CT4471 Drinking water I

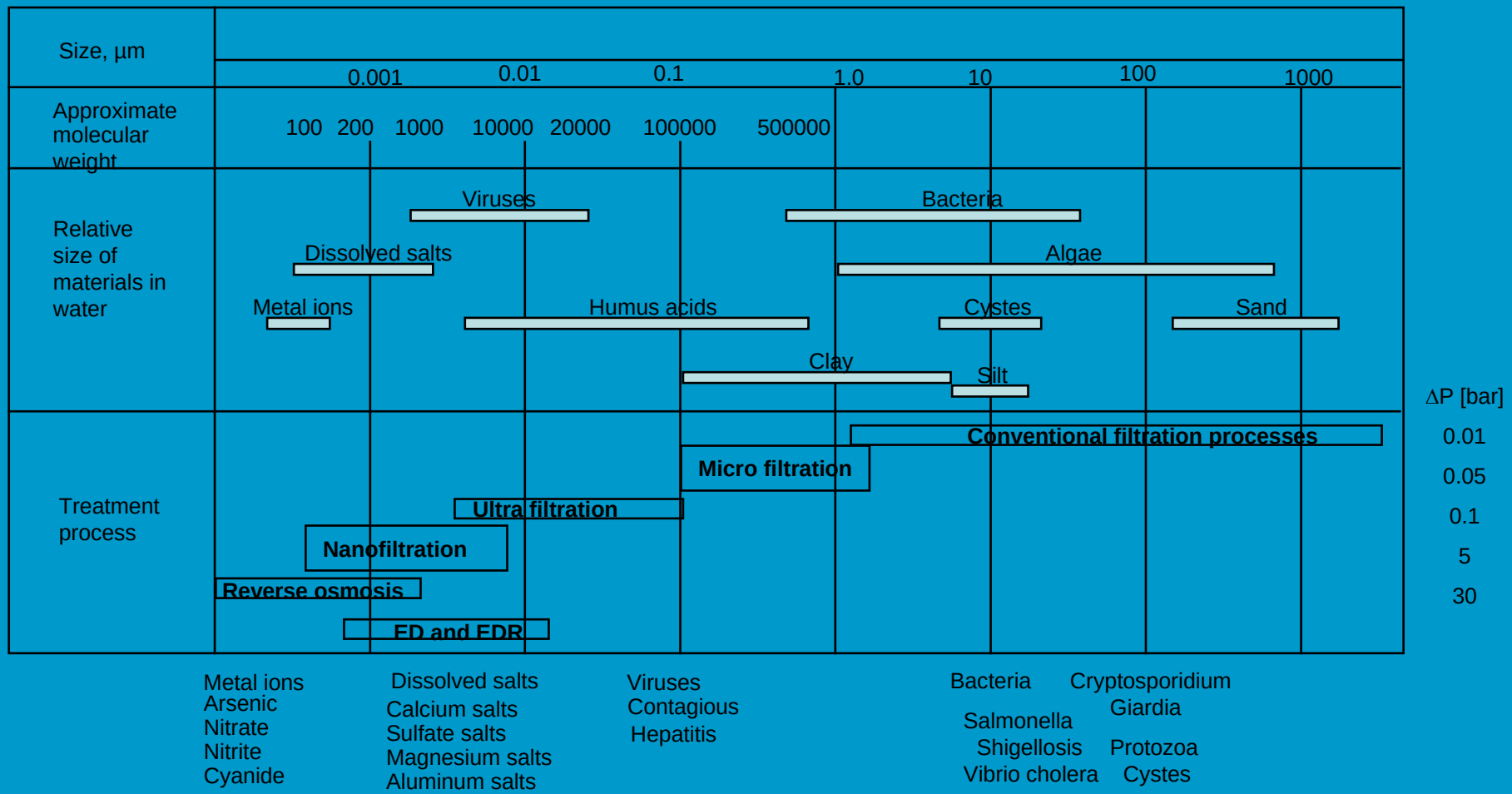
Dr.ir. S.G.J. Heijman
nanofiltration and reverse osmosis

Nanofiltration and reverse osmosis

TU Delft
Delft University of Technology

Contents

Introduction

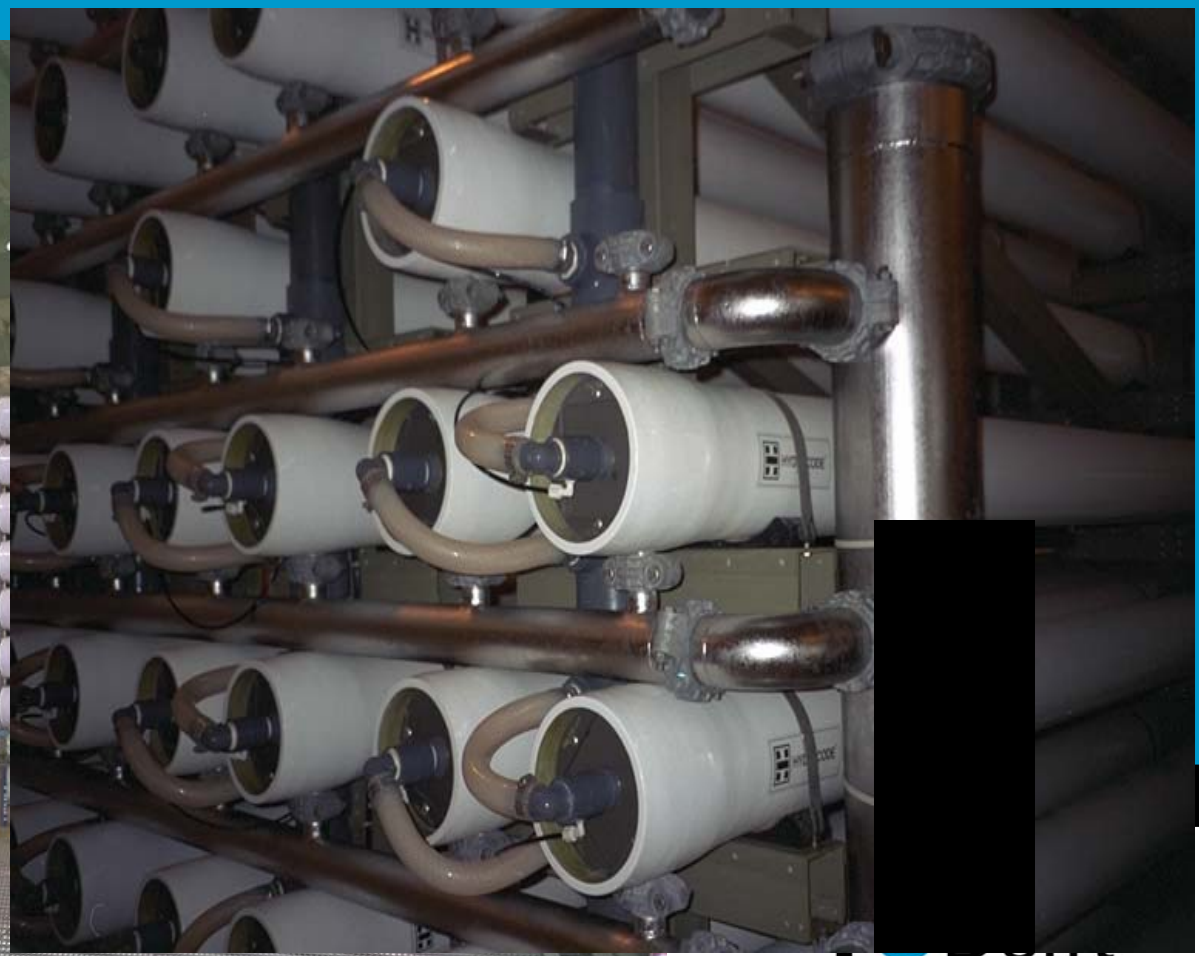


Introduction

	•Bacteria	•Virusses	•Multivalent salts	•Monovalent salts
Microfiltration MF	+	-	-	-
Ultrafiltration UF	+	+	-	-
Nanofiltration NF	+	+	+	-
Reversed Osmosis RO	+	+	+	+

