Leachate Treatment Technology

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December 2, 2022

China Everbright Environment Group Limited.

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01 Introduction to Leachate

Landfill Leachate

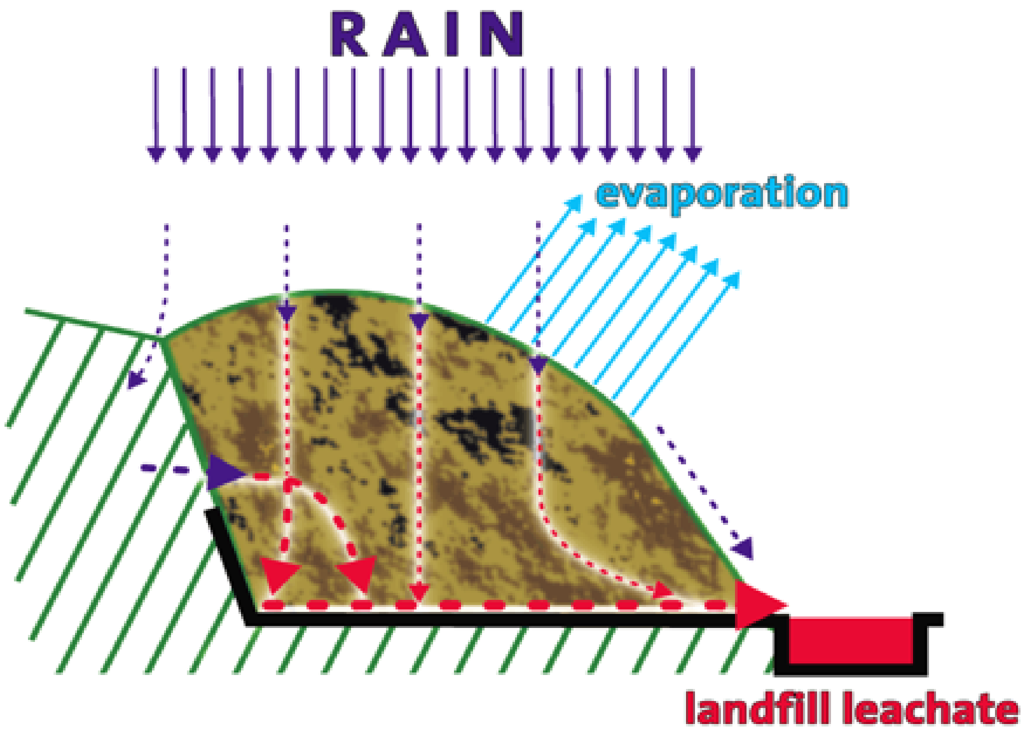
Landfill Leachate collection system

(Jiujiang city, Jiangxi Province, China)

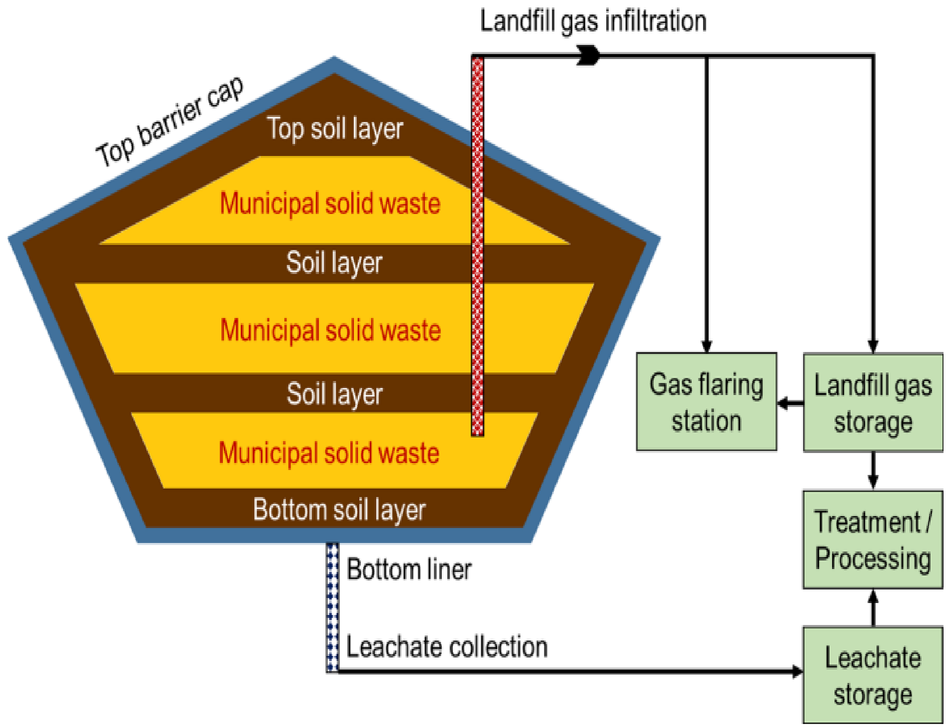
Landfill Leachate

From: ①water in waste ② waster generated by aerobic digestion
③ rain, snow, surface water infiltration

A closed landfill site may continue to generate leachate for 30–50 years .



Valley type landfill



Typical sanitary landfill

Leachate in waste-to-energy plant ("Fresh leachate")

An operator was loading garbage by a grabber (a waste-to energy plant of Everbright Environment)

How leachate looks like?

Leachate characteristics

Garbage produced per capital： 1 kg/d
Leachate generated per capital： 0.15-0.2 L/d

1

Complex contaminants composition

Organic contaminants (BOD\COD)， ammonia, heavy metals, inorganic materials, toxic materials, refractory organics

2

Variations of flow rate

The quantity of leachate vary greatly

The flow rate difference between the flood season and the dry period is more than 50%.

3

High concentration

Suspended solids(SS)	10,000 mg/L
Organic contaminants (COD)	70,000 mg/L
Ammonia (NH_4-N)	1500~3,000 mg/L
Salts (TDS)	15,000~25,000 mg/L

Flow Rate variations

a) Seasonal and regional variations--the highest in summer (May to September).

b) Management: collection ,storage and transportation

c) The composition of garbage: water content, industrial solid waste, food waste, etc.

d) Fermentation conditions: temperature, retention time and degree of fermentation

	Leachate percentage in garbage by mass （%）				
Month	Suzhou	Nanjing	Jinan	Ningbo	Boluo
June	21.77	26.34	22.66	22.54	17.76
July	26.88	26.39	27.06	22.75	17.96
Aug.	24.78	24.64	28.73	21.51	16.51
Sept.	21.43	24.02	-	18.42	15.18
Oct.	24.08	23.79	15.37	21.62	-
Nov.	19.03	19.43	19.15	15.69	19.18
Dec.	18.10	18.14	13.24	15.23	9.87
Jan.	26.69	17.86	12.67	15.11	10.79
Feb.	15.39	20.43	13.45	14.48	12.39
Mar	17.48	20.04	16.25	15.70	10.33
April	22.16	20.85	16.22	19.10	14.85
May	24.92	25.63	18.81	19.11	16.79

Challenge for Treatment

Variations of flow rate and quality

Climatic conditions, geographical conditions , management and economic conditions

High Concentration of Contaminants

Organic contaminants (COD)	70,000 mg/L
Ammonia (NH_4-N)	1500~3,000 mg/L
Salts (TDS)	15,000~25,000 mg/L

Complex composition

Leachate contains multiple contaminants, organics, NH_4^+-N, heavy metals, salts, etc…
Hazardous byproducts such as H_2S, NH_3, CH_3SH during treatment

Footprint limitation

Limited land available for leachate treatment in a waste-to-energy plant

02 Overview of Treatment Process

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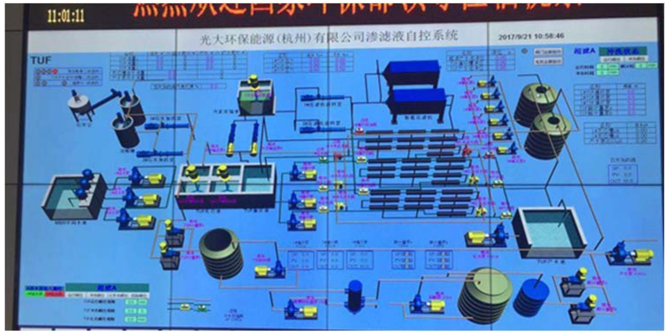
Leachate treatment facility in a waste-to-energy plant



1000 t/d leachate treatment facility in Jiangyin waste-to-energy plant

Leachate treatment facility in a waste-to-energy plant

Leachate treatment in Ningbo waste-to-energy plant

Leachate treatment facility in a waste-to-energy plant

Leachate treatment in Wujiang waste-to-energy plant of EB

Statistics of EB

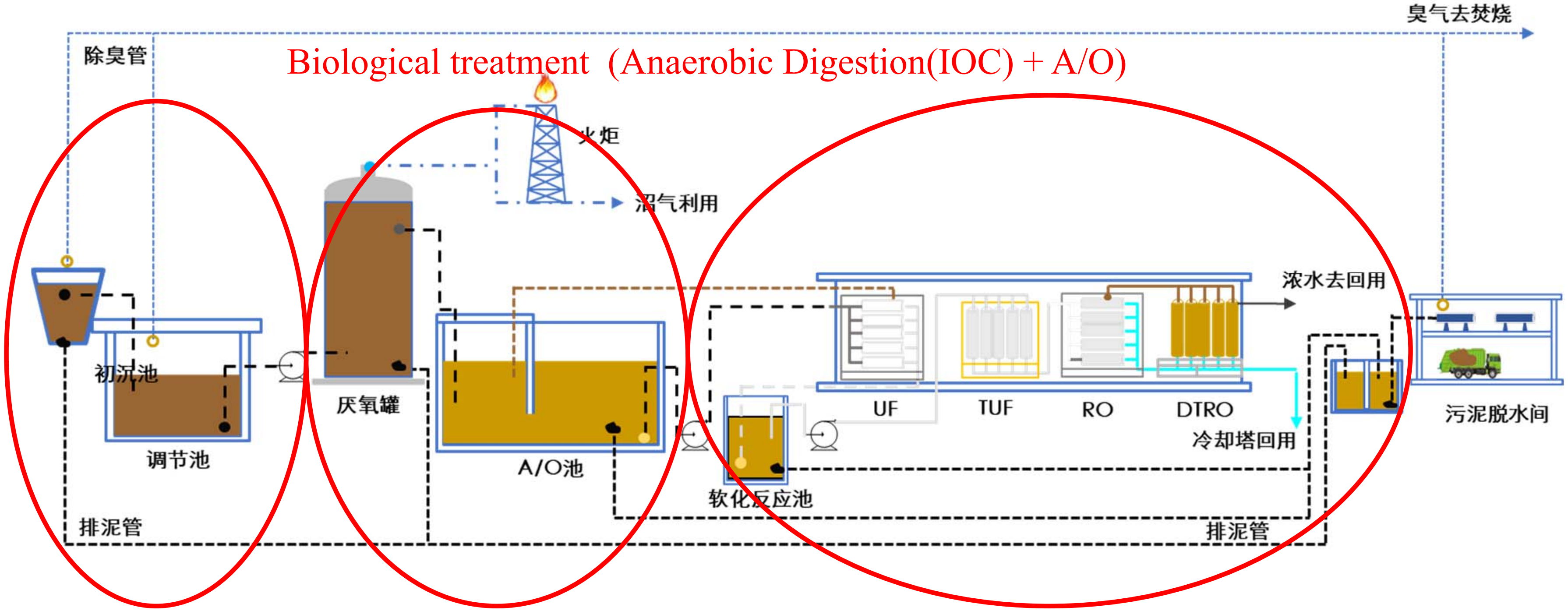
In 2021,

- **528 projects**
- **9,635,000 m^3 of leachate treated**
- **740,000 t of COD removed and recovered as biogas**

Leachate treatment process in waste-to-energy plant

For water recycle and zero discharge

Biological treatment (Anaerobic Digestion(IOC) + A/O)



Pretreatment (grit removal and sedimentation)

Salts and heavy metals removal

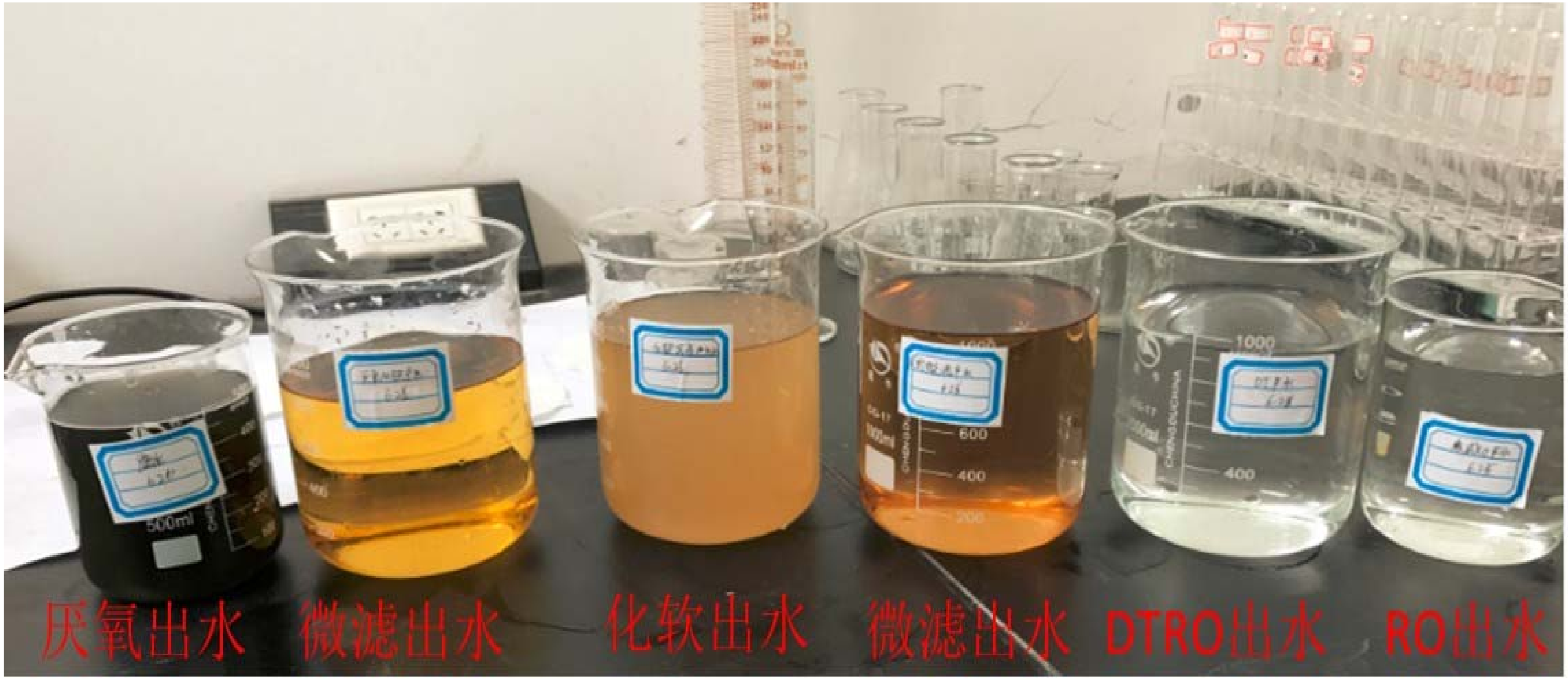
(Chemical softening + RO + DTRO)

