WATER FUTURE

International conference

THE FUTURE OF WATER SERVICES

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THURSDAY 7TH | FRIDAY 8TH

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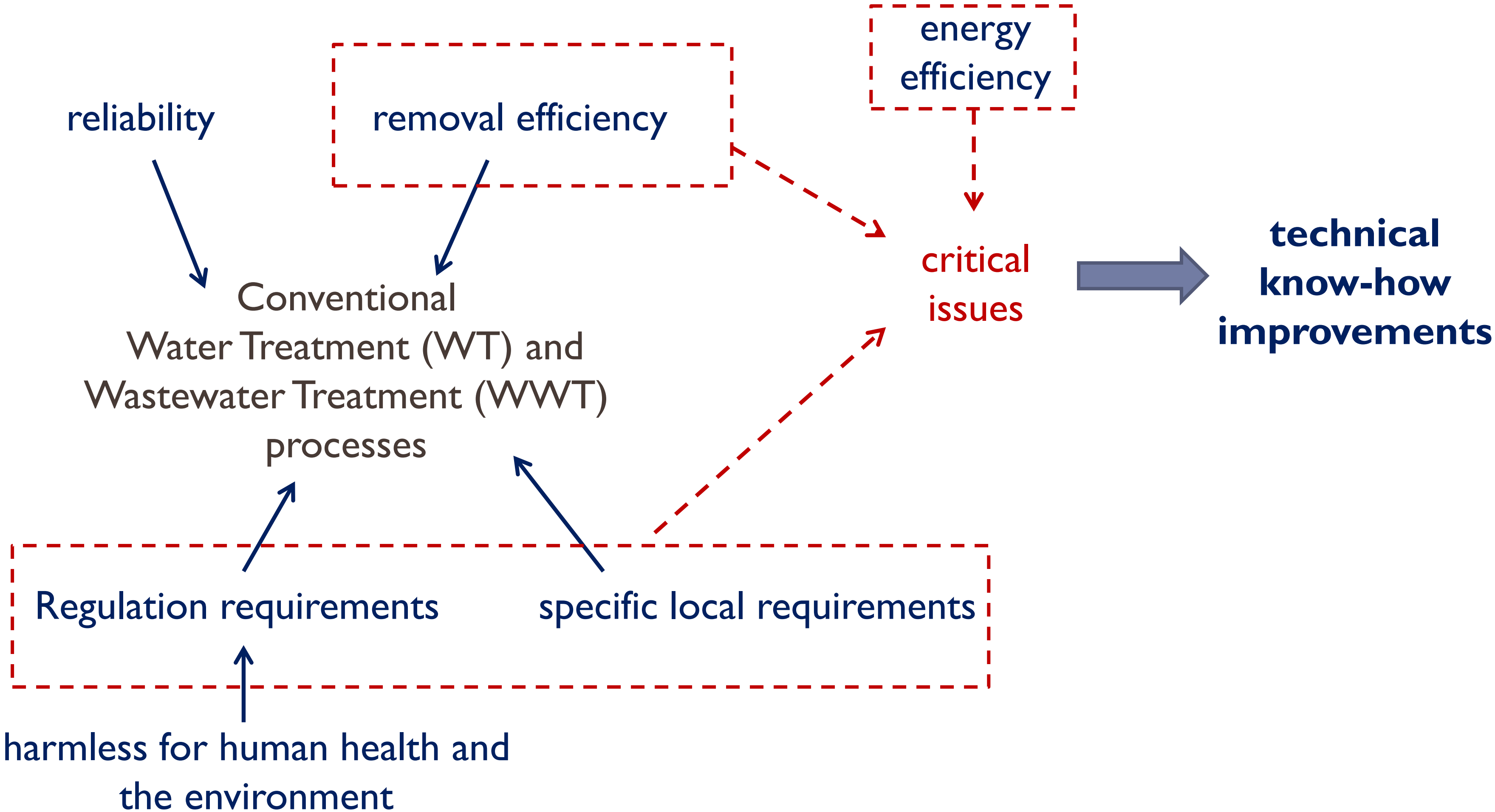
Technological advances in Sanitation and Drinking Water Treatment

Prof. Mariachiara Zanetti

DIATI, Politecnico di Torino

Overview


reliability
removal efficiency
energy efficiency
Conventional Water Treatment (WT) and Wastewater Treatment (WWT) processes
critical issues
technical know-how improvements
Regulation requirements
specific local requirements
harmless for human health and the environment

WT processes: framework

groundwater → * → filtration → disinfection →

*Fe/Mn: oxidation
*VOC, NH_3: stripping, oxidation
*non volatile organic compounds: GAC

surface water → screening → oxidation → coagulation/ flocculation → sedimentation
↓
filtration
↓
disinfection
↓

WT processes: critical issues

- Pathogens → disinfection: chlorine compounds (HClO, ClO_2)
  O_3, UV, membranes
- Suspended solids → filtration (sand/GAC)
  coagulation/flocculation
- Pollutants: inorganic → oxidation, GAC/PAC
  organic → oxidation, stripping

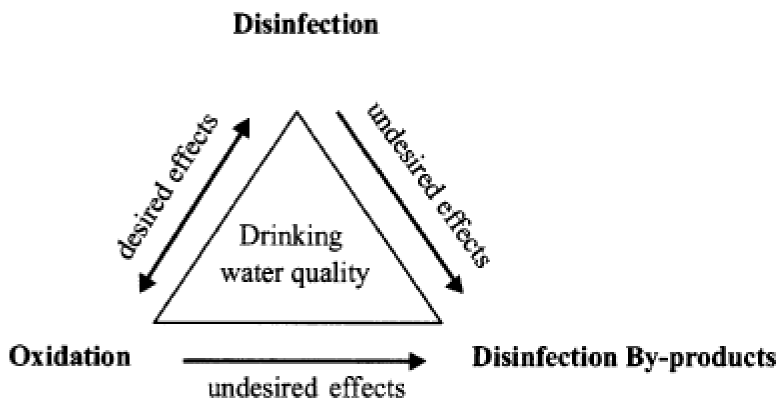
Disinfection by-products (DBPs)

