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Direct Filtration of Municipal Wastewater using Flat-sheet Ceramic Membrane for pollutant removal and resource recovery

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Wastewater Treatment

Pollutants in wastewater

- **Organics: Oxygen depletion in water**
- **Nutrients (N and P): Algal blooms**

(http://www.rznews.cn/news/)

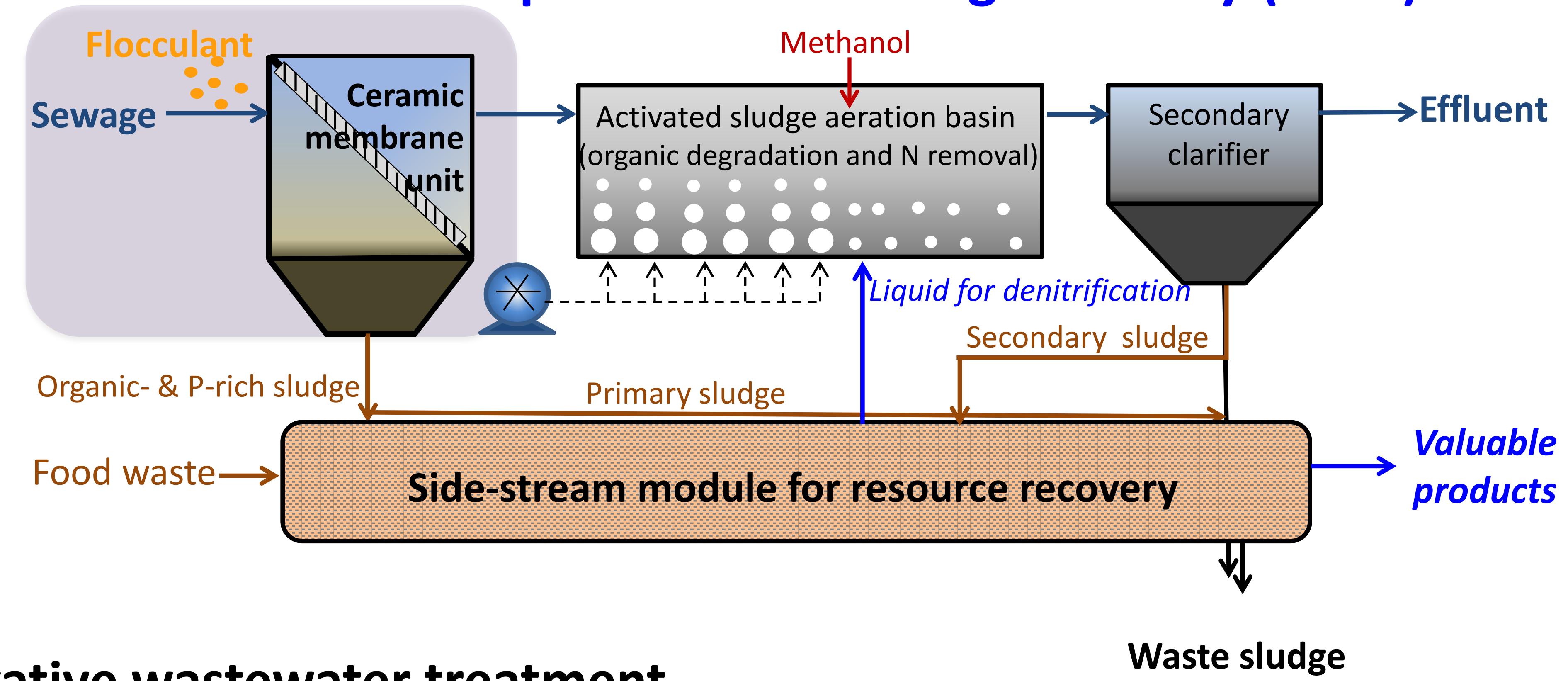
Problems in municipal wastewater treatment

- **An energy-intensive, end-of-the-pipe operation**
  - **High energy consumption** (aeration)
    for biological **organic** oxidation: >0.3 kWh/m^3
  - **Resources in wastewater are wasted:**
    Energy, water, nutrients and organics (into sludge)
- **Difficult to meet stringent discharge limits**
  - **Methanol addition for N removal, Fe(III) dosing for P removal**

Conventional Technology

New Technology

- Enhanced separation and sludge refinery (ESSR)



Innovative wastewater treatment

I. Chemically-enhanced membrane filtration

Use of ceramic membranes to concentrate pollutants into the sludge and reduce the load on treatment.

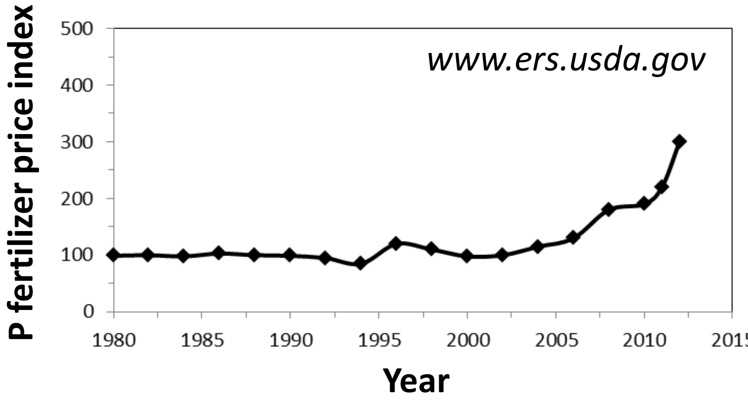
II. Side-stream process for resource recovery

Co-fermentation of sludge & food waste for P recovery, and caporate and bioplastic (PHA) productions.

Resource (P & VFAs) Recovery

Phosphorus (P-fertilizer)

- **Fossil fuels: deplete by 2150.**
  (http://www.eco-info.net/fossil-fuel-depletion.html)
- **Fossil P reserve: depletes by 2080.**



Volatile fatty acids (VFAs-organic carbon source)

- **Denitrification** (for N removal)
- **Polyhydroxyalkanoates (PHAs)**
  - **Bioplastics: complete biodegradability**
  - **Produced by biosynthesis from organic substrates** (e.g. starch)
  - **Increasing demand, but still expensive** (>HK$40/kg)
  - **Production cost can be greatly reduced if waste organics were used**

