Municipal wastewater treatment by microsieving, microfiltration and forward osmosis

Concepts and potentials

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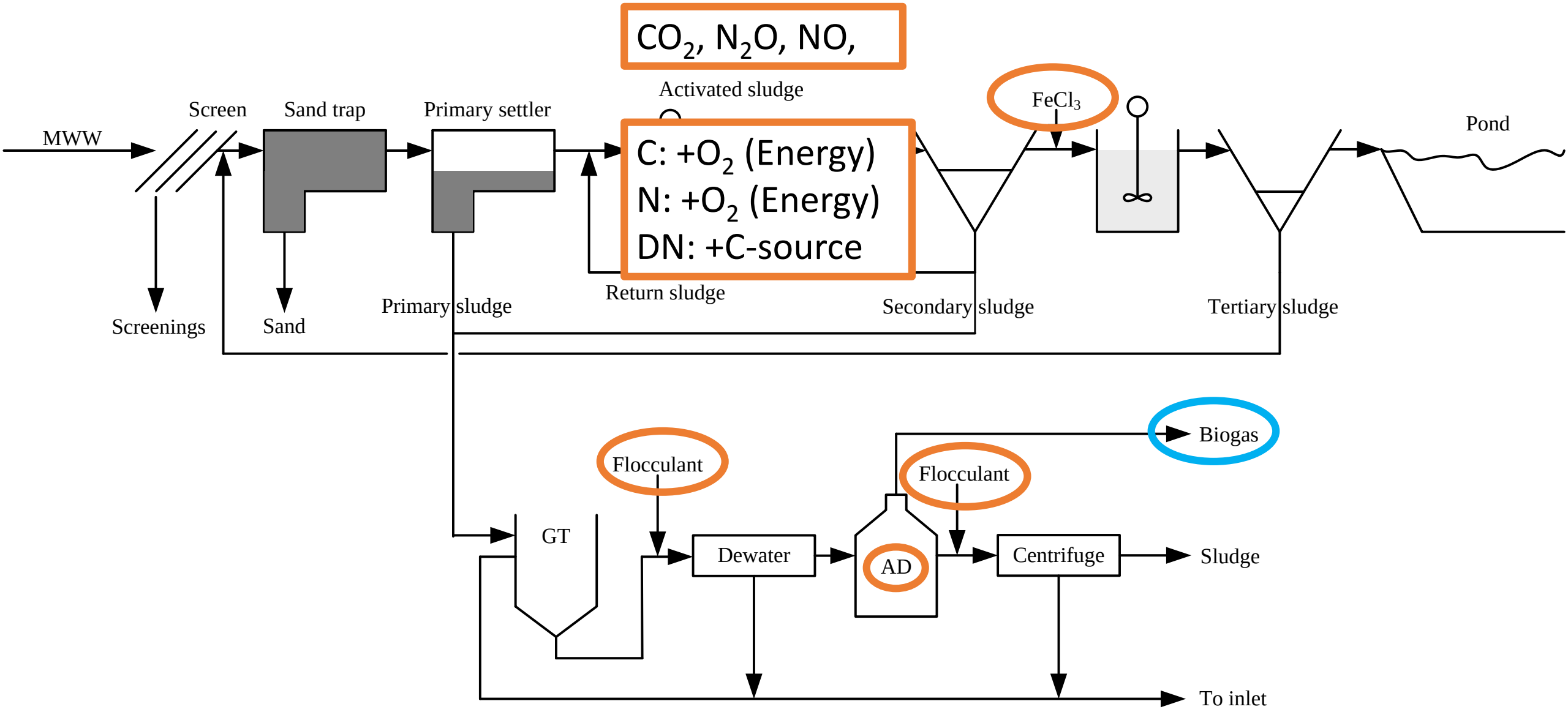
Introduction

Municipal wastewater treatment

- Urbanisation: 50% already live in cities→ 2/3 in 2050
- Increase in wastewater which needs treatment to protect nature and human from adverse effects
- Wastewater is treated at wastewater treatment plants requiring energy and space
- In Sweden: 95% of sewage is treated by 411 wastewater treatment plants. 50% of these WWTPs are in the size of 2 000 – 10 000 PE.
- In the future space may become limiting and more energy is required to accommodate future wastewater loads
- This study investigates the feasibility to treat municipal wastewater without involving the biological treatment step in the main stream process.


Va Syd Källby
Avlopps- & Reningsverk
Google


CO_2, N_2O, NO,
Activated sludge
C: +O_2 (Energy)
N: +O_2 (Energy)
DN: +C-source
MWW
Screen
Sand trap
Primary settler
$FeCl_3$
Pond
Screenings
Sand
Primary sludge
Return sludge
Secondary sludge
Tertiary sludge
Biogas
Flocculant
Flocculant
GT
Dewater
AD
Centrifuge
Sludge
To inlet

Aims and objectives

‘Provide proof-of-concept for treating municipal wastewater without biological treatment step to use different separation techniques.’

Specific objectives:

- To test different treatment concepts
- To operate microfiltration without backflushing
- To investigate the effects of coagulation and flocculation
- To identify and evaluate suitable treatment configuration(s)

Background

Municipal wastewater

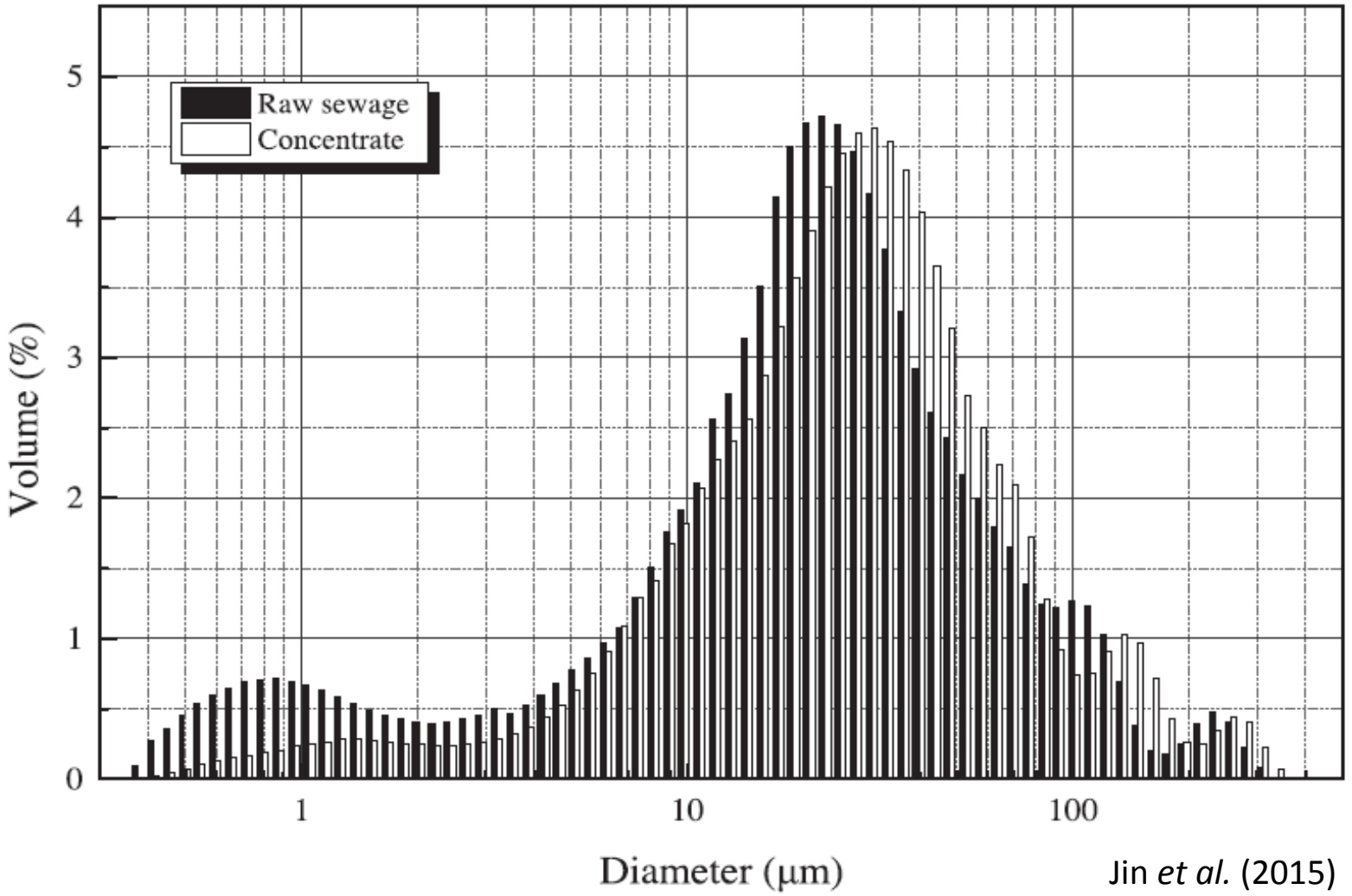
Direct membrane filtration

Municipal wastewater

Particles

Soluble components

Water (H_2O)

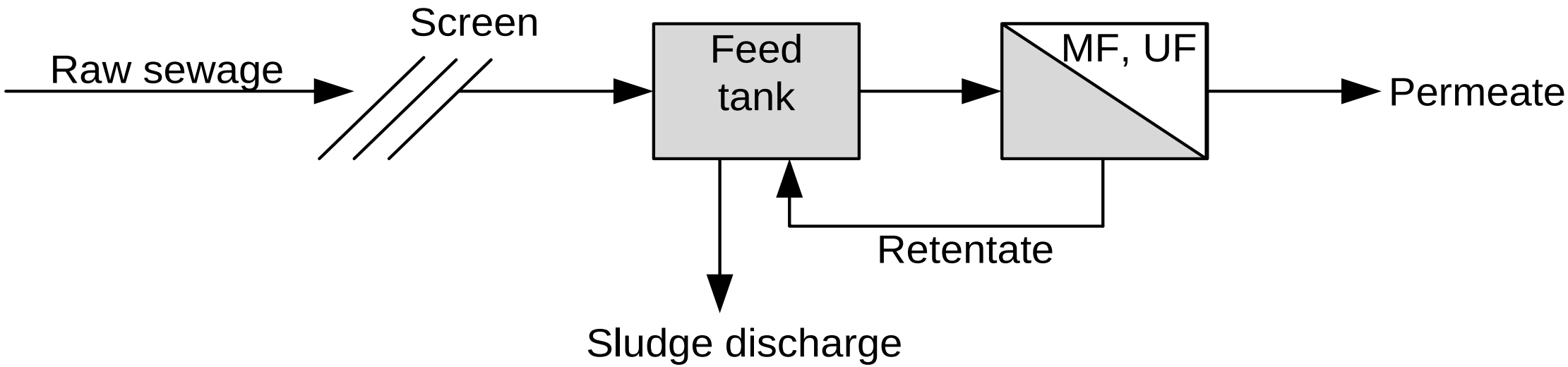


Jin *et al.* (2015)

