Cartwright Consulting Co., LLC

www.cartwright-consulting.com

pscartwright@msn.com

United States Office
8324 16th Avenue South
Minneapolis, MN 55425-1742
Phone: (952) 854-4911
Fax: (952) 854-6964

European Office
President Kennedylaan 94
2343 GT Oegstgeest
The Netherlands
Phone: 31-71-5154417

Wastewater Recovery & Reuse – Part II

Presented at:

Saudi Arabia Water Environment Association

by
Peter S. Cartwright, PE

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Biological Wastewater Treatment

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Bioremediation Technologies

Primary Treatment – Screening
Primary Treatment – Clarification
Secondary Treatment – Bioremediation
Tertiary Treatment - MBR

AEROBIC – with oxygen

ANAEROBIC – without oxygen

ANOXIC – oxygen deficient

Anaerobic and Aerobic Bioremediation Compared

Parameters	Anaerobic	Aerobic
Power Requirements (kWhr)	1.5	65
Net Production of Biosolids (kg)	15-100	200-600
Useable Energy Produced	140	NiL

(based on 1,000 kg COD)

Application of Biological Treatment Processes

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Suspended Growth – Activated Sludge

Fixed Film:

- Trickling Filters
- Rotating Biological Contactors (RBC)
- Moving Bed Biofilm Reactors (MBBR)

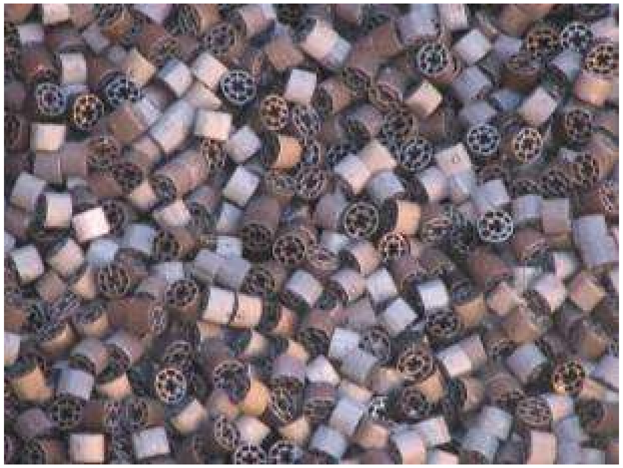
Secondary Treatment Comparison

SUSPENDED GROWTH	FIXED-FILM	
ACTIVATED SLUDGE	**RBC**	**MBBR**
Requires residual suspended solids (MLSS)	No residual suspended solids	No residual suspended solids
Operator adjusts MLSS levels	Self regulating, no operator adjustments	Self regulating, no operator adjustments
MLSS sludge recycled back through plant	Single pass flow through	Single pass flow through
MLSS can be flushed out with high flows	Biology stripped of media with high flows	Not affected by high flows
Moderate mechanical equipment	High mechanical equipment	Low mechanical equipment
Unstable nutrient removal	Unstable nutrient removal	Stable nutrient removal

Types of Fixed Film Technologies

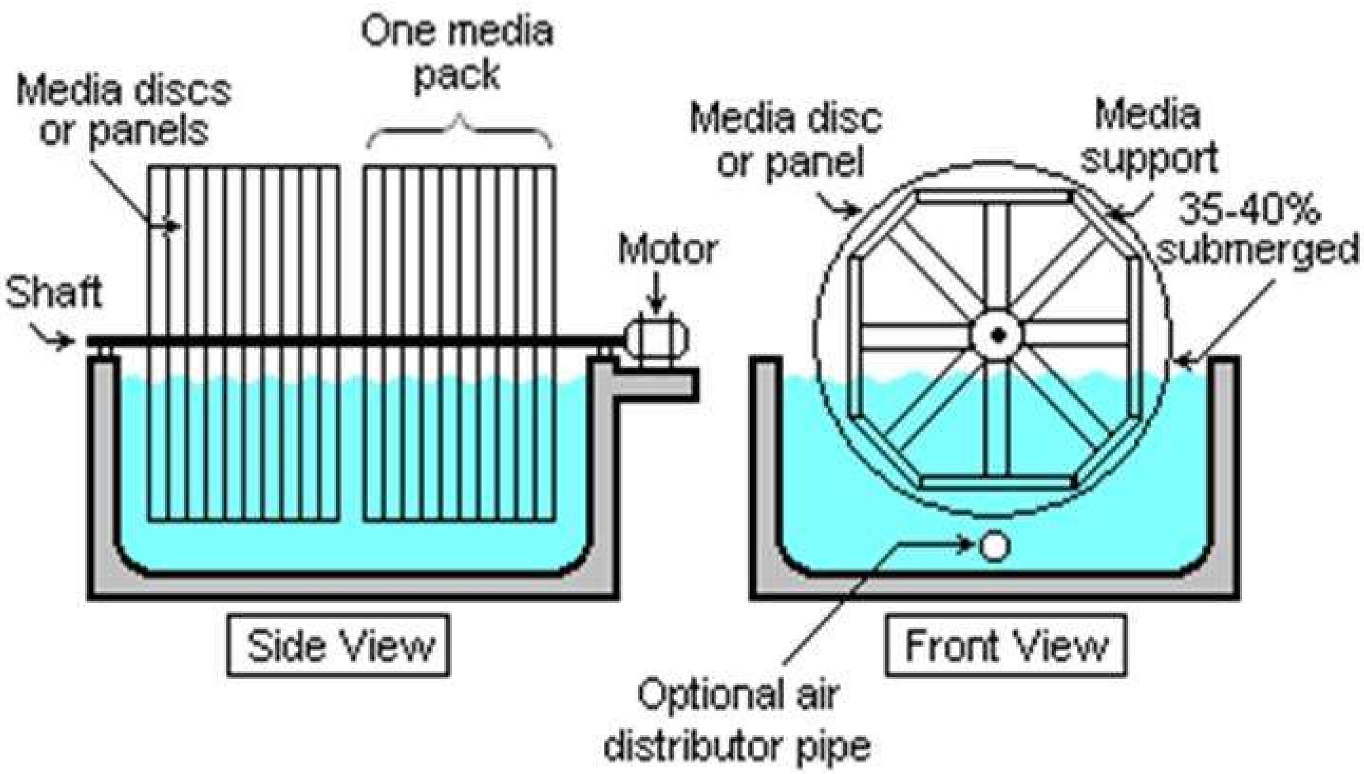
Trickling filters are a static, air phase fixed film treatment system.

RBCs are partially water and air phase.



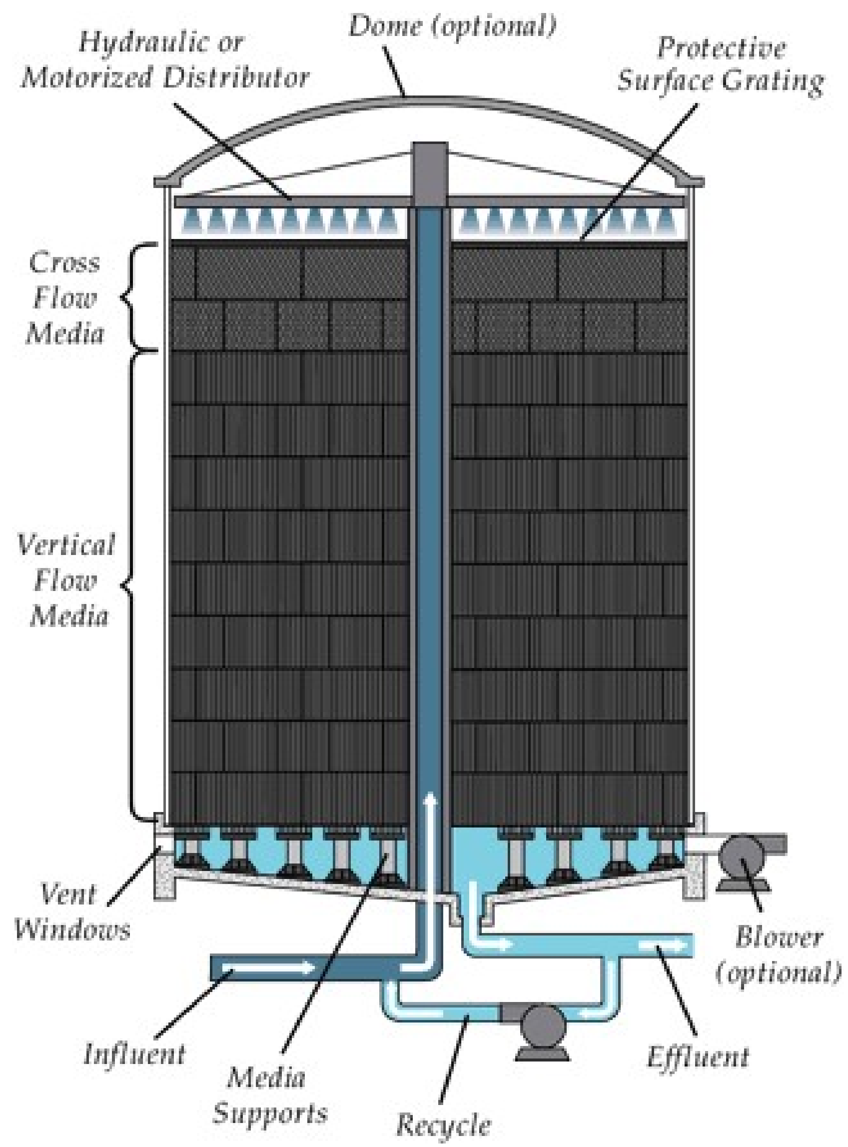
MBBRs are dynamic, water phase fixed film treatment systems

Rotating Biological Contactor



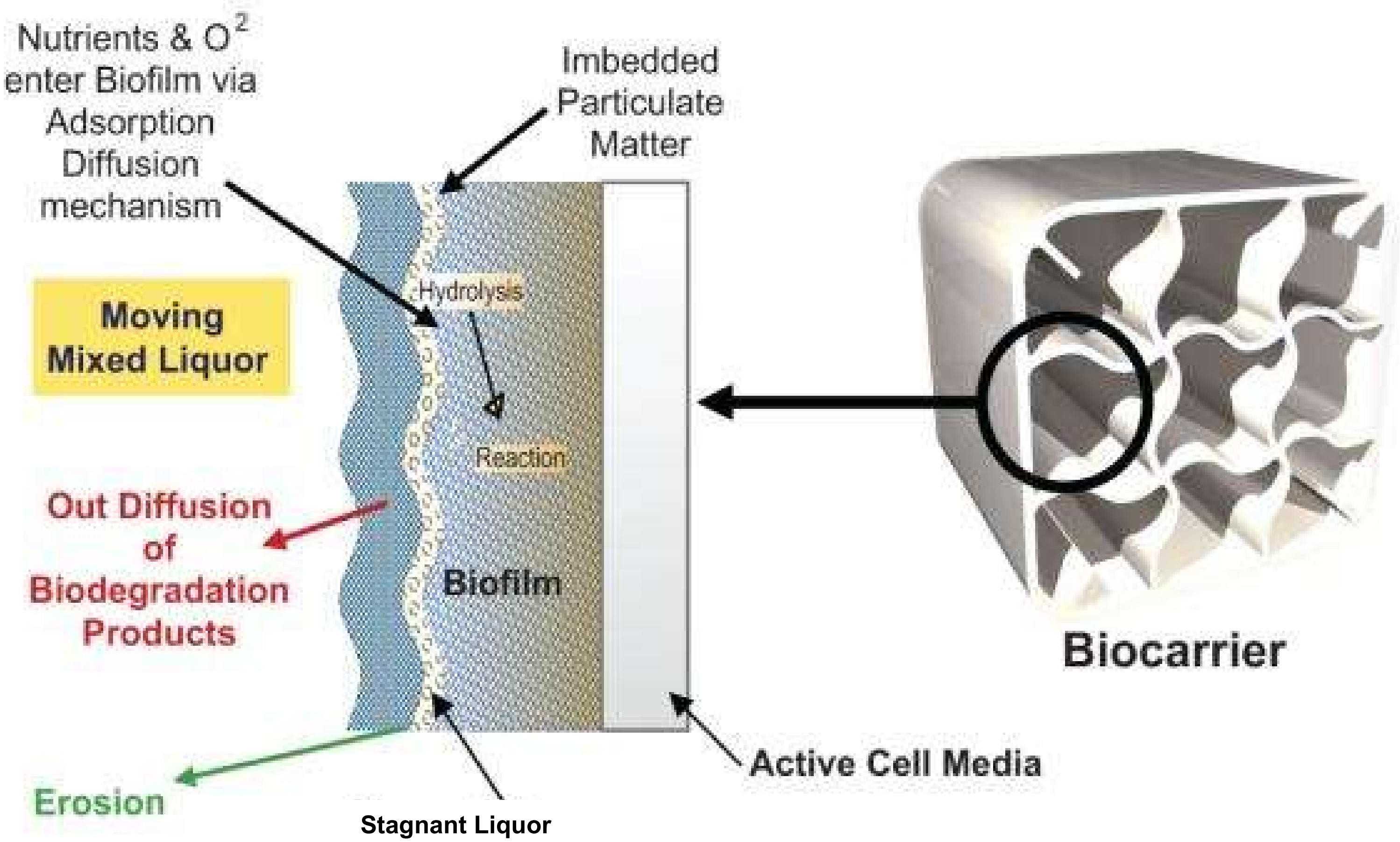
Wikipedia "Sewage Treatment"

Modern Bio-Tower



BRENTWOOD INDUSTRIES

Dynamic Water Phase Fixed Films



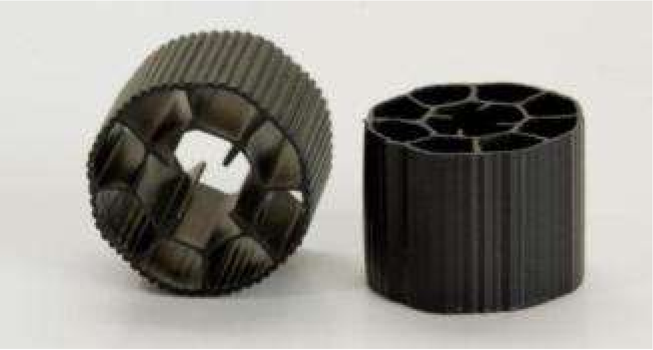
MBBR
Moving Bed Biofilm Reactor

- Process is based on the biofilm principle using polyethylene carrier elements.
- The carrier elements, which are less dense than water, 0.93-0.95 SG, provide a large protected surface for bacteria culture.
- MBBR provides advantages of Activated Sludge and Trickling Filter systems without their disadvantages.
- MBBR is one of the most documented processes with many technical publications and presentations.

Key Components: MBBR

Aeration Grid

Retention Sieves



ActiveCell® Media

Cartwright Consulting Co.

HeadworksBIO™

www.headworksbio.com

Carrier Material

MBR

MBR

Biomediation (activated sludge)
with
MF/UF Membrane Filtration
(tertiary treatment)

MBR Permeate

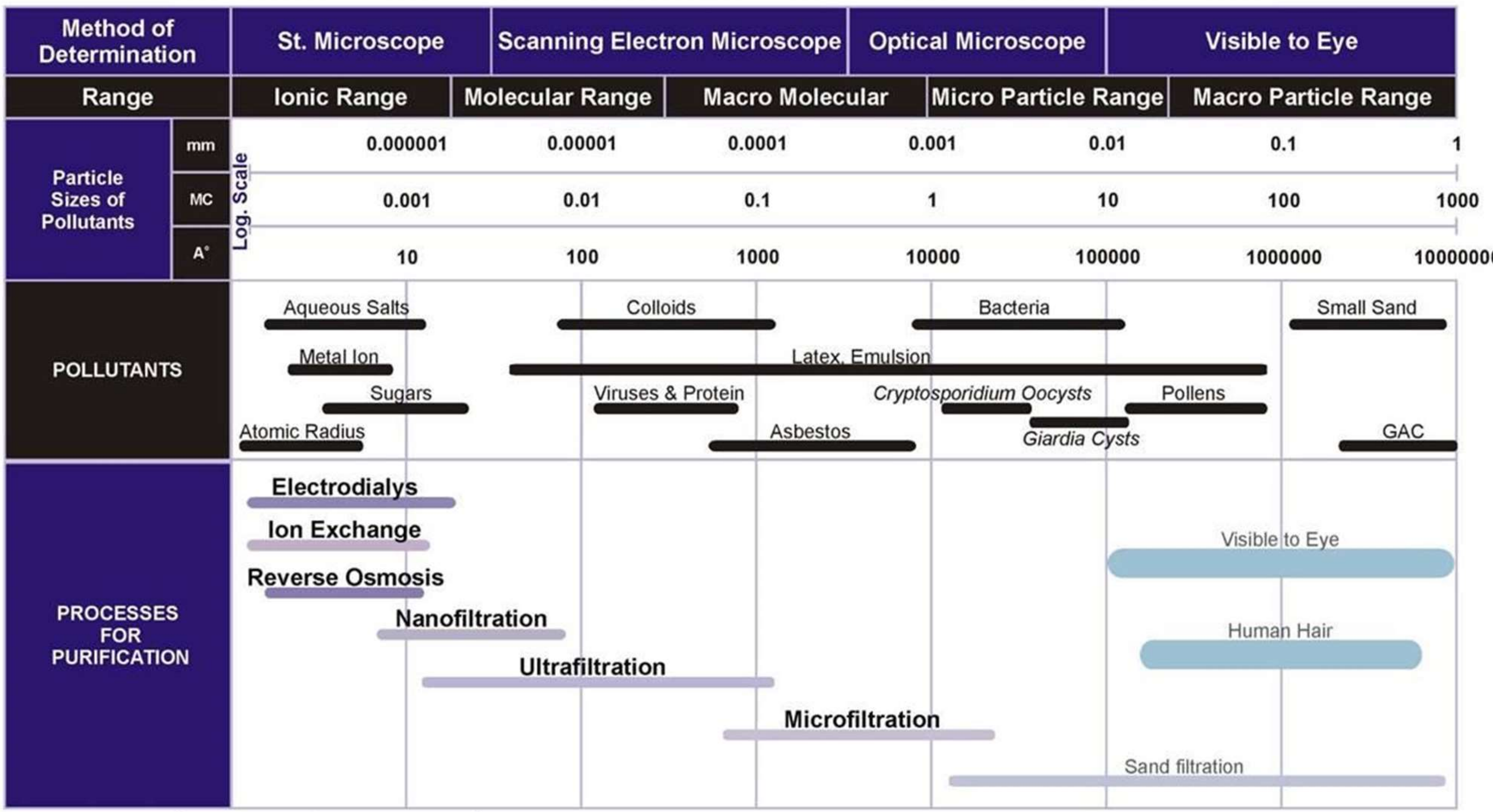
Very Low In:

- BOD
- COD
- TSS
- Coliform Bacteria

MBR Applications Include:

- Residential development projects
  - Single dwellings
  - Housing clusters
  - Apartment buildings/condominiums
- Commercial projects
- Mining camps and other remote installations
- Emergency response
- Military installations
- Sports facilities
- Recreation parks
- Schools
- Shopping centers
- Office parks

Water Contaminants, Sizes and Treatment Technologies



1 Angstrom(A°) = 10^{-10}Meter(m) = 10^{-4}Microns(MC) = 10^{-7}Milimeter(mm)

Courtesy Val S. Frankel, Ph.D., P.E., D.WRE., Kennedy/Jenks Consultants

Biological Treatment Process

Evaluation Parameter	Trickling Filter	Rotating Biological Contractor (RBC)	Sequencing Batch Reactor (SBR)	Membrane Bioreactor (MBR)	Powdered Activated Carbon Treatment (PACT)
Effective BOD Removal			x	x	x
Effective COD Removal			x	x	x
Low O&M Costs		x			
Low Sludge Production	x	x		x	
Low Sludge Disposal Costs	x	x		x	x
Good Operability: Winter			x	x	
Good Operability: Summer	x	x	x	x	x
Good Performance: High Water Temperature	x			x	x
Good Performance: Low Water Temperature			x	x	x
Minimal Operator Attention		x			
Quick Upset Recovery	x	x	x		x
Easy Expandability		x			
Efficient Nitrification			x	x	x
Easy Installation		x			
Energy Efficient	x	x			
Minimal Space Requirements			x	x	x

Comparisons are made based on wastewater with a COD of 600 mg/L and BOD of 250 mg/L

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MBR Technology

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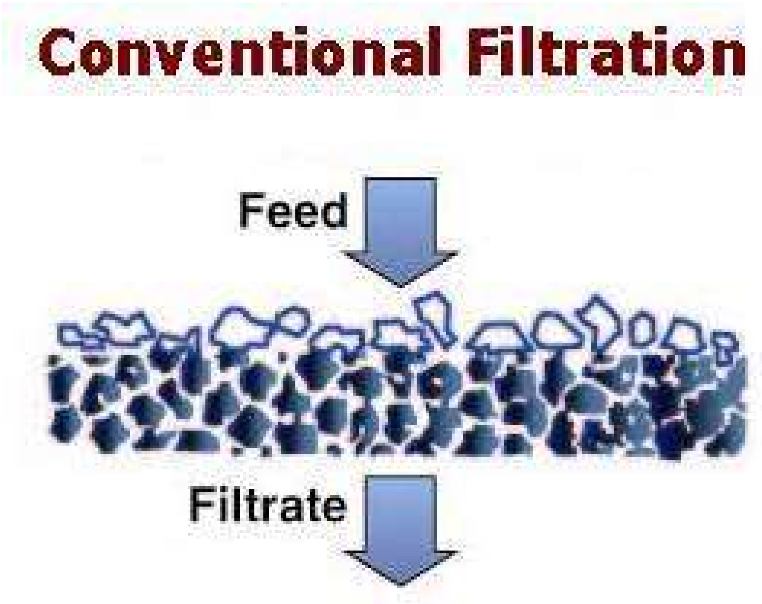
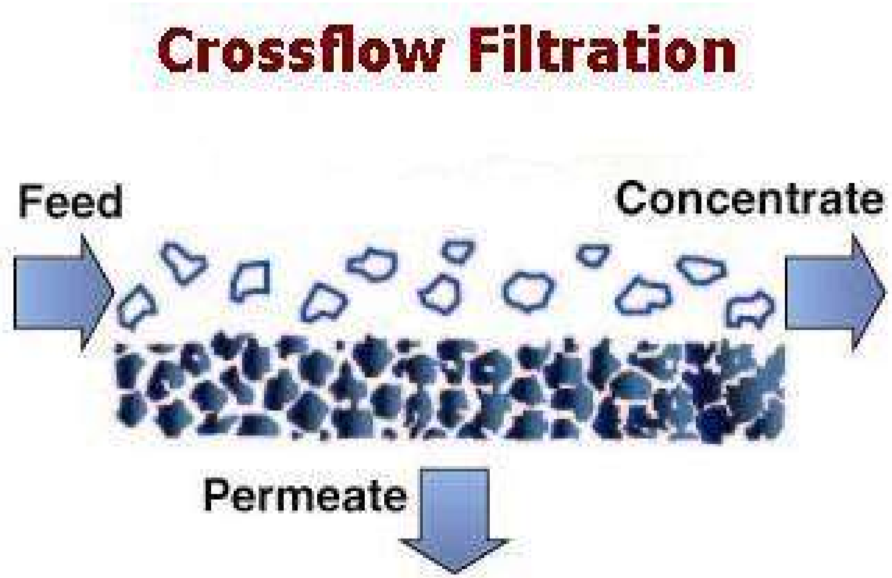
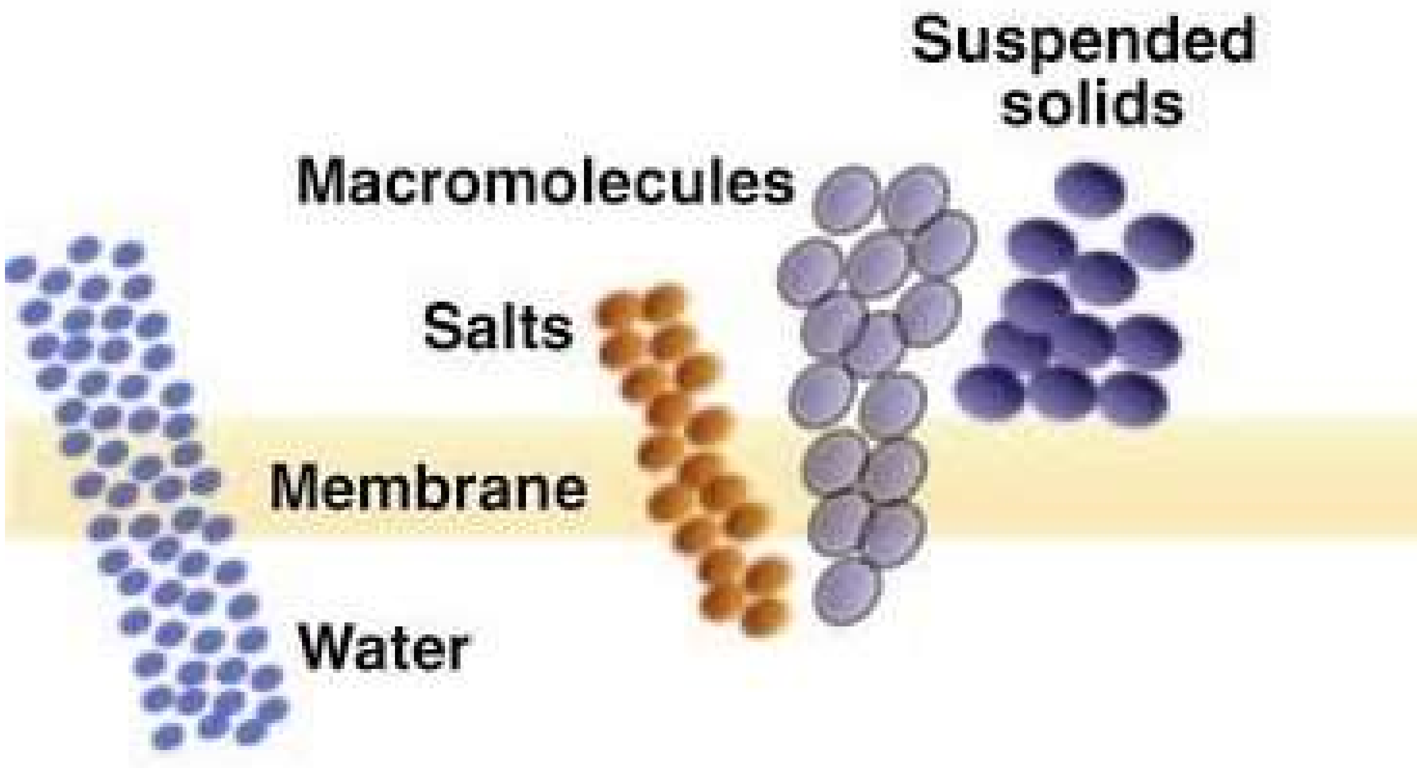
MEMBRANE TECHNOLOGY