Emerging Contaminants

efficiency

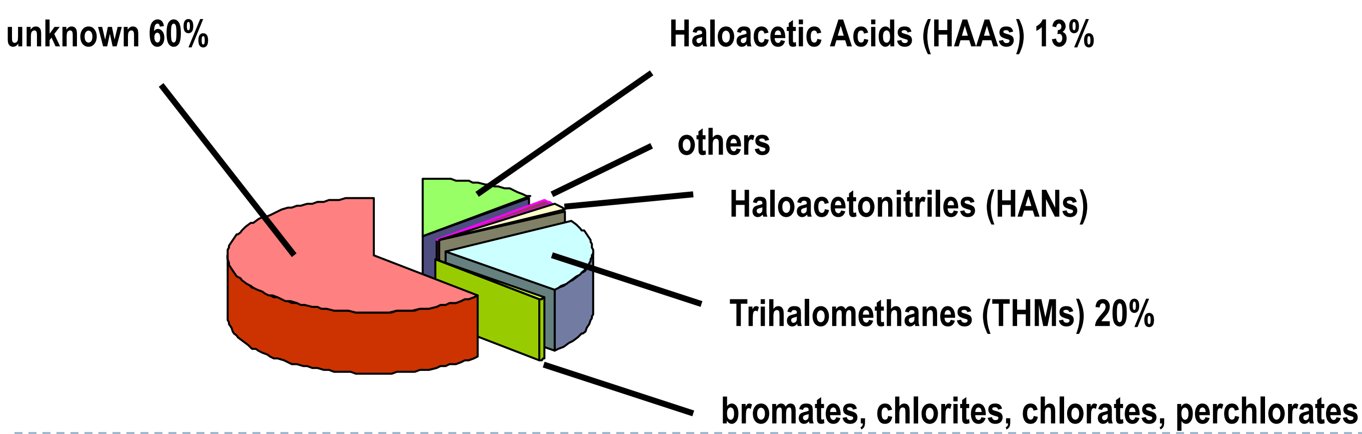
critical issues

WT processes critical issues: DBPs



Disinfection by-products (DBPs):
inorganic, organic
volatile, hydrophobic
non volatile, hydrophylic
chlorinated, non chlorinated
aliphatic, aromatic

Generated by chlorine disinfectants (HClO, ClO_2) and O_3



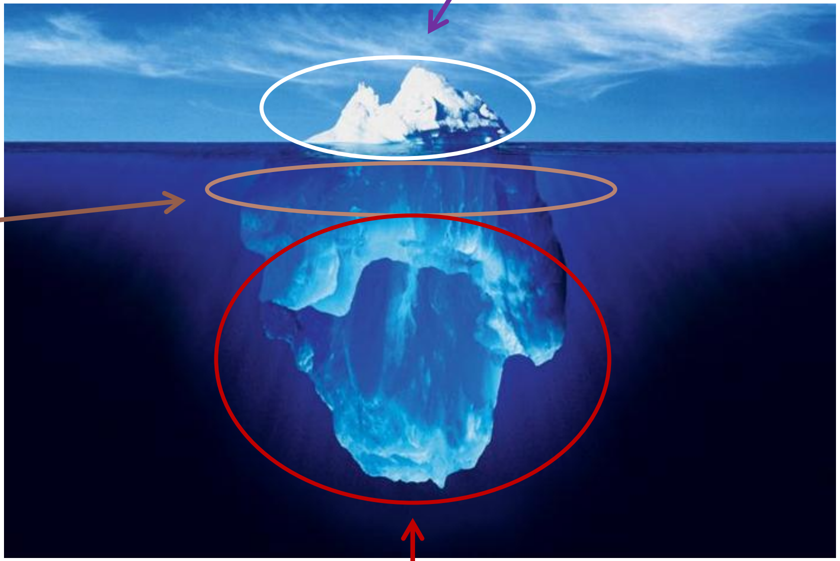
WT processes critical issues: DBPs

DBPs precursors:

Natural Organic Matter (NOM)
Turbidity, Fe
Temperature, pH
Disinfectant dose
NH_3/NH_4^+

known DBPs limited by regulations

known DBPs UNlimited by regulations



UNknown DBPs

WT processes critical issues: DBPs

DBPs features:

probable carcinogenic
probable endocrine disruptor

	WHO 2011	EPA 2008	EU DIR 1998	I DL 2001
THMs	Cloroformio: 300 Bromoformio: 100 Dibromoclorometano: 100 Bromodiclorometano: 60	80	100 (150*)	30
CHLORITE	700	1000	700	700 (200*)
CHLORATE	700	-	-	-
BROMATE	10	10	10 (25*)	10 (25*)
PERCHLORATE	-	15	-	-

* temporary value

WT processes critical issues: DBPs

DBPs + precursors removal:

conventional processes: chemical oxidation (ClO_2, O_3, H_2O_2)
adsorption on activated carbon (GAC or PAC)

Novel processes: ADVANCED OXIDATION PROCESSES (AOPs)
Oxidant: hydroxyl radical ·OH

- H_2O_2 / Fe^{2+} (Fenton)
- H_2O_2 / Fe^{3+} (Fenton - like)
- H_2O_2 / Fe^{2+} (Fe^{3+}) / UV (Photo assisted Fenton)
- H_2O_2 / Fe^{3+}- Oxalate
- Mn^{2+}/Oxalic acid/Ozone
- TiO_2 / hv/ O_2 (Photocatalysis)
- O_3 / H_2O_2
- O_3 / UV
- H_2O_2 / UV

R. Andreozzi et al. / Catalysis Today 53 (1999) 51–59

Advanced Oxidation Processes (AOPs):

Agente ossidante	Potenziale di ossidazione elettrochimica (E), Volts	Valori di E relativi al Cloro
Fluoro (F_2)	3.06	2.25
Radicale ossidrile ($OH^\bullet$)	2.80	2.05
Ossigeno (atomico) ($O^\bullet$)	2.42	1.78
Ozono (O_3)	2.08	1.52
Perossido di Idrogeno (H_2O_2)	1.78	1.39
Radicale Idroperossido ($HO_2^\bullet$)	1.70	1.30
Ipoclorito (HOCl)	1.49	1.10
Cloro (Cl_2)	1.36	1.00
Biossido di Cloro (ClO_2)	1.27	0.93
Ossigeno (molecolare) (O_2)	1.23	0.90

WT processes critical issues: inorganic pollutants

conventional treatments

Mn (II), Fe (II)
H_2S/S^{2-} → chemical oxidation

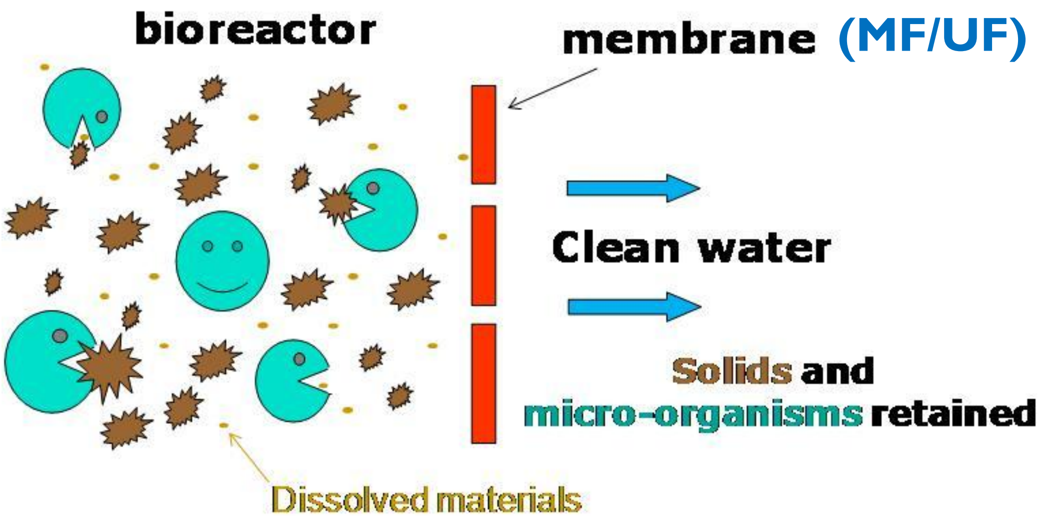
NH_3/NH_4^+ → stripping, chemical oxidation

