental Engineering Research (2024)

Patent

- Crystallization reaction apparatus of Calcium fluoride (10-2023-01-86845)
- System and Method of recovering high purity calcium difluoride particles (10-2023-01-86845)

Advanced industrial wastewater Reuse and Resource Recovery Technology

: ⑤ Resource Recovery (Secondary Battery): High-purity Gypsum Recovery Process

◎ A Company Secondary-Battery Wastewater

Pollutants	Concentration	Note
Na_2SO_4(g/L)	-	High-concentration salt wastewater
TOC(mg/)	200~600	Varies depending on the manufacturing process
Li	Heavy metals Concentration (100~200 mg/L)	Li and Ni have very high ecological toxicity
Ni		
Co		
Mn 등		

◎ B Company Secondary-Battery Wastewater

Pollutants	Wastewater_1	Wastewater_2
TOC(mg/L)	13	13
Li(mg/L)	6	120~200
Na(g/L)	-	-
T.SO4(g/L)	-	-
pH	-	-

◎ C Company Secondary-Battery Wastewater

Pollutants	Concentration
TOC(mg/L)	382
T.SO4(g/L)	-

- **Gypsum Recovery**

⇒ Production of high-purity gypsum

- **Ettringite Recovery**
- **Li_2CO_3 Recovery**

⇒ Recycling of Secondary Battery Cathode Materials

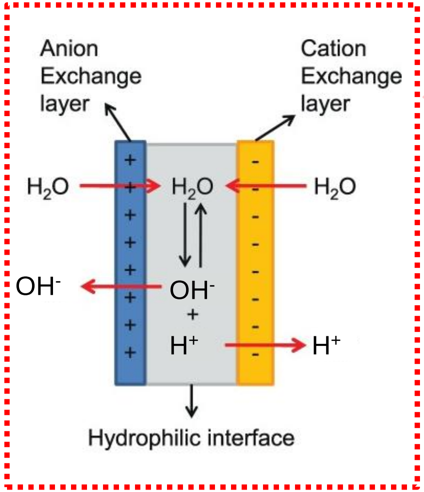
Resource Recovery System Concept & Pilot System

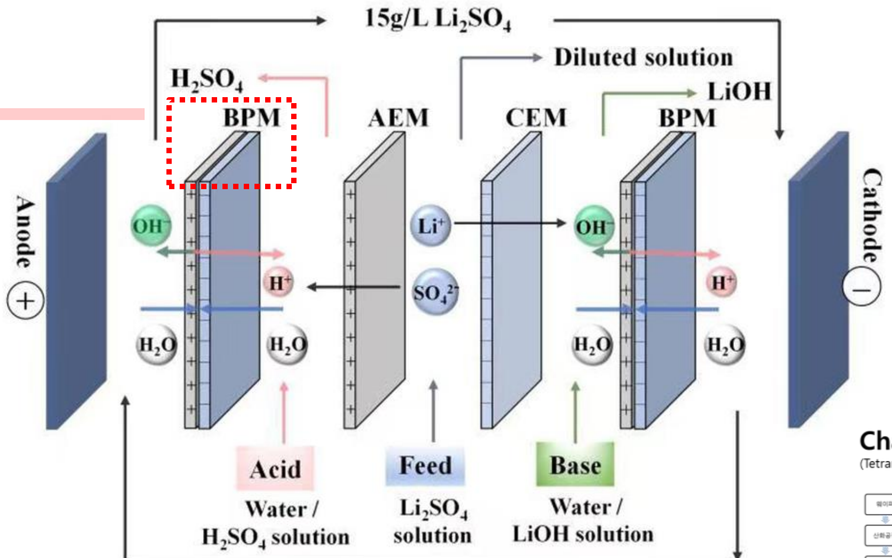
Advanced industrial wastewater Reuse and Resource Recovery Technology

: ⑥ Resource Recovery Technology (Semiconductor, Secondary-Battery): BPED Process

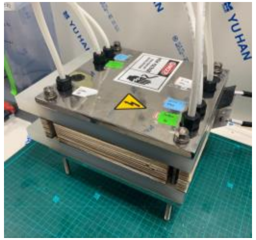
※ Electrodialysis :Using DC voltage as the driving force to selectively separate ions based on their charge

◎ Bipolar-membrane electrodialysis, BPED





Bipolar ED Stack

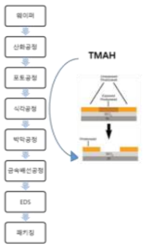


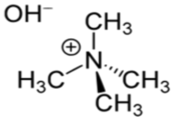
TMAH (Semiconductor Wastewater)

Na_2SO_4 (Secondary-Battery Wastewater)