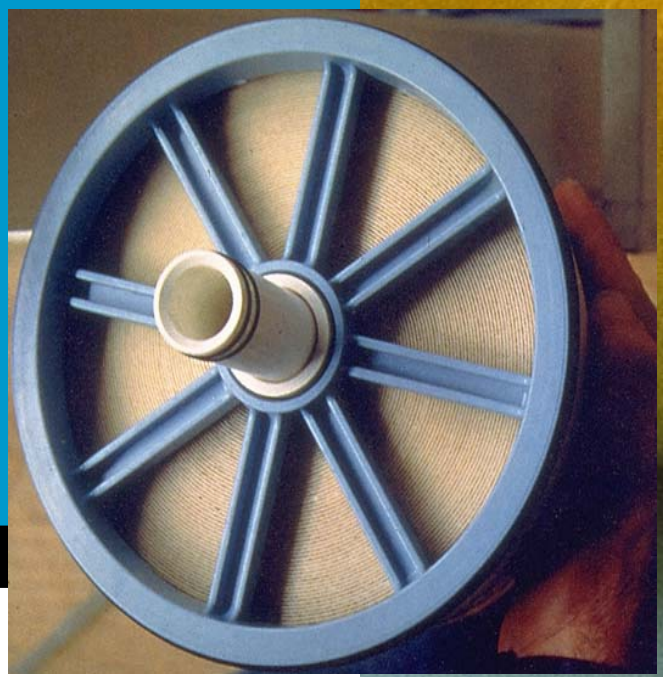
TU Delft

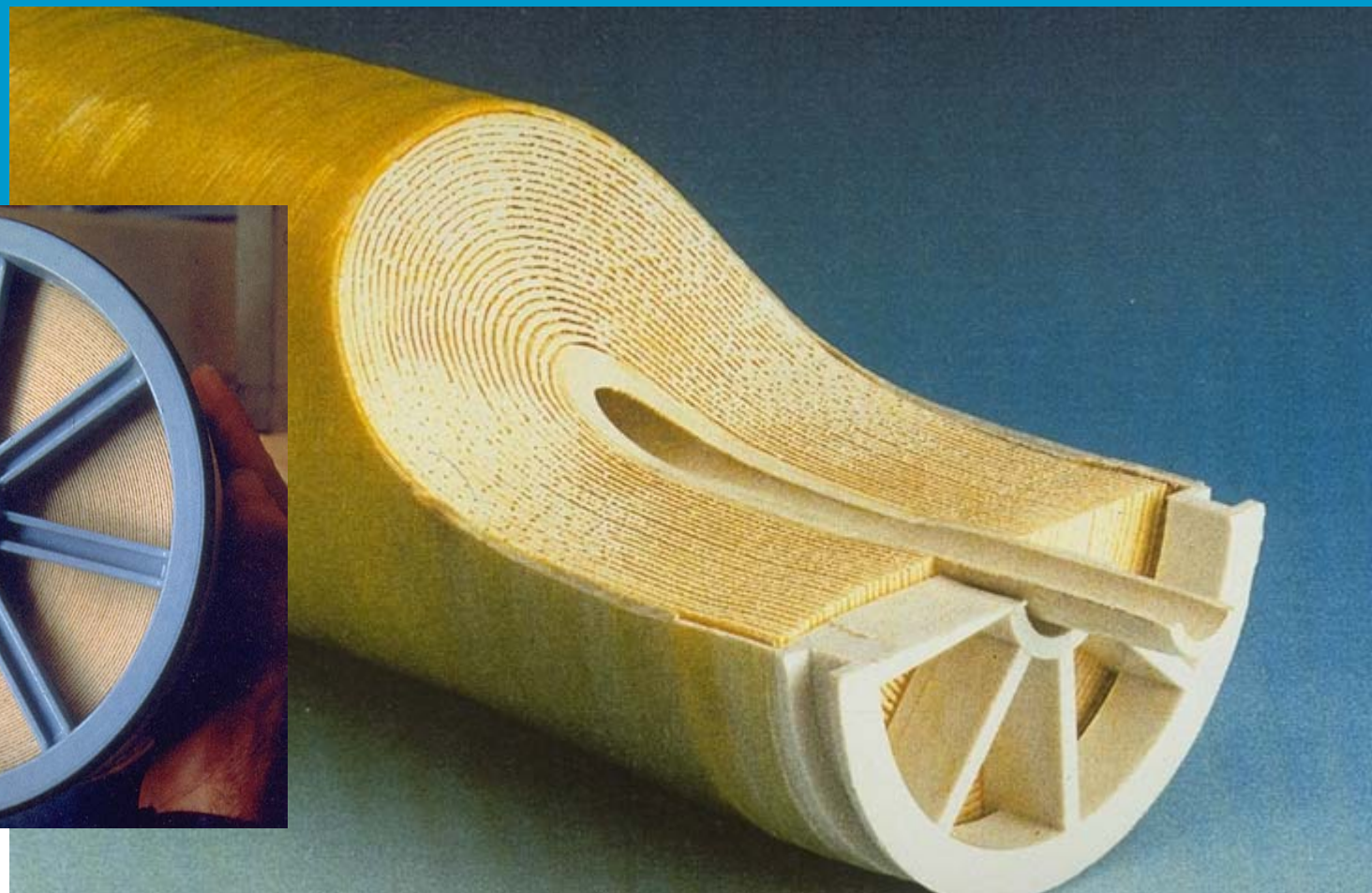
Introduction



Introduction

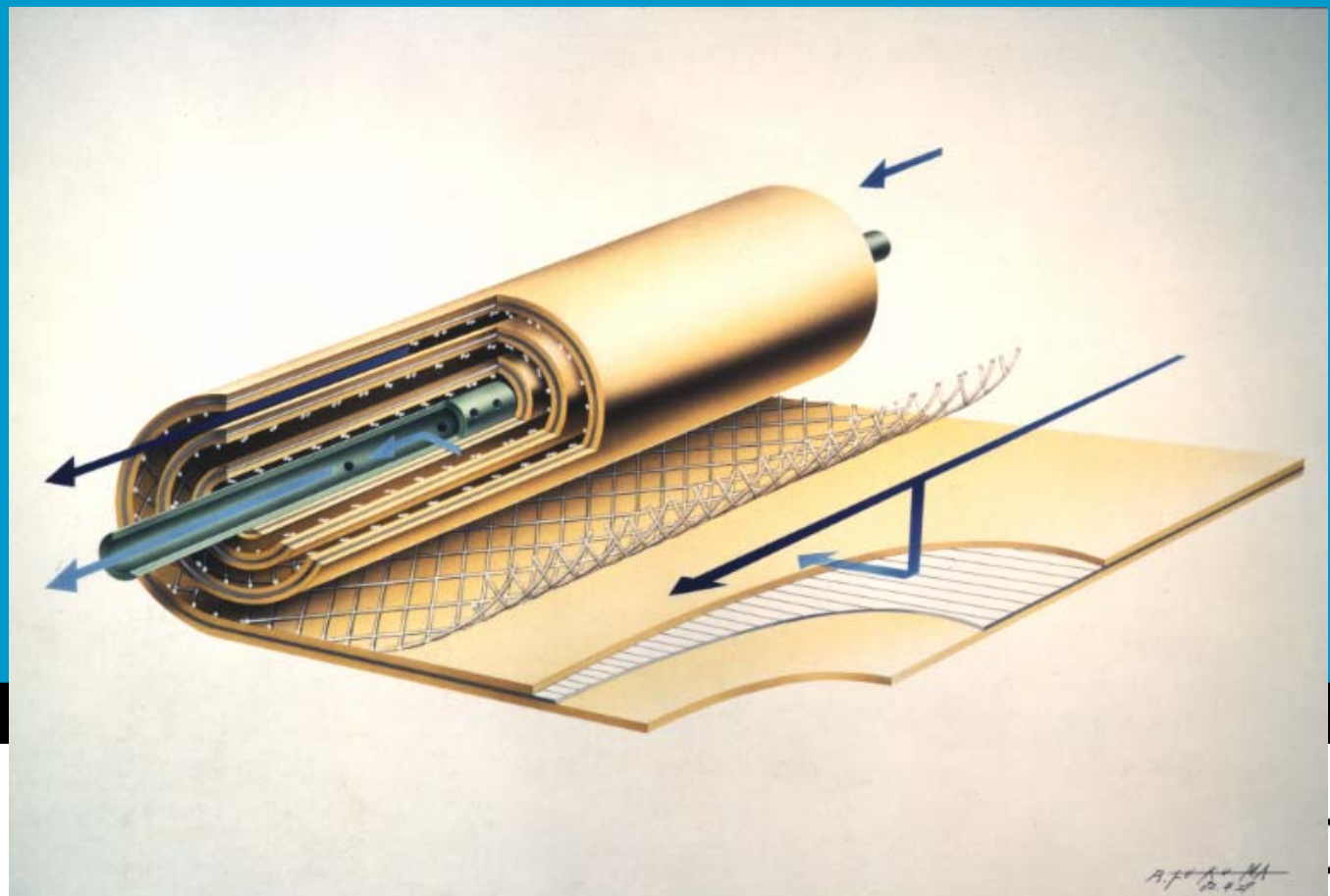
- Spiral wound membrane





Modules

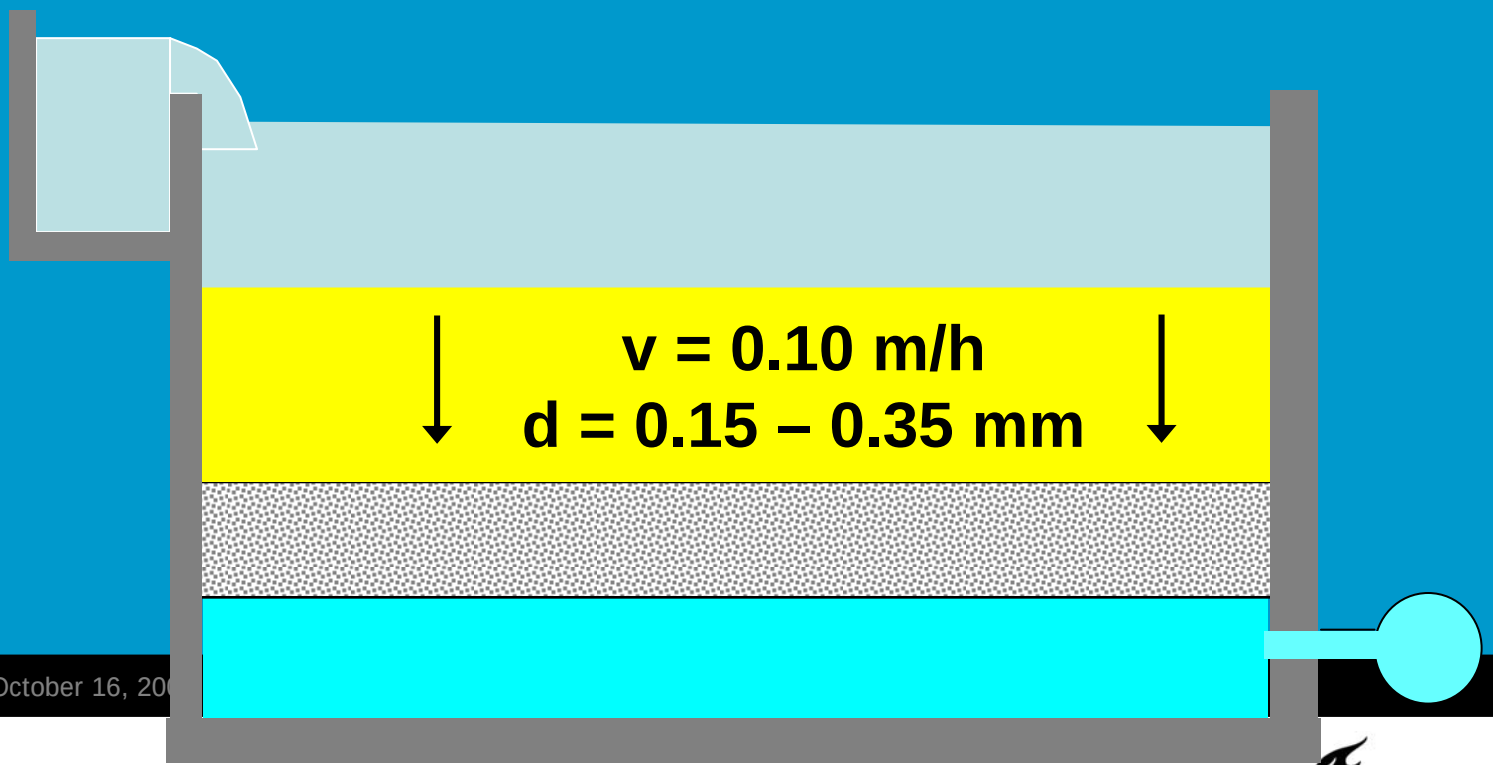
- Spiral wound membranes



Delft

Introduction

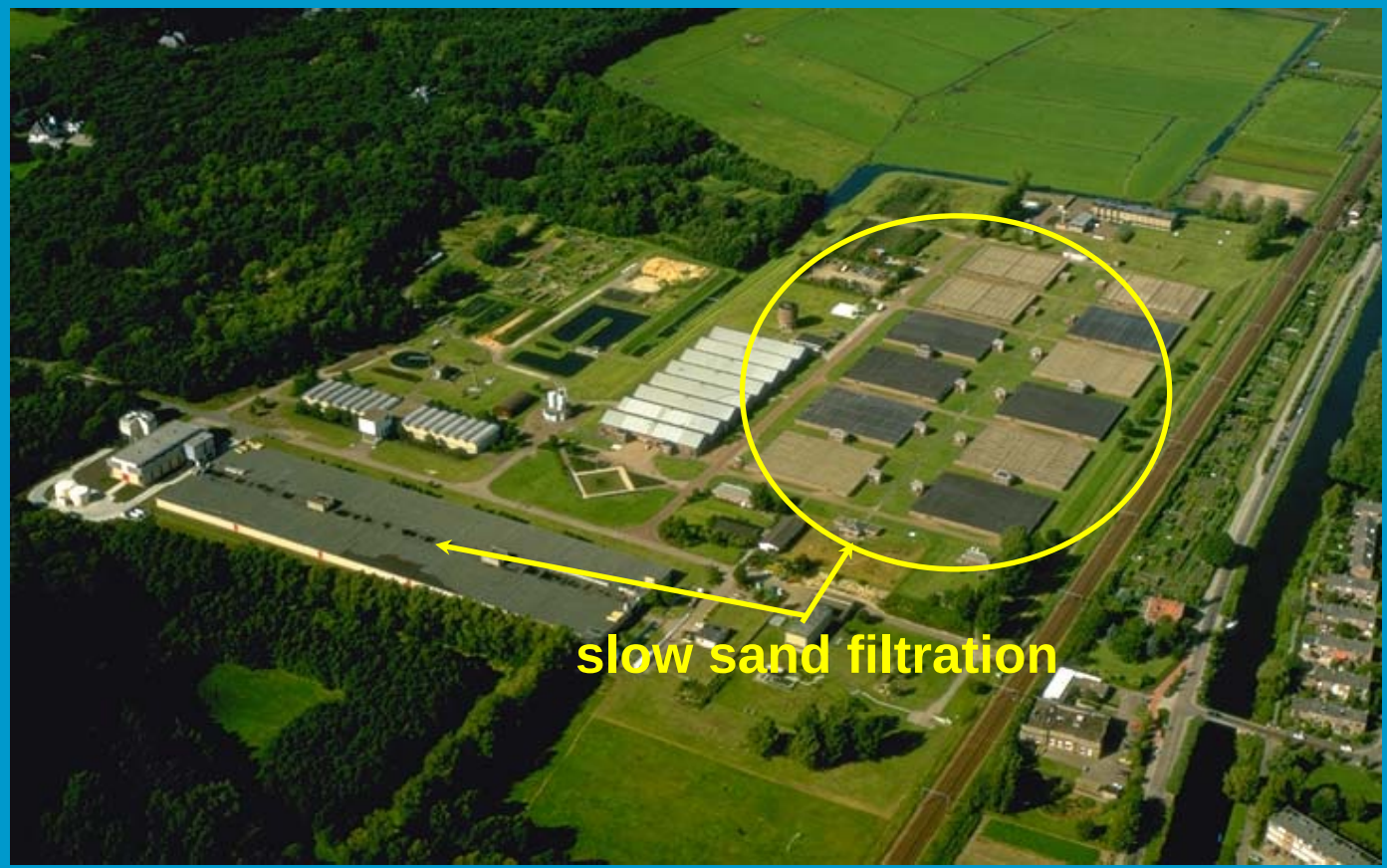
- Principle slow sand filtration



TU Delft

Introduction

- Slow sand filtration

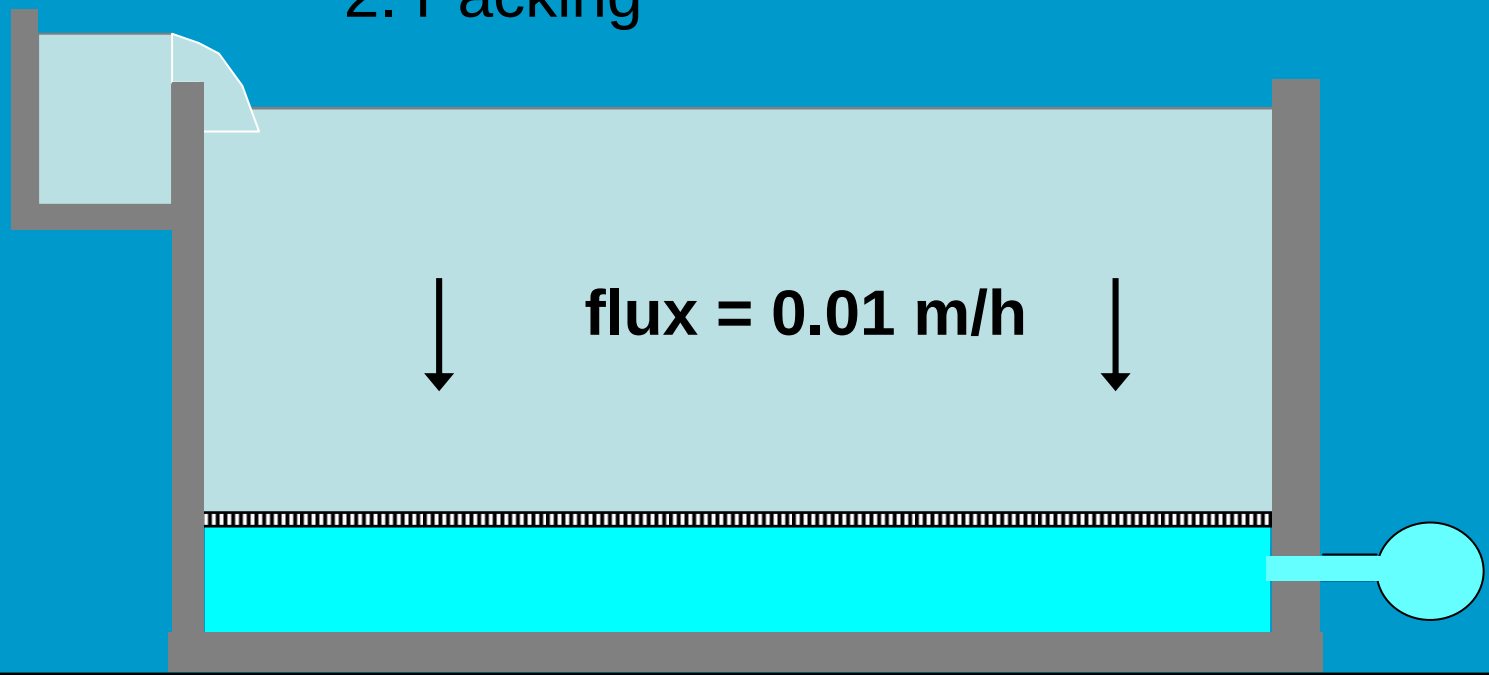


TU Delft

Introduction

- Parallel MF/SSF

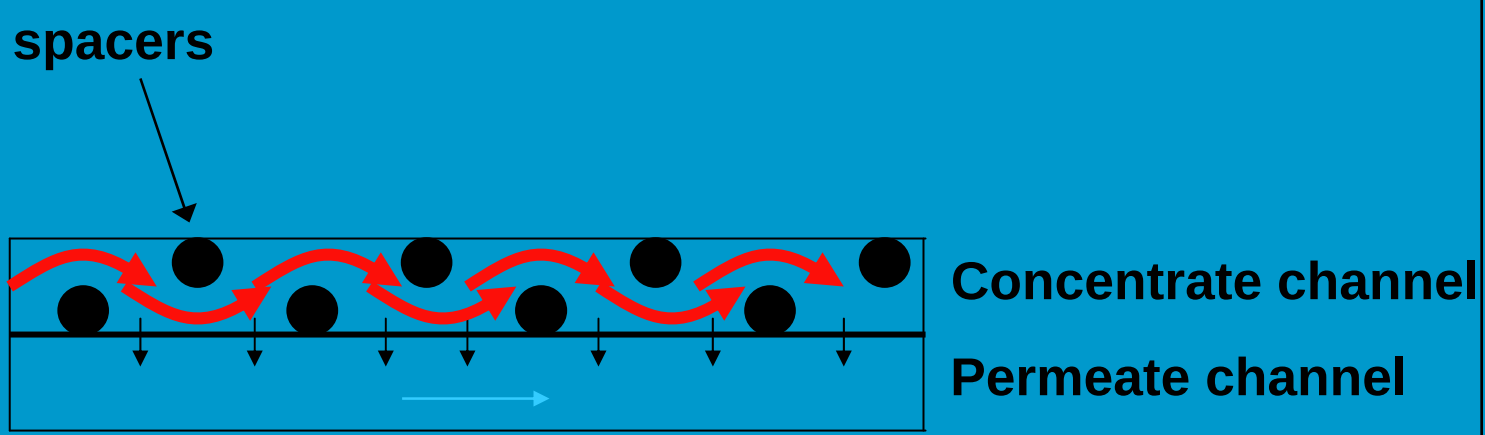
Problems: 1. Fouling
2. Packing



TU Delft

Introduction

- Traditional RO/NF - fouling



Turbulent flow <u>across</u> membranes

TU Delft

Introduction

- Filtration process and particle size

	Particle size [nm]	pressure [bar]	MWCO	flux [$m^3/m^2 \cdot h$]
Micro filtration	> 100	< 1		0.04 - 0.2
Ultra filtration	10 - 100	< 2	1000 - 10000	0.08 - 0.2
Nano filtration	1 - 2	5 - 10	200 - 500	0.02 - 0.08
Reverse osmosis	0.2 - 1	15 - 60	100	0.01 - 0.04