Conventional vs. Crossflow

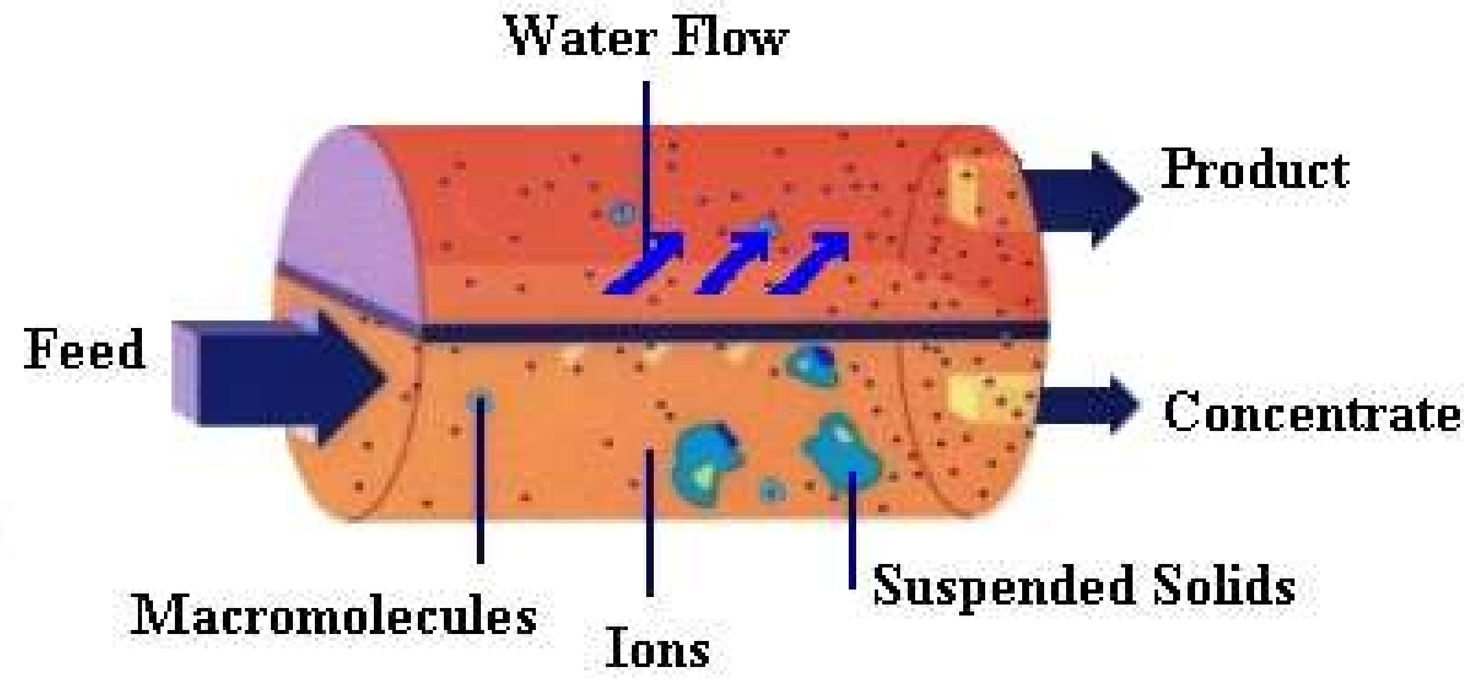




Microfiltration



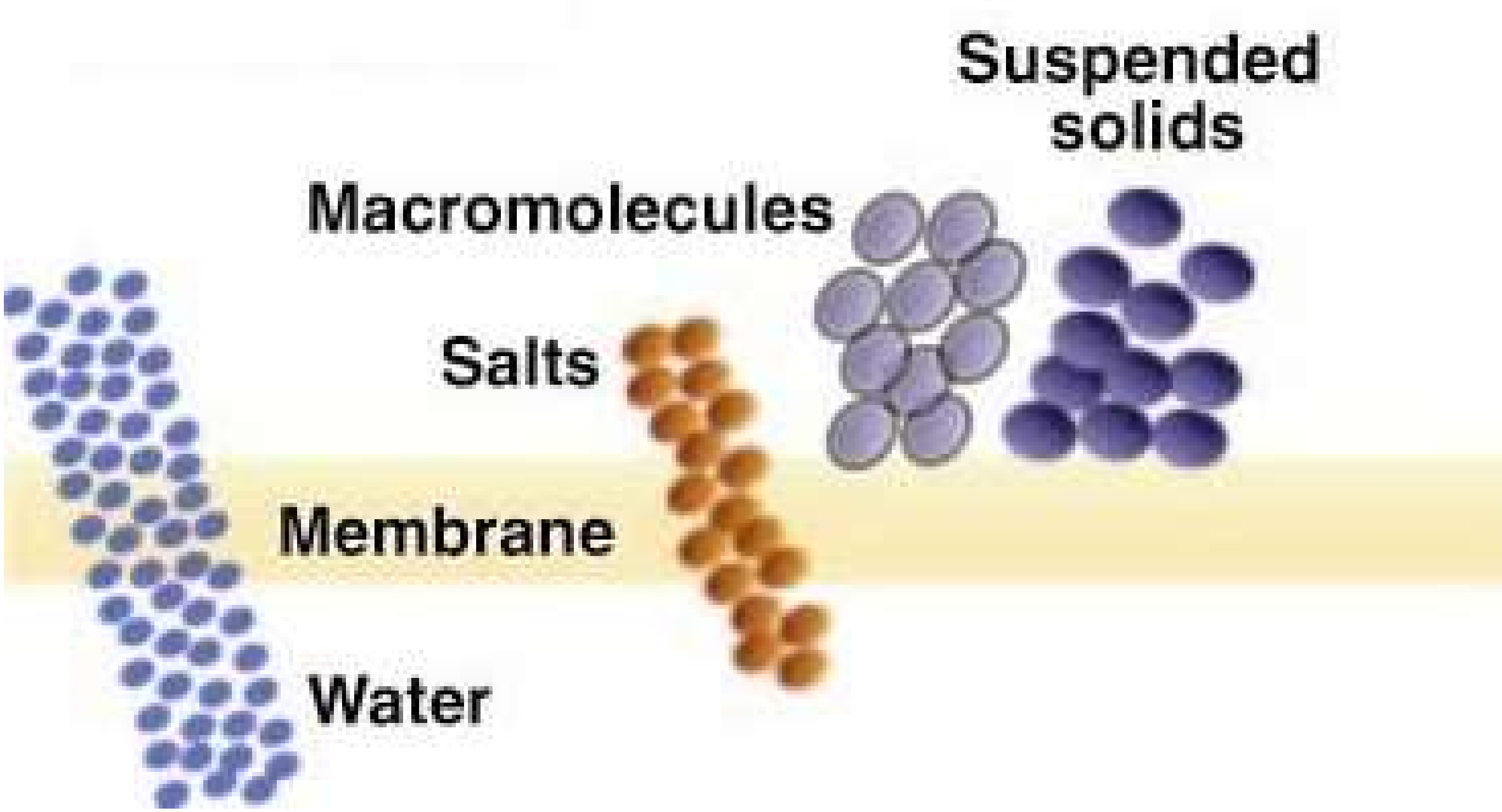
Microfiltration



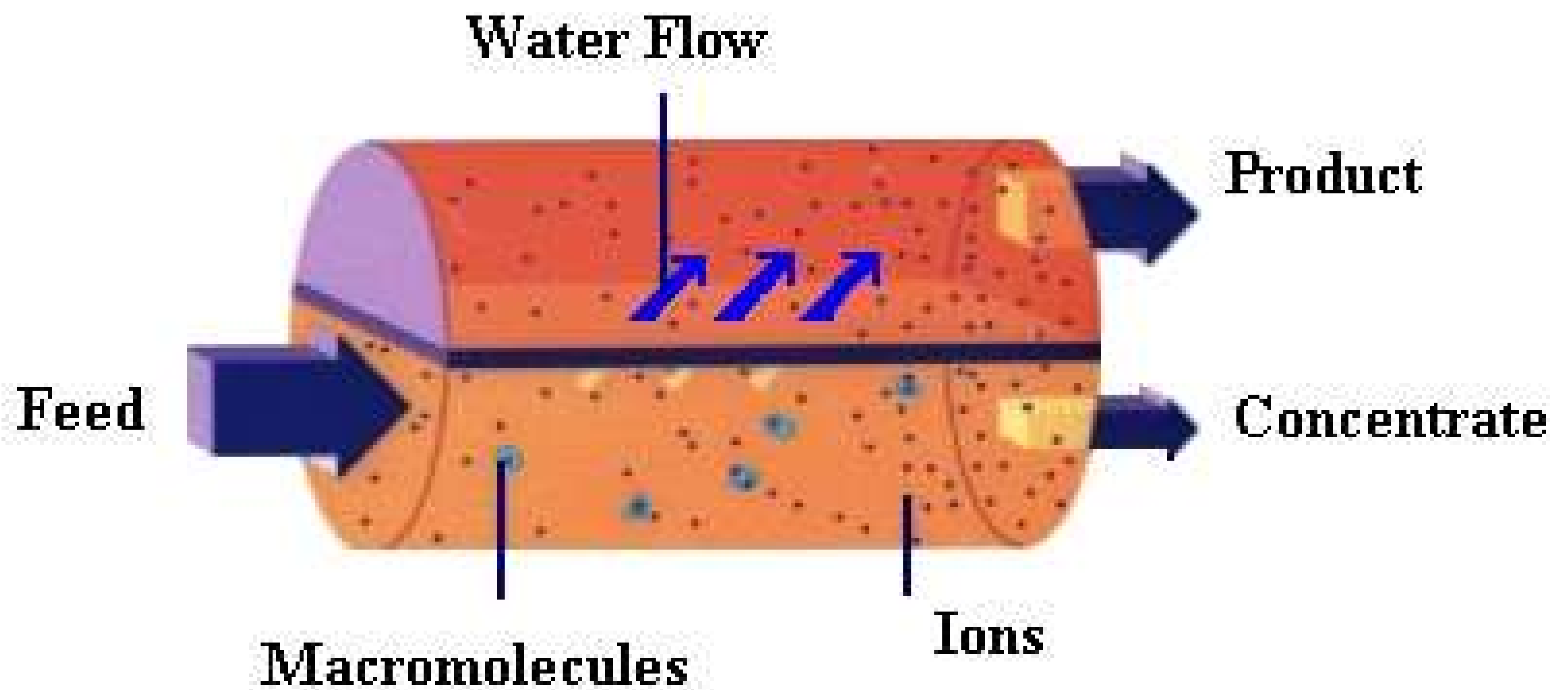
Microfiltration

Microfiltration is utilized to remove submicron suspended materials on a continuous basis. The size range is from approximately 0.01 to 1 micron (100 to 10,000 angstroms). By definition, microfiltration does not remove dissolved materials.

Ultrafiltration



Ultrafiltration

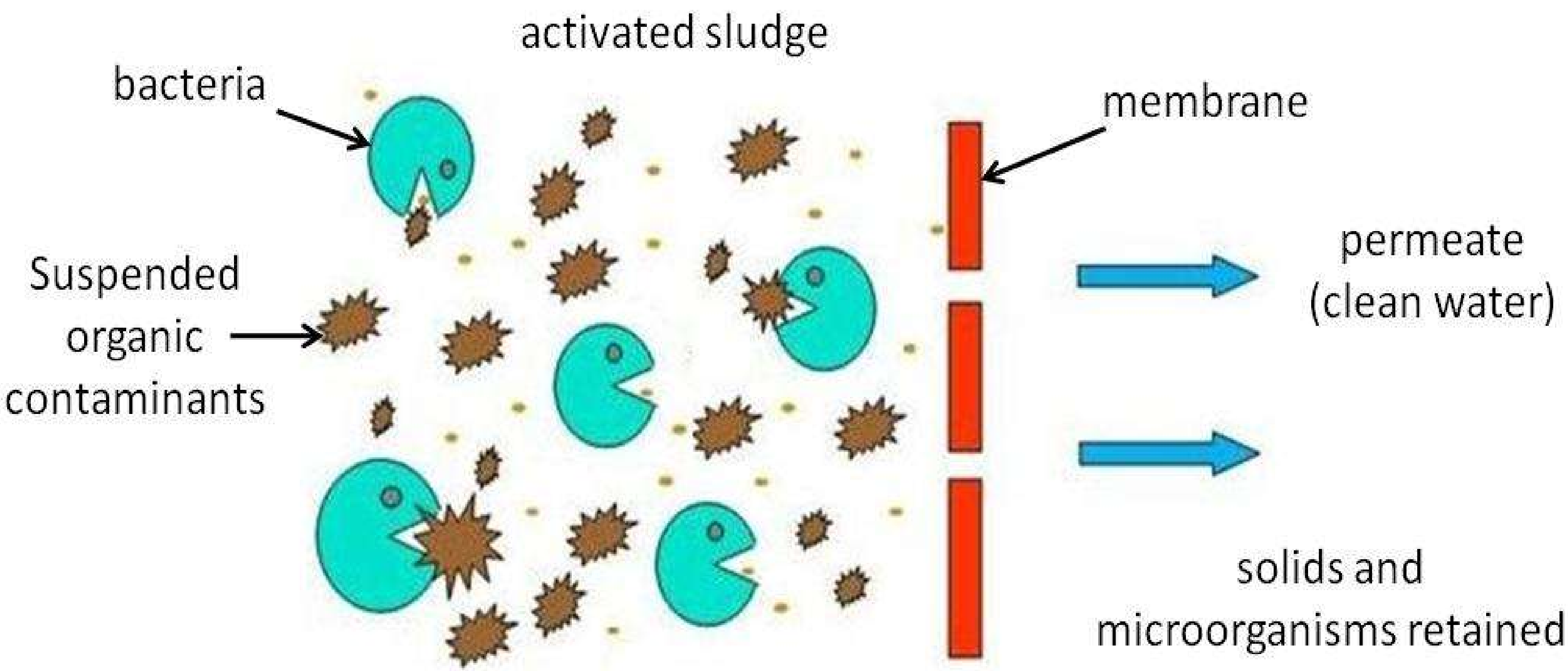


Ultrafiltration

Ultrafiltration is the membrane process which removes dissolved non-ionic solute, typically organic materials (macromolecules). Ultrafiltration membranes are usually rated by "molecular weight cutoff" (MWCO), the maximum molecular weight of the compound that will pass through the membrane pores into the permeate stream. Ultrafiltration pore sizes are usually smaller than 0.01 micron (100 angstroms) in size.

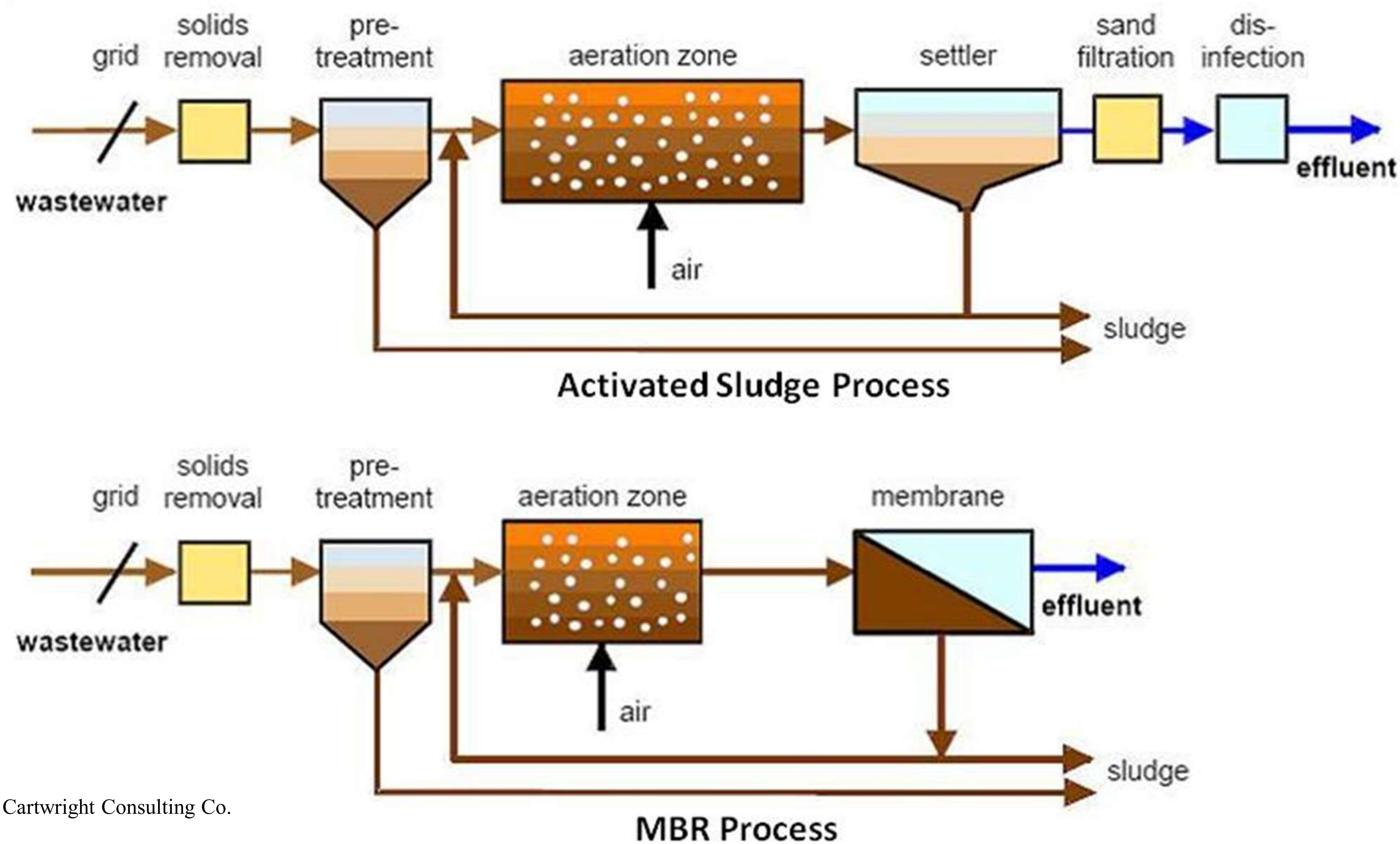
MBR Process

MBR Process



activated sludge
bacteria
membrane
permeate
(clean water)
Suspended
organic
contaminants
solids and
microorganisms retained

Activated Sludge Process vs. MBR Process



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MBR Advantages

- High-quality effluent, almost free from suspended solids
- The ability to disinfect without the need for chemicals
- Complete independent control of HRT (Hydraulic Retention Time) and SRT (Sludge Retention Time), which allow more complete reduction of COD, and improved stability of such processes as nitrification
- Reduced sludge production
- Process intensification through high biomass concentrations with MLSS (Mixed Liquor Suspended Solids) over 25,000 mg/L
- Ability to treat high strength wastes
- More compact systems, resulting in a smaller footprint
- Process unaffected by solids settling
- Longer retention time for more complete nitrification
- Reduction in post treatment disinfection requirements

MBR Disadvantages

- Higher capital cost, primarily resulting from the membrane unit cost
- Higher operating costs associated with the energy requirements of the air blower and pumps
- Operation at high SRTs may increase levels of inorganic chemicals that are harmful to the microbial populations

Membrane Configurations

- Plate & Frame
- Tubular
- Hollow (Capillary) Fiber
- Spiral Wound

Membrane Devices

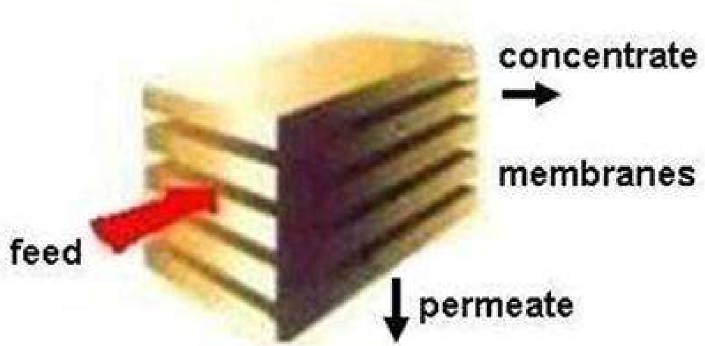
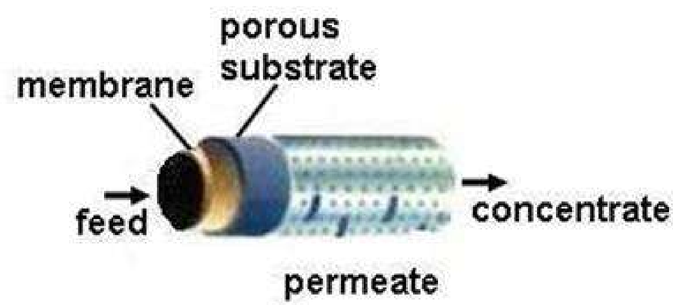
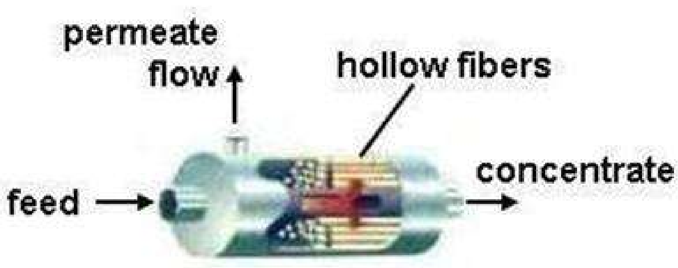