Direct membrane filtration

Background

Direct membrane filtration (DMF)



- Part of the COD fraction consists of particulate organic matter which can be separated with membrane(s) and utilised for biogas production in one step

Wastewater

Microsieve

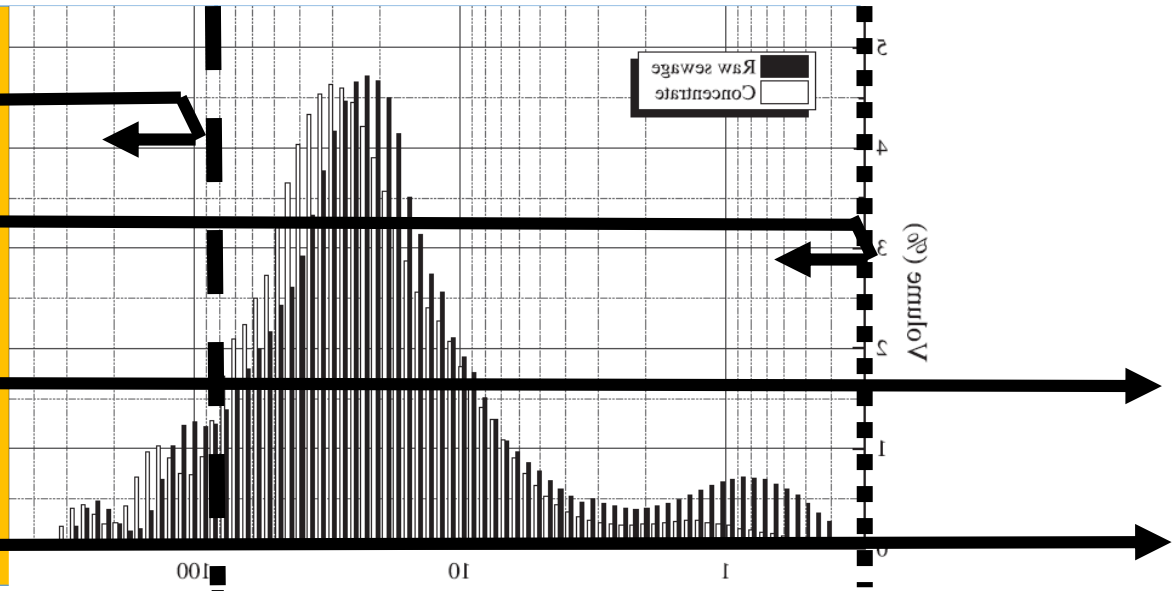
Microfiltration

Particles (>100 µm)

Particles (>0.2 µm)

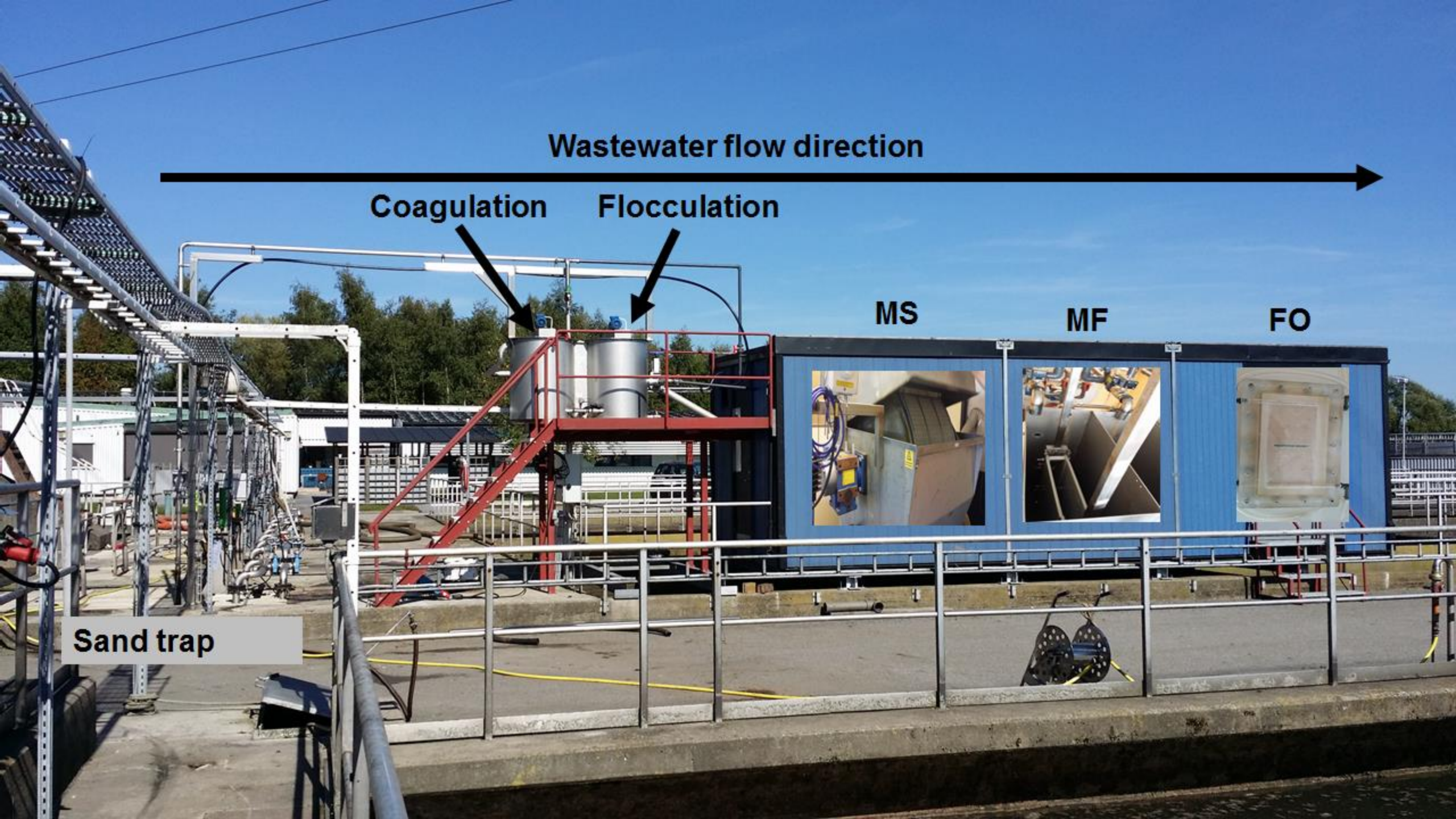
Soluble components

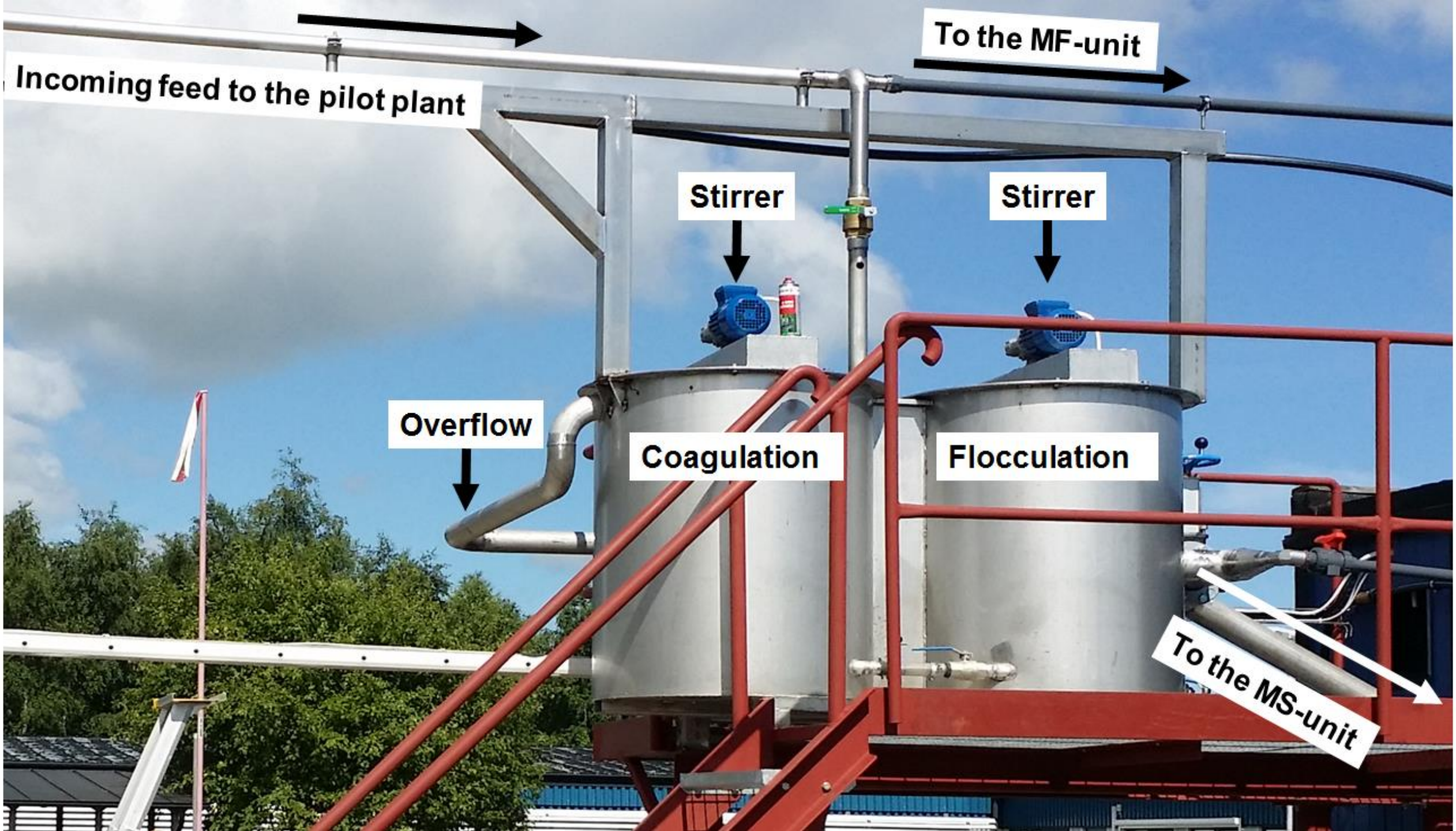
Water (H_2O)