MWCO = Molecular Weight Cut Off
= 90% of organic molecules is removed

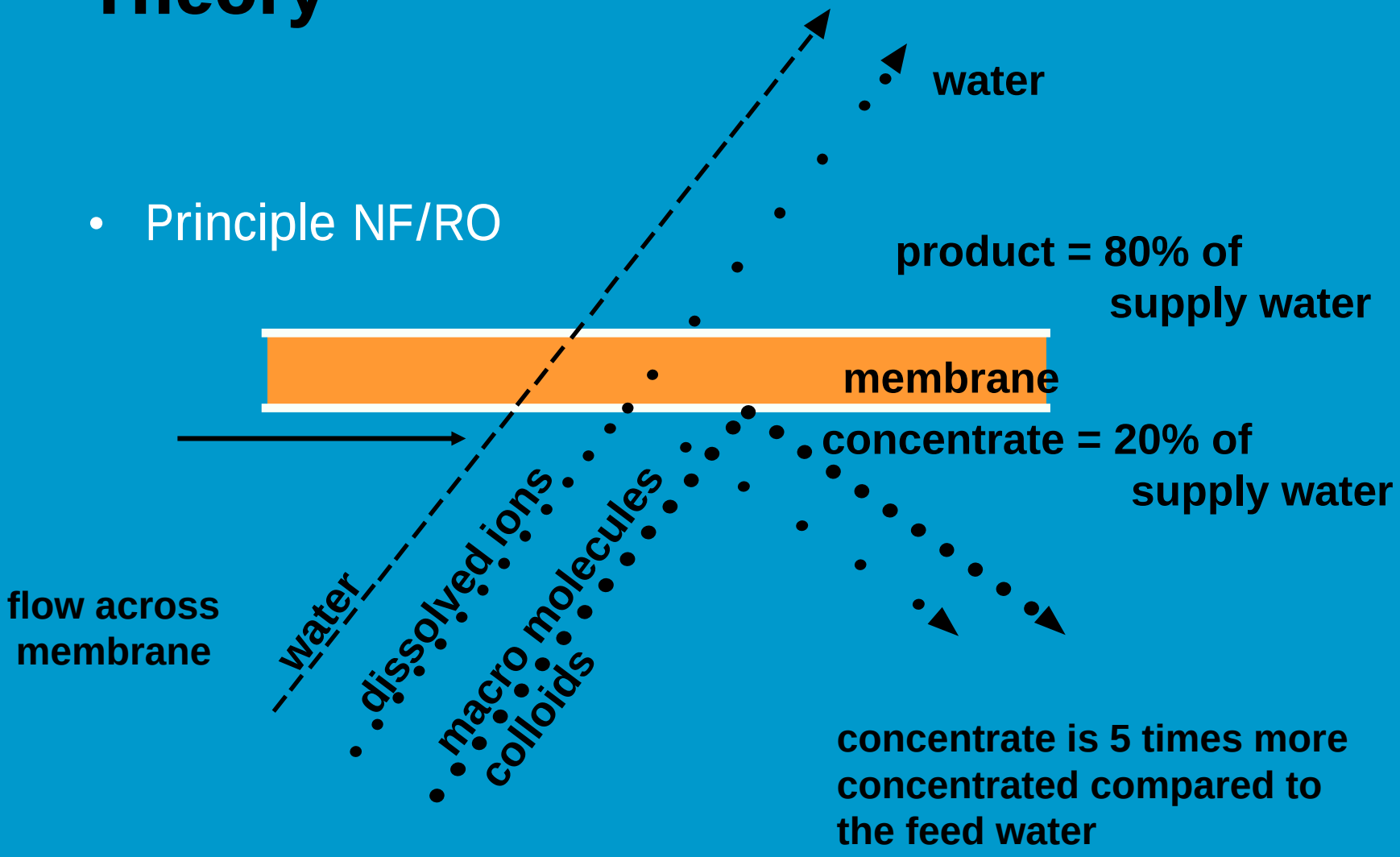
TU Delft

Contents

1. Introduction
2. Theory
3. Membrane modules
4. Applications
5. Design
6. Fouling control

Theory

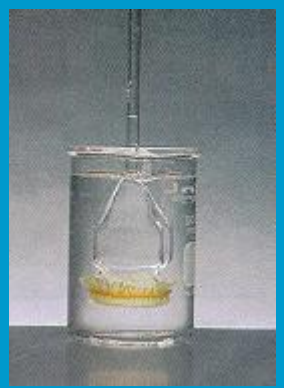
- Principle NF/RO

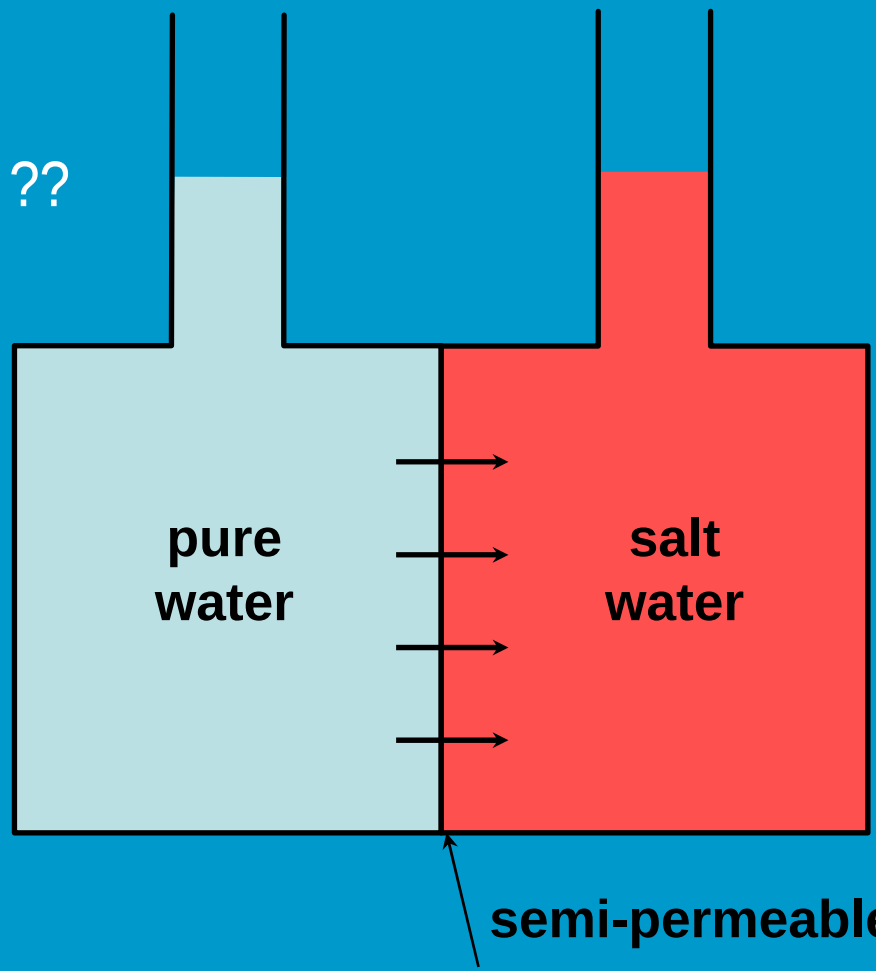


TU Delft

Theory

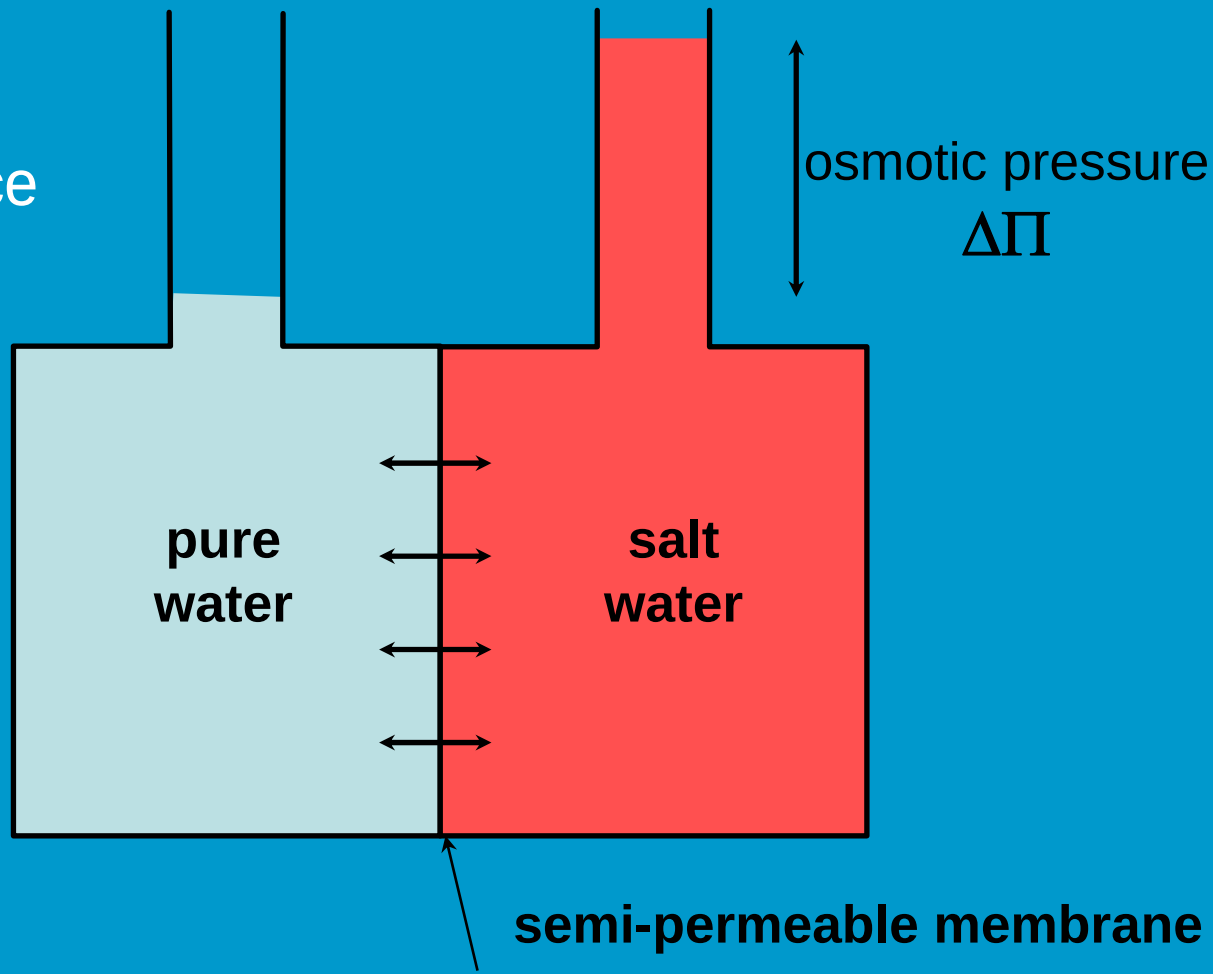
- Reverse Osmosis ??