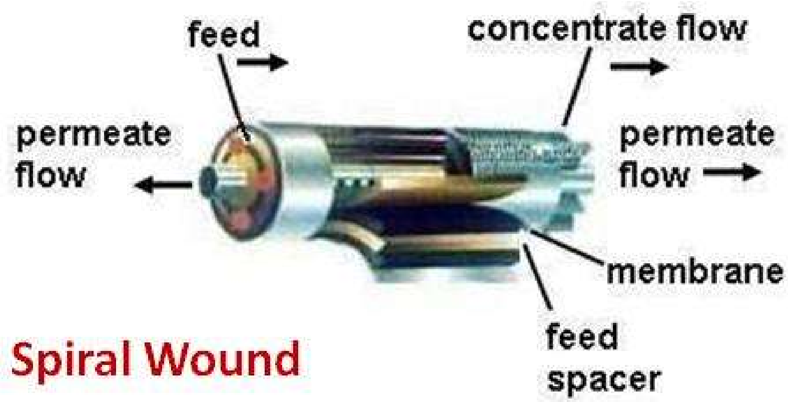
Plate & Frame



Tubular



Hollow (capillary) Fiber



Spiral Wound

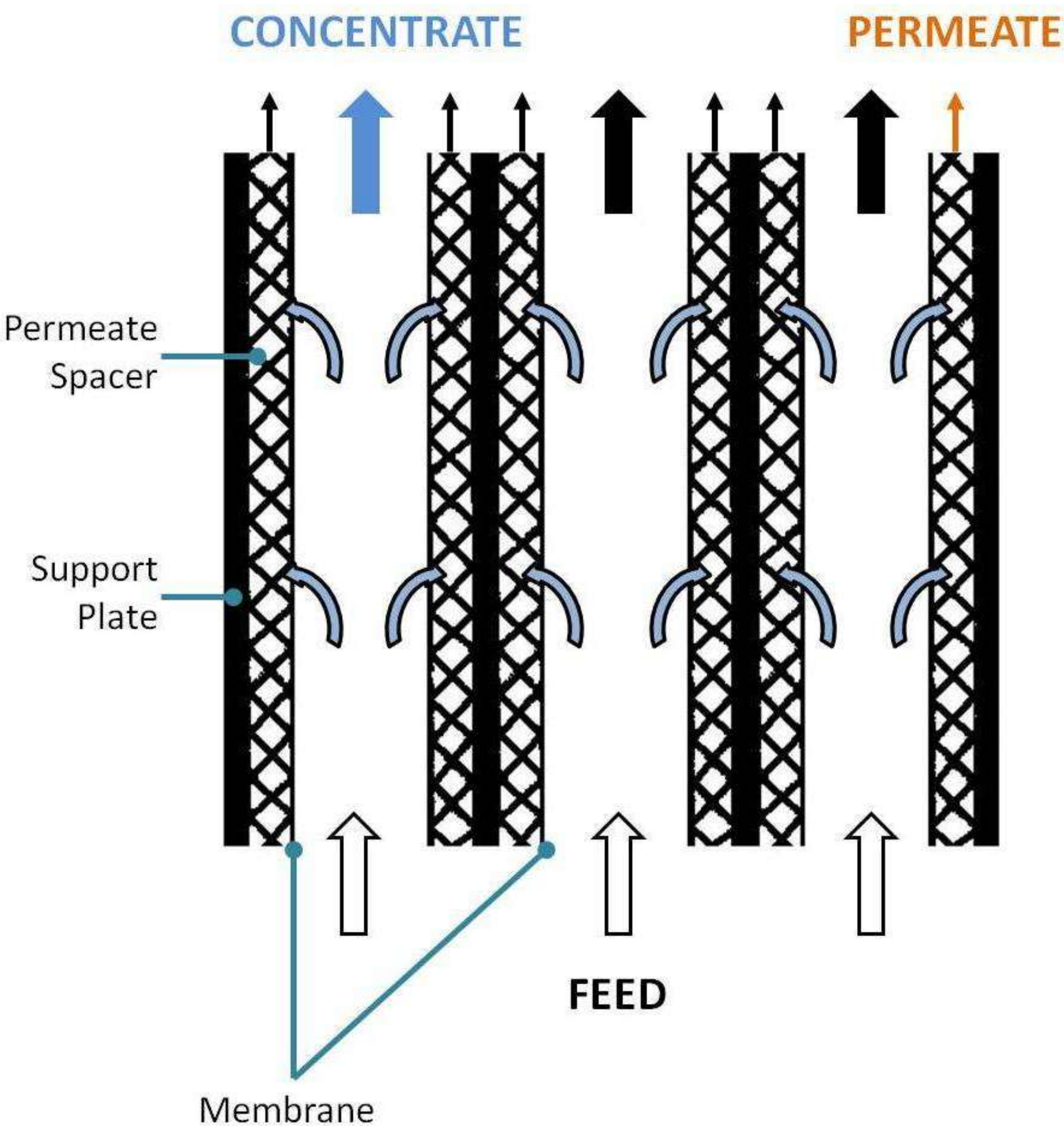

CONCENTRATE
PERMEATE
Permeate Spacer
Support Plate
FEED
Membrane

Plate & Frame

Plate & Frame

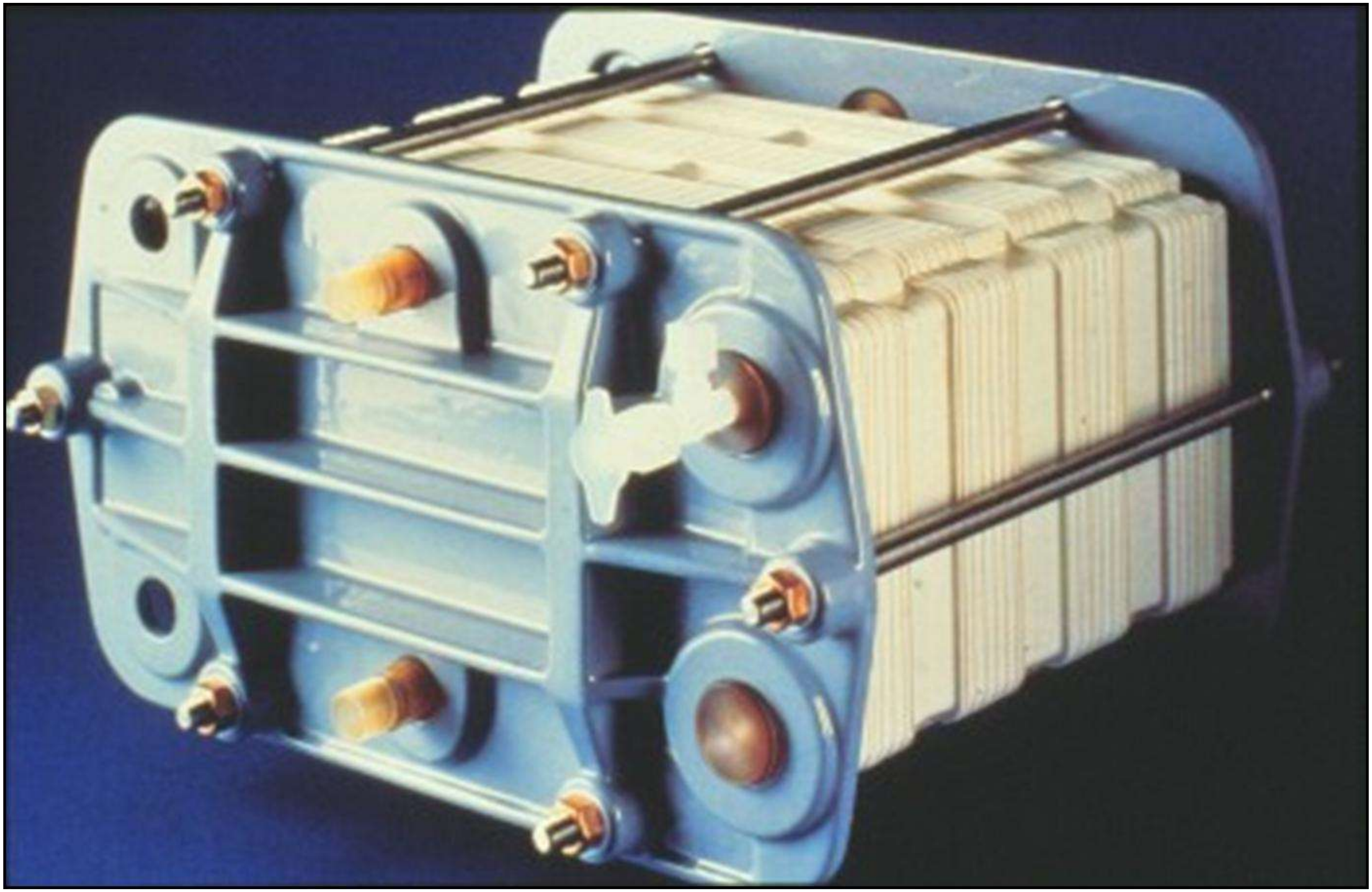
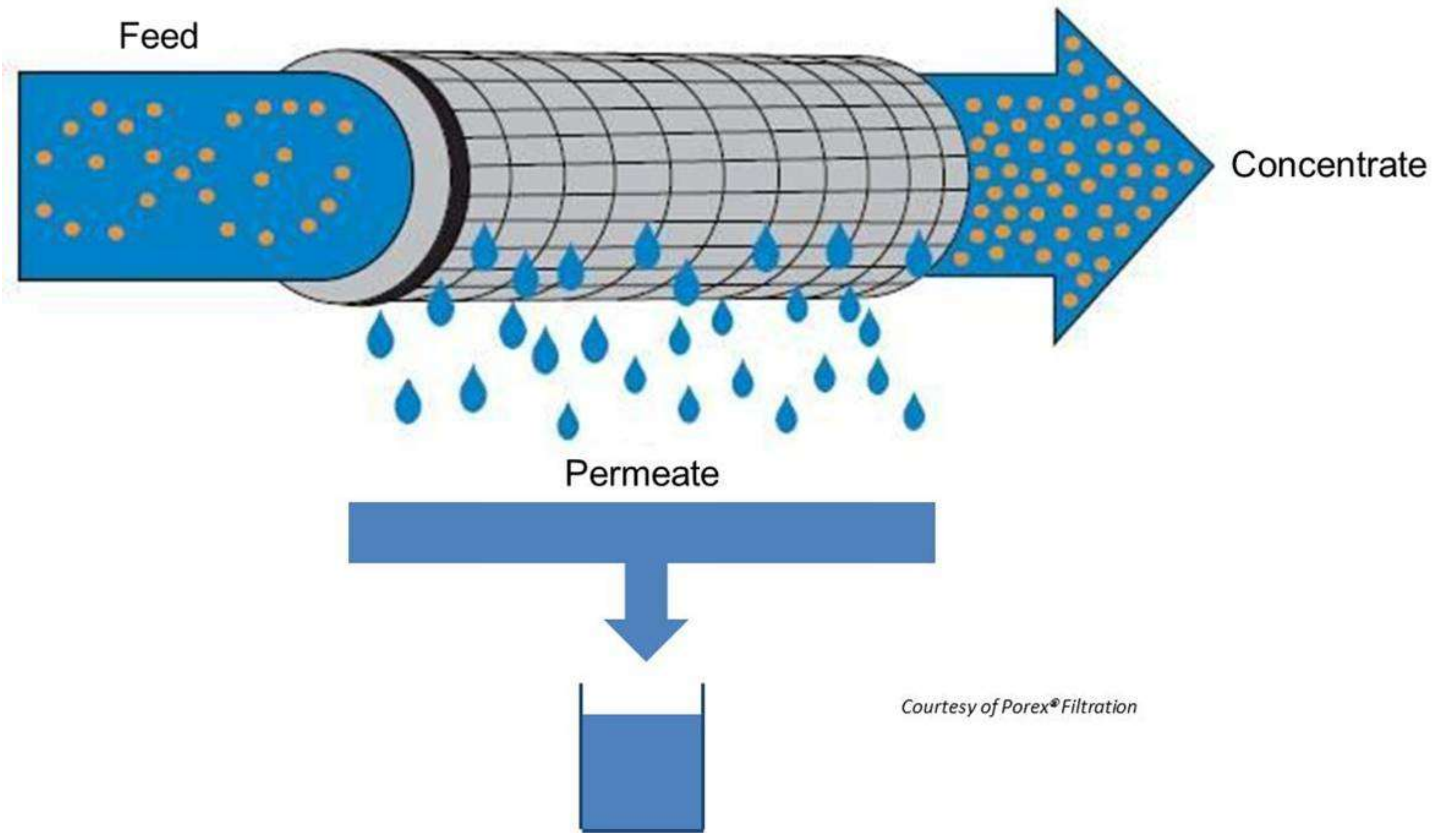


Plate & Frame Variables

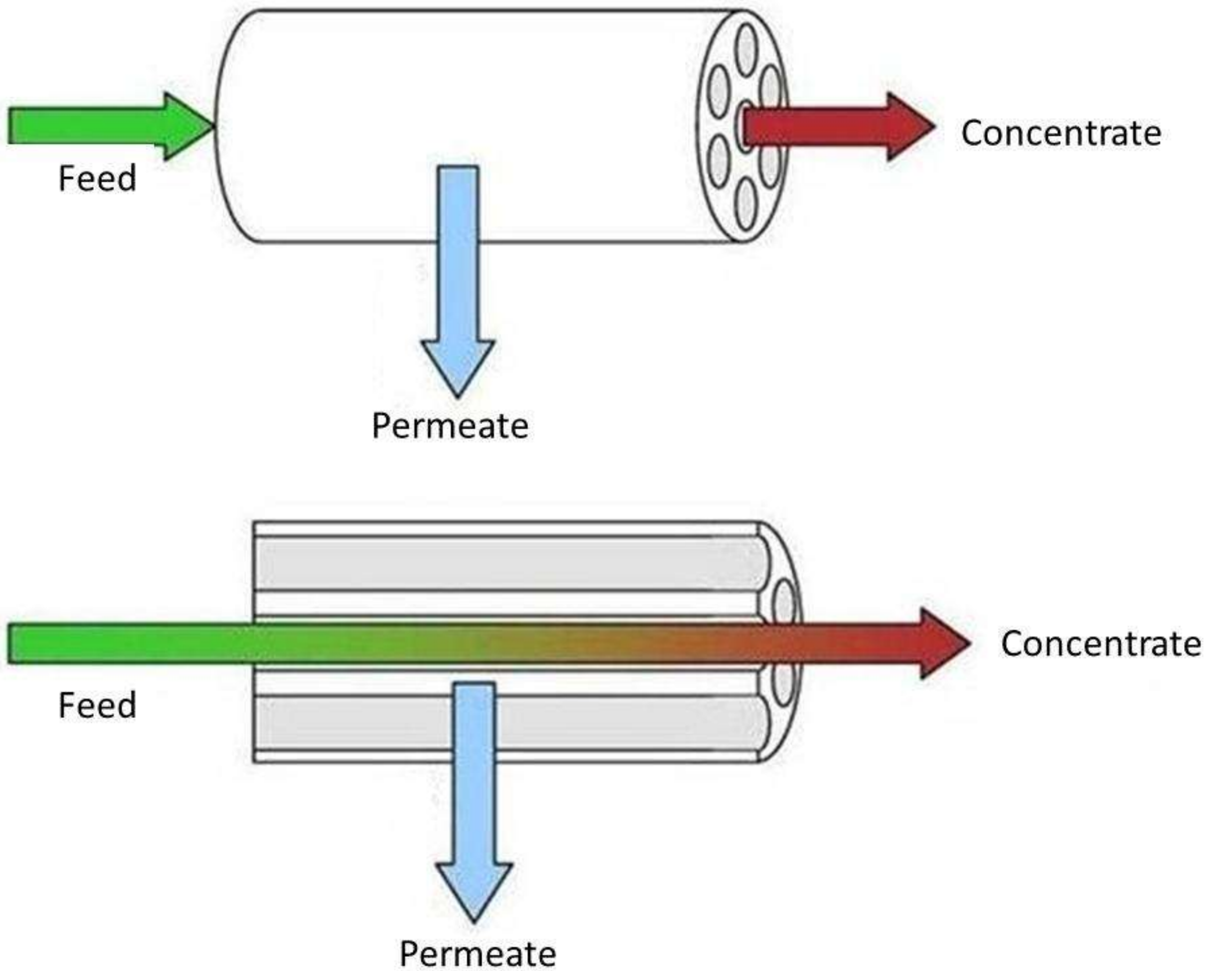
- Panel size
- Panel material
- Membrane material
- Pore size
- Operating pressure
- Reliance on biohydraulics
- Membrane to panel attachment method

Tubular

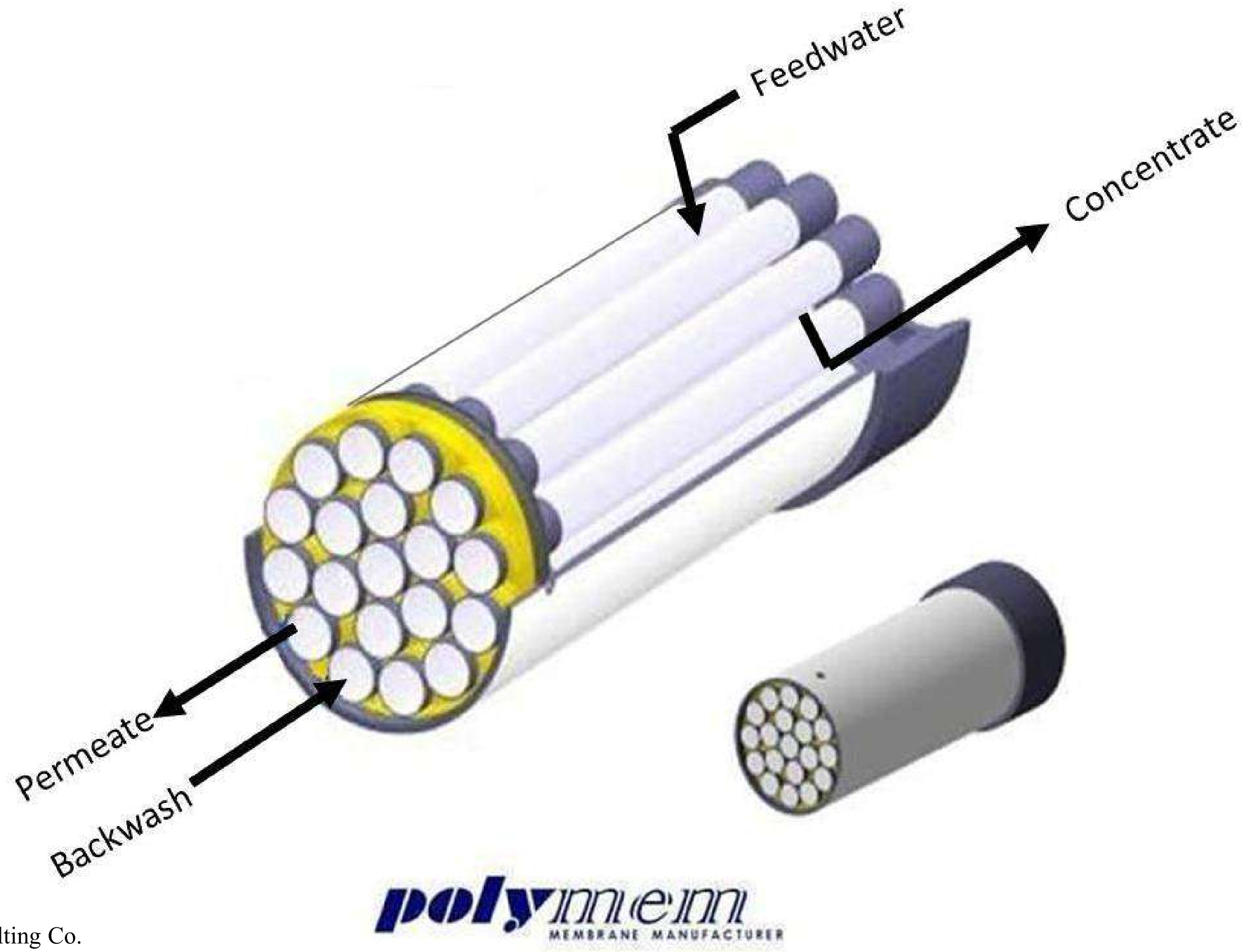


Courtesy of Porex® Filtration

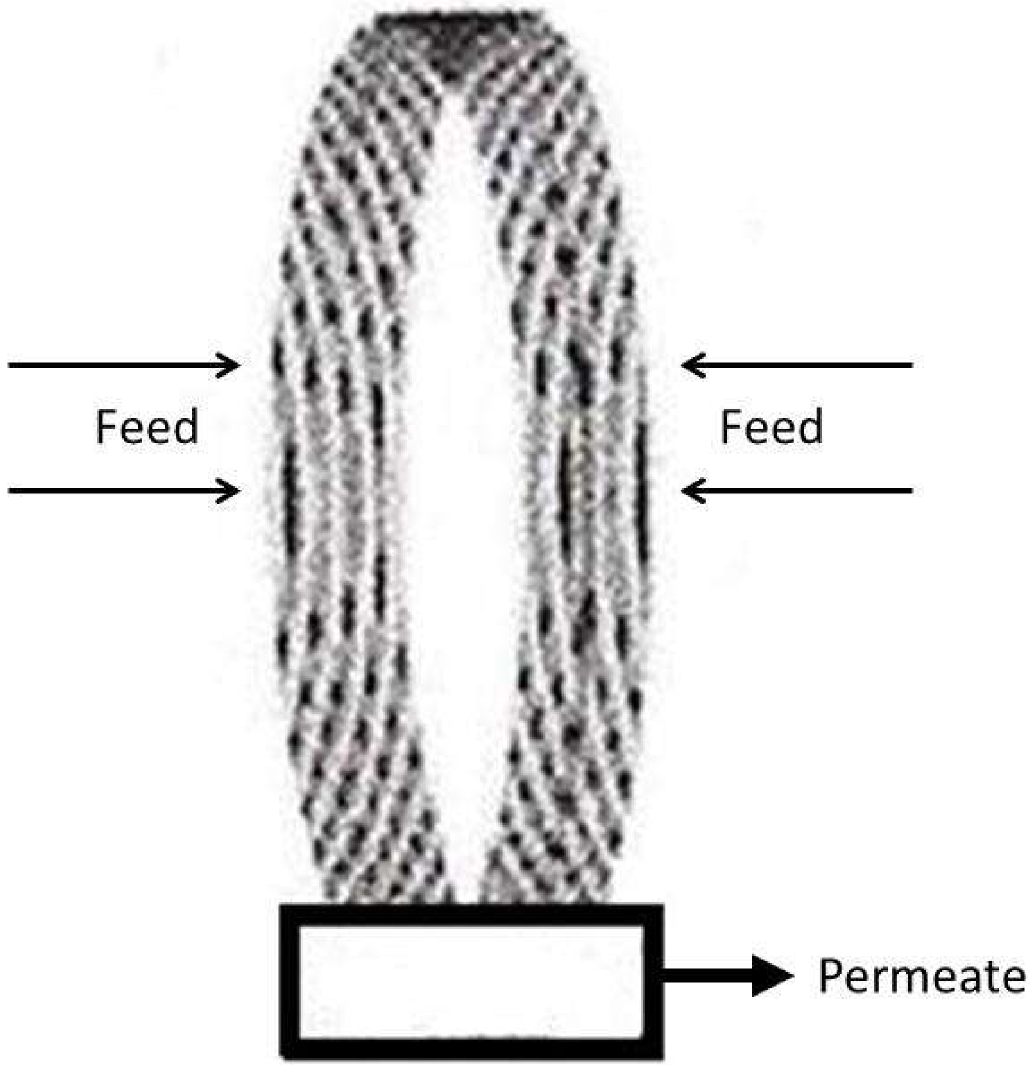
Tubular



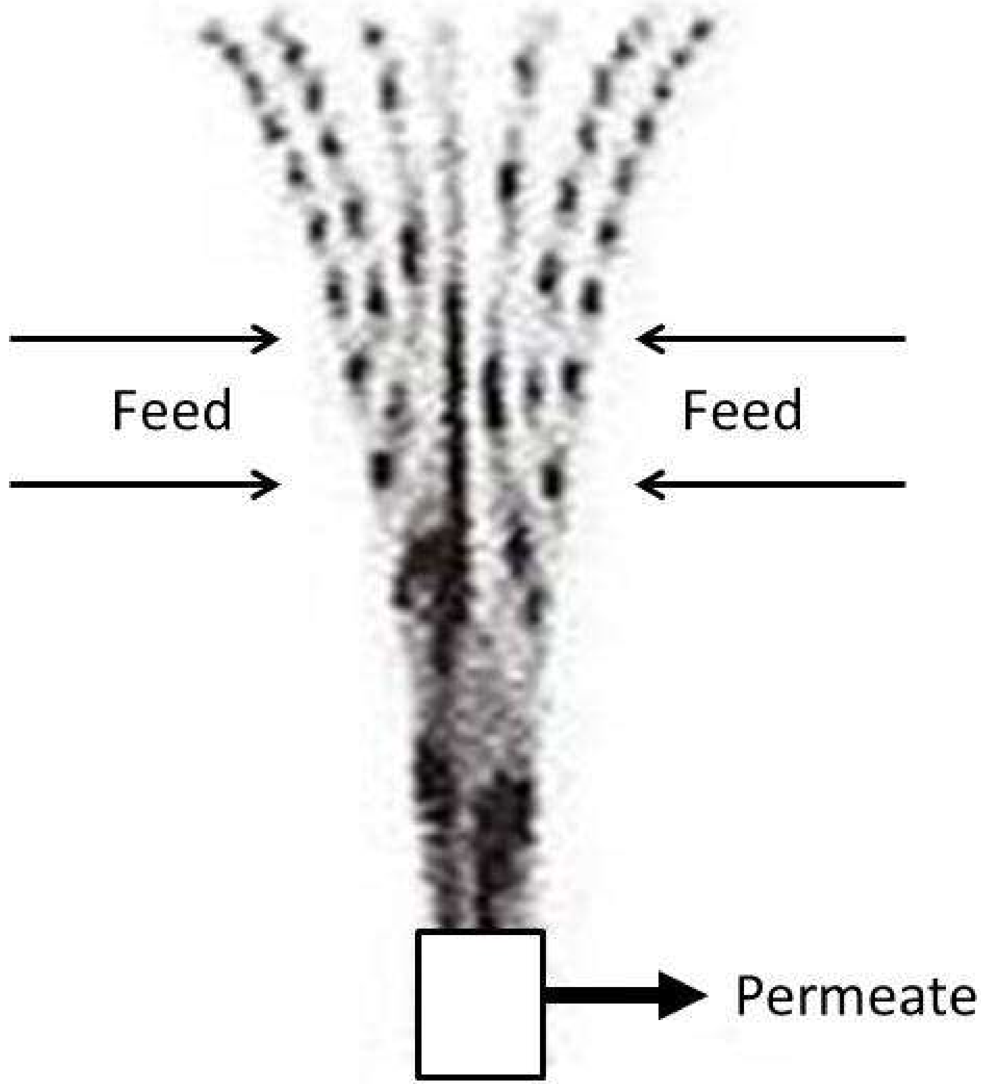
Hollow Fiber



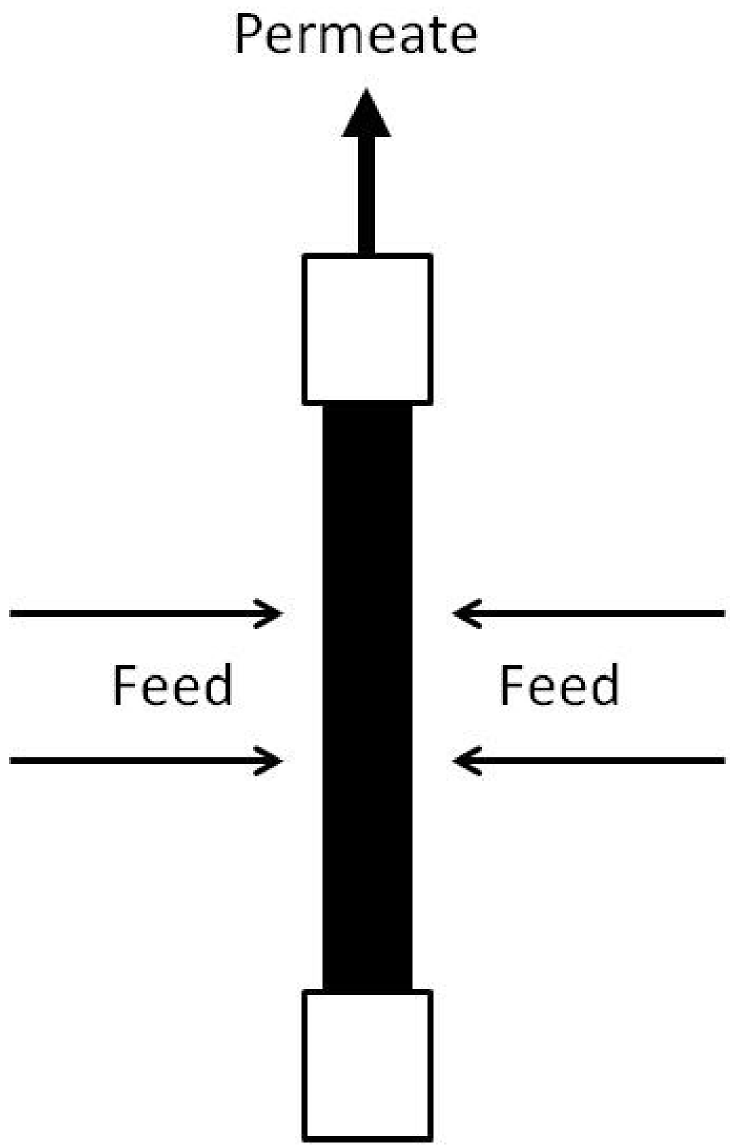
U-Shaped Bundle



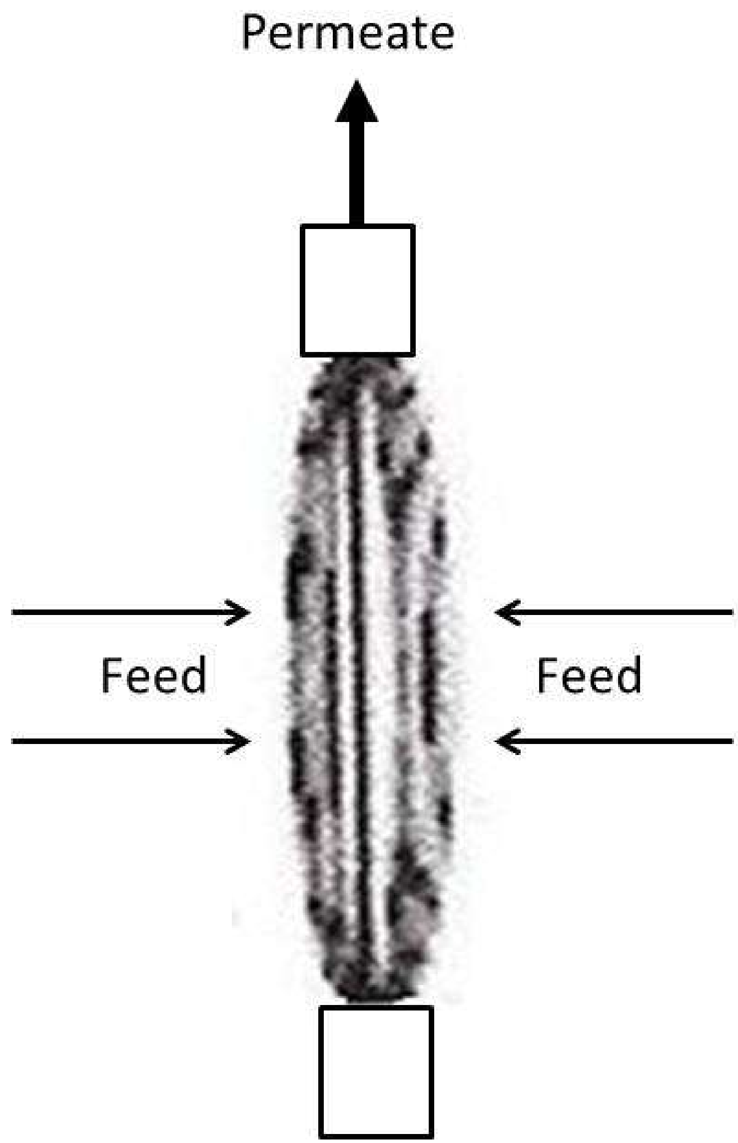
One-Sided Potted



Rigid Fiber Bundle



Both Ends Potted



Hollow Fiber Variables

- Fiber diameter
- Method used to bundle the strands
- Number of strands per bundle
- Membrane material
- The method in which air is applied to the bundle
- Wall thickness