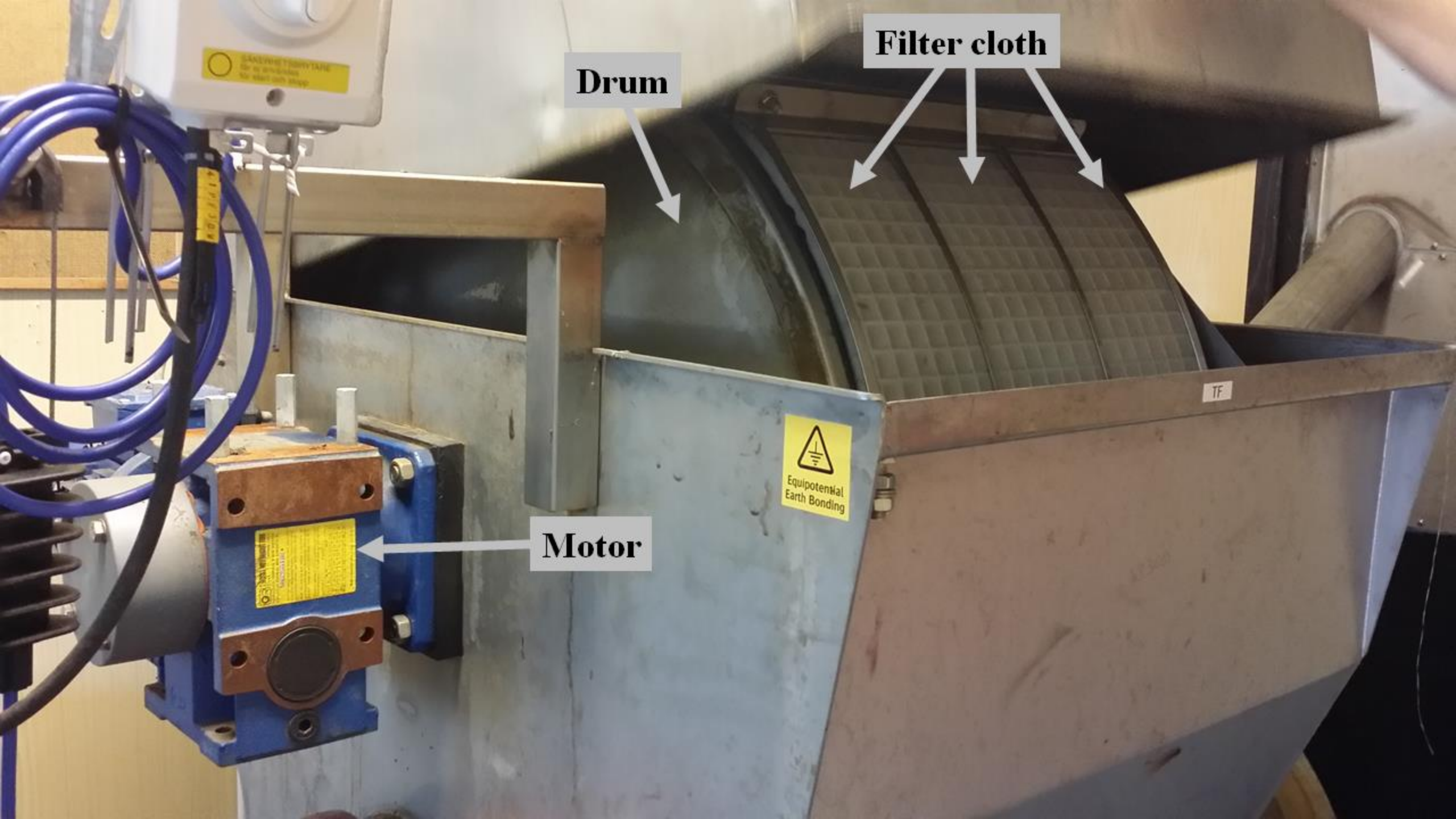


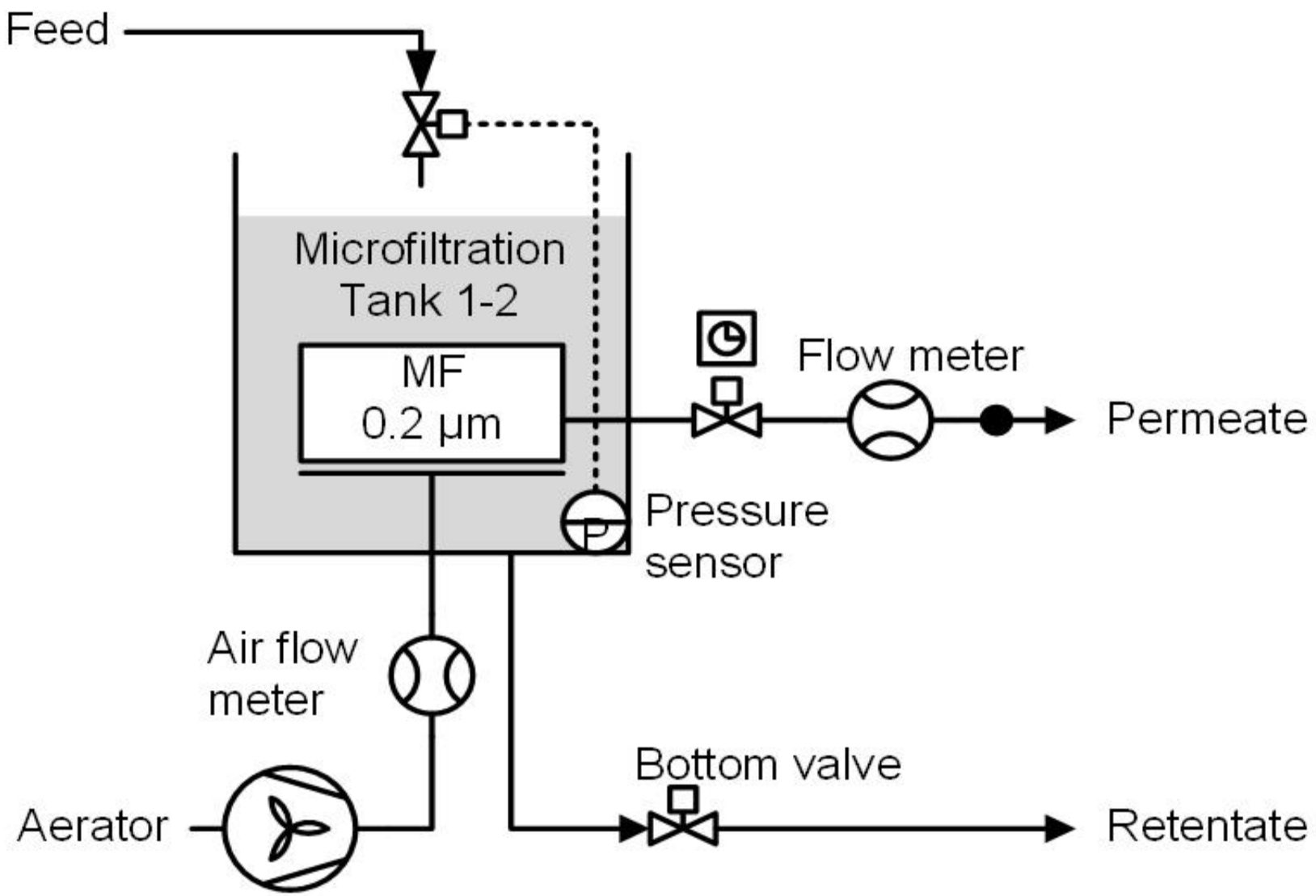
Pilot plant and bench scale

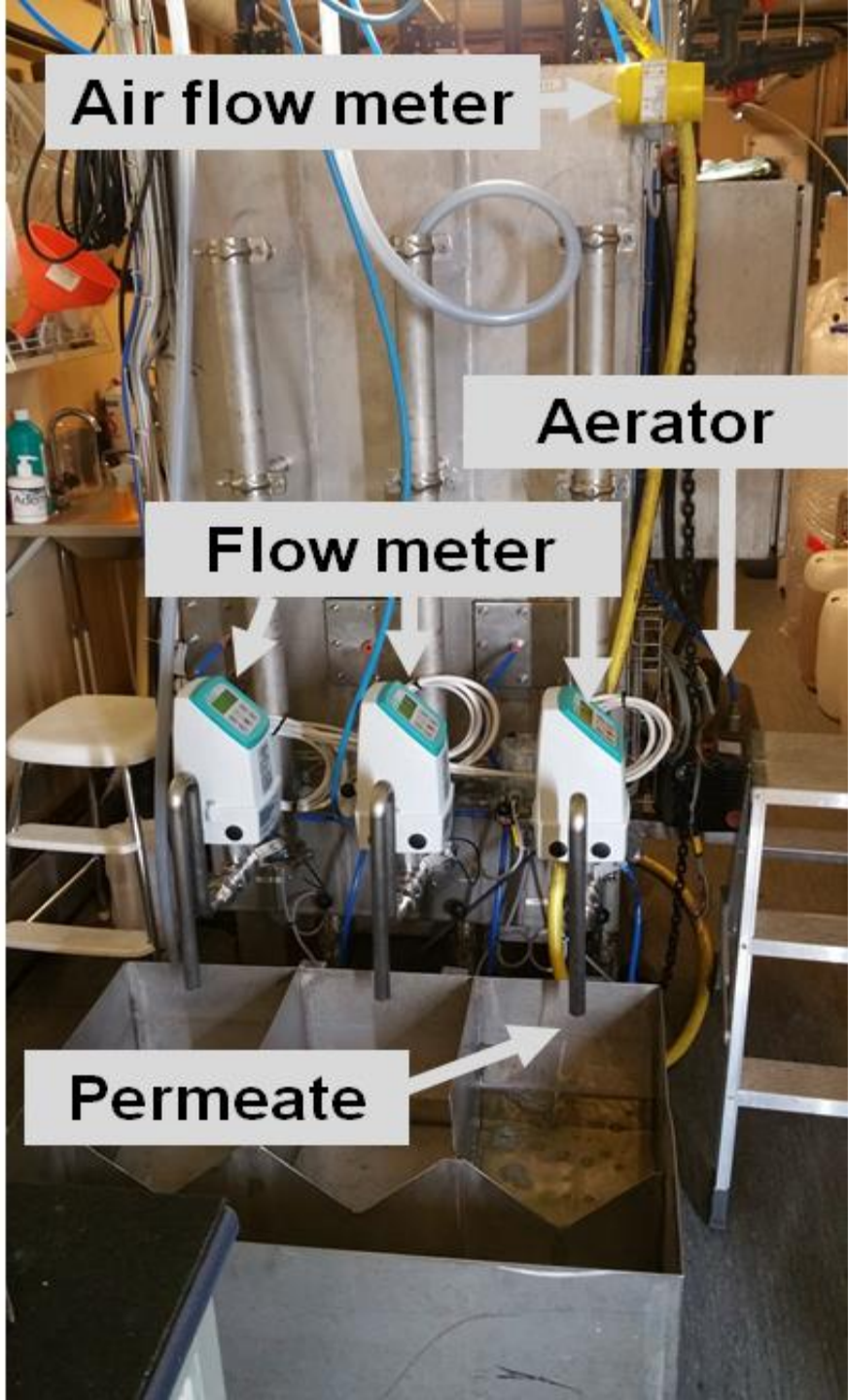
At the Källby wastewater treatment plant


