Less-Water Bev.Tech Project

Cip Eco-Innovation

Alma Mater Studiorum – University of Bologna

Department of Industrial Engineering (DIN)

Ultrafiltration Technology: Overview & Drivers for Applications

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Agenda

✓ Fundamentals

- Operating principle
- Range of application
- *Pros & Cons*
- Shape & dimensions

✓ *Focus 1*: Membranes

- Structures
- Materials

✓ *Focus 2*: Working methods

- Dead-end vs. Cross-flow filtration
- Hybrid-flow filtration

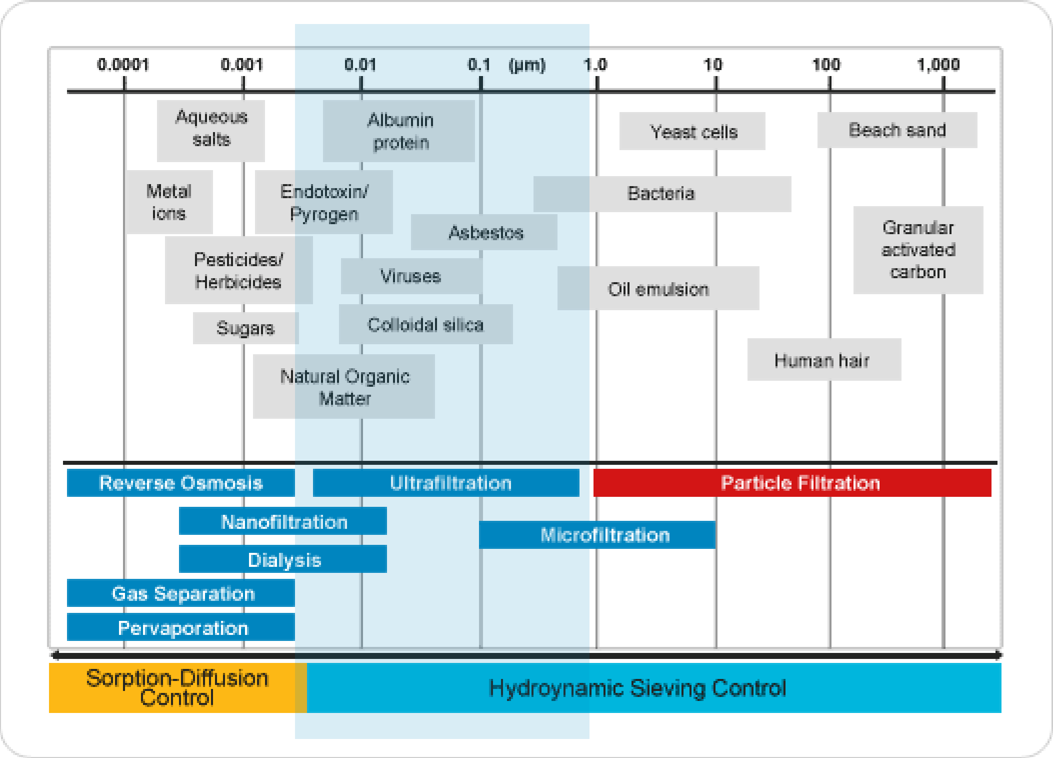
✓ *Focus 3*: Operating & Maintenance (O&M)

- Membrane fouling
- Pretreatment options
- Operation condition effects on fouling
- Cleaning methods

Ultrafiltration (UF)

"UF is recognized as a low-pressure membrane filtration process; it is usually defined to be limited to membranes with pore diameters from 0.005µm to 0.1µm. When the source water is passing through the filter under a trans-membrane pressure provided by the gravity or a pump, the bacteria and most viruses can be removed, […] the drinking water quality can be satisfied for consumers, and the use of chemicals, capital, and operating cost can be reduced."

(Gao et al., 2011)



Mechanical sieve theory

UF uses the different pressure on the two membrane sides to separate the fluid contents

- ✓ Physical rejection
- ✓ Chemical reaction
- ✓ Biological degradation

Food & Beverage UF industrial applications

- ✓ 20–30% of the current €250 million turnover of membrane used in the manufacturing industry worldwide.

- ✓ Dairy industry: the dairy industry is the pioneer in the development of UF equipment and techniques for the production of cheese. *(Daufin et al., 2001)*
- ✓ Beverage industry: UF employed for processing a variety of fruit and vegetable juices (orange, lemon, grapefruit, tangerine, tomato, cucumber, carrot and mushroom). In juice clarification, UF is used to separate juices into fibrous concentrated pulp (retentate) and a clarified fraction free of spoilage microorganisms (permeate). UF is also applied to the concentration process in fruit juice processing industry proving to recover bioactive components in fruit juice. *(Cheryan, 1998; Cassano et al., 2008)*
- ✓ Fish & poultry industry: UF is mainly used for fractionation and waste recovery processes. The wastewaters generated in fish and poultry processing industries contain a large amount of organic load. *(Afonso et al., 2002, 2004; Chabeaud et al., 2009)*

→ *Water and Waste water treatment/pretreatment*

(Mohammad et al., 2012)

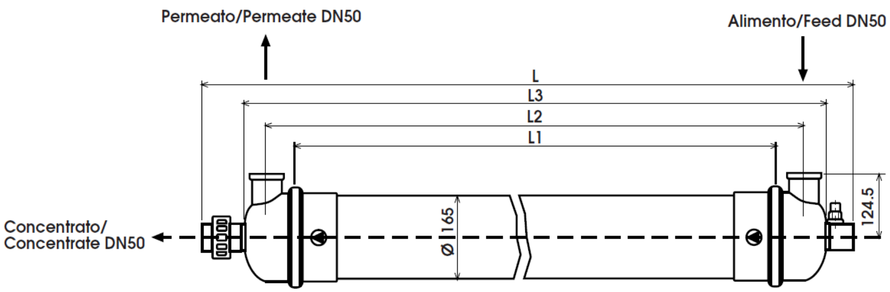
Overall Operating Conditions & Output

- ✓ Pressures: 0.03 ÷ 3 bar
- ✓ Pore diameter: 0.005 ÷ 0.1 µm
- ✓ Withholding molecular amount: 1 ÷ 500 kDalton
- ✓ Membrane structure: porous anisotropic structure *(Cieszko, 2009)*
- ✓ Typical removed impurities: suspension, colloids, bacteria, dissolved organics (*partially*)
- ✓ Unremoved solutes: fine minerals, soluble salts, metal ions
- ✓ Flow rate: 40 ÷ 90 l/m^{2}h (depending on the treated water) Hagen-Poiseuille Carman-Kozeny equations *(Munir, 2006)*

Distinctive features vs. (micro)-filtration

- ✓ Low pressure (pro)
- ✓ No high temperature required (pro)
- ✓ Smallest pore diameter (pro & con)
- ✓ High dynamics of the process → flux decrease due to *fouling* → wash every 20 ÷ 60 minutes (depending on the treated water) (con)

Shape & Dimensions (example)



MISURE IN mm/PARAMETERS (mm)

	L	L1	L2	L3
Dimensions	1356	1000	1110	1210
	1856	1500	1610	1710
	2356	2000	2110	2210

Feed water type	NTU	TOC (mg/l)	Filtration Velocity (L/m^{2}h)	Backwash Interval (minutes)	Air Scrub Frequency (per day)	Diffuse Chemically Wash
Underground water	<2	<1	90	60	1	Not recommended
Tape water	<3	<2	75	60	2	Usable
Surface water	2-5	<2	75	60	2	Usable
Surface water	5-15	<3	60	40	3	Usable
Surface water	15-50	<3	45	20	4	Recommended
Sea water	<20	/	60	30	4	Usable
Depth treated waste water	0-5	/	40	20	6	Recommended

(http://www.hytekintl.com)

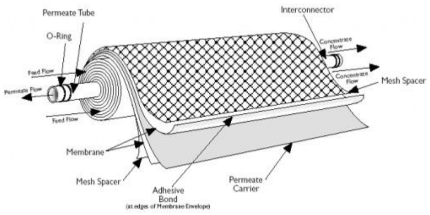
Flexibility

Modularity

Integration with RO unit (series)

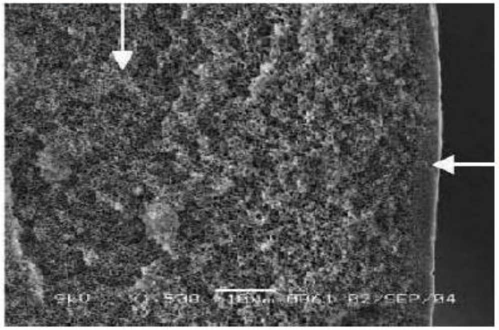
UF membrane existing structures

- ✓ Hollow fibre
- ✓ Tubular
- ✓ Spiral



Asymmetric structure made of two elements:

- ✓ Compact cerebral cortex → high filtration capacity
- ✓ Sponge support layer → low resistance

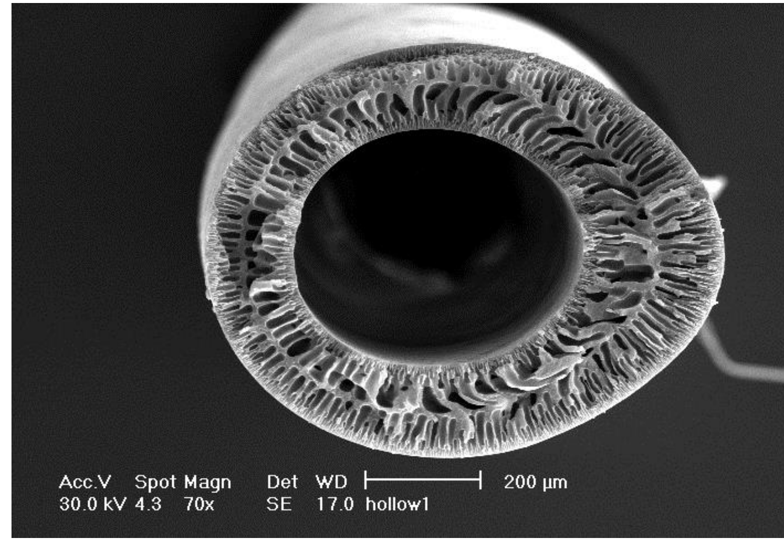


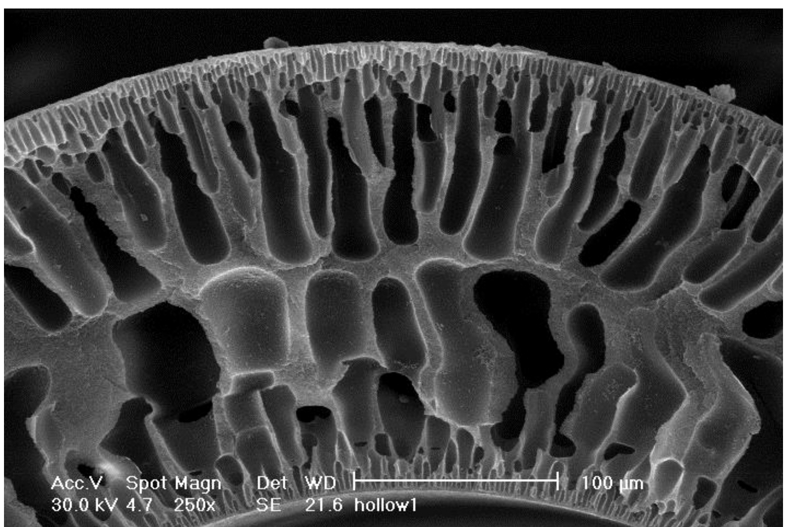
	Hollow Fibre	Spiral-wound	Ceramic Tubular
pH	2-13	2-11	3-7
Feed Pressure (psi)	9-15	<30-120	60-100
Backwash Pressure (psi)	9-15	20-40	10-30
Temperature (°C)	5-30	5-45	5-400
Total Dissolved Solids (mg/L)	<1000	<600	<500
Total Suspended Solids (mg/L)	<500	<450	<300
Turbidity (NTU)	<15	<1	<10
Iron (mg/L)	<5	<5	<5
Oils and Greases (mg/L)	<0.1	<0.1	<0.1
Solvents, phenols (mg/L)	<0.1	<0.1	<0.1

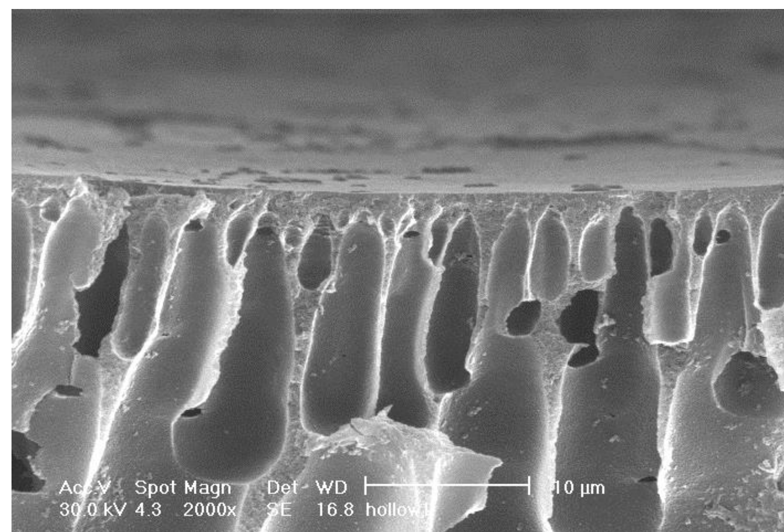
(http://www.hytekintl.com)

UF membranes (2)

Std. diameter: 0.8mm







http://www.memfil.com

UF membranes (3)

UF membrane materials

- ✓ Polyvinylidiene fluoride (PVDF)
- ✓ Polyether sulfone (PES)
- ✓ Polysulfone (PS)
- ✓ Polyacrylonitrile (PAN)
- ✓ Polyethylene (PE)
- ✓ Polypropylene (PP)
- ✓ Polyvinyl chloride (PVC)

Current standards
(> 85% solutions)

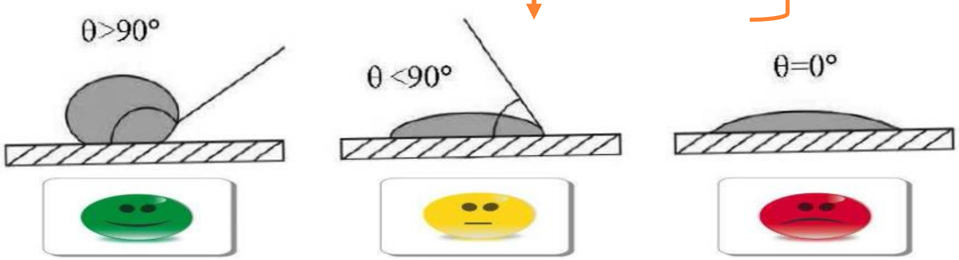
PVDF
- ✓ Chemical stability (NaClO)
- ✓ Mechanical strength
- ✓ Durability

PES
- ✓ Hydrophilicity
- ✓ Low polymer cost
- ✓ History (early '90s)

UF membrane expected properties

- ✓ Mechanical strength
- ✓ Hydrophilicity
- ✓ Durability
- ✓ Chemical stability
- ✓ Low polymer cost

(Wilf, 2008)



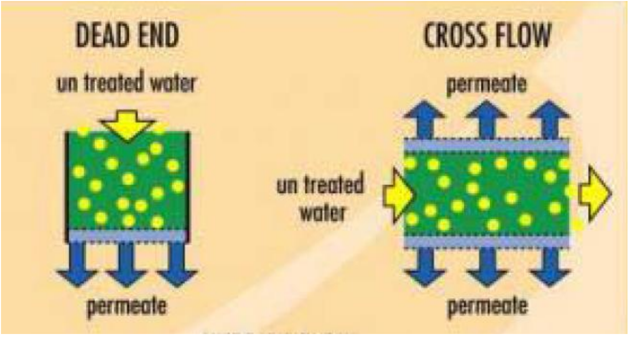
Membrane material	Contact angle
Fiber	12 ~ 45°
PES	44 ~ 81°
PP	108°
PS	38 ~ 81°
PVDF	30 ~ 66°

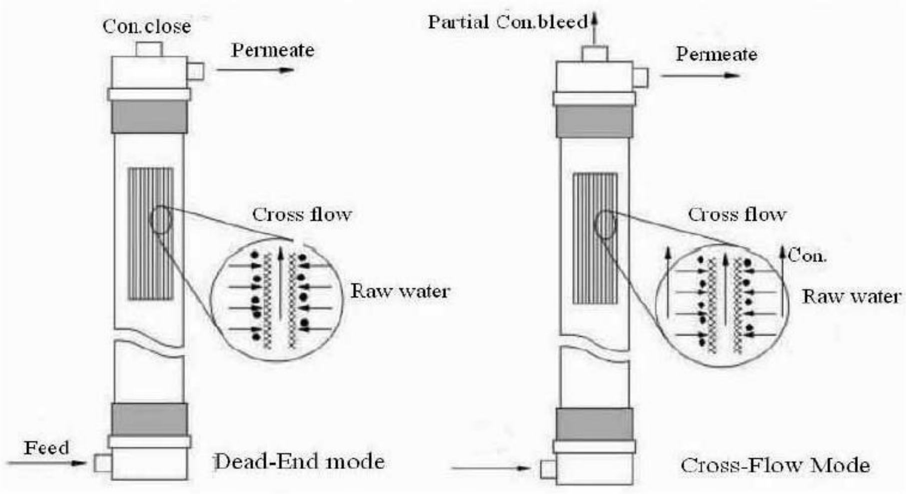
Dead-end filtration

The complete feed flow is forced through the membrane and the filtered matter is accumulated on the surface of the membrane. The dead-end filtration is a batch process as accumulated matter on the filter decreases the filtration capacity, due to clogging. A next process step to remove the accumulated matter is required.

Cross-flow filtration

A constant turbulent flow along the membrane surface prevents the accumulation of matter on the membrane surface. The feed flow through the membrane tube has an higher pressure as driving force for the filtration process and a high flow speed to create turbulent conditions. The process is referred to as "cross-flow", because the feed flow and filtration flow direction have a 90 degrees angle.





(Munir, 2006)

Dead-end filtration

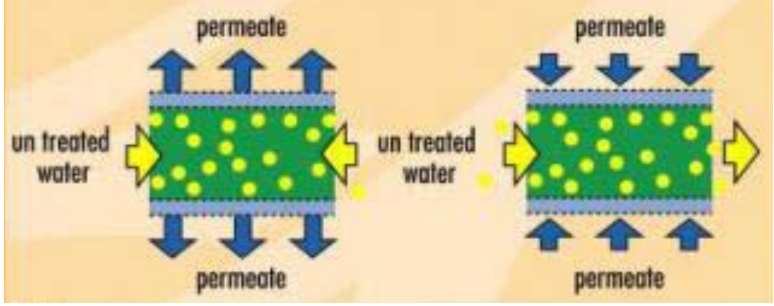
- ✓ Batch process
- ✓ No concentrate/no waste
- ✓ Low pressure (< 1 bar)
- ✓ Low concentration of filtrable matter (underground/tape water)

Cross-flow filtration

- ✓ Continuous process
- ✓ Concentrate/waste
- ✓ High pressure (1 ÷ 3 bar)
- ✓ High concentration of filtrable matter (surface/sea/wastewater)

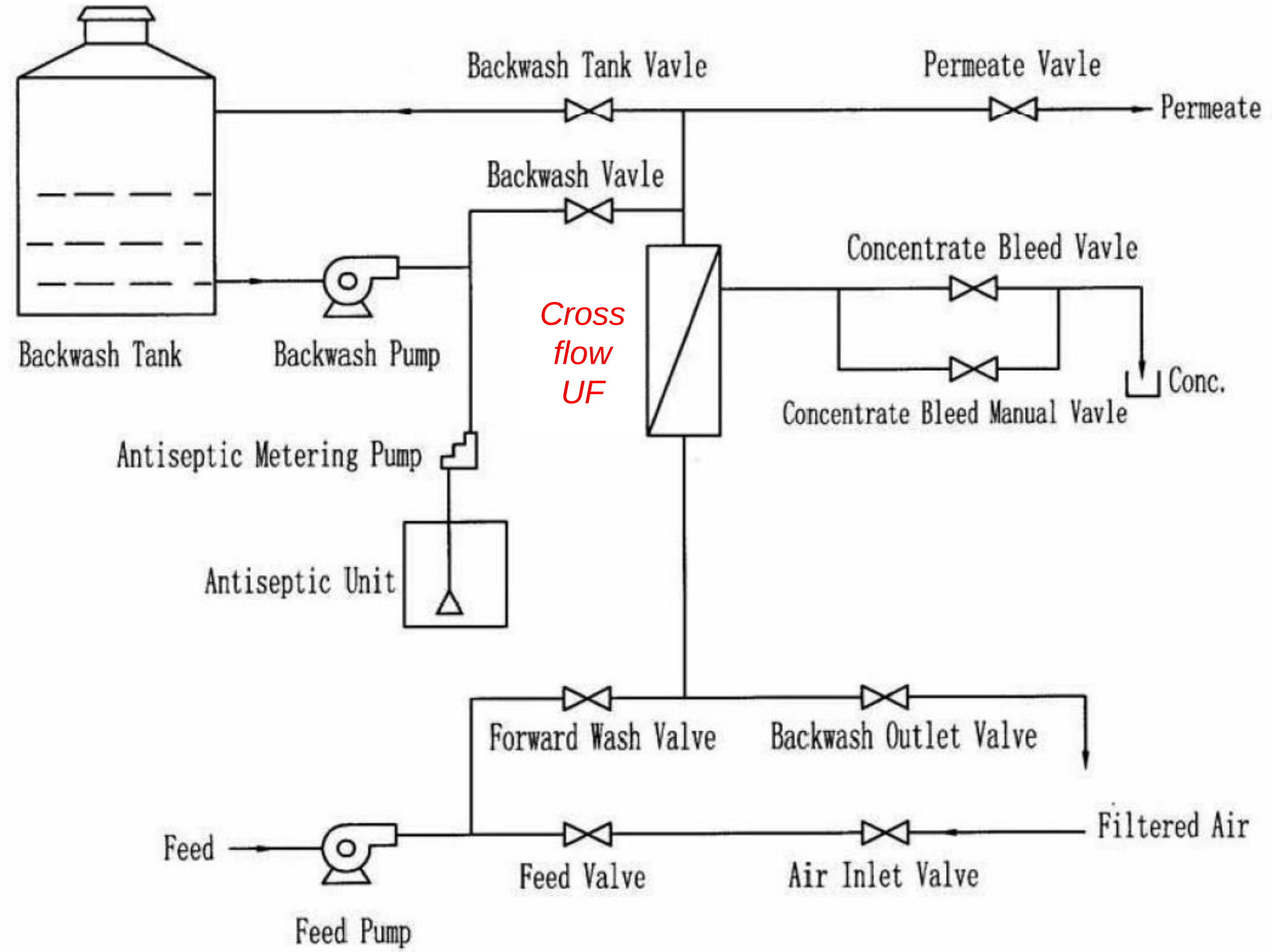
Hybrid-flow filtration

It combines the dead-end and the cross-flow principle. The filtration process has two phases: the production phase and the flushing phase. During the production phase, the tubes are closed on one side and a dead-end filtration is performed. During the flushing phase, the tube is open on both sides and the fraction that did not pass through the membranes is removed in order to clean the membrane surface as in cross-flow filtration. This filtration technique is especially suitable for treating water streams containing suspended solids in low concentrations.



(Munir, 2006)

UF working/cleaning plant



Membrane fouling

UF involves physical, chemical, and biological reactions among the impurities or between the impurities and the membrane surface. In the practical operation, the reactions are often influenced by each other, and therefore, present more complicated effects on membrane fouling.

The UF membrane is prone to losing permeability because of the accumulation of impurities (physic-, chemic-, and bio-substances) on or inside the membrane matrices.

The membrane fouling is responsible for the permeability yields with low/no effect on the water quality (permeate).

Types of foulant

- ✓ Particles' fouling on membrane surface and inside the pores
- ✓ Organic fouling caused by natural organic matter from the source water and interactions
- ✓ Bio-fouling from aquatic organisms, such as algae, forming colonies

(Gao et al., 2011)

UF Operating & Maintenance (2)

Pretreatment options

TABLE 1. List of the mechanisms, effects, and applications of major pretreatments for membrane filtration

pretreatment	coagulation	adsorption	preoxidation	prefiltration
chemicals applied	coagulants (or flocculants) at proper dose	porous or nonporous adsorbents in suspension or fixed contactor	gaseous or liquid oxidants	granular media with/without coagulants, membranes
dose effects	under-, optimal, or overdose (optimal for enhanced coagulation)	minimal effective dose if used as suspended particles	minimal effective dose	none
physical mechanisms	increases the size of aquatic contaminants to filterable level	binds small contaminants to adsorbents much larger than membrane pores	may cause dissociation of organic colloids into smaller sizes or the release of EPS by aquatic organisms	removes coarse materials that may cause cake/gel layer formation on downstream membranes
chemical mechanisms	destabilizes contaminants to cause aggregation or adsorption on coagulant precipitates or membrane surfaces	provides new interfaces to adsorb/accumulate substances detrimental to membrane performance	oxidizes and/or partially decomposes NOM, possible mineralization if VUV used	selectively removes contaminants or other particles that are sticky to filter media and downstream membranes
biological mechanisms	partially removes autochthonous NOM and hinder bacterial growth in feedwater or on membrane	may adsorb organic contaminants relevant to biofouling	suppresses microbial growth	partially removes microorganisms that can cause biofouling
targeted contaminants	viruses, humic/fulvic acids, proteins, polysaccharides with acidic groups, colloids smaller than membrane pores	humic/fulvic acids, small natural organic acids, some DBPs, pesticides and other synthetic organic compounds	viruses and organic contaminants with ozonation	particulate and colloidal organic/inorganic substances, microbiota
effects on membrane fouling	reduces colloidal fouling and NOM fouling	may increase or decrease membrane fouling	may reduce biofouling and NOM fouling	may reduce fouling to different extents
advantages	significantly improves LPM performance (less fouling and greater rejection)	increases the removal of DBPs and DBP precursors	reduces the occurrence of biofouling; increases organic removal (ozonation)	may reduce biofouling, colloidal fouling, and/or solids loading
disadvantages	(i) requires proper dose that can be difficult to meet if feedwater quality varies rapidly/significantly, (ii) may exacerbate fouling, (iii) produce solid wastes, (iv) ineffective in mitigating the fouling by hydrophilic neutral organics	(i) possible exacerbation of LPM fouling, (ii) difficulty in removing PAC powders from treatment facilities	(i) formation of DBPs; (ii) may damage membranes incompatible with oxidants; (iii) may be ineffective in suppressing the growth of some microbiota resistant to oxidation	(i) performance of prefilters may deteriorate and be difficult to recover, (ii) may require pretreatment (e.g., coagulation or preoxidation) to enhance the efficacy

(Huang et al., 2009)

Operation condition effects on fouling

Some proper operation (and cleaning) strategies inhibit the complicated reaction before it happens and their combined benefits could be an ideal way to control or reduce the membrane fouling.

Evidences from the field

- ✓ A relatively low flux is bound to bring a lower rate of fouling but more membrane required would increase the building and operating cost
- ✓ Constant pressure operation present more effective fouling control than constant permeate flux when applied to cold water (below 5°C) treatment *(Guo et al., 2009)*
- ✓ Lee et al. state that proper constant flux was favorable than constant pressure operation *(Lee et al., 2008)*
- ✓ The proper running modes used now are mostly based on the experience, and often in a conservative way

(Lipp et al., 2003; Gao et al., 2011)

Cleaning methods

- ✓ Rinsings
  - Forward flushing
  - Back-washing
- ✓ Air scrub
- ✓ Chemical cleaning
  - Acid solution (inorganic fouling)
  - Alkali solution (organic fouling)
  - Biocide solution (bio-fouling)

Feed water type	NTU	TOC (mg/l)	Filtration Velocity (L/m^{2}h)	Backwash Interval (minutes)	Air Scrub Frequency (per day)	Diffuse Chemically Wash
Underground water	<2	<1	90	60	1	Not recommended
Tape water	<3	<2	75	60	2	Usable
Surface water	2-5	<2	75	60	2	Usable
Surface water	5-15	<3	60	40	3	Usable
Surface water	15-50	<3	45	20	4	Recommended
Sea water	<20	/	60	30	4	Usable
Depth treated waste water	0-5	/	40	20	6	Recommended

Backwash Frequency		Once every 20-60 minutes (depends on the water source)
Backwash Duration		30-60 seconds
Backwash filtrate velocity		100-150 L/m^2.h
Air Scrub	Max inlet pressure	2.5 bar
	Air flow per unit	5-12 N m^3/h
	Duration	30-180 seconds
	Air-water mix flush entrance pressure	≤ 1 bar
	Air requirement	Non oil Compressed Air
Diffuse Chemical Wash	Frequency	depends on the water source
	Duration	5-10 seconds
	Chemicals	0,1% HCl - 0,1% NaClO(Cl_2)
Chemical Wash	Frequency	When TMP is 1 bar higher than origin
	Duration	60-90 minuti
	Chemicals	1-2% Citric Acid; 0,4% HCl 0,1%NaOH + 0,2% NaClO(Cl_2)
	Cleaning Flux	1 m^3/h
	Temperature	10 – 40 °C

(Gao et al., 2011)

Scientific literature

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References & Links (2)

Industrial links

- ✓ *http://www.hyfluxmembranes.com*
- ✓ *http://www.kochmembrane.com*
- ✓ *http://www.imtmembranes.nl*