Technologies used in leachate treatment

Anaerobic Digestion	N-removal	Membrane Separation	Evaporation and Zero Discharge
UASB Up flow anaerobic sludge blanket	A/O Biological nitrogen removal	TUF Tubular Ultrafiltration	LTE Low-temperature Evaporation
IOC Inter & Outer Circulation Reacto	Ammonia steam-stripping	ED Electrodialysis	SCE Submerged Combustion Evaporation
AnMBR Anaerobic Membrane Bioreactor	Anammox	FO Forward Osmosis	MVR Mechanical Vapor Recompression
		Emerging membranes	

COD removal **Nitrogen removal** **Advanced treatment for water re-use**
Membrane + Evaporation

From leachate to clean water for re-use



Anaerobic digestate | A/O+MBR | Chemical softening | UF softening | DTRO | RO

03 Anaerobic digestion

Anaerobic Digestion (AD)

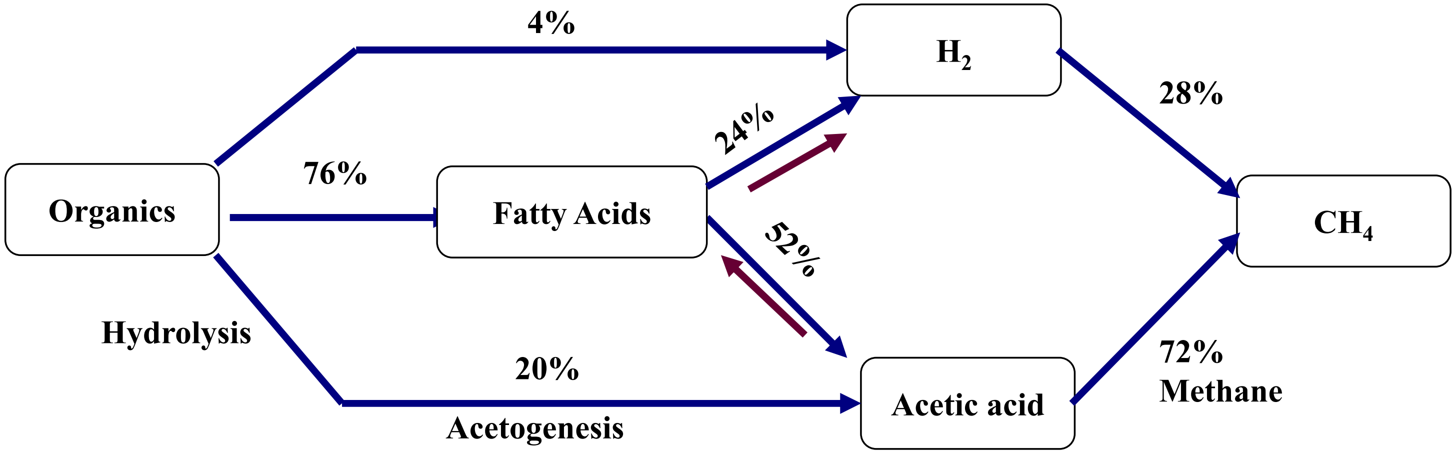
The bacteria break down organic matter without oxygen and generate biogas
The 60~70% of biogas is methane CH_4 (Natural gas)

1. Hydrolysis stage: Complex organic matter is broken down by enzymes into simple sugars and monomers which can be readily accessible to bacteria by bacteria
2. Acidolysis and Acetogenesis: formation of acetic acid with the help of acetogens

$$CH_3CH_2COOH \rightarrow CO_2 + CH_3COOH + H_2$$

3. Methanogenesis: the intermediate product from other steps is used to produce methane by Bacteria

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$
$$2CH_3COOH \rightarrow 2CH_4 + 2CO_2$$



AD advantages

◆ High efficient organic contaminants removal rate

Organic loading rate ＞5.0 $kgCOD/m^3 \cdot d$

◆ Energy Recovery by high biogas production

~50-70 m^3/t biogas can be harvested from “fresh” leachate from a waste-to-energy plant

◆ Low investment and operating costs

Relatively small footprint, low investment cost, and low operational cost with adequate mixing technology

◆ Low sludge yield

◆ Reliable for operation and maintenance

The Drawbacks of AD

◆ **Effluent quality (COD) is not as good as Aerobic treatment**

The emerging AnMBR (Anaerobic + UF Membrane) may greatly improve water quality

◆ **Nitrogen (TN) can not be removed**

◆ **The Methanogenesis is sensitive to temperature, pH, and toxic substances**

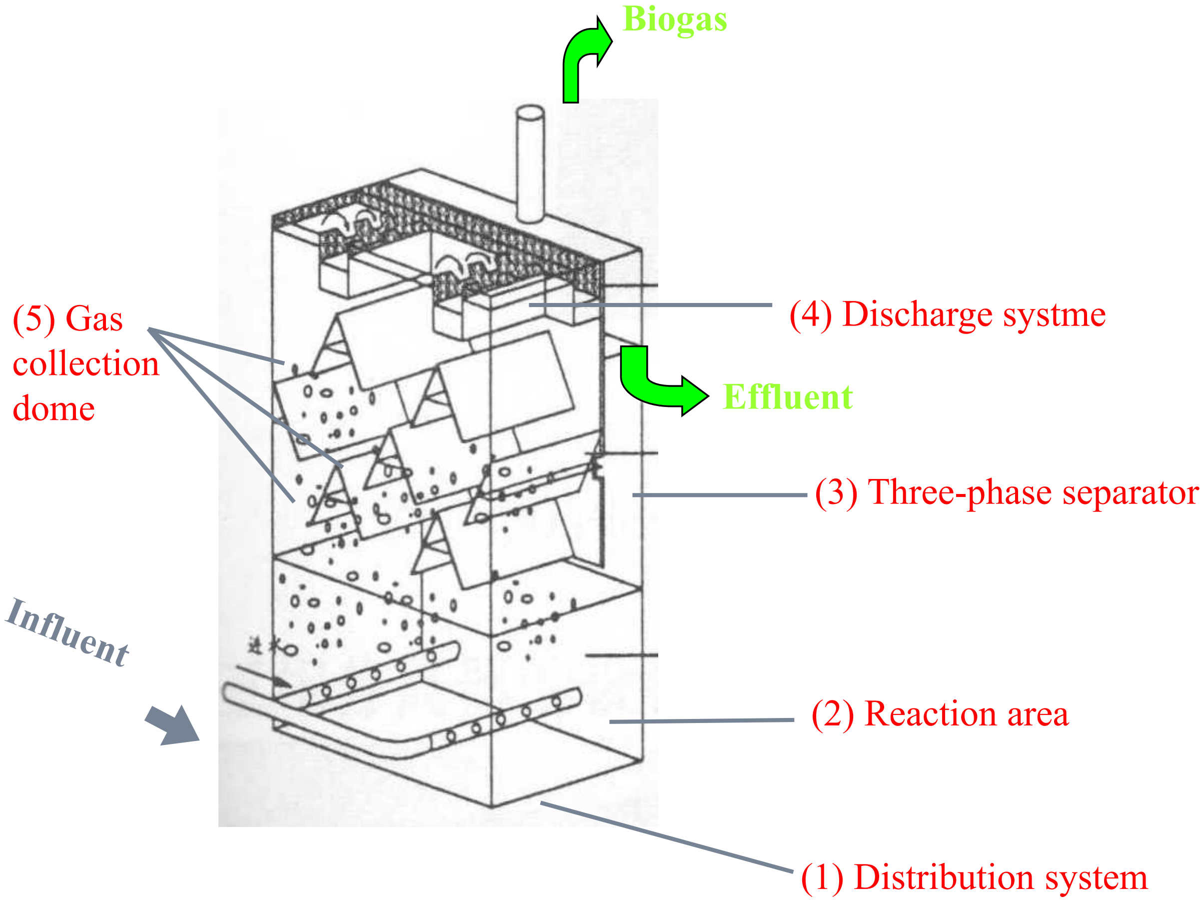
◆ **Long start-up time since the growth rate of anaerobic bacteria is much slower than aerobic microorganisms**

(8-12 weeks vs. ~7 days)

◆ **Odour problems and digestate treatment**

Typical Anaerobic Reactor-- UASB

UASB(Up flow anaerobic sludge blanket)



Typical Anaerobic Reactors—IOC

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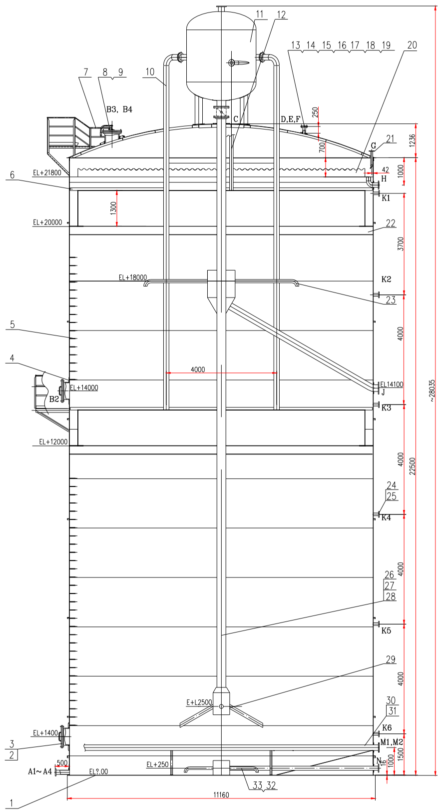
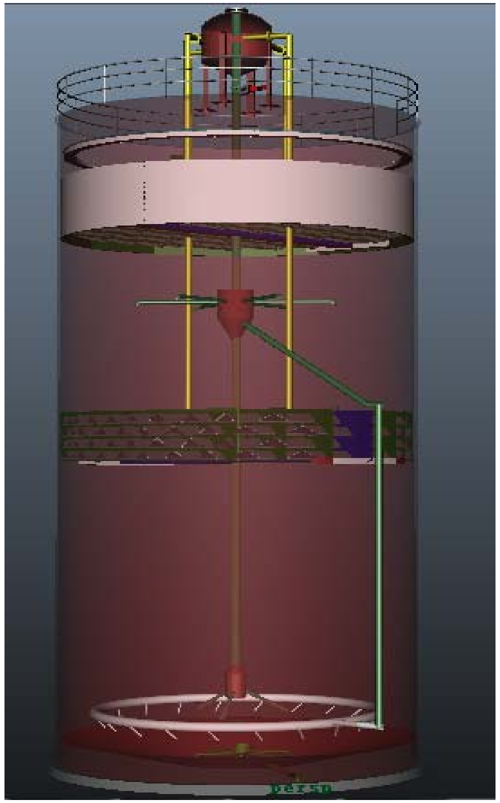
Inter & Outer Circulation Reactor System (IOC) by EB China





CFD Simulation for AD Reactor Design

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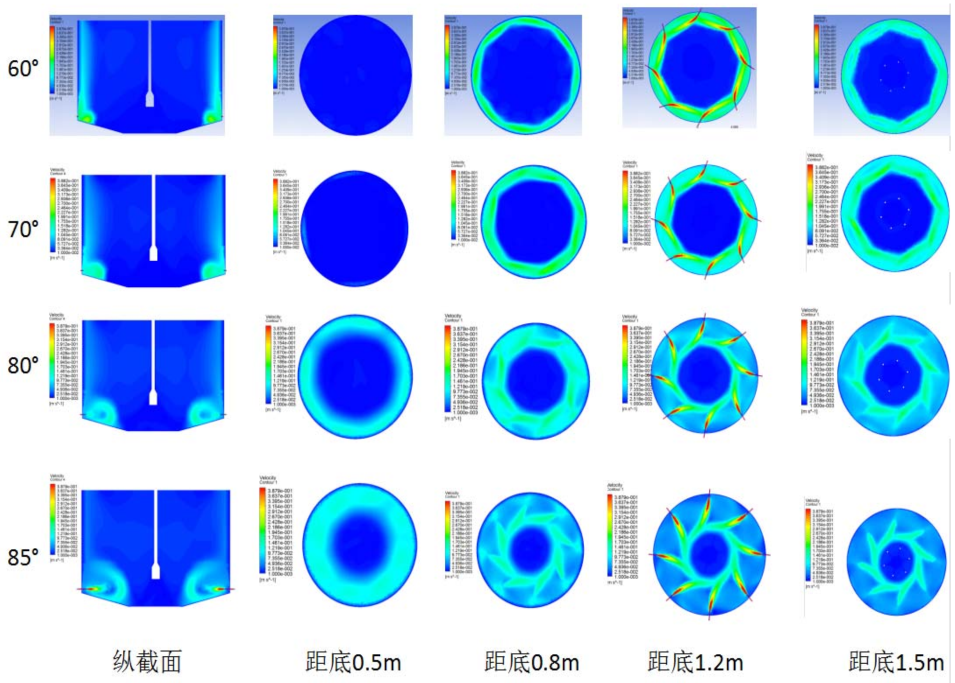
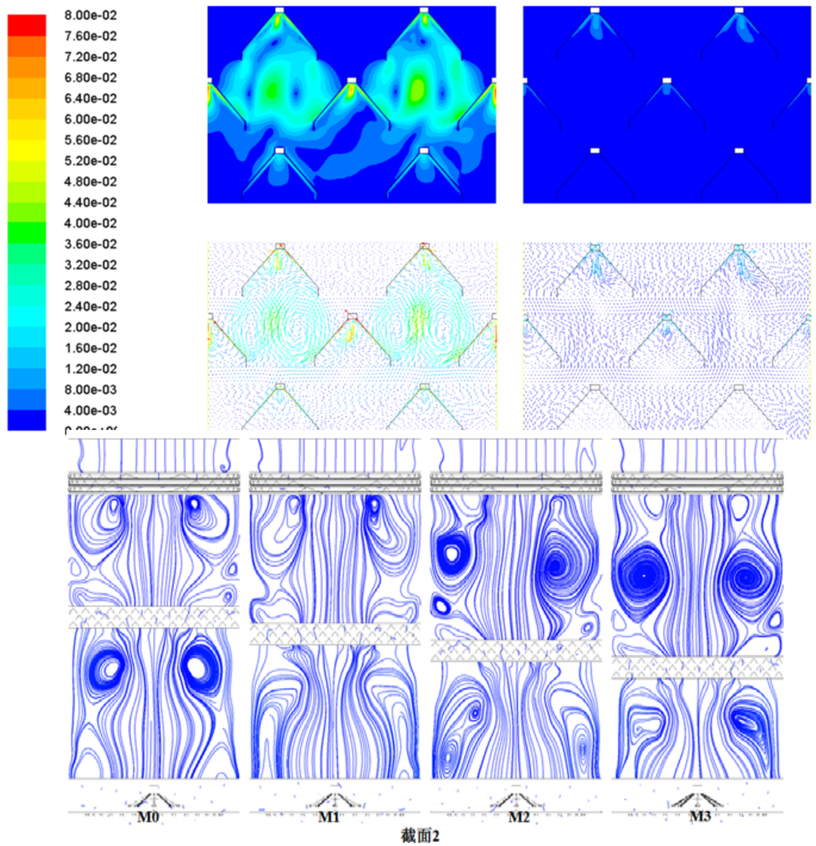
Computational Fluid Dynamics (CFD)