Wastewater flow direction
Coagulation
Flocculation
MS
MF
FO
Sand trap


Incoming feed to the pilot plant
To the MF-unit
Stirrer
Stirrer
Overflow
Coagulation
Flocculation
To the MS-unit

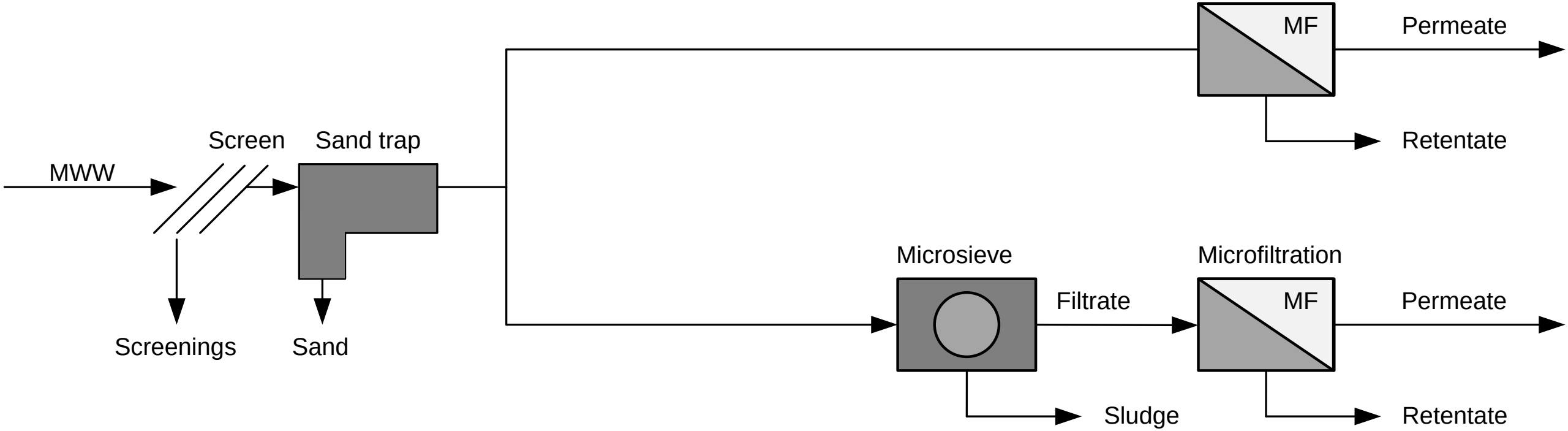

Filter cloth
Drum
Motor
Equipotential
Earth Bonding
TF


Feed
Microfiltration
Tank 1-2
MF
0.2 µm
Flow meter
Permeate
Pressure
sensor
Air flow
meter
Bottom valve
Aerator
Retentate