As ($H_2AsO_3^-$)
CN^-, Br^-
ClO_4^-
NO_3^- → coagulation/flocculation, adsorption, ion exchange

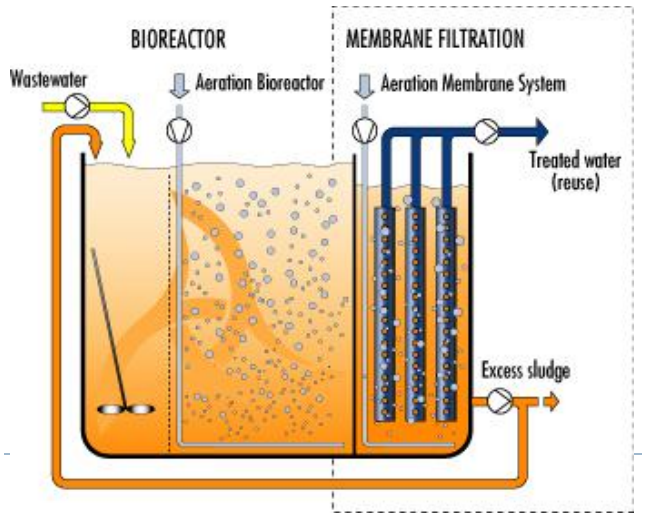
novel treatments

biological oxidation: Membrane Biofilm Reactor (MBR)
membrane processes: microfiltration + reverse osmosis (RO)
nanofiltration + ultralow pressure RO

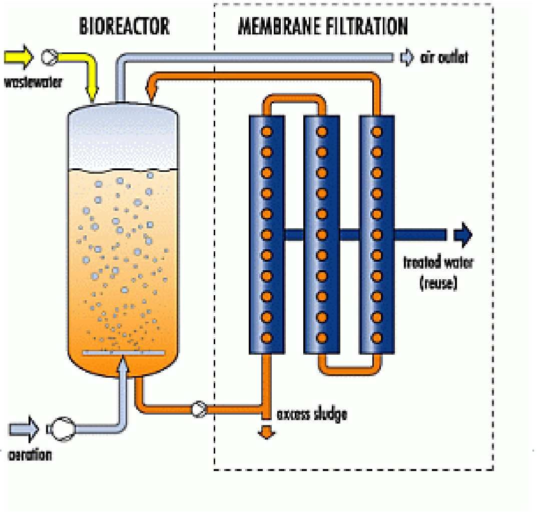
Biological oxidation + membrane processes



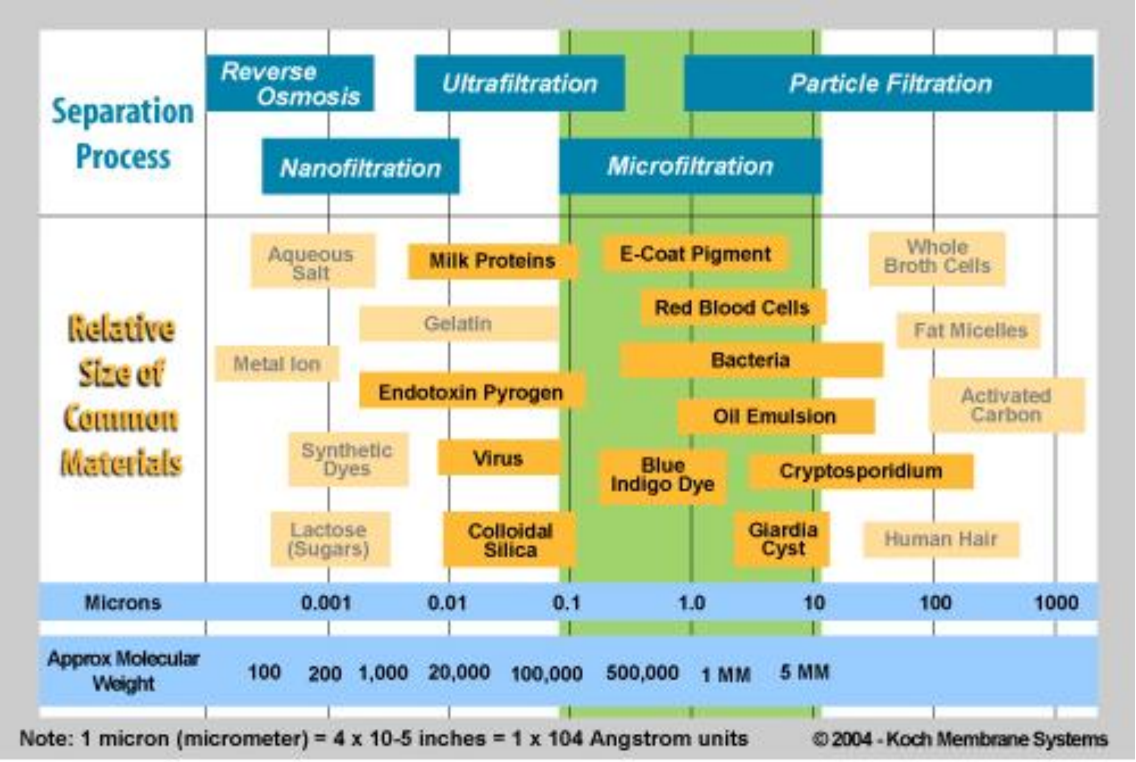
Integrated MBR



Recirculated MBR



Membrane processes



WT processes critical issues: organic pollutants

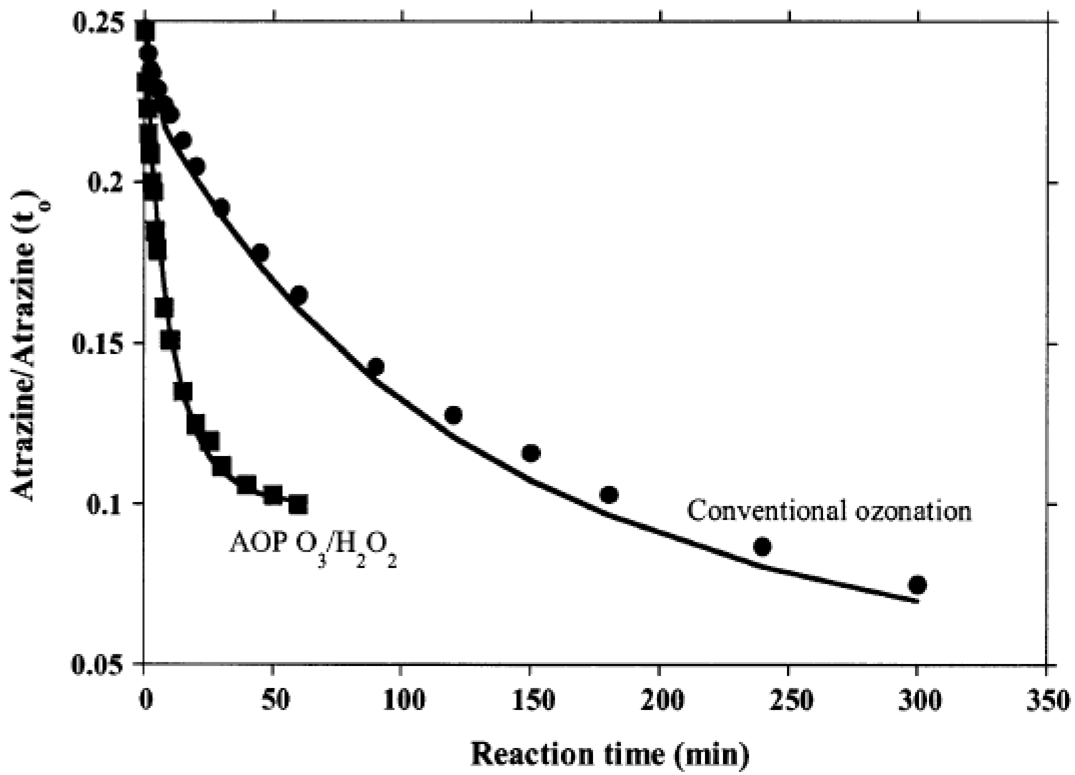
pesticides, solvents, phenols, PAH
fuel additives (BTEX, MTBE)
DBPs, pharmaceuticals

