"Comprehensive guide to industrial wastewater treatment technologies, applications, design, optimization, and environmental compliance for engineering students an environmental professionals."

INDUSTRIAL WASTEWATER TREATMENT GUIDE

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Chapter 1: Introduction

The treatment of industrial wastewater is a critical component of sustainable environmental management. Unlike municipal wastewater, industrial effluents vary significantly in composition, flow, and toxicity depending on the specific processes of each facility. Industrial discharges can contain high concentrations of organic matter, heavy metals, salts, oils, surfactants, and other potentially hazardous substances.

This guide aims to provide engineers, consultants, and facility managers with a comprehensive overview of the technologies and methodologies used to manage and treat industrial wastewater effectively. The focus is not only on achieving compliance with discharge regulations but also on promoting water reuse, minimizing waste, and optimizing energy and chemical consumption.

The selection of an appropriate treatment train is highly dependent on several factors:
- Nature and concentration of contaminants
- Flow regime (continuous or batch)
- Final objective (e.g., discharge to natural body, sewer network, internal reuse)
- Economic and space constraints
- Regulatory standards

Modern industrial wastewater treatment systems integrate multiple technologies in a modular approach, allowing for flexible adaptation to changing loads or new treatment targets. Advances in membrane technology, process automation, and resource recovery (water, energy, chemicals) have also opened new opportunities for industries aiming to reduce their environmental footprint.

The subsequent chapters provide a structured analysis of:
- Wastewater characterization
- Pretreatment and primary treatment technologies
- Biological and physicochemical treatment options
- Membrane and advanced separation systems
- Zero Liquid Discharge (ZLD) and Minimum Liquid Discharge (MLD) strategies
- Design considerations and performance calculations
- Energy and chemical usage
- Cost structures and case studies

Ultimately, this guide serves as a practical tool for designing, evaluating, and optimizing treatment strategies tailored to industrial needs, see separated ***calculation templates*** helping to prepare a budget investment and cost analysis

Chapter 2: Characterization of Industrial Effluents

2.1 Key Parameters

Understanding the nature and concentration of contaminants in industrial effluents is essential for selecting appropriate treatment processes. The most common parameters to evaluate include:

- Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD_5)
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)
- pH and temperature
- Oil and grease (FOG)
- Ammonium (NH_4^+), Total Kjeldahl Nitrogen (TKN), Nitrate, Nitrite
- Total Phosphorus and Orthophosphate (PO_4^{3-})
- Sulfates, Chlorides, Fluorides
- Heavy metals (Zn, Cu, Cr, Pb, Ni, etc.)
- Toxic and inhibitory compounds (e.g., surfactants, solvents, phenols)
- Pathogens (only in some sectors)

2.2 Flow and Sampling Considerations

Effluent flow rate is critical for dimensioning treatment systems. Flow profiles may be continuous or batch, and should be measured in:

- Average flow (m^3/h or m^3/day)
- Peak flow (max instantaneous m^3/h)
- Hydraulic retention time (HRT) required for different processes

Sampling must reflect the real variability of the effluent:

- Composite sampling over time is preferred over grab sampling
- Samples should be preserved and analyzed promptly
- Flow-proportional sampling helps correlate contaminant load with operational events

Image 1: Automatic Sampler (Endress &Hauser)

2.3 General technology choosing attending pollutant type (Table I)

PARAMETER	Technology	Flow m3/day	Final effluent mg/l	Remarks 1	Remarks 2
NO2,NO3 mg/l					
100	Ion Exchange	1 to 1000	≤10	no DBO	produce eluates
200-1000	SBR	100-1000	≤20	needs BOD	produce sludge
100-500	SOD	50-1000	≤20	no DBO	direct conversion N2
1000-5000	RO	50-1000	≤10	no DBO	produce rejects
5000-100000	Evaporation	1-500	≤10	no DBO	produce concentrate
NH4-N					
100	Ion Exchange	1 to 1000	≤10	no DBO	produce eluates
200-1000	SBR	100-1000	≤20	needs BOD	produce sludge
100-5000	Air stripping	50-1000	≤20	no DBO	needs NH3 absortion (scrubber)
100-500	RO	50-1000	≤10	no DBO	produce rejects
5000-100000	Distilation/Reboiler	1-500	≤10	no DBO	conversion to ammonia 20% sol
DQO/BOD					
200-3000	Biocarb	10-1000	≤50	BOD ≥20% COD	short TRH, 30% mas COD sludge
500-15000	MBR	100-5000	≤20	BOD ≥40% COD	long TRH, 50% mass COD sludge
500-5000	SBR	50-1000	≤20	BOD ≥50% COD	medium term TRH, 60% COD slud
100-100000	Evaporation	1-500	≤10	no needs BOD	produce concentrates
TDS					
100-1000	Ion exchange	1 - 1000	≤10	Produce brine eluates	needs evaporator for eluates
1000-30000	SWRO	50-1000	≤10	Produce reject brine	needs evaporator for rejects
5000-100000	Evaporation	1-500	≤10	Produce concentrate	MLD to disposal
100000-300000	Crystalization	1-200	≤50	crystals	resource recovery
VOC'S (WATER)					
100-1000	SBR	100-1000	≤50	produce sludge	medium term TRH, 60% COD slud
1000-5000	MBR	100-5000	≤30	produce sludge	long TRH, 50% mass COD sludge
1000-10000	Air/Steam stripping	10-1000	≤50	needs condensation	needs distilation column to purify condensate
≥10000	Distillation/Reboiler	1-500	≤50	solvents to recovery	Classified Exproof equipment
TSS					
1-100	Filtration	1-10000	≤0,001	Tear&Wear cost	Option by MF or UF
100-2000	settling	100-5000	≤50	Needs coag/floc	Lamella prefeara bily
2000-10000	Centrifugue	10-1000	≤10	Decanter centrif	solid fraction moisture 80%
10000-300000	Filter Press	10-1000	≤100	Batch Process	Cake moisture 50%
≥300000	Sludge Dryer	1-100	≤0,001	Batch process	needs steam or thermal fluid
Metals (I)-Cations-					**Alkali Metals, Metaloids: Li, Na, K,Ca, Mg,B,Si,**
1-100	Ion Exchange	1-1000	≤1	Produce brine eluates	needs evaporator for eluates
100-5000	Ph/Chemical or EC	1-5000	≤50	produce sludge	Limitated to Ca, Mg needs chemicals
5000-50000	Evaporation	1-500	≤1	produce concentrate	concentrates MLD to disposal
50000-500000	Crystallization	1-200	≤10	Crystals	Resource recovery
Metals (II)-Cations-					**Ti, Zr,Cr, Mo, Mn,Fe, Co, Ni, Cu, Ag, Au, Zn, Cd, Hg, Al, Sn,Pb,**
1-100	Ion Exchange	1-1000	≤1	Produce brine eluates	needs evaporator for eluates
100-5000	Ph/Chemical or EC	1-5000	≤5	produce sludge	needs chemicals
5000-50000	Electrowinning	1-500	≤1000	Recovery no treatment	Limitated to Co, NI, Cu, Ag, Au, Zn, Sn Pb
5000-100000	Crystallization	1-200	≤10	Crystalas	Resource recovery
Anions (I)					**Anions : Cl, SO3,SO4, F, PO3,PO4**
1-100	Ion Exchange	1-1000	≤1	Produce brine eluates	needs evaporator for eluates
100-5000	Ph/Chemical or EC	1-5000	≤10	produce sludge	Limitated to F,PO3,PO4
100-5000	RO	1-5000	≤5	produce rejects	needs evaporator for eluates
5000-50000	Evaporation	1-500	≤10	Produce hypersaline brines	concentrate MLD or crystalization
5000-100000	Crystallization	1-200	≤50	Crystals	Resource recovery
Phenol					
1-100	tivated carbon GAC/PA	1-1000	90-95% less influent	30% phenol adsorbed x 1 kg AC	Replace AC bed and disposal
100-500	Biocarb	1-500	98% less influent	produce sludge	higher values of phenol produces toxicity
100-5000	Ph/Chemical Fenton	1-1000	98% less influent	consume H2O2 and Fe salts	Needs neutraliztion and filtration
5000-50000	iquid/liquid extractior	1-500	90% less influent	using organic extractants	needs des-extractant system
Formaldehide					
1-100	MBBR	1-1000	≤5	Produce sludge	higher than 200 mg/l is toxic
100-500	AOP	1-1000	≤10	Catalytic process with H2O2+UV	
100-5000	Ph/Chem	1-500	≤10	eeds Urea; complex formol/Ure	batch needs 24 hours to complete reaction
5000-50000	Evaporation	1-500	≤100	tilate recover 90-95% fomaldeh	evaporator blowdown needs treatment to meet Dis Lim
Hydrocarbons (no emulsion)					
1-100	CAF	1-1000	≤10	Flotation separation	HC can content 10% of water
100-5000	API	1-5000	≤10	API separators	HC can content 10% of water
5000-50000	Centrifugue	1-5000	≤5	disc centrifugue	HC can content 2% of water

2.4 Sector-Specific Characteristics:

Different industries produce effluents with unique compositions and treatment challenges:

- Metalworking: high COD, FOG, and suspended solids
- Textile: high COD, color, surfactants, salinity
- Dairy and food: high BOD, COD, FOG, nutrients
- Chemical and pharmaceutical: high toxicity, variable pH, solvents
- Mining: heavy metals, sulfates, TSS, TDS, CN, chlorides
- Landfills: high COD, ammonia, TDS, leachates with complex chemistry

Proper characterization enables the customization of treatment trains tailored to each sector's needs and regulatory targets. See separate Wastewater Guide for Industrial Activities (Annex 1)

Chapter 3: Pretreatment Technologies

3.1 Screening and Grit Removal

Screening and grit removal represent the first stage in industrial wastewater treatment. They aim to eliminate coarse solids and inert particles that may damage or clog downstream equipment.

Typical Equipment:
- Bar screens (manual or automated)
- Step screens (up to 6 mm spacing)
- Drum screens (rotating, self-cleaning, 1–3 mm openings)
- Grit chambers (horizontal flow or vortex type)

Design Criteria:
- Flow velocity in channels: 0.3–0.6 m/s (to avoid settling or suspension)
- Head loss across screens: 0.1–0.3 m
- Grit removal efficiency: 90–95% for particles >500 μm

Calculation Example:
For a flow of 100 m^3/h, a grit chamber should have a detention time of ~60 seconds.
Volume = 100 m^3/h × (60/3600) h ≈ 1.67 m^3 minimum.

Image 2 Grit Removal (Salher)

3.2 Oil and Grease Separation (API, CPI, DAF)

FOG (Fats, Oils, Grease) removal is essential before biological or membrane treatment stages.

Technologies:
- API Separator: gravity-based, suitable for large droplets >150 µm
- CPI (Corrugated Plate Interceptor): enhanced coalescence with inclined plates
- DAF (Dissolved Air Flotation): uses microbubbles to lift emulsified oils to the surface

Design Guidelines:
- API detention time: 30–60 minutes
- DAF air-to-solids ratio: 0.02–0.06
- Surface loading (DAF): 5–15 $m^3/m^2 \cdot h$

Performance:
- FOG removal: up to 95% (DAF)
- TSS reduction: 50–90% (with coagulant dosing)

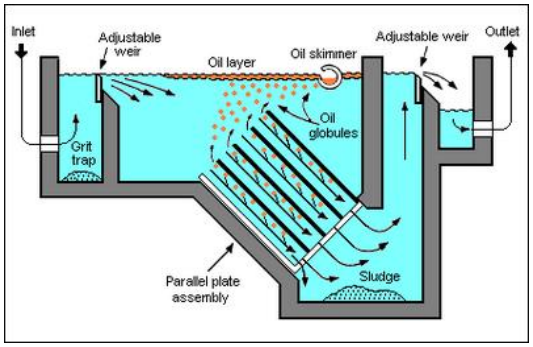
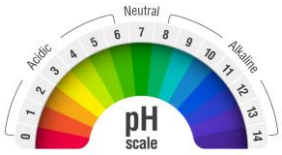


Image 3 API Oil-Water separator (American Petroleum Institute)

3.3 pH Neutralization

pH correction is often required for regulatory compliance and to protect biological systems.
Neutralizing Agents:
- Acids: sulfuric acid (H_2SO_4), hydrochloric acid (HCl), preferably diluted (10-50% in water)
- Bases: sodium hydroxide (NaOH), preferably diluted (20-50%), lime ($Ca(OH)_2$) 20% slurry
Control Methods:
- Inline static mixers for fast reaction
- Feedback control with pH sensors and PLC dosing

4. pHmeter



5. pH scale

Neutralization Requirements by pH (indicative amounts) Table II

pH	[H+] (mol/L)	NaOH required (g) for 1 m^3 of water	H2SO4 required (g) for 1 m^3 water
0.0	1.0e+00	40000	
1.0	1.0e-01	4000	
2.0	1.0e-02	400	
3.0	1.0e-03	40	
4.0	1.0e-04	4.0	
5.0	1.0e-05	0.4	
6.0	1.0e-06	0.04	
7.0	1.0e-07	0.00	0.00
8.0	1.0e-08		0.05
9.0	1.0e-09		0.49
10.0	1.0e-10		4.90
11.0	1.0e-11		49
12.0	1.0e-12		490
13.0	1.0e-13		4904
14.0	1.0e-14		49040

3.4 Chemical Coagulation and Precipitation

Used to remove fine suspended particles, colloids, metals, and phosphorus.
Coagulants:
- Ferric chloride, aluminum sulfate, poly aluminum chloride (PAC)
- Lime and caustic soda for pH adjustment

Typical Dosage:
- Ferric chloride: 50–200 mg/L
- Flocculants (polymer): 1–5 mg/L

Design Parameters:
- Rapid mixing: 800–1200 s^{-1} (G value), 30–60 seconds
- Slow mixing: 20–80 s^{-1} for 15–30 min
- Settling velocity: 0.5–1 m/h (lamella settlers up to 3 m/h)

Sludge Production:
- 1–2% of treated volume as wet sludge (≈3–6 kg/m^3)

The ***Jar Test*** is a laboratory procedure used to simulate and optimize coagulation-flocculation processes in water and wastewater treatment. It helps determine the ideal type and dosage of coagulants and flocculants required to clarify water by removing suspended solids and turbidity.

Key Features:
- Performed using multiple jars (beakers) with identical water samples.
- Different doses of coagulants (e.g., alum, ferric chloride) are added.
- Samples are stirred rapidly (coagulation) and then gently mixed (flocculation).
- After settling, the clarity of each jar is compared to assess effectiveness.

Purpose:
- Optimize chemical dosage.
- Reduce operating costs and sludge production.
- Improve treatment efficiency.

Image 6. Jar Test equipment (Sigmadaf)

3.5 Electrocoagulation

Generates coagulant in situ via anodic dissolution of iron or aluminum electrodes (sacrifice).

Reaction Example:
$Fe \rightarrow Fe^{2+} + 2e^-$ (anode)
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (cathode)

Advantages:
- Reduced chemical dosing
- Effective for emulsified oils, heavy metals, dyes

Operating Parameters:
- Current density: 10–50 A/m^2
- Electrode spacing: 1–3 cm
- Power consumption: 0.5–2.5 kWh/m^3

Sludge Characteristics:
- Finer, more stable flocs
- Reduced volume compared to conventional coagulation

Image 7. Electrocoagulation equipment (Proelec.tech)

3.6 Sludge Thickening and Dewatering

Pretreatment generates sludge that must be concentrated and dewatered before disposal.

Technologies:
- Gravity thickeners (3–5% solids)
- Dissolved air flotation (DAF) for sludge (5–6%)
- Belt filter presses (15–20%)
- Screw presses (18–25%)
- Decanter centrifuges (20–25%)

Key Parameters:
- Polymer dosage: 2–8 g/kg dry solids
- Filtrate quality: <500 mg/L TSS

Volume Reduction:
- Raw sludge: 0.5–1% solids → dewatered cake: 20–25%
- 1 m^3 raw sludge → 0.04 m^3 dewatered cake + 0.96 m^3 filtrate

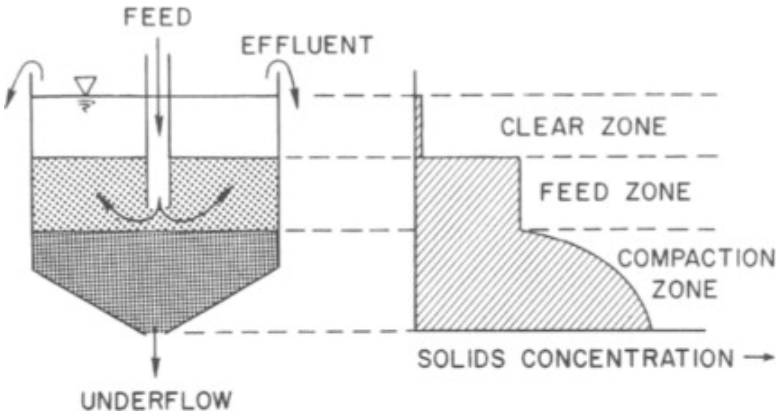


Image 8. Sludge thickening definition (Scribd)

Chapter 4: Biological Treatment Processes

4.1 Activated Sludge (CAS, SBR)

The conventional activated sludge (CAS) process is widely used for removing biodegradable organic matter and nutrients. It involves aeration of wastewater with a microbial culture, followed by solid-liquid separation.