Characteristics of TMAH

(Tetramethylammonium hydroxide)



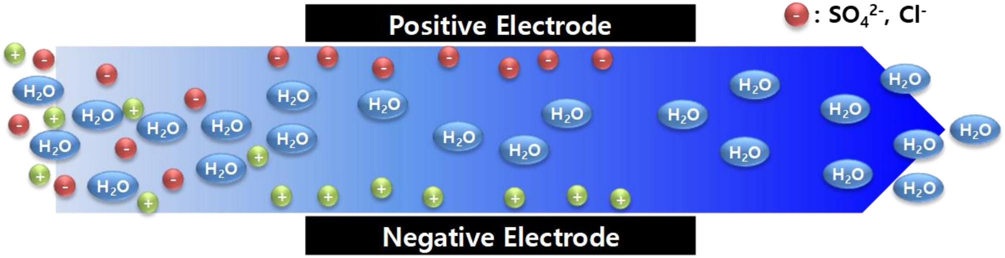


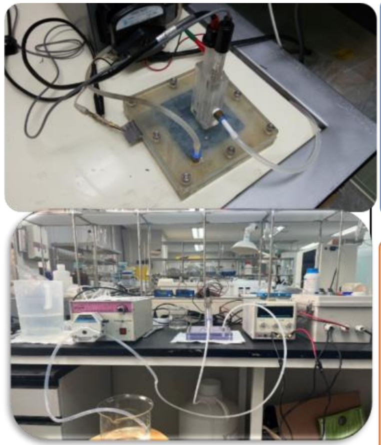
Parameter		Value
분자량 (g/mol)		91.15
Water solubility at 25℃ (mg/L)		1.0×10^{6} (est)
log K_{ow}		-2.47 (est)
K_{oc}		8 (est)
Henry's law const.	at 25℃ (atm·L/mol)	4.35×10^{-13} (est)
Vapor pressure at 25℃ (mmHg)		1.16×10^{-6} (est)

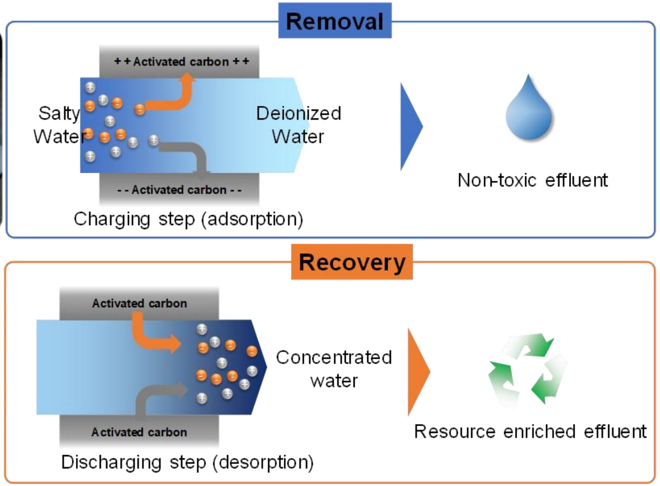
Advanced industrial wastewater Reuse and Resource Recovery Technology

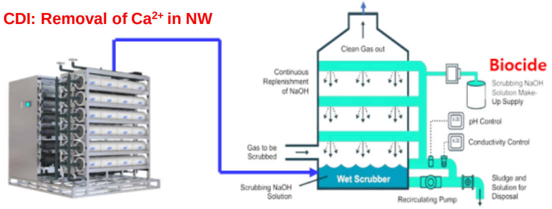
: ⑦ Wastewater Recycling technology: CDI Process

◎ CDI (Capacitive Deionization)

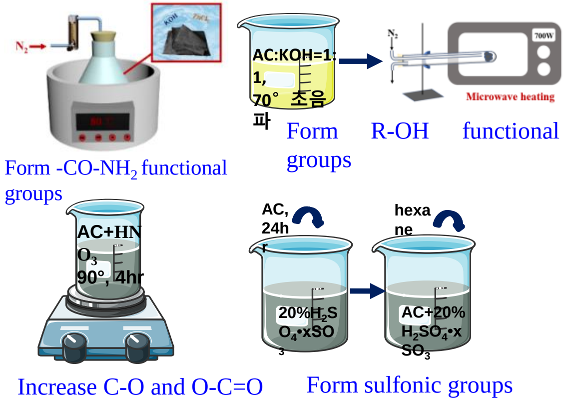








- Selective Ca^{2+} Removal through surface modification of activatd carbon
- Urea removal through surface modification of activated carbon



■ Chung(2025) Selective adsorption of calcium and magnesium ions for capacitive deionization by surface modification on porous carbon electrodes, Water Research, In Preparation.