Conventional treatments: adsorption on activated carbon (GAC or PAC)
chemical oxidation (ClO_2, O_3, H_2O_2)

Novel treatments: biological oxidation
Advanced Oxidation Processes (AOPs)

WT processes critical issues: organic pollutants

ADVANCED OXIDATION PROCESSES (AOPs)



U. von Gunten / Water Research 37 (2003) 1443–1467

WT processes critical issues: bio-pollutants

Warm temperature + high nutrient load → blooming of ALGAL PRODUCTS and cyanobacteria (blue-green algae)

Toxin growth, depletion of water organoleptic features

Conventional treatments: coagulation/flocculation

Novel treatments:
membrane processes
acidification (CO_2 or HCl) + coagulation/flocculation

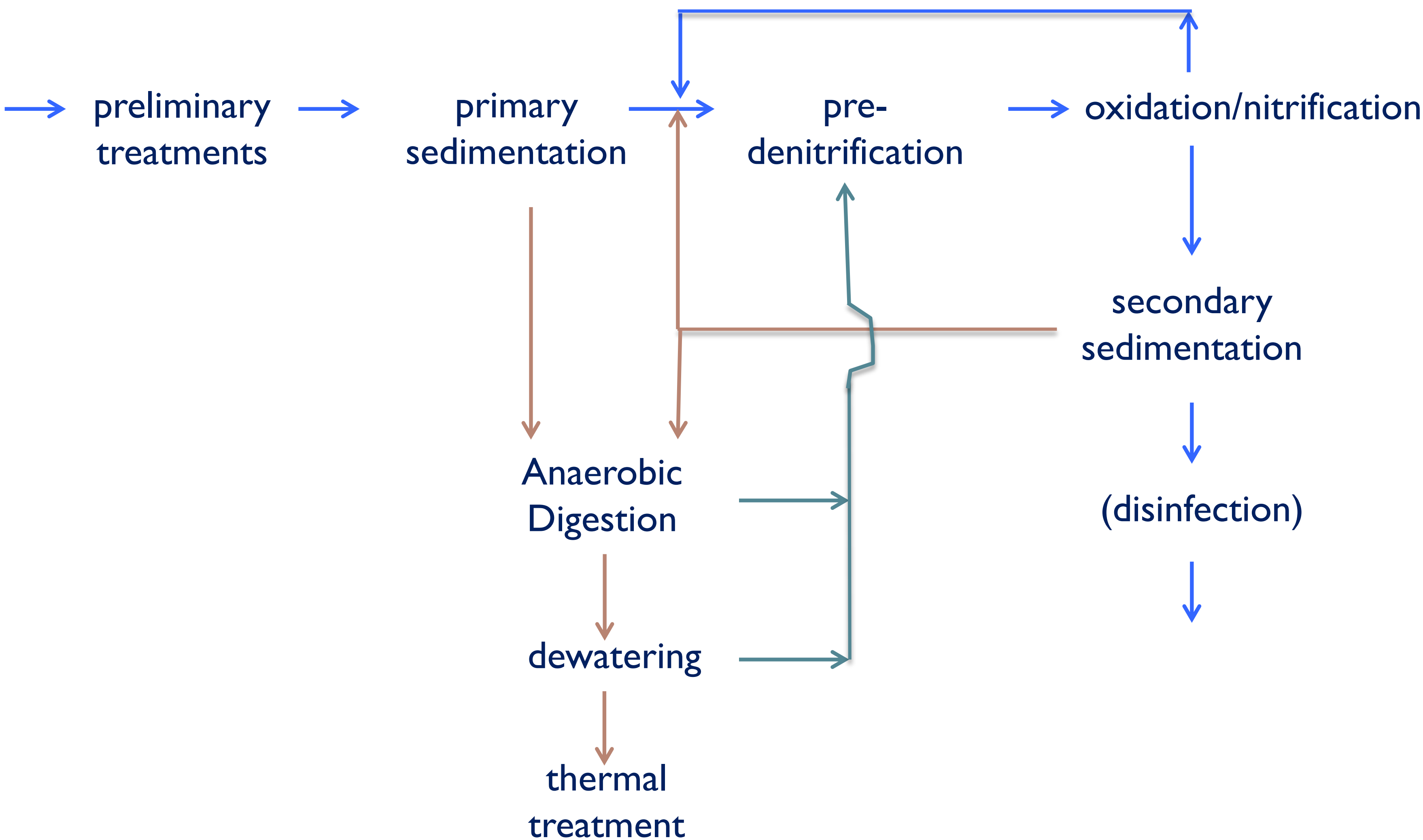
Coagulation/flocculation critical issues

Removal of turbidity
algal products
NOM
dissolved salts

Technical improvements:

1) new coagulants: new poly aluminium chloride (PAC) reagents, Fe +Al salts, pre-hydrolyzed reagents with cationic polymers, organic polymers;
2) coagulation/flocculation + other unit processes:
   ferric sulfate + ion exchange
   nano activated carbon + alum
   coagulation + membrane processes

WWT processes: framework



WT processes: critical issues

- Improvement of Removal efficiency:
  - Nitrogen removal
  - specific local requirements about N, P
  - Emerging Contaminants

- Enhancement of sludge valorization

  $\Rightarrow$ energy efficiency

  $\Rightarrow$ environmental sustainability

WT processes critical issues: N removal

- Conventional processes: pre-denitrification/nitrification
  Sequencing Batch Reactor (SBR)

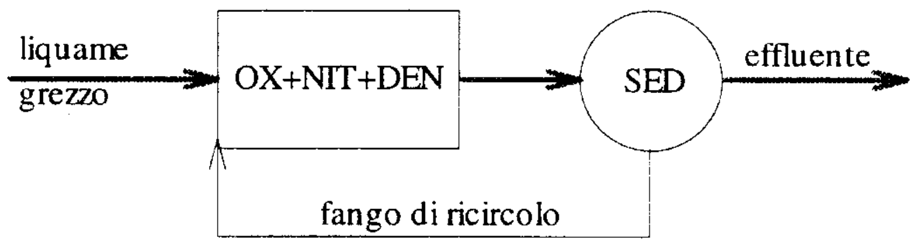
- Critical issues: **sidestreams with low C/N (<1)**
  (++ sludge water from Anaerobic Digestion)