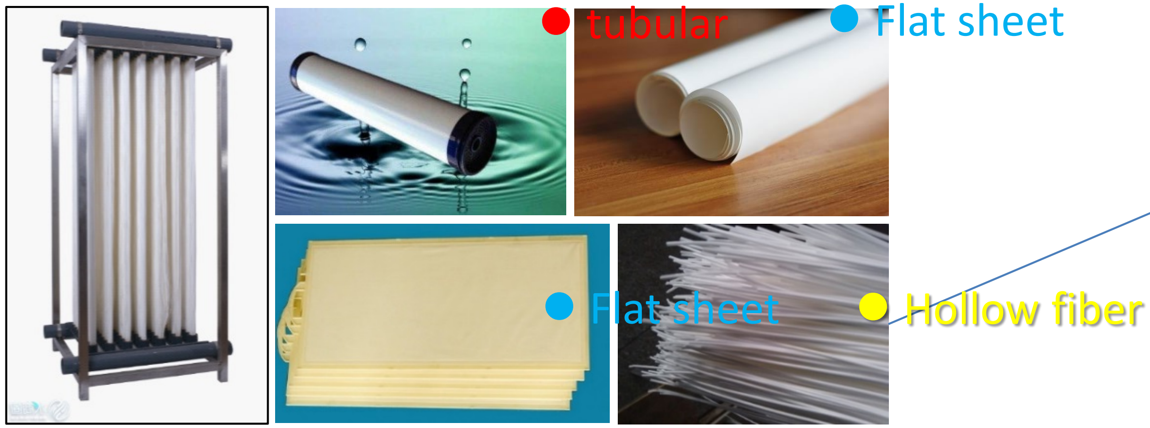
BIOPLASTICS SUPPLY AND PRICE

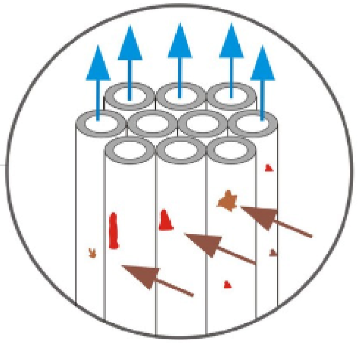
Renewable base	Manufacturer	Capacity ('000 tonnes/year)	Application	Price ($/lb)
Starch-based polymers	Cereplast	36*	Films, molding,	$1.07–3.00
	Novamont	80	extrusion	
Polyhydroxyalkanoates	Meredian/Kaneka	Not disclosed	Molding, films	$2.00–2.75
	Telles	50		
	Tianan	2		
Polylactic acid	Hi-Sun	5	Films, molding, fibers	$0.85–3.00
	Inventa Fischer	60		
	NatureWorks	140		
	Purac	75		
	Teijin	5		
	Others	7		
Green polyethylene	Braskem	200	Films, injection,	$0.80–1.00
	Dow Chemical	350	molding	

NOTE: * Cereplast capacity is for both compostables and hybrids *Capacities announced for 2009–2012 period
SOURCE: Argeni