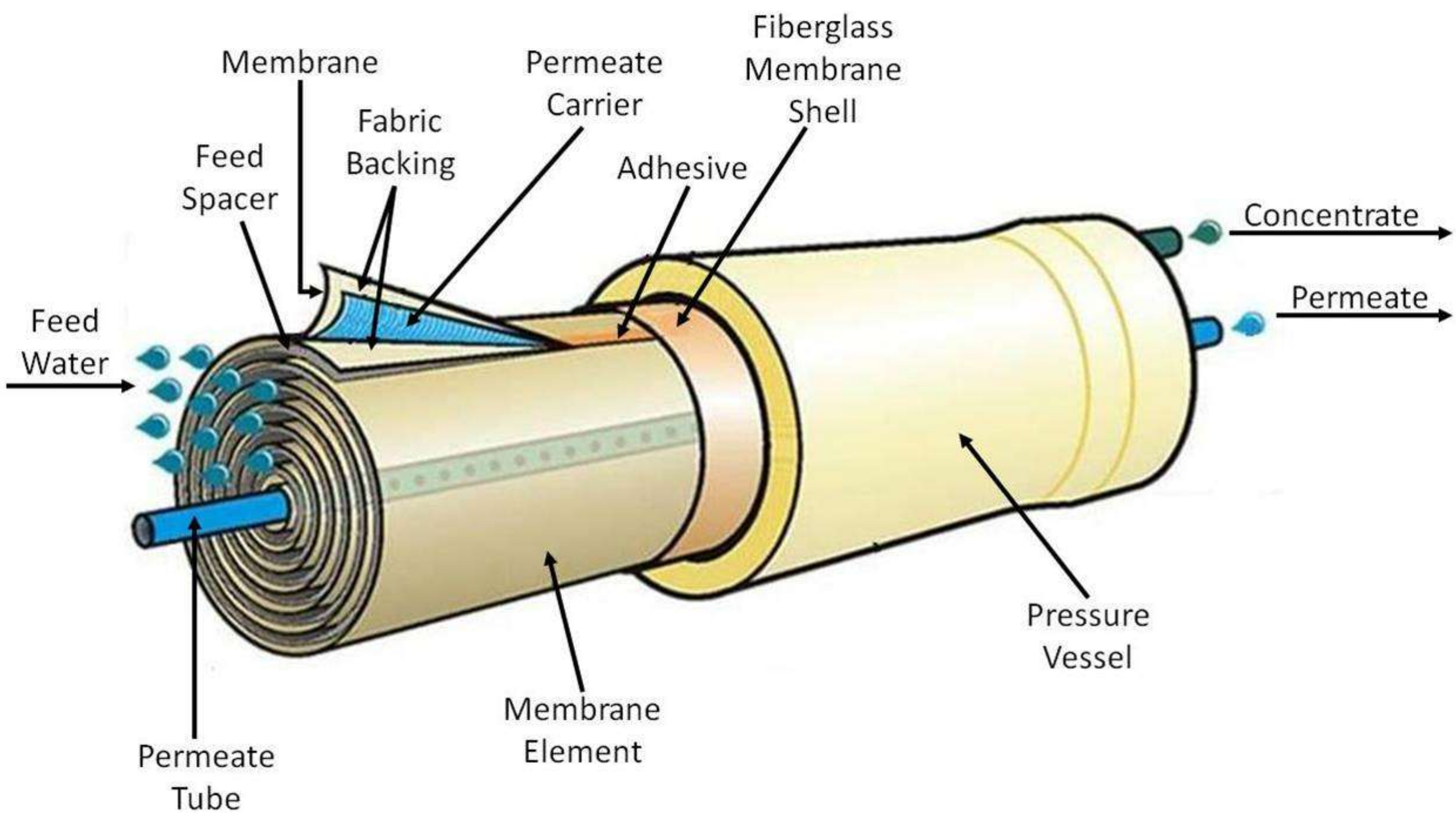
MBR Membrane Elements Compared

	Membrane Element Configuration		
Parameter	**Plate and Frame**	**Hollow Fiber**	**Tubular**
Packing Density *	Moderate	High	Low
Fouling Resistance	Moderate	Moderate	High
Energy Requirement	Moderate	Low	High
Backwashable	No	Yes	Yes
Cleaning Ease	Moderate	Moderate	Easy
Net Flux Range ($L/m^2/hr$)	15-25	20-30	70-200
MLSS (mg/L)	10,000-15,000	10,000-15,000	10,000-30,000

** Membrane area per total element volume*

Spiral Wound

Spiral Wound



Membrane Materials

Microfiltration (MF) & Ultrafiltration (UF)

Materials of Construction	Device Configuration			
	Hollow Fiber	Tubular	Plate & Frame	Spiral Wound
Polymeric				
PS	X	X	X	X
PES	X	X	X	X
PAN	X	X	X	X
PE	—	X	—	—
PP	X	X	X	—
PVC	—	X	—	—
PVDF	X	X	—	—
PTFE	X	—	X	—
PVP	X	X	—	—
CA	X	—	—	—
Non-Polymeric				
Coated 316LSS	—	X	—	—
a- Alumina	—	X	X	—
Titanium Dioxide	—	X	—	—
Silicon Dioxide	—	X	—	—

PS = Polysulfone

PES = Polyethersulfone

PE = Polyethylene

PP = Polypropylene

PAN = Polyacrylonitrile

PVDF = Polyvinylidene Fluoride

PTFE = Polytetrafluoroethylene

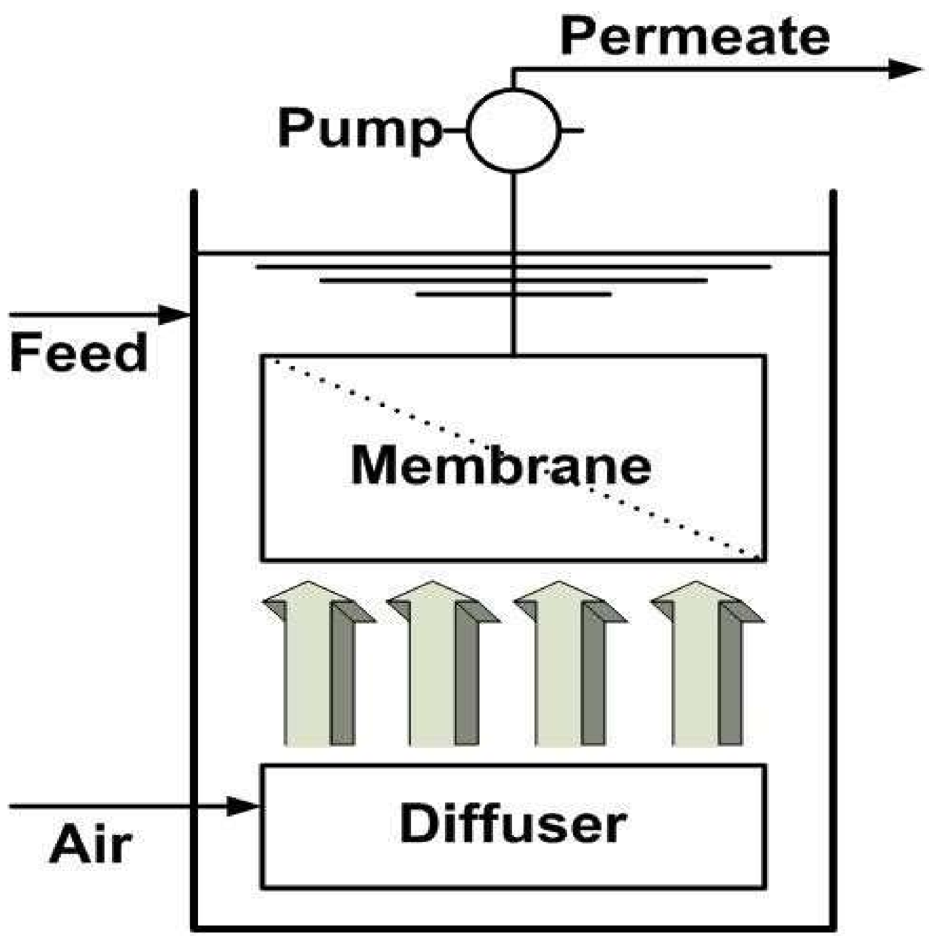
CA = Cellulose Acetate

PVP = Polyvinylpyrrolidone

TF = Thin Film Composite

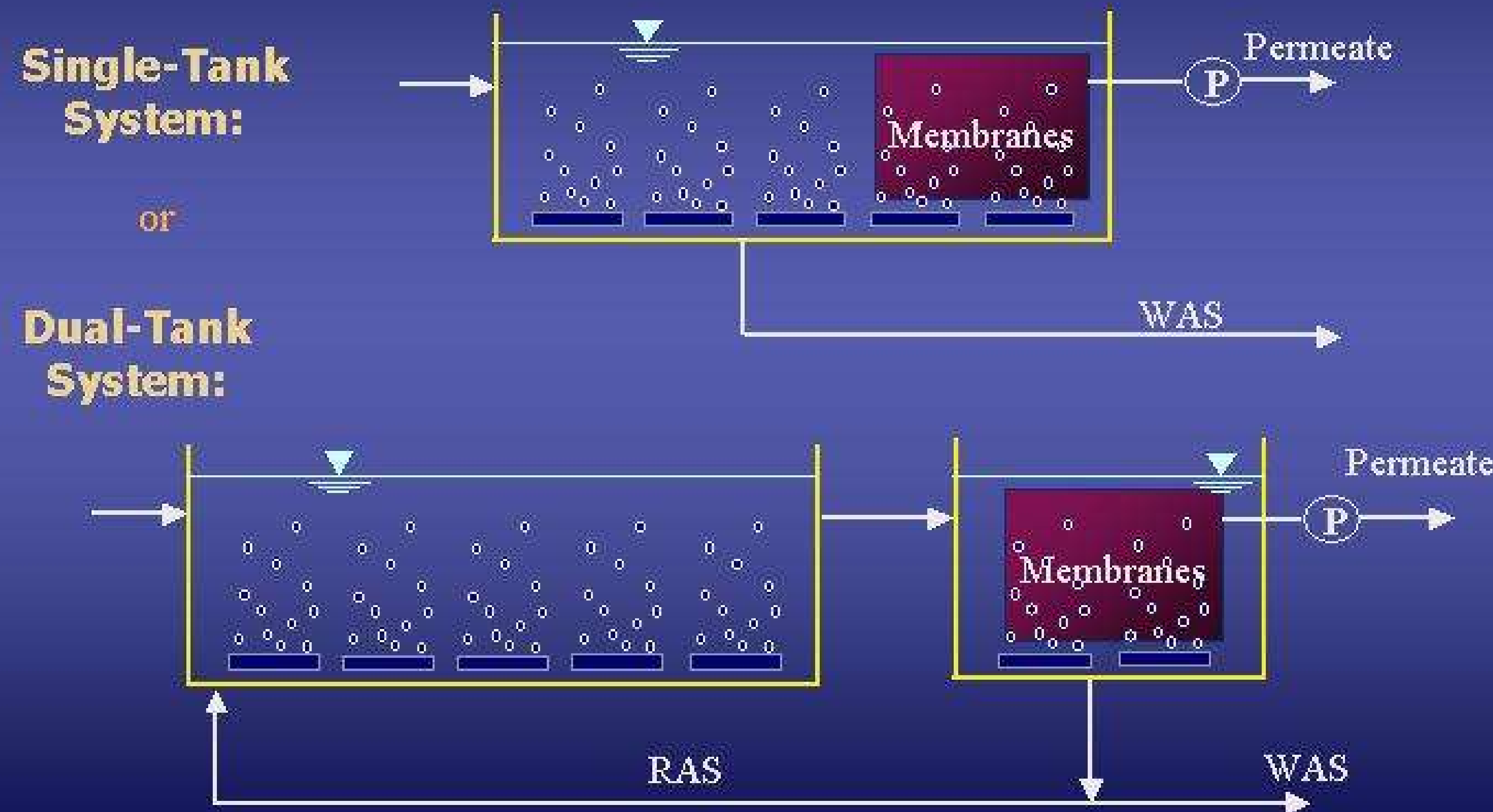
System Design

Immersed Application

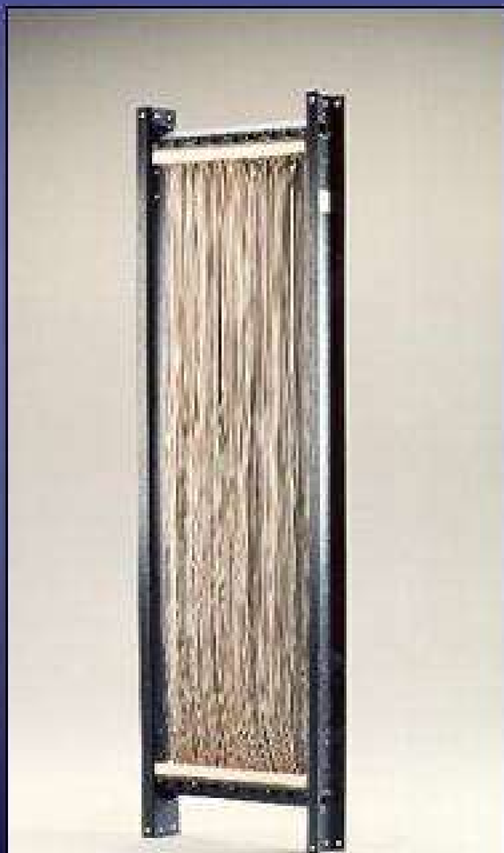


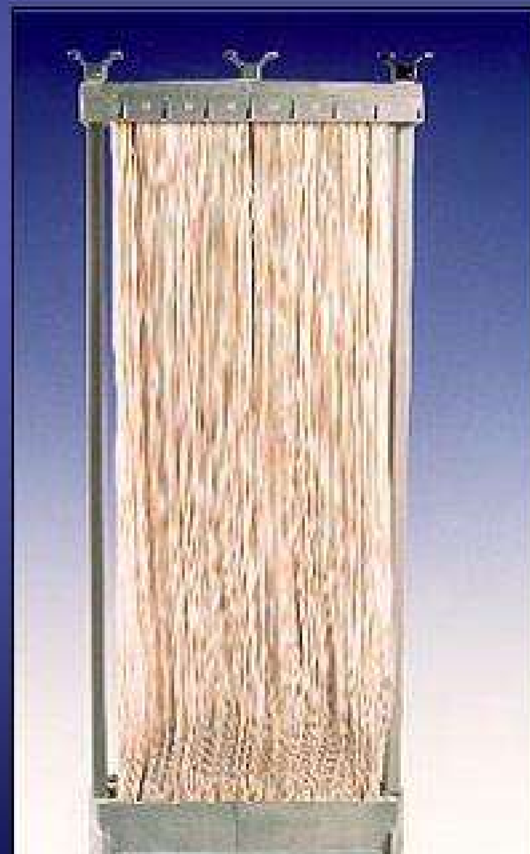
IMMERSED

Immersed MBR Configuration



Examples of Immersed Hollow-Fiber Membranes (Vertical Configuration)





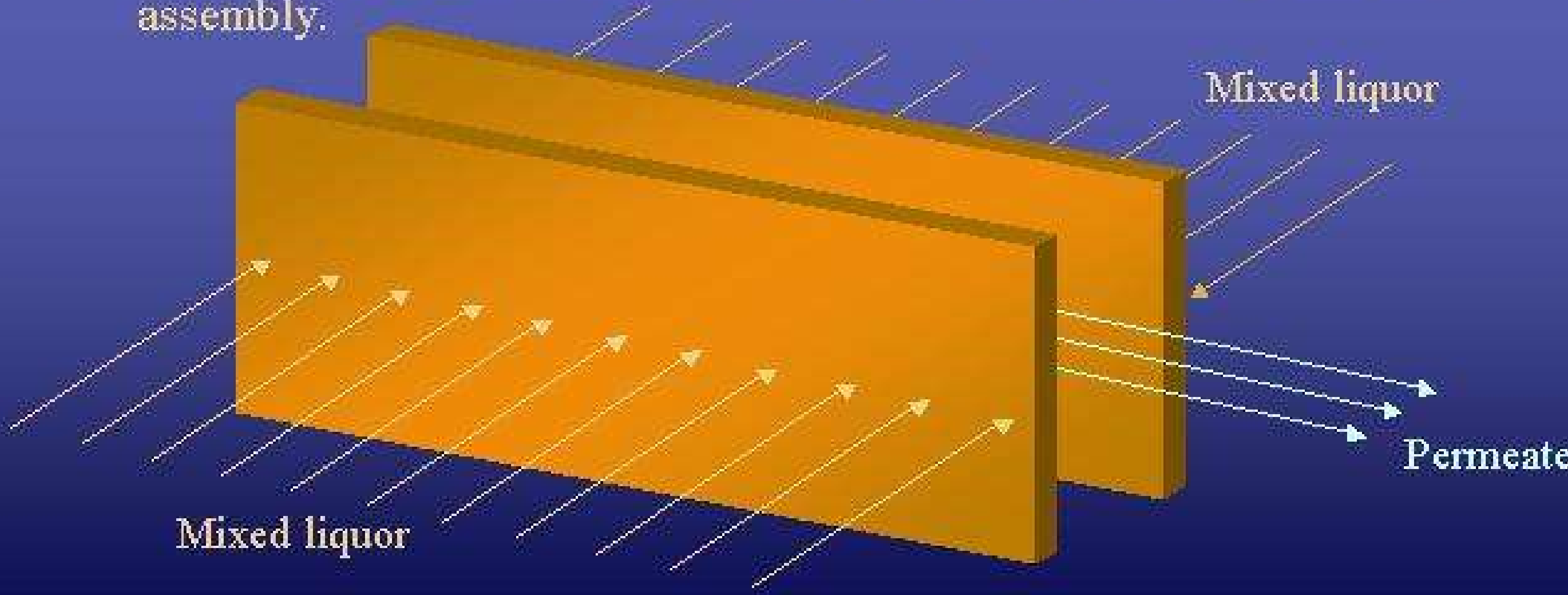
Courtesy of ZENON Environmental Inc.

Example of Immersed Hollow-Fiber Membrane Cassette (Vertical)

Courtesy of
ZENON Environmental Inc.

Types of Immersed Membranes (Cont'd)

- **Flat sheets**
  - Flow is from outside of a pair of flat sheets to the inside between the flat sheets.
  - An intermediate media is typically included between the flat sheet membranes to allow the free passage of water from the membrane assembly.



Example of Immersed Flat-Sheet Membrane Cassette (Vertical)

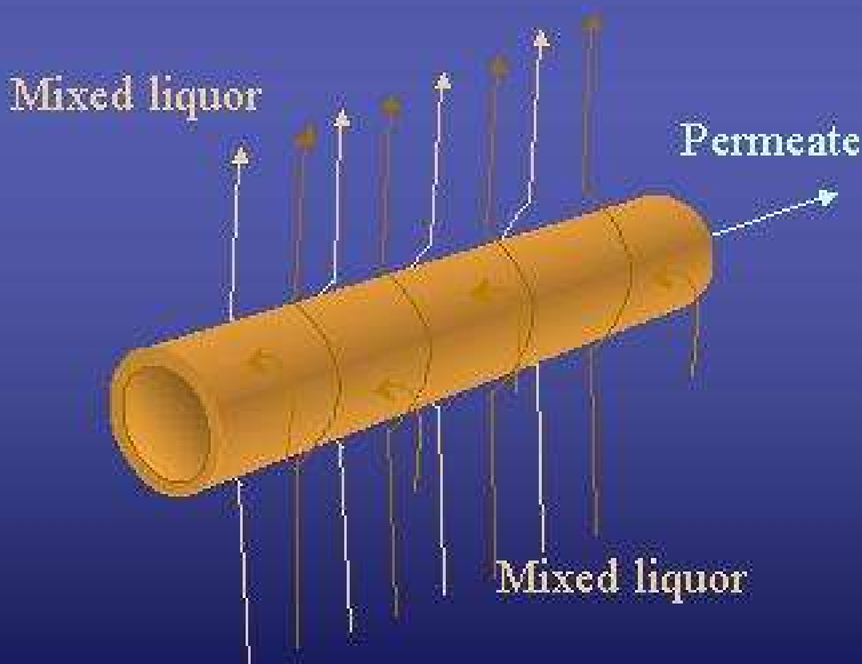
Courtesy of Kubota Corporation

Example of Immersed Flat Sheet Membrane Cassette Array (Vertical)

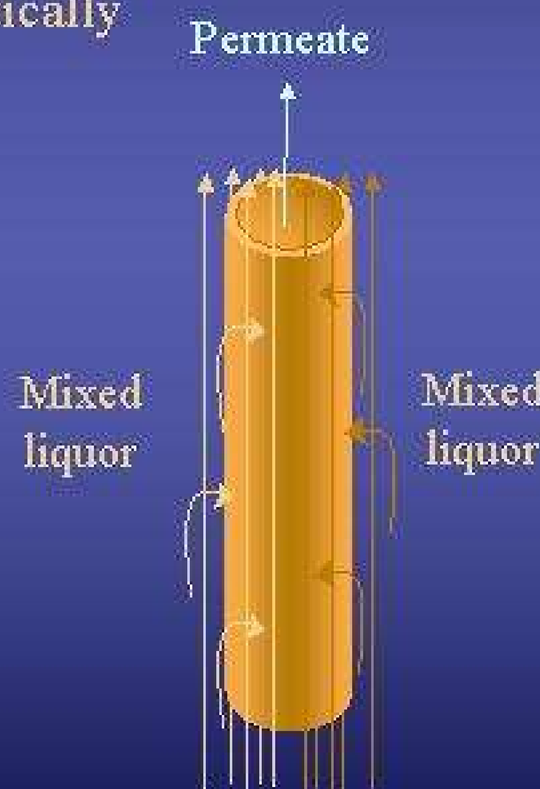
Courtesy of Kubota Corporation

Types of Immersed Membranes

- Hollow fiber
  - fiber oriented either horizontally or vertically
  - flow is from outside of fiber to inside

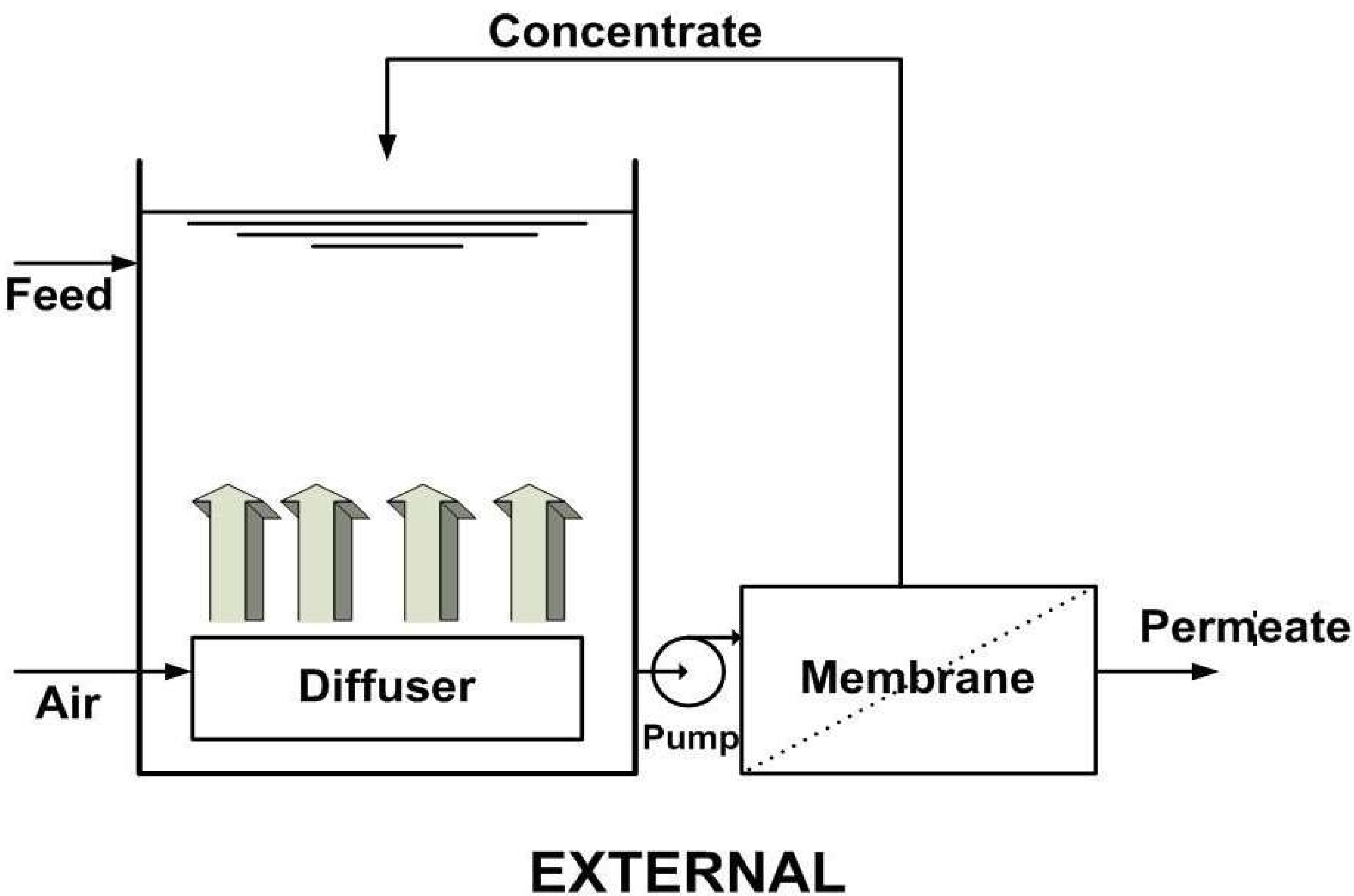


Horizontal Configuration

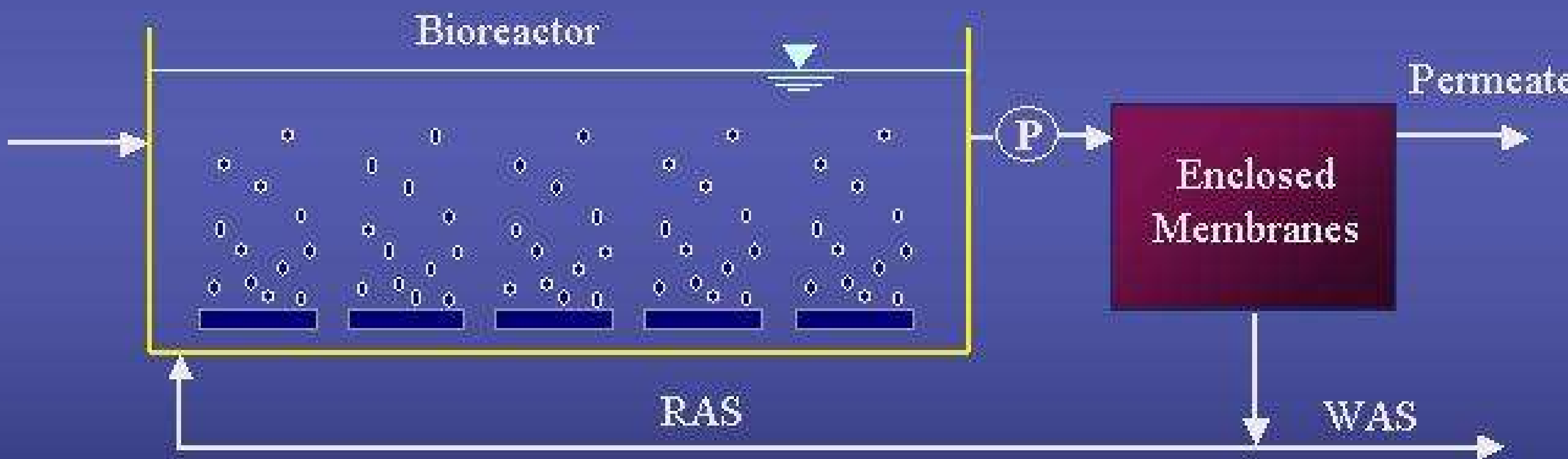


Vertical Configuration

External Application



No.4 External MBR Configuration

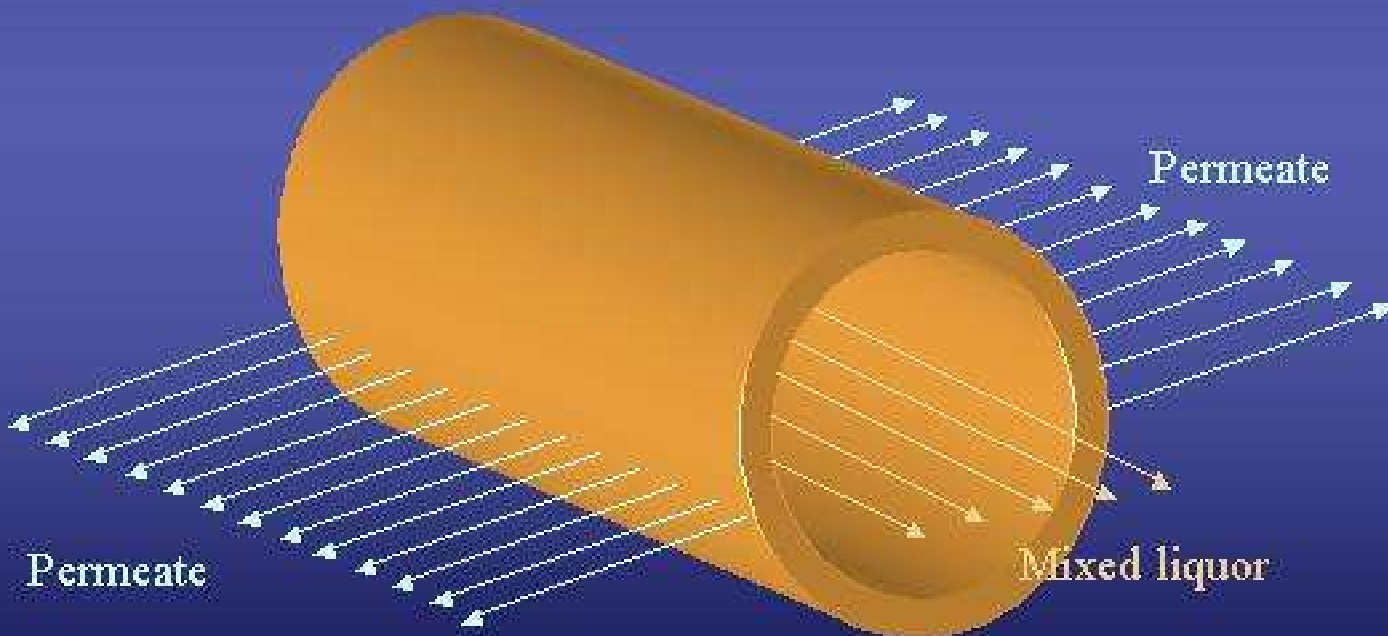


Example of Tubular External Membranes

Courtesy of ZENON Environmental, Inc.