Key Design Parameters (CAS):

	In a CAS (conventional activated sludge)
Biological reactor:	**Range**
Typical Flow (m3/h)	betw een 0,5-500
CV: COD volumetric load (kg/m3 day):	betw een 0,5-1,2
MLSS: SS Mixed liquor (mg MLSS/L):	betw een 500-2000
% SSV/SS:	0,85
MLSSV: Volatile SS mixture liquor (mg MLSSV/L):	betw een 425-1700
CM: Mass load (kg COD/kg MLSSV/day):	betw een 0.1-0.4
HRT: Hydraulic retention time (hours):	betw een 0.5-7 days
Energy consumption (kW/m³):	betw een 0.2-0.4
Y: Cell production coefficient (g SSV/g BOD):	betw een 0.3-0.6
Kd: Endogenous respiration coefficient at 20 °C (1/d):	betw een 0.06-0.15
TRC: Cell retention time at 20 °C (days):	betw een 5-15
Aeration system:	
Oxygen required to remove BOD (kg O2/kg BOD removed):	betw een 0.9-1.3 for TRC betw een 5-20
Diffuser unit flow rate (Nm3/h):	betw een 1.70-6.80
DO: Dissolved oxygen (mg/L):	betw een 1-2
SOTE (%):	betw een 22-29
Kg O2 per m3 of air	0,28
Oxygen transfer factor	0,15
Nutrients required:	
Nitrogen required (g N/g BOD):	5 g of N per 100 g of BOD
Phosphorus required (g P/g BOD):	1 g of P per 100 g of BOD

Energy Consumption: Aeration: 0.8–1.8 kWh/m^3 depending on load and efficiency

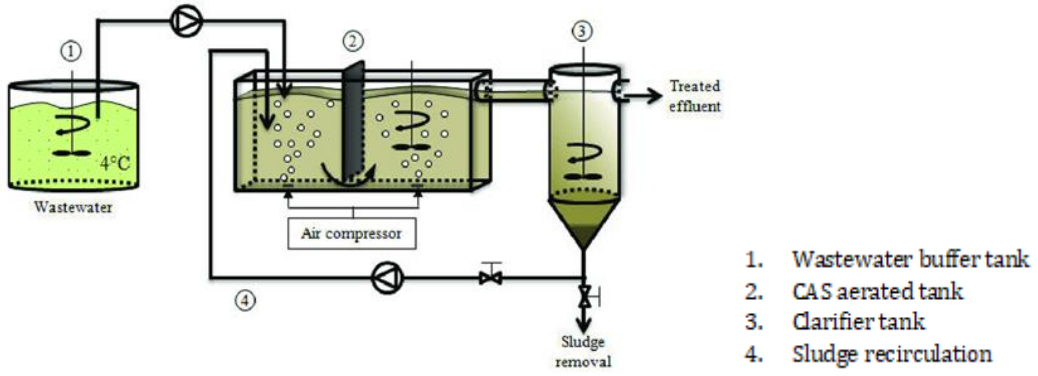


Image 9 CAS process (ResearchGate)

1.

Sequencing Batch Reactor (SBR):
Operates in a single tank with sequential phases: Fill, React, Settle, Draw, Idle. Suitable for intermittent flows and a smaller footprint.

Performance:
- BOD removal: >95%
- TSS removal: >90%
- Ammonia removal (nitrification): up to 90% with long SRT

Energy Consumption:

- Aeration: 0.6–1.5 kWh/m^3 depending on load and efficiency

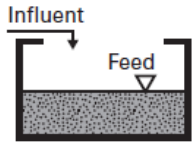
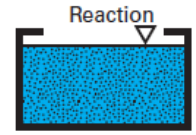
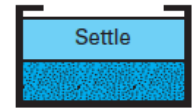
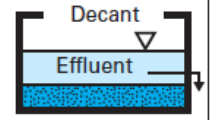
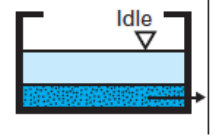
Sequence	Volume taken up (as a % of capacity)	Sequence duration (as a % of cycle)	Cycle stage	Object of the sequence	Air
1	60 to 100	33		Substrate input (denitrification)	With or without (optional)
2	100	33		Carbon removal (and nitrification)	With
3	100	16		Clarification	Without
4	100 to 65	14		Treated water removal	Without
5	65 to 60	4		Excess sludge	Without

Image 10 SBR process example (Degremont)

4.2 Membrane Bioreactor (MBR)

MBRs integrate biological treatment with membrane filtration, replacing secondary clarifiers and ensuring complete solid-liquid separation.

Membrane Types: UF immersed or UF external tangential filtration
Design parameters:

	In an MBR
Biological reactor:	**Range**
Typical Flow (m3/h)	betw een 2-100
CV: COD volumetric load (kg/m3 day):	betw een 1.2-3.2
MLSS: SS Mixed liquor (mg MLSS/L):	betw een 5000-20000
% SSV/SS:	0,85
MLSSV: Volatile SS mixture liquor (mg MLSSV/L):	betw een 4000-16000
CM: Mass load (kg COD/kg MLSSV/day):	betw een 0.1-0.4
HRT: Hydraulic retention time (hours):	betw een 4-6
Energy consumption (kW/m³):	betw een 0.2-0.4
Y: Cell production coefficient (g SSV/g BOD):	betw een 0.3-0.6
Kd: Endogenous respiration coefficient at 20 °C (1/d):	betw een 0.06-0.15
TRC: Cell retention time at 20 °C (days):	betw een 5-20
Aeration system:	
Oxygen required to remove BOD (kg O2/kg BOD removed):	betw een 0.9-1.3 for TRC betw een 5-20
Diffuser unit flow rate (Nm3/h):	betw een 1.70-6.80
DO: Dissolved oxygen (mg/L):	betw een 1-2
SOTE (%):	betw een 22-29
Kg O2 per m3 of air	0,28
Oxygen transfer factor	0,15
Nutrients required:	
Nitrogen required (g N/g BOD):	5 g of N per 100 g of BOD
Phosphorus required (g P/g BOD):	1 g of P per 100 g of BOD

Advantages:
- Excellent effluent quality (BOD < 10 mg/L, TSS < 1 mg/L)
- Compact design and modularity
- Suitable for water reuse and ZLD systems

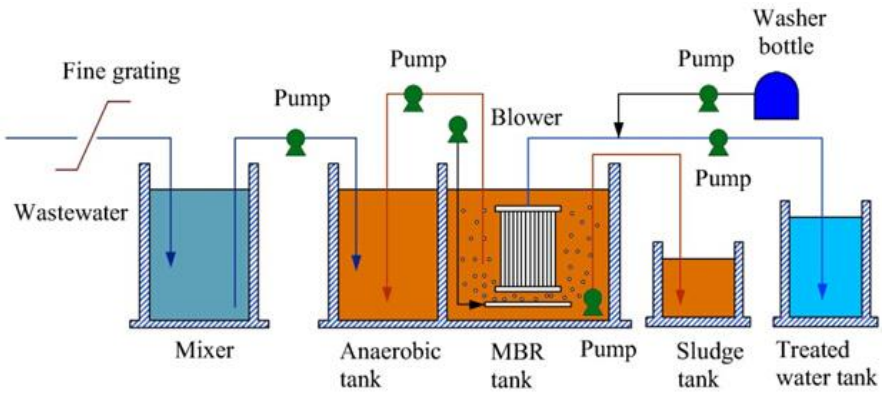


Image 11. MBR scheme (Greentech Env Serv)

4.3 Moving Bed Biofilm Reactor (MBBR)

MBBR uses free-floating plastic carriers in aerated or anoxic tanks to support biofilm development. Ideal for variable or high-strength loads.

Design Criteria: (Use CAS design except data below)
- Carrier fill fraction: 50–70% of tank volume
- Specific surface area: 500–1200 m^2/m^3
- HRT: 3–6 hours

Advantages:
- Resilient to load and temperature fluctuations
- Low sludge yield (0.2–0.5 kg TSS/kg COD)
- No need for sludge return

Applications:
- COD/BOD removal, nitrification/denitrification, industrial shock loads

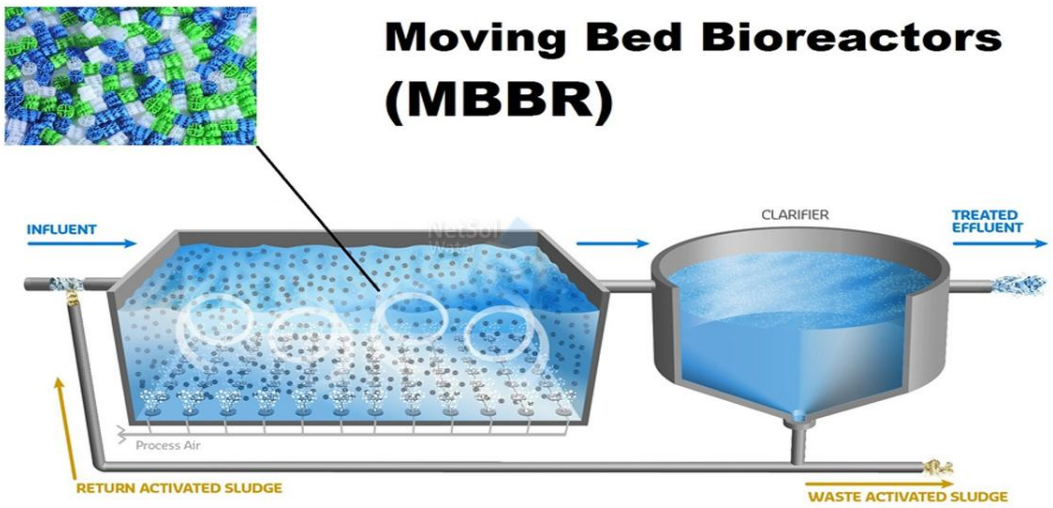


Image 12. Moving Bed Bioreactor (ResearchGate)

4.4 Anaerobic Treatment (UASB, EGSB)

Anaerobic reactors are used for high-strength wastewater (>3000 mg/L COD). They produce biogas (CH_4 + CO_2) as a renewable energy source.

Technologies:
- UASB: Upflow Anaerobic Sludge Blanket (granular sludge)
- EGSB: Expanded Granular Sludge Bed (higher upflow velocity)

Comparison: UASB vs EGSB Anaerobic Reactors

Both Upflow Anaerobic Sludge Blanket (UASB) and Expanded Granular Sludge Bed (EGSB) reactors are anaerobic wastewater treatment technologies. They share the basic principle of using granular sludge for biological degradation, but differ significantly in hydraulic design, loading capacity, and application range. Below is a technical comparison:

Table III Comparison

Feature	UASB (Upflow Anaerobic Sludge Blanket)	EGSB (Expanded Granular Sludge Bed)
Flow pattern	Up flow through a dense sludge blanket; low velocity keeps the bed compact.	Up flow at high velocity, causing partial fluidization and expansion of the sludge bed.
Superficial upflow velocity	0.5–1 m/h	3–10 m/h
Mixing	Mainly by biogas lift, with limited hydraulic mixing.	More intense mixing from biogas lifts and high hydraulic velocity.
Sludge type	Granular anaerobic sludge; dense and well settled.	Granular anaerobic sludge; more expanded for better wastewater contact.
Hydraulic Retention Time (HRT)	6–12 hours typical.	2–6 hours typical.
Organic Loading Rate (OLR)	5–10 kg COD/m^3·day.	10–25 kg COD/m^3·day.
Wastewater strength suitability	Medium- to high-strength wastewater can tolerate some suspended solids.	High-strength, low-suspended-solids wastewaters require high-rate treatment.
Performance at low temperatures	More sensitive to temperature drop.	Better performance at low temperatures due to higher mass transfer (still sensitive below ~15 °C).
Reactor height	Lower height-to-diameter ratio (H/D ~2–4).	Tall, slender design (H/D up to 10+).
Biogas–liquid–solid separation	Three-phase separator at top; less hydraulic stress.	Three-phase separator designed for higher flow velocities.
Footprint	Larger footprint for the same capacity.	Smaller footprint for the same capacity.

Design Parameters:
- HRT: 6–24 hours
- Organic Loading Rate (OLR): 2–10 kg COD/m^3·d
- Biogas yield: ~0.35 m^3/kg COD removed

Considerations:
- Temperature control (optimal: 30–38°C)
- Slow start-up and granule formation
- Requires post-treatment (e.g., CAS, MBR)

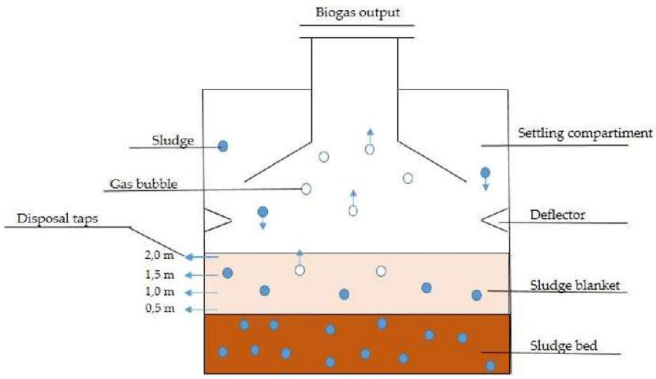


Image 13. UASB scheme (ResearchGate)

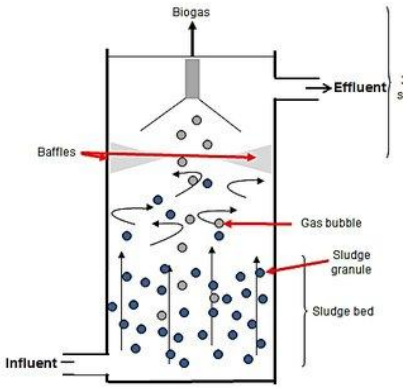


Image 14. EGSB scheme (ResearchGate)

4.5 Fixed-Bed Systems

Fixed-film reactors use stationary media (plastic, lignite coke, etc.) to which biomass attaches. They can operate under aerobic or anaerobic conditions, using lignite coke media (Biocarb® system), which can adsorb pick loads, inflows, and then regenerate carbon by M.O. action

Design Data: - Media surface area: 100–300 m^2/m^3

	In a Biocarb UBFB
Biological reactor:	**Range**
Typical Flow (m3/h)	between 1-15
CV: COD volumetric load (kg/m3 day):	between 2.0-4.0
MLSS: SS Mixed liquor (mg MLSS/L):	between 3000-6000
% SSV/SS:	0,85
MLSSV: Volatile SS mixture liquor (mg MLSSV/L):	between 2550-5100
CM: Mass load (kg COD/kg MLSSV/day):	between 0.1-0.4
HRT: Hydraulic retention time (hours):	between 4-6
Energy consumption (kW/m³):	between 0.2-0.4
Y: Cell production coefficient (g SSV/g BOD):	between 0.3-0.6
Kd: Endogenous respiration coefficient at 20 °C (1/d):	between 0.06-0.15
TRC: Cell retention time at 20 °C (days):	between 5-20
Aeration system:	
Oxygen required to remove BOD (kg O2/kg BOD removed):	between 0.9-1.3 for TRC between 5-20
Diffuser unit flow rate (Nm3/h):	between 1.70-6.80
DO: Dissolved oxygen (mg/L):	between 2-3
SOTE (%):	between 22-29
Kg O2 per m3 of air	0,28
Oxygen transfer factor	0,15
Nutrients required:	
Nitrogen required (g N/g BOD):	5 g of N per 100 g of BOD
Phosphorus required (g P/g BOD):	1 g of P per 100 g of BOD

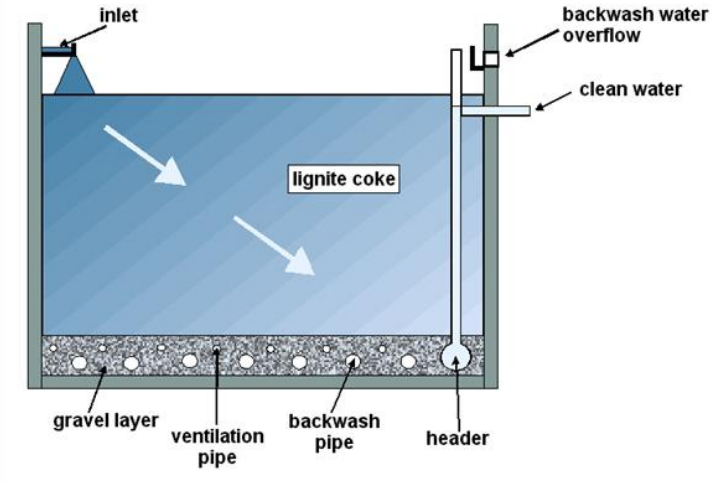


Image 15 Up flow Fix Bed Reactor (Biocarb®, Condorchem)

4.6 Nitrification and Denitrification

Biological nitrogen removal involves two main stages: nitrification and denitrification.