- 15-20% of influent N load
- TKN = 600 – 1000 mg/L
- Alkalinity: ~50% of the necessary amount to obtain a complete nitrification

Parameter	Value / Range	References
pH	7.18 - 8.42	Marsalek et al. (2004)
BOD_5 (mg/l)	230	Helliga et al, (1999)
	109 ± 44	Vandaele et al., (2000)
	1400 - 2000	Gali Serra A., (2006)
COD (mg/l)	650	Köz Utku, (2007)
	700 - 1000	Wett et al., (1998)
BOD_5/ COD	0.14 - 0.2	Vymazal (2010)
COD_{sol}/ NH_4^+-N	0.29 - 1.19	Marsalek et al. (2004)
NH_4^+-N (mg/l)	943 - 1513	Marsalek et al. (2004)
	1180 ± 140	Van Dongen et al., (2001)
	800 - 900	Dosta et al., (2007)
	450 - 750	Vymazal (2010)
TKN (mg/l)	1053	Helliga et al, (1999)
	859	Vymazal (2010)
NO_2^--N, NO_3^--N (mg/l)	0-3	Vymazal (2010)

N removal: innovative processes

Continuous flow nitrification/denitrification in an alternated single phase



- CSTR with on/off temporized aeration
- on-line monitoring of process parameters (DO, ORP, pH, NH_4^+, NO_3^-)
- tailored lenght of biological process phases $\Rightarrow$ removal efficiency improvement
- no mixed liquor recirculation + aeration optimization $\Rightarrow$ energy efficiency improvement
- several full scale applications in Italy

N removal: innovative processes

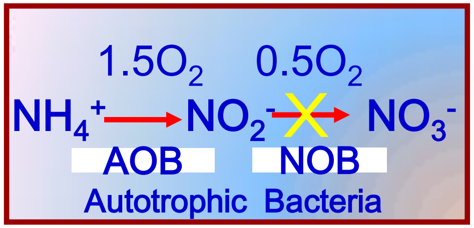
Autotrophic processes:

Nitritation/Denitritation

Nitritation: $NH_4^+ + 1.5O_2 \rightarrow NO_2^- + 2H_2O + 2H^+$

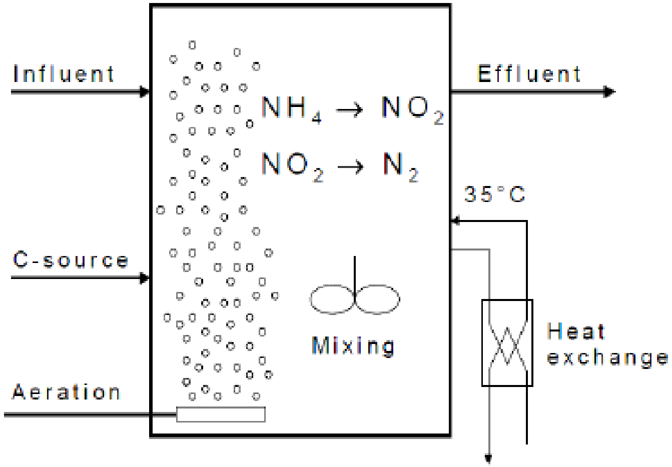
Denitritation: $NO_2^- + 0.5CH_3OH \rightarrow 0.5N_2 + 0.5CO_2 + 0.5H_2O + OH^-$

NITRITATION



AOB (ammonia oxidant bacteria) growth is promoted against NOB (nitrate oxidant bacteria):

- T >25°C
- DO < 2 mg/L
- NH_4^+ (pH >7.5-8)
- low HRT

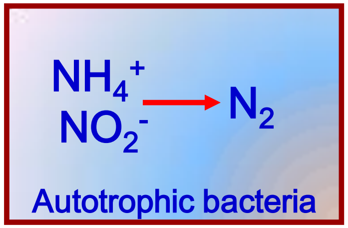


SHARON® (Single Reactor High Activity Ammonia Removal over Nitrite) (1990, Delft University)

- 25% Oxygen demand
- 40% C demand
- sludge generation lower than active sludge processes
- several full scale applications worldwide

WT processes critical issues: N removal

Autotrophic processes:



ANAMMOX® (Anaerobic Ammonium Oxidation) (1999, Delft)

$$NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 2.03H_2O + 0.066CH_2O_{0.5}N_{0.15}$$

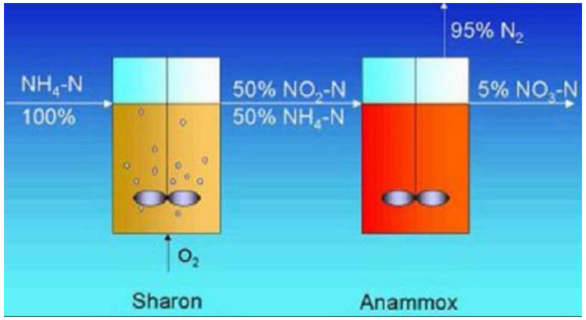
NH_4^+ is directly oxidized to N_2 using NO_2^- as the e- acceptor under anoxic conditions

- no need of Oxygen
- no need of Carbon (CO_2 is employed to produce biomass)
- depletion of 60/90% energy demand
- reduction of CO_2 emissions (up to 90%)
- sludge generation lower than active sludge processes

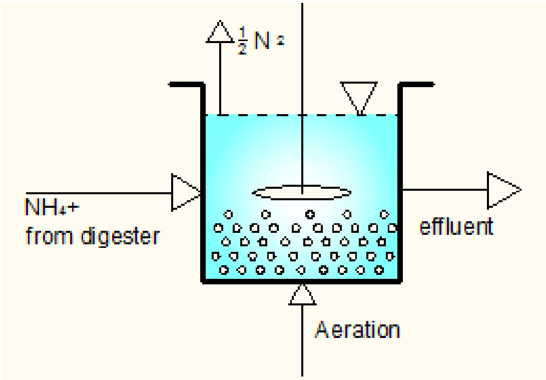
N removal, autotrophic processes:

- several full scale applications worldwide:

SHARON + ANAMMOX in 2 separate reactors



CANON ® **(Completely Autotrophic N Removal over Nitrite) or SNAP ® (Single stage Nitrogen removal using Anammox and Partial Nitritation)** (SHARON + ANAMMOX in a single reactor)