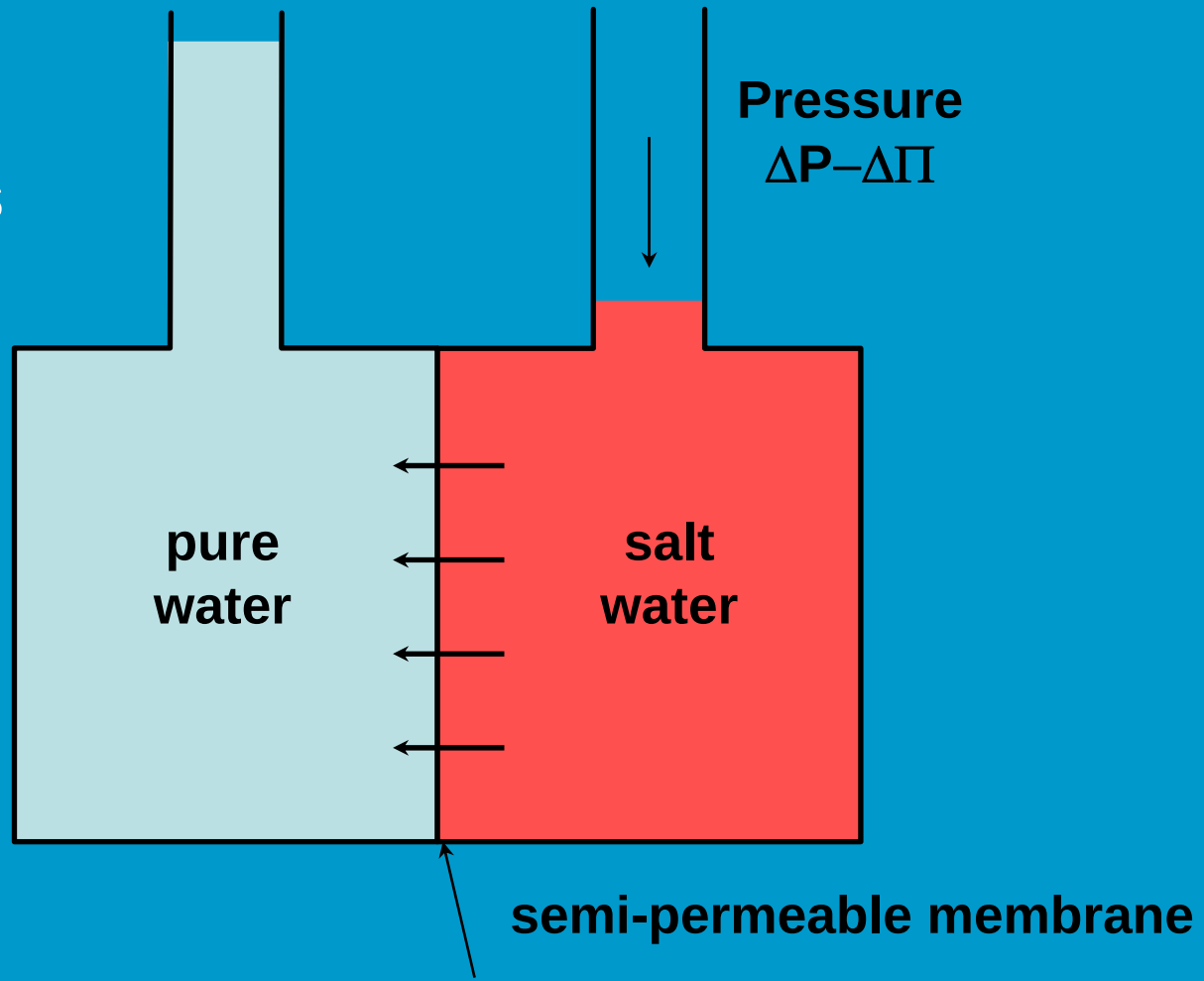
Theory

- Osmotic balance

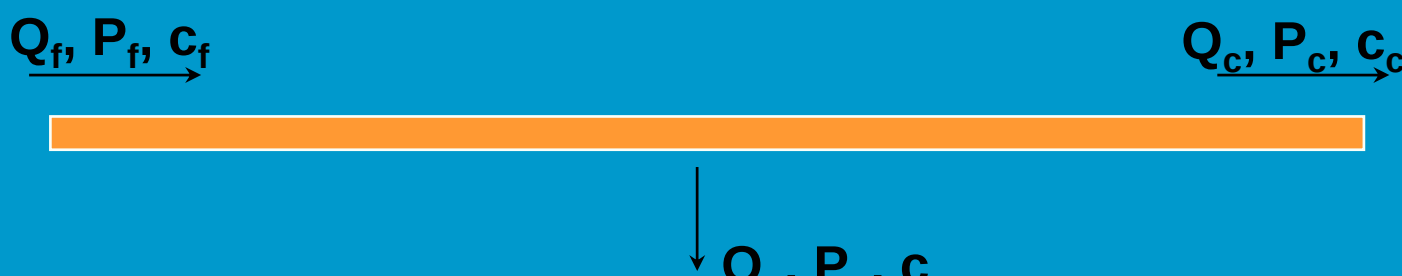


Theory

- Reverse osmosis



Theory



Mass balance water: $Q_f = Q_c + Q_p$

Recovery $\gamma = \frac{Q_p}{Q_f}$

Mass balance salt: $Q_f \cdot c_f = Q_c \cdot c_c + Q_p \cdot c_p$

$c_c = c_f \cdot \frac{1}{1-\gamma}, \quad c_p \approx 0$

Retention $Ret = 1 - \frac{c_p}{c_f}$

TU Delft

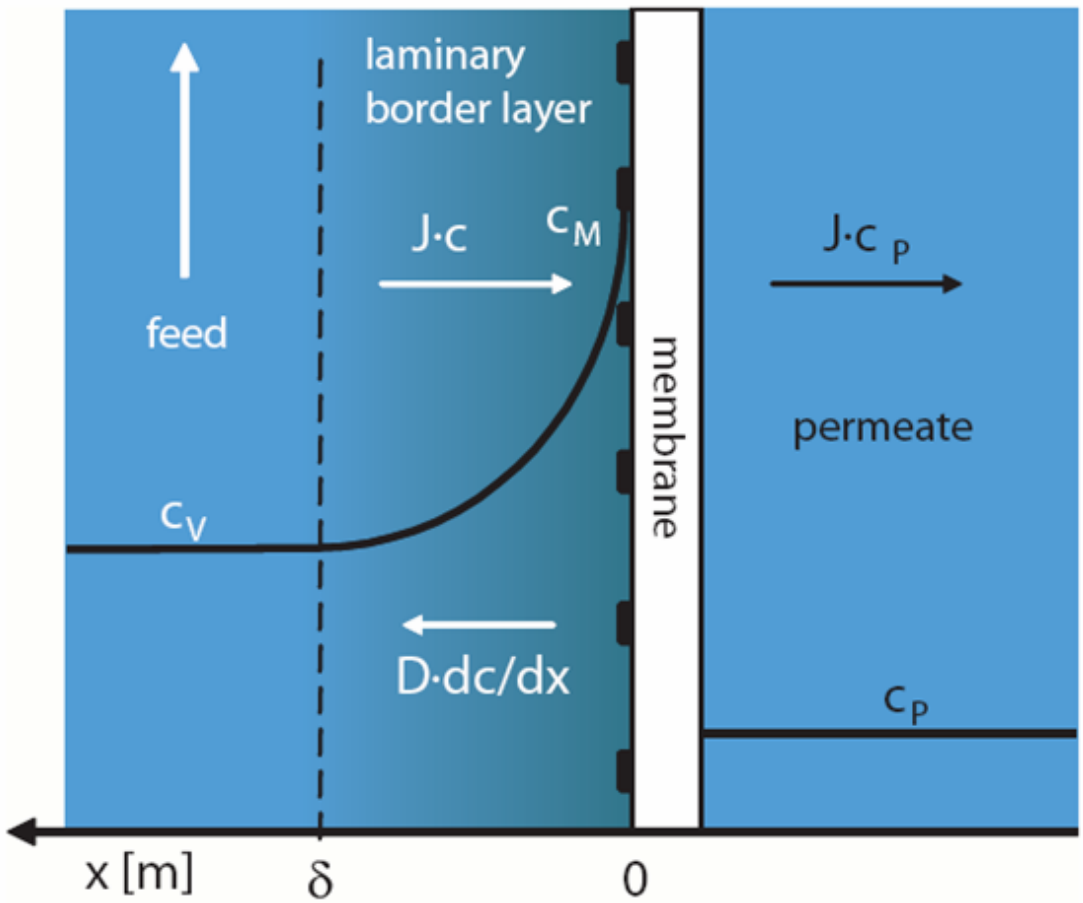
Theory

	Reverse osmosis		nanofiltration
parameter	Sea water	Brackish water	Ground water
T [°C]	25	25	25
c_f [g/m^3]	35000	2000	100
γ [–]	0.3	0.8	0.8
ΔP [bar]	55	25	10
R_o [-]	0.995	0.95	0.85
η [–]	0.7	0.7	0.7
η_{rec} [–]	0.7	0.7	0.7
π_f [bar]	30	1.7	0.1
$\Delta\pi$ [bar]	36	5.1	0.5
ΔP-$\Delta\pi$ [bar]	19	20	9.5
R [-]	0.994	0.85	0.55
c_p [g/m^3]	210	300	45
E [kWh/m^3]	7.2	1.2	0.5
E_{rec} [kWh/m^3]	2.5	0.1	0.05

TU Delft

Theory

- Concentration
- polarisation



TU Delft

Contents

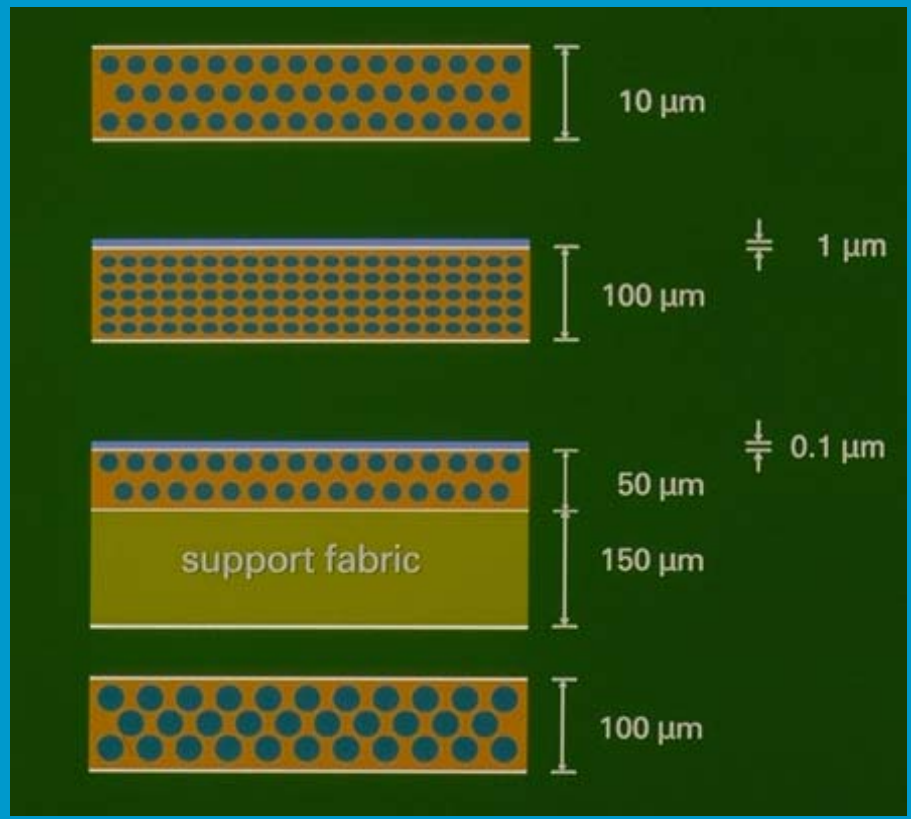
Membranes structure

Homogenous

Asymmetric

Composite

Liquid



Membrane modules

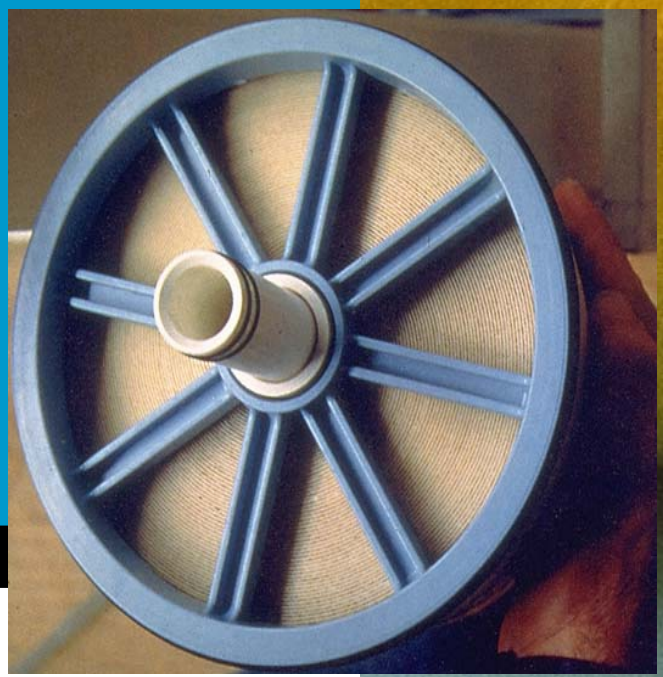
Tubular membranes	20 - 200 m^2/m^3
Plate and frame membranes	400 - 600 m^2/m^3
Spiral wound membranes	900 - 1000 m^2/m^3
Hollow fiber membranes	until 12000 m^2/m^3