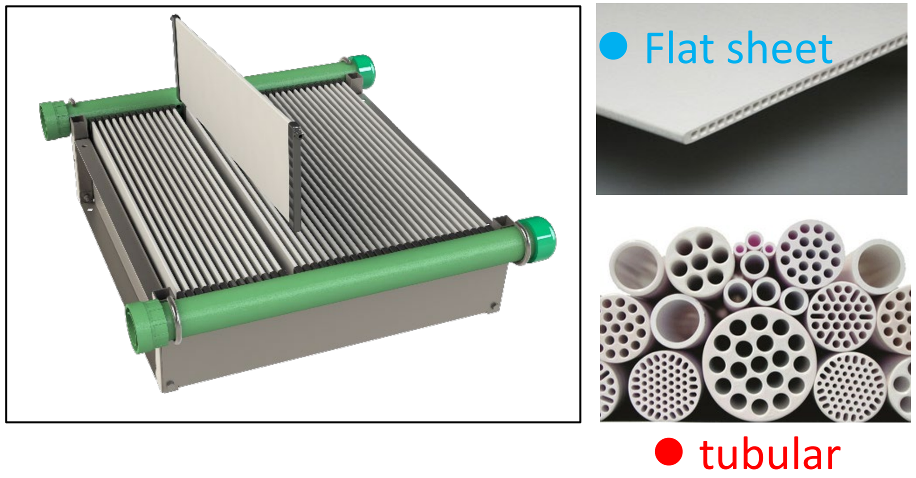
Membranes and Membrane Fouling

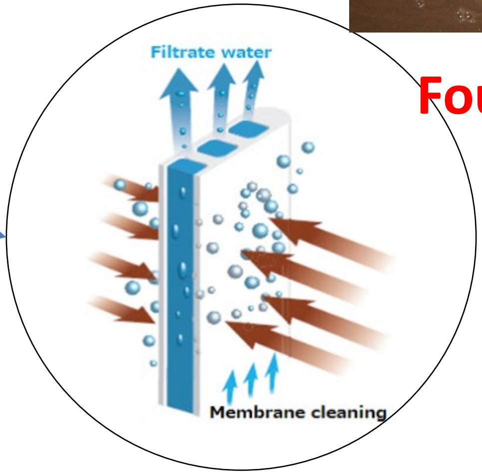
Polymeric membrane





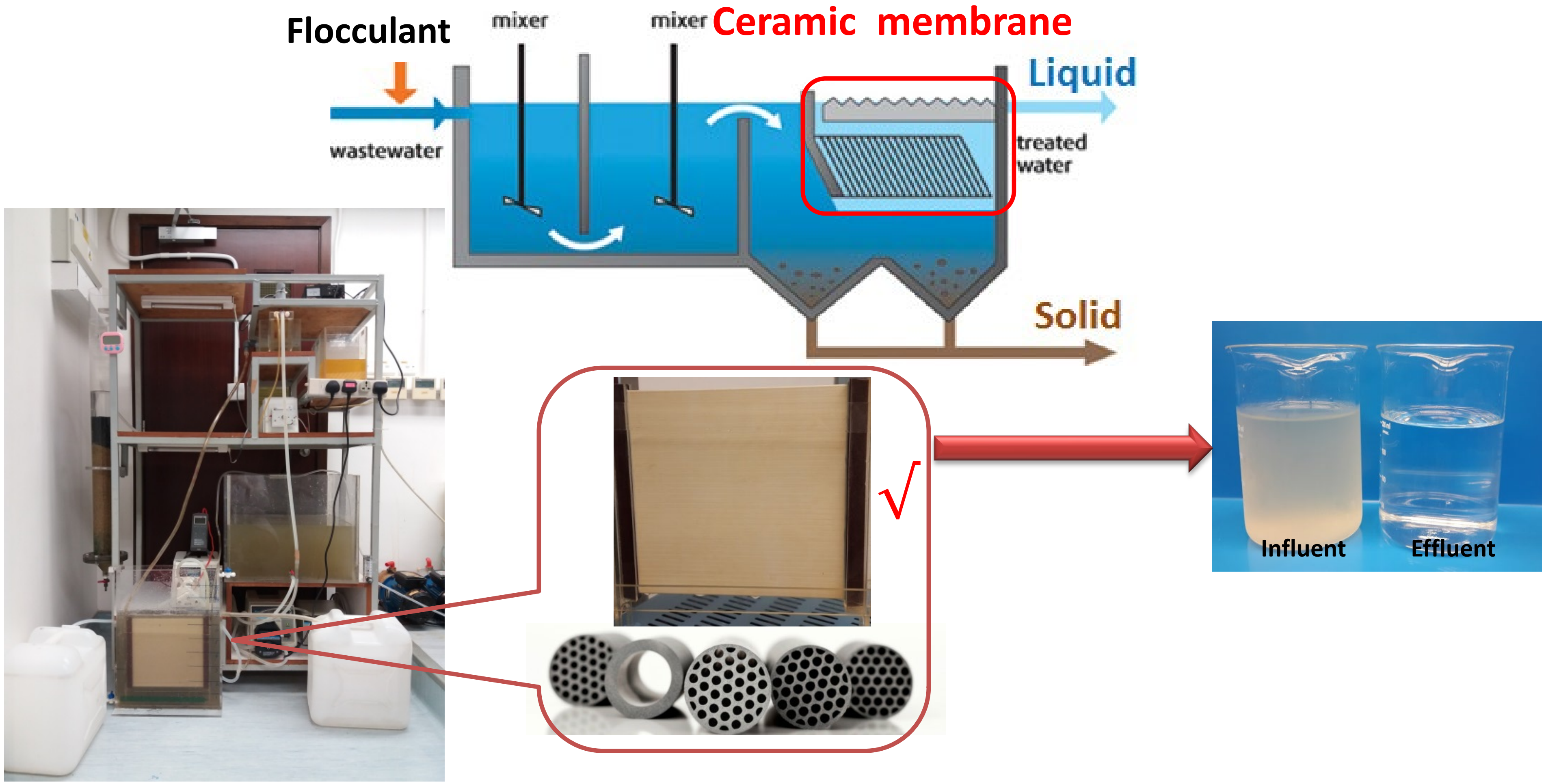
Ceramic membrane





Fouled membranes

Chemically-enhanced membrane filtration with ceramic membranes



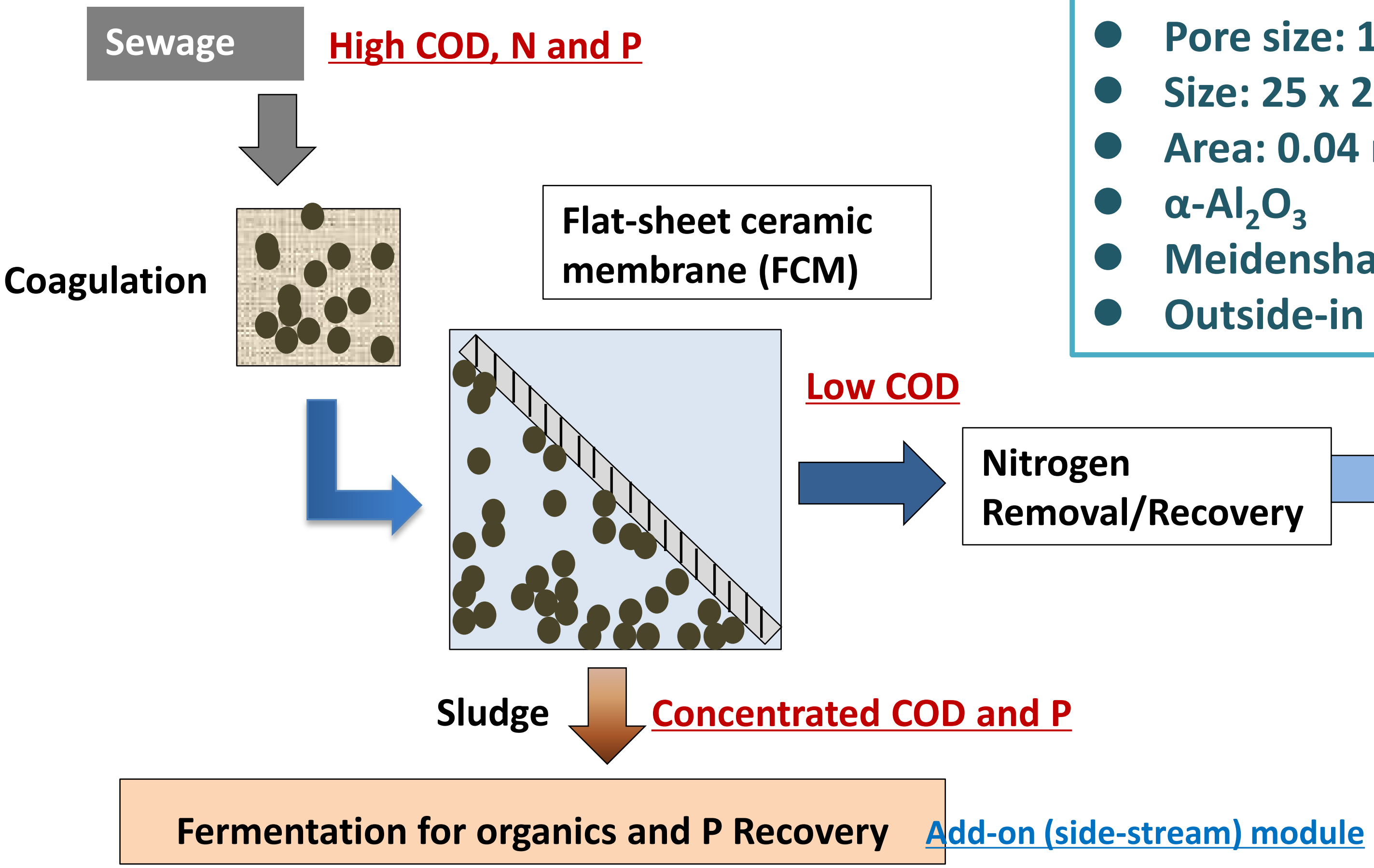
- Chemically-facilitated flocculation for the enhanced organic and P removals.
- Novel <u>flat-sheet ceramic membranes</u> for solids-liquid separation.

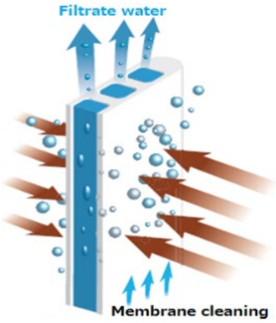
Membrane and materials

- **Test water: Stanley Sewage Treatment Works (Stanley STW)**
- **Coagulants: $FeCl_3$, Polyaluminum chloride (PACl)**

Flat-sheet ceramic membrane:

- Pore size: 100 nm
- Size: 25 x 25 x 5 mm
- Area: 0.04 m^2
- α-Al_2O_3
- Meidensha corporation, Japan
- Outside-in filtration mode





Results and Findings

I. **Pollutant Removal** — Pollutant removal performance by flat sheet ceramic membrane (FSCM) filtration, with the chemical enhanced primary treatment.

II. **Long-term filtration performance** — Long-term operation of the coagulation – FSCM filtration system with different cleaning strategies.