CFD Simulation for distribution system



CFD simulation for the there-phase separator

The Innovated AnMBR Technology

AnMBR (Anaerobic membrane bioreactor)

Anaerobic reactor + membrane technology (MF or UF)

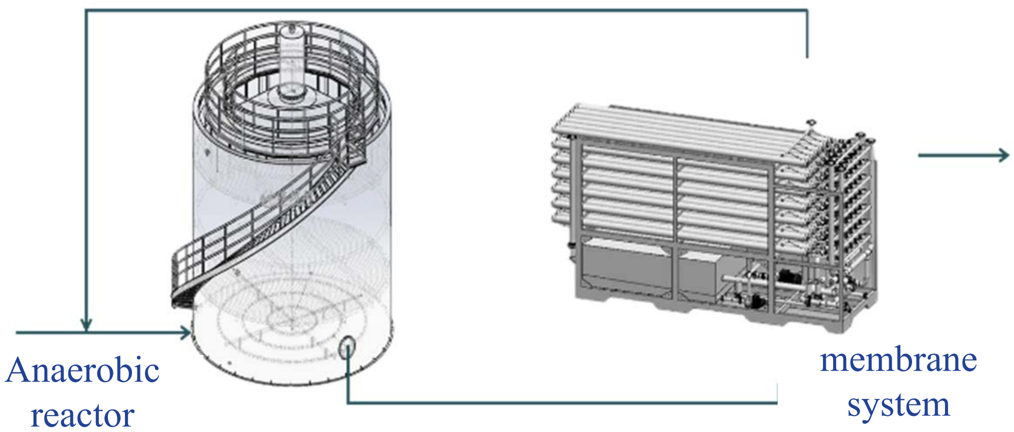
Complete retention of all microorganisms in the bioreactor (**means more bacteria work for AD**), independent of HRT, AnMBR provides sufficient SRT(sludge retention time) for methanogens

Advantages:

a) Extremely high effluent quality

b) High OLR

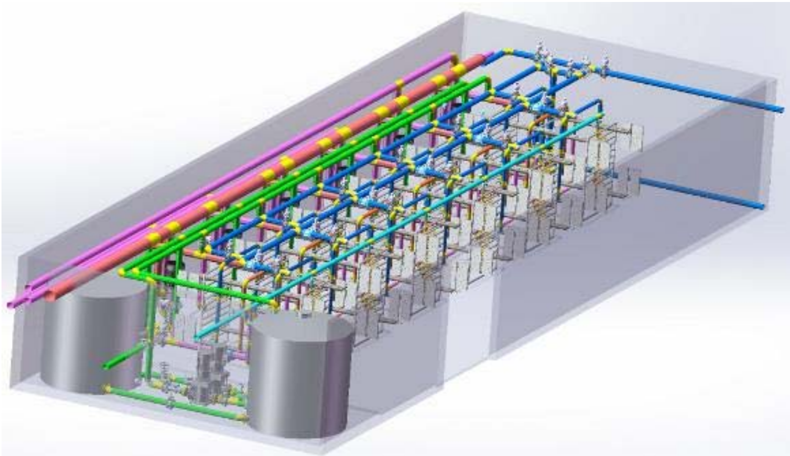
c) High energy recovery



Schematic of AnMBR system

AnMBR Demonstration Project (Full-scale)

An AnMBR System is now under construction in EB's Suzhou waste-to-energy plant after 3 years pilot study (the 1st AnMBR process to treat leachate in China)



04 Nitrogen Removal

Nitrogen pollution

Lake Eutrophication
(Taihu Lake, China)

Ammonium-N and Total Nitrogen emission standards

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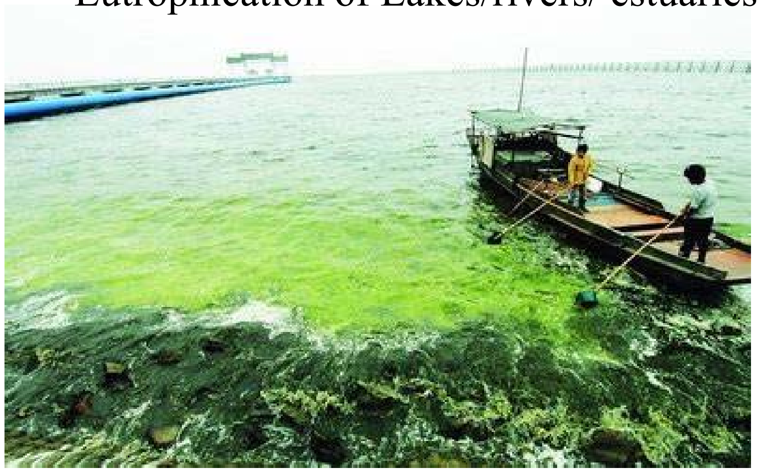
Ammonia（NH_4^+-N) problems

- The consumption of dissolved oxygen (DO) in the water body causes hypoxia (dead zones)
- **Fish toxicity: 1.9 mg TAN/L** (pH=7.0, 20°C) (U.S. EPA AWQC 2013)

Total Nitrogen（TN）

- Eutrophication of Lakes/rivers/ estuaries



Ammonium-N in municipal wastewater vs. Leachate

Municipal wastewater : 20-50 mg/L

Leachate concentration: 1000-3000 mg/L

National Emission Standards in China

For municipal wastewater plant (GB18918-2002)
TN <15 mg/L

For landfill leachate treatment (GB16889-2008)
NH_4^+-N <25 mg/L TN <40 mg/L

For water reuse in waste-to-energy plants(GB/T19923-2005)
NH_4^+-N <10 mg/L

>99% N removal for leachate treatment !

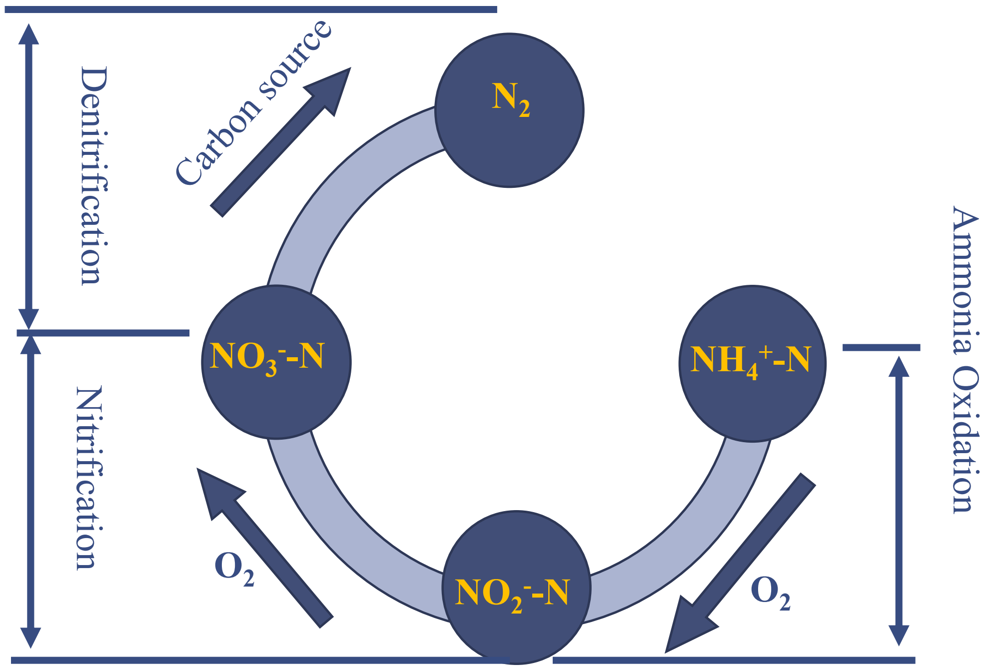
A/O (Anoxic–oxic) Process

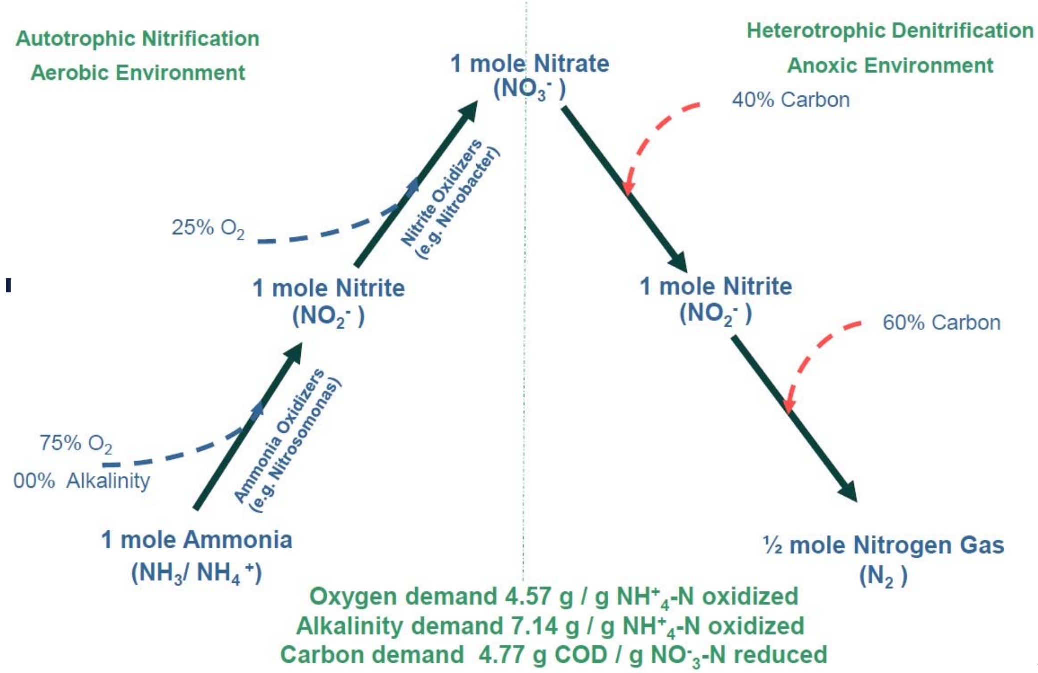
Biological nitrogen removal process

Step1: ammonia is converted aerobically to nitrite (ammonia oxidation)

Step2: Then nitrite is converted aerobically to nitrate (nitrification)

Setp3: Nitrate is then reduced to nitrogen gas in Anoxic condition by supplying carbon sources (denitrification).





A/O (Anoxic–oxic) Process—Aerators

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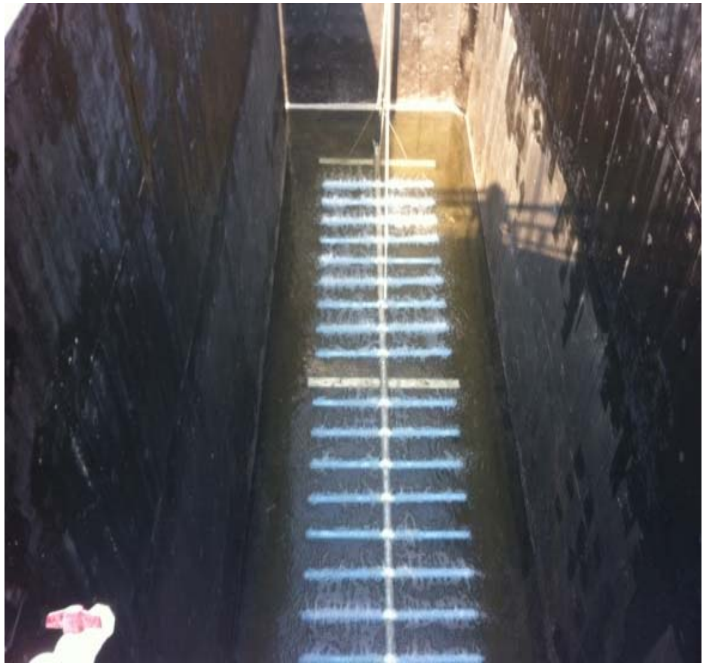