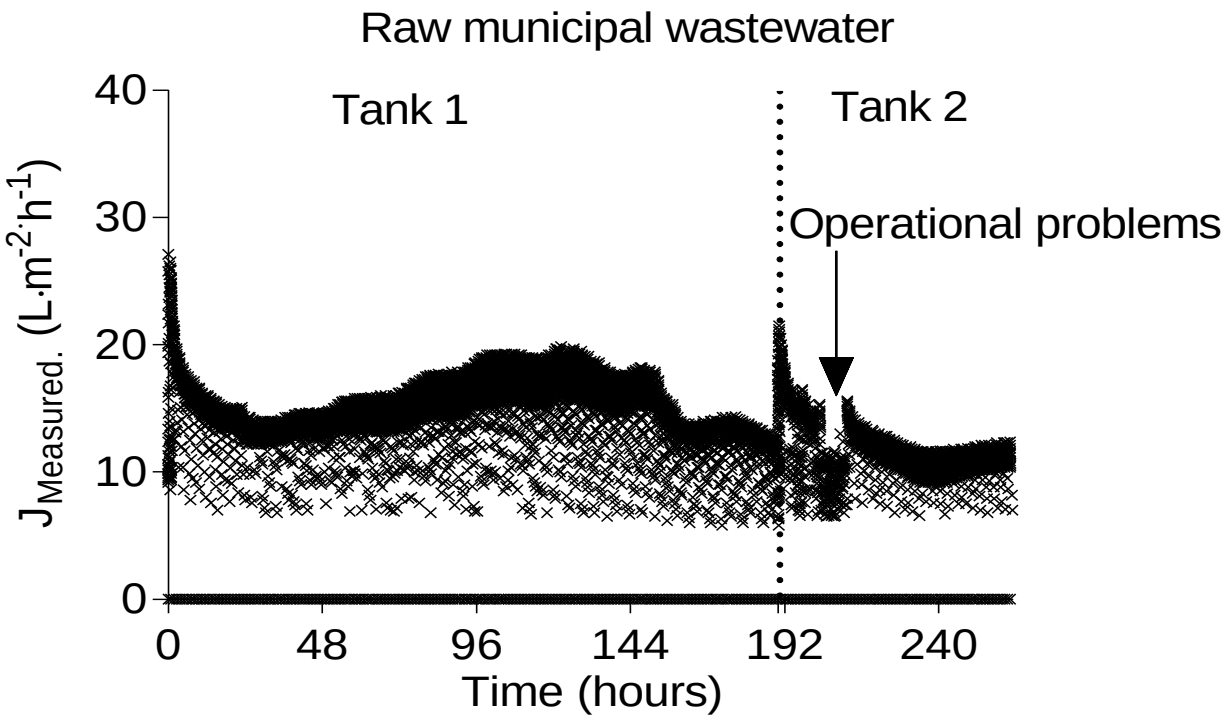

Air flow meter
Aerator
Flow meter
Permeate

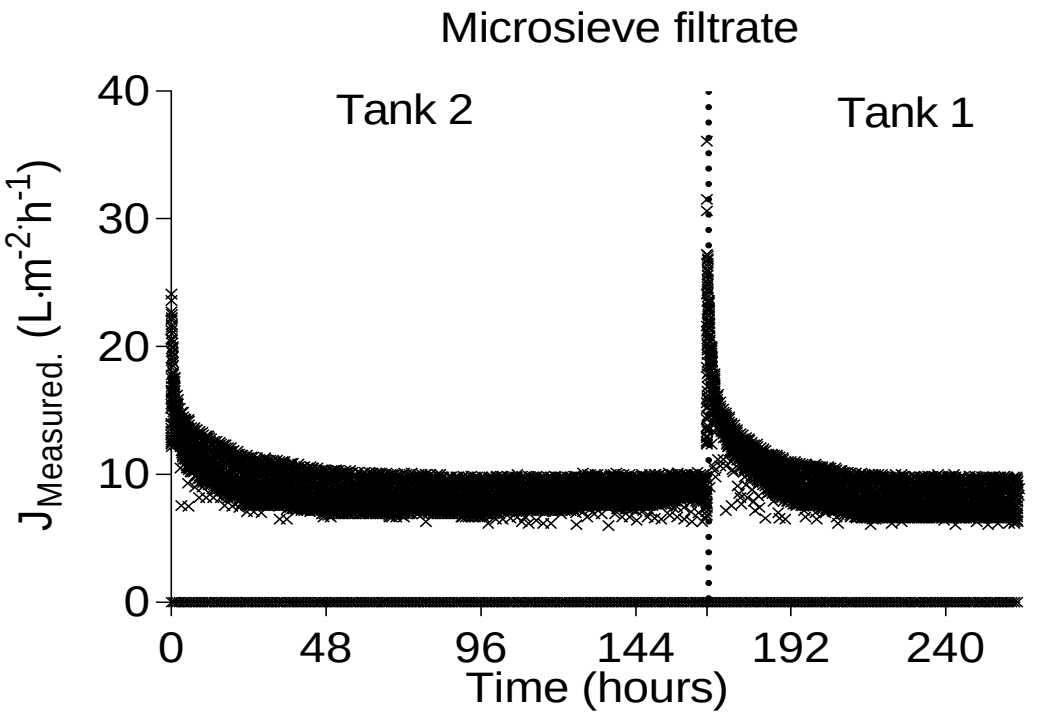
Conducted experiments and Results

Mechanical pre-treatment

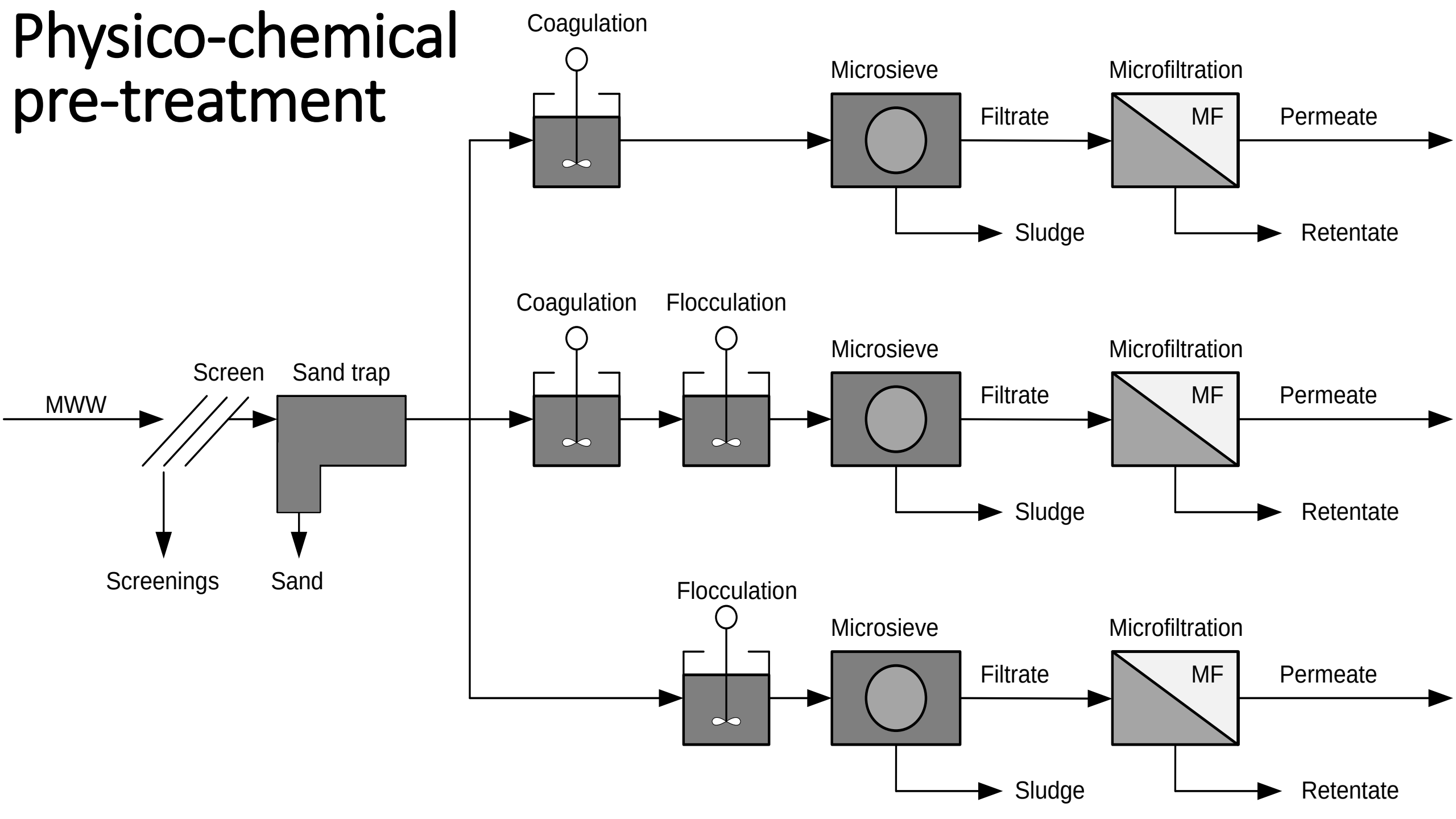


Mechanical pre-treatment





Physico-chemical pre-treatment



Results

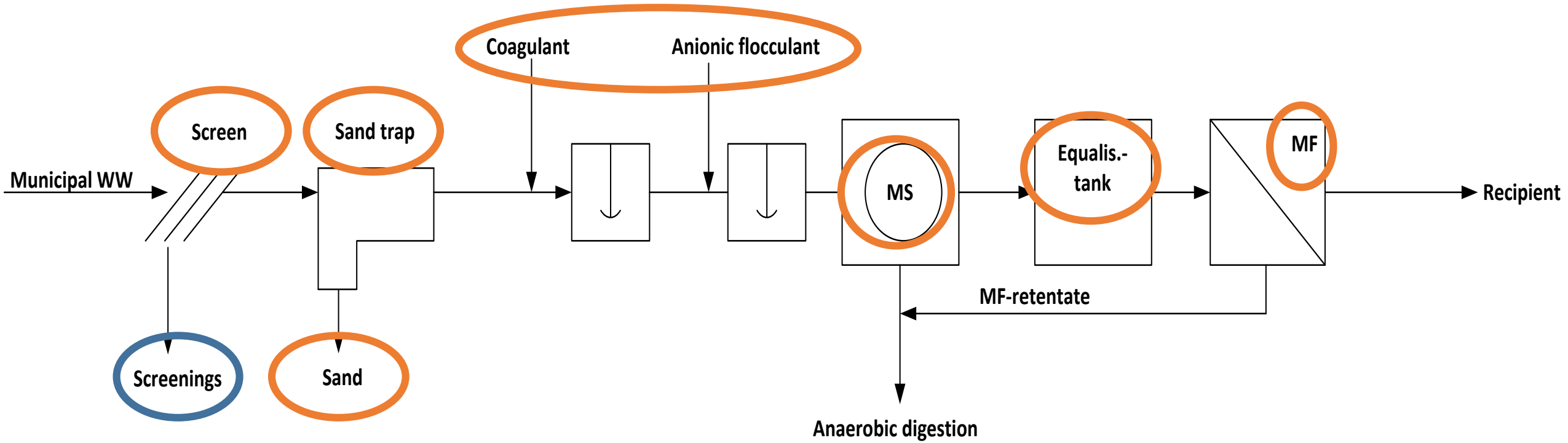
	BOD_7 ($mg \cdot L^{-1}$)	SS ($mg \cdot L^{-1}$)	CODt ($mg \cdot L^{-1}$)	TNt ($mg \cdot L^{-1}$)	NH_4-N ($mg \cdot L^{-1}$)	TPt ($mg \cdot L^{-1}$)	J_w ($L \cdot m^{-2} \cdot h^{-1}$) ($L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$)
Mechanical	17±5	0±0	73±27	37±10	32±5	2.4±0.6	2.6 87
Coagulation	11±2	0±0	41±11	42±4	41±4	0.2±0.3	6.2 207
Flocculation(+)	13±2	0±0	48±6	36±6	36±6	2.4±1	2.6 87
Coagulation + anionic polymer	16±13	0±0	41±26	34±10	34±11	<0.03	6.1 203
Coagulation + cationic polymer	13±2	0±0	44±10	30±6	30±6	<0.03	2.9 97