III. **Resource recovery** — Mass balance analysis and Resource recovery

1. Pollutant removal by coagulation-membrane filtration

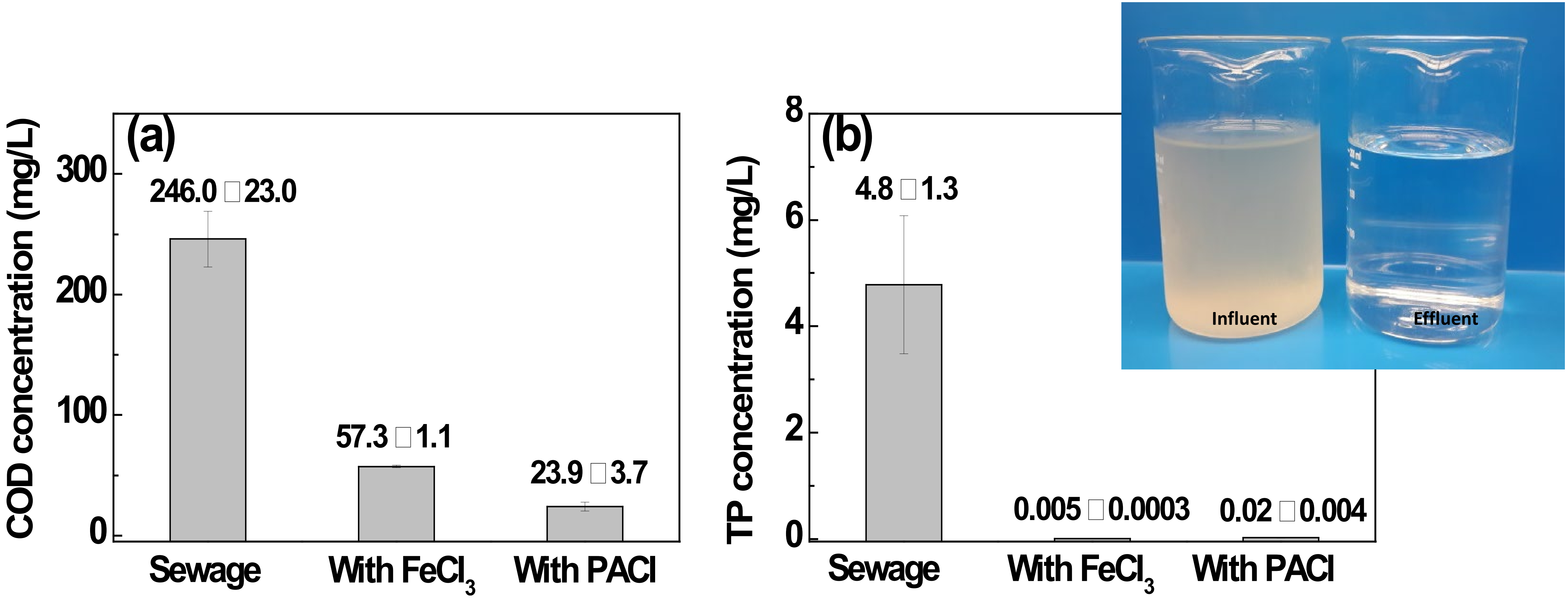


Fig. Performance of direct sewage filtration with pre-coagulation with $FeCl_3$ or PACl: (a) COD removal, (b) TP removal. (Filtration flux was set at 1.0 m/d (41.7 LMH))

1. Performance of the coagulation-membrane process

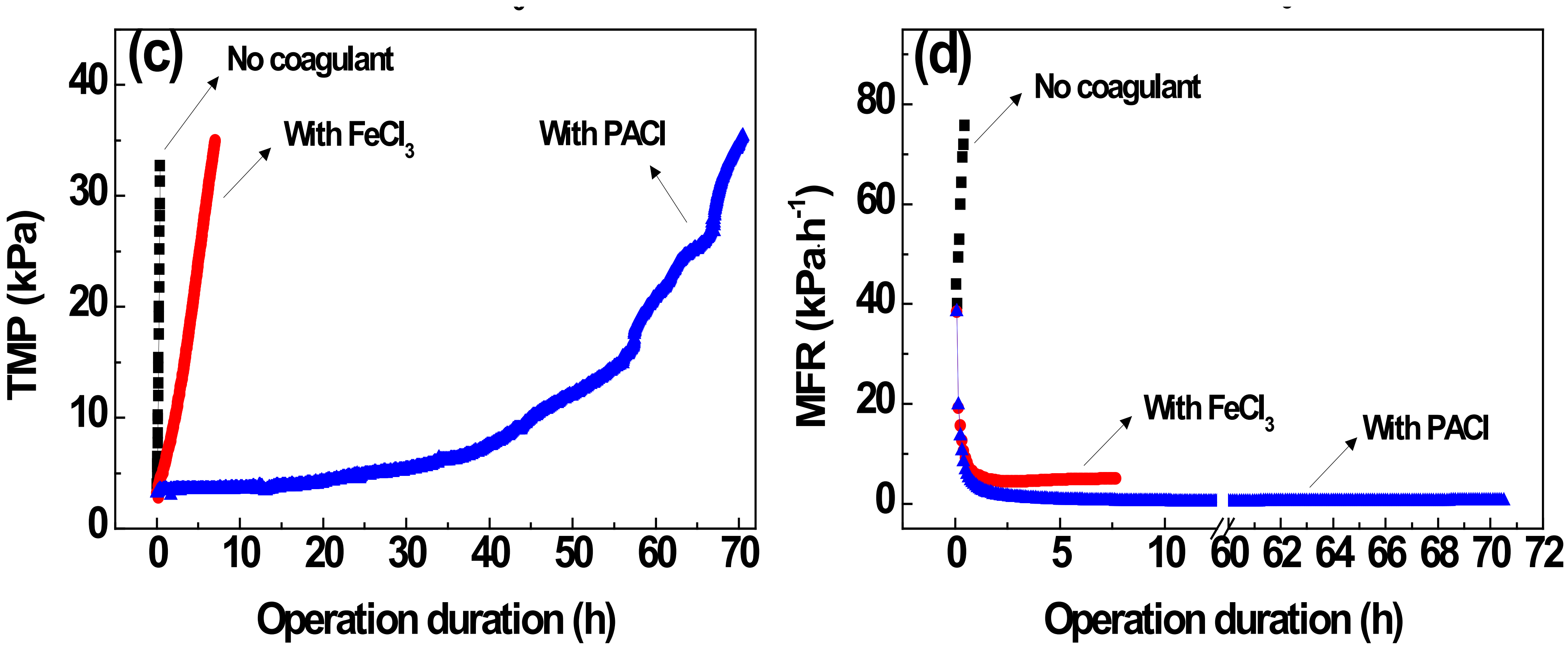


Fig. Reduction of the membrane fouling rate by pre-coagulation with $FeCl_3$ or PACl: (c) increase in TMP and (d) the related MFR values.

2. Long-term operation and performance

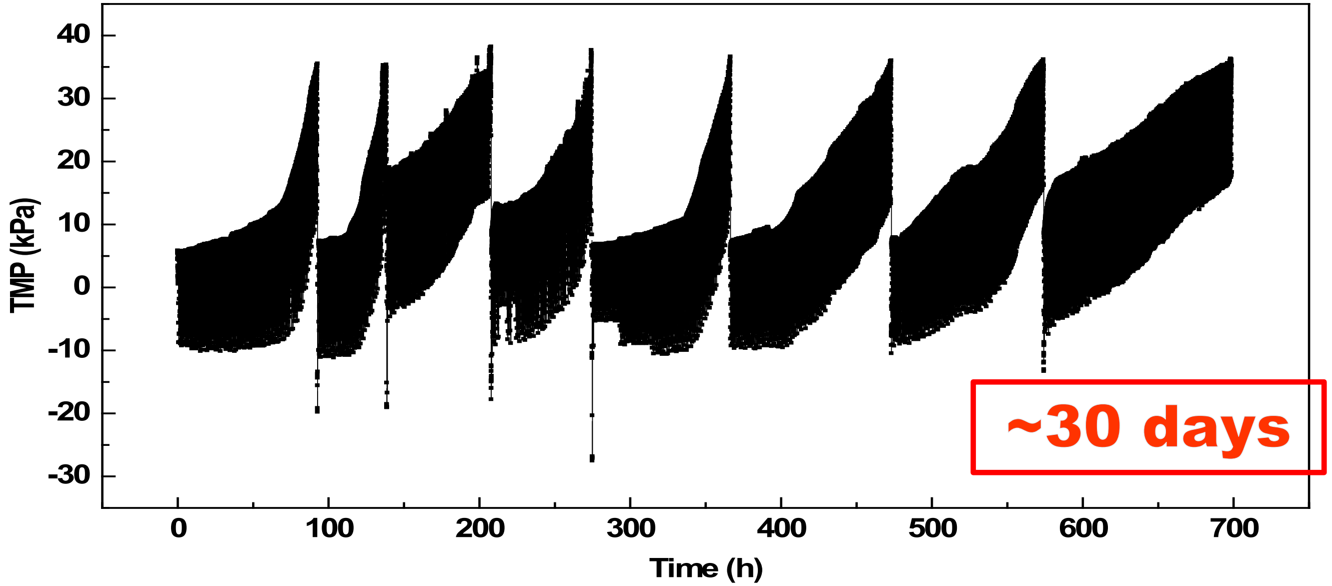


Fig. Change in TMP with filtration time during the continuous operation of the coagulation-FSCM filtration process.