Types of Enclosed Membranes

- Tubular
- Modified plate and frame (ROCHEM type)



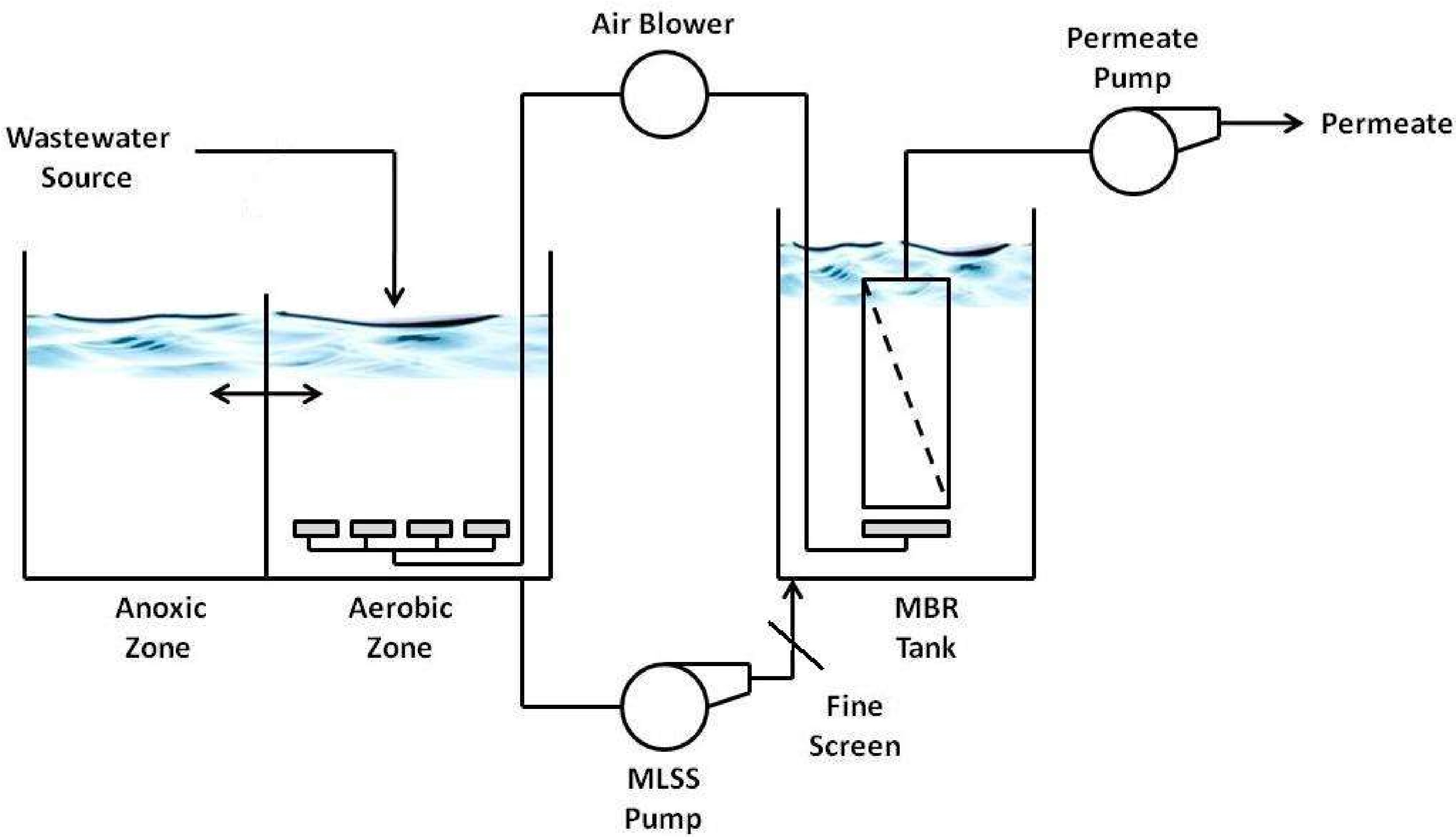
Immersed and External Designs Compared

Parameters	Immersed	External
Aeration Cost	High	Low
Pumping Cost	Low	High
Membrane Flux	Low	High
Cleaning Frequency	Low	High
Total Operating Cost	Low	High
Total Capital Cost	High	Low

MBR System Components

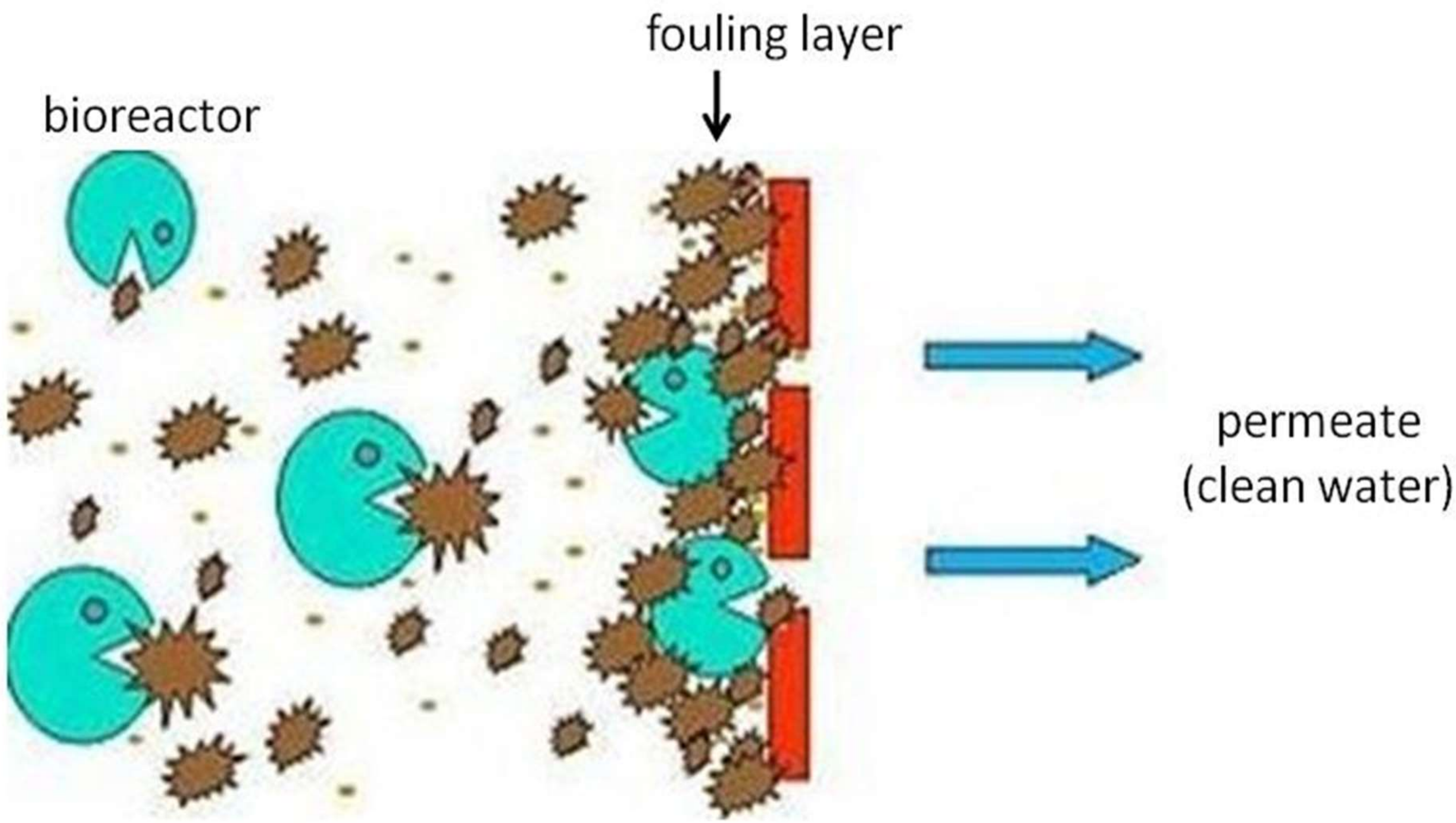
- Fine screen
- Membrane cassettes containing elements
- Bioremediation tank(s)
- Permeate or feed pump
- Blowers with diffusers
- CIP (clean-in-place) system
- Backwashing/Backpulsing equipment

MBR Schematic

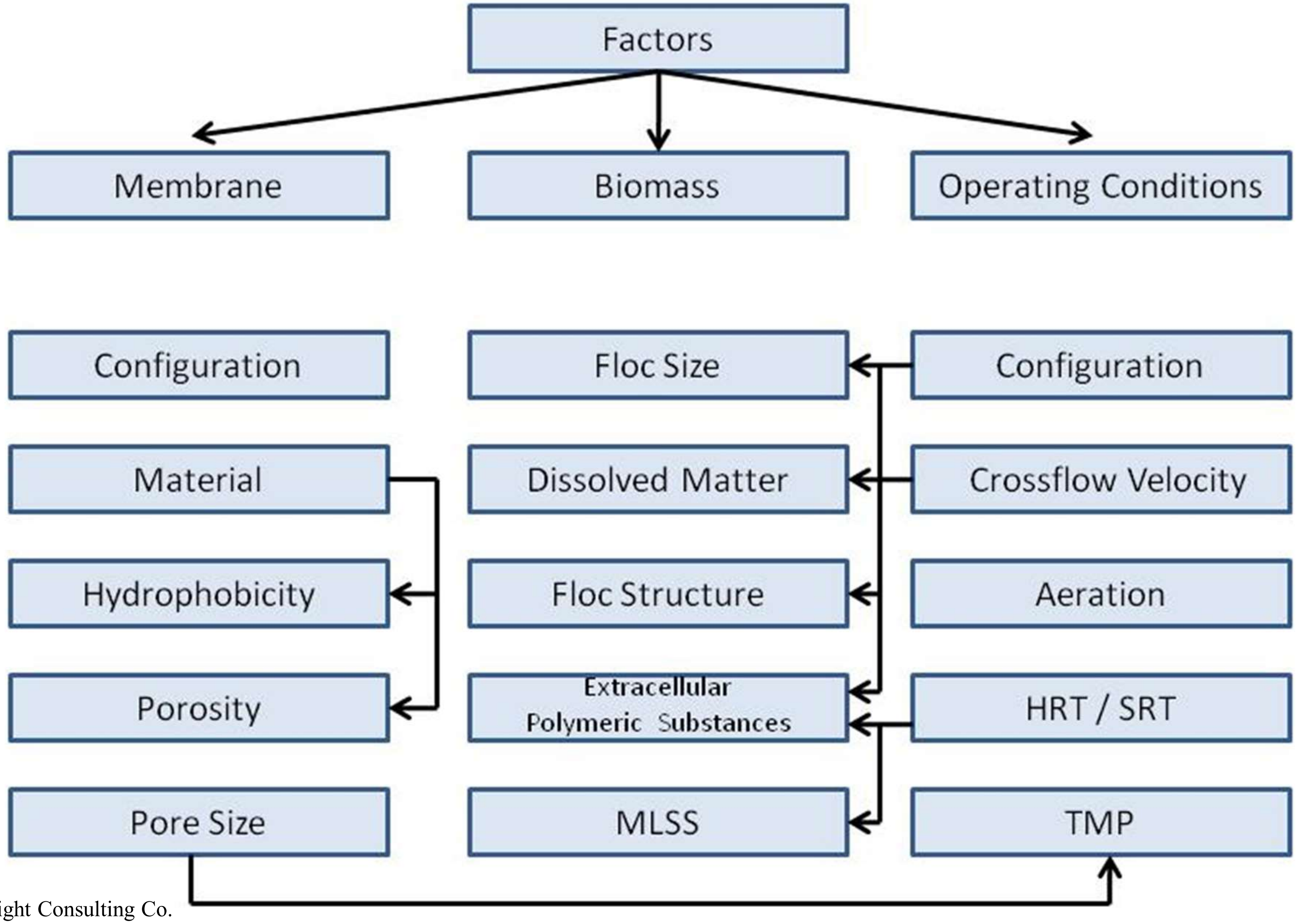


Operating Considerations

Membrane Fouling



Fouling Factors



Foulants

Municipal

Hair
Fibers
Plastics
Rags
Chemicals
Other

Industrial

F.O.G.
Chemicals
Other

Anti-Fouling Strategies

- Relaxing
- Backwashing
- Backpulsing – Air/Permeate
- Chemicals

Chemical Cleanings

- Enhanced Backwash (daily)
- Maintenance Cleaning (weekly)
- Intensive Cleaning (1-2x/year)

MBR Cleaning Chemicals

Agent	Chemical	Formula/Notation	Concentration
Detergent	Sodium hypochlorite	$NaOCl$	200 ppm Cl_2
Detergent	Hydrogen Peroxide (50%)	H_2O_2	0.5% (w/w)
Detergent	KOH, NaOH, NTA-Na-Salts	—	1% (w/w)
Enzymes	Ultrasil 67 + Ultrasil 69 (ECOLAB)	U67 + U69	0.5% (w/v) and 1% (w/v)
Acid	Hydrochloric acid	HCl	0.056% (w/w)
Acid	Citric Acid	$C_6H_8O_2$	1% (w/w)
Acid	HNO_3, H_3PO_4	—	1% (w/w)

Conditions: pH: 2-11

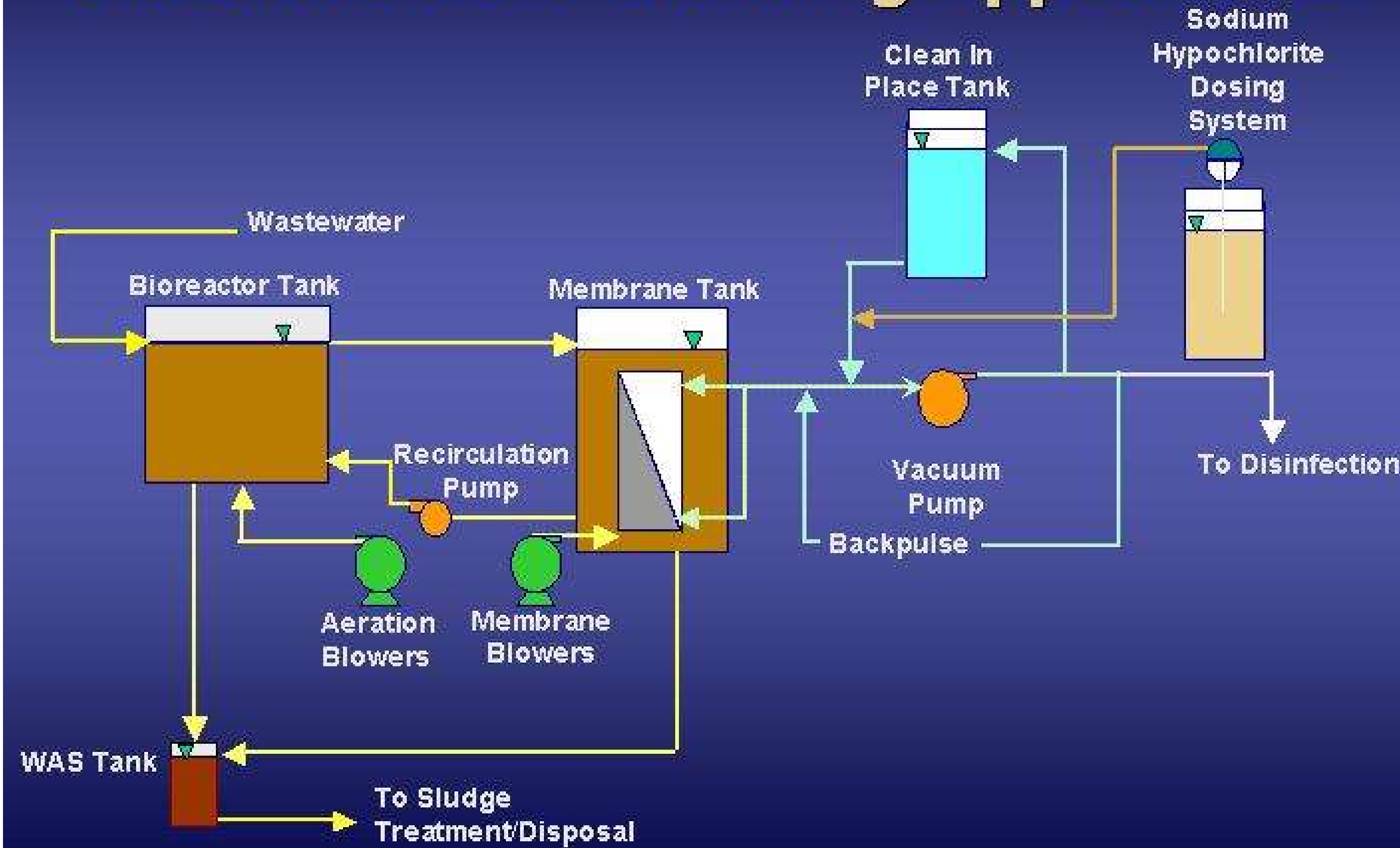
Temperature: 20°C (Elevated temperatures may improve cleaning)

Time: 2 hour soak

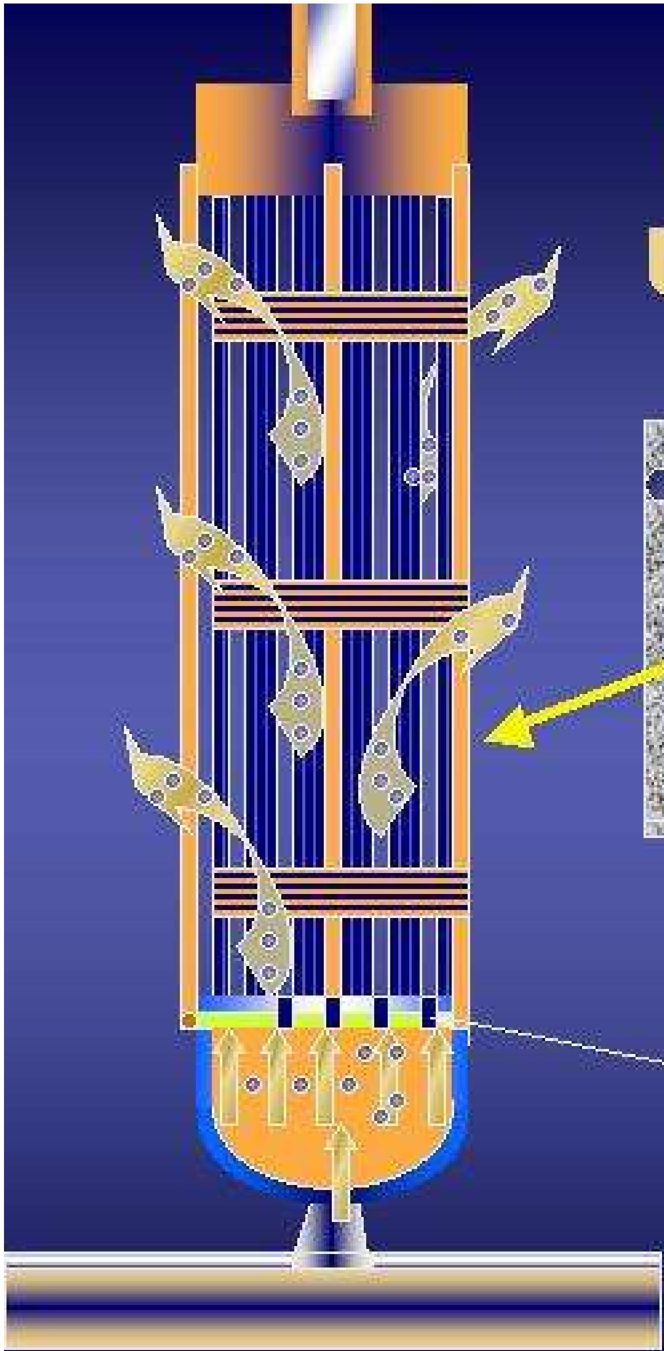
No.5 Membrane Cleaning Approaches

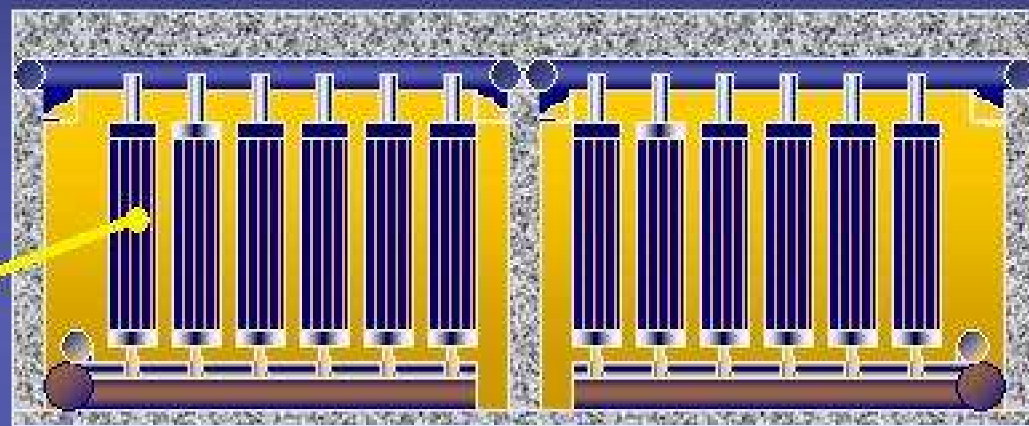
- Frequent backpulsing of the membranes with clean permeate.
- "Maintenance cleaning" via prolonged backpulsing of the membranes with sodium hypochlorite-enhanced permeate.
- "Recovery cleaning" via in-situ soaking of the membranes in a solution of sodium hypochlorite, citric acid or other cleaning solution depending on the type of foulant.
- Air scour via membrane aeration blowers to minimize the buildup of solids on the membrane surface.

Zenon's ZenoGem® System Uses the Four Cleaning Approaches



USFilter's Jet Aeration Uses Air Scour Cleaning





MBR Applications

No. 1 Treatment Objectives

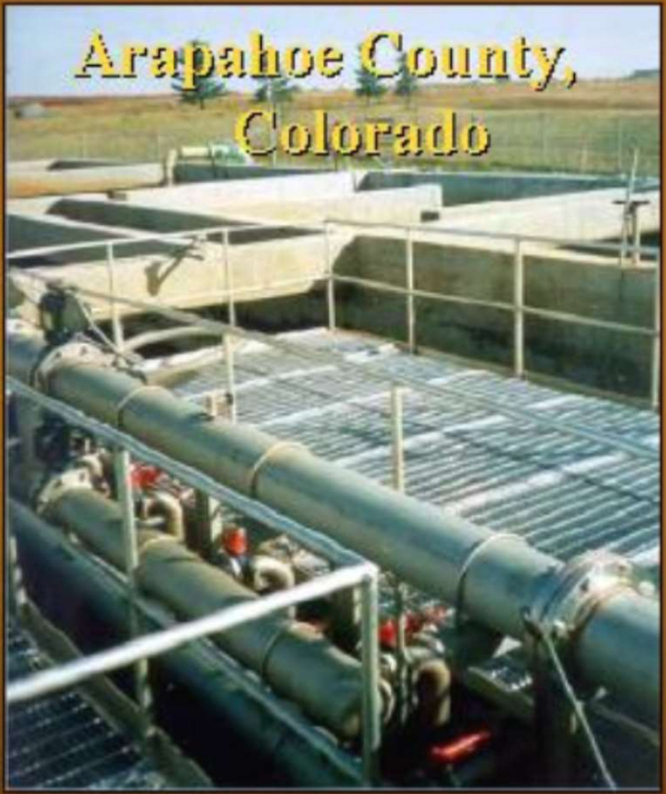
Wastewater can be treated at municipal and industrial plants for either discharge or reuse:

A. Treatment for **Discharge**:
   - Surface water

B. Treatment for **Reuse**:
   - Non-Potable Reuse:
     - Dual distribution system
     - Groundwater recharge
     - Irrigation
     - Industrial reuse
   - Indirect Potable Reuse
     - Groundwater (aquifer) recharge
     - Surface water augmentation

Treatment for Discharge: Surface Water

Nitrification and phosphorus removal, but not denitrification.