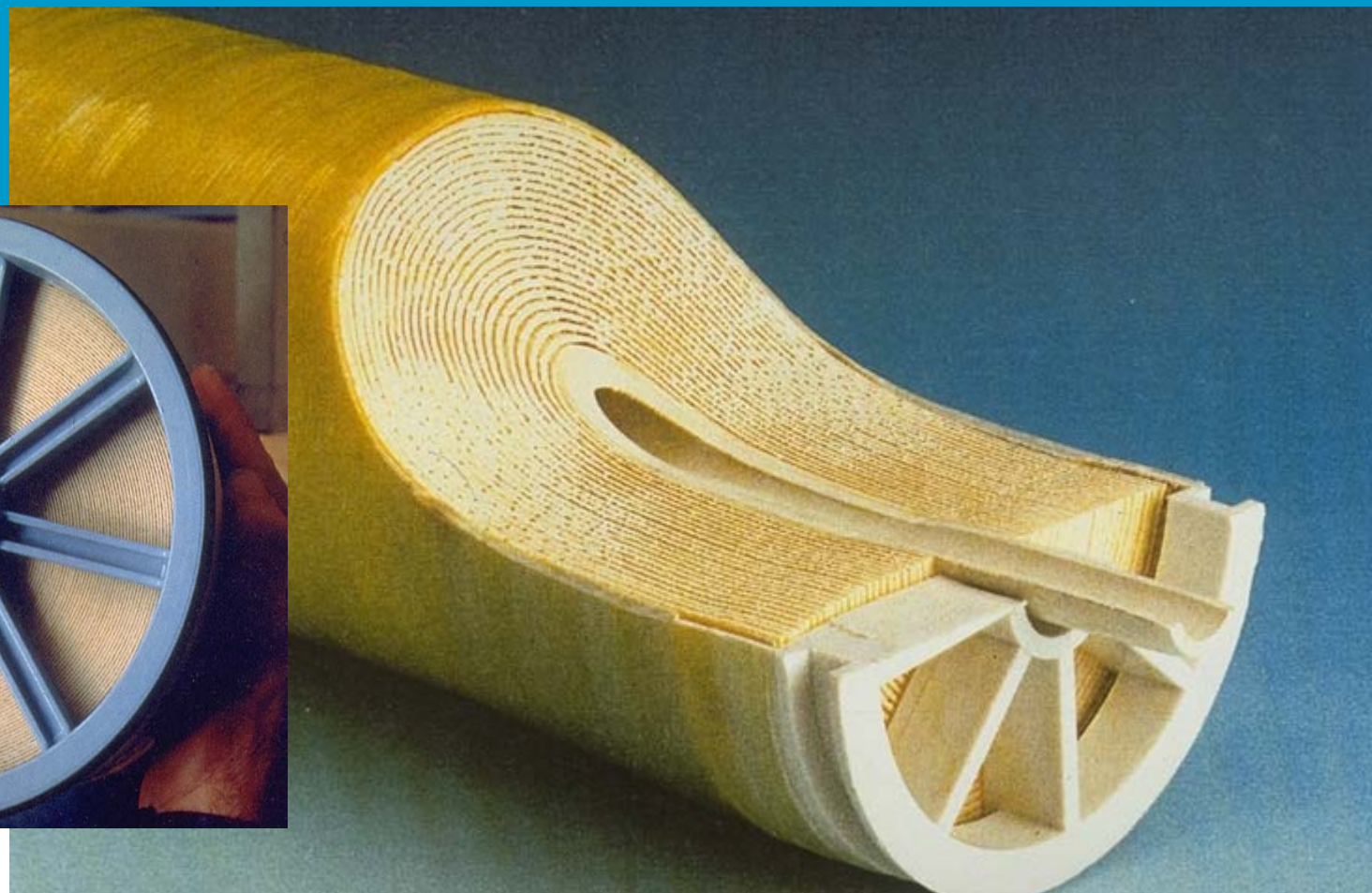
Modules

- Tubular membranes

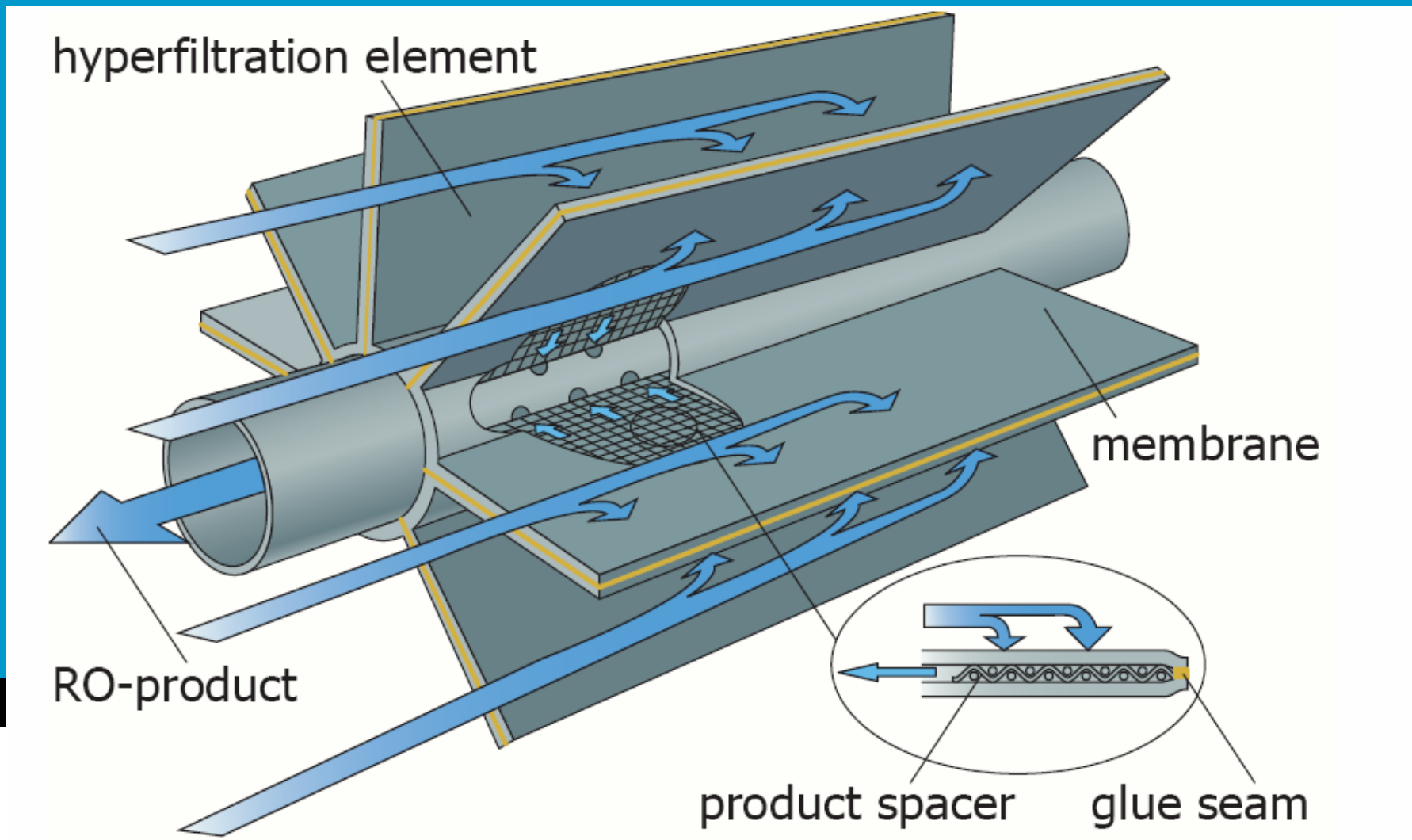
Modules

- Spiral wound membrane

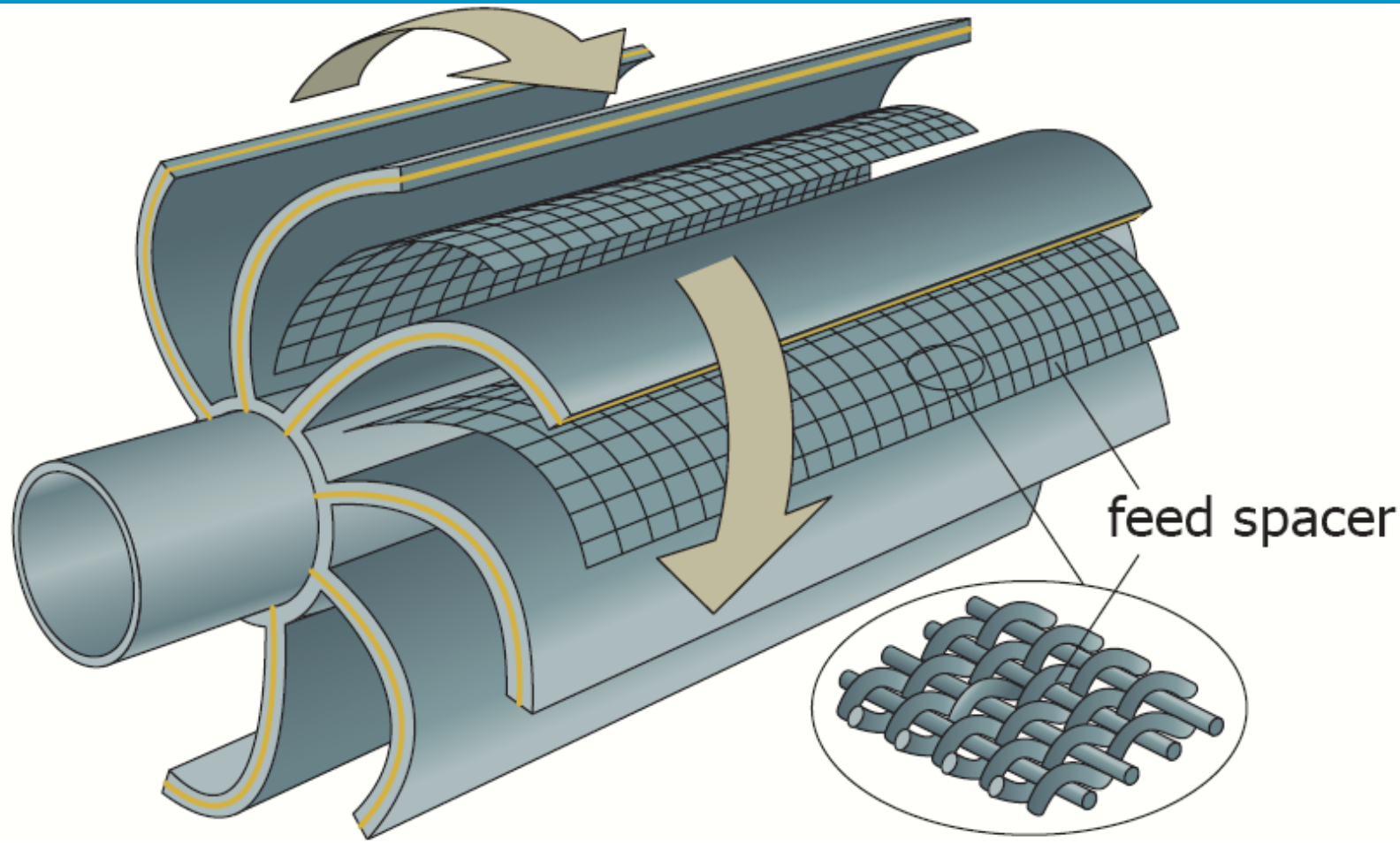




Modules


hyperfiltration element
membrane
RO-product
product spacer
glue seam

Modules



TU Delft

Contents

Applications RO

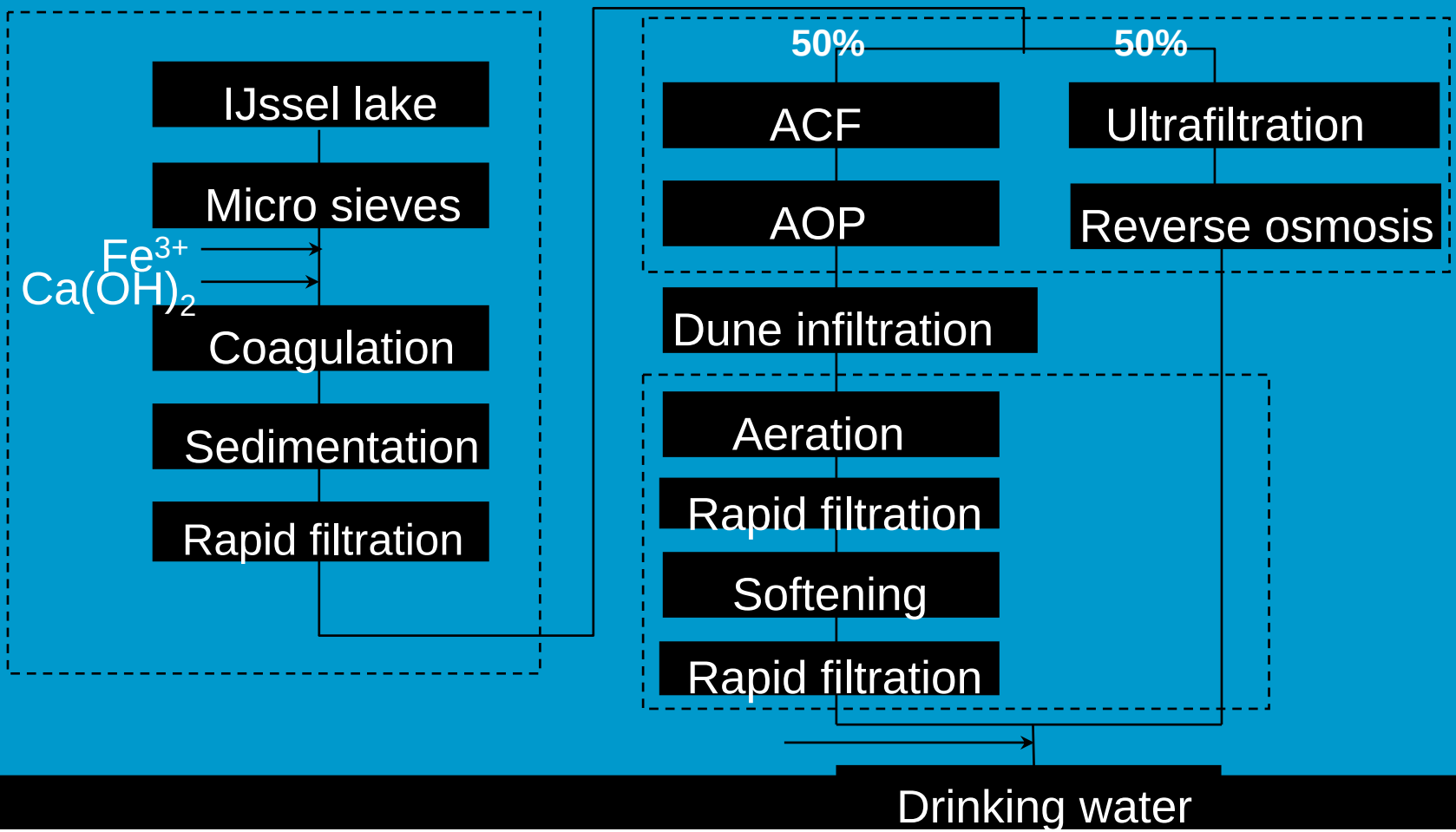
1. Desalinization of sea or brackish water
   - high costs: (1.0 euro /m^3 till 3.5 euro /m^3 sea water)
   - examples: Heineken
     Greenhouse agriculture
2. Split flow membrane filtration
   - costs: 50 euro cents/m^3 product
   - example: Na^+/Cl^- Andijk (PWN)

3. Direct treatment of surface water
   - removal of micro organisms, organic compounds, hardness and salts
   - examples:

TU Delft

Application RO

- Treatment Heemskerk (PWN)



TU Delft

Application RO

- Treatment Heemskerk (PWN)

TU Delft

Application RO

- Treatment Heemskerk (PWN)

TU Delft

Application RO

TU Delft

Performance NF/RO

Removal percentage [%]	NF	RO
Pesticides	> 90%	> 95%
DOC	> 90%	> 95%
Hardness (Ca^{2+}, Mg^{2+})	> 90%	> 99%
Salts (Na^{+}, Cl^{-}, NO_3^{-})	50 - 70%	> 90 %
Disinfection		
- bacteria, viruses	> 99.99%	> 99.99%
- Giardia, Cryptosporidium	> 99.99%	> 99.99%

TU Delft

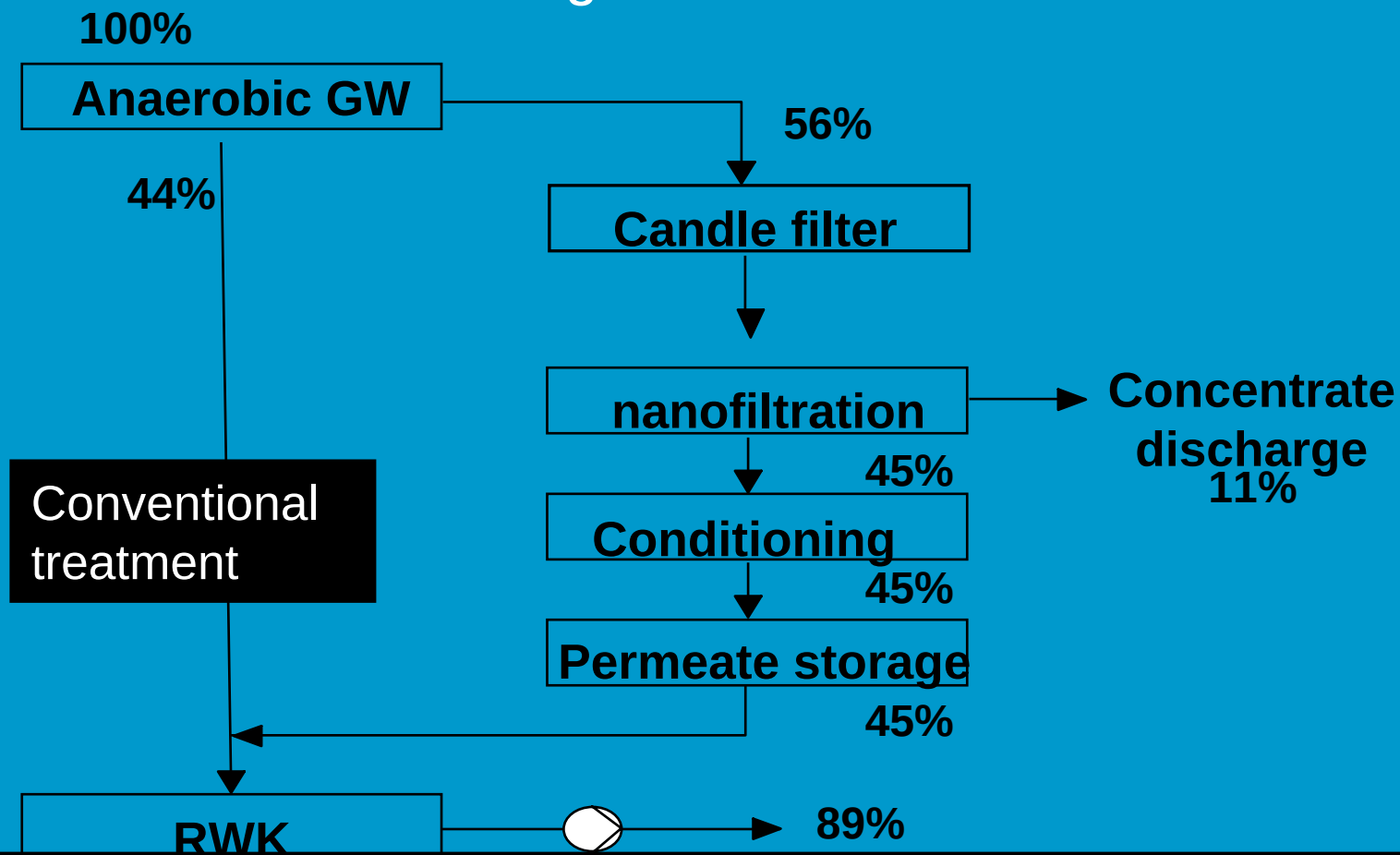
Application NF

1. Split flow membrane filtration for softening and removal of organic compounds
   - alternative for softening and activated carbon filtration
   - examples: colored ground water
     bank filtration water
     pretreatment for infiltration (IB)
   - costs: 35 euro cents/m^3 product