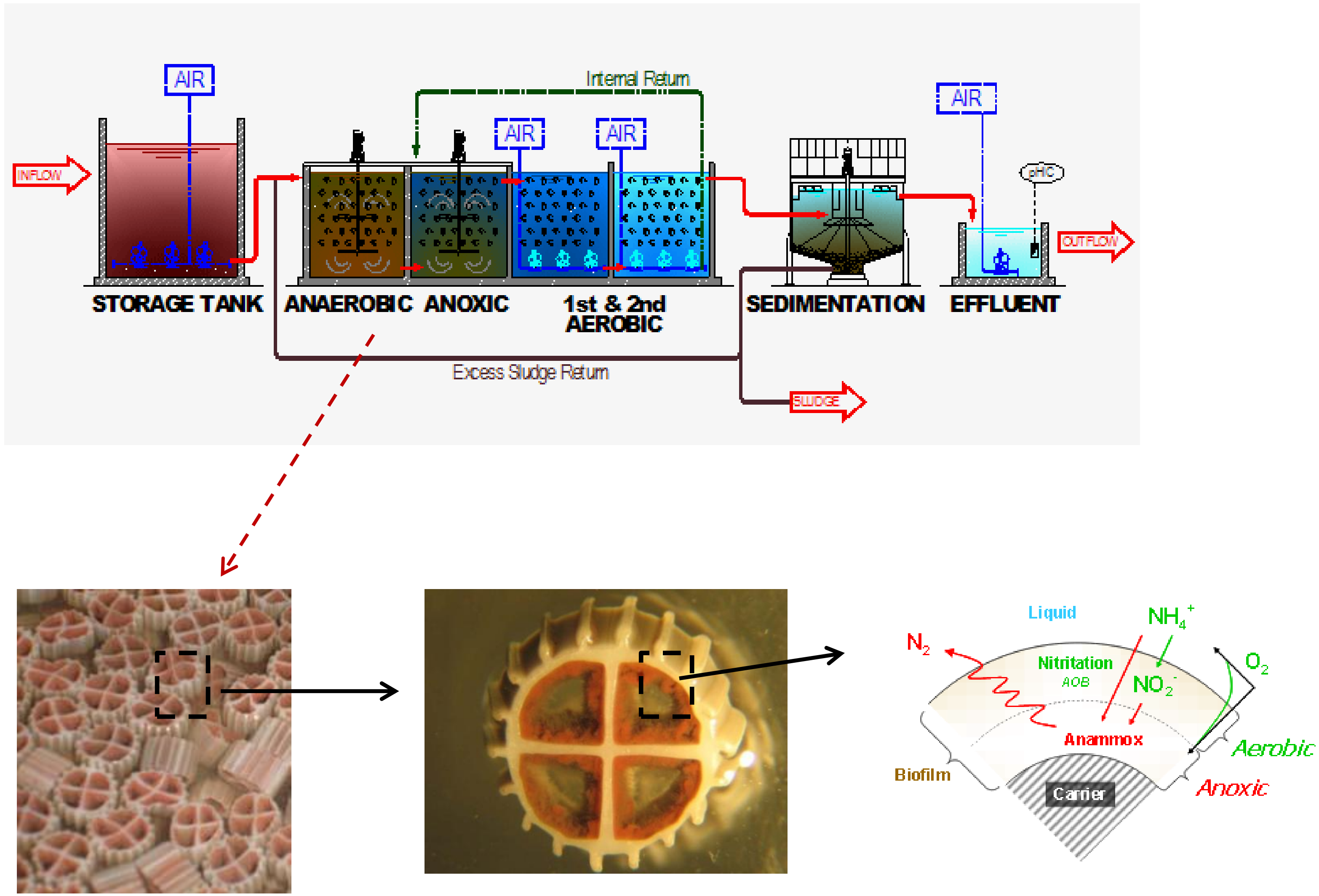
DEANNAMMOX ® **or DEMON ®**(denitrification + ANAMMOX)

Industrial/full scale applications:

Processo	Configurazione impiantistica	Alimentazione	T (°C)	DO (mg/l)	ANR* (kgN/m^3d)	Fattori di controllo	Rif.
CANON - Completely Autotrophic nitrogen removal over nitrite	SBR		30	<0,1	0,06	DO, ammonia, AOB population	Sliekers et al. (2002)
	Air pulsing SBR	Sludge liquor	21	0,5	0,36		Padìn et al. (2009)
	Airlift	Syntetic	-	0,5	1,5		Sliekers et al. (2003)
	UASB	Sludge liquor	30	External aeration 0,6	0,06		Ahn & Choi (2006)
	MBBR	Sludge liquor	30	1,8	0,36		Cema et al. (2006)
	MABR	Syntetic	35	0,5	0,77		Gong et al. (2007)
DEMON - DEamMONification	SBR	Sludge liquor	28	0,3	0,70	Time, pH, DO	Wett (2007)
OLAND - Oxygen – limited autotrophic nitrification and denitrification	RBC	Sludge liquor	14	1,0	0,42	-	Pynaert et al. (2004)
	SBR	Syntetic	33	low	0,05	Time, pH,	Kuai et al. (1998)
	SBR, high rate		-	-	1,058	Time, pH	Pynaert et al. (2003)
Aerobic Deammonification	RBC	Leachate	-	-	0,6	-	Hippen et al (1997)
SNAP Single Stage Nitrogen Removal	+ biomass carrier	Leachate	35	0,5 – 2,5	0,31-0,45	HRT, aeration rate, T, pH	Lieu et al. (2005)

** ANR = Nitrogen Removal rate by Anammox bacteria*

i.e. Phosphorous removal and Demon Moving Bed Biofilm Reactor (Demon MBBR)



WT processes critical issues: Emerging Contaminants (EC)

- Xenobiotic compounds
- Endocrine disruptor compounds
- Organic micropollutants
- Pharmaceuticals and Personal Care Products (PPCPs)
- ……….