Micro-bubble diffusers

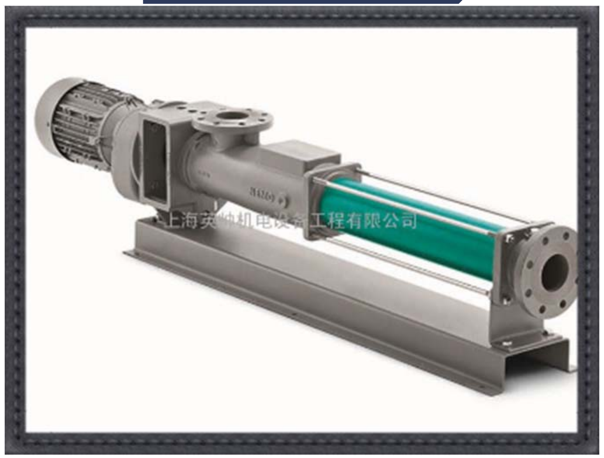
Jet aerator

Surface aerator

A/O (Anoxic–oxic) Process—Pumps

Centrifugal PUMPs

Slurry pumps



Screw pumps

A/O (Anoxic–oxic) Process--Mixers

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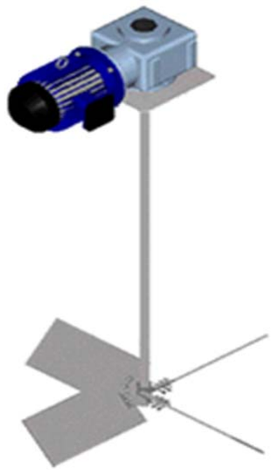
Submersible agitator

vertical paddle mixer



A/O (Anoxic–oxic) Process--Blowers

positive displacement blowers

Centrifugal Blowers

HIGH SPEED TURBO BLOWERS

A/O (Anoxic–oxic) Process—Sludge Dewatering

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Rotary filter press

Centrifuge

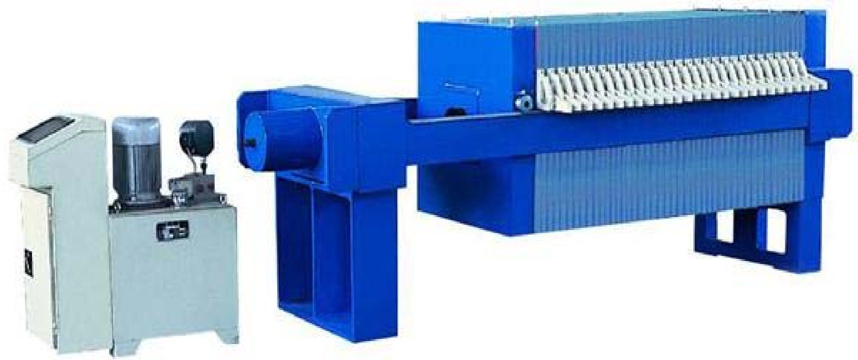


Plate and frame filter press

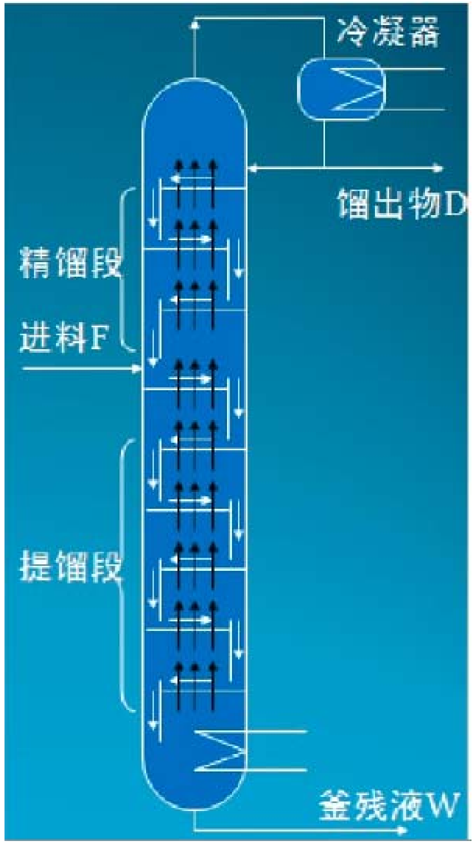
A/O (Anoxic–oxic) Process—MF and UF

Ammonia steam-stripping Process Physical N-removal Technology

- **continuous distillation**, gas-liquid flow countercurrent and fully contact, to achieve the separation and enrichment of water and ammonia by **difference of volatility**, heavy component (water) transferred to liquid phase and light component (ammonia) transferred to gas phase.

- **Advantages :**
  - Much Small footprint (vs. A/O)
  - Ammonia Recovery
  - Phase separation can be controlled automatically

- **Disadvantages:**
  - Energy intensive (80-100 kg/t steam required)
  - Higher Ammonium concentration (> 2000mg/L), more efficent



Schematic diagram of Ammonia steam-stripping

Ammonia steam-stripping Process

Application in petrochemical(Left) and coking(Right) industry

Application in leachate treatment

Ammonia steam-stripping Process

- EB Jiujiang Landfill leachate treatment plant

Ammonia Steam-stripping Process

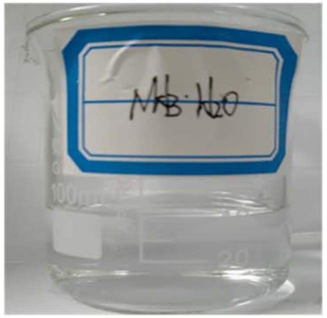
Recovered Ammonia bicarbonate fertilizer

Ammonia steam-stripping Process

- Leachate treatment in EB Suzhou waste-to-energy plant

400m^3/d ASS system

800m^3/d ASS system

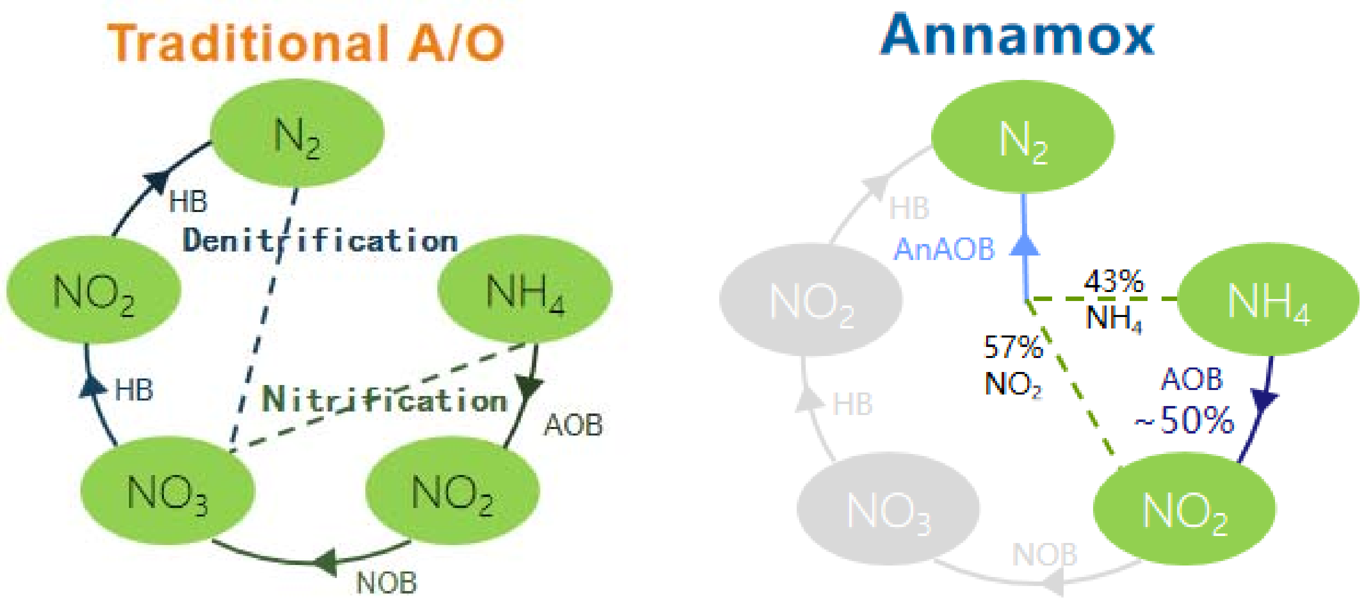


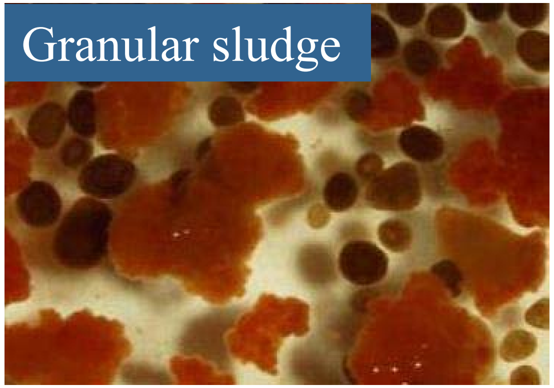
10-15wt% recovered Ammonia

Innovated ANAMMOX Technology

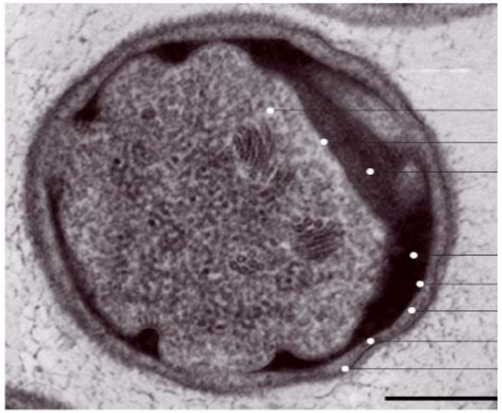
ANAMMOX (Anaerobic ammonium oxidation)

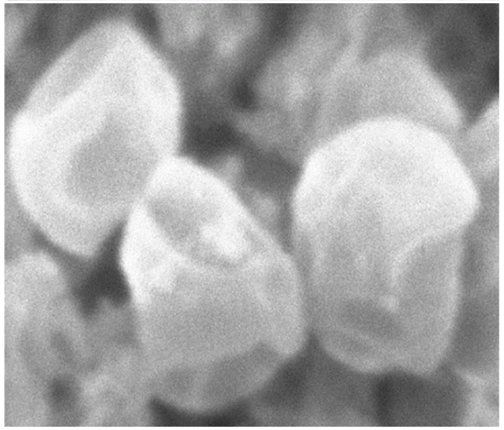
Fundamentals





What do Experts Say about ANAMMOX?





The traditional approach with nitrification and denitrification is highly energy consuming……A less energy-wasteful approach is the newer anammox process.

Perry L. McCarty et al., *ES&T*, 2011

Wastewater treatment including high rate anammox processes have the potential to become energy-neutral or even energy-producing.

M. C. M. van Loosdrecht et al., *Science*, 2010

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ANAMMOX Bacteria Strains

Planctomycetia, Brocadiaceae 22 species in 6 genera

Genus	Species	Sources	References
Anammoxoglobus	'*Candidatus* Anammoxoglobus propionicus'	Synthetic wastewater	Kartal et al. (2007)
	'*Candidatus* Anammoxoglobus sulfate'	Synthetic wastewater	Liu et al. (2008a)
Brocadia	'*Candidatus* Brocadia anammoxidans'	Wastewater	Strous et al. (2006)
	'*Candidatus* Brocadia fulgida'	Wastewater	Kartal et al. (2008)
	'*Candidatus* Brocadia sinica'	Wastewater	Oshiki et al. (2011)
	'*Candidatus* Brocadia caroliniensis'	Wastewater	Rothrock et al. (2011)
	'*Candidatus* Brocadia sp. 40'	Wastewater	Park et al. (2010)
Jettenia	'*Candidatus* Jettenia asiatica'	Wastewater	Hu et al. (2011)
	'*Candidatus* Jettenia caeni'	Wastewater	Ali et al. (2015a)
	'*Candidatus* Jettenia moscovienalis'	Wastewater	Nikolaev et al. (2015)
Kuenenia	'*Candidatus* Kuenen stuttgartiensis'	Wastewater freshwater	Strous et al. (2006)
Scalindua	'*Candidatus* Scalindua wagneri'	Wastewater (marine)	Schmid et al. (2003)
	'*Candidatus* Scalindua brodae'	Wastewater (marine)	Schmid et al. (2003)
	'*Candidatus* Scalindua profunda'	Marine	van de Vossenberg et al. (2013)
	Candidatus Scalindua sorokinii'	Sea water	Schmid et al. (2003)
	'*Candidatus* Scalindua arabica'	Marine (Arabian sea)	Woebken et al. (2008)
	'*Candidatus* Scalindua zhenghei'	Deep-sea sediments	Hong et al. (2011)
	'*Candidatus* Scalindua richardsii'	Black Sea suboxic zone	Fuchsman et al. (2012)
	'*Candidatus* Scalindua sp.'	Marine	Awata et al. (2015)
	'*Candidatus* Scalindua marina'	Marine sediments	Brandsma et al. (2011)
	'*Candidatus* Scalindua sinooilfield'	Oilfields	Li et al. (2010)
Anammoximicrobium	'*Candidatus* Anammoximicrobium moscowii'	Wastewater sludge	Khramenkov et al. (2013)

Source: Adapted from Mao, et al. "Engineering application of anaerobic ammonium oxidation process in wastewater treatment." World Journal of Microbiology & Biotechnology 33.8 (2017): 153-153.

Annamox Process Advantages

◆ Low energy consumption

Compare to traditional A/O, annamox has a lower aeration requirement, a higher oxygen utilization rate by using microporous aeration and no cooling tower.