Discharge limit for WWTPs ≤ 10 000 p.e.: BOD_7: 15 mg/L, Tot-P: 0.5 mg/L

Concept evaluations

Selected concepts and evaluated Results

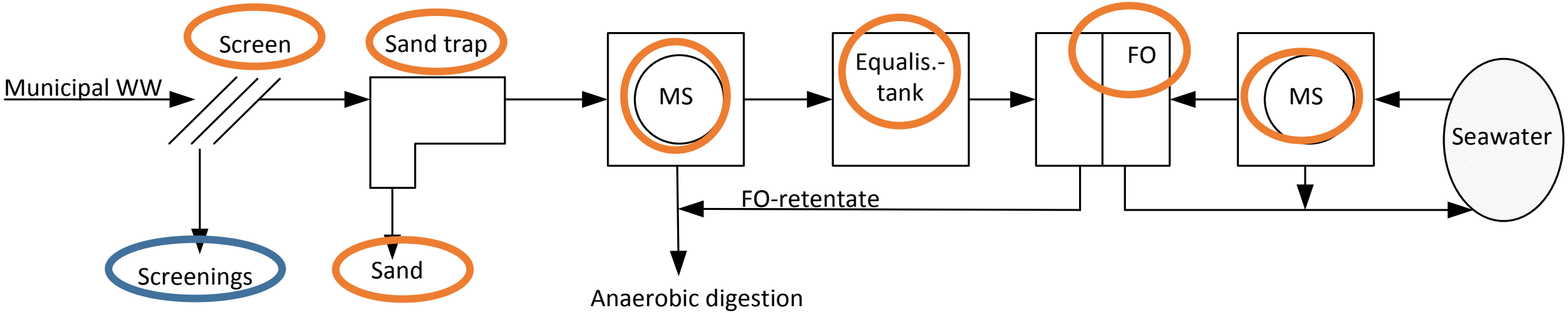
Direct membrane filtration



Energy-/electricity consuming

Energy-/electricity producing

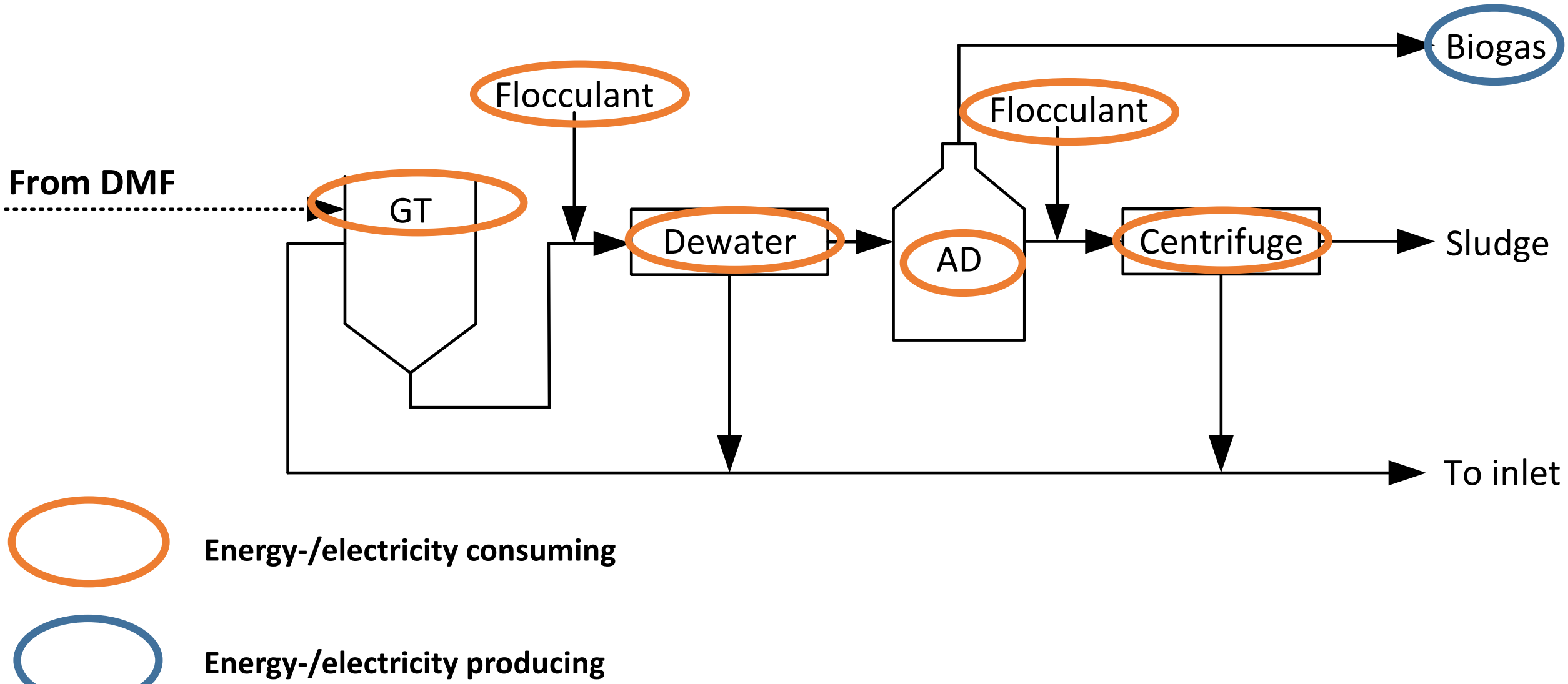
Direct forward osmosis



Energy-/electricity consuming

Energy-/electricity producing

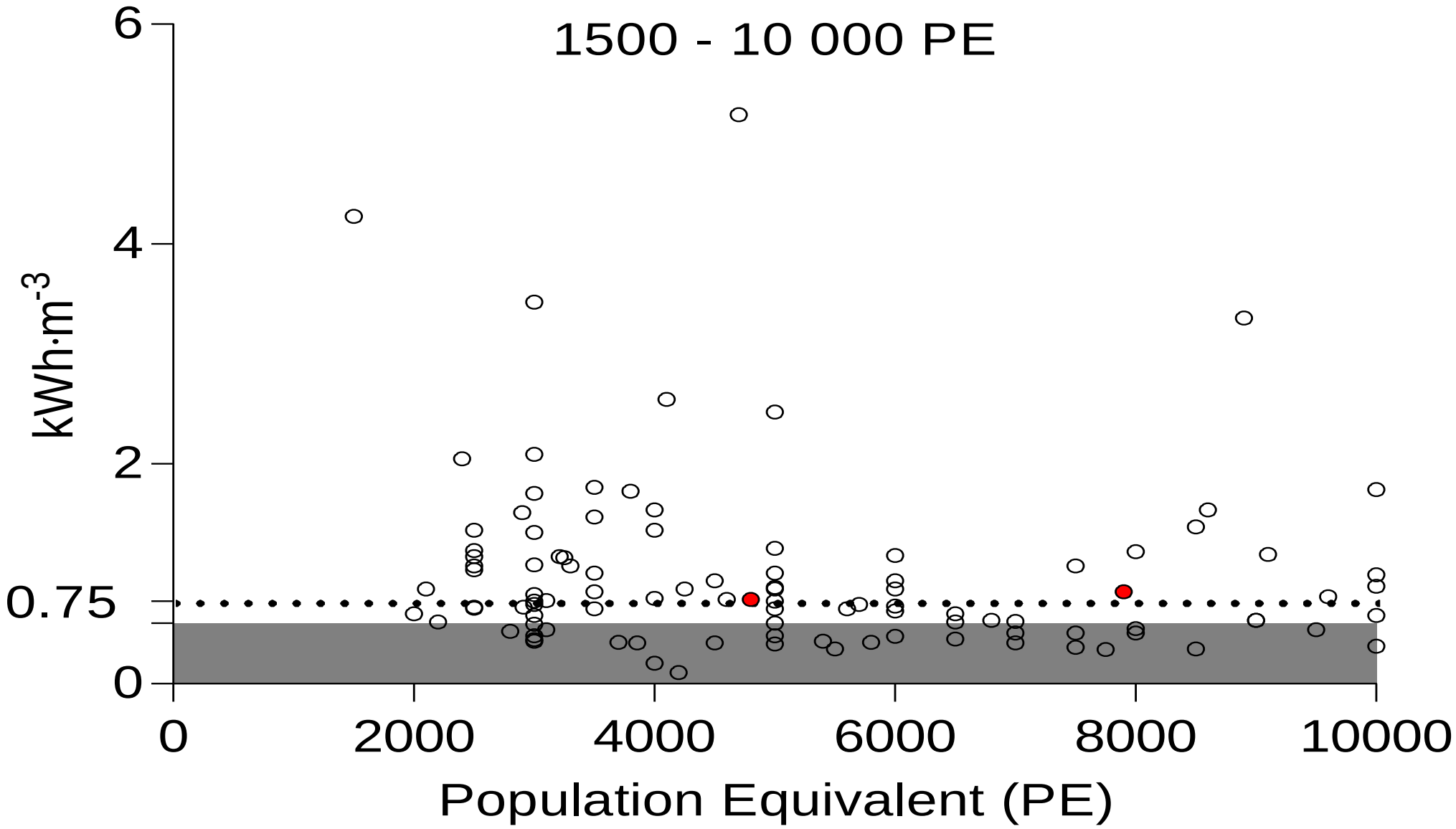
Anaerobic digestion



Specific electricity, energy and area demand

Wastewater treatment plant	Size	Specific electricity consumption	Specific area demand
	PE	$kWh_{el} \cdot m^{-3}$	$m^2 \cdot PE^{-1}$
Sjölunda	370 000	0.42	0.107
Källby	100 000	0.41	0.155
Klagshamn	60 000	0.45	0.132
Direct membrane filtration	10 000	0.55	0.046
Södra Sandby	7 900	0.84	0.228
Veberöd	4 800	0.77	0.190

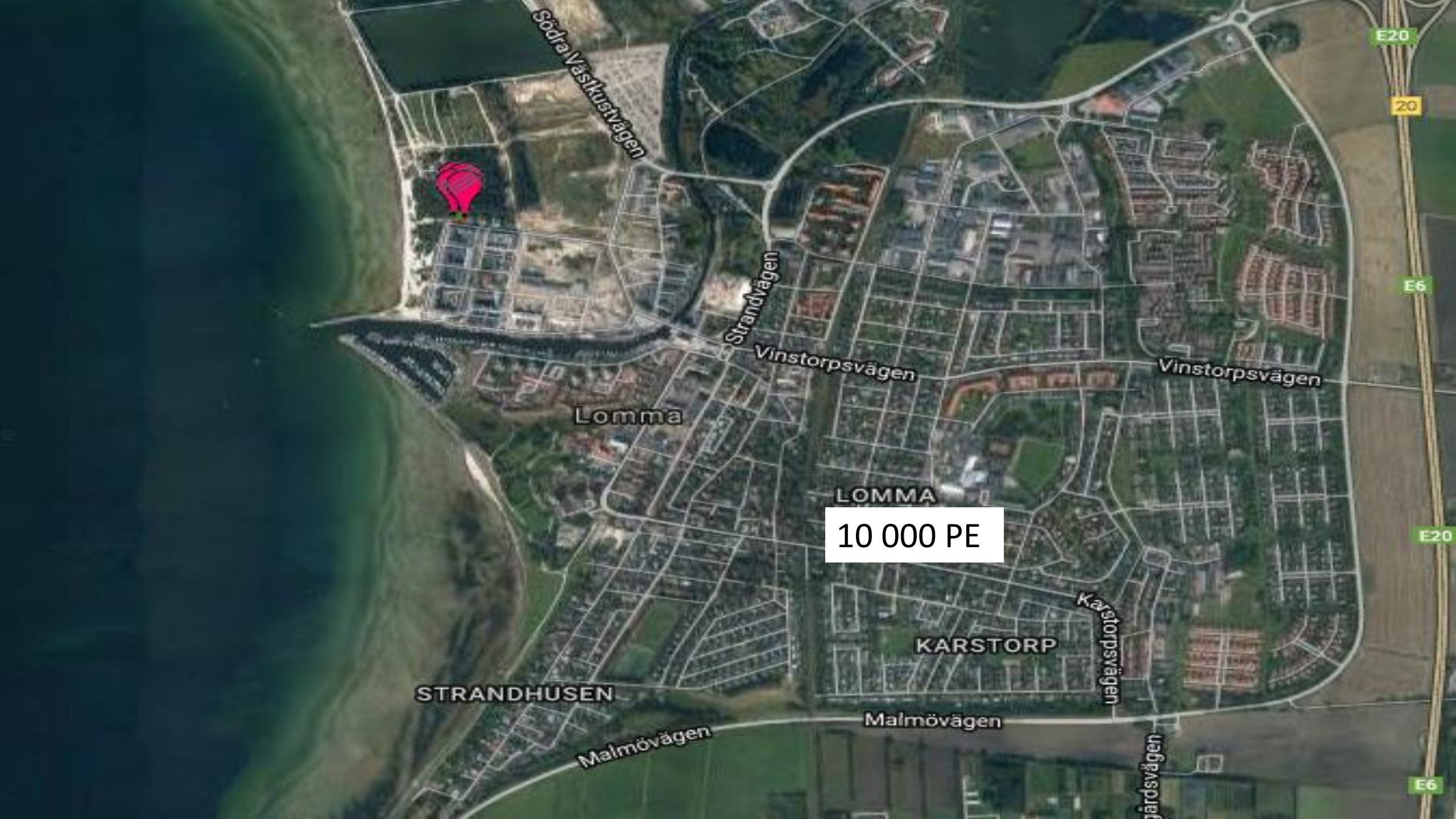
Specific electricity consumption



Net electricity and energy outcome of the DMF concept

	Specific electricity net surplus		Specific heat net surplus	
	$kWh_{el} \cdot PE^{-1} \cdot year^{-1}$	$Wh_{el} \cdot m^{-3}$	$kWh \cdot PE^{-1} \cdot year^{-1}$	$kWh \cdot m^{-3}$
Direct membrane filtration (Coagulation, flocculation)	1	14	43	0.6

Specific area demand


Södra Västkustvägen
Strandvägen
Vinstorpsvägen
Vinstorpsvägen
Lomma
LOMMA
10 000 PE
Karstorpsvägen
KARSTORP
STRANDHUSEN
Malmövägen
Malmövägen
E20
20
E6
E20
E6


Satellit
Källby WWTP
1550 m²
DMF
551 m²
Sjögatan
Sjögatan
Sjögatan
Sjögatan
Sjögatan
Strandpromenaden
Strandpromenaden
Kryssgränd
Kryssgränd
Lövartsgränd
Google

Conclusions

‘The Swedish discharge demands for small- and medium-sized wastewater treatment plants can be met without using biological treatment’

- More carbon can be retained and more electricity and energy can be generated
- The direct membrane filtration concept indicated to be net electricity and energy neutral/positive
- Municipal wastewater can be treated on a smaller footprint
- The direct membrane filtration concept can be used up to 10 000 PE