2. Direct treatment of surface water
   - removal of micro organisms, organic compounds and hardness

Application NF

- Treatment anaerobic groundwater

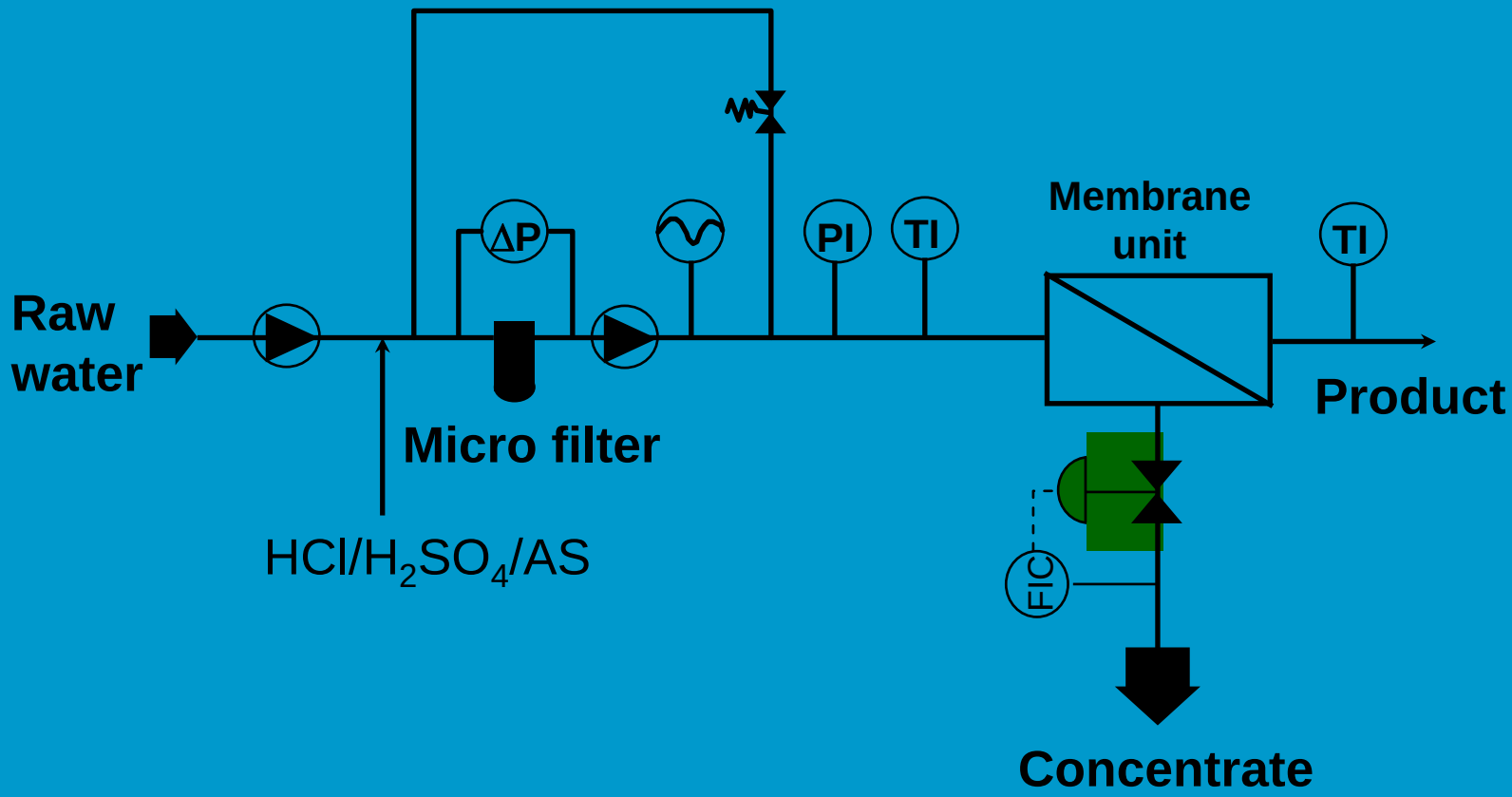


TU Delft

Contents

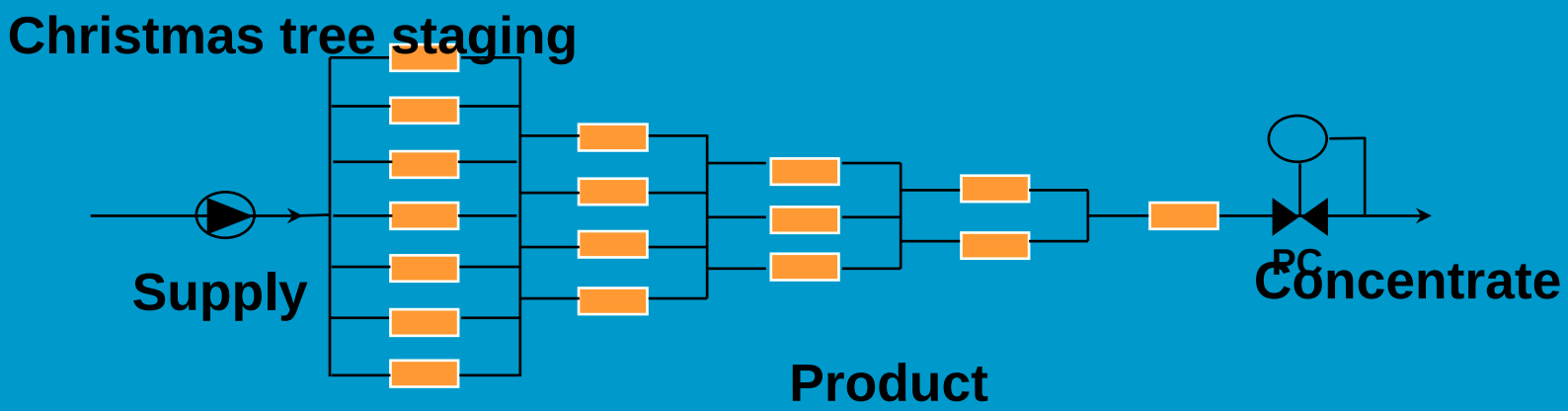
1. Introduction
2. Theory
3. Membrane modules
4. Applications
5. Design
6. Fouling control

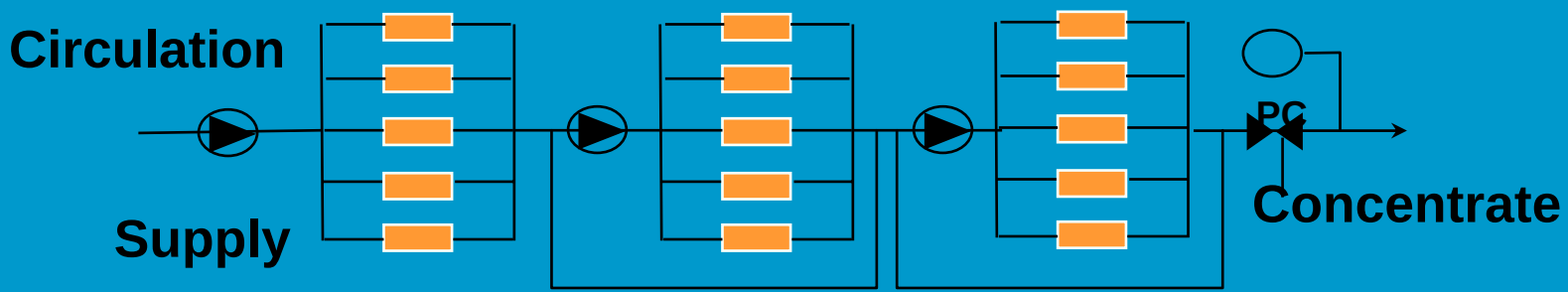
Design


Raw water
ΔP
PI
TI
Membrane unit
TI
Product
Micro filter
HCl/H2SO4/AS
FIC
Concentrate

Design

- Membrane staging



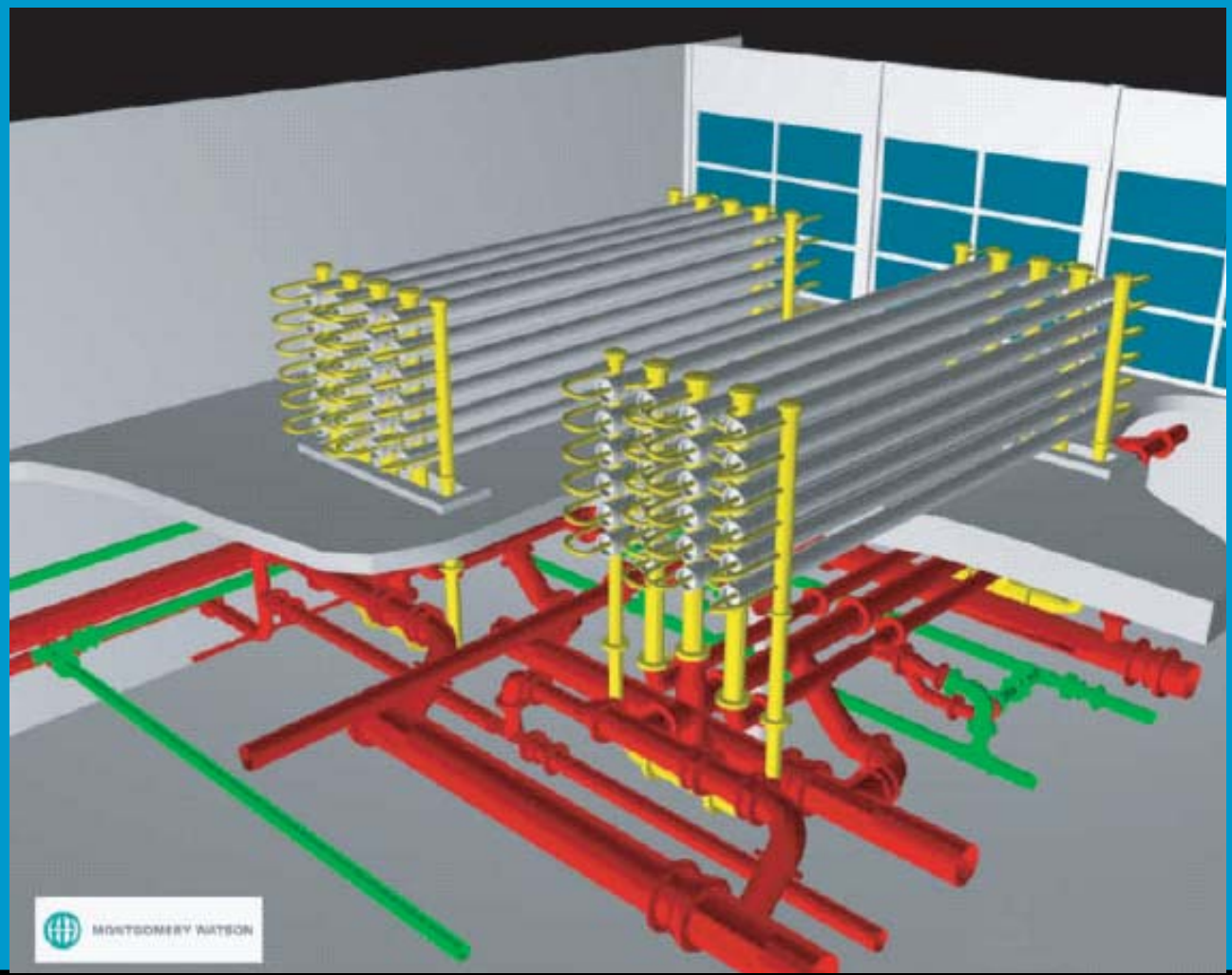


Design

- Staging 22-11-5

TU Delft

Design



TU Delft

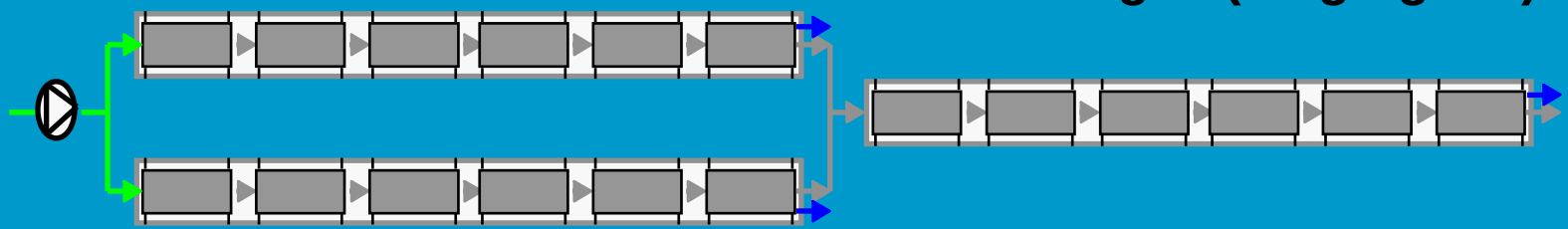
Design

- Standard design

standard design:

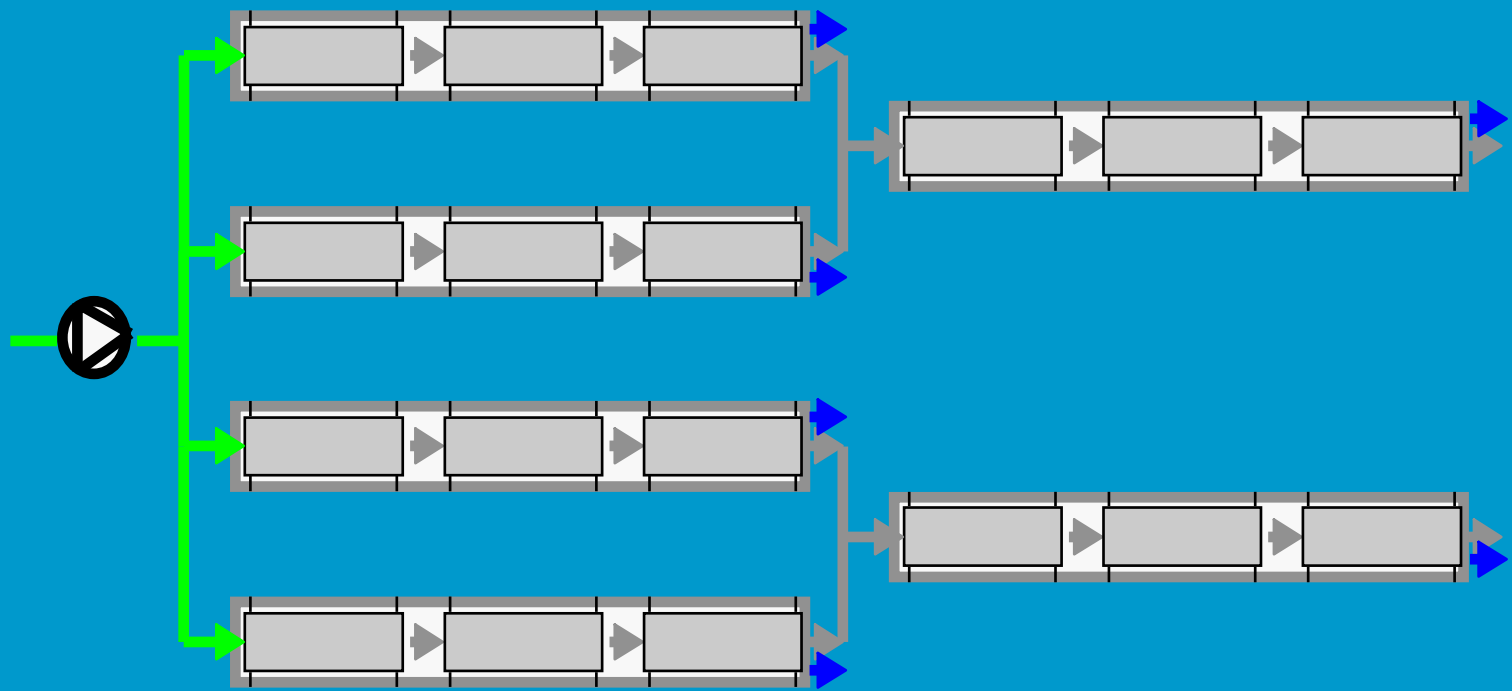
6 elements/vessel

2 stages (staging 2:1)