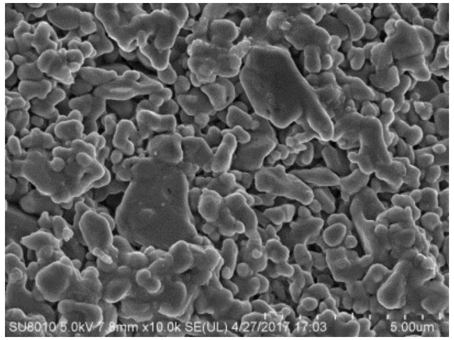
- Flux: 1.0 m/d (41.7 LMH)
- Coagulation HRT : 2min
- Filtration tank HRT : 36 min

Table. Membrane cleaning strategies.

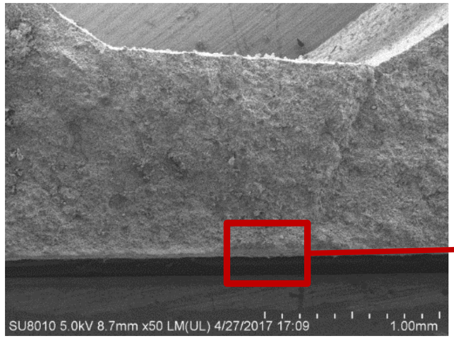
Cycle	Cleaning strategy			Membrane recovery rate	Duration
	Chemicals	Backwash period	Backwash flux (m/d)		
1st	-	-	-	-	92.7 h/3.9 d
2nd	1.5% NaClO	5 min	5.4	87%	45.0 h/1.9 d
3rd	1.5% H_2O_2	5 min	5.4	90%	69.3 h/2.9 d
4th	0.1 M citric acid	5 min	5.4	80%	66.7 h/2.8 d
5th	0.1 M NaOH, 0.1 M HCl	10 min	5.4	94%	91.2 h/3.8 d
6th	0.1 M NaOH bath, 0.1 M HCl bath	[b]4 h	-	95%	106.7 h/4.4 d
7th	1.5% NaClO, 0.1 M citric acid	[c]10 min	1.8	98%	101.1 h/4.2 d

2. Membrane fouling and cleaning

New Ceramic membrane



Surface



Cross section

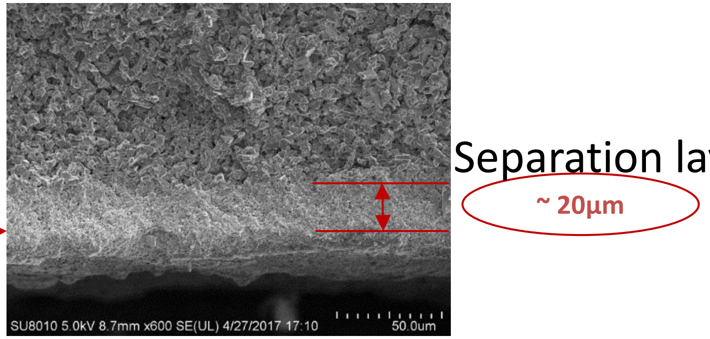
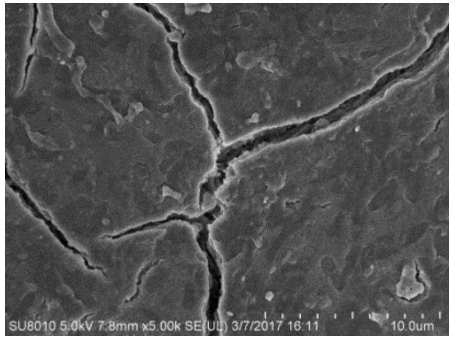
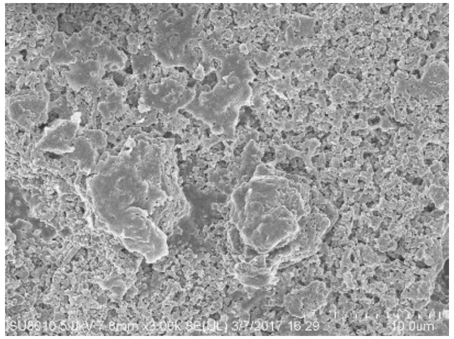


Fig. The SEM photos of the new ceramic membrane (surface and the cross section)

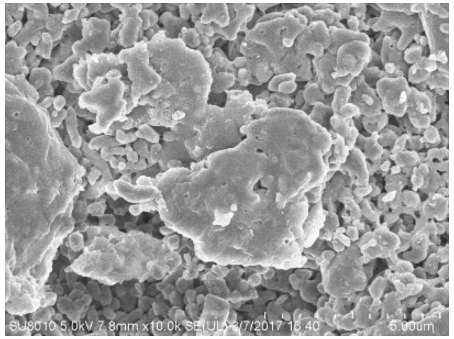
Polluted membrane and its cleaning by different methods



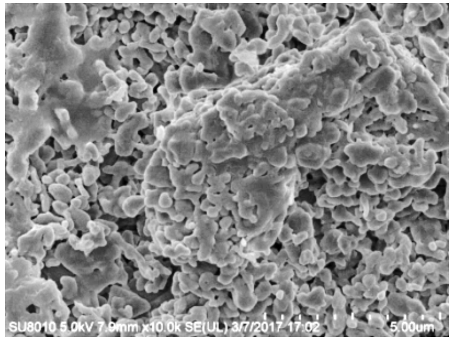
Polluted



After brushing



After Sonication



After NaOH and HCl bath

Fig. The SEM photos of the polluted ceramic membrane surface before and after varied cleaning strategies.