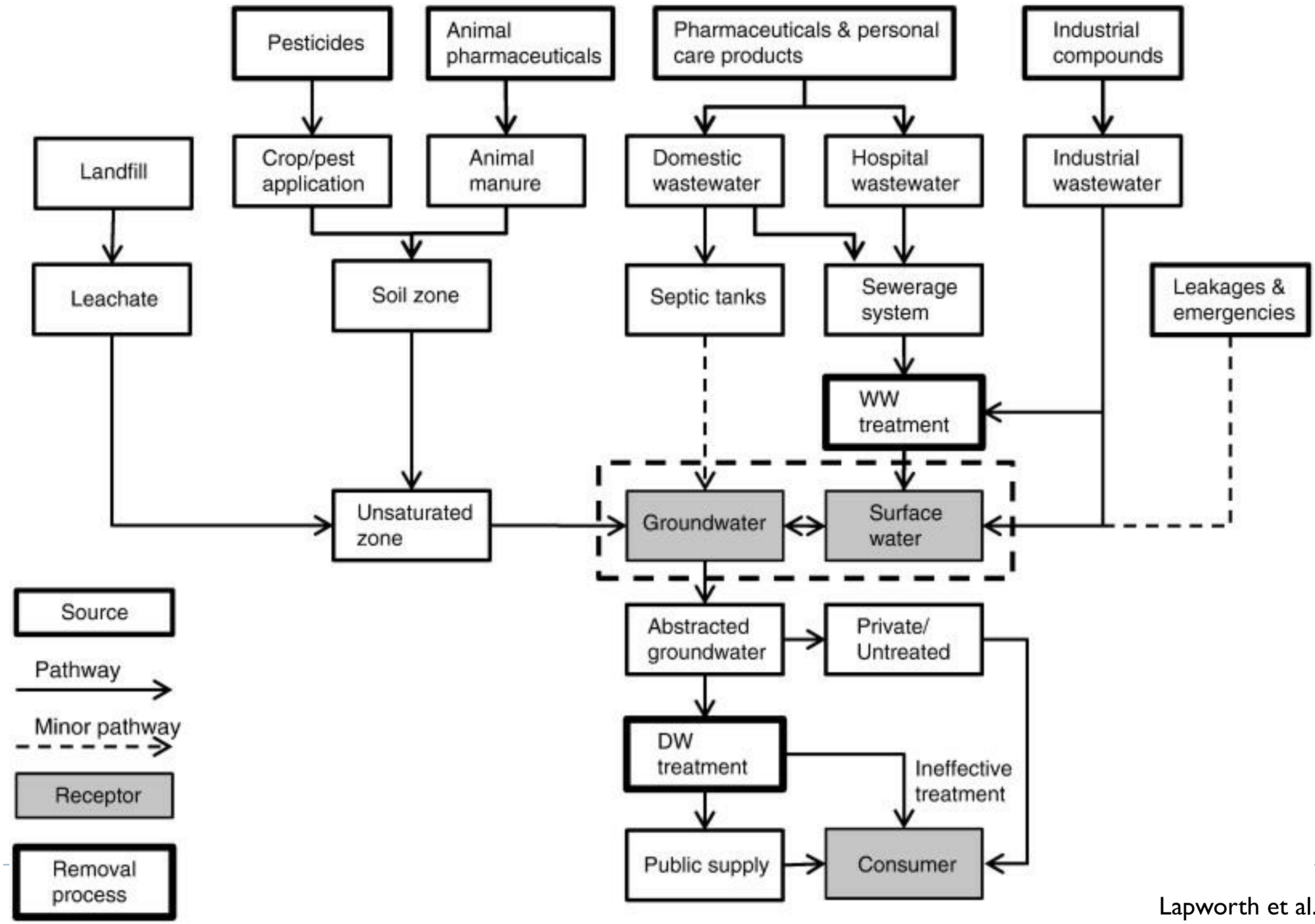
↓

antiseptics/disinfectants, fragrances, pesticides, insects repellents, sun protection lotions, alkylphenols
External use, NO METABOLIC PROCESSES involved

↓

Persistant Organic Pollutants

Emerging Contaminants (EC): origin and diffusion

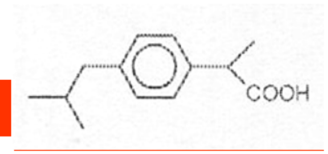


Lapworth et al., 2012

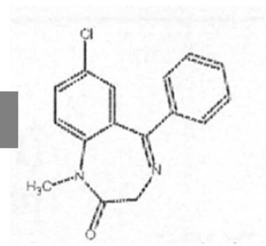
Pharmaceuticals

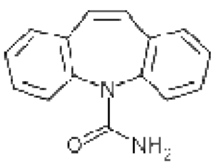
- Antiflogistici (ibuprofene)
- Regolatori di lipidi (acido clofibrico)
- Antiepilettici (carbamazepina)
- Psicoattivi, tranquillanti (diazepam)
- Betabloccanti (sotalol)
- Antistaminici
- Citostatici
- Mezzi di contrasto (iopromide)
- Antibiotici (eritromicina)
- Ormoni (17α–etinilestradiolo)

ibuprofene

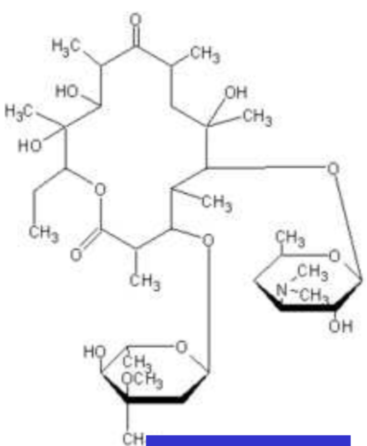


diazepam



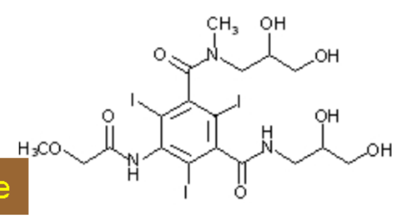


carbamazepina



eritromicina

iopromide



Pharmaceuticals: diffusion

Table 1
Occurrence level of several EDCs detected in municipal wastewaters, surface waters and drinking waters

Type of water	Location	Compounds detected	Conc., (ng/L)
Municipal wastewaters	UK [7]	Nonylphenol	1.2–2.7
		Estrone (E1)	15–220
		Estradiol (E2)	7–88
	Germany [8]	Nonylphenol	199
		Estrone (E1)	3.4
		Estradiol (E2)	0.9
		Ethinylestradiol (EE2)	1.4
	Japan [9]	Nonylphenol	80–1240
		Estradiol (E2)	2.7–48
Surface waters	Germany [8]	Nonylphenol	34
		Estrone (E1)	0.7
		Estradiol (E2)	0.6
	Japan [10]	Nonylphenol	250
		Estradiol (E2)	2.1
Drinking water	Germany [8]	Nonylphenol	8
		Estrone (E1)	0.4
		Estradiol (E2)	0.3

N. Bolong et al. / Desalination 239 (2009) 229–246

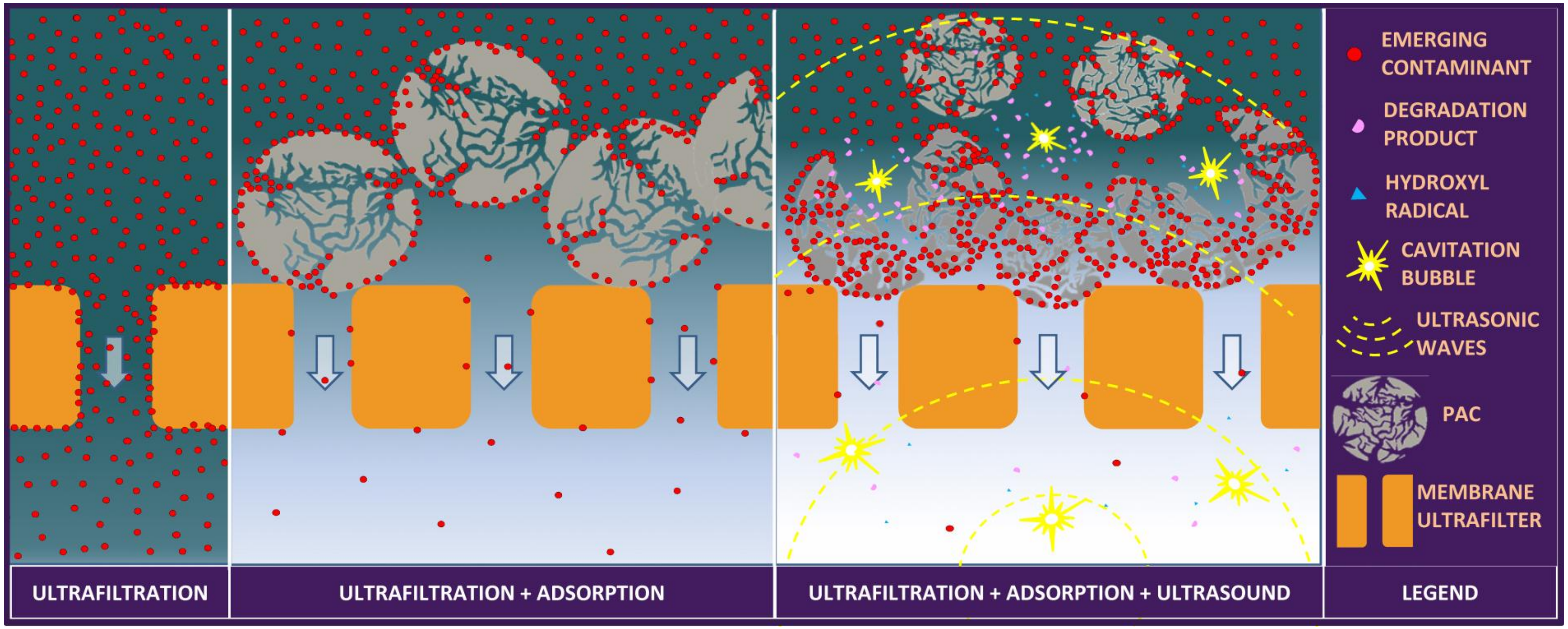
Conventional treatments:	Removal efficiency
Adsorption on activated carbon	40-90%
Coagulation/flocculation	<20%
Chemical oxidation	60-90%
Biological processes	40-80%