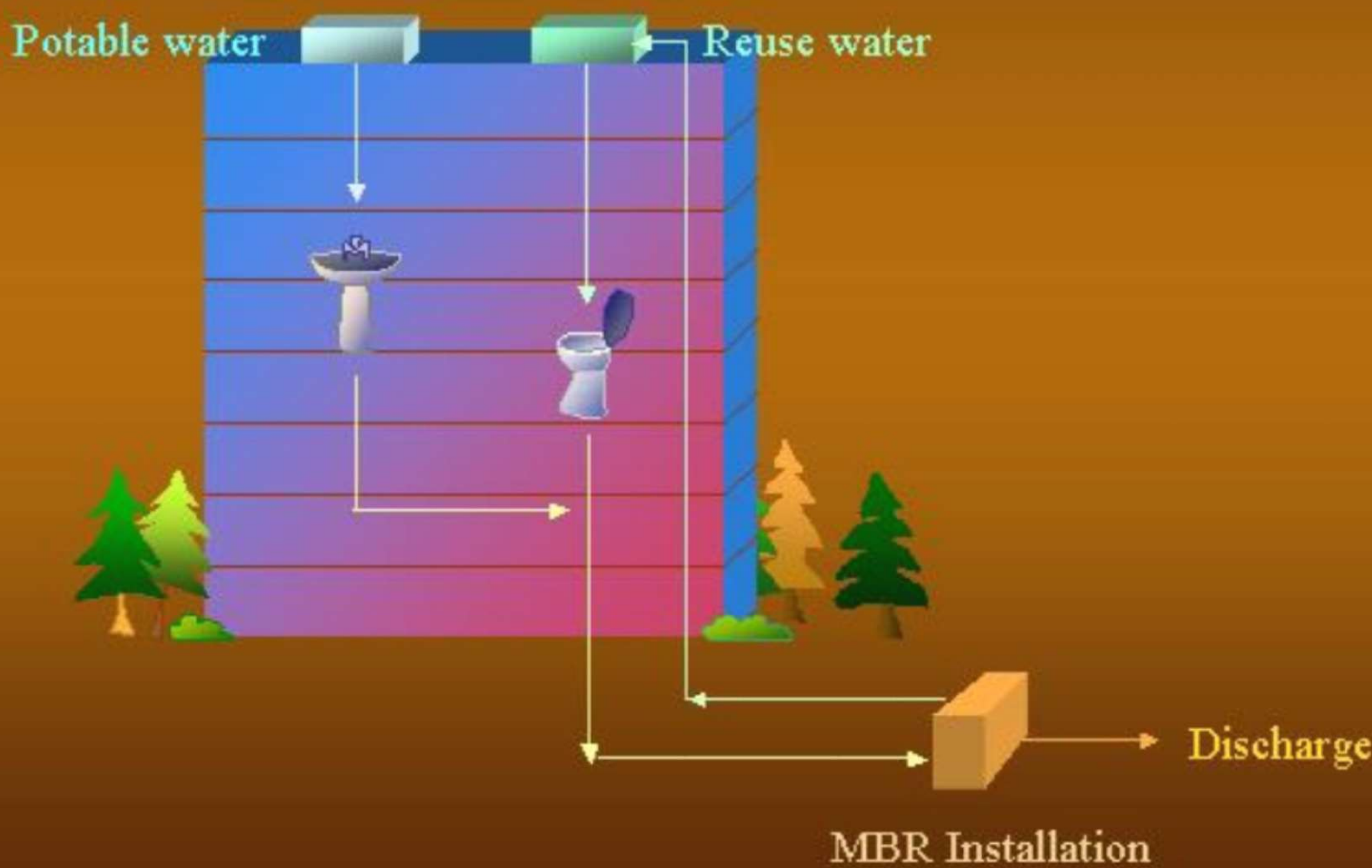


Nitrification, denitrification and phosphorus removal.

Treatment for Discharge: Surface Water (Cont'd)

- **Application:**
  - MBRs replace conventional clarifiers and filters in municipal wastewater treatment plants.
- **Competing technologies:**
  - Solids separation using clarifiers.
- **Advantages of using MBRs:**
  - Operational ease
  - Relatively simple upgrade to an existing treatment plant
  - Improved effluent quality
  - Easier process control
- **How widely is the application practiced:**
  - Most plants in the US currently use conventional clarifier technology. However, interest in MBR technology has increased dramatically in the last few years.

No.3 Non-Potable Reuse: Dual Distribution System



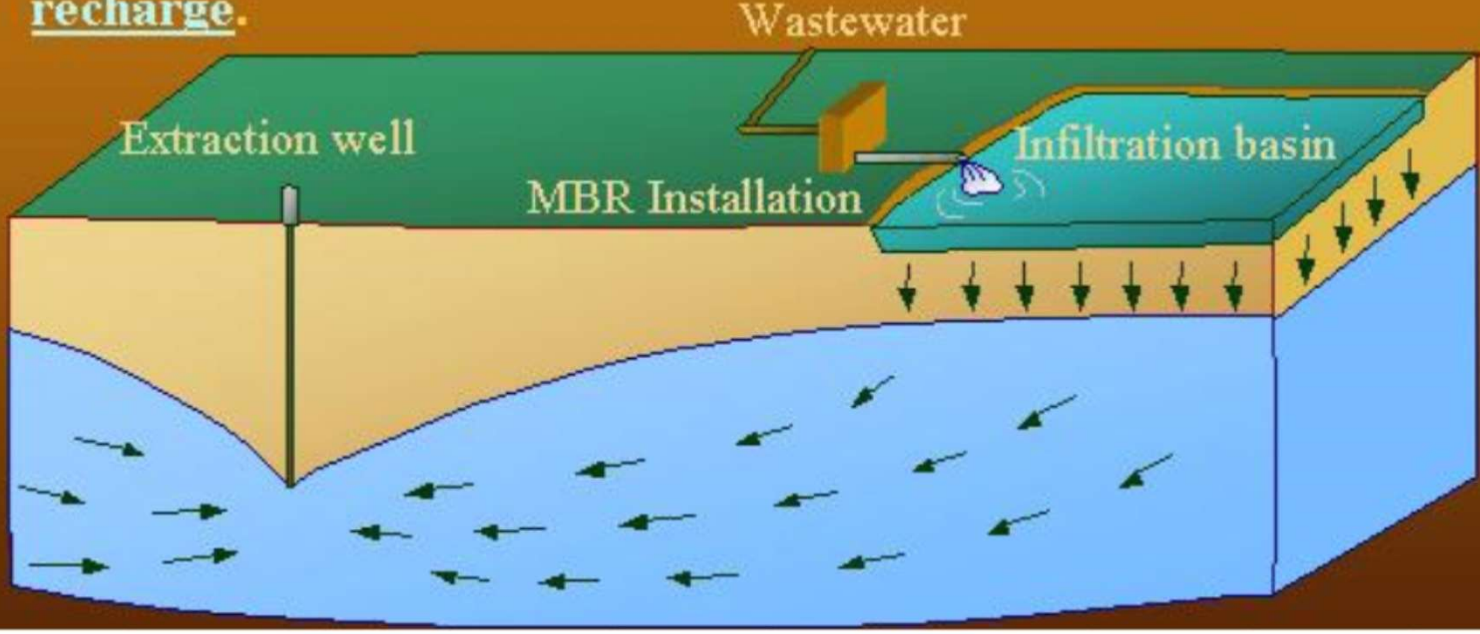
Non-Potable Reuse: Dual Distribution System (Cont'd)

- **Application:**
  - Domestic wastewater treated and reused for non-potable applications.
- **Competing technologies:**
  - Small scale conventional biological treatment processes
- **Advantages of using MBRs:**
  - Operational ease
  - Better quality effluent
  - Easier process control
- **How widely is the application practiced:**
  - A number of high rise buildings and holiday resorts are using MBRs for this purpose.

Non-Potable Reuse: Groundwater Recharge

No.4

- Effluent is recharged to groundwater and extracted at later date for non-potable uses.
- Movement of recharged effluent is carefully controlled using monitoring wells to ensure it does not impact groundwater used for potable uses
- Using an infiltration basin is one technique used for groundwater recharge.



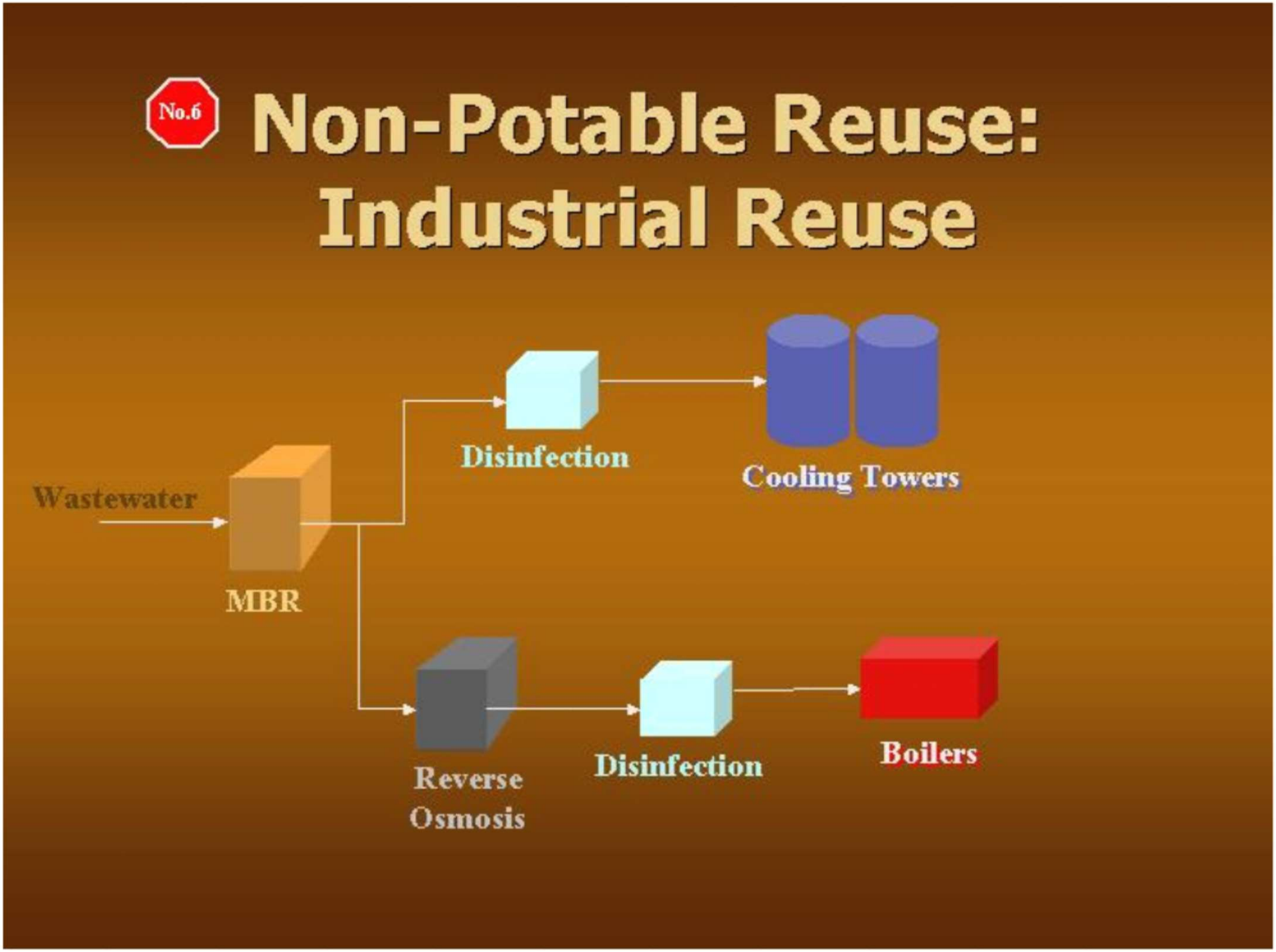
Non-Potable Reuse: Groundwater Recharge (Cont'd)

- **Application:**
  - Municipal/industrial wastewater is treated with MBR technology, producing an effluent which is discharged to storage ponds and allowed to percolate into groundwater aquifers.
  - Vadose zone, direct injection alternatives.
- **Competing technologies:**
  - Chemical flocculation and sedimentation followed by microfiltration/ultrafiltration (MF/UF) or by granular media filtration.
- **Advantages of using MBRs:**
  - Operational ease.
  - High quality effluent which will allow recharge of groundwater aquifers and potential reuse when extracted through boreholes.
- **How widely is the application practiced:**
  - Not widely practiced yet, but a growing number of facilities are considering this approach, often in conjunction with reverse osmosis (RO) post-treatment of MBR effluent.

No.5 Non-Potable Reuse: Irrigation

Non-Potable Reuse: Irrigation (Cont'd)

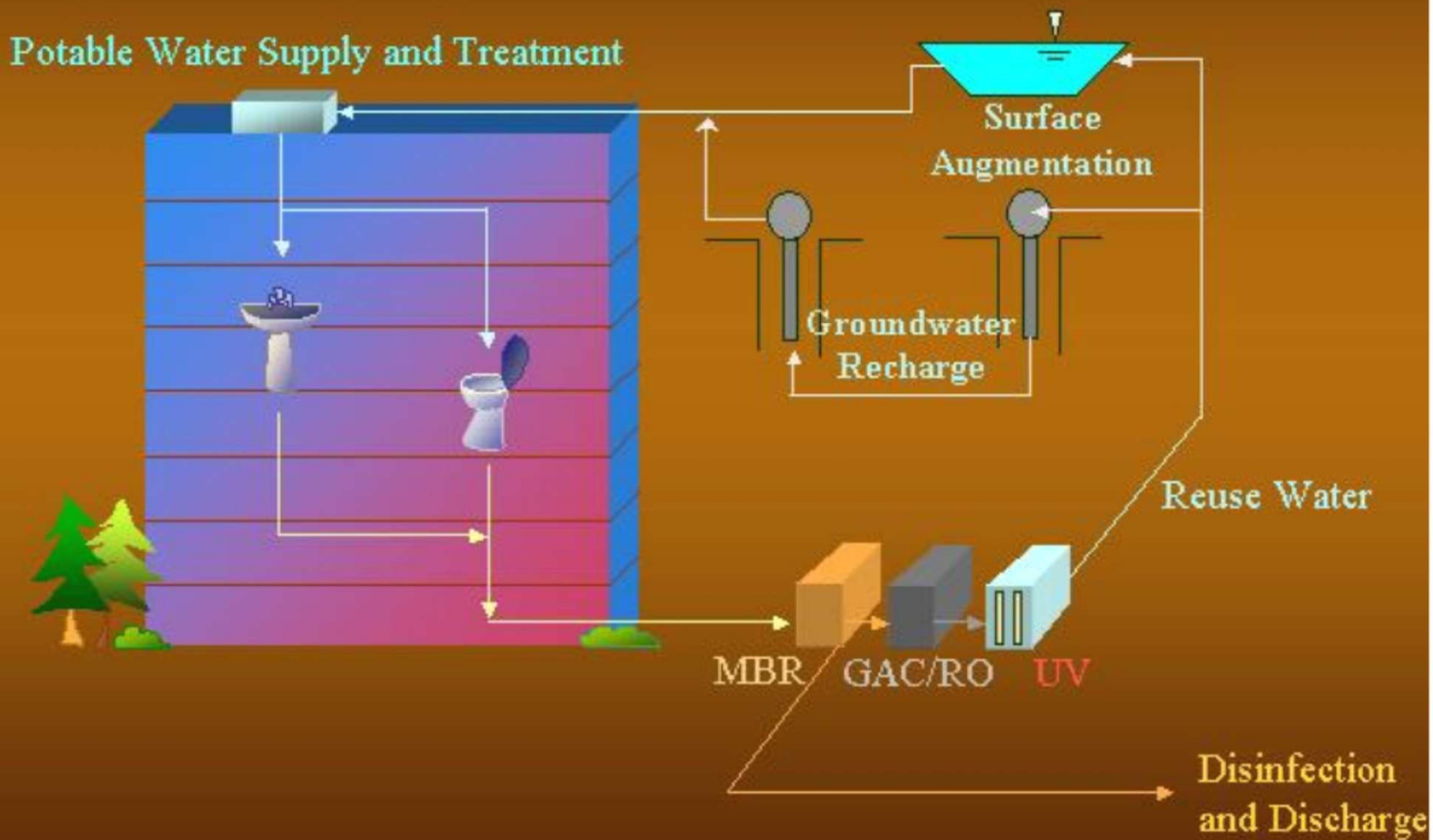
- **Application:**
  - Irrigation application of final MBR effluent
- **Competing technologies:**
  - Conventional biological treatment processes, with or without tertiary filtration
- **Advantages of using MBRs:**
  - Higher quality effluent
  - Smaller footprint than required for conventional activated sludge processes
  - Easier process control
- **How widely is the application practiced:**
  - Irrigation use is currently restricted because of the higher cost of MBR compared to conventional treatment.


No.6
Non-Potable Reuse:
Industrial Reuse
Wastewater
MBR
Disinfection
Cooling Towers
Reverse
Osmosis
Disinfection
Boilers

Non-Potable Reuse: Industrial Reuse (Cont'd)

- **Application:**
  - Cooling tower make-up
  - Boiler feedwater
- **Competing technologies:**
  - Conventional biological treatment process, with or without nitrification (for cooling tower make-up)
  - Conventional biological treatment process followed by MF/UF and RO (for boiler feedwater)
- **Advantages of using MBRs:**
  - Higher quality effluent; small facility footprint; easier process control
  - For boiler feedwater, MF/UF process is eliminated.
- **How widely is the application practiced:**
  - Not widely practiced yet, but application will grow as advantages are recognized and MBR experience base builds.

No.7 Indirect Potable Reuse



Indirect Potable Reuse (Cont'd)

- **Application:**
  - Municipal/industrial effluent treated with MBR technology, followed by tertiary treatment such as GAC or RO and a disinfection step.
  - Surface water augmentation
  - Groundwater recharge
- **Competing technologies:**
  - Conventional biological treatment processes followed by MF/UF, either RO or granular activated carbon (GAC) filtration, and ultraviolet (UV) disinfection
- **Advantages of using MBRs:**
  - Operational ease
  - Smaller footprint than required for conventional activated sludge and stand-alone MF/UF processes
  - Reduced waste stream volume
  - Easier process control
- **How widely is the application practiced:**
  - Very limited current application, but is increasingly becoming a viable treatment option

No.6

Replacing a Clarifier with a Membrane Separator

Potential Benefits

- **Benefit 1: Virtually all biomass is retained.**
  - Effluent SS concentrations <1mg/L, compared to clarifier effluent SS concentrations typically 5 to 20 mg/L.
  - Excellent, consistent effluent quality is achieved. Solids loss commonly observed in clarifiers due to such factors as flow surges and blanket rising, is prevented with a membrane separator.
  - Membranes provide a positive barrier to and removal of most pathogens.
  - Can be beneficial for water reuse or recycling applications.

Replacing a Clarifier with a Membrane Separator (Cont'd)

- **Benefit 2: High SRTs can be achieved.**
  - A more stable high SRT (and therefore high MLSS) can be maintained with membranes since uncontrolled loss of solids over the weirs of gravity settlers is avoided.
  - A high SRT should result in reduced sludge production.
  - A high SRT is needed when slow-growing bacteria must be retained, such as nitrifiers for NOD oxidation.
  - Higher MLSS concentrations allow smaller aeration basins to be utilized, which reduces cost and footprint.
  - Odor control is simplified by decreasing surface area of biological treatment reactors.
- **Benefit 3: Secondary clarifiers and effluent filters can be eliminated, thereby reducing complexity of overall treatment plant layout and footprint area.**

Replacing a Clarifier with a Membrane Separator (Cont'd)

Potential Drawbacks

- **Drawback 1:** Higher capital investment costs.
- **Drawback 2:** Higher operational costs (e.g. membrane replacement and air scour energy).
- **Drawback 3:** Complex cleaning systems.
- **Drawback 4:** High operation and maintenance effort required (for membrane cleaning of single-tank systems).

Myths and Realities

MBR Myths & Realities

Ten persistent myths and the realities of MBR technology for municipal applications

B. Lesjean, A. Tazi-Pain, D. Thaure,
H. Moeslang and H. Buisson

Cartwright Consulting Co.

MBR Myths & Realities

	Subject	Prevalent Perception	The Facts
1	MBR Market	The MBR market is an industrial duopoly.	The two pioneering companies Kubota and GE-Zenon are leaders but other commercial systems are available and increased competition is expected in coming years.
2	Filtration flux	The technology has become more competitive following increasing design and operation flux.	In the last decade, the design and operation filtration flux has increased only moderately.
3	Energy demand	Specific energy demand of an MBR system is <1 kWh/m^3.	True only for larger plants operated under nominal design with optimized operation.
4	Competitiveness	The MBR technology will extensively replace conventional activated sludge plants.	Extensive switch unlikely unless further significant technological breakthroughs.
5	Decentralized systems	The MBR technology is a viable solution for decentralized sanitation.	With current commercial solutions, not cost-effective for most decentralized or semi-central applications.

B. Lesjean, A. Tazi-Pain, D. Thaure, H. Moeslang and H. Buisson

MBR Myths & Realities

	Subject	Prevalent Perception	The Facts
6	Membrane impact on treatment	The membrane contributes to the treatment performance.	Direct contribution is insignificant except for the disinfection and turbidity removal.
7	Disinfection	UF membranes guarantee better disinfection performance than MF membranes.	Not true for bacteria: both MF and UF achieve 6 LRU (log removal unit). Minor superiority of UF membranes for virus removal (both achieve 4 LRU).
8	Trace organics	MBR plants are better for removing organic micropollutants.	Under similar operation conditions, MBR shows very similar performances to conventional activated sludge.
9	Sludge production	MBR produces less sludge than conventional activated sludge plants.	Wrong statement. MBR sludge yield is slightly higher due to complete retention by the membrane of particles and colloids.
10	Fouling indicator	Polysaccharides, proteins, Capillary Suction Time (CST), Time to Filter (TTF), etc., are relevant indicators of membrane fouling.	No recent studies could identify universal single indicators.

B. Lesjean, A. Tazi-Pain, D. Thaure, H. Moeslang and H. Buisson

Conclusions

- ✓ MBR is a proven technology
- ✓ Capital costs going down
- ✓ Provides direct reuse
- ✓ Smaller footprint (land conservation)

Disinfection

Waterborne Pathogens

A pathogen which grows in the water.

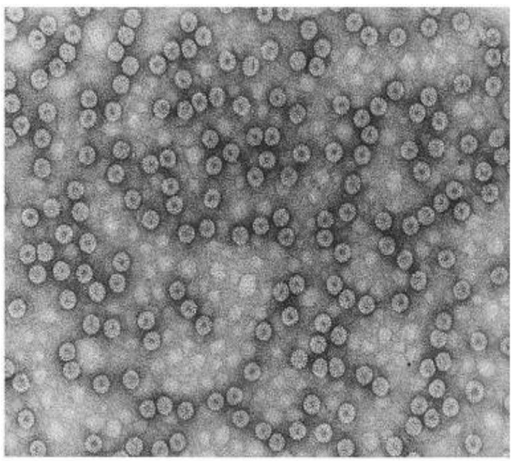
Approximately 300 in the U.S.

Examples found in tap water.

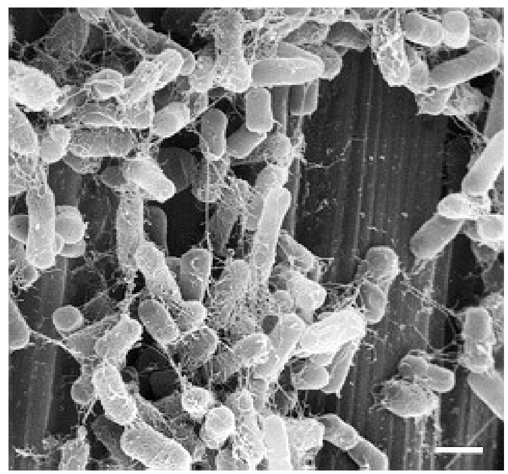
- ***Legionella***
- ***Pseudomonas aeruginosa***
- ***Mycobacterium avium***
- ***Acanthamoeba***

Waterborne Pathogens

Viruses



Bacteria

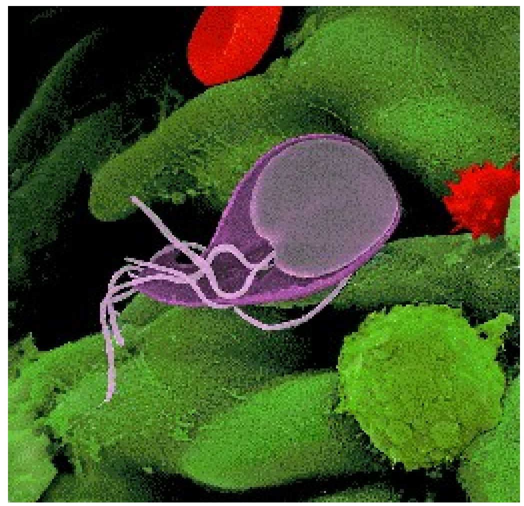
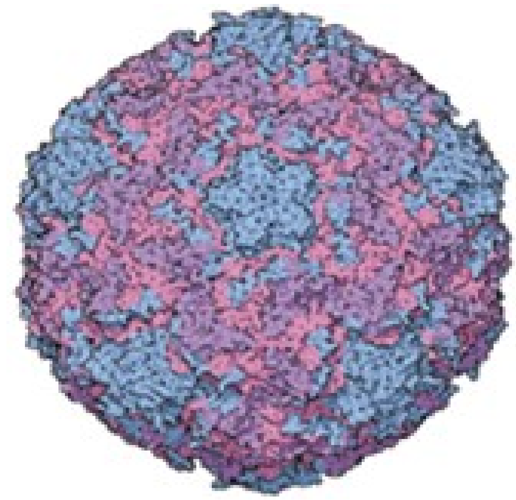


Parasites

Categories of Microorganisms

- *Bacteria*
- *Protozoa*
- *Viruses*

Illustrations

Bacteria	Parasites	Viruses
		

Agents of Waterborne Disease

Category	Pathogen
Bacteria	*Vibrio cholerae*
	Salmonella spp.
	Shigella spp.
	Toxigenic Escherichia coli
	Campylobacter spp.
	Yersinia enterocolitica
	Plesiomonas shigelloides
	Legionella
	Helicobacter pylori
Protozoa	*Giardia lamblia*
	Cryptosporidium parvum
	Entamoeba histolitica
	Cyclospora cayetanensis
	Isospora belli
	Microsporidia
	Ballantidium coli
	Toxoplasma gondii
	Naegleria fowleri

Category	Pathogen
Viruses	Norovirus
	Sapprovirus
	Poliovirus
	Coxsackievirus
	Echovirus
	Paraechovirus
	Enteroviruses 69-91
	Reovirus
	Adenovirus
	Hepatitis A
	Hepatitis E
	Rotavirus
	Astrovirus
	Picobirnavirus
	Coronavirus

Sensitive Population

- Elderly (>65 years)
- Very young (<5 years)
- Chronically ill (diabetes, dialysis patients, AIDS)
- Immunosuppressed (organ transplants, cancer treatment)
- Pregnant women

Sensitive Sub-Populations in the United States

35,000,000	persons >65 years old
19,000,000	children under 5
10,000,000	person with diabetes
8,200,000	cancer patients
3,800,000	pregnant persons
350,000	AIDS patients
50,000	organ transplants

20-26% of the U.S. population

Estimated Number of Endemic Cases of Waterborne Illness in U.S.