2. Membrane fouling and cleaning strategies

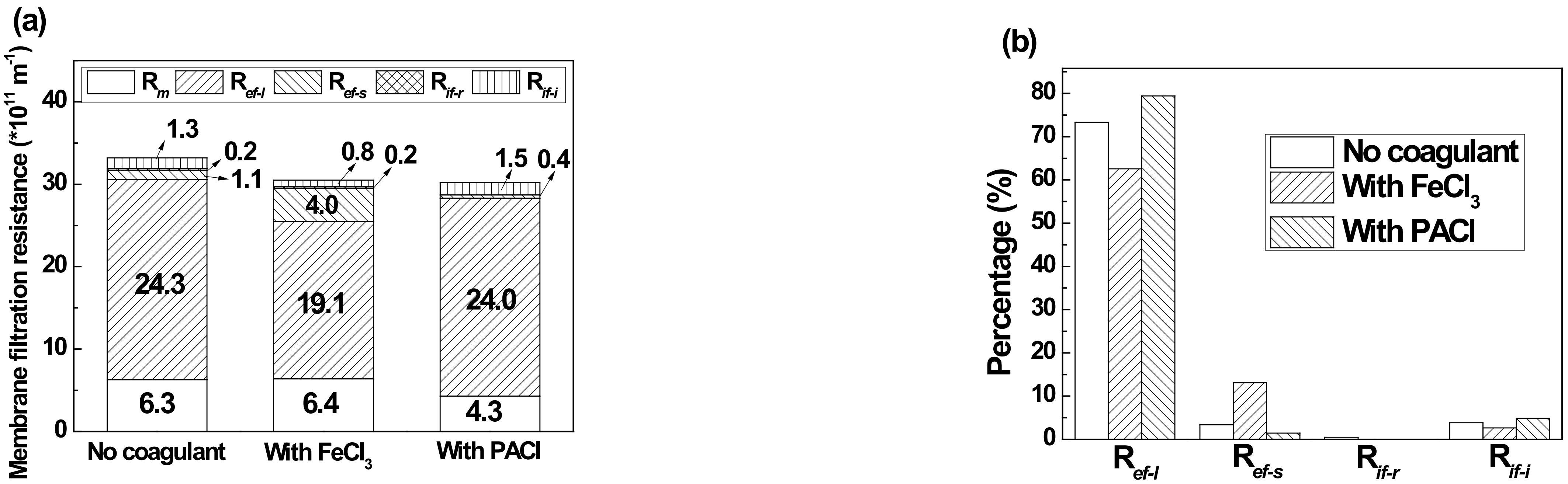


Fig. Membrane fouling resistance with/without coagulation: (a) quantitative analysis; (b) percentage distribution analysis.

- LAP: Loosely Attached Pollutant, causing $R_{ef\text{-}l}$
- SAP: Strongly Attached Pollutant, causing $R_{ef\text{-}s}$
- IRP: Internal Reversible Pollutant, causing $R_{if\text{-}r}$
- IIRP: Internal Irreversible Pollutant, causing R_{irr}

$$R_t = \frac{TMP}{\mu J} = R_m + R_f = R_m + R_{ef} + R_{if}$$

$$R_{ef} = R_{ef-l} + R_{ef-s}$$

$$R_{if} = R_{if-r} + R_{irr}$$

$R_{ef\text{-}l} = (TMP_1 - TMP_2)/(\mu J)$; $R_{ef\text{-}s} = (TMP_2 - TMP_3)/(\mu J)$

$R_{if\text{-}r} = (TMP_3 - TMP_4)/(\mu J)$; $R_{irr} = (TMP_4 - TMP_0)/(\mu J)$

2. Membrane fouling and cleaning strategies

■ Influence of the cleaning method on the membrane anti-fouling propensity

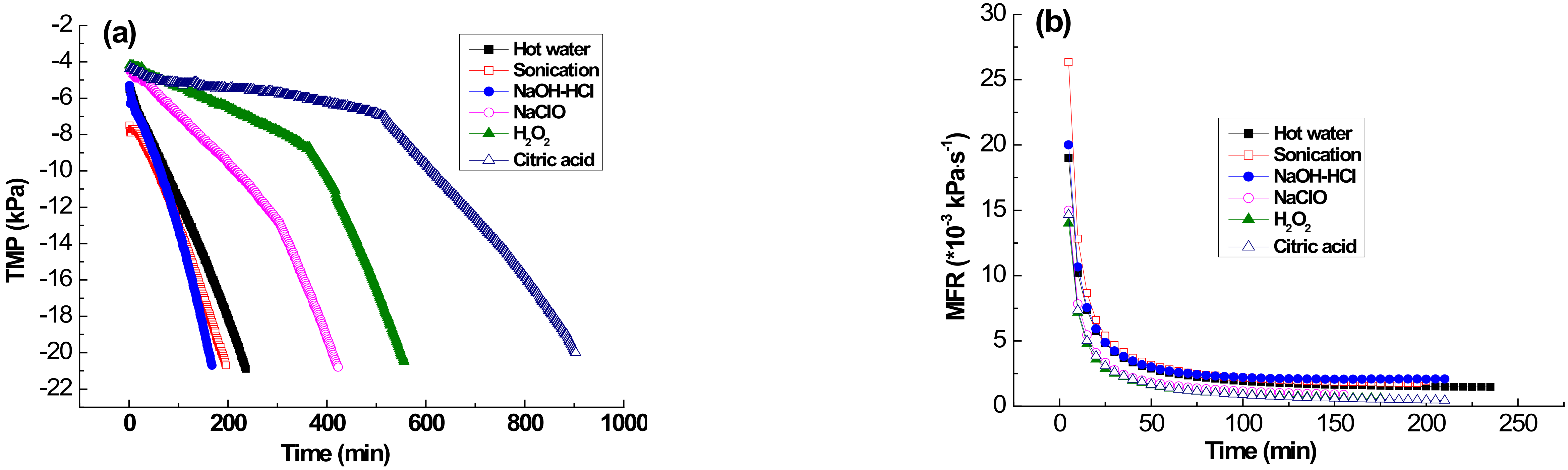


Fig. Selection of backwash solution influenced membrane anti-fouling performance: (a) change of TMP with filtration time; (b) change of membrane fouling rate with filtration time.

■ **De-fouling effect:** H_2O_2 > Citric acid > NaClO > Hot water > Sonication > NaOH-HCl

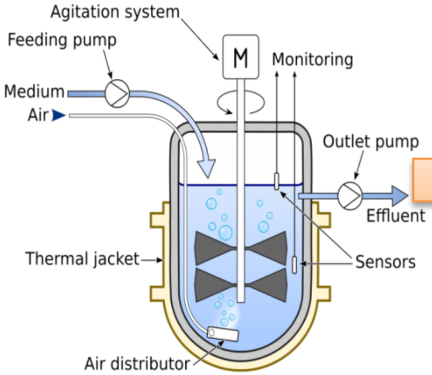
3. Mass balance analysis and resource recovery

☐ *Sludge fermentation for P and VFA release and biosynthesis for PHA production*