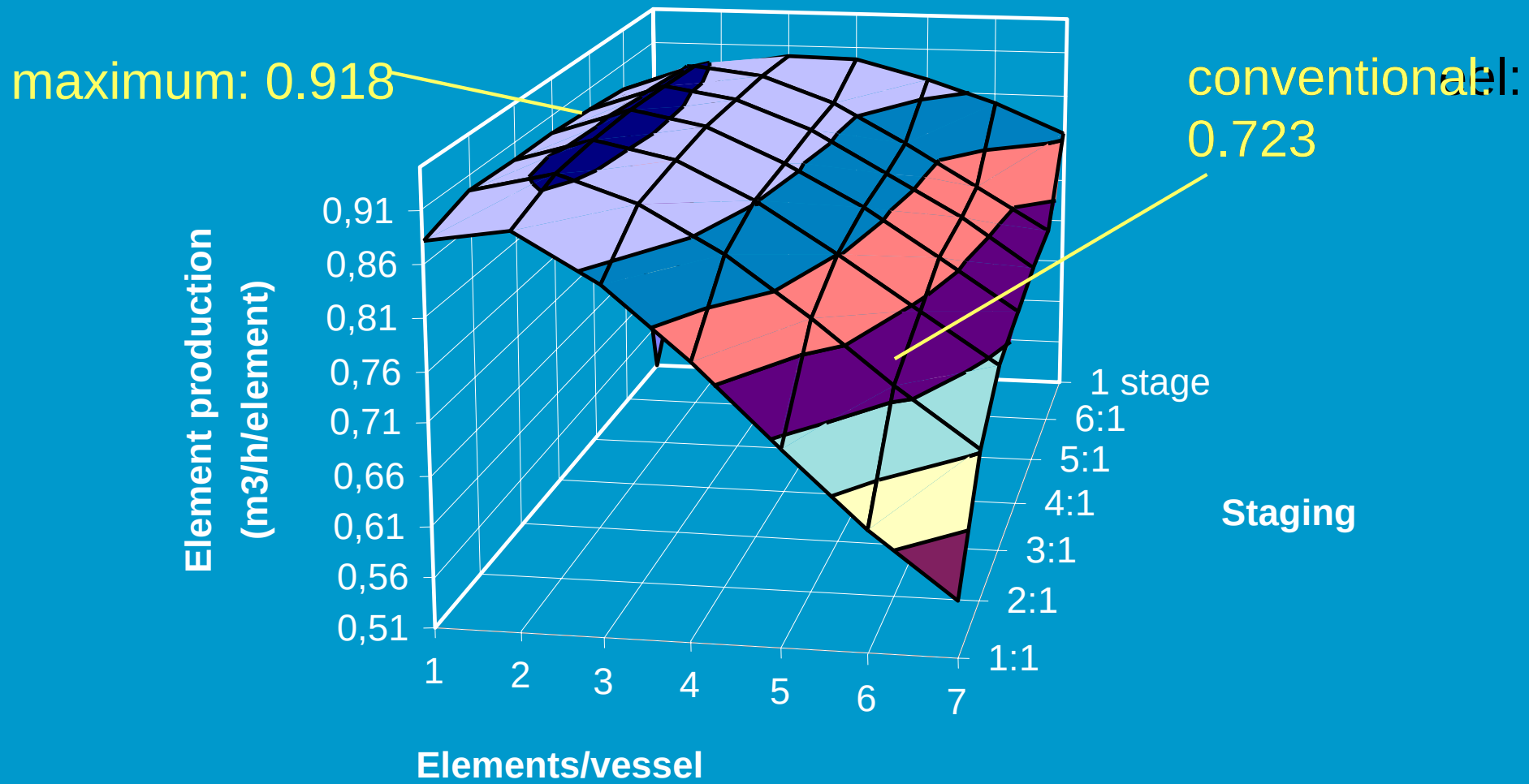
Design

- Recent research

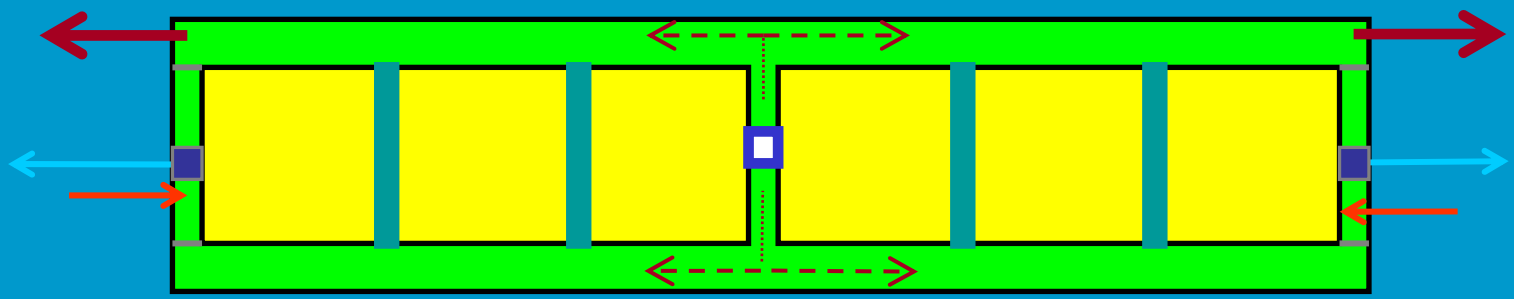


Design

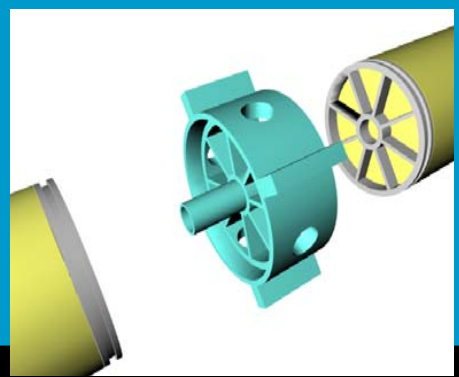
- Production per element



Design Optiflux®



Addapted pressure vessel with special connector



TU Delft

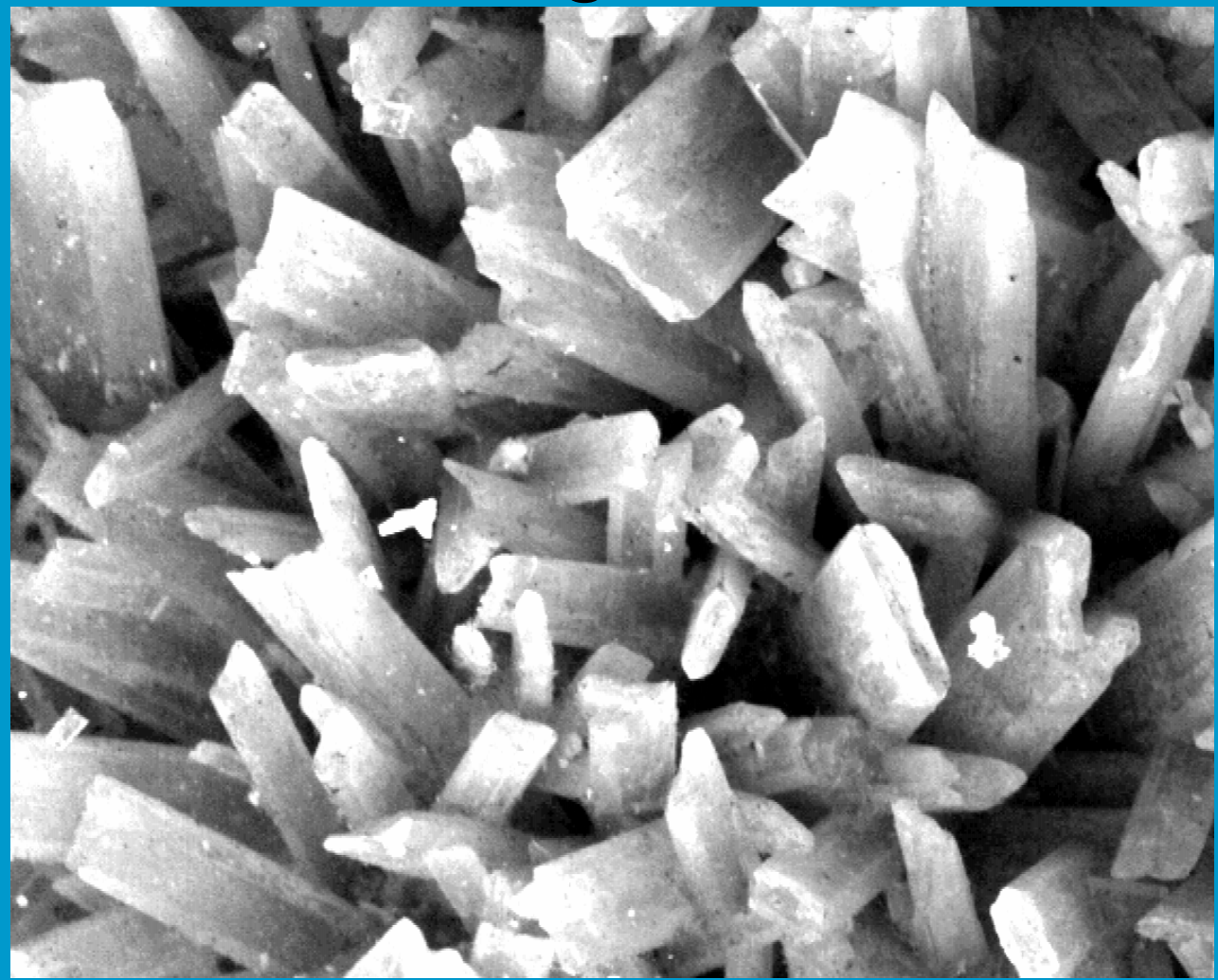
Contents

Fouling control

	Pre-treatment	Optimali-sation process conditions	cleaning
Particles	++	-	+
Scaling	-	++	+/-
Biofouling	++	+/-	?
Organic fouling	+	++	+

TU Delft

Fouling control: scaling



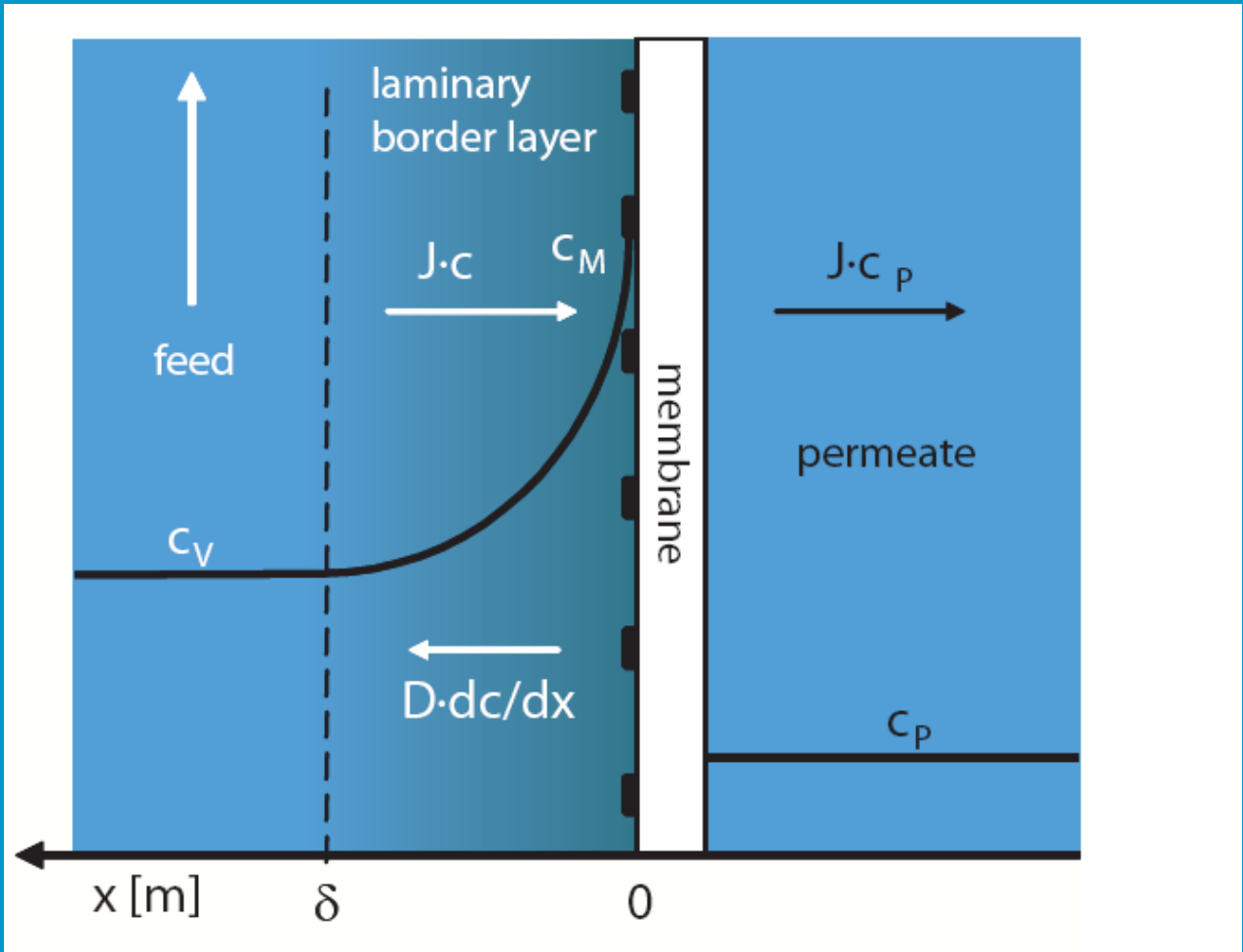
TU Delft

Fouling control: scaling

- Process design:
  - module design
  - staging
- operational parameters:
  - cross flow velocity
  - flux
  - recovery
  - acid or anti-scalant