◆ High nitrogen removal rate

Nitrogen removal rate > 0.8 $kgN/m^3 \cdot d$

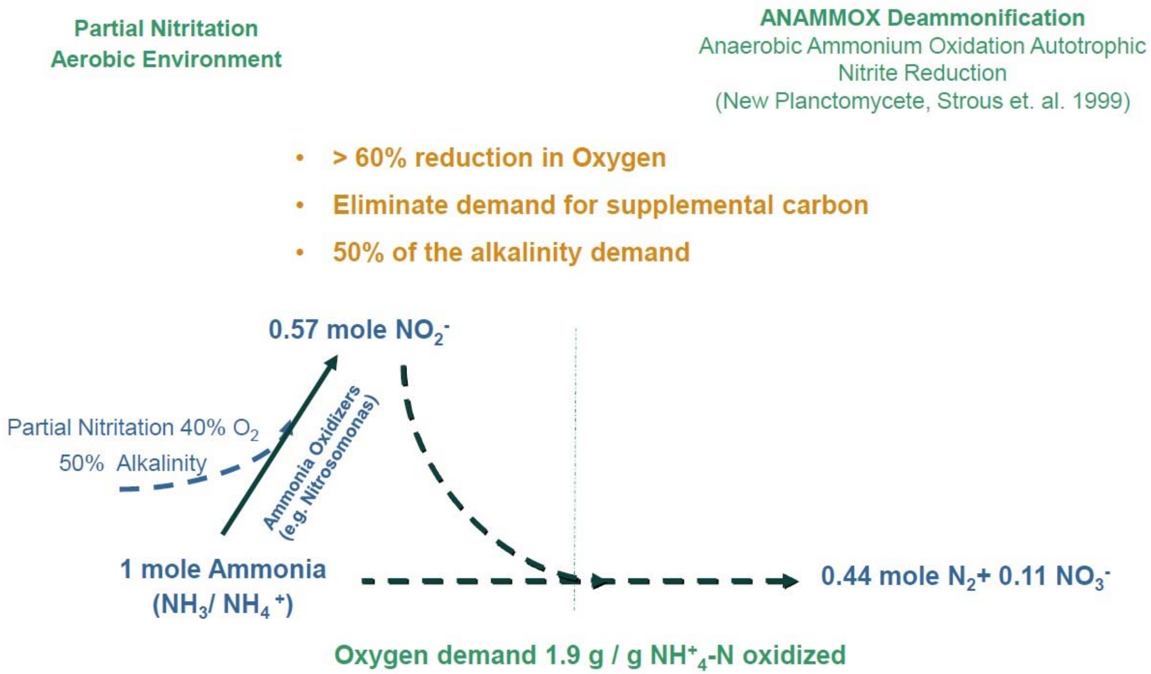
◆ Small footprint

◆ Carbon emission reduction

No organic carbon sources needed

Carbon emissions reduced by more than 90% (vs. A/O)

◆ low excess sludge yield



Annamox Pilot Study

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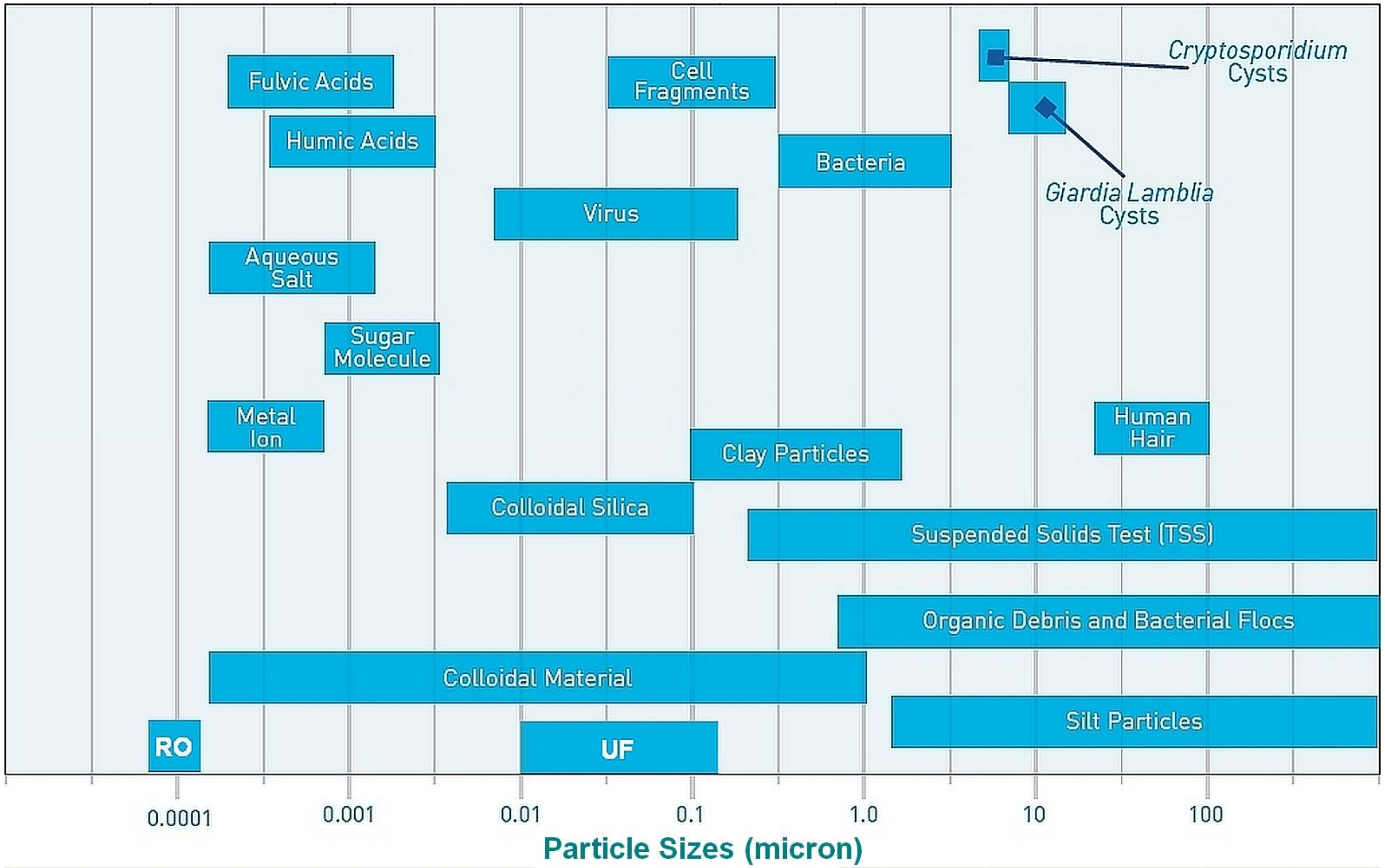
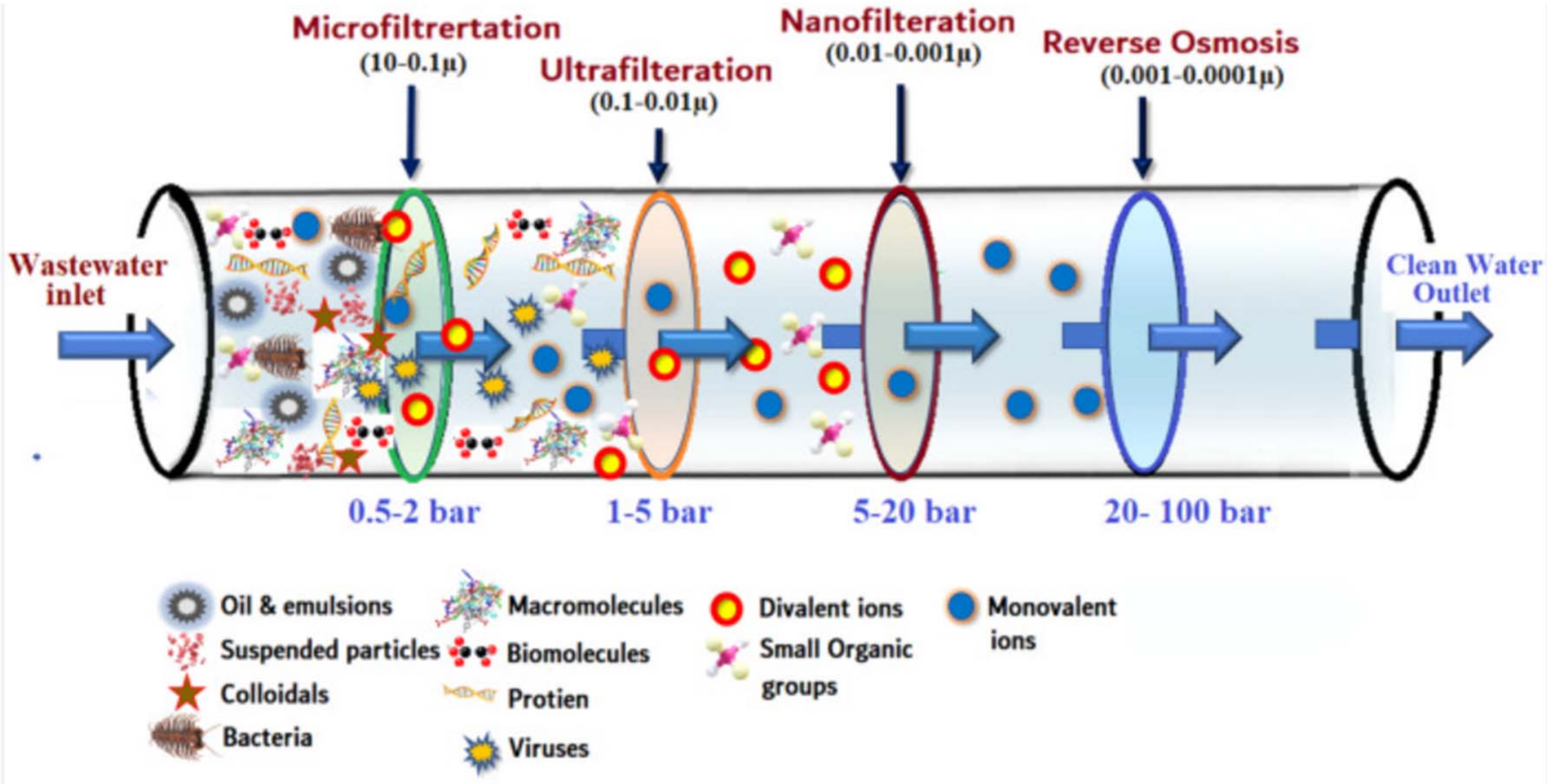
05 Membrane Separation and Evaporation

Particle Sizes



Membrane Pore Size and Pressure Required

Smaller pore size, higher pressure, more energy required, and more fouling propensity



Membrane pore size and pressure applied

Pesticides Remediation Technologies from Water and Wastewater,2022, Pages 143-156

Types of Membrane

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MF

Microfiltration membrane: **0.1~ 1 microns**
MF allow macromolecules and dissolved solids (inorganic salts) to pass through, but trap suspended solids, bacteria, and macromolecular weight colloids

UF

Ultra-filtration: pore size of ultrafiltration membrane is **0.001-0.1 microns**, and the molecular weight interception of 1,000-1,000,000 Dalton, can completely filter out bacteria, colloids in water

NF

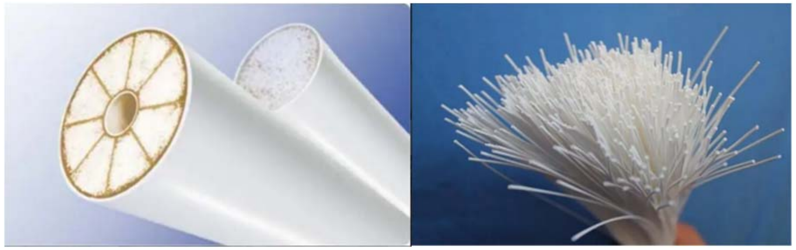
Nano-filtration: a membrane separation between reverse osmosis and ultrafiltration, the interception molecular weight of nanofiltration is between **200~2000 Daltons**, and the membrane pore size is 1nm

RO

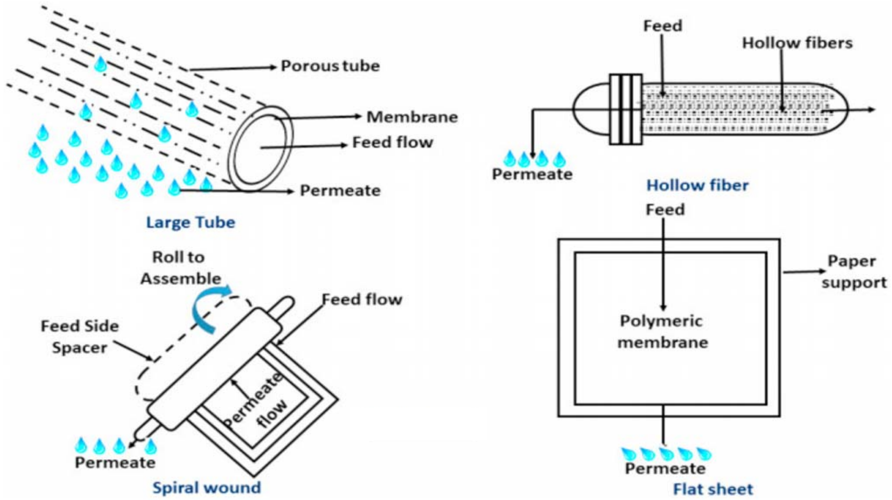
Reverse osmosis: a semi-permeable membrane to remove ions and unwanted molecules by pressure