Nitrification (aerobic):
- Converts ammonium (NH_4^+) to nitrite (NO_2^-) and then nitrate (NO_3^-).
- Requires dissolved oxygen (DO > 2 mg/L), optimal temperature 25–35°C, and long SRT (>10 days).
- Key microorganisms: Nitrosomonas (ammonia oxidizers), Nitrobacter (nitrite oxidizers)

Denitrification (anoxic):
- Converts nitrate (NO_3^-) to nitrogen gas (N_2), removing it from the water.
- Requires carbon source (e.g., methanol, ethanol, acetate), DO < 0.5 mg/L
- SRT: 6–10 days, temperature: >15°C

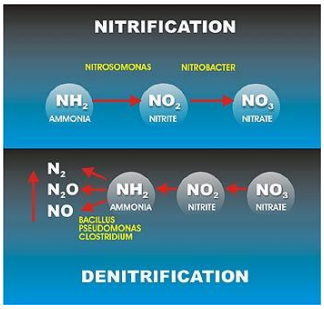


Image 16 Nitrification/Denitrification scheme (Jeontech)

There are two extended systems for nitrification-denitrification: CAS N_DN and MLE

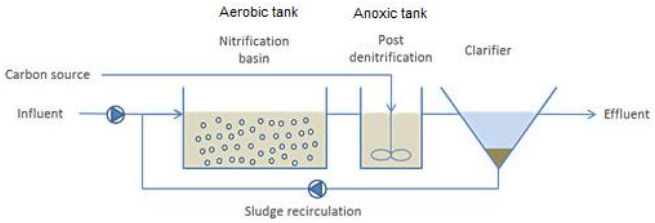


Image 17: Conventional CAS N-DN (ResearchGate)

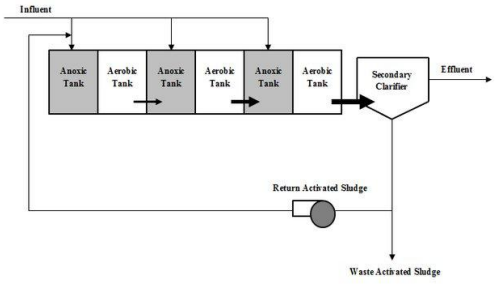


Image 18 MLE scheme (ResearchGate)

AEROBIC PROCESS

BOD and NH4 are eliminated in the presence of pure oxygen (O2)

Elimination of organic matter through oxidation with pure O2:

O.M. + microorganisms + nutrients + O2 ----> end products + new microorganisms + energy

2.2 g of O2 are needed to oxidize 1 g of BOD

Nitrification reaction (oxidation of NH4+ with pure O2):

2 NH4+ + 4 O2 --------> 2 NO3- + 4 H+ + 2 H2O

2 NH4+ + 3O2 ---> 2 NO2- + 4 H^+ + 2 H2O (Nitrosome bacteria)

2 NO2- + O2 ------> 2 NO3- (Nitrobacter bacteria)

4.57 g of O2 are needed to oxidize 1 g of NH4+

ANOXIC PROCESS

BOD (methanol or other) and NO3- are eliminated without the presence of pure oxygen (O2)

BOD (methanol) serves as an energy and carbon source, donating electrons (oxidizing) to reduce NO3

Heterotrophic denitrification reaction:

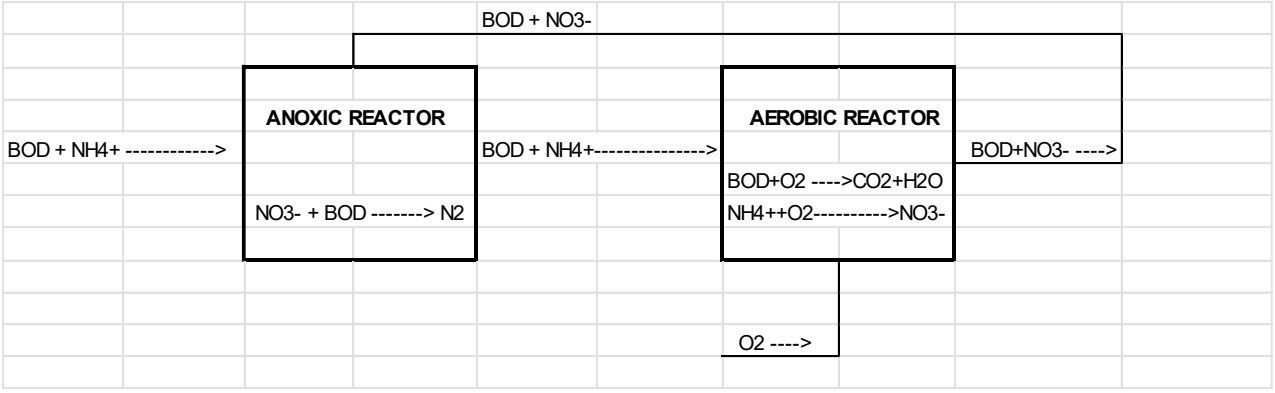
6 NO3- + 5 CH3OH --------> 3 N2 + 5 CO2 + 7 H2O + 6 OH

6 NO3- + 2CH3OH ------> 6 NO2- + 2 CO2 + 4 H2O

6 NO2- + 3CH3OH --> 3N2 + 3CO2 + 3H2O + 6 OH

2.86 g of O2 are needed to reduce 1 g of NO3

4.6 g of BOD (methanol) are needed to reduce 1 g of NO3



Comparison: Conventional Nitrification–Denitrification (CAS) vs Modified Ludzack–Ettinger (MLE)

Both Conventional Activated Sludge (CAS) nitrification–denitrification and the Modified Ludzack–Ettinger (MLE) process are biological nitrogen removal methods, but differ in configuration, carbon use, and energy demand. Below is a technical comparison: Table IV

Feature	Conventional Nitrification–Denitrification (CAS)	Modified Ludzack–Ettinger (MLE)
Basic principle	Two-step process: (1) Aerobic nitrification converts $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$; (2) Anoxic denitrification converts $NO_3^- \rightarrow N_2$ gas using organic carbon.	Similar steps, but with an anoxic zone first and internal recycling from aerobic to anoxic for pre-denitrification.
Configuration	Aerobic zone followed by an anoxic zone (post-denitrification).	Anoxic zone first, followed by aerobic zone; internal recycle rate typically 200–400% of influent flow.
Carbon source	Relies on influent BOD; may require external carbon if BOD is low.	Uses influent BOD more efficiently for denitrification, reducing the need for external carbon.
Oxygen demand	High: full nitrification of all NH_4^+ to NO_3^-.	Slightly lower than CAS due to pre-denitrification removing some nitrate before full nitrification.
Sludge age (SRT)	8–15 days at 20°C to sustain nitrifiers.	As with CAS, it must support nitrifiers in the aerobic zone.
COD/N removal ratio	Approximately 4–6 g COD per g N removed.	Approximately 3–5 g COD/g N removed (better carbon efficiency).
Temperature sensitivity	Performs best above 12°C; efficiency drops in colder conditions.	Like CAS, slightly better carbon efficiency in the same temperature range.
Energy consumption	High due to aeration demand for full nitrification.	Slightly reduced aeration compared to CAS; additional pumping energy for internal recycle.
By-products	Produces N_2 gas; potential N_2O emissions.	Same as CAS.
Main advantages	Proven, robust, flexible; handles variable loads well.	Better carbon utilization; lower external carbon requirement.
Main limitations	High energy and carbon requirements; high sludge production.	Requires large internal recycled pumps; nitrate leakage is possible.
Best application	Municipal/industrial plants with sufficient carbon and moderate energy cost.	Municipal WWTPs optimize carbon use and nitrogen removal without high carbon cost.

4.7 Autotrophic Denitrification: SOD and ANAMMOX ®

Autotrophic denitrification is a biological process that converts Nitrate ($NO3^-$) to nitrogen (N_2) under anoxic conditions using inorganic compounds, like sulfur or hydrogen, as electron donors rather than organic carbon

4.7.1 Sulfur-Oxidizing Denitrification (SOD)

SOD is an advanced process used to remove nitrates from wastewater using autotrophic elemental sulfur (S^0) or sulfides (H_2S) as electron donors under anoxic conditions

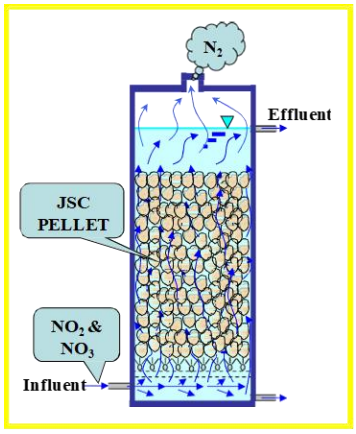
Key Reaction:
$2NO_3^- + 5S + 4H_2O \rightarrow N_2 + 5SO_4^{2-} + 8H^+$

Applications:
- Industrial effluents with high nitrate and low BOD
- Landfill leachate, mining water, fertilizer runoff

Design Conditions:
- pH range: 6.5–7.5 (buffer may be required due to acid generation)
- Reactor types: packed bed, fluidized bed, SBR
- S: N molar ratio ~2.5:1

Advantages:
- No external organic carbon source needed
- Efficient nitrate removal (>90%)
- Sulfate generation must be monitored and managed

Limitations:
- Sensitive to pH drops due to sulfur oxidation (except in JSC Pellets)
- Potential formation of elemental sulfur clogging in fixed media systems



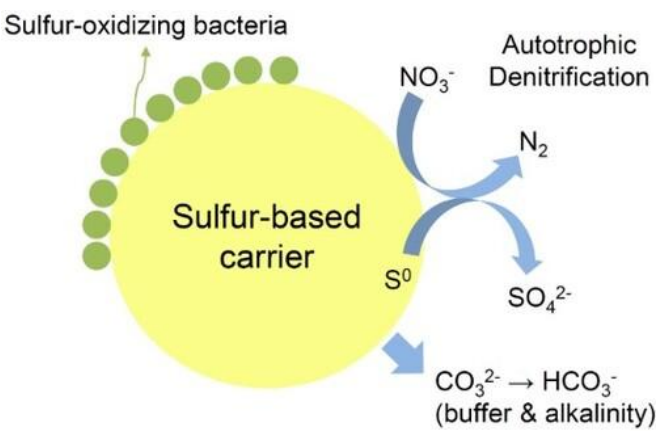


Image 19 JTC SOD Reactor (Jeontech) *Image 20 SOD process scheme (ResearchGate)*

4.7. ANAMMOX ® Process

Anammox (Anaerobic Ammonium Oxidation) is a biological nitrogen removal process where specialized autotrophic bacteria oxidize ammonium (NH_4^+) using nitrite (NO_2^-) as the electron acceptor, producing nitrogen gas (N_2) under anoxic conditions. It bypasses conventional denitrification, eliminating the need for organic carbon and reducing oxygen demand.

Key Reaction:
Overall stoichiometry (Strous et al., 1999):
$NH_4^+ + 1.32\ NO_2^- + 0.066\ HCO_3^- + 0.13\ H^+ \rightarrow 1.02\ N_2 + 0.26\ NO_3^- + 0.066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$

Applications
- Side stream treatment of anaerobic digester centrate or sludge dewatering liquors (high NH_4^+, low COD, warm temperature).
- Landfill leachate nitrogen removal, Industrial effluents with high ammonia and low biodegradable carbon (fertilizer plants, food industry, fermentation industry).

Design Conditions:
- pH range: 7.0-8.3
- Reactor types: SBR, MBBR, granular sludge, IFAS
- Nitrate to Ammonium molar ratio: ~1.3:1

Advantages
- No organic carbon requirement – works with very low COD/N ratio.
- ~60% lower aeration energy compared to conventional nitrification–denitrification.
- ~90% less sludge production due to autotrophic growth.
- Compact footprint due to high volumetric nitrogen removal rates.

Limitations
- Slow biomass growth (doubling time 10–30 days) – long start-up times (3–6 months).
- Temperature sensitivity – efficiency drops sharply below 15 °C.
- Sensitive to oxygen intrusion – requires careful DO control.

Image 20 ANAMMOX scheme

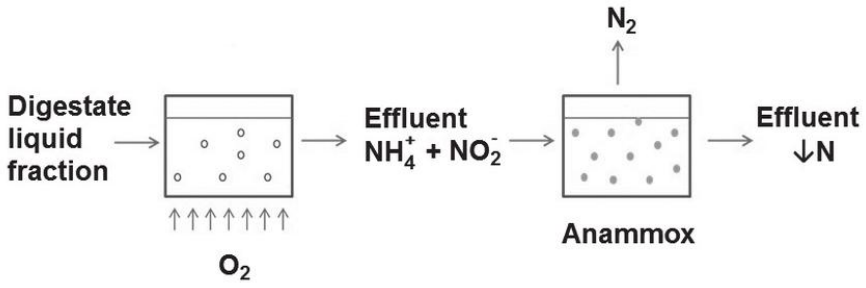


Image 21 ANAMMOX scheme (ResearchGate)

Table Comparison: Sulfur-Oxidizing Denitrification (SOD) vs Anammox

This table compares Sulfur-Oxidizing Denitrification (SOD), where sulfur compounds act as the electron donor for nitrate/nitrite reduction, with the Anammox process, where ammonium is oxidized with nitrite under anoxic conditions. Both are used for nitrogen removal but differ significantly in chemistry, requirements, and applications.

Table V comparison

Feature	**SOD (Sulfur-Oxidizing Denitrification)**	**Anammox (Anaerobic Ammonium Oxidation)**
Basic principle	Autotrophic denitrification using reduced sulfur (e.g., elemental S, sulfide, thiosulfate) as an electron donor to reduce NO_3^-/NO_2^- to N_2	Autotrophic anaerobic ammonium oxidation: NH_4^+ + NO_2^- → N_2 + small NO_3^-.
Electron donor	Sulfur compounds (S^0, S^{2-}, $S_2O_3^{2-}$).	Ammonium (NH_4^+).
Electron acceptor	Nitrate (NO_3^-) or nitrite (NO_2^-).	Nitrite (NO_2^-).
Carbon source req.	No organic carbon needed; inorganic carbon for biomass.	No organic carbon needed; inorganic carbon for biomass.
Oxygen demand	Anaerobic/anoxic process, no aeration needed except upstream nitrification if treating ammonia.	Partial aeration needed upstream for partial nitrification; ~60% less than conventional N-removal.
By-products	Sulfate (SO_4^{2-}) formed from sulfur oxidation; it increases TDS.	Small amount of nitrate (~10–15% of N removed).
Sludge production	Low (autotrophic process).	Very low (~90% less than conventional).
Temperature range	Broad, typically 10–35 °C.	Optimum 30–35 °C; performance drops <15 °C.
Start-up time	Moderate (weeks to months, depending on sulfur source).	Long (3–6 months) due to slow growth of Anammox bacteria.
Potential issues	Sulfate increase in effluent; potential H_2S generation if the process goes anaerobic.	NO_2^- inhibition at high concentrations; oxygen sensitivity; temperature limitations.
Best application	Low-COD, nitrate-rich waters (e.g., drinking water denitrification, mining wastewater).	High-strength ammonia wastewaters with low COD (side streams, digester centrate, landfill leachate).

Chapter 5: Physicochemical and Advanced Treatments

5.1 Coagulation and Flocculation

These processes destabilize colloids and promote aggregation, leading to floc formation.

Typical Coagulants:
- Inorganic: Aluminum sulfate, ferric chloride, PAC
- Organic: PolyDADMAC (cationic), PAM (anionic)

Equipment Used:
- In-line static mixers or mechanical rapid mixers for coagulation (30–60 sec)
- Hydraulic or mechanical flocculators (15–30 min)
- Lamella settlers or static clarifiers for solid-liquid separation
- DAF system (Dissolved Air Flotation)

Performance:
- TSS removal: 80–95%
- COD reduction: 20–60%
- Sludge generation: 1.5–5 kg/m^3 treated

Sludge treatment:
- Sludge thickening: gravity thickeners
- Sludge dewatering: belt press, filter press, centrifuge

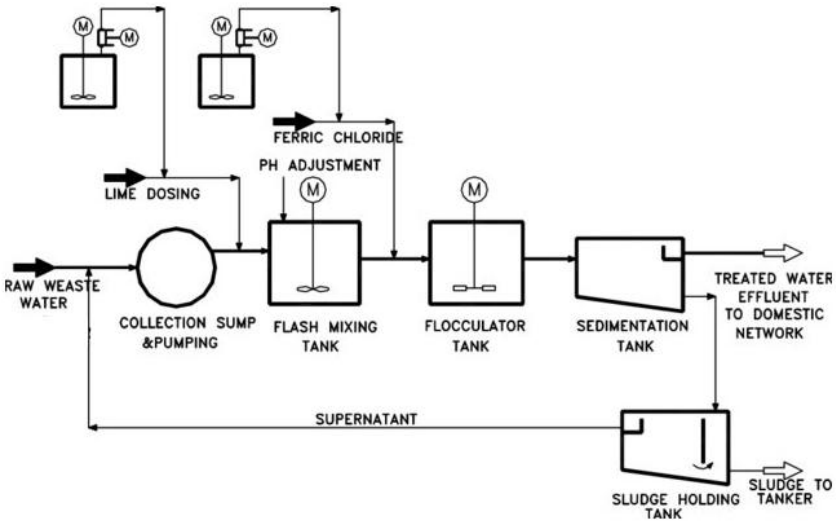


Image 22 Physicochemical process scheme (ResearchGate)

5.2 Chemical Precipitation (Metals, Phosphorus)

Used to remove dissolved metals and phosphates by forming insoluble precipitates.

Reagents:
- Lime, NaOH for pH adjustment
- Metal salts ($FeCl_3$, $Al_2(SO_4)_3$, $CaCl_2$)

Equipment Used:
- Reaction tanks with agitation
- In-line pH sensors and dosing systems
- Lamella clarifiers or static settlers for solid separation

Design Notes:
- Metal precipitation pH range varies by metal (e.g., Zn: 9–10)
- Sludge management: thickeners + filter press or rotary drum vacuum filters

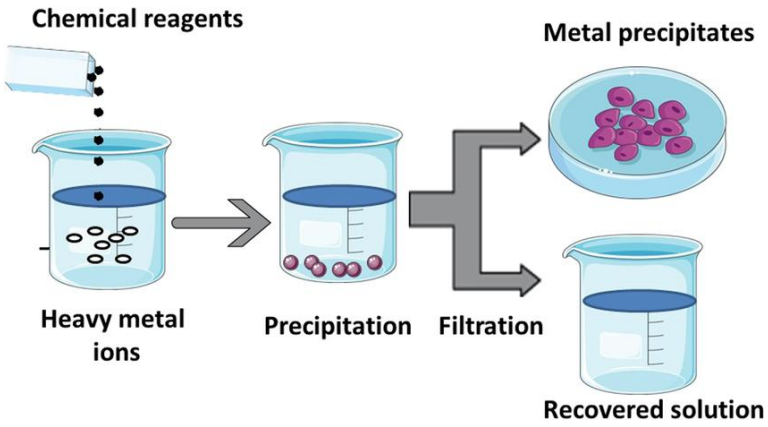


Image 23 Metal precipitation scheme (ResearchGate)

5.3 Pretreatment of Cr (VI) and Cyanides in Wastewater

5.3.1. Chromium (VI) Reduction to Chromium (III)

Cr (VI) is highly toxic, carcinogenic, and soluble. It must be reduced to Cr (III), which can be precipitated as insoluble $Cr(OH)_3$ for removal.

Chemical Reactions

Using ferrous sulfate ($FeSO_4 \cdot 7H_2O$):

$$Cr_2O_7^{2-} + 6\ Fe^{2+} + 14\ H^+ \rightarrow 2\ Cr^{3+} + 6\ Fe^{3+} + 7\ H_2O$$

Using sodium metabisulfite ($Na_2S_2O_5$):

$$Cr_2O_7^{2-} + 3\ HSO_3^- + 5\ H^+ \rightarrow 2\ Cr^{3+} + 3\ SO_4^{2-} + 4\ H_2O$$

Process Parameters

- pH: 2–3 for optimal reduction.
- ORP: ~+250 mV (Ag/AgCl reference).
- Dosage: Stoichiometric + 10–20% excess.
- After reduction, pH raised to 8–9 to precipitate $Cr(OH)_3$.

Common Reagents

- Ferrous sulfate ($FeSO_4 \cdot 7H_2O$)
- Sodium metabisulfite
- Sulfur dioxide

5.3.2 Cyanide (CN^-) Oxidation to Cyanate (CNO^-)

Cyanide is acutely toxic and inhibits biological treatment. Oxidizing CN^- to cyanate (CNO^-) reduces toxicity; cyanate can hydrolyze to CO_2 and N_2.