low-medium biodegradability

Pharmaceuticals: novel treatments

many patented Advanced Oxidation Processes (AOPs) tested on laboratory/pilot scale:

i.e. **USAMe® (SEED, UniSA)**



WT processes critical issues: **sludge treatment**

Pre-treatments aimed to increase biogas production in AD:

- **mechanical**: ultrasonic, lysis centrifuge, liquid shear, grinding
- **chemical**: oxidation (O_3, H_2O_2, Fenton) – alkali treatments (NaOH > KOH > $Mg(OH)_2$ and $Ca(OH)_2$)
- **thermal** : low (< 100°C) and high (> 100 °C) temperatures

Pretreatment method	Treatment conditions	Feed concentration	VS destruction	Electrical consumed ($kWh\ kg^{-1}$ VS fed)	Thermal consumed ($kWh\ kg^{-1}$ VS fed)	Max biogas ($kWh\ kg^{-1}$ TS fed)
None-mesophilic		6%	40%	0.04	0.5	1.9
None-thermophilic		6%	50%	0.03	1.0	2.4
Biological (thermal)	70 °C 9–48 h	6%	50%	0.03	1.0	2.4
Thermal hydrolysis	170 °C 15–30 min	9%	60%	0.04	2.0	2.9
Sonication	100 W, 16 s, 30 kW m^{-3}	6%	50%	0.37	0.5	2.4
Ball milling		6%	50%	1.04	0.5	2.4
High pressure	200 bar	6%	50%	0.33	1.0	2.6

from Carrère et al., 2010

WT processes critical issues: **sludge disposal**

Conventional management strategies:

- landfilling: traditional strategy
  not allowed by current Regulations;

- agricultural use: material recovery
  limits defined by Regulations
  persistent organic pollutants

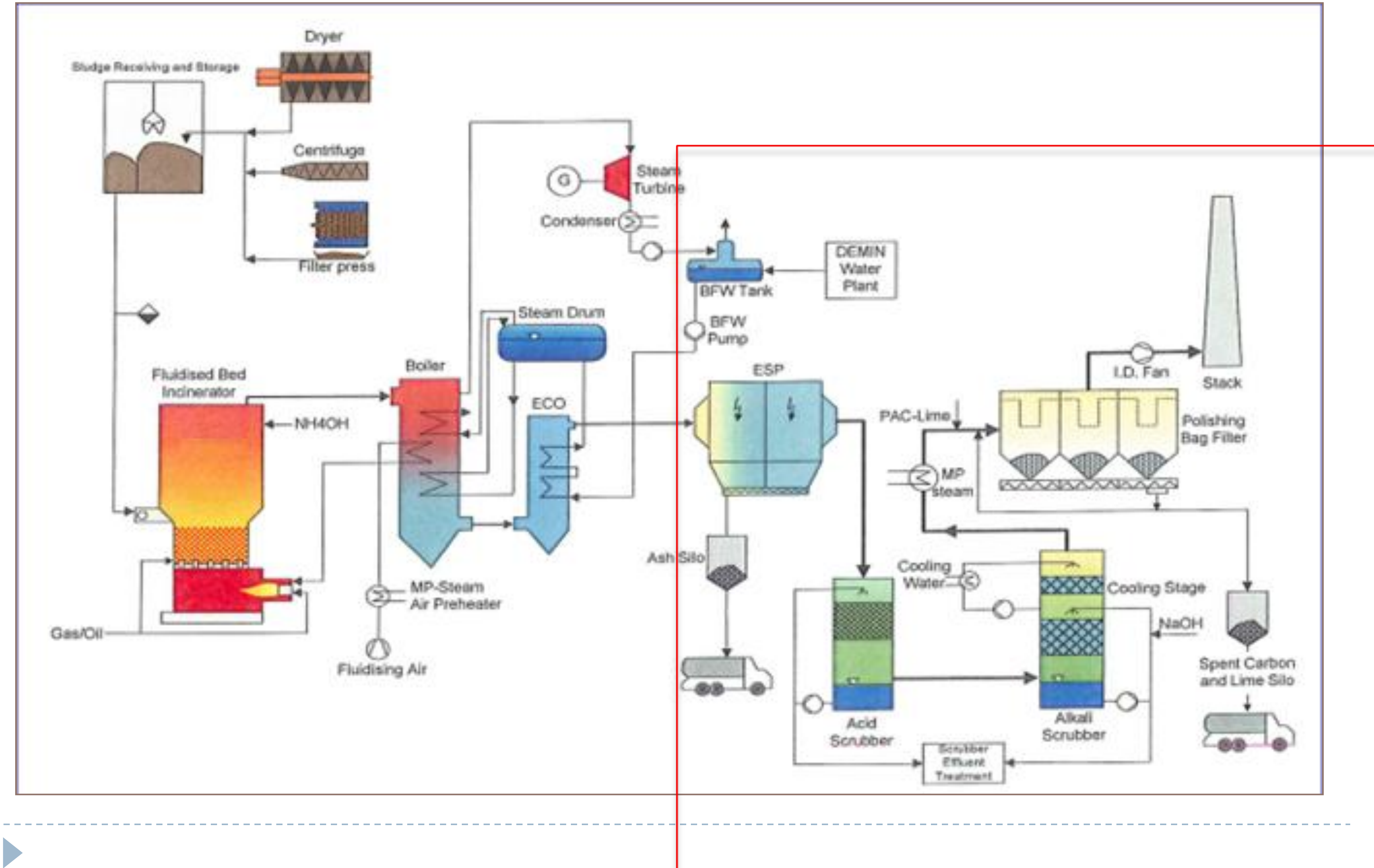
- thermal treatments

WT processes critical issues: sludges