Four Configurations of membrane

Tubular



Hollow fiber



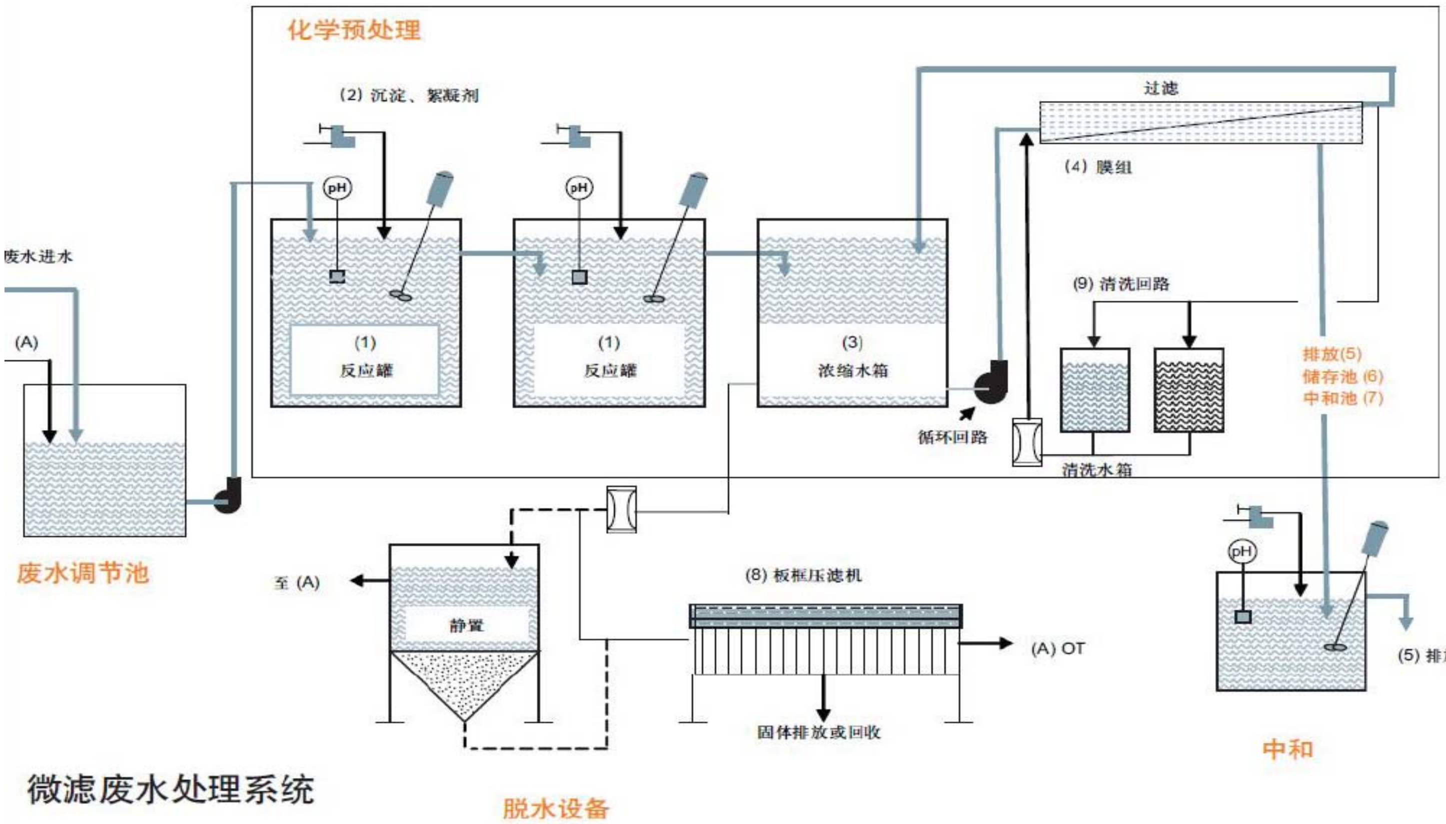
The common membrane modules

Spiral wound

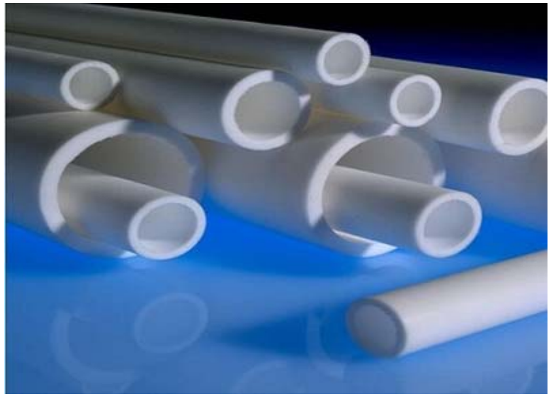
Flat sheet

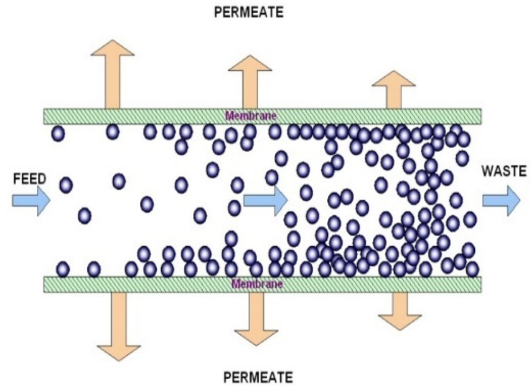
MF for MBR (A/O process)

sludge/water separation in the biochemical treatment process (A/O)



MF Parameters





Items	Parameters
materials	Polyvinylidene fluoride
Pore sizes	0.5,0.1,0.05um
Size	Φ150×1800，Φ200×1800
Pipe size	Φ12.5mm，37芯，42芯
Areas	2.6m²，2.97m²

Pressure：0.3-7bar

Cross flow rate: 3~4m/s

Sludge conc.：0.25%~18%

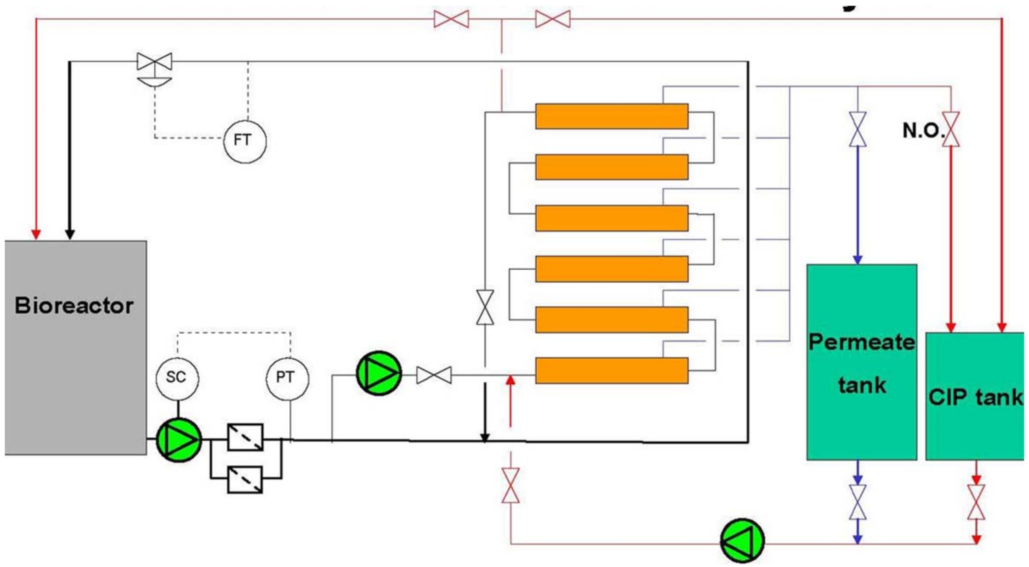
ΔP：4.1bar

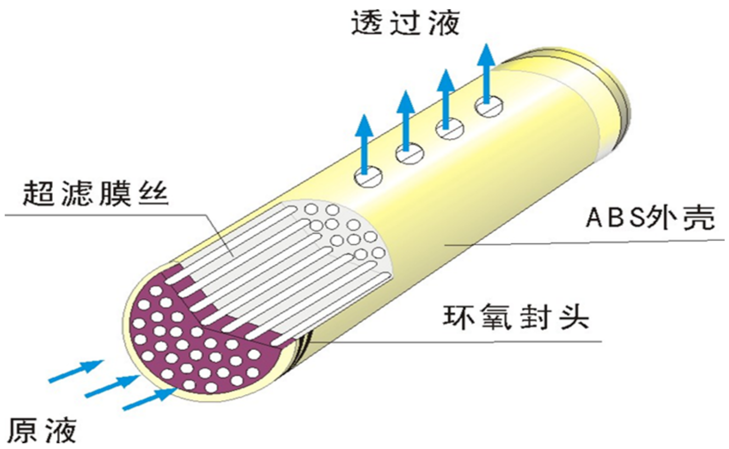
ΔP for back-wash：1.4bar

UF for MBR and Chemical softening

Tubular ultrafiltration

- Sludge-water separation for leachate biochemical treatment (MBR reactor)
- chemical softening (Ca and Mg removal) for chemical-sludge water separation



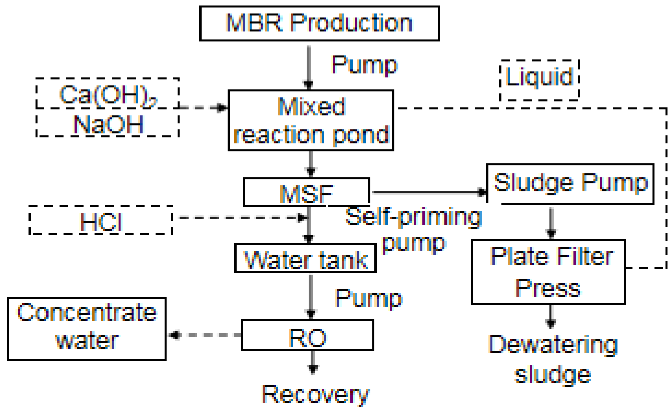


UF for Chemical Softening

Precipitate Ca^{2+} and Mg^{2+} by softening agents (NaOH or $Ca(OH)_2$) by tubular ultrafiltration

Advantages (vs. Sedimentation and Clarification)

- Very high water quality for the effluent
- Prevent risk of fouling on subsequent RO process
- High efficiency of hardness elimination rate
- Small footprint
- Low operating costs

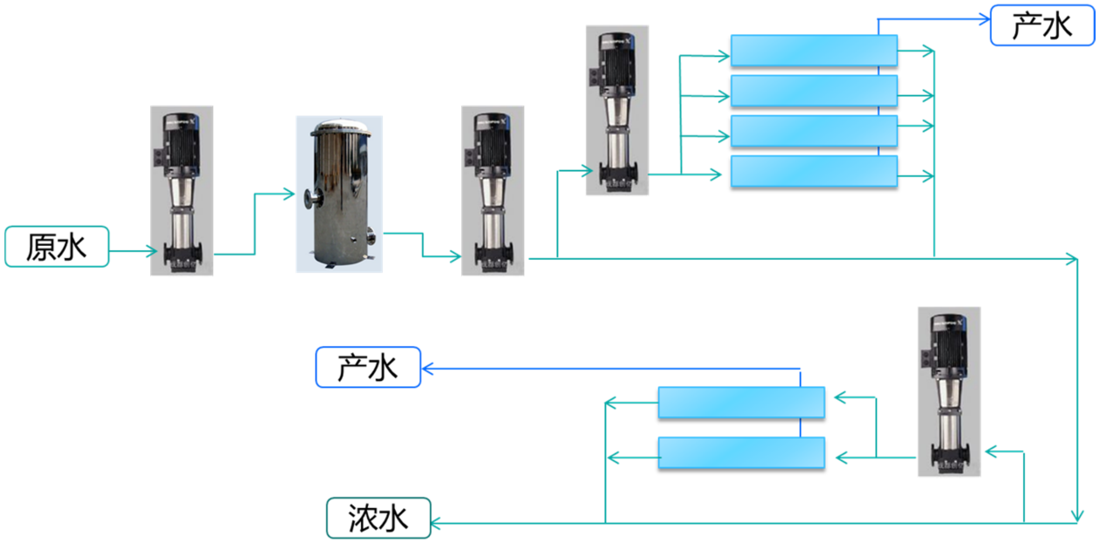


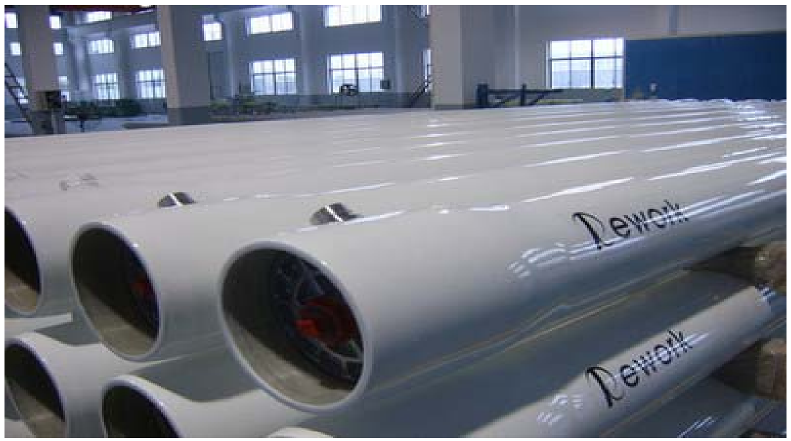
Schematic of CF+TUF

CF+TUF

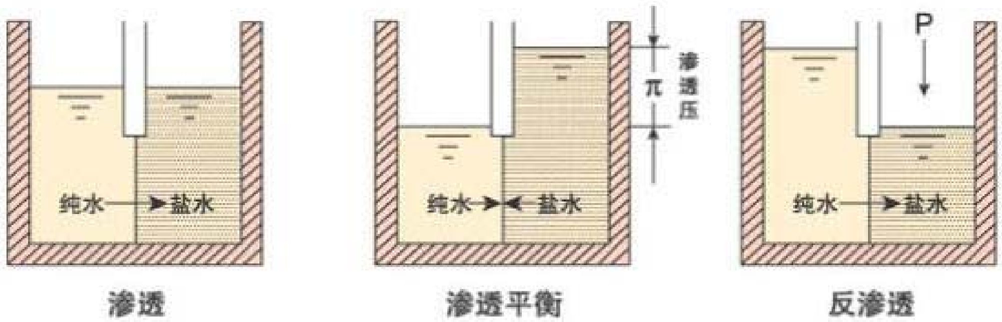
NF

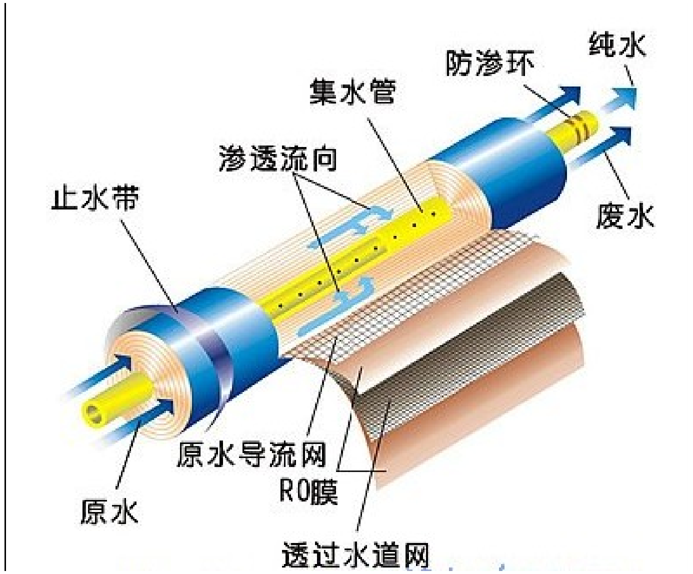
- Remove and reduce soluble CODs (e.g. polymers, humic acids, etc.) after ultrafiltration
- Remove partial divalent salts before reverse osmosis (RO)