Chemical Reactions

Using alkaline chlorination (pH 10–11):

$$CN^- + Cl_2 \rightarrow CNCl + Cl^-$$

$$CNCl + 2\ OH^- \rightarrow CNO^- + Cl^- + H_2O$$

Overall:

$$CN^- + Cl_2 + 2\ OH^- \rightarrow CNO^- + 2\ Cl^- + H_2O$$

Process Parameters

- pH: 10–11 to prevent release of HCN gas.
- ORP: 600–650 mV for oxidation to cyanate.
- Dosage: 1 mg CN^- requires ~2.73 mg Cl_2 (stoichiometric) + 25% excess.

Common Reagents

- Sodium hypochlorite (NaOCl)
- Chlorine gas (Cl_2)
- Calcium hypochlorite [Ca $(OCl)_2$]

5.3.3. Control and Monitoring

- Continuous pH control with automatic dosing.
- Online ORP monitoring (different setpoints for reduction and oxidation).
- Regular sampling before and after treatment.

5.3.4. Alternative/Advanced Technologies

For Cr (VI):
- Ion exchange resins.
- Membrane filtration.
- Electrochemical reduction (Electrocoagulation with Fe electrodes).

For Cyanides:
- Ozone oxidation.
- Hydrogen peroxide oxidation with a catalyst.
- Electrochemical oxidation.
- Wet air oxidation.

5.4 Advanced Oxidation Processes (AOPs) for organic pollutant degradation in wastewater

Advanced oxidation processes (AOPs) are treatment technologies designed to generate highly reactive hydroxyl radicals (OH)
capable of oxidizing and mineralizing refractory organic compounds in wastewater. These radicals are non-selective and can degrade
a wide range of contaminants, including phenols, dyes, pharmaceuticals, and volatile organics.

UV/H_2O_2 Process

Main reactions: $H_2O_2 + hv \rightarrow 2{\bullet}OH$
$\bullet OH + RH \rightarrow H_2O + R\bullet$

Operating conditions: pH 5–9; UV 254 nm; H_2O_2 1–2× stoichiometric O_2; 10–30 min retention

Applications: Pharmaceuticals, Phenols, dyes

Advantages: No sludge, moderate COD range

Limitations: UV absorption by color, high energy demand

Typical COD removal: 50–80%

O_3/H_2O_2 (Peroxone Process)

Main reactions: $O_3 + H_2O_2 \rightarrow HO_2\bullet + O_2 + \bullet OH$
$O_3 + HO_2\bullet \rightarrow \bullet OH + O_2 + O_2\bullet^-$

Operating conditions: pH 7–9; O_3 10–30 mg/L; H_2O_2/O_3 ratio 1/10–1/5

Applications: Refractory organics, pesticides, solvents

Advantages: Strong oxidation, effective at neutral pH

Limitations: Needs efficient gas–liquid contact

Typical COD removal: 50–90%

O_3 (Ozone Oxidation)

Main reactions: $O_3 + RH \rightarrow RO\bullet + O_2$
$O_3 + H_2O \rightarrow 2{\bullet}OH + O_2$ (slow, pH-dependent)

Operating conditions: pH 2–10 (better at high pH); contact 10–60 min

Applications: Color, phenols, cyanides

Advantages: Simple, disinfecting capability

Limitations: Limited mineralization, high ozone demand

Typical COD removal: 30–60%

Fenton Process

Main reactions: $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH^-$
$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HO_2\bullet + H^+$

Operating conditions: pH 2.5–3.0; Fe^{2+} 20–100 mg/L; H_2O_2 1.5–2.5 g/g COD; 30–60 min

Applications: Textile, tannery, landfill leachate, tobacco wastewater

Advantages: Very effective, simple operation

Limitations: Acidic pH, sludge generation

Typical COD removal: 50–80%

Photo-Fenton Process

Main reactions: $Fe\ (OH)^{2+} + hv \rightarrow Fe^{2+} + \bullet OH$
$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH^-$

Operating conditions: pH 2.5–3.0; UV-A or solar; lower H_2O_2 demand

Applications: Industrial, phenolic, pharmaceutical wastewater

Advantages: Higher radical yield, less sludge

Limitations: Requires UV transparency

Typical COD removal: 70–95%

UV/TiO_2 Photocatalysis

Main reactions: $TiO_2 + hv \rightarrow e^- + h^+$
$h^+ + H_2O \rightarrow \bullet OH + H^+$
$e^- + O_2 \rightarrow O_2\bullet^-$
$\bullet OH + RH \rightarrow$ oxidized products

Operating conditions: pH 4–9; TiO_2 0.1–1 g/L; UV-A 365 nm

Applications: Pesticides, dyes, phenols

Advantages: Reusable catalyst, no sludge

Limitations: Turbidity interferes with light

Typical COD removal: 60–90%

Comparative Summary Table

Process	Main Oxidant(s)	Catalyst	pH	COD Removal (%)	Sludge	Main Applications
O_3	O_3	None	2–10	30–60	None	Color, phenols
O_3/H_2O_2	$O_3 + H_2O_2$	None	7–9	50–90	None	Refractory organics
UV/H_2O_2	H_2O_2 + UV	None	5–9	50–80	None	Dyes, phenols
Fenton	H_2O_2	Fe^{2+}	2.5–3.0	50–80	Yes	Colored effluents
Photo-Fenton	H_2O_2 + UV	Fe^{2+}	2.5–3.0	70–95	Moderate	Industrial wastewater
UV/TiO_2	O_2 + UV	TiO_2	4–9	60–90	None	Dyes, organics

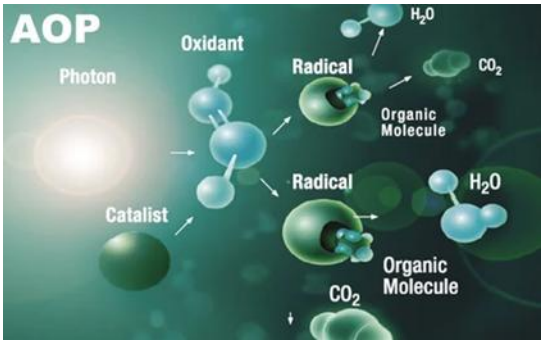


Image 24 AOP process for organic matter degradation (Nanobubble)

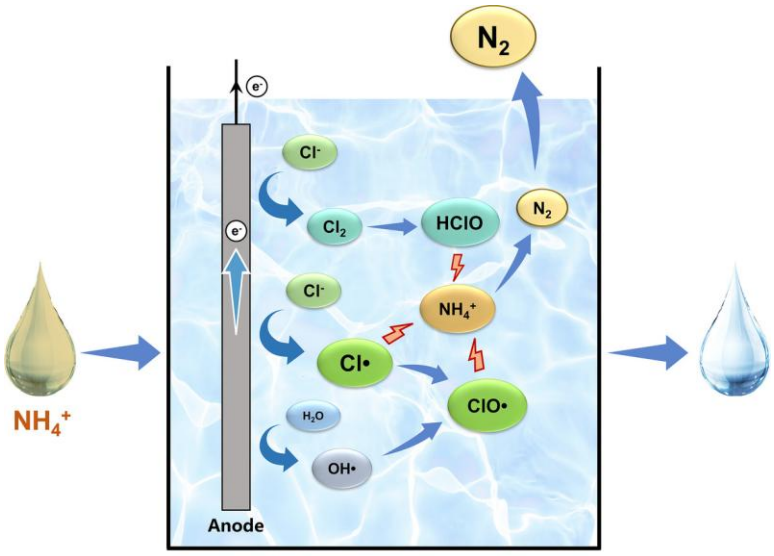
5.5 Electrooxidation

EO treats wastewater by applying an electric current to generate oxidative species, generally chlorine, using electrolysis of water containing almost 4000 mg/l of NaCl, Another expression for EO is electrochlorination

Equipment:
- EO cells with power supply: electrodes like BDD or Ti/Pt in continuous flow or batch mode

Operating Conditions:
- Current: 10–50 A/m^2, Voltage: 5–20 V
- EO for organics, surfactants, color, ammonia, phenol, etc. removal

Post treatment: recommended use activated carbon filters GAC to remove chloramines and other byproducts after EO using chlorines as oxidant species



$$2NH_4^+ + 3HClO \rightarrow N_2 + 3H_2O + 5H^+ + 3Cl^-$$

$$2NH_4^+ + 6Cl^{\bullet} \rightarrow N_2 + 6Cl^- + 8H^+$$

$$2NH_4^+ + 2ClO^{\bullet} \rightarrow N_2 + 2H_2O + 2Cl^- + 4H^+$$

Image 25: EO scheme for ammonia removal from WW (Elsevier STE volume 896)

5.6 Evaporation

Water evaporation is the **phase change** of water from liquid to vapor, occurring when molecules at the surface gain enough energy to overcome intermolecular forces and enter the gaseous phase.
This process requires **latent heat of vaporization**, which can come from the surrounding air, the liquid itself, or an external heat source.

Table 5 Types of Evaporation:

Type	Description	Heat Source	Temperature Change in Liquid	Typical Applications
Natural Evaporation	Occurs spontaneously due to differences in vapor pressure between the water surface and the surrounding air. Influenced by temperature, humidity, wind, and surface area.	Environment (sunlight, warm air, wind).	Yes – liquid cools unless replenished by ambient heat.	Evaporation from lakes, open tanks, and wet surfaces.
Adiabatic Evaporation	There is no need for a heat exchanger with the surroundings; latent heat comes from the liquid and the air, reducing their temperatures.	Internal energy of liquid and air.	Yes – temperature drops during evaporation.	Cooling towers, evaporative coolers, spray humidifiers.
Isothermal Evaporation	Evaporation at constant temperature; heat supplied externally matches the latent heat required for vaporization.	External heat source (steam, electric heating).	No – remains constant during evaporation.	Industrial evaporators, desalination, and concentration of solutions.

Table 6 Natural and adiabatic process

Type	Process	Water Recovery (condensed)	Heating needs	Equipment
NATURAL EVAPORATION	Solar Ponds	NO spread to the atmosphere	NO	Civil works
MECHANICAL EVAPORATION	Solar Ponds with atomizers	NO spread to the atmosphere	NO	Civil Works +Atomizers
FORCED AIR HUMIDIFICATION	Humidification Columns	NO spread to the atmosphere	YES	Mechanical Equipment
FORCED AIR HUMIDIFICATION	Humidification / Dehumidification columns	YES 75-80% rest spread to the atmosphere	YES	Mechanical Equipment

5.6.1 Natural Evaporation (ZLD)

Evaporation ponds are shallow basins designed to concentrate or dispose of wastewater by using natural evaporation from sun and wind. They are commonly used for brine disposal (desalination plants), mining and mineral recovery, and industrial wastewater with low organic load

The design of an evaporation pond requires the following information:
- Wastewater volume to be disposed of per year (m^3/year).
- Evaporation rate at the site (mm/year or m/year) from meteorological data.
- Rainfall (mm/year) to calculate net evaporation.
- Allowable water depth (m).
- Soil permeability or need for liners (HDPE, clay).
- Concentration factor if product recovery is needed.

Net Evaporation Rate Calculation

The net evaporation rate is calculated as:
$E_{net} = E_{gross} - P$
Where:
- E_{net} = net evaporation (m/year)
- E_{gross} = gross evaporation from weather data (m/year)
- P = precipitation (m/year)

Surface Area Calculation

If inflow rate is Qin (m^3/year):
$A = Q_{in} / E_{net}$
Where:
- A = pond surface area (m^2)
- E_{net} in m/year.

Depth and Volume

Typical pond depths range from 0.3 to 1.5 m for efficient evaporation. Shallower ponds evaporate faster but require more surface area. Depth also affects the hydraulic retention time (HRT), calculated as:
HRT = Volume of pond / Daily inflow

Shape and Layout

Ponds should have elongated or irregular shapes to maximize wind exposure. Multiple cells provide operational flexibility, allowing sequential filling and drying, and enabling maintenance without total shutdown.

Lining and Seepage Control

HDPE liners or compacted clay layers are used to prevent groundwater contamination. Maximum seepage rates are typically specified below 1×10^{-6} m/s.

Additional Considerations and Atomizer Integration

A freeboard of 0.3–0.5 m above the maximum water level should be included to handle rain events. If salt precipitation occurs, a plan for periodic removal is necessary. Safety measures include fencing, signage, and wildlife deterrents, and environmental permits must be obtained.

To increase evaporation capacity, atomizers or spray systems can be installed to create a fine mist of wastewater. This increases the surface area exposed to air, accelerating evaporation rates. Atomizers are especially effective in dry, windy climates and can be operated during peak sun hours to maximize efficiency.

Image 26 Mechanical Forced Evaporation (ORS)

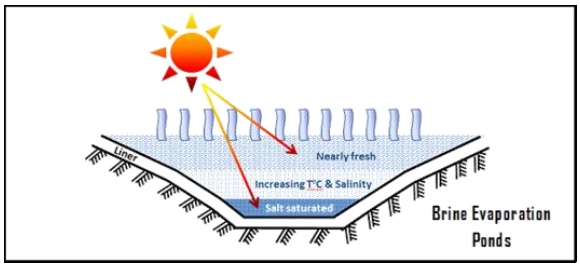


Image 27 Natural Evaporation Pond (Lenntech)

5.6.2 Adiabatic evaporation (MLD)

Adiabatic evaporators use the latent heat of vaporization, drawn from the liquid and the surrounding air without external heat input, to evaporate water or process liquid. The process results in a drop in temperature of both the liquid and air stream. They are used in cooling towers, air humidification systems, and wastewater concentration.

To design an adiabatic evaporator, the following data are required:
- Inlet air temperature (°C) and relative humidity (%).
- Air flow rate (m^3/h).
- Liquid flow rate (m^3/h) to be evaporated.
- Target outlet air relative humidity or wet bulb approach.
- Height and type of packing or contact media.
- Pressure drop limitations across the packing.
- For HD and HDH systems, intended humidity output and heating integration.

-Basic HD and HDH Principles

HD (Humidification-Dehumidification) systems operate by:
- HD: Air is brought into contact with liquid in a packed bed or spray chamber, absorbing moisture and cooling adiabatically until close to the wet bulb temperature.
- HDH: After humidification, the warm, moist air passes through a condenser where moisture condenses, recovering distilled water. Additional heating before humidification can increase evaporation capacity.

-Air-Water Contact Design

The effectiveness of an adiabatic evaporator depends on maximizing the contact area and time between air and water. Common designs use structured packing, random packing, or spray nozzles to create a large surface area for evaporation.

-Mass and Energy Balance

The evaporated water mass flow rate ($m_{\_evap}$) can be estimated by:

$m_{evap} = m_{air} \times (\omega_{out} - \omega_{in})$

Where:
- m_{air} = dry air mass flow rate (kg/s)
- ω_{in}, ω_{out} = humidity ratios (kg water/kg dry air) at inlet and outlet

Energy balance:
$h_{out} \approx h_{in}$ (adiabatic) → Sensible heat converts to latent heat for evaporation

-Sizing the Contact Media Height (HDH)

The height of packing (HD) or total column height (HDH) is determined by the number of transfer units (NTU) and the mass transfer coefficient. Higher packing height increases the approach to equilibrium humidity.

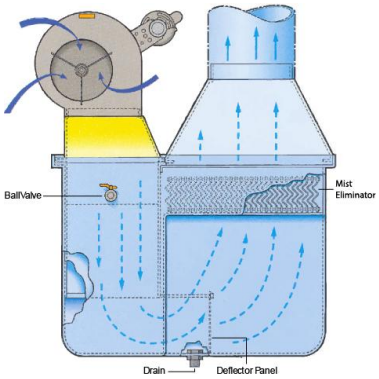
-Additional Considerations

- Use corrosion-resistant materials due to continuous moisture exposure.
- Ensure droplet separators to prevent carryover.
- For HDH: Optimize condenser heat recovery.
- For HD: Select fans capable of handling required air flow at acceptable pressure drop.

-Example Calculation Summary

Given:
- Inlet air: 35°C, 30% RH
- Outlet air target: 90% RH
- Air flow: 10,000 m^3/h

Calculate the inlet and outlet humidity ratios from psychrometric charts, apply a mass balance to determine the evaporation rate, and select the packing size and fan power accordingly.



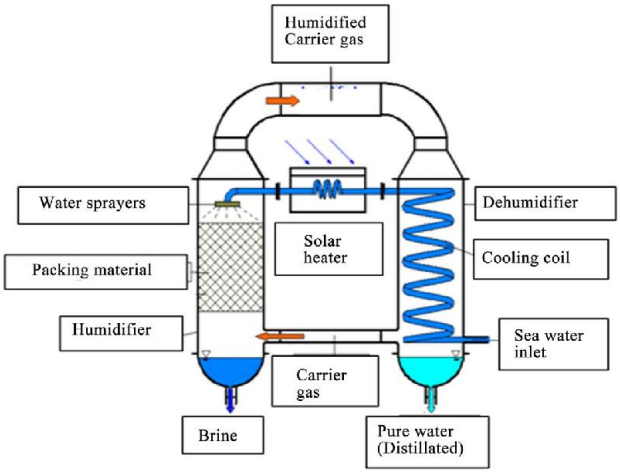


Image 28: Humidification evaporator (Met-Chem) *Image 29 HDH evaporation scheme (ResearchGate)*

Comments about Natural Evaporation Ponds and Adiabatic Evaporation

Evaporation ponds are a long-term method for concentrating brine from mining tailings, oil and gas produced water, brine rejects from desalination plants, olive mill liquid waste, and similar sources. Obviously, the field needs to be in warm, dry, and wind areas; in other cases, the evaporation is negligible

Pros: Moderate cost in capital (land, excavation, and lining), very low operation cost
Cons: Poor balance between evaporated water and filled water in the rainy season. Evaporated water cannot be recovered

Environmental concerns: Groundwater contamination from leaks; attraction of wildlife, leading to mortality or bioaccumulation in the food chain; overflow during rainfall; odors dispersed by wind; and community complaints.

Adiabatic Evaporators: A poorly extended procedure for concentrating liquid wastes, treating low COD or organics wastewater to avoid spread to the atmosphere, brines, and RO reject preconcentration before crystallization, landfill leachate with moderate organic load, concentrating rinsing water from metal finishing and electroplating

Pros: Moderate cost in capital, can use medium temperature (40-60º C) waste thermal energy, geothermal water, CHP water cooling circuit, etc.
Cons: Extremely sensitive to ambient air humidity, production falls drastically when humid air is present; in case that needs use, an external heat source produced by fuel or electricity is required, the operation cost is too high; the concentration capacity is moderate, due to the risk of clogging internal column elements

Environmental concerns: Volatile compounds are emitted into the atmosphere, requiring an air permitting upgrade, and odors are emitted, leading to community complaints.