TU Delft

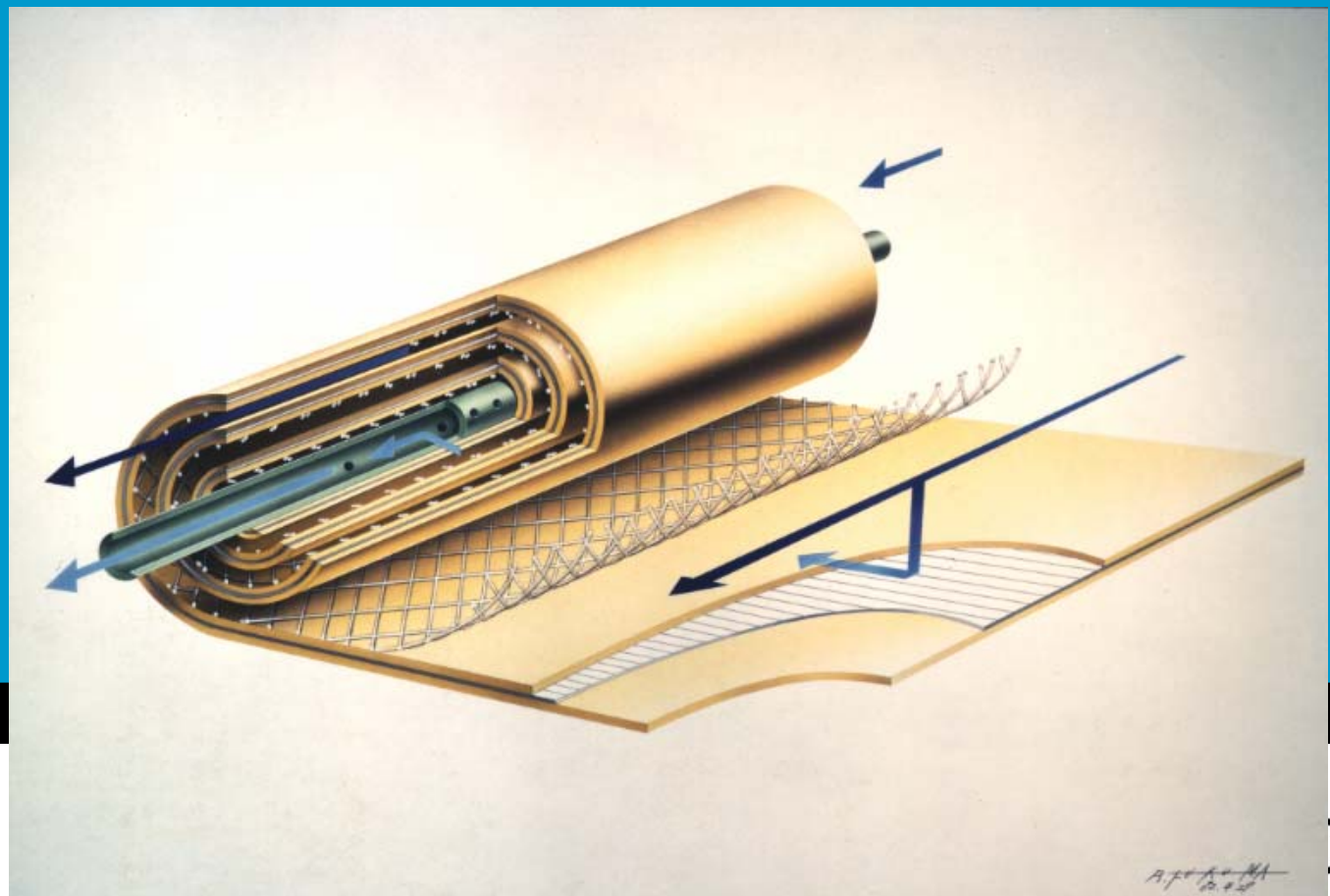
Fouling control: scaling



TU Delft

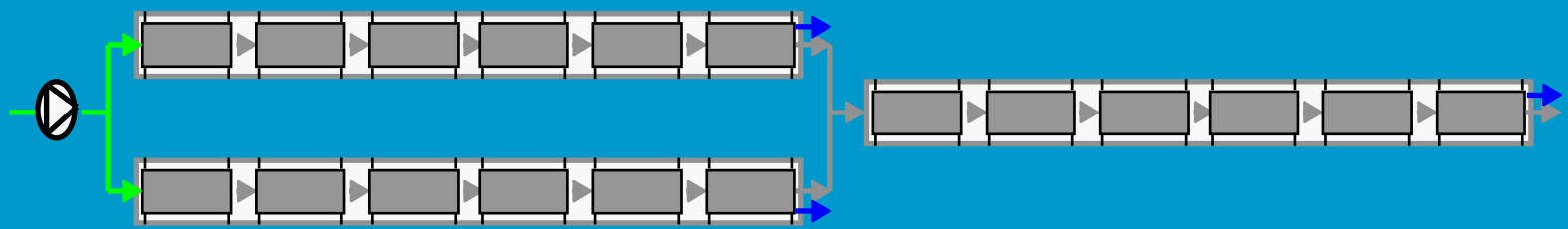
Fouling control: scaling

- Spiral wound membranes



Fouling control: scaling

- Staging: increasing cross-flow velocity in second stage



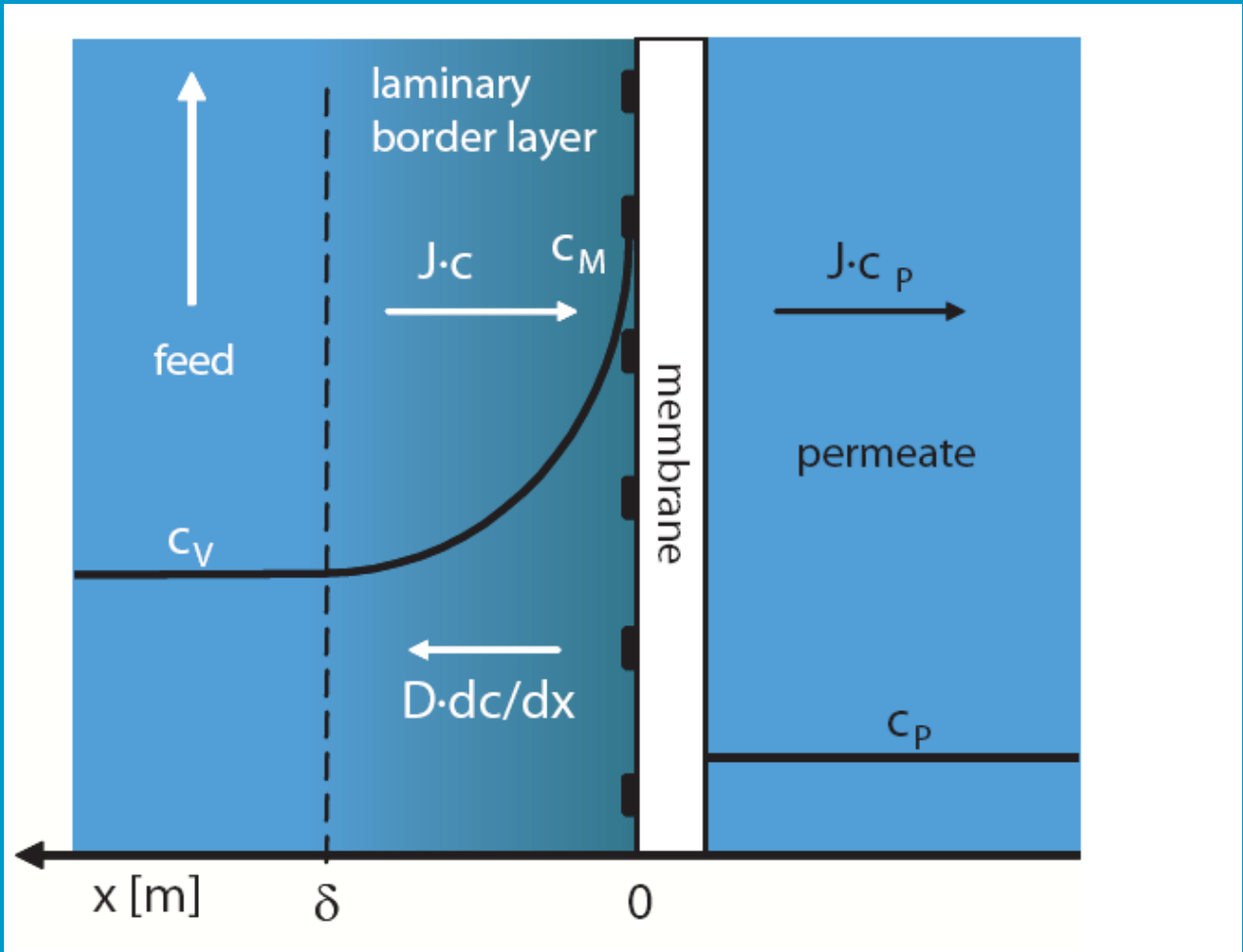
TU Delft

Fouling control: scaling

- Process design:
  - module design
  - staging
- operational parameters:
  - cross flow velocity
  - flux
  - recovery
  - acid or anti-scalant

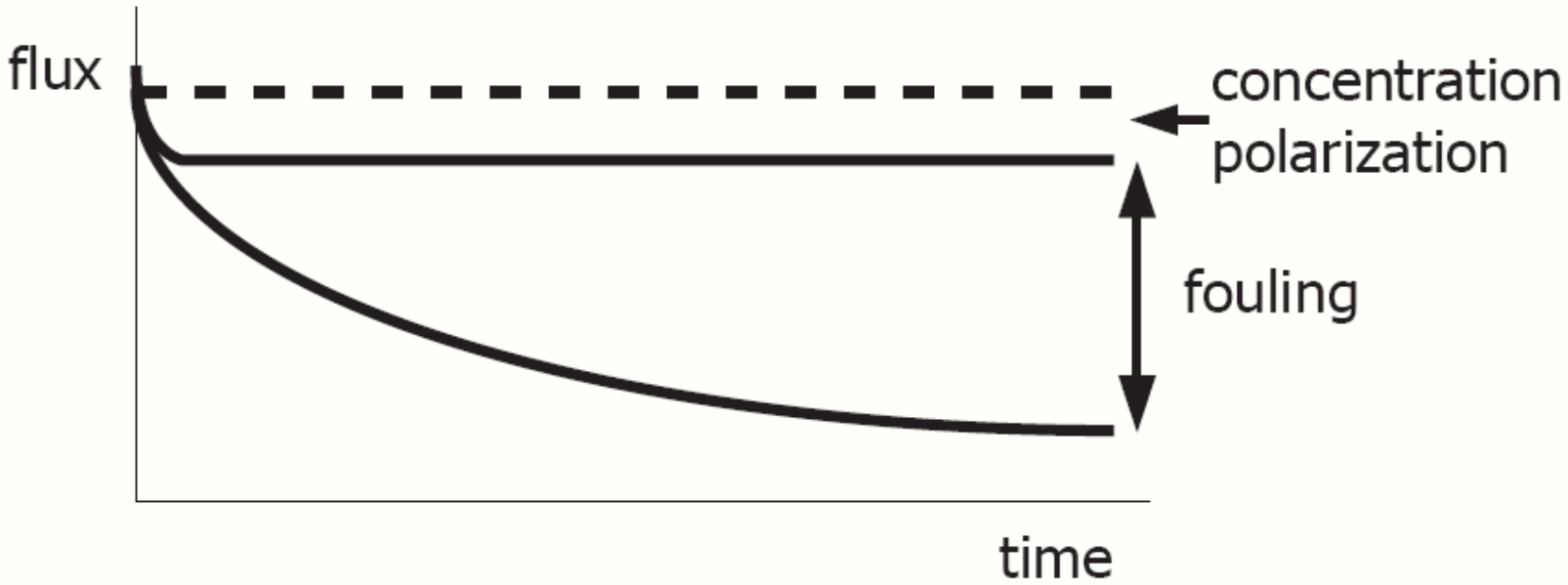
TU Delft

Fouling control: scaling



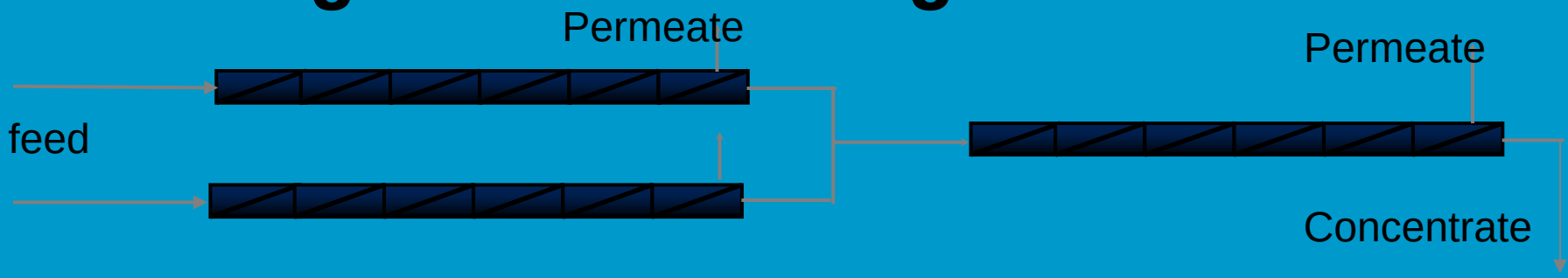
TU Delft

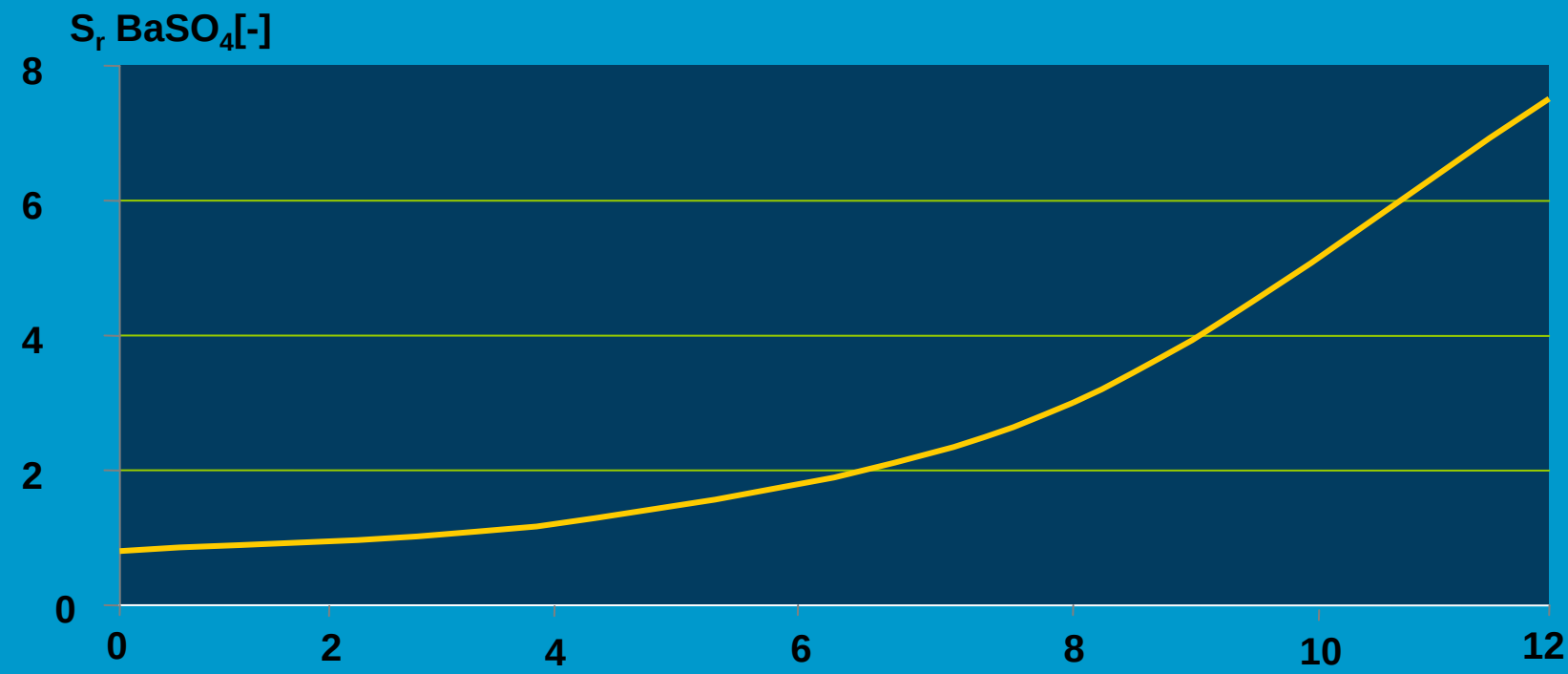
Fouling control: scaling



TU Delft

Fouling control: scaling





TU Delft

Fouling control: scaling

- Process design:
  - module design
  - staging
- operational parameters:
  - cross flow velocity
  - flux
  - recovery
  - acid or anti-scalant

TU Delft