Direct membrane filtration

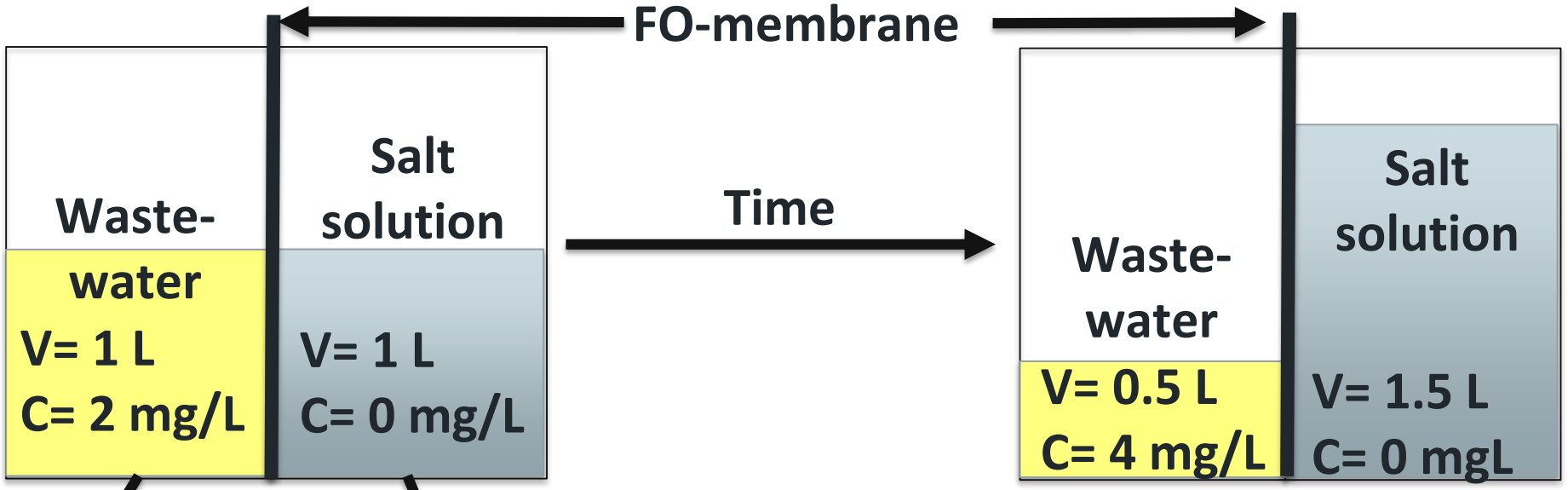
- Coagulant and flocculant are necessary for high permeate flux and to comply discharge demands
- Available for full-scale installation
- Air scouring consumes most electricity

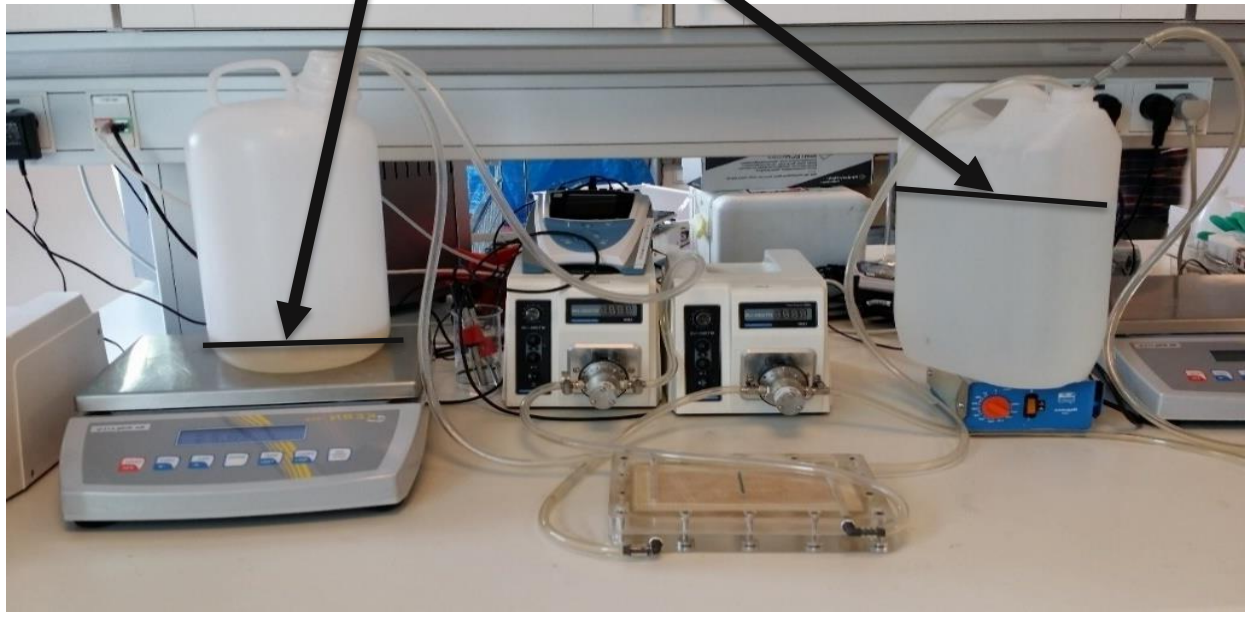
Do we have time for Future music?

Forward osmosis

Background

Forward osmosis





Wastewater

Microsieve

Microfiltration

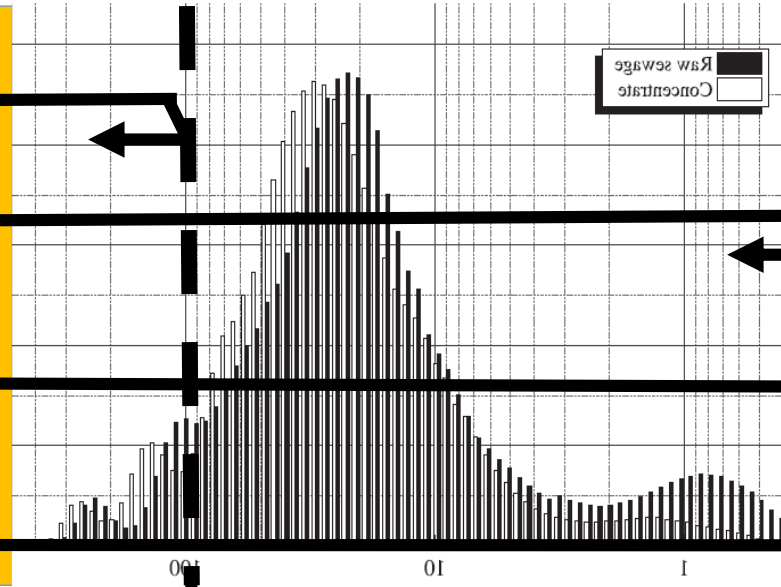
Forward osmosis

Particles (>100 µm)

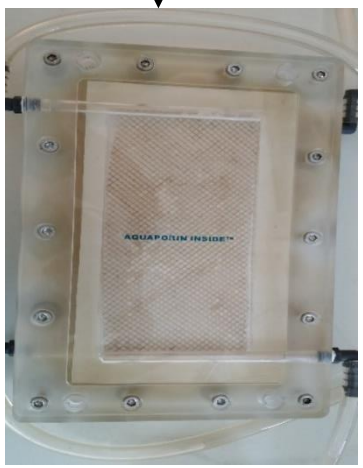
Particles (>0.2 µm)

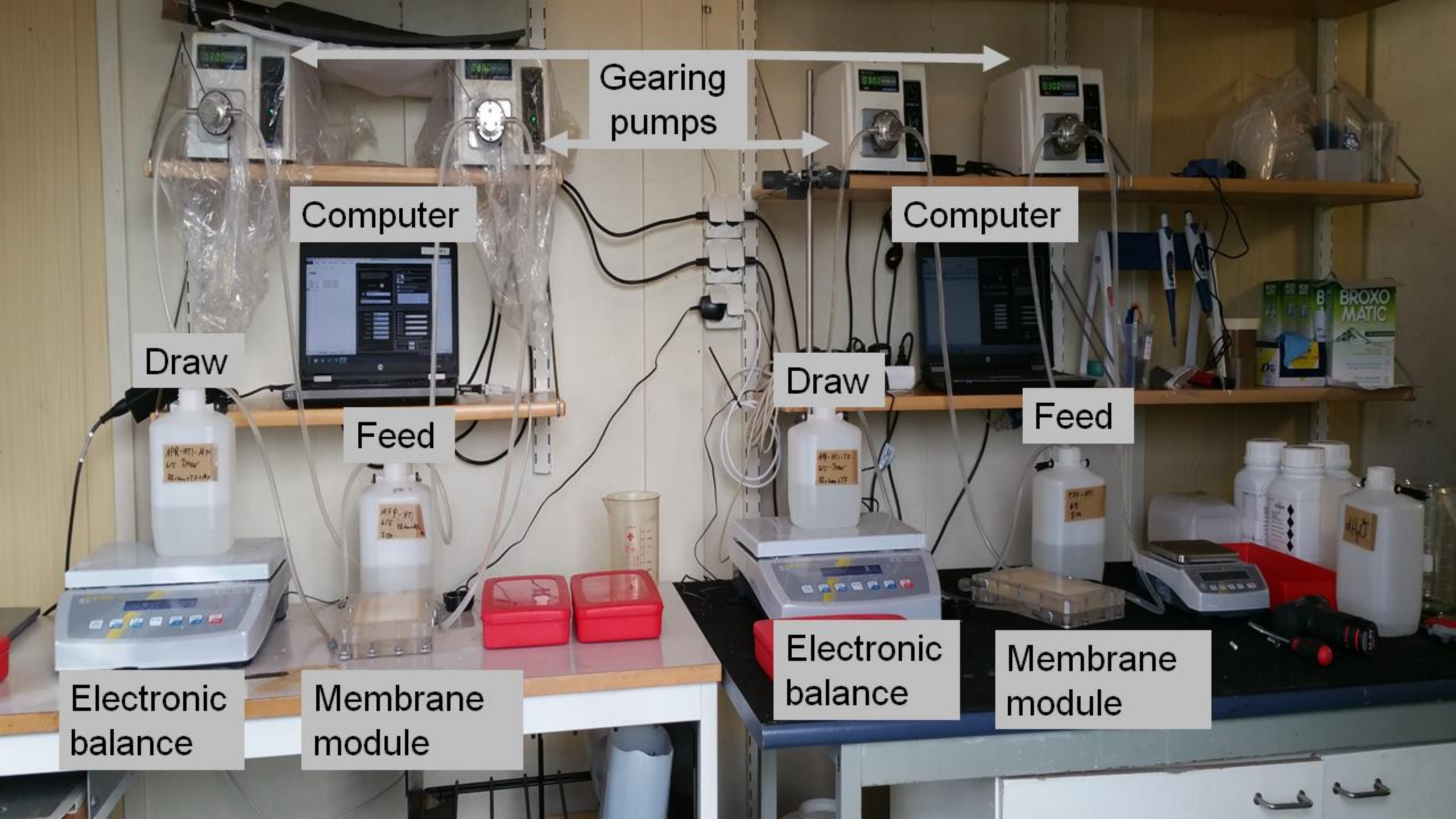
Soluble components

Water (H_2O)