5.6.3 Isothermal evaporation (MLD)

Isothermal evaporation involves phase change from liquid to vapor at constant temperature, with the heat of vaporization supplied from an external source. The choice of operating pressure and heating method determines efficiency, complexity, and suitability for different products.

Table 7: Isothermal Evaporators Classification and Comparison

Category	Evaporator Type	Pressure	Heat Source	Main Characteristics
Atmospheric Pressure	Direct-fired Evaporator	Atmospheric	Burner (gas/diesel)	Simple design, high energy use, releases vapor to the atmosphere
Atmospheric Pressure	Steam-heated Evaporator	Atmospheric	Steam from the boiler	Moderate efficiency, relatively high steam consumption, vented vapor
Vacuum	Single-effect Vacuum	Vacuum (AP <100 mbar)	Heat pump	Lower boiling point, energy saving, compact
Vacuum	Multiple effect (MEE)	Vacuum cascade	Steam	2–6 stages; reuses latent heat, better energy efficiency
Vacuum	Mechanical Vapor Recompression (MVR)	Vacuum (AP <950 mbar)	Electricity (compressor)	Very low OPEX, efficient for large volumes, closed loop
Vacuum	Thermal Vapor Recompression (TVR)	Vacuum cascade	Steam (ejector)	Intermediate between MEE and MVR in efficiency

5.6.3.1 Atmospheric Pressure. Direct-fired/Steam-heated

An atmospheric evaporator operates at near-atmospheric pressure (1 bar abs), so water boils around 100 °C. It is a simple, robust system for concentrating solutions by water evaporation without vacuum or vapor compression.
- Gas-fired: uses direct flame burners or heat exchangers powered by natural gas or LPG.
- Steam-heated: uses saturated steam in a heat exchanger (coil or jacket).

Table 8 Comparison

Feature	**Gas-Fired**	**Steam-Heated**
Simplicity	High. No boiler is needed if the burner is available	High, but requires an external boiler
Capital Cost	Lower if a burner exists	Lower if the steam network is available
Maintenance	Medium: burners need cleaning and emission control	Low: if a well-designed exchanger
Thermal Efficiency	Lower (~50–60%)	Higher if from cogeneration (~80–90%)
Temperature Control	Harder with a direct burner	Better via steam valves
Vapor Recovery	Usually lost	Can be partially reused

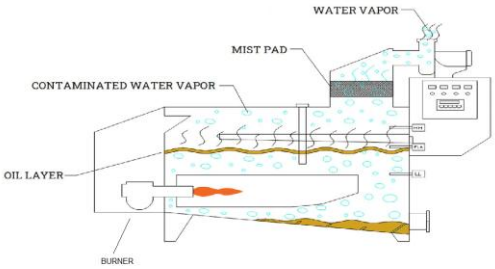


Image 28 Gas-Fired Thermal Evaporator (IQS)

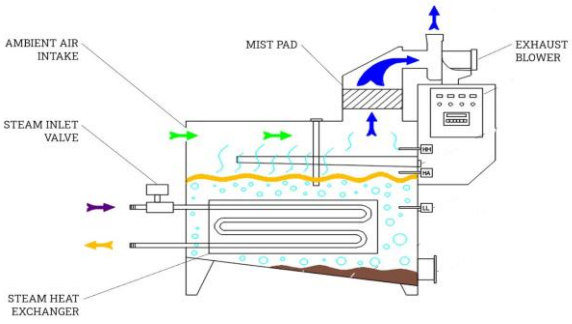


Image 29 Steam-Heated Thermal Evaporator (IQS)

5.6.3.2 Vacuum Evaporators

Vacuum evaporators operate at sub-atmospheric pressure to lower the boiling point, thereby minimizing thermal degradation and scaling. They require a heat source and a vacuum system.

Heat Pump Evaporators

- Use a refrigeration cycle to recover latent heat from vapor and reuse it for evaporation.
- High energy efficiency for low to medium capacity (0.1-2.0 m3/h)
- Typical for wastewater concentration and zero liquid discharge (ZLD) applications
-Works a low boiling water temperature (32-38 ºC)

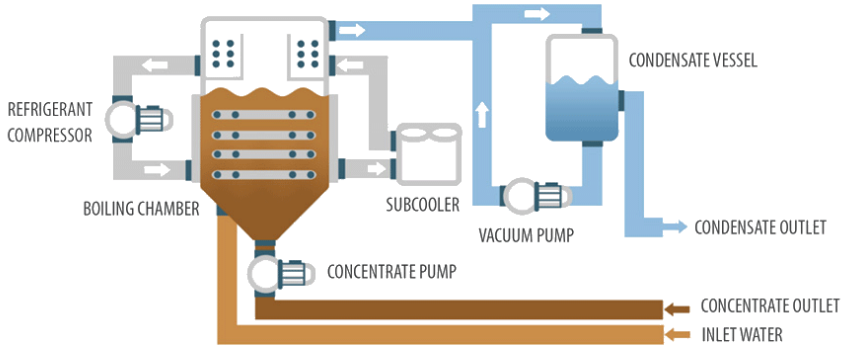


Image 30 Heat Pump low temperature evaporator (Condorchem)

Design Considerations

- Calculate the evaporation rate and match it with the heat pump capacity.
- Select compressor type (rotary, screw) based on capacity and temperature lift.
- Ensure proper heat exchanger design for both evaporator and condenser sides.
- Evaluate potential foaming production: anti-foaming agent needs
- Calculate maximum concentration according to the TDS feed wastewater

Mechanical Vapor Recompression (MVR)

- The heart of the system is the blower; the blower draws the saturated vapor and compresses it to raise the temperature and pressure, producing superheated steam, which is reused as heating steam that condenses in the HX and gives the latent heat to the fluid to evaporate.
- High efficiency for large capacities.
- Operates at constant temperature with reduced external steam demand.

In Mechanical Vapor Recompression (MVR) systems, Roots blowers and turbo fans are used to compress and recirculate vapor. Below is a technical comparison of their most relevant characteristics.

Table 9 Comparison: Roots Blower vs Turbo Fan for MVR

Feature	Roots Pump / Roots Blower	Turbo Fan / High-Speed Centrifugal Fan
Compression principle	Positive displacement – traps vapor between lobes and casing, compression occurs externally in the system.	Dynamic compression – the impeller accelerates the vapor; the diffuser converts velocity into pressure.
Typical pressure ratio	Low: ΔP ≈ 0.1–0.3 bar per stage, nearly constant flow over a wide pressure range.	Low: ΔP ≈ 0.05–0.15 bar per stage, performance more dependent on operating point.
Isentropic efficiency	50–65% higher energy consumption for the same duty than a turbo fan.	65–80% at design point, lower kWh/t evaporated if properly matched.
Flow rate range	Small to medium (up to ~3000 kg/h steam in MVR service).	Medium to very large (up to ~50,000 kg/h steam)
Rotational speed	Low to moderate (1,500–3,600 rpm).	Very high (8,000–20,000 rpm or more).
Maintenance	Simple, robust, better tolerance to droplets and contamination. Requires oil changes and lobe clearance checks.	More sensitive to droplets or solids, it requires precise balancing and maintenance of impellers and bearings.
Tolerance to wet vapor	High – handles saturated or slightly wet vapor without issues.	Low risk of erosion or fouling; requires efficient moisture separators.
Noise level	Higher requires an acoustic enclosure.	Lower-tonal noise but high-frequency noise may require an acoustic enclosure.
Capital cost (CAPEX)	Lower for small/medium capacities.	Higher for small capacities, more competitive at large flows.
Best MVR application	Small to medium plants, harsher vapor quality.	Large plants, stable operation, clean vapor conditions.

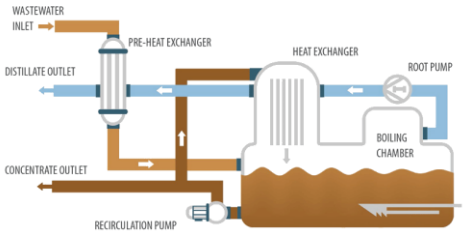


Image 31: MVR evaporator with Root Pump

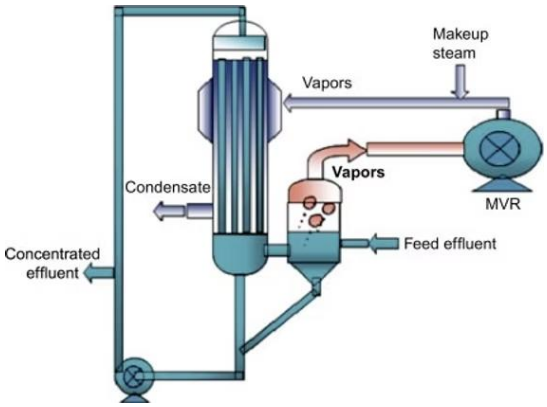


Image 32 MRV with Turbo Fan

Image 33: Root Pump (Kaeser)

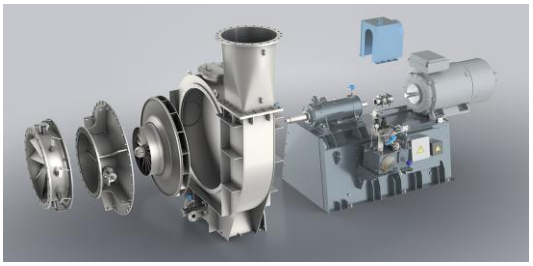


Image 34: Turbo Fan (Piller)

Design Considerations

- Determine vapor flow rate and compression ratio.
- Select blower or compressor type.
- Size heat transfer surfaces for small temperature differences (ΔT = 3–6°C).

Multiple-Effect Evaporators (MFE)

- The most robust, flexible, and easiest to maintain evaporator among others
-Vapor from one effect is used to heat the next, operating at progressively lower pressures.
-Reduces steam consumption compared to single-effect systems.
-Works in serial or parallel, co-current or countercurrent

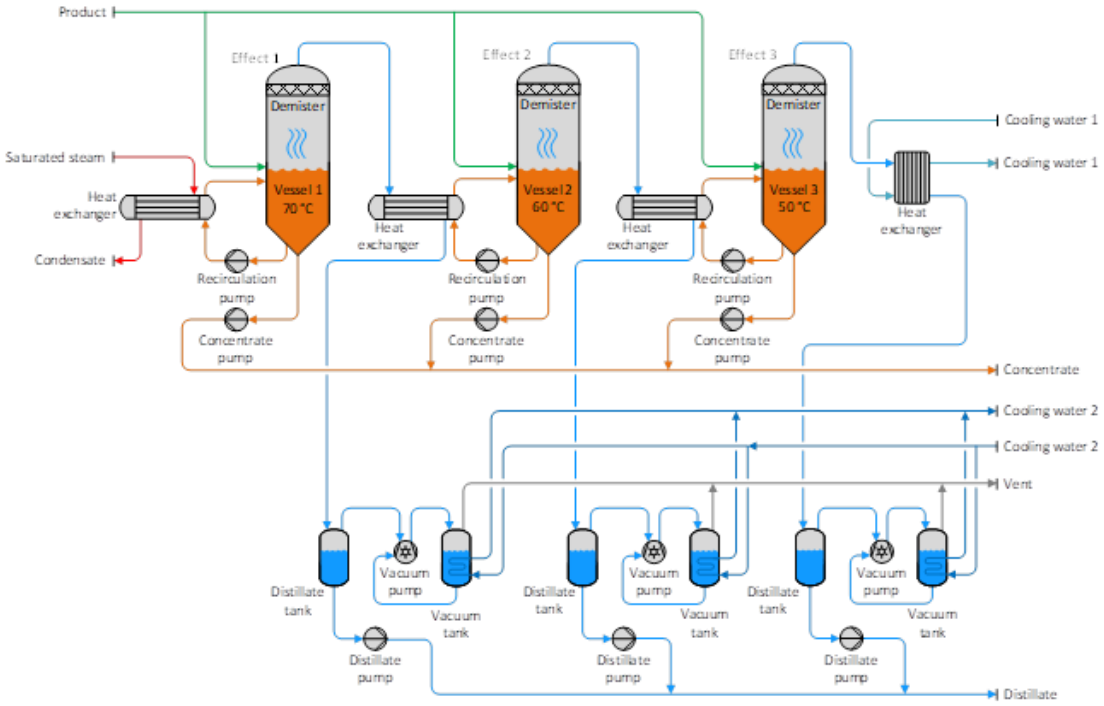


Image 35 MFE evaporator process scheme

Image 36: MFE 3 efects evaporator

Design Considerations

- Decide the number of effects based on energy savings and capital cost.
- Balance heat transfer areas across effects.
- Control vapor and condensate flow to prevent flooding.

Thermal Vapor Recompression (TVR)

- Uses a steam ejector to mix high-pressure motive steam with low-pressure vapor, increasing temperature for reuse.
- Intermediate efficiency and lower capital cost than MVR.

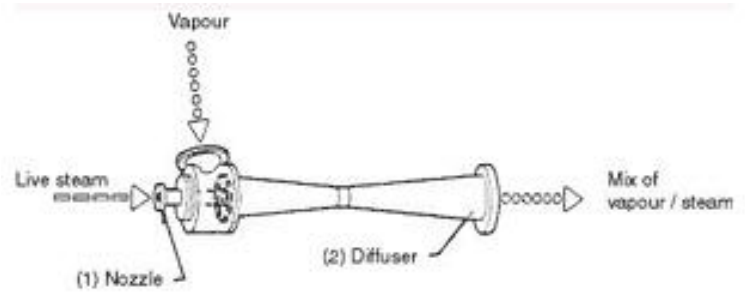


Image 37: Steam ejector

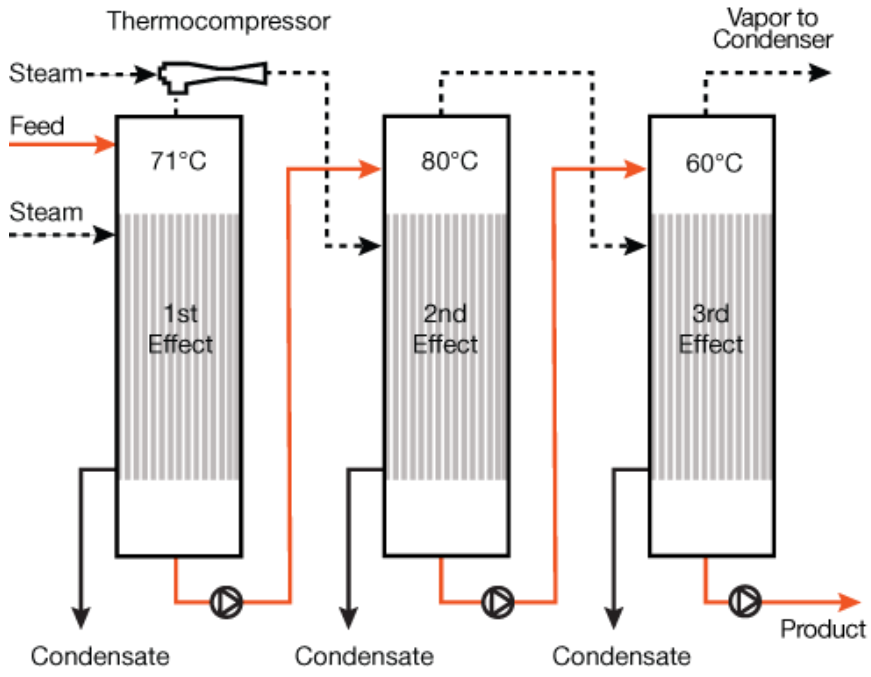


Image 37: TVR 3 effects evaporator

Design Considerations

- Select ejector size and motive steam pressure.
- Integrate with single or multiple-effect evaporators.
- Monitor for nozzle wear and efficiency loss.

Conclusion

The selection of the isothermal evaporator type depends on product sensitivity, energy cost, water removal rate, and available utilities. Atmospheric pressure units offer simplicity but low efficiency. Vacuum systems, particularly MVR, TVR, and MFE, offer high efficiency while preserving product quality. Heat pump evaporators are ideal for low-temperature and small to medium-scale operations.

5.7 Crystallization Systems (ZLD)

Crystallization recovers dissolved salts by promoting crystal formation.