RO



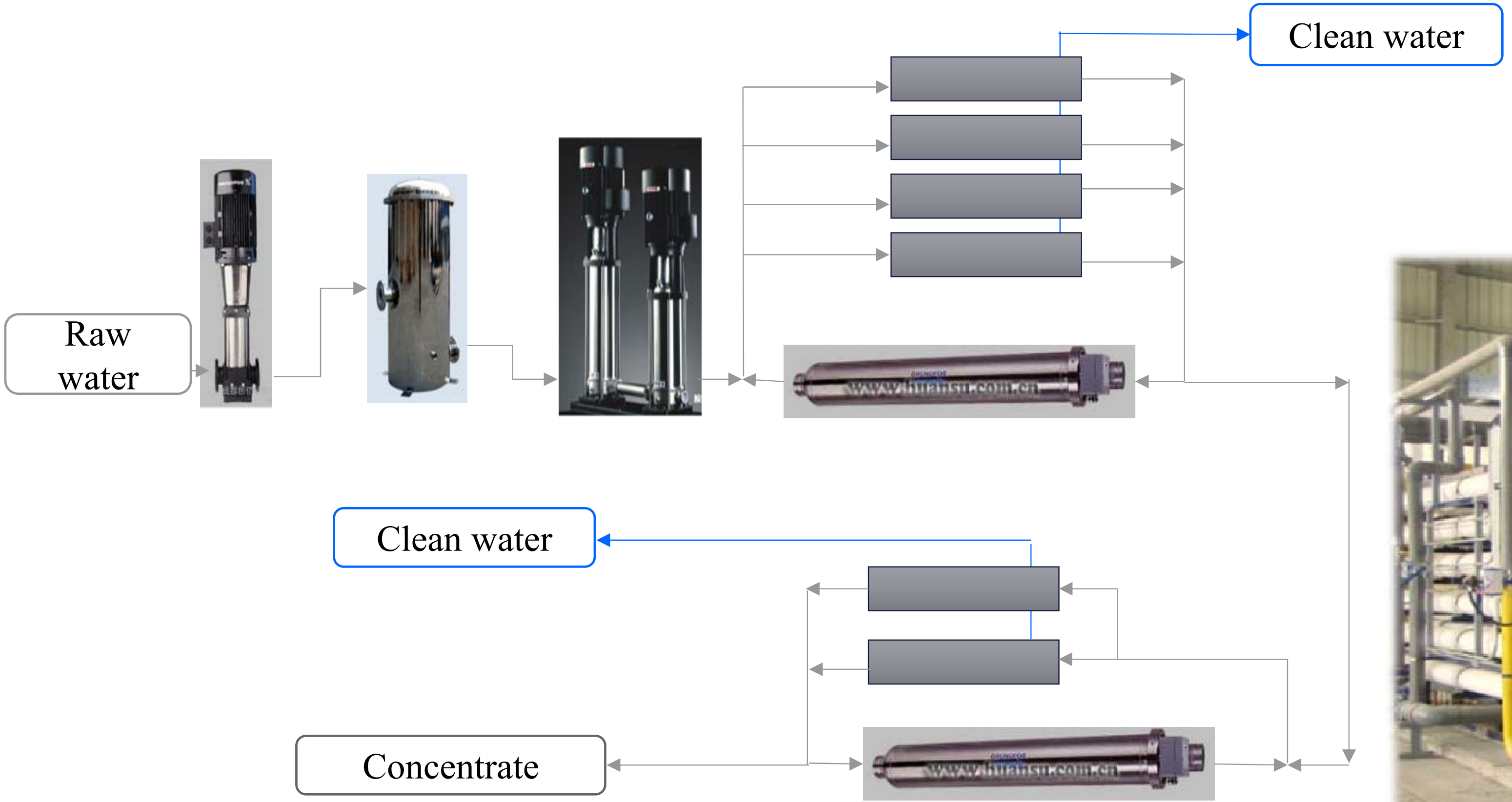


To apply greater pressure than the natural osmotic pressure in salty water (such as raw water), the water molecules in the raw influent are pressed to the other side of the membrane to be clean water

The salts in leachate is generally about 10,000mg/L, RO membrane is widely used

Suppliers: DOW's SW series, GE's desalination series, etc.

RO Process



Evaporation Process--SCE

Submerged Combustion Evaporation (SCE)

Fundamentals

Hot combustion gas bubble through the under - evaporated liquid

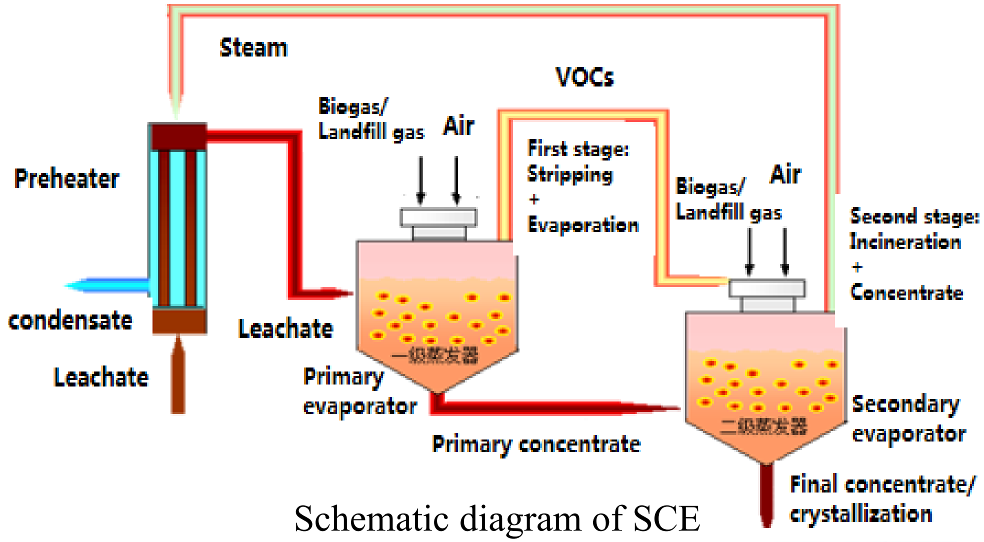
Direct heat-transfer takes place between the hot gases and the liquid without any fixed interface

Applications

Applicable for corrosive, thick, high COD concentration or high salt concentration

Disadvantages

Biogas/landfill gas consumption



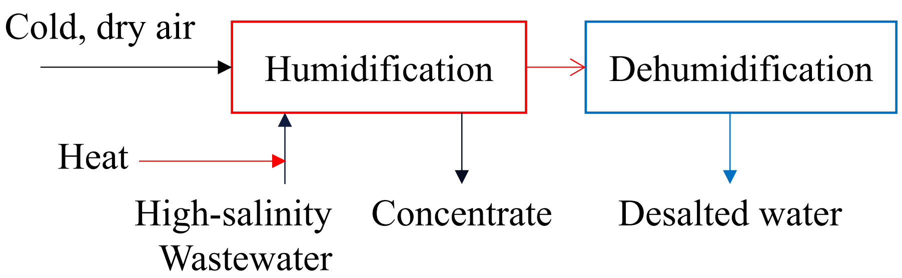
Schematic diagram of SCE

SCE System

Evaporation Process--LTE

Low Temperature Evaporation (LTE)

Fundamentals



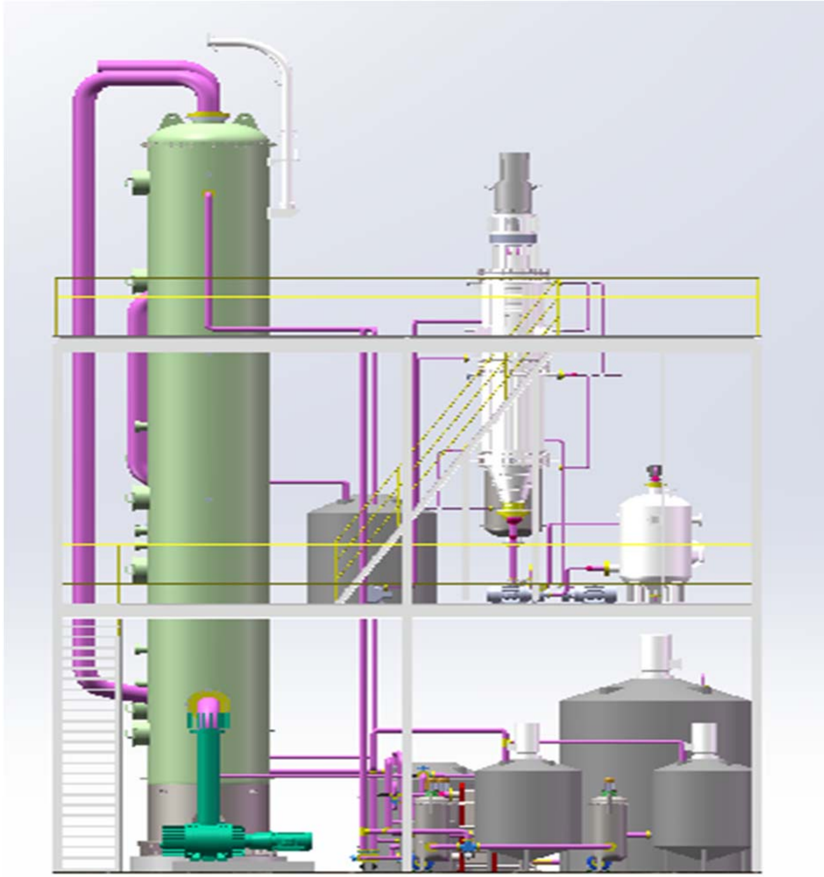
Main structure

- **Evaporator**: Separation salt-water, heat transfer between liquid and bubbles;
- **Condenser**: Recovery desalted water and energy;
- Only **preheater and heater** require daily non-stop cleaning.

LTE process likes cloud and rain

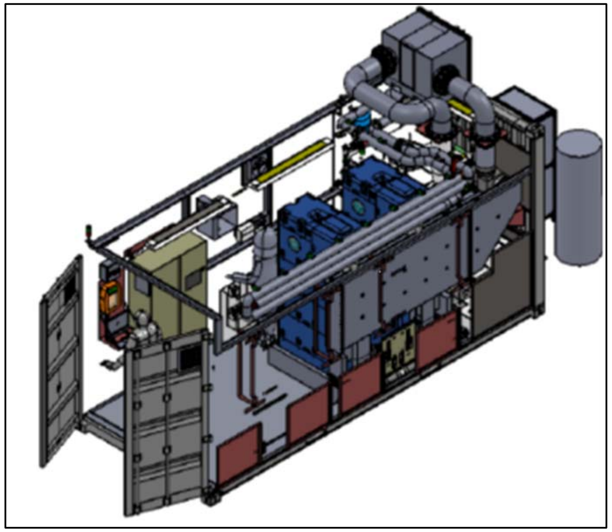
LTE advantages

- Low-grade heat sources such as excess heat, waste heat and hot water can be used
- Heat exchange surface and evaporation surface are separated by non-metallic materials, which are resistant to corrosion.
- Low operating and investment costs, operating costs reduced >20%, investment reduced 20%.
- High water recovery rate, better effluent quality.
- Utilization in ZLD treatment



LTE system

LTE design and applications



Modular design
Capacity: 1 - 20 m^3/day

Large-scale application
Capacity: 10 - 500 m^3/day

Picture of LTE system

Electrodialysis Technology (ED)

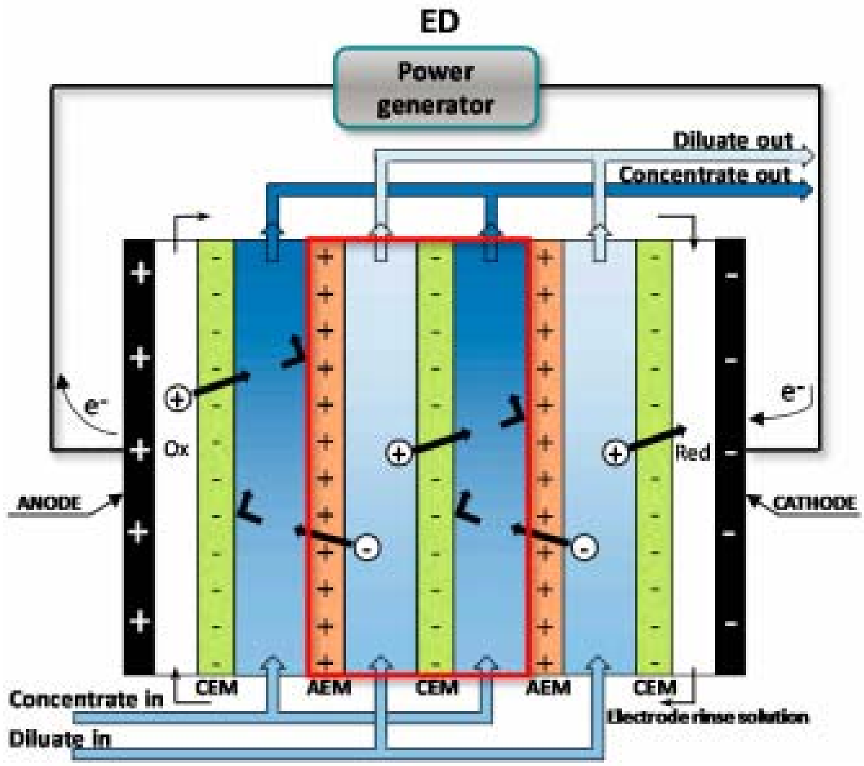
Electrodialysis: ED is a membrane process of separation under the action of an electric field, where ions are selectively transported across ion-exchange membranes (IEMs)

Main structure

AEM CEM	Anode Cathode	Dilute Concentrate

Fundamentals

Under the electric field, cations and anions migrating towards the cathode and the anode, then block by the IEMs leads to a selective transport with a resulting salt concentration reduction/increase in the dilute/concentrate channels.



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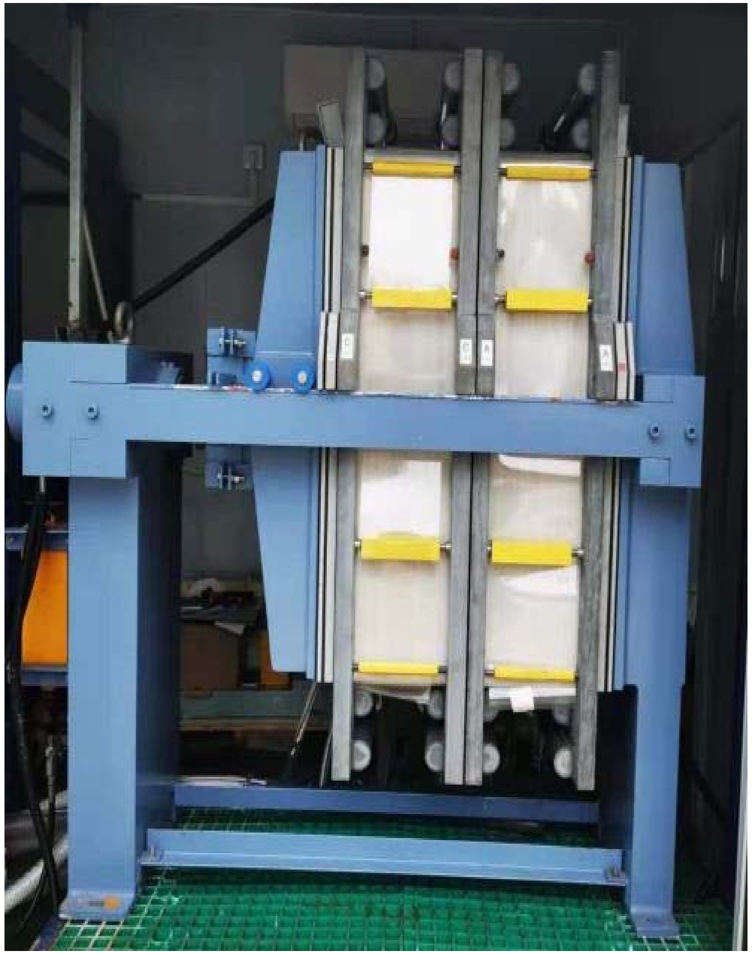
ED Modular



ED Membrane Modular (Flat sheet)

ED Advantages

◆ High processing efficiency

Hing salt concentration in concentrate(15%~20%); high reaction speed.