- Groundwater (municipal) = 5,400,000
- Groundwater (non-community) = 1,100,000
- Surface water supplies = 13,000,000
- Intrusion into distribution System = 5,000,000

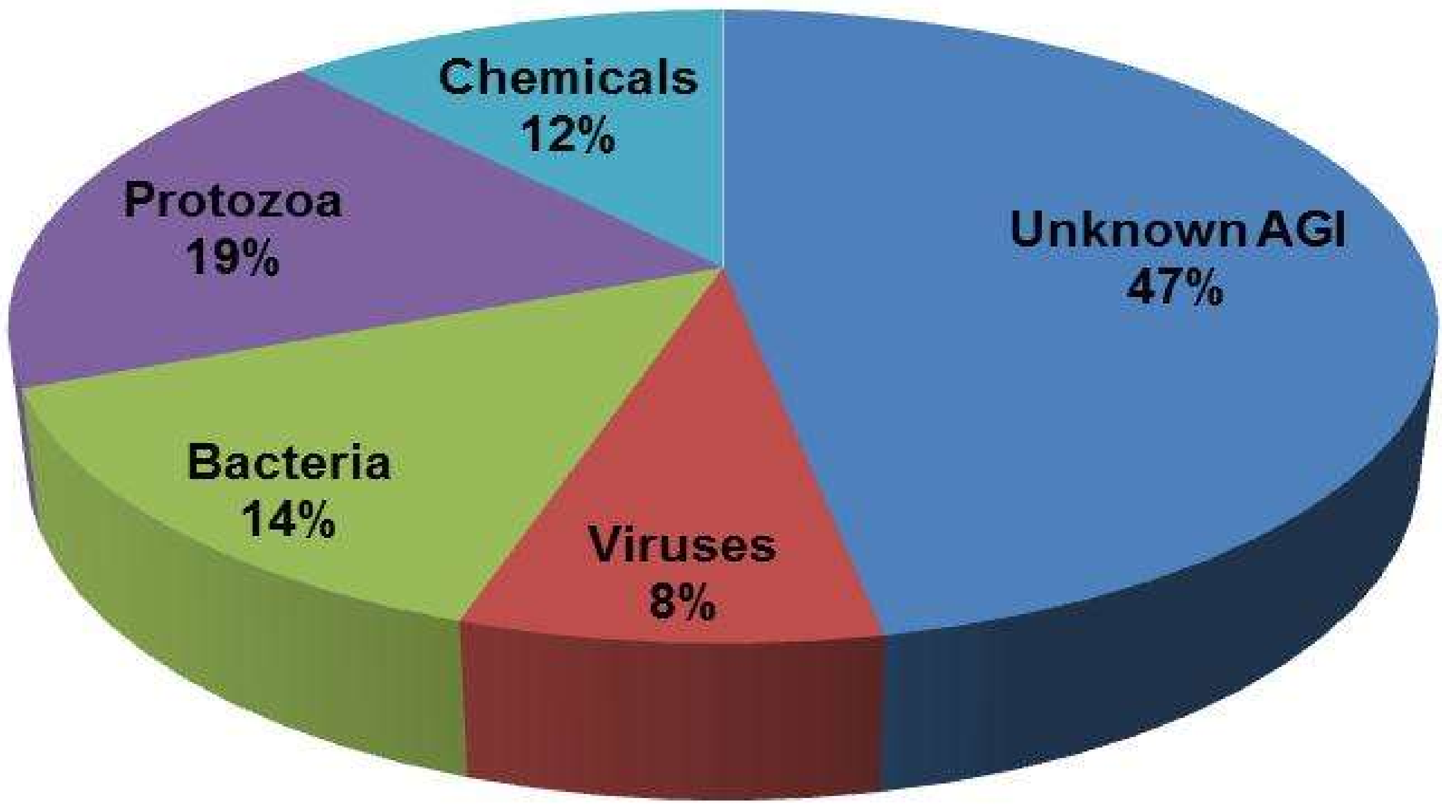
Total estimate = 24,500,000 cases/year

Impact of Diarrhea

Worldwide Morbidity and Mortality of Common Infections

Disease	Cases / Yr	Deaths / Yr
Diarrhea	3 to 5 billion	5 to 10 million
Respiratory Infections	3 to 5 billion	4 to 5 million
Malaria	150 million	1.2 million
Measles	80 million	0.9 million
Schistosomiasis	20 million	0.75 million
Wooping Cough	20 million	0.3 million

U.S. Drinking Water Outbreaks (1971 - 2002)



Water Contamination Concerns

- **Treatment**
  - Pathogen removal efficacy/ Treatment plant reliability
  - Untreated private/groundwater supplies
  - Disinfection by-products/ resistance
  - Decentralized wastewater reuse/treatment
  - Climatic events
- **Distribution system**
  - Intrusion events
  - Uneven contaminant distribution
  - Water-based pathogens
- **Monitoring**
  - Poor indicators of quality
  - Lack of real-time technologies
- **Risk Assessment**
  - Population susceptibilities, perceptions, compliance

Bacteria

- Single-celled organisms
- Enclosed within a cell wall
- Size: 0.1 to 10µ
- Survive any environment
- Form biofilms

Bacteria

- Survive in any environment
- Form biofilms

Waterborne Bacteria

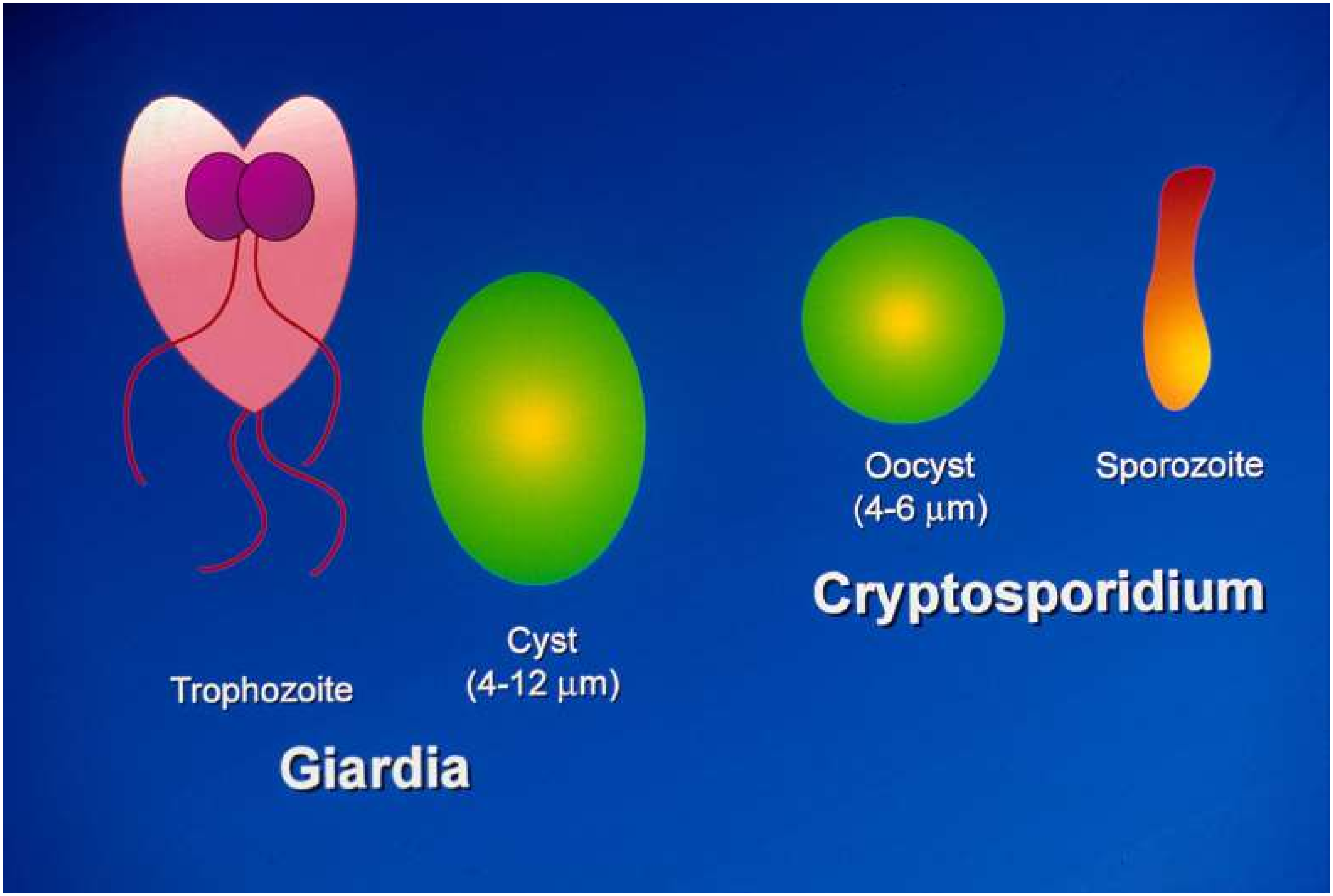
Aeromonas hydrophila	sepsis, gastrointestinal illness
Yersinia enterocolitica	gastroenteritis
Salmonella (non)/typhi	paratyphoid fever, gastroenteritis, typhoid fever
E. coli O157:H7	gastroenteritis, vomiting, hemolytic uremic syndrome, hemorrhagic colitis
Shigella spp.	dysentery
Campylobacter sp.	gastroenteritis, nervous system disorders
Helicobacter pylori	Ulcers, gastric cancer
Legionella pnemophila	Legionnaires Disease, Pontiac fever, pneumonia
Vibrio cholerae	diarrhea

Protozoa

- Single-celled animals
- Live and multiply in gastrointestinal tract
- Size: 1-100μ
- Produce cyst/oocyst – protective shell

Waterborne Protozoa

Cryptosporidium parvum	cryptosporidiosis
Microspora	gastroenteritis
Giardia lamblia	giardiasis
Entamoeba histolytica	dysentery
Cyclospora cayetanensis	gastroenteritis
Acanthamoeba	eye infections
Toxoplasma gondii	similar to mononucleosis
Naegleria fowleri	amoebic meningoencephalitis


Trophozoite
Cyst
(4-12 µm)
Giardia
Oocyst
(4-6 µm)
Sporozoite
Cryptosporidium

Naegleria Fowleri

- Thermophilic – 25 to 30^{o}C optimal, but can grow at 44-45^{o}C
- Cysts can tolerate 51 to 65^{o}C
- Cysts survive poorly at 0^{o}C
- Cysts and trophozites are sensitive to drying

Viruses

- Intracellular parasites require host to replicate.
- Can survive for weeks or months in water.
- Greatest infectivity of all pathogens.
- Require lowest number to cause infection.
- Size: 0.01 to 0.10µ.

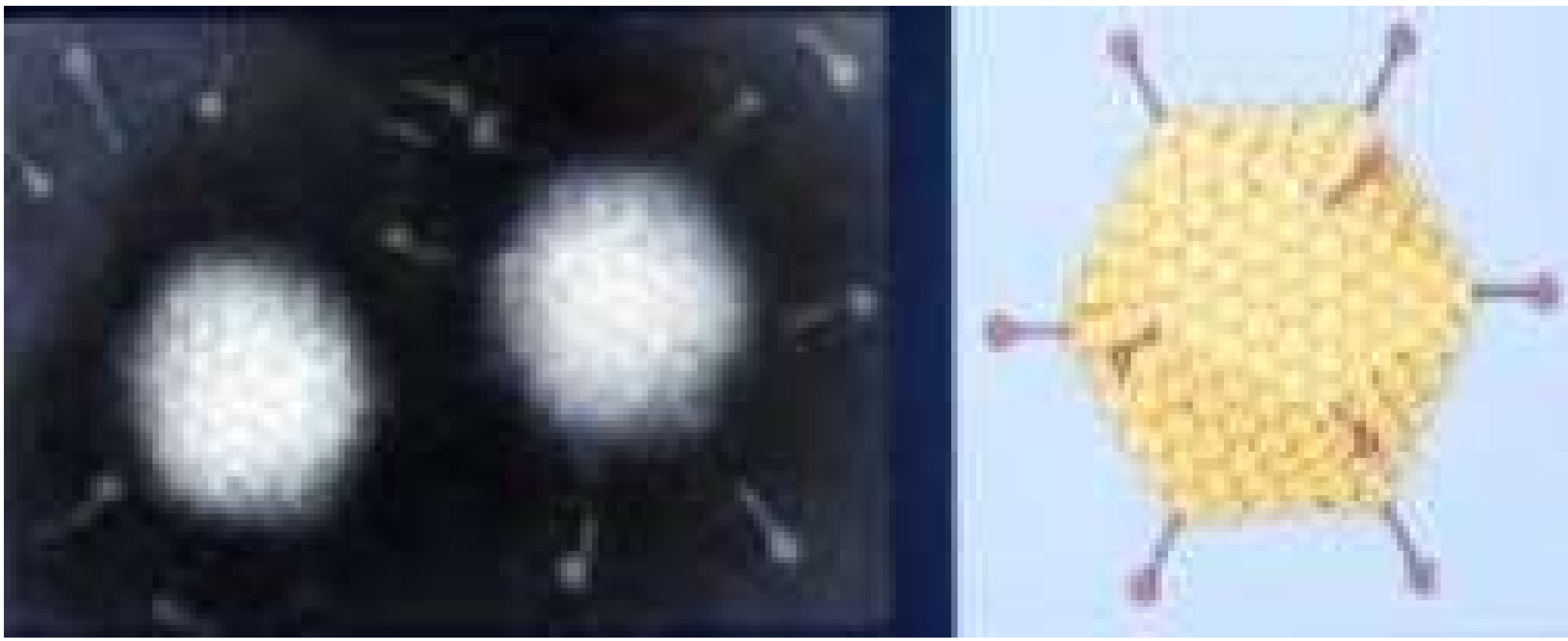
Waterborne Viruses

adenovirus	conjunctivitis, diarrhea, encephalitis, respiratory & heart disease
astrovirus	diarrhea
calicivirus	diarrhea, “stomach flu”
coronavirus	diarrhea
hepatitis A virus	hepatitis
rotavirus	diarrhea
enterovirus	paralysis, meningitis, rash, fever, myocarditis, respiratory disease, diarrhea
reovirus	respiratory disease

Adenovirus

- Second most common cause of childhood gastroenteritis
- Cause of eye, throat, and respiratory infections
- Outbreaks associated with swimming and drinking water
- Most common enteric virus in sewage
- Longest surviving enteric virus in water?
- Enteric virus most resistant to UV light disinfection

Adenovirus



Norovirus

- No long lasting immunity
- Susceptibility related to types A, B and O blood groups
- Number of outbreaks in Japan have increased ten fold over last year
- Outbreaks in hospitals, cruise ships, schools, hotels, casinos

Number of Microorganisms Shed from an Ill Individual

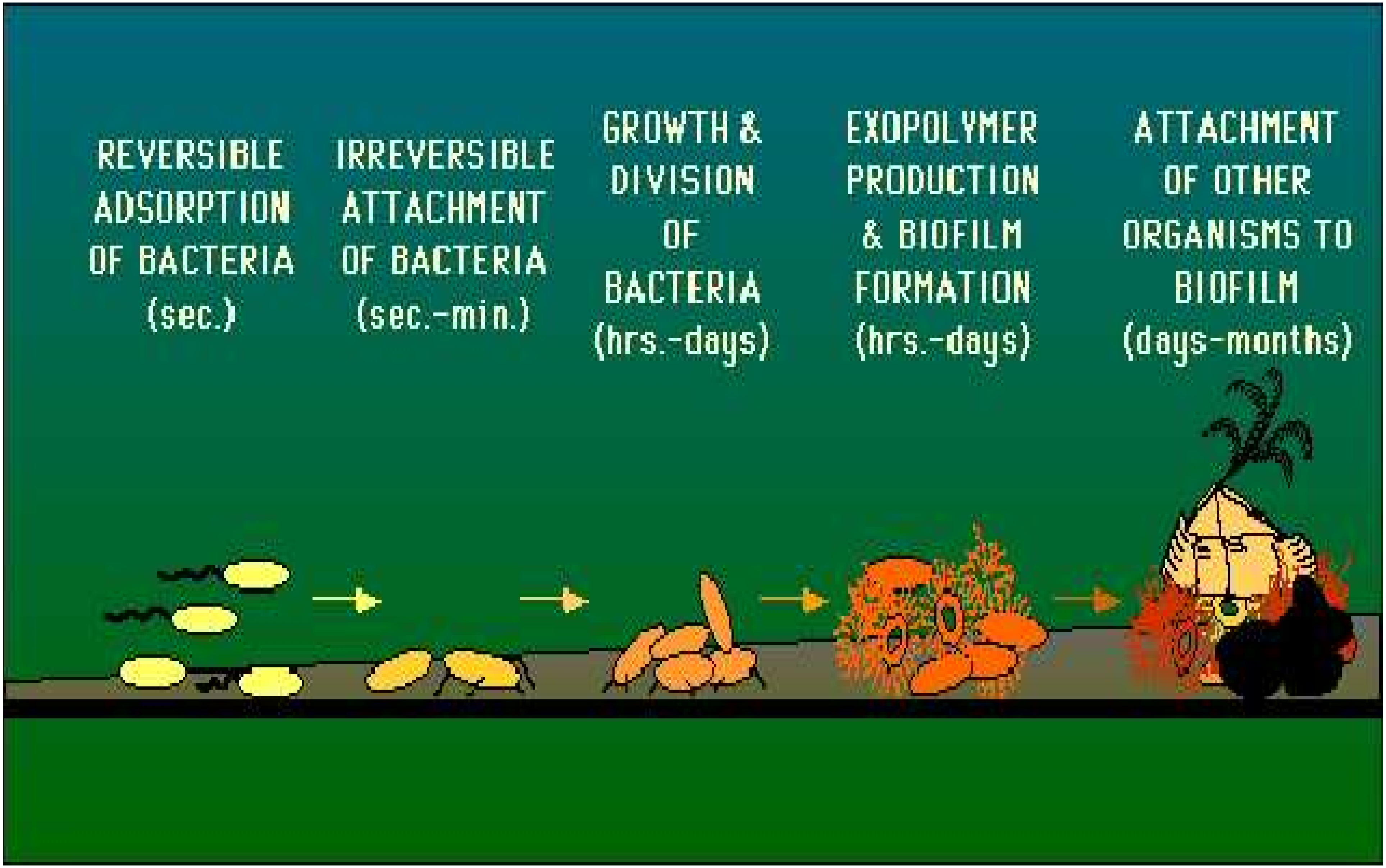
- Ingesting 1-10 norovirus can make you sick
- A single 500 mL diarrhea stool can contain over 1 billion noroviruses (7 million per mL)
  - 10-20 diarrheal stools per day
  - 10 x 10^9 = 10 billion virions from one sick individual in one day

Populations at Greatest Risk

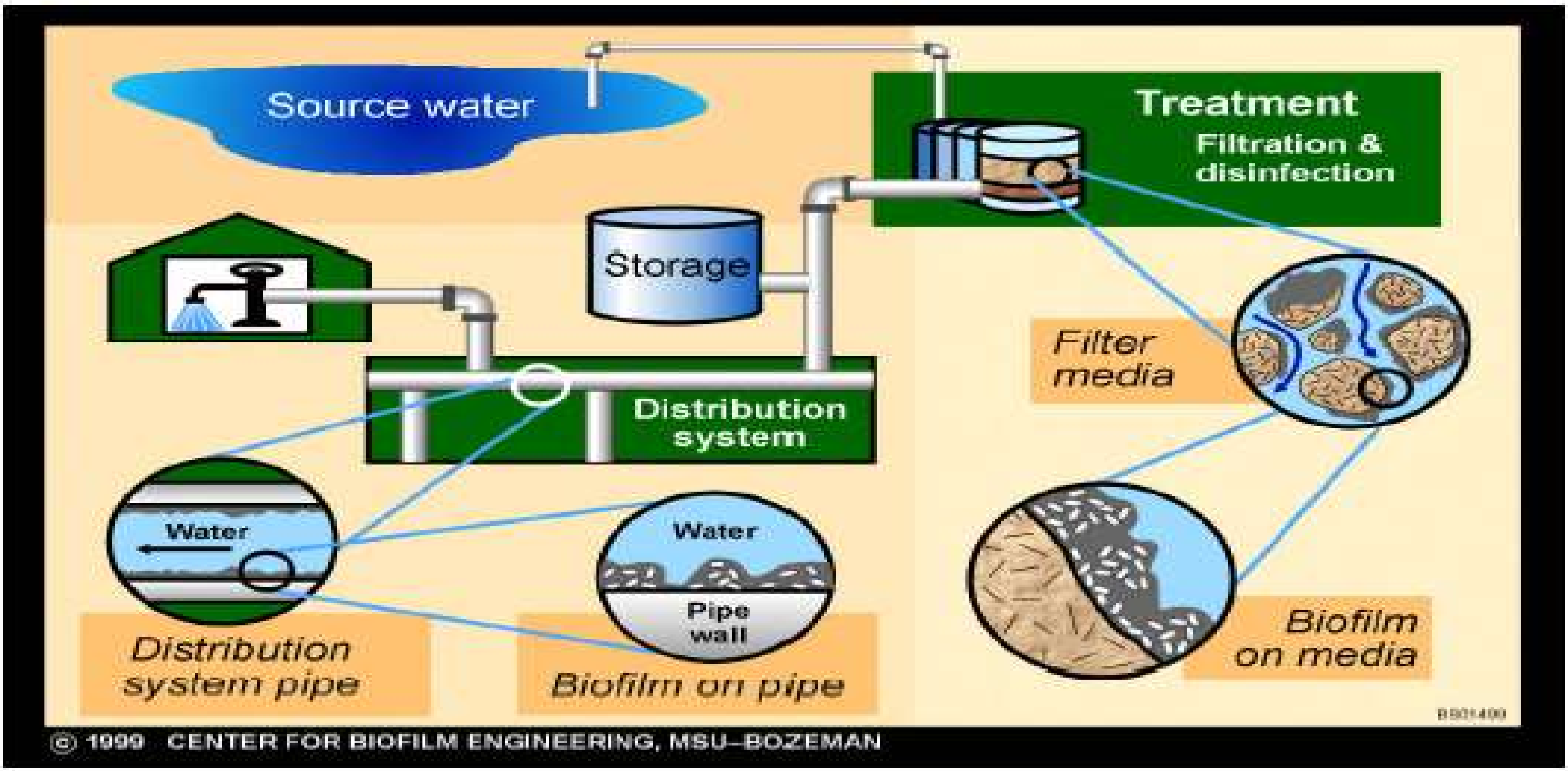
- Immunocompromised 10-100 times more likely to die from exposure to a microbial pathogen (Hierholzer, 1992; Meyers, 1989)
- 12% of clinical AIDS patients infected with adenovirus
- *Cryptosporidium* mortality rates in AIDS patients up to 50%
- BMT mortality rates from enteric virus infections, 59% (Yolken et al., 1982)
- *Cryptosporidium* prevalence in transplant patients, 20% (Udgiri et al., 2004)

BIOFILMS

Biofilm Formation



Biofilms



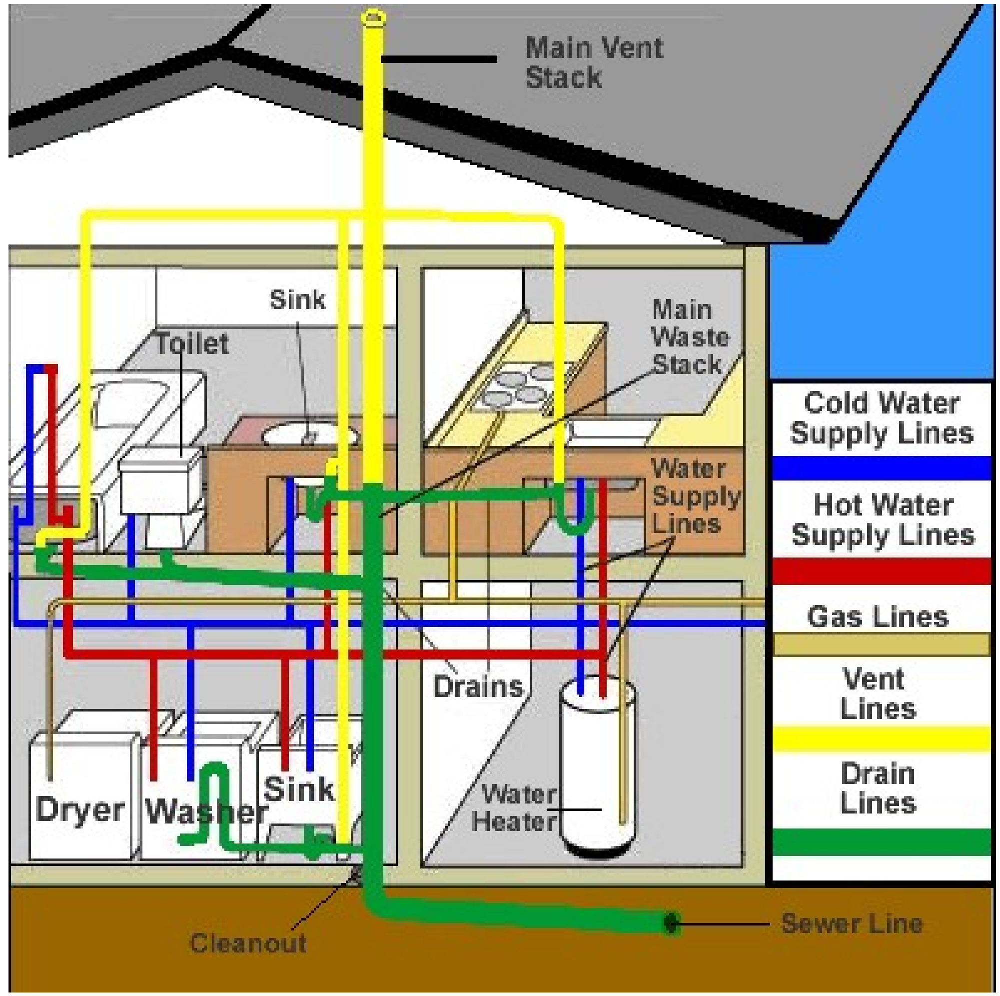
Source water
Treatment
Filtration & disinfection
Storage
Filter media
Distribution system
Water
Water
Pipe wall
Distribution system pipe
Biofilm on pipe
Biofilm on media
© 1999 CENTER FOR BIOFILM ENGINEERING, MSU–BOZEMAN

95% of Bacteria in Drinking Water Systems are in Biofilms

We know very little about biofilms

- Attachment/Detachment Mechanisms
- Bacteria Survival & Reproduction inside biofilms
- Effects of external factors on biofilms
    - Water Chemistry
    - pH
    - Temperature
    - Surface characteristics
    - Piping materials
    - Flow characteristics

10 to 1,000,000 greater bacteria concentration in household plumbing over supply lines



Mitigation

- Disinfection technologies
- Physical removal
- Plumbing system design, operation and maintenance

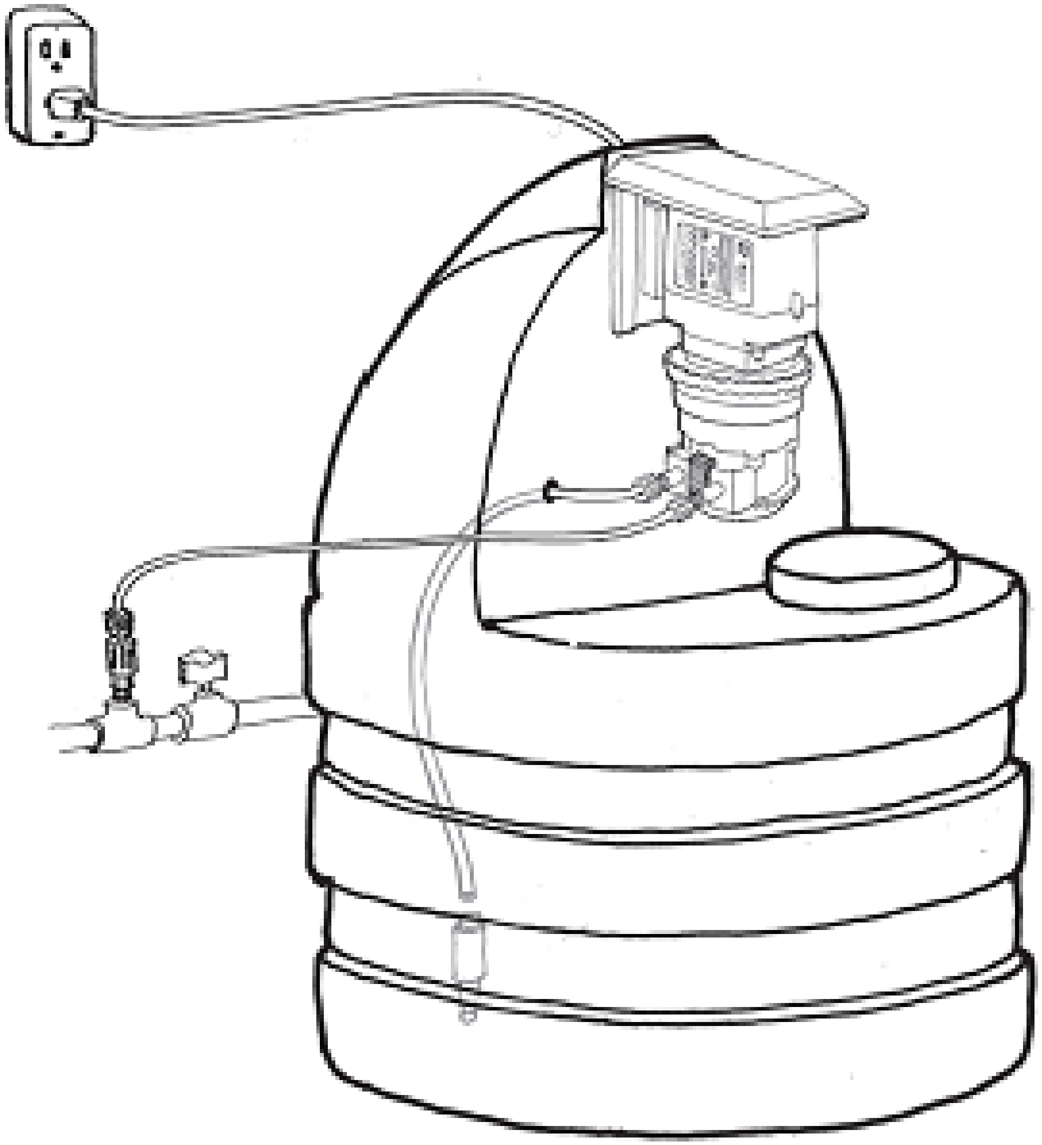
Ideal Disinfectant

- Kills (or inactivates) microorganisms.
- Has no deleterious effect on materials of construction or components of the water treatment system.
- Is stable and retains its effectiveness during the disinfection process.
- Is easily removed from the entire water treatment system.
- Is easily monitored with a simple test kit.