Co-Fermentation

P recovery

Volatile fatty acids



Biosynthesis

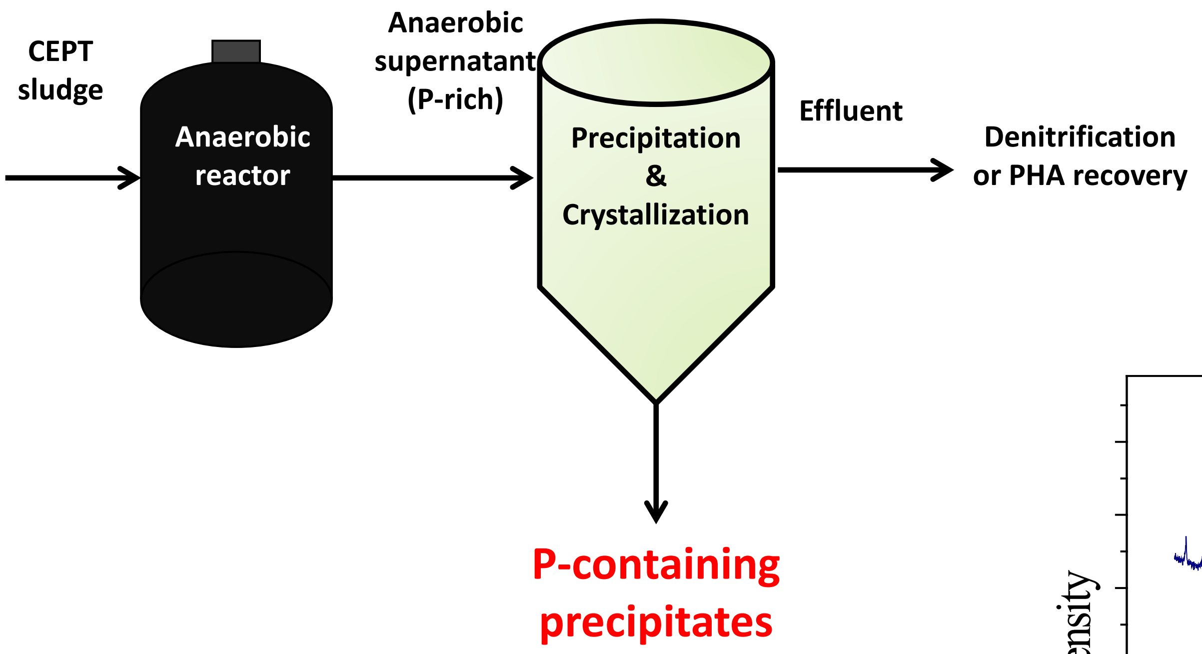
Polyhydroxyalkanoate (PHA) production

Bioplastics (high value-added products)

- ➢ **Sludge fermentation for organic hydrolysis and P recovery.**
- ➢ **Organic recovery from the sludge supernatant for PHA production.**
- ➢ **Use of the residual organic in the sludge liquor for N removal by denitrification.**

3. Resource recovery

☐ *Application 1: Co-fermentation of sludge and food waste for P recovery*



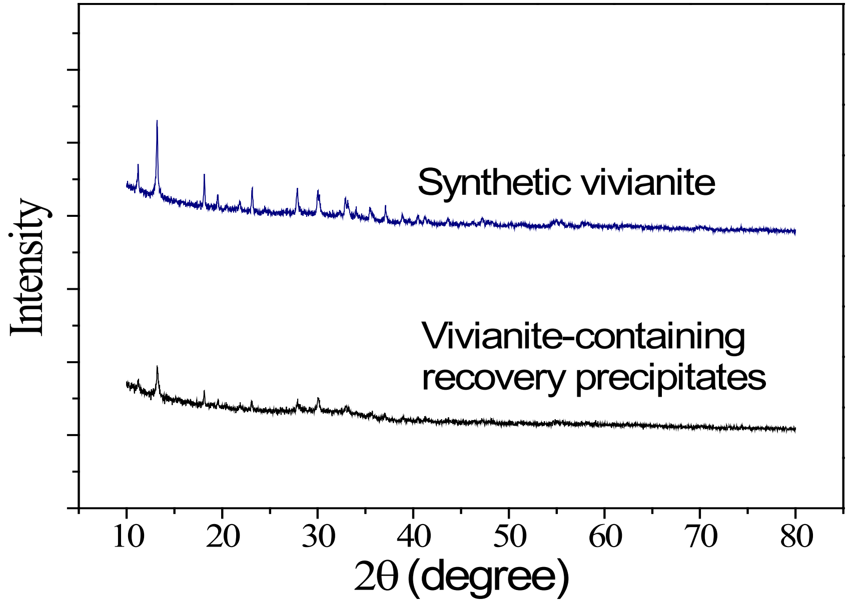
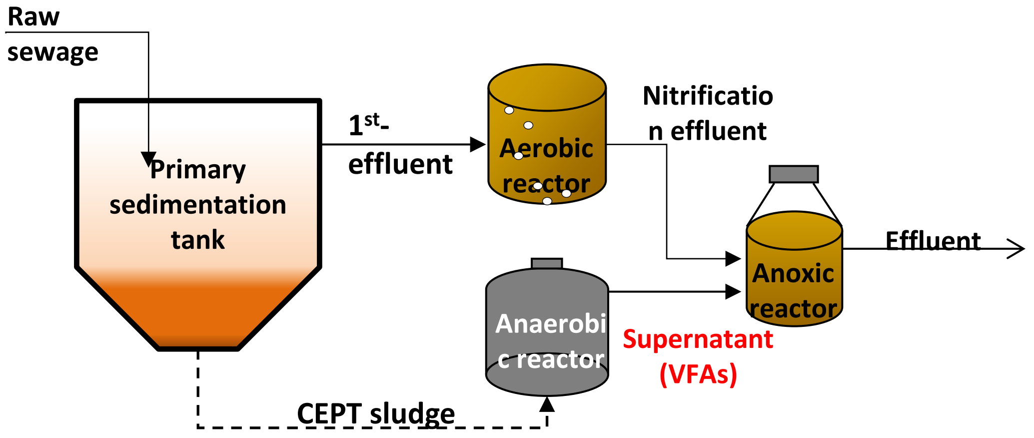


Fig. X-Ray Diffraction (XRD) analysis of the P recovery products

3. Resource recovery

☐ *Application 2: VFAs in sludge liquor for denitrification*



Nitrification: $NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$

Denitrification: $NO_3^- +$ **VFAs** $\rightarrow N_2 + H_2O + CO_2$

↑ Sludge liquor

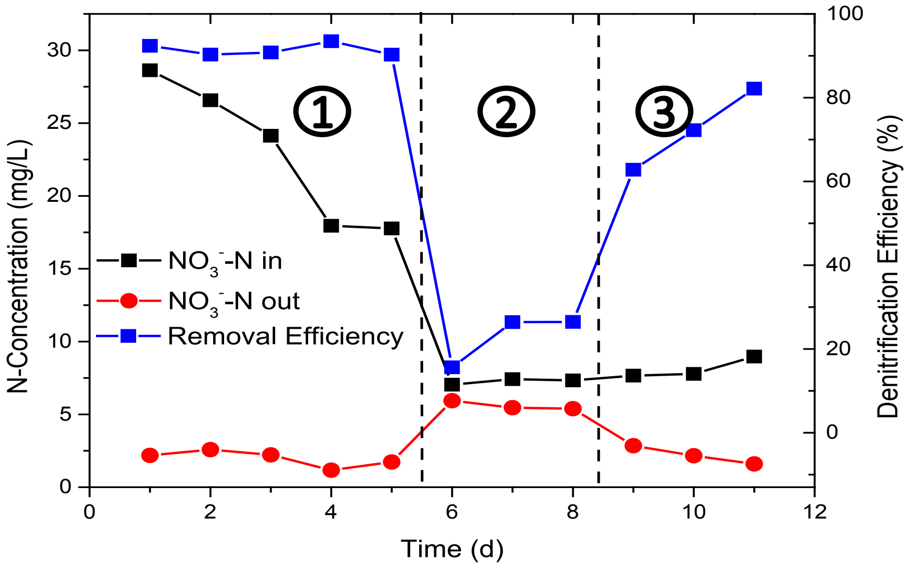
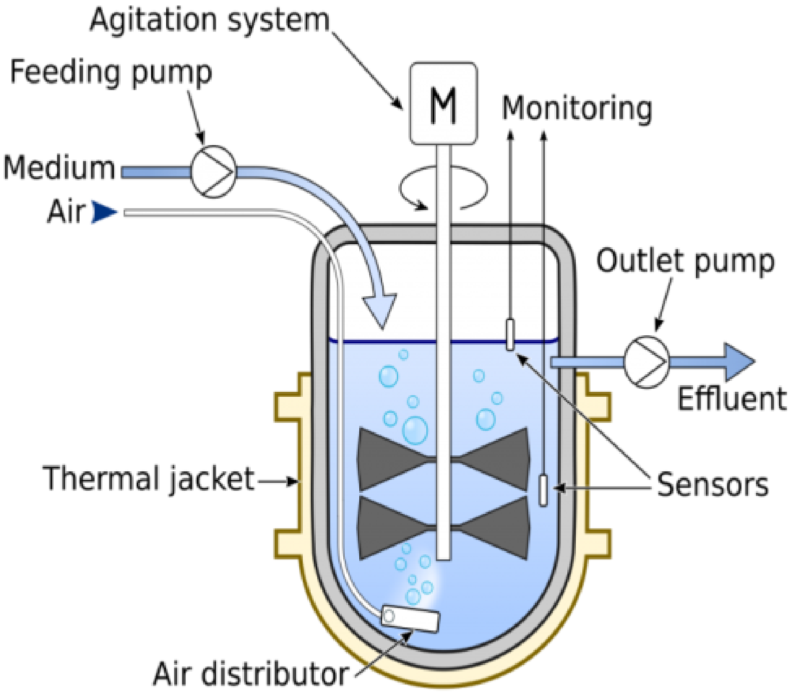