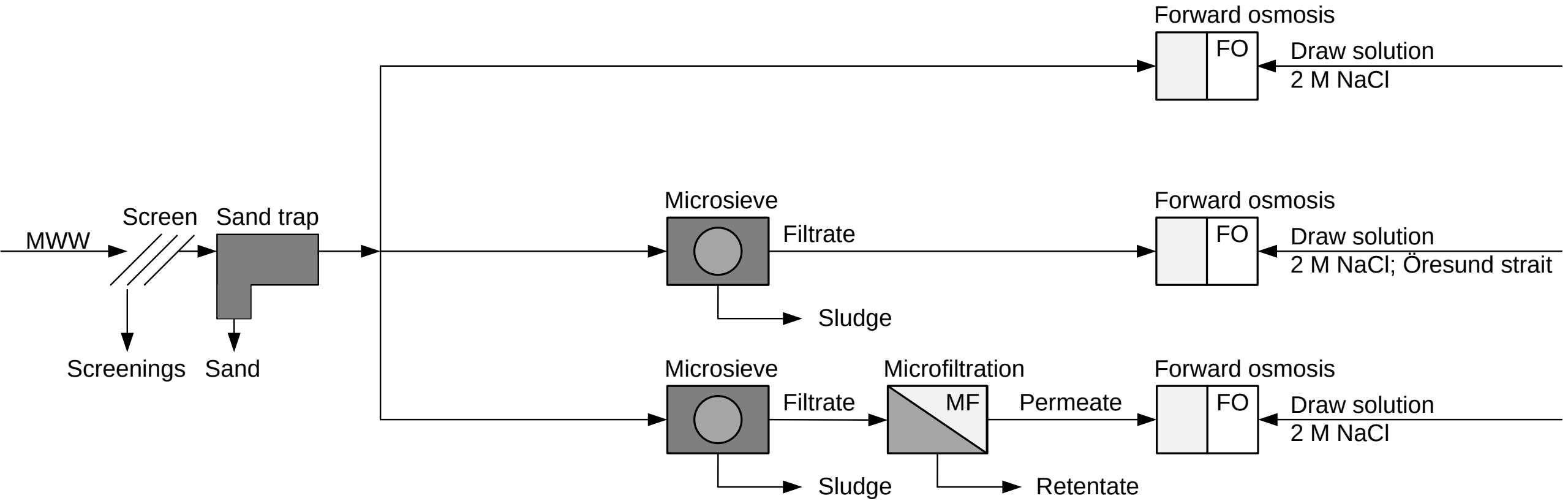
Seawater




Gearing pumps
Computer
Computer
Draw
Feed
Draw
Feed
Electronic balance
Membrane module
Electronic balance
Membrane module

Conducted experiments and Results

Mechanical pre-treatment

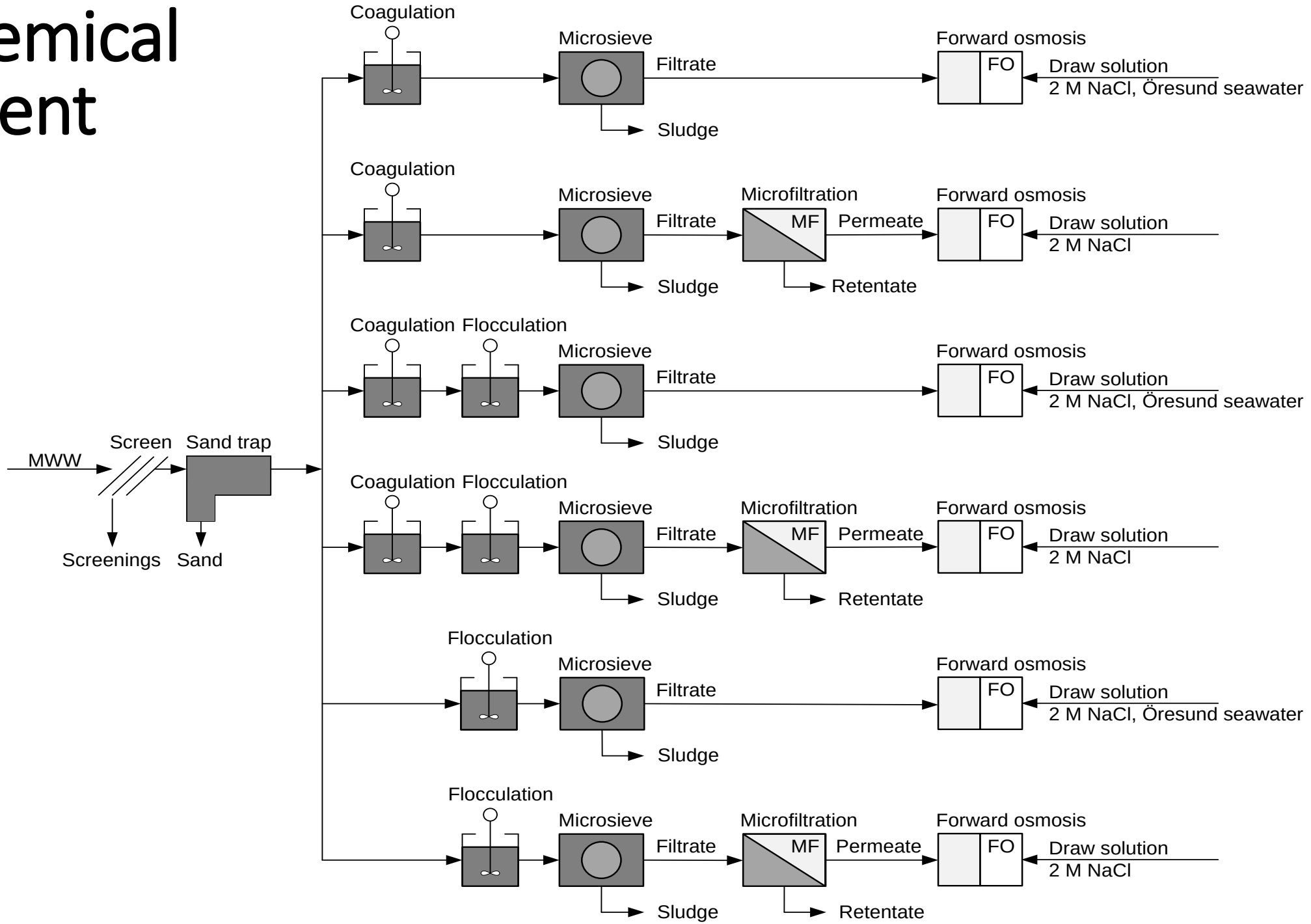


Results: Mechanical pre-treatment

Parameter	Raw MWW	Microsieve filtrate	Microfiltration permeate
J_W (L·m^{-2}·h^{-1})	9.3	9.3	10.0
BOD_7 (mg·L^{-1})	1.1	0.3	0.4
TNt (mg·L^{-1})	38	27	41
TNf (mg·L^{-1})	38	26	41
TPt (mg·L^{-1})	0.15	0.03	0.04
TPf (mg·L^{-1})	0.03	0.03	0.04

Discharge limit for WWTPs ≤ 10 000 p.e.: BOD_7: 15 mg/L, Tot-P: 0.5 mg/L

Physico-chemical pre-treatment



Results: Physico-chemical pre-treatment

Parameter	PACl		Cationic polymer		PACl + anionic polymer		PACl + cationic polymer	
	MSF	MFP	MSF	MFP	MSF	MFP	MSF	MFP
J_W (L·m^{-2}·h^{-1})	8.9	11.0	9.0	10.9	9.8	12.0	8.7	9.2
BOD_7 (mg·L^{-1})	7	3	21	14	5	5	18	16
TNt (mg·L^{-1})	19	32	11	26	13	13	14	18
TNf (mg·L^{-1})	19	30	12	26	35	35	13	19
TPt (mg·L^{-1})	0.06	0.05	0.1	0.05	0.05	0.04	0.05	<0.03
TPf (mg·L^{-1})	0.06	0.05	0.1	0.05	0.05	0.04	0.05	<0.03

Discharge limit for WWTPs ≤ 10 000 p.e.: BOD_7: 15 mg/L, Tot-P: 0.5 mg/L

Results (2M NaCl)

Parameter	Mechanical	PACl	PACl + anionic polymer
	MSF	MSF	MSF
J_W ($L \cdot m^{-2} \cdot h^{-1}$)	9.3	8.9	9.8
BOD_7 ($mg \cdot L^{-1}$)	0.3	7	5
TNt ($mg \cdot L^{-1}$)	27	19	13
TNf ($mg \cdot L^{-1}$)	26	19	35
TPt ($mg \cdot L^{-1}$)	0.03	0.06	0.05
TPf ($mg \cdot L^{-1}$)	0.03	0.06	0.05

Direct forward osmosis: Summary (Seawater)

Parameter	Mechanical	PACl	PACl + anionic polymer
	MSF	MSF	MSF
J_W ($L \cdot m^{-2} \cdot h^{-1}$)	1.1	1.5	1.4
BOD_7 ($mg \cdot L^{-1}$)	1.6	3.7	6.7
TPt ($mg \cdot L^{-1}$)	0.02	0.02	0.02
TPf ($mg \cdot L^{-1}$)	0.02	0.02	0.05

DMF Vs. DFO
Results

Wastewater treatment plant	Size	Specific electricity consumption	Specific area demand
	PE	$kWh_{el} \cdot m^{-3}$	$m^2 \cdot PE^{-1}$
Sjölunda	370 000	0.42	0.107
Källby	100 000	0.41	0.155
Klagshamn	60 000	0.45	0.132
DMF	10 000	0.55	0.046
DFO (Öresund)	10 000	0.55	0.051
Södra Sandby	7 900	0.84	0.228
Veberöd	4 800	0.77	0.190

Net outcome of the DMF and DFO concepts

	Specific electricity net surplus		Specific heat net surplus	
	$kWh_{el} \cdot PE^{-1} \cdot year^{-1}$	$Wh_{el} \cdot m^{-3}$	$kWh \cdot PE^{-1} \cdot year^{-1}$	$kWh \cdot m^{-3}$
Direct membrane filtration (Coagulation, flocculation)	1	14	43	0.6
Direct forward osmosis (Öresund)	4	55	58	0.8