Types of Crystallizers:

1. By Concentration (**Thermal Crystallization**):
   - Forced circulation or falling film evaporative crystallizers
   - High-energy but robust for ZLD
   - Suitable for NaCl, Na_2SO_4, KCl

2. Cold Crystallization (**Chilled Crystallization**):
   - Induces oversaturation by cooling
   - Requires refrigeration units and heat exchangers
   - Used when solubility drops significantly with temperature
   - Suitable for products when solubility decreases at low temperatures

3. Antisolvent Crystallization (**Precipitation by displacement**)
   - Addition of solvents like ethanol, acetone, to reduce solubility
   - Applied in pharmaceutical or specialty chemical recovery

Equipment:
- Crystallizers (batch, continuous)
- Agitated tanks or fluidized beds
- Seed dosing systems
- Centrifuges or filters for solid-liquid separation

Parameters:
- Supersaturation control is critical (ΔC)
- Crystal size, purity, and yield depend on temperature gradients and residence time

Thermal crystallizers

Using thermal energy to produce solvent evaporation by ebullition and create supersaturation in the product, then precipitate, creating seeds of crystals. The product obtained in discharge is named Slurry (a mixture of mother liquor saturated and solids)

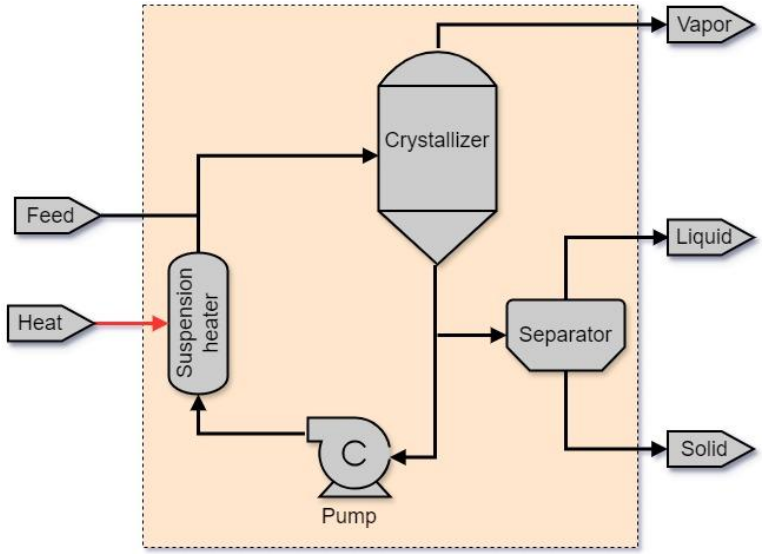
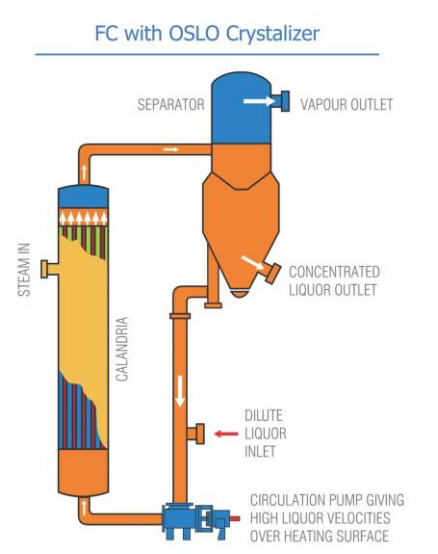


Image 38: General scheme for thermal crystallization (ResearchGate)

Types of thermal crystallizers

-Oslo: magma circulation (external HX)
-Flash forced circulation (external HX)
-Jacketed HX and internal scrapper



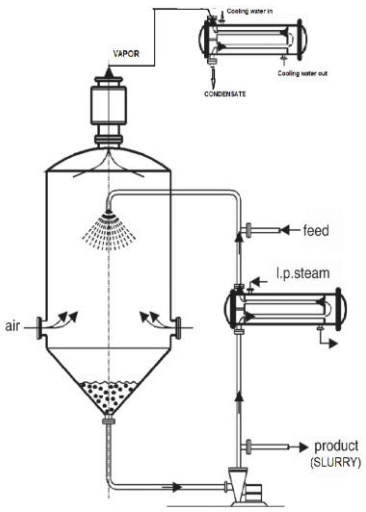


Image 39 OSLO crystallizer (CT)

Image 40 F.C. flash crystallizer (horizontal HX)(Scribd)

Low temperature Super concentrator & Dryer

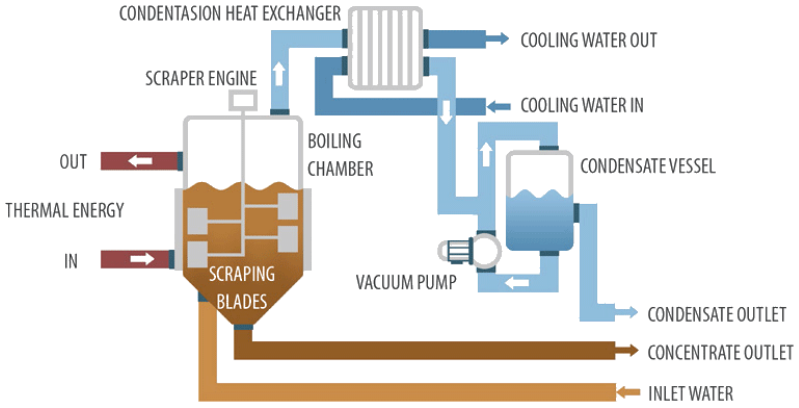


Image 41 Low or medium T crystallizer jacketed HX with internal scraper (Condorchem)

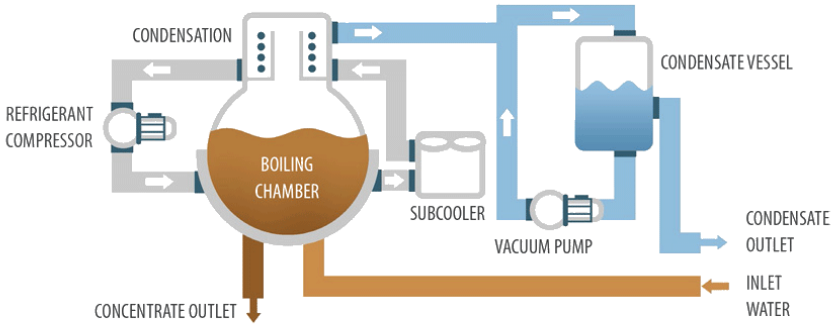


Image 42 Low T horizontal crystallizer and dryer (Condorchem)

Cooling Crystallizers

Based on the supersaturation produced by chilling the solution to produce salt precipitation

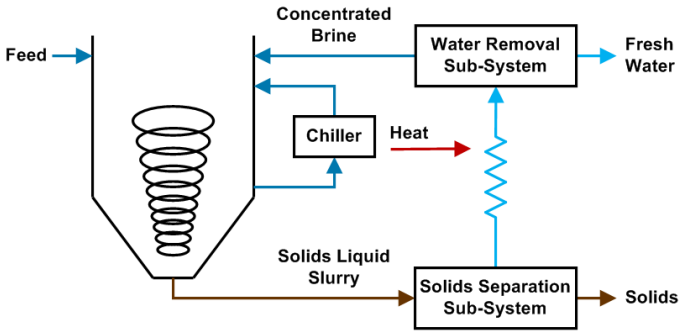


Image 43. General scheme for Chilled (cooling) crystallizers (Scribd)

Application	Examples	Why Suitable
Inorganic salts	Sodium sulfate, potassium nitrate, ammonium chloride	High solubility at high T, low solubility at low T
Organic chemicals	Sugar, citric acid, urea	Solubility strongly decreases with cooling
Pharmaceutical compounds	APIs such as paracetamol, aspirin	Allows size and purity control
Metal salts & hydrates	Fe $SO_4 \cdot 7H_2O$, Mg $SO_4 \cdot 7H_2O$	Formation of crystals upon cooling from a hot solution
Purification after evaporation	Brine concentration processes	Cooling induces the precipitation of salts selectively

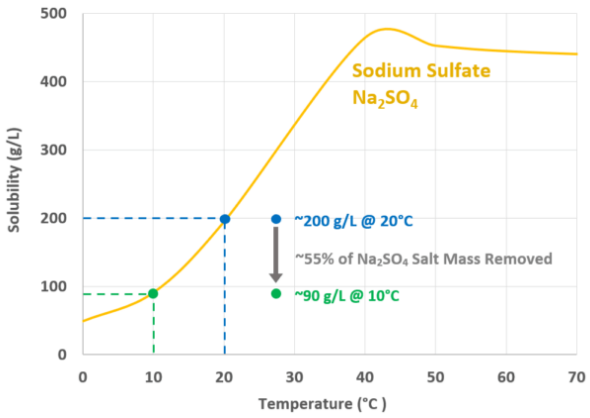


Image 44. Solubility for NaSO4 in water, depending on temperature

Slurry solid/liquid separation and salt dehydration

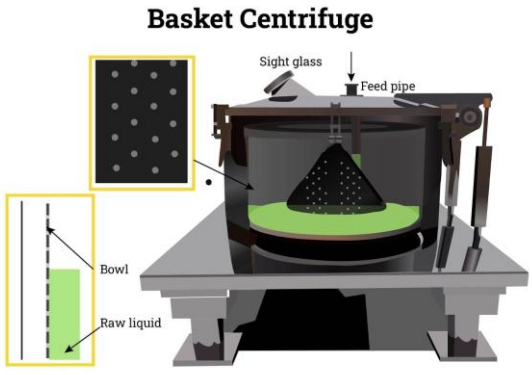
The centrifuge process is a mechanical separation technique used to separate solid crystals from the mother liquor after crystallization.
It applies centrifugal force to accelerate solid–liquid separation, enabling efficient washing and partial drying of crystals.

Process Description

After crystallization, the slurry contains solid crystals suspended in the mother liquor. The centrifuge separates these two phases through the following steps:
1. Feeding of slurry into the centrifuge bowl or basket.
2. Acceleration and solid–liquid separation by centrifugal force.
3. Filtration of the mother liquor through a screen or filter cloth.
4. Washing the crystal cake with clean solvent.
5. Partial drying of the cake by continued spinning.
6. Discharge of the crystals and collection of the separated mother liquor.

Principle of Operation

Centrifugal separation exploits the density difference between the solid and liquid phases. When the basket or bowl rotates at high speed, centrifugal force drives denser solids toward the wall, while the lighter liquid passes through the filter medium and exits the centrifuge.
The centrifugal force is expressed as: $F = m \times \omega^2 \times r$



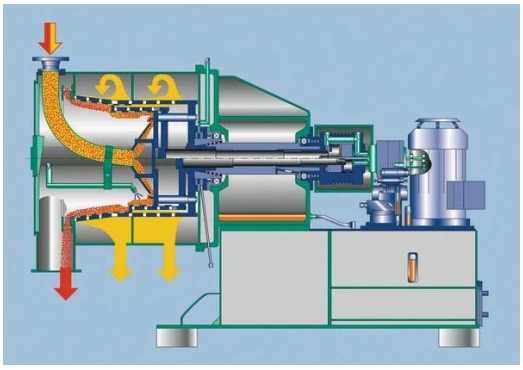


Image 45 Vertical basket centrifuge *Image 46 Pusher Centrifuge*

Types of Centrifuges in Crystallization

Table 10

Type	Description	Typical Use	Operation
Perforated basket centrifuge	Rotating basket with a perforated wall and filter cloth.	Large salt or sugar crystals.	Batch
Peeler centrifuge	The peeling knife scrapes off the solid cake after drainage.	Fine or fragile crystals.	Batch/continuous
Pusher centrifuge	The reciprocating piston pushes solids continuously through the screen.	Large-scale salt or fertilizer separation.	Continuous
Screen scroll centrifuge	Screw conveyor moves solids while the liquid drains through the screen.	Fine or slurry-like crystals.	Continuous

Advantages and Limitations

Advantages:
- High separation efficiency and high product purity.
- Short cycle times, with continuous operation possible.
- Integrated washing and partial drying within one unit.
- Easy scale-up from pilot to industrial size.

Limitations:
- Inefficient for very fine or compressible solids.
- Fragile crystals may break under strong centrifugal stress.
- Residual moisture requires additional drying.
- Higher energy consumption than gravity settling or filtration.

Integration in Crystallization Plants

Typical process flow:
Crystallizer → Slurry Tank → Centrifuge (centrate return to crystallizer) +Solids → Dryer → Product Storage → Packaging
The separated mother liquor is commonly recycled to the crystallizer or treated to recover dissolved materials.

5.8: Air Stripping of Volatile Contaminants

Air stripping is a widely used physicochemical technique for removing volatile and semi-volatile contaminants from industrial wastewater streams. It is particularly effective for the treatment of compounds with a high Henry's law constant, such as certain organics and inorganics.

Process Description

The air stripping process involves transferring volatile substances from the liquid phase (wastewater) into the gas phase (air) by increasing the contact surface area between air and water. This is commonly achieved through packed towers, diffused aeration, or spray systems.

Typical Contaminants Removed

- Ammonia (NH_3)
- Hydrogen sulfide (H_2S)
- Volatile organic compounds (VOCs) such as:
  - Benzene, Toluene, Ethylbenzene, Xylenes (BTEX)
  - Trichloroethylene (TCE), Tetrachloroethylene (PCE)
- Aldehydes and ketones (e.g., acetone, formaldehyde)
- Carbon dioxide (for pH adjustment applications)

Typical System Configurations

1. Packed Tower Strippers: Vertical towers filled with structured or random packing to maximize surface area. Air is blown counter-current to the descending wastewater.
2. Aeration Basins with Diffusers: Also named *Air sparging*, Air is bubbled into a basin or tank, typically for moderate stripping applications.
3. Spray Towers: Water is sprayed into a chamber with airflow, used less commonly but effectively in high-flow applications.

Design Considerations

- Air-to-water ratio (typically >100:1 for VOCs)
- Temperature of the water (higher temperature enhances stripping)
- pH (especially relevant for ammonia stripping; optimum pH >10)
- Contact time and packing height in towers
- Treatment goals and regulatory discharge limits

Post-Treatment Requirements

Stripped air must often be treated before being released into the atmosphere, especially if it contains hazardous VOCs. Common air treatment methods include:

- Activated carbon adsorption
- Thermal or catalytic oxidation
- Biofiltration (for biodegradable gases such as H_2S or VOCs)

Applications and Benefits

Air stripping is used in many sectors, including chemical manufacturing, petroleum refining, groundwater remediation, and food processing.

Benefits include:

- High efficiency for volatile substances
- Relatively simple operation and low energy cost
- Can be combined with other technologies for complete treatment (e.g., biological, adsorption, AOP)

Tools: https://data.mendeley.com/datasets/289m8hcgt2/3?

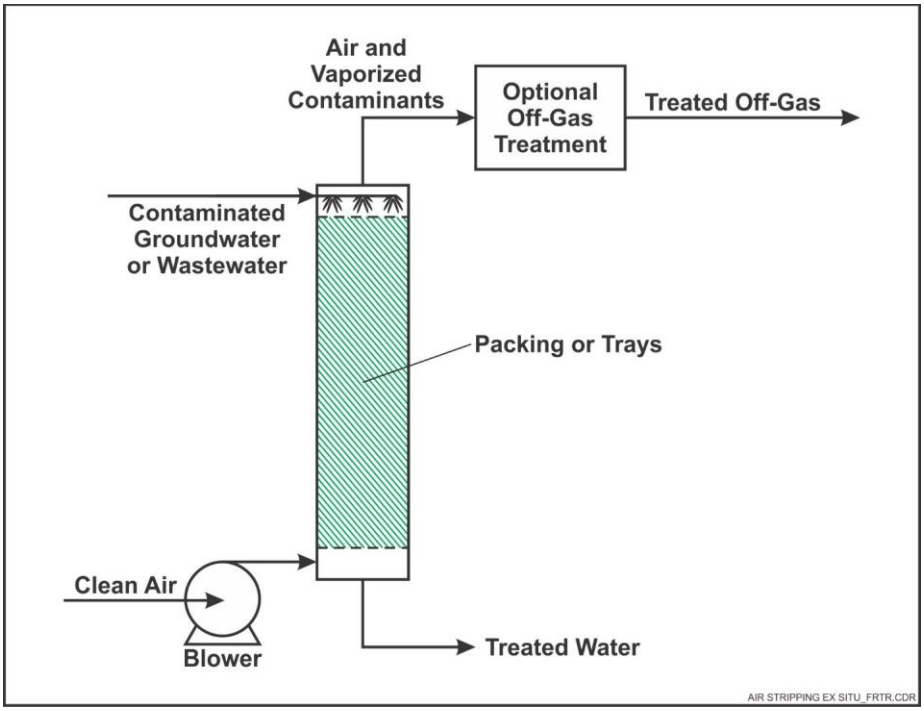


Image 47 Air stripping column (FRTR)

Chapter 6: Membrane Separation & Adsorption Technologies

Membrane technologies are widely used in industrial wastewater treatment for solid-liquid separation, contaminant rejection, and water recovery. They are categorized by pore size, driving force, and application.

6.1 Membrane Processes by Filtration Type

1. Microfiltration (MF) – 0.1–10 µm pore size
   - Removes suspended solids, bacteria
   - Operates at low pressure (0.5–2 bar)
2. Ultrafiltration (UF) – 0.01–0.1 µm
   - Removes colloids, proteins, macromolecules
   - Operating pressure: 2–6 bar
3. Nanofiltration (NF) – 200–1000 Da MWCO
   - Removes divalent salts, organics, and hardness
   - Pressure: 4–30 bar
4. Reverse Osmosis (RO) – <100 Da
   - Removes salts, TOC, micropollutants
   - Pressure: 8–80 bar
5. High-Pressure RO (RRO, UHRO, SWRO)
   - RRO: 60–90 bar; UHRO: 100–120 bar; SWRO (seawater): 60–80 bar
   - Applications: brine minimization, seawater desalination

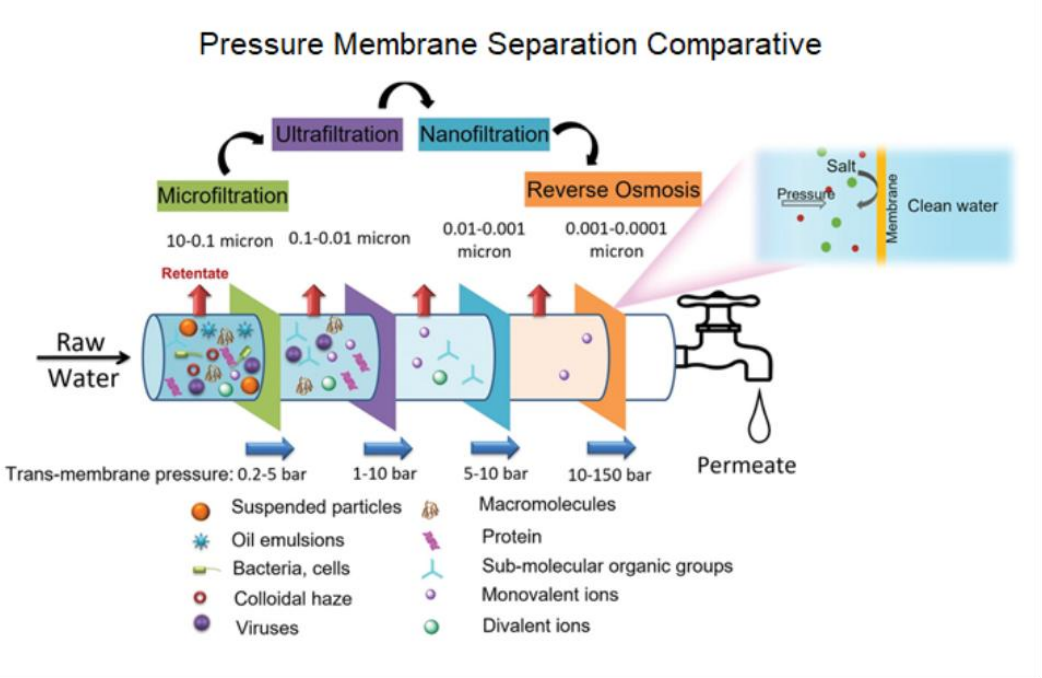


Image 48 Pressure Membrane Separation comparative (ReserachGate)

6.2 Membrane Configurations and Materials

Membranes are manufactured in various geometries and materials to meet process needs.

Configurations:
- Flat-sheet: common in UF, RO, MBR (cassette modules)
- Spiral-wound: most compact, used in NF and RO
- Hollow fiber: used in UF, MBR, MF (outside-in or inside-out flow)
- Tubular: for high-fouling liquids, easy to clean (MF, UF)
- Ceramic: robust, high temp & pH tolerance (UF, MF)
- Disc/turbulent flow modules: reduce fouling, low footprint

Materials:
- Organic (polymeric): PES, PVDF, PA, PAN, PTFE
- Inorganic: ceramic (Al_2O_3, ZrO_2), sintered stainless steel

Pre-treatment requirements: Filtration, pH adjustment, anti-scaling for RO/NF

Tools: Free software for membrane plant design

https://www.water.toray/knowledge/tool/

https://www.dupont.com/water/resources/design-software.html

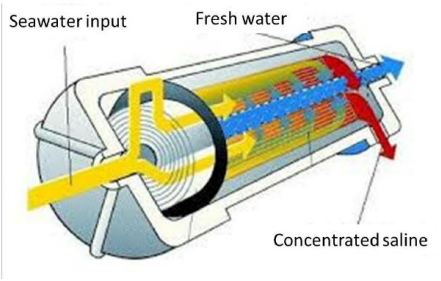


Image 48. Spiral wound RO/NF membrane (ResearchGate)

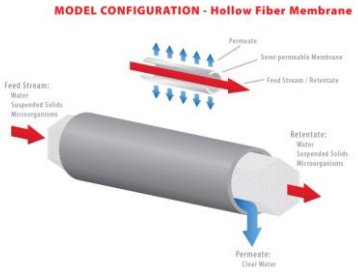


Image 49 Hollow Fiber UF membrane (Synder)

Image 50. Ceramic monolith membrane (Lightech)

6.3 Electrodialysis and Electro-Deionization

ED technologies use electric fields and selective ion-exchange membranes to remove ionic species.

Types:
- ED: Direct current moves ions through cation/anion membranes
- EDR: Periodically reverses polarity to reduce scaling/fouling
- CEDI: Combines ion exchange resins and ED membranes for ultrapure water
- Selective ED: Tailored membranes for specific ion separations (e.g., Na^+/Li^+, Cl^-/NO_3^-)

Operating Parameters:
- Voltage: 10–40 V per stack
- Recovery: 70–90%
- Applications: brine treatment, desalination, water reuse

Advantages:
- Lower energy than RO for low salinity
- Targeted ion removal

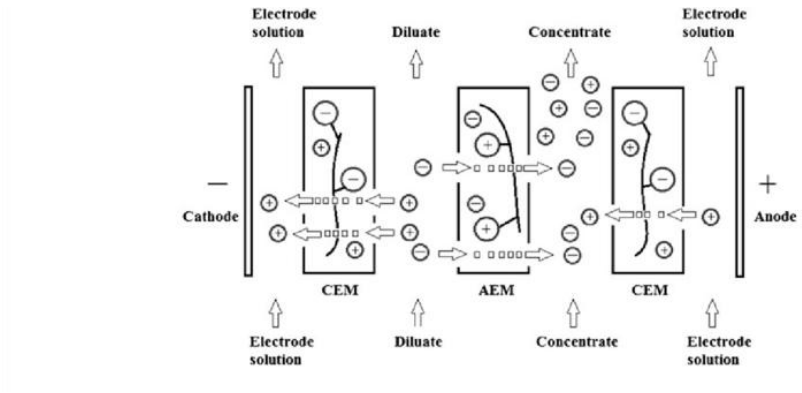


Image 51. Electrodialysis Scheme. CEM = Cation Exchange Membrane, AEM = Anion Exchange Membrane

6.4 Hybrid Systems and Applications

Membrane systems are often integrated with other technologies to form hybrid systems:

- MBR (Membrane Bioreactor): Combines biological treatment with UF membranes
- NF/RO after MBR: For ZLD/MLD strategies
- RO + Evaporation: For high TDS brines
- ED + Ion Exchange: For selective demineralization or lithium recovery

Applications:
- Water reuse within industry
- Waste minimization before discharge or crystallization
- High recovery in space-constrained plants

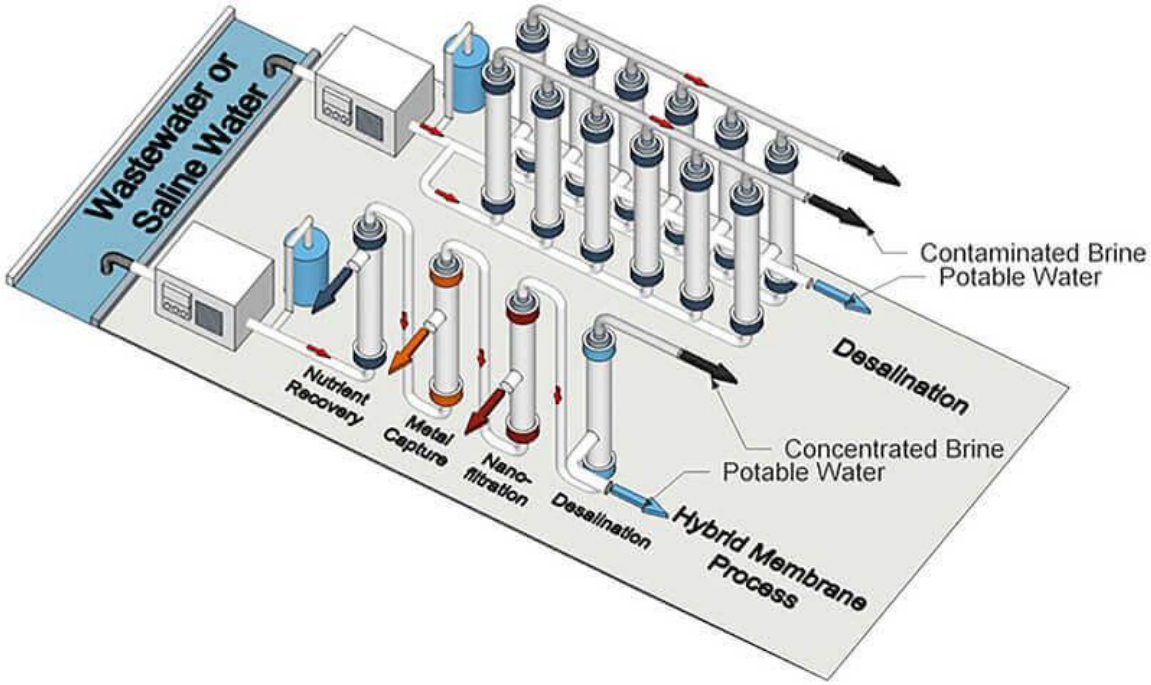


Image 52. Hybrid treatment system (Purdue Univ)

6.5 Adsorption Technologies

Adsorption is a key process in wastewater treatment used for removing dissolved organic and inorganic pollutants.
It involves the accumulation of contaminants on the surface of a solid material (the adsorbent), enabling the selective removal of target compounds from water.
Technologies range from conventional systems using activated carbon and ion exchange resins to advanced materials such as chelating resins, bio adsorbents, and nanomaterials.

Principle of Adsorption

Adsorption occurs when molecules or ions from the liquid phase adhere to the surface of a solid adsorbent.
The process may involve physical forces (physisorption) or chemical bonding (chemisorption). The performance depends on pH, temperature,
ionic strength, adsorbent surface area, and contact time. Adsorption is typically described by isotherm models (Langmuir or Freundlich)
and can be applied in batch reactors or fixed-bed columns.

Conventional Adsorption Technologies

Activated Carbon

Activated carbon (AC) is a porous carbon-based material with surface areas ranging from 500–1500 m^2/g. It is commonly produced from coal, coconut shells, or wood and used to remove organic pollutants, color, odor, and micro-pollutants.

Mechanism: Physisorption and hydrophobic interactions between organic molecules and the carbon surface.

Advantages	**Limitations**
High adsorption capacity for organic compounds	Limited removal of ionic species
Can be regenerated thermally or chemically	Fouling by suspended solids or oil
Proven, widely available technology	High cost of regeneration

53. Image Granular Activated Carbon

Ion Exchange Resins

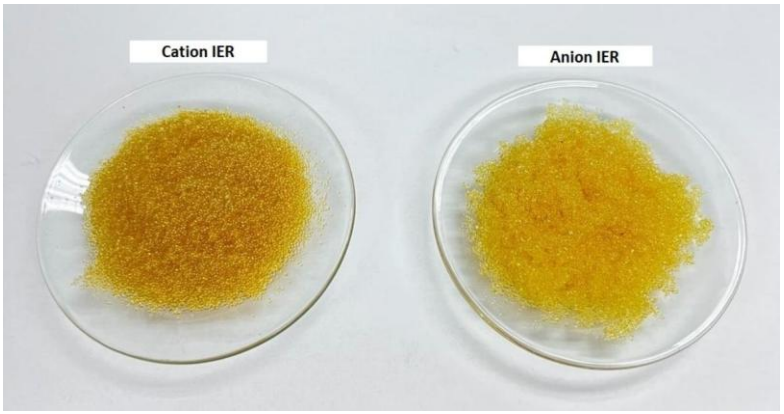
Ion exchange resins (IERs) are synthetic polymeric beads containing charged functional groups that exchange ions with the aqueous phase.
They are highly effective for removing dissolved metals, hardness ions, nitrates, and other ionic species.

Tools: https://www.purolite.com/index/Company/Tools/purolite-resin-system-modeling-software;

https://resins.jacobi.net/support/

Mechanism: Electrostatic ion exchange between resin sites and ions in solution.

Advantages	**Limitations**
High selectivity for specific ions	Sensitive to fouling and organic matter
Regenerable using acid or base	Produces concentrated brine waste
Applicable for heavy metal removal	Performance depends on pH and competing ions



Advanced Adsorption Technologies

Chelating Resins

Chelating resins are specialized ion-exchange materials functionalized with ligands that form coordination complexes with specific metal ions.
They provide highly selective removal of metals even at trace concentrations. Common ligands include iminodiacetic acid, thiol, and amidoxime groups.

Advantages	Limitations
High selectivity for target metals	Higher cost than standard ion exchangers
Effective at low concentrations	Requires controlled regeneration conditions
Allows metal recovery	Sensitive to oxidation and fouling

Functionalized and Hybrid Adsorbents

Advanced adsorbents such as activated alumina, zeolites, bioadsorbents (chitosan, cellulose, biochar), and nanomaterials (graphene oxide, MOFs, Fe_3O_4 nanoparticles) are gaining attention for multi-contaminant removal. These materials combine large surface area, tunable chemistry, and high adsorption capacity.

Comparison of Adsorption Technologies

Technology	Target Pollutants	Mechanism	Regenerable	Typical Applications
Activated Carbon	Organics, color, odor	Physical adsorption	Yes	Water polishing, COD reduction
Ion Exchange Resin	Metals, anions	Electrostatic ion exchange	Yes	Softening, heavy metal removal
Chelating Resin	Specific metals	Chemical complexation	Yes	Metal recovery, electroplating wastewater
Zeolite	Ammonia, metals	Ion exchange	Yes	Nutrient removal, mining wastewater
Activated Alumina	Fluoride, arsenic	Ligand exchange	Yes	Groundwater treatment
Biochar / Chitosan	Organics, metals	Adsorption + chelation	Partial	Low-cost adsorption
MOFs / Nanomaterials	Organics, PFAS, metals	Pore confinement and surface binding	Limited	High-performance polishing

Summary

Adsorption technologies remain indispensable in wastewater treatment due to their versatility and efficiency. While conventional materials like activated carbon and ion exchange resins dominate general applications, advanced adsorbents, such as chelating resins, biochar, and nanostructured materials, offer superior selectivity, capacity, and potential for resource recovery. The optimal selection depends on the pollutant type, required purity, cost, and regeneration capability.

Chapter 7: Sludge and Brine Management

7.1 Sludge Management

Sludge is generated primarily from physicochemical and biological processes. Proper management is essential to minimize volume, reduce environmental impact, and optimize disposal or reuse.

Typical Sludge Types:
- Primary sludge: from sedimentation/clarifiers
- Biological sludge: from MBR, CAS, MBBR
- Chemical sludge: from metal precipitation, coagulation

Mechanical Dewatering Methods:
- Belt filter press: continuous operation, dry solids 15–25%
- Filter press: batch, high dryness (35–55%), good for small flows
- Centrifuge: decanter or vertical, 15–30% DS
- Pusher or Peeler centrifuge (only crystals): 90-97% DM

Post-Dewatering Drying Techniques:
1. Thermal Drying (Drum or Belt dryers)
   - Indirect or direct heating using gas or steam
   - Final DS up to 90%
2. Solar Drying
   - Greenhouses with ventilation systems
   - Low energy, weather-dependent
3. Vacuum Drying
   - Low-temp evaporation under vacuum; suitable for hazardous sludge

Applications:
- Agricultural reuse (biosolids)
- Co-incineration in cement kilns
- Landfilling (requires stabilization if hazardous)

7.2 Brine and Concentrate Management

Brine is produced after RO, NF, ED, or evaporation processes and must be treated to minimize environmental impact.

Volume Reduction (MLD)
- Additional RO stages (RRO, UHRO)
- Vacuum evaporation (HP, MVR, MEE)

Crystallization of Salts (ZLD)
1. Thermal Crystallizers:
   - Forced circulation and falling film types
   - Used to precipitate NaCl, Na_2SO_4, K_2SO_4, etc

2. Selective Crystallization:
   - Controlled temperature and concentration to extract one salt at a time
   - Enhances recovery and purity (e.g., sequential Na_2SO_4 then NaCl)

Solid-Liquid Separation:
- Basket centrifuges: batch solid-liquid separation
- Decanter centrifuges: continuous mode
- Nutsche filters for pharma-grade salts

Salt Washing and Purification:
- Washing with cold water or solvents to remove impurities
- Used for food-grade or industrial salt valorization

Thermal Drying of Salts:
- Rotary dryers or fluid bed dryers to reach <5% humidity
- Optional after centrifugation

Stabilization of Slurries for Landfilling:
- Mix with cement, fly ash, lime, or pozzolanic agents
- Adjust liquid/solid ratio to ensure geotechnical stability
- Suitable for hazardous or mixed brines

Applications:
- ZLD for metal finishing, textile, pharma, mining
- Brine valorization for the circular economy

Chapter 8: Energy and Chemical Consumption

Energy and chemical consumption significantly influence the operational cost, environmental footprint, and long-term viability of wastewater treatment systems. This chapter expands on the requirements for major treatment technologies, including layout implications and asset replacement cycles.

8.1 Energy Consumption by Process

Typical energy consumption by unit operation (in kWh/m^3 treated):

- Screening, grit removal: <0.05

- DAF with air saturation: 0.2–0.6

- Coagulation–flocculation: 0.05–0.15

- Sedimentation (static or lamella): negligible

- MBBR, SBR (blowers/mixers/pumps): 0.3–0.8

- MBR (Blowers/pumps): 0.8–1.5

- Fixed-bed biofilters (Blower/pumps): 0.2–0.6 (mainly recirculation)

- Conventional nitrification/denitrification (blowers/mixers/pumps): 0.6–1.8 (due to high oxygen demand)

- Anammox systems (only pumps): 0.2–0.5

- RO (brackish): 0.6–2.5 | SWRO: 3–6 | UHRO: 8–12

- ED/EDR: 0.3–2.0

- Electrocoagulation: 0.5–2.5 (depending on conductivity)

- AOPs ($UV/O_3/H_2O_2$): 1.5–5.0

- Vacuum evaporation:
  - MVR: 20–80

  - Heat Pump: 100-200

  - MEE: pumps 12–25 (heating needs steam or thermal fluid: 210-600 kWth/m3 and same amount of energy for condensing by cooling water CT)

8.2 Chemical Consumption by Process

Chemical use varies by process type, load, and design. Typical ranges include:

- Coagulants: 50–300 mg/L ($FeCl_3$, PAC, $Al_2(SO_4)_3$)

- Polymers (flocculants, sludge dewatering): 1–100 mg/L

- pH adjustment: Lime, NaOH, HCl, depending on buffer capacity

- Metal precipitation: Sulfides, hydroxides, carbonate salts

- Anti-scalants (RO/NF): 1–5 mg/L

-Anti-scalants (Evaporation): 5-100 mg/l)

- Oxidants: O_3 (5–30 mg/L), H_2O_2 (10–100 mg/L), Cl_2 (10-200 mg/l)

- Electrocoagulation: 3–10 kg Al/Fe plates per 1000 m^3

- Fenton reagent: Fe^{2+} + H_2O_2 = 1:10 molar (pH ~3)

- Nutrients for biological systems: Typical BOD: N: P = 100:5:1

- External carbon source (methanol, acetate): up to 150 mg/L as COD if TOC is insufficient for denitrification

8.3 Layout Considerations: Civil vs. Mechanical Scope

Each technology includes civil and mechanical components. Approximate contributions are:

- Screening & grit chambers: 70% civil (channels), 30% mechanical

- DAF: 30% civil (tank), 70% mechanical (saturator, pumps, scrapers)

- Sedimentation: 90% civil (basin), 10% mechanical (scraper, valves)

-Manufactured settling tanks: 10% civil (supports), 90% mechanical

- Coagulation/flocculation units: 40% civil (tanks), 60% mechanical (mixers, dosing)

- MBR: 50% civil (tank), 50% mechanical (membranes, blowers, pumps)

- MBBR/SBR: 60% civil (tank), 40% mechanical (aerators, mixers)

-Fix Bed (Biocarb): 40% civil, 60% tanks and mechanical devices

-UASB, EGSB: 80% civil, 20% mechanical

-MLE, SOD: 80% civil, 20% mechanical

- RO/NF: 20% civil (skid support), 80% mechanical

- Electrocoagulation: 30% civil, 70% electrical + mechanical

- Evaporation/Crystallization: 10–20% civil (support), 80–90% mechanical

-Evaporation ponds: 100% civil

- ED/EDR: ~90% mechanical (skid-mounted)

-Ion Exchange: ~90% mechanical (skid-mounted)

-Activated carbon/Adsorbents: ~90% mechanical (skid-mounted)

8.4 Asset Lifetime and Replacement Guide

Operational budgets must consider lifespan and renewal costs: **Equipment Type**	**Expected Life (Years) |**	**Replacement Notes**
Instruments	5-10	Calibration periodically
Pumps and Blowers	8–15	May require rebuild kits every 3–5years
DAF Saturator	10–15	Stainless steel preferred
Membranes (UF, MF), ceramic membranes	5–7	Affected by fouling and cleaning cycles
RO/NF polymeric Membranes	1–3	Brine quality and scaling are critical
EC Electrodes	Sacrificial material (3 months to 12 months)	Based on the wall thickness material, current density, and use
UV Lamps	1 year	Replace annually or after 8000 h
Evaporator Heat Exchangers	15–25	Descaling and mild CIP prolong the lifespan
Centrifuges, Filter Press	10-20	Bearings and sealing are replaced periodically
Plastic Vessels	10-15	Leakage test, repair leakage, when possible, reapply UV protection coating

Regular maintenance and preventive asset management improve OPEX stability and reliability.