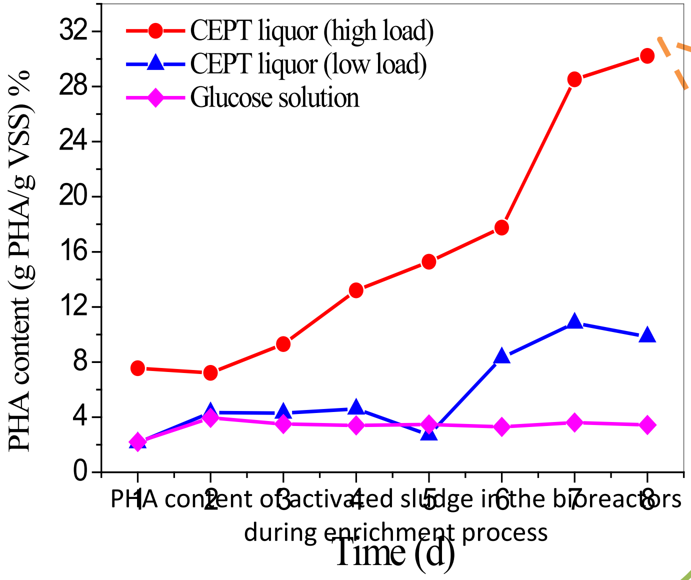
Fig. Denitrification (N removal) results.

Stage	V(An-sup)/V(N-eff)
1	1:4
2	1:10
3	1:6

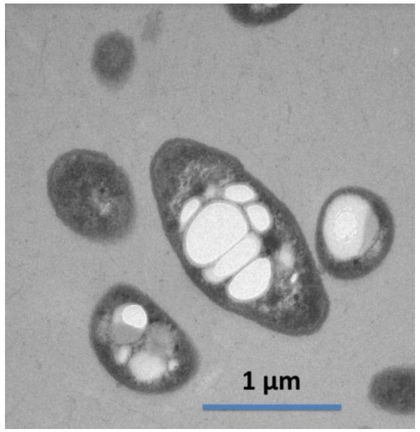
Effective denitrification with a V(sludge liquor)/V(nitrified effluent) >1:6.

Application 3: VFAs in sludge liquor for PHA biosynthesis





PHA content of activated sludge in the bioreactors during enrichment process



TEM image of intracellular PHAs found in the PHA-producing sludge from R1

PHA

(Polyhydroxyalkanoates)

Bioplastics

Conclusions

- **Flat-sheet ceramic membrane (FSCM) filtration replacing the primary sedimentation:**
  - ✓ Improves effluent quality, reducing organic load on the down-stream treatment process
  - ✓ Concentrates sludge with organic recovery of 78.3%, facilitating the follow-up resource recovery
- **Stable operation of the system was achieved. The sludge was concentrated by >10 times with the high COD and P contents for potential resource recovery.**
  - ✓ Co-fermentation for P release for fertilizer, VFA for denitrification and PHA production.
- **PACl-FSCM filtration has a much reduced fouling rate, and the membrane fouling is mainly caused by loosely attached pollutants (LAP) that can be readily cleaned.**

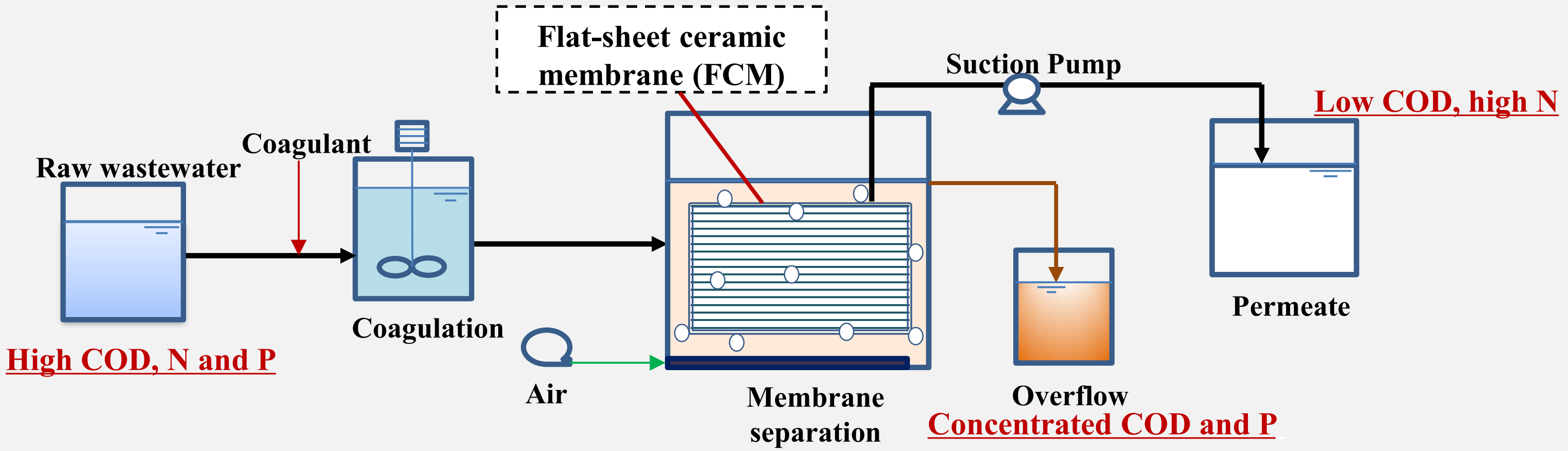


Fig. Schematic sof the coagulation and flat-sheet ceramic membrane (C-FSCM) filtration process

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