◆ Stable operating situation

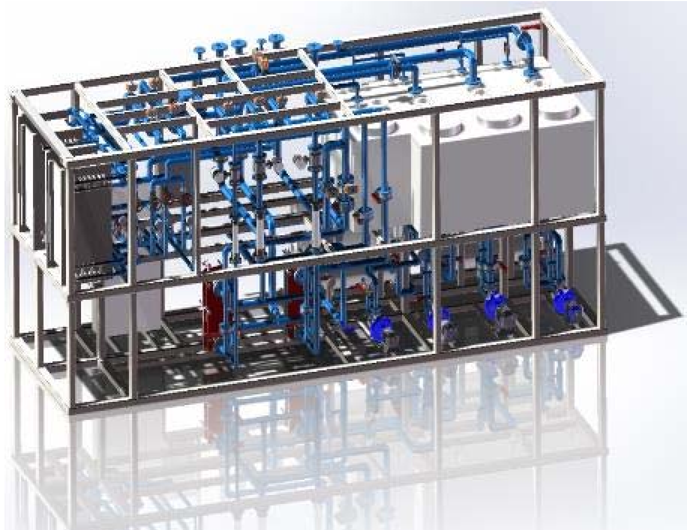
Low pressure operating, high degree of automation.

◆ Good operating environment

Small footprint, low noise operation, no chemical agent is necessary.

◆ Convenient operation and maintenance:

ED methods can be applied for effluents originating from various qualities.



Modular design of ED

Forward Osmosis (FO)—under development

Forward Osmosis: FO is driven by osmotic pressure gradient to make the water pass through the membrane from feed solution (FS) to draw solution (DS), to achieve the concentration of feed solution

Main structure

◆FO system (FS, DS, FO membrane): Driven by osmotic pressure, concentrate FS

FS: Leachate, waste water etc.

DS: High salinity solution(NaCl, NH_4HCO_3, $MgCl_2$, seawater etc.)

FO membrane: Spiral wound, Hollow fiber, plat and frame etc.

◆Recovery system: Concentrate and recycle DS, obtain clean water.

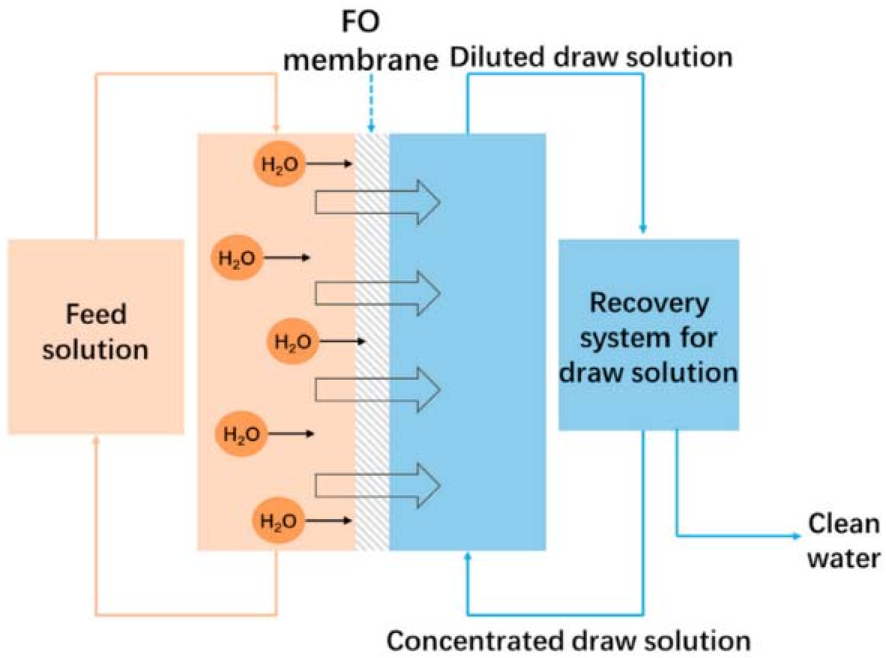
FO advantages

◆ Low pressure applied and low energy consumption

◆High water flux, high water production rate

◆Low fouling tendency, high fouling resistance

◆Strong adaptability



Schematic diagram of FO

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06 The Prospect

Think of A typical Wastewater treatment plant

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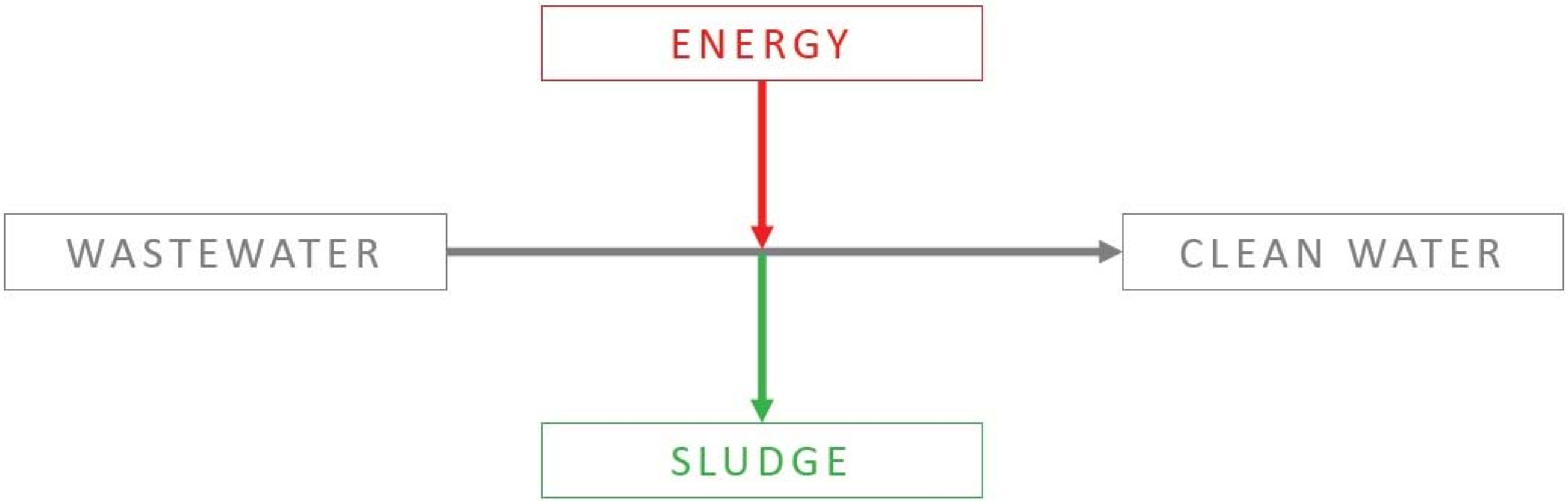
NOW: Center of Cost



Source： https://www.interreg-central.eu/Content.Node/05-Reef-2W-WATERLEAU-compressed.pdf

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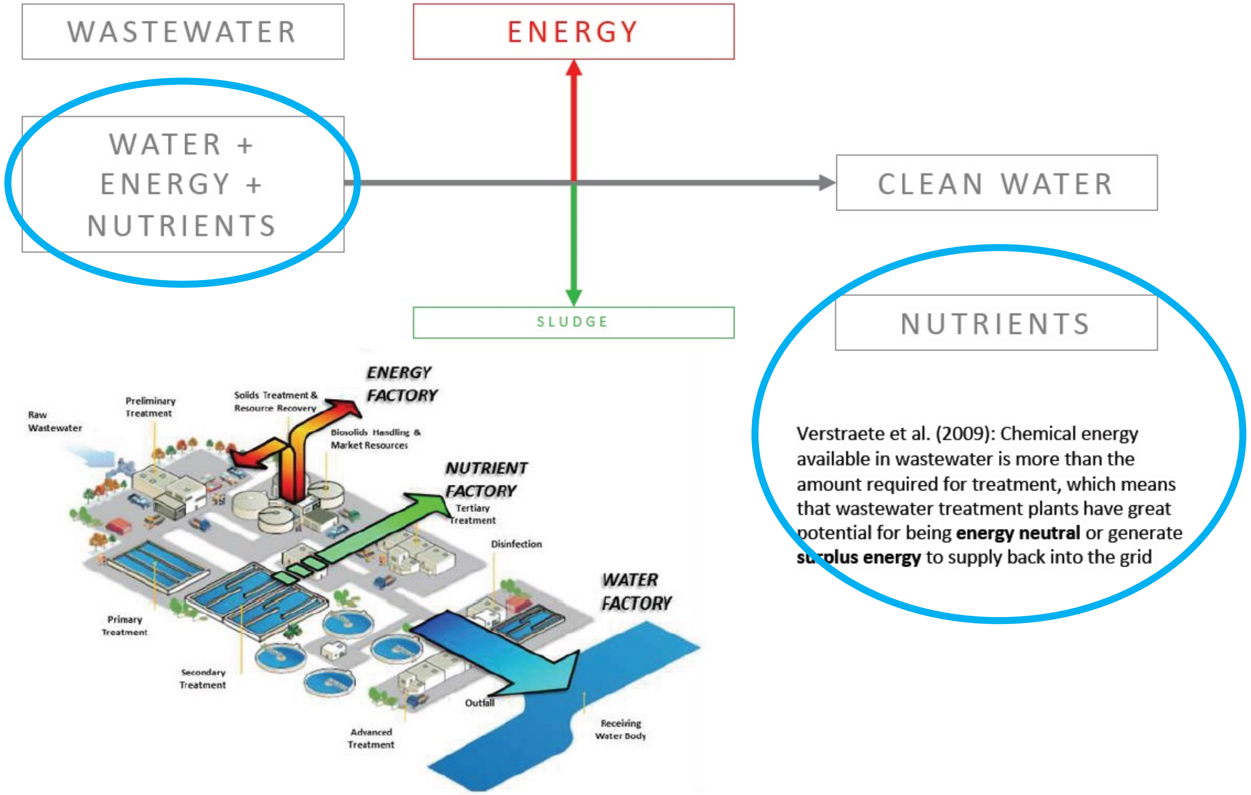
Think of A typical Wastewater treatment plant

Future： Center of Resources



Source：https://www.interreg-central.eu/Content.Node/05-Reef-2W-WATERLEAU-compressed.pdf

Prospect for A Leachate Treatment Plant

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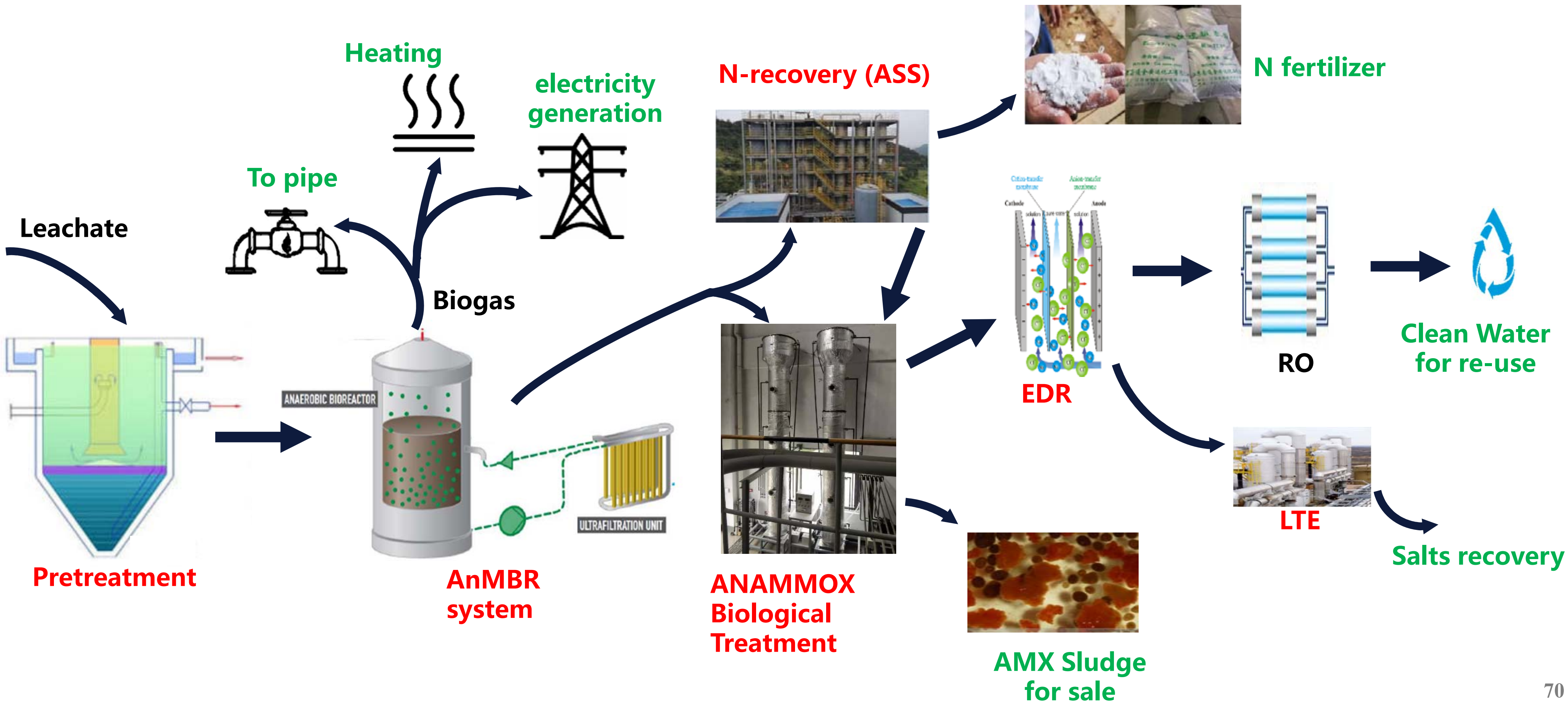
Energy recovery, Water re-use, and N, Salts recycle



Team

Institute of Technology, Everbright Environment

Thanks！

Question?