Chapter 9: Space Requirements, Layout, and Tank Specifications

This chapter integrates space planning, layout strategies, indoor/outdoor installation criteria, and detailed tank specifications for industrial wastewater treatment systems. Proper design ensures reliable performance, ease of maintenance, and compliance with environmental and construction standards.

9.1 General Design Considerations

Key factors influencing plant layout:
- Available area and site topography
- Gravity flow vs. pumped systems when possible
- Access for operation, delivery, and maintenance according to safety regulations or specs
- Design and construction of access stairs, walkways, and safety railings
- Separation of chemical, sludge, and clean water areas
- Environmental regulations and climate considerations

9.2 Space Requirements Guideline by Equipment

Technology	**Area ($m^2/m^3/h$)**	**Outdoor/Indoor Suitability**
Screening	1-2	Outdoor (covered or insulated)
DAF	2–4	Indoor or outdoor with enclosure
Coagulation + Sedimentation	3–6	Outdoor possible, insulated tanks
SBR	4–8	Outdoor, protect controls
MBBR	2–4	Outdoor-friendly
MBR	3–6	Outdoor-friendly
UF/NF/RO	1.5–3	Indoor (skid/containerized
Activated carbon/Ion Exchange	1-1.5	Indoor (skid containerized)
Electrocoagulation	1–2	Modular, outdoor with shelter
Vacuum Evaporation	3–5	Indoor recommended/outdoor with enclosure
ED/EDR	1–2	Indoor preferred
AOP (UV, O_3, Fenton)	1–3	Indoor only
Crystallization	4–7	Indoor (controlled temperature)

9.3 Tank Sizing, Materials, and Recommendations

Tank volumes depend on process flow and retention needs. Below are typical recommendations:

Tank Function	**Min. Volume Guideline**	**Recommended Material**	**Common Types**
Equalization/Homogenization	≥ 4–6 h of influent flow	Concrete, HDPE, FRP	Underground or surface-mounted
Coagulation/Flocculation	10–30 min retention	PP, PE, coated steel	Cylindrical with mixer
Clarification/Sedimentation	2–4 h of flow	Concrete, PP, coated steel	Conical/ Circular/rectangular Tanks or basins
DAF Buffer/Saturation	5–15 min	Stainless steel	Pressurized horizontal tanks
Biological Reactor (SBR/ MBR/MBBR)	SBR: 4–8 h HRT MBBR: 8-12 HRT MBR: 12-48 HRT	Concrete, epoxy-coated steel	Compartmentalized tanks/ basins
UF/NF/RO Feed/Buffer	0.5–1 h	PE, PP, FRP, SS	Closed Vertical tanks
Treated Water Storage	1–2 h	PE, SS, GRP	Covered with level control
Concentrate/Brine Holding	≥8–12 h	PP, FRP	Horizontal/vertical
Sludge Buffer Tank	12–24 h of sludge production	SS, PP, PE, FRP	With mixer & decant line, conical bottom tank
Evaporator/Crystallizer Feed	Feed Batch cycle or ≥2 h	SS316L, lined steel	Jacketed or insulated

9.4 Outdoor Installation and Protection Measures

Climate Protection:
- UV-stable materials or coating
- Insulation with aluminum jacketing
- Electric or glycol tracing for antifreeze protection
- Ventilation to avoid heat buildup

Structural and Safety Requirements:
- Wind/seismic anchoring
- Non-slip walkways and safety railings
- Anti-flood berms or bunds (110% capacity)

Leak Containment:
- Bund walls or secondary containment basins
- Leak sensors and shut-off systems
- Proper drainage to confined sump areas

Tank Placement Tips:
- Avoid low points and drainage lines
- Allow top access for maintenance
- Locate chemical tanks in shaded/ventilated areas

9.5 Vertical and Modular Installation Strategies

For sites with limited footprint or urban constraints:

- Stack process tanks (e.g., buffer above MBR)
- Rack-mounted multistage UF/NF/RO
- Use containerized mobile units for plug-and-play
- Elevate storage tanks to use gravity feed
- Mount evaporators above collection or crystallization tanks

Modular designs improve scalability, reduce on-site assembly, and minimize civil works.

Chapter 10: Case Studies and Integrated Solutions

This chapter presents a series of real-world case studies covering a wide range of industrial sectors and treatment technologies. Each case illustrates the contaminants involved, process design, system integration, and resource recovery strategies for either discharge or reuse.

10.1 Case Study: Metal Finishing Wastewater

- Industry: Electroplating (zinc, chromium)
- Flow: 5 m^3/h | COD: 1500 mg/L | Cr, Ni, Zn | Low pH
- Goal: Internal reuse (ZLD)

Integrated Solution:
• pH neutralization + EC (iron plates) → Lamella clarifier → Sand filtration
• RO (double pass) → Vacuum evaporator → Crystallizer

Performance:
• Heavy metals removal > 95%, Permeate recovery: 85%, Final TDS < 100 mg/L

10.2 Case Study: Dairy Wastewater

- Industry: Cheese & milk
- Flow: 20 m^3/h | COD: 6000 mg/L | FOG: 400 mg/L
- Goal: Discharge to a natural water body

Integrated Solution:
• CPI separator → DAF (polymer + FeCl3) → MBR → UV

Performance:
• COD reduction > 96%, Final COD: 150 mg/L, BOD: <10 mg/L, TSS: <5 mg/L

10.3 Case Study: Electronics Manufacturer

- Industry: Circuit boards
- Flow: 3 m^3/h | TDS: 7000 mg/L | Cu, surfactants
- Goal: ZLD

Integrated Solution:
• Neutralization → Cartridge filtration → RO → MVR evaporation → Crystallizer

Performance:
• Permeate reuse: 80%, Brine reduction: 95%, Cu recovered from sludge

10.4 Case Study: Pharmaceutical Factory

- Industry: Generic drug production
- Flow: 8 m^3/h (batch) | COD: 5000 mg/L | Antibiotics, solvents
- Goal: Sewer discharge Integrated Solution:
• Equalization + pH correction → Fenton AOP → Activated carbon → Sand filter

Performance:
• COD removal: 85%, API reduction: >90%, Sewer compliant

10.5 Case Study: Landfill Leachate

- Industry: Waste management
- Flow: 12 m^3/h | NH_4-N: 500 mg/L | COD: 4000 mg/L | TDS: 6000 mg/L
- Goal: ZLD + ammonia recovery

Integrated Solution:
• Air stripping tower → MBR → RO → MVR evaporator

Performance:
• NH_4-N removal > 95%, Final COD < 200 mg/L, Concentrate reduced by 90%

10.6 Case Study: Beverage Plant (Glass Bottle Washing)

- Industry: Soft drink manufacturer (Coca-Cola bottler)
- Flow: 30 m^3/h | COD: 2500 mg/L | Detergents, phosphates, turbidity
- Goal: Partial reuse + sewer discharge

Integrated Solution:
• Equalization tank → DAF → MBBR → UF → RO (part of stream)

Performance:
• COD reduced > 90%, Permeate used for bottle rinse, Concentrate sent to sewer

10.7 Case Study: Food & Snack Industry

- Industry: Potato chips and snacks
- Flow: 25 m^3/h | COD: 4000 mg/L | Starch, oils, sodium
- Goal: MLD (minimize disposal cost)

Integrated Solution:
• Screening → DAF → MBR → RO → Partial evaporation

Performance:
• 75% reuse rate, Brine volume reduced by 85%, Oil/starch reused for biogas

10.8 Case Study: Chemical Industry (DMSO)

- Industry: Organic solvents (Dimethyl sulfoxide)
- Flow: 15 m^3/h | COD: 10,000 mg/L | DMSO, acids, salts
- Goal: ZLD + solvent recovery

Integrated Solution:
• Equalization → EC → DAF → AOP (UV + H2O2) → RO → Evaporation → Crystallization

Performance:
• Solvent capture > 70%, COD reduced to <200 mg/L, Final solids sent for reuse or landfill

10.9 Integrated Solutions and Resource Recovery

An integrated treatment train improves performance, reduces waste, and enables recovery of valuable resources.

Examples of recovery:
- Water: Permeate or Distillate reused in cleaning, cooling, or process water
- Chemicals: Recovery of acids, metals (e.g., Cu, Zn), nutrients
- Energy: Biogas from anaerobic digestion or calorific sludge
- Solids: Crystallized salts sold or reused (NaCl, Na_2SO_4, etc.)
- Organic products: Oils, starches reused or sold as feed/energy

Strategic Considerations:
- Choose modular equipment to adapt to demand changes
- Combine membrane + thermal + EC or AOP to maximize removal
- Manage sludge and brine with resource recovery in mind
- Integrate analytics for predictive maintenance and process control

Chapter 11: Design and Engineering Tools

This chapter presents key engineering tools, design considerations, and resources for the planning and dimensioning of industrial wastewater treatment plants. It provides typical design parameters and highlights trusted manuals and digital tools for system sizing.

11.1 Flow and Load Estimation

• Average Flow (Q_avg): measured or estimated daily flow [m^3/day]
• Peak Flow (Q_peak): design peak flow [m^3/h]
• Organic Load: COD or BOD × Q_avg → [kg/day]
• Solid Load: TSS × Q_avg → [kg/day]
• Nutrient Loads: TN and TP × Q_avg → [kg/day]

11.2 Hydraulic Retention Time (HRT)

HRT = Reactor Volume / Flow Rate [h]
• Key for reactors (equalization, biological, chemical)
• Typical values:
- Equalization Tanks: 4–6 h
- Anaerobic Reactors: 8–24 h
- MBBR: 6–12 h
- SBR: 6–24 h
- Clarifiers: 2–4 h

11.3 Surface Loading

• Surface Loading Rate (Overflow Rate): Flow / Surface Area [$m^3/m^2 \cdot h$]
- Clarifiers: 0.5 – 1.2 $m^3/m^2 \cdot h$
- Lamella Settlers: 3 – 5 $m^3/m^2 \cdot h$
- DAF Units: 5 – 10 $m^3/m^2 \cdot h$

11.4 Settling velocity criteria for WW treatment

Settling (or sedimentation) is a key physical process in wastewater treatment that separates suspended solids from the liquid by gravity.
The settling velocity (v_s) represents the speed at which a particle falls through the fluid. For design, v_s is compared to the surface overflow rate (SOR) or hydraulic loading rate of the settling tank.

Design criterion: Particles with a settling velocity greater than the surface overflow rate (SOR = Q/A) will be removed.

Types of settling in wastewater

Type	Description	Examples	Design Notes
Type I – Discrete	Individual particles settle independently.	Sand, grit chambers	Apply Stokes' Law.
Type II – Flocculent	Particles flocculate during settling.	Primary clarifiers	Empirical velocity from lab tests.
Type III – Hindered	Particles interfere with each other at high concentrations.	Secondary clarifiers	Velocity decreases with the solids concentration.
Type IV – Compression	Particles form a structure that compresses under its own weight.	Sludge thickeners	Design based on solids flux.

Typical settling velocities

Particle Type	Typical v_s (m/h)	Application
Fine clay	< 0.1	Difficult to settle
Flocculated solids	0.3 – 1	Secondary clarifiers
Biological flocs	0.5 – 2	Activated sludge
Sand (0.1 mm)	30 – 60	Grit chambers
Heavy grit (>0.2 mm)	60 – 100	Grit removal
Sludge blanket	0.05 – 0.3	Thickeners

Design Criteria

Unit	Surface Overflow Rate (SOR)	Detention Time
Primary clarifier	25–40 $m^3/m^2 \cdot d$ (≈ 1–1.7 m/h)	1.5–2.5 h
Secondary clarifier	15–30 $m^3/m^2 \cdot d$ (≈ 0.6–1.3 m/h)	2–3 h
Grit chamber	Particle v_s > 30 m/h	30–60 s
Sludge thickener	0.05–0.3 m/h	Variable

11.4 Recommended Design Tools and Software

• CapdetWorks™ – Process design and cost estimation for wastewater plants
• BioWin™ – Simulation of biological processes including MBBR, MBR, and nitrification/denitrification
• GPS-X™ – Process modeling for biological and hybrid systems
• WatPro™ – Drinking and industrial water treatment simulation
• Aspen Plus® – Used for evaporation, crystallization, and thermal processes
• Excel with custom models – widely used for early-stage design and mass balances
• COMSOL Multiphysics® – CFD for reactor design and membrane flow analysis

11.5 Reference Literature and Manuals

• Metcalf & Eddy – Wastewater Engineering: Treatment and Resource Recovery
• Water Environment Federation (WEF) Manuals of Practice (MOPs)
• US EPA Wastewater Technology Fact Sheets
• WHO & UNEP Guidelines for Industrial Wastewater Management
• ECHA & REACH Guidance Documents for chemical usage and limits
• Manuals from manufacturers (GE, Veolia, Xylem, Alfa Laval, etc.) for membranes, clarifiers, evaporators, etc.
• Scientific papers and case studies from journals like Water Research, Journal of Membrane Science, and Desalination

Chapter 12: Annexes

12.1 Glossary of Terms

• COD – Chemical Oxygen Demand
• BOD – Biochemical Oxygen Demand (5 days)
• TSS – Total Suspended Solids
• TDS – Total Dissolved Solids
• FOG – Fats, Oils, and Grease
• EC – Electrocoagulation
• DAF – Dissolved Air Flotation
• MBBR – Moving Bed Biofilm Reactor
• MBR – Membrane Bioreactor
• SBR – Sequential Biological Reactor
• RO – Reverse Osmosis
• NF – Nanofiltration
• MF/UF – Microfiltration/Ultrafiltration

• ZLD – Zero Liquid Discharge
• MLD – Minimum Liquid Discharge
• AOP – Advanced Oxidation Process
• ED – Electrodialysis
• CFR – Code of Federal Regulations (USA)
• EWC – European Waste Catalog (EU)
• USA NPDS – National Pollutant Discharge Elimination System

12.2 Regulatory Framework for Wastewater Discharge

Applicable regulations for discharges to surface water bodies (rivers, lakes) and to public sewage networks vary by jurisdiction.

USA - Federal Regulations (CFR)

• 40 CFR Part 122 – National Pollutant Discharge Elimination System (NPDES)
• 40 CFR Part 403 – General Pretreatment Regulations for Existing and New Sources of Pollution
• 40 CFR Part 131 – Water Quality Standards
• Prohibited Discharges (40 CFR § 403.5):
- pH < 5.0 (unless neutralization system installed)
- Flammable substances (flashpoint < 60°C)
- Solid or viscous pollutants (e.g., plastics, ashes, hair, rags)
- Petroleum oil, non-biodegradable cutting oil
- Toxic pollutants (as listed under 40 CFR Part 401/414/455)
- Substances causing interference with POTW operations or sludge use/disposal

EU - Directives and National Applications

• Council Directive 91/271/EEC – Urban Wastewater Treatment Directive
• Directive 2000/60/EC – Water Framework Directive
• National implementation includes maximum discharge limits per Member State
• Typical Prohibited Substances:
- Persistent organic pollutants (e.g., PCBs, PAHs)
- Toxic metals (Cd, Hg, Pb, Ni, etc.) above threshold
- Cyanides, halogenated hydrocarbons, chlorinated solvents
- EWC Codes for waste substances: e.g., 13 01 10* (mineral oil waste), 07 01 03* (halogenated solvents)

12.3 Reference Discharge Values

Parameter	Surface Water (EU)	Municipal Sewer (EU)	USA NPDES (Range)
pH	6.5–9.0	6.0–9.5	6.0–9.0
COD (mg/L)	<125–250	<500–1500	<120–160
BOD_5 (mg/L)	<25	<300	<30–45
TSS (mg/L)	<35	<400	<30–100
NH_4-N (mg/L)	<10–15	<50	<10–25
TDS (mg/L)	<2000	<5000	<500–1500
Conductivity (µS/cm)	<2500	<6000–7000	<1000–2000
Chlorides (mg/L)	<250	<1000	<250–500
Sulfates (mg/L)	<250	<1000	<250–500
Inhibitory Substances*	Minimal	Limited	Limited
Toxicity (TU or Equitox) |	<1–2 TU	<5–10 TU	<0.3-1 TU

*Inhibitory substances include surfactants, solvents, phenols, etc., that may affect biological treatment or aquatic life.

Annexes

Annexes: please send email to author to require annexes: tusetsergio@gmail.com

About Sergio Tuset – International Senior Consultant- Degree in Chemical Engineering

Professional Profile: Chemical engineer with over 30 years of experience in the environmental sector. He has been the founder and CEO of several engineering companies, including Condorchem Envitech, Envitech France, Energy & Waste, and Nucleantech. He's a specialist in thermal separation (ZLD and MLD), membrane separation, biogas cleaning & upgrading, adsorption, and advanced oxidation processes. Also, he has expertise in treating volatile organic compounds (VOCs), inorganic gases (including DeNOx systems), and odor mitigation, using technologies that enable organic solvent recovery. He has participated in more than 400 projects worldwide, covering innovative solutions in environmental engineering. In addition, I have presented at technical conferences, published articles in specialized journals, and authored and co-invented several national and international patents.

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Throughout these years, our joint efforts in water and waste treatment engineering have been a continuous source of learning and a driving force for technological innovation and environmental progress. This guide is, in many ways, the result of that collective expertise — a reflection of the dedication, creativity, and professionalism that define the Condorchem team.
To all of you, my sincere thanks for your support, collaboration, and friendship during this rewarding professional journey.