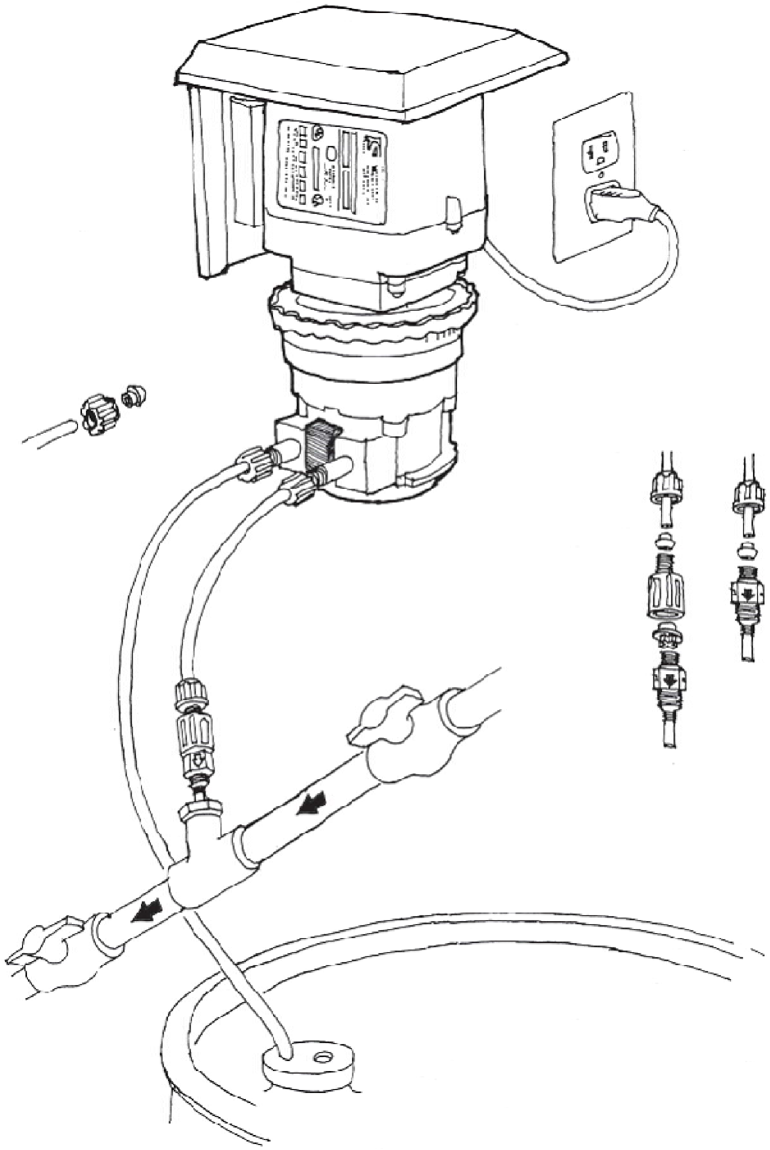
THE IDEAL DISINFECTANT DOES NOT EXIST

Chemical Disinfectants

- Chlorine
- Chloramines
- Chlorine Dioxide
- Iodine
- Ozone



Chemical Injection



Chemical Injection

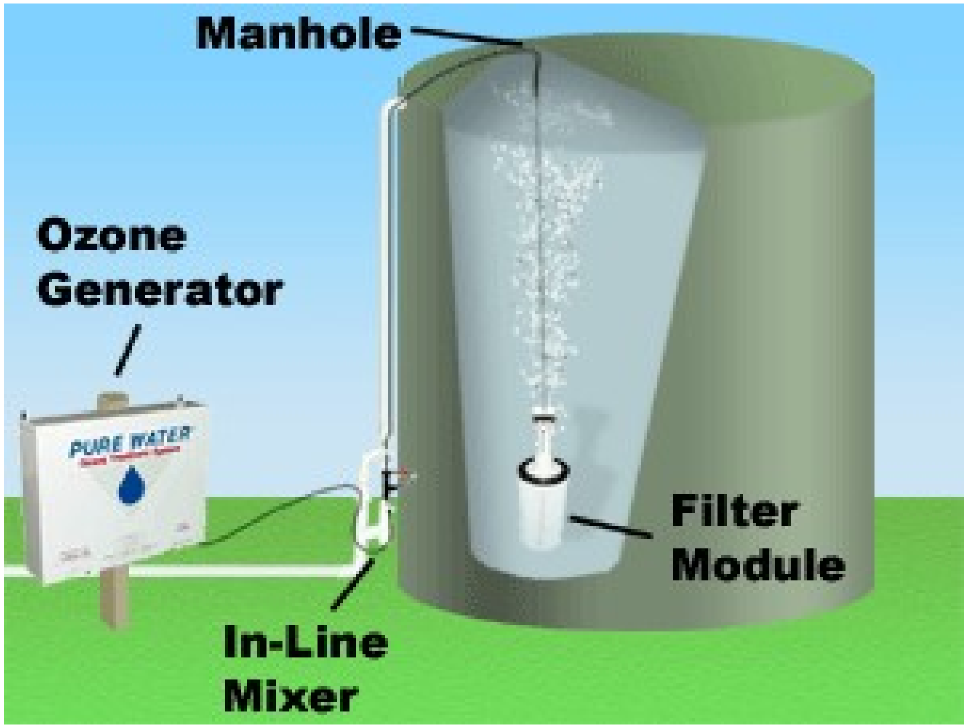
C·t Values for Chlorine Inactivation of Microorganisms* in Water

Organism	Temp	pH	C·t
E. coli	5	6.0	0.04
E. coli	23	10.0	0.6
L. pneumophila	20	7.7	1.1
Poliovirus	5	6.0	1.7
G. lamblia	5	6.0	54-87
Cryptosporidium	25	7.0	>7200

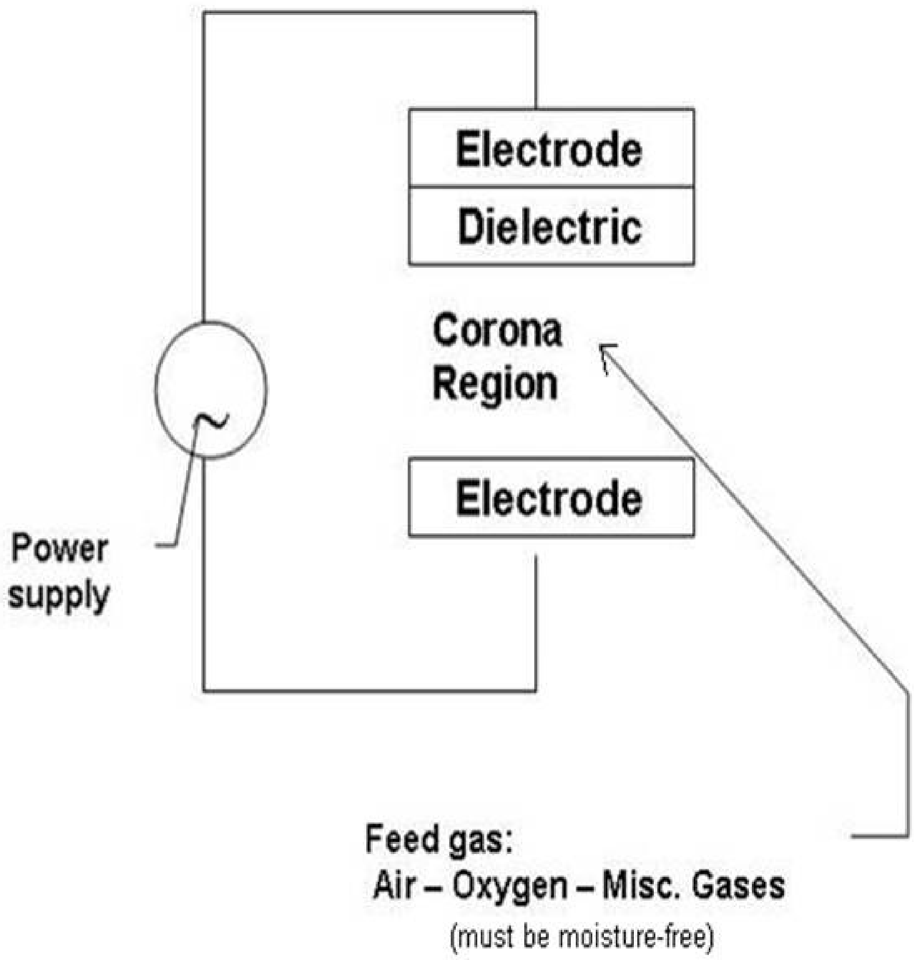
*99% Inactivation

Ozone Disinfection

- Unstable colorless gas produced by discharging electricity in dry air
- Generated at the point of use (not shipped in gas cylinders)
- Produced by discharging electricity in dry air (corona discharge)
- Soluble in water up to about 5 mg/L



Corona Discharge Ozone Generation

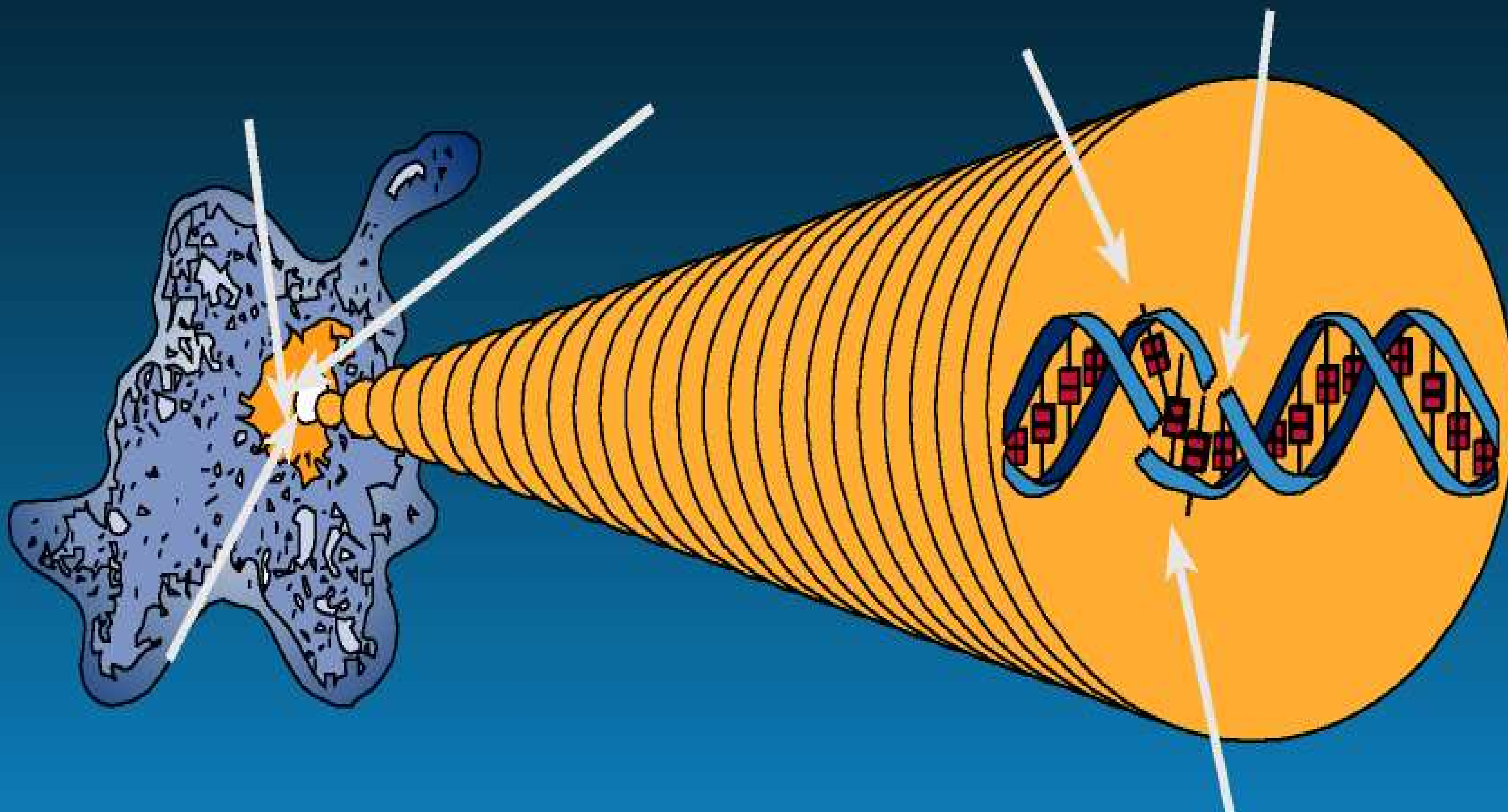


Non- Chemical Disinfectants

- Ultraviolet Irradiation
- Heat

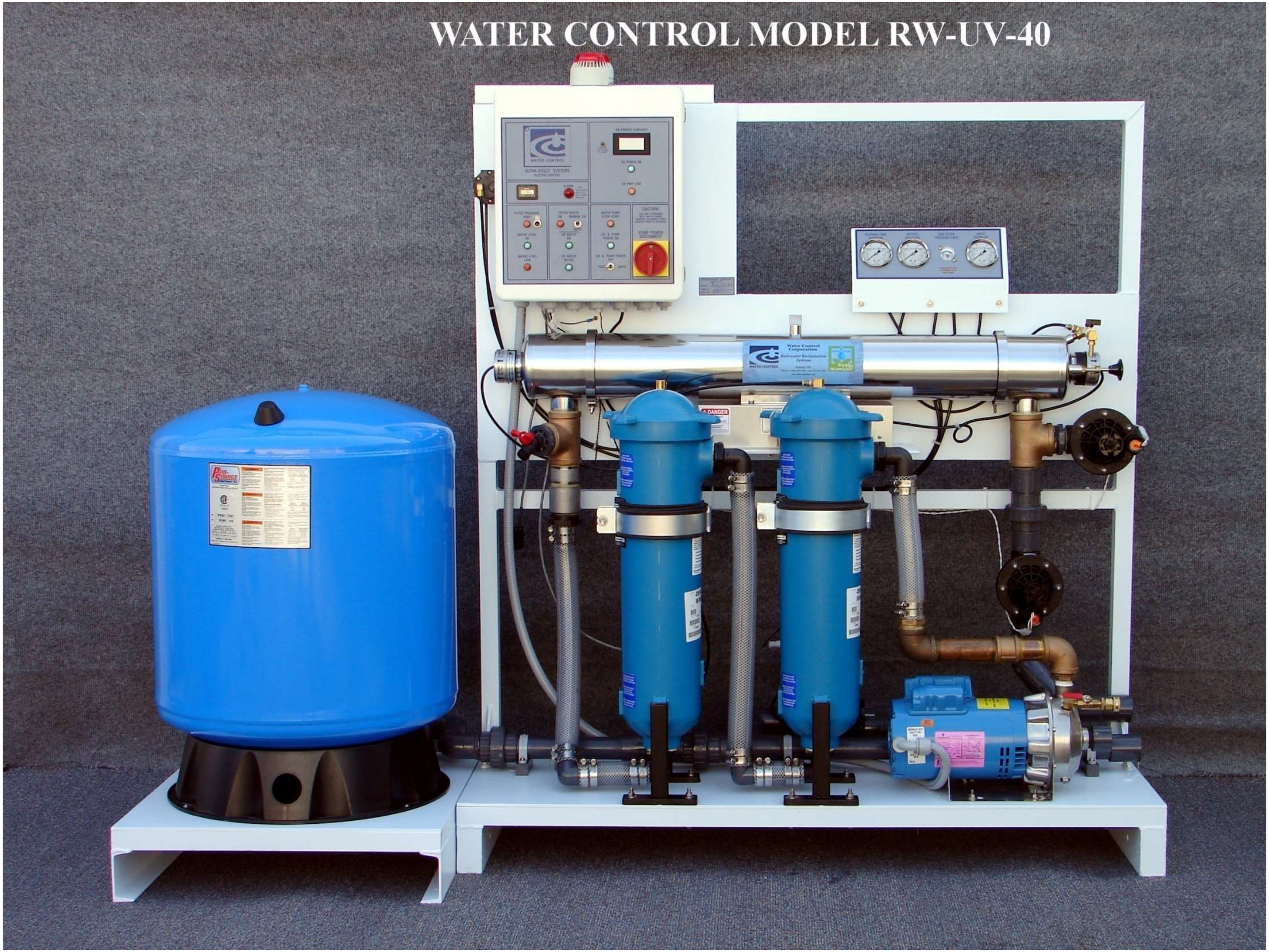
How UV Works

Ultraviolet light penetrates the membranes and breaks down the molecular structure of a microbes's DNA, rendering it harmless.



UV Dosage for 99% Inactivation

Pathogen	UV Dosage MWs/cm^2
Enteric bacteria	3-8
Mycobacterium intracellulare	25
Cryptosporidium parvum	3-5
Giardia lamblia	40
Encephalitozoon intestinalis	5
Acanthamoeba	60
Adenovirus	109



WATER CONTROL MODEL RW-UV-40

Heat

Water Temperature >140°F (60°C)

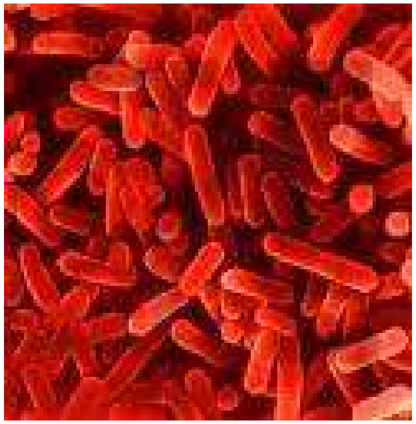
Problems:

- Handling difficulties
- Regulations
- Materials of construction
- Energy
- Temperature at outlets

LEGIONNAIRES' DISEASE

Legionella bacteria can cause Legionnaires' Disease

Legionella Spp.



Legionella Transmission is by Aerosol Inhalation

no person-to-person transmission

INHALATION ONLY UNDER REPORTED - >18,000 CASES/YR >10% ARE FATAL

Transmitted Via:

- Showers
- Faucets
- Ventilators
- Misters
- Cooling Towers
- Decorative Fountains
- Ice Machines
- Nasogastric Tube Feeder

ASHRAE STANDARD 188P

Controlling Legionella Bacteria

- Copper-Silver Ionization
- Chlorine Dioxide
- Chloramines
- Hyperchlorination
- POU Filtration
- UV Irradiation

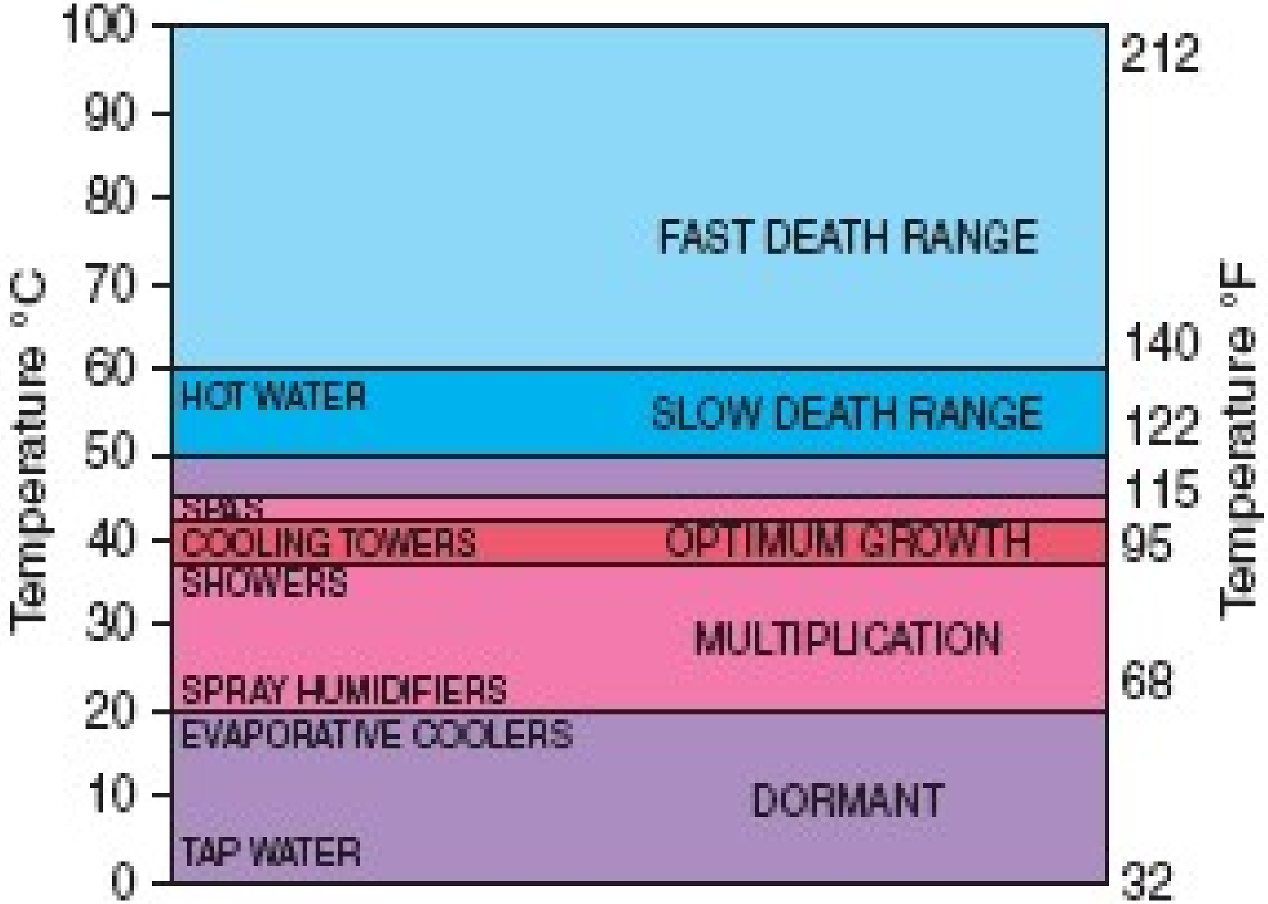


FIGURE 22.6 The effect of temperature on the growth of *Legionella*

Copper-Silver Ionization

Chlorine Dioxide

Physical Removal

- POU Filters

Impact of Point-of-use filtration on *Pseudomonas* Infections in an Intensive care unit (Trautmann et al, 2008)

- *Pseudomonas* infections were decreased by 85% ($p<0.005$)
- Invasive infections declined by 56%

POU Filtration

Plumbing Design & Operation

- Maintain turbulent flow conditions in piping (velocity 10-15 ft/sec)
- Maintain adequate pressure
- Minimize stagnant flow
- Eliminate deadlegs
- Hot water continuous recirculation
- Smooth interior joints
- Materials of construction
  - Copper-biostatic
    - Subject to corrosion
    - Physically strong
  - Plastic
    - Not subject to corrosion
    - Not as strong
- Backflow prevention

Flow

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Reynolds Number

$$Re = \frac{\text{diameter x mass velocity}}{\text{viscosity}}$$

Re <2,000 = Laminar Flow

Re >4,000 = Turbulent Flow

Water Treatment: A Multi-barrier Approach

- **Source water protection**
  - developmental boundaries
  - wastewater treatment requirements
  - pollutant discharge regulations
  - controlling wild animal activity in the area
- **Municipal water treatment (160K+)**
  - Coagulation and Sedimentation
  - Filtration
  - Disinfection
- **Secure distribution**
  - Disinfectant residual

Distribution

- Maintaining a residual disinfectant in the distribution pipes is critical
  - Cross connections between sewer and water lines
  - Back siphoning due to pressure changes
  - Reduction of biofilm growth on the interior of the pipes
  - Tucson has 4,000 miles of drinking water mains (2004)

Home Distribution Systems – The Big Unknown

- Bacteriological water quality of water significantly deteriorates in the home distribution system. (Pepper et al., 2004)
  - HPC bacteria in
    - Groundwater source 1-10 cfu/mL
    - Distribution system 10-100 cfu/mL
    - Household tap 1,000-1,000,000 cfu/mL

- The source of *Legionella*,
- *M. avium*, *H. pylori, Naegleria, etc.*

POU Health Benefits

- Milwaukee outbreak- prevent morbidity/mortality
- Payment et al. (1991) gastrointestinal illness reduced by $\leq$50% by drinking RO treated tap water vs tap water.
- Tapwater bottled at the treatment plant: 14% more illness than purified bottled water drinkers (Payment, 1997).
- Children gain the most by having a POU system in place.
  - 2-5 y: 40% more infections from tap water
  - 17% more disease in children drinking bottled tap water vs POU treated water (Payment, 1997).

Site Specific

Conclusions

Game is Changing

New pathogens

More immunocomprised individuals

Contact Information

Peter S. Cartwright, PE

pscartwright@msn.com

www.cartwright-consulting.com

1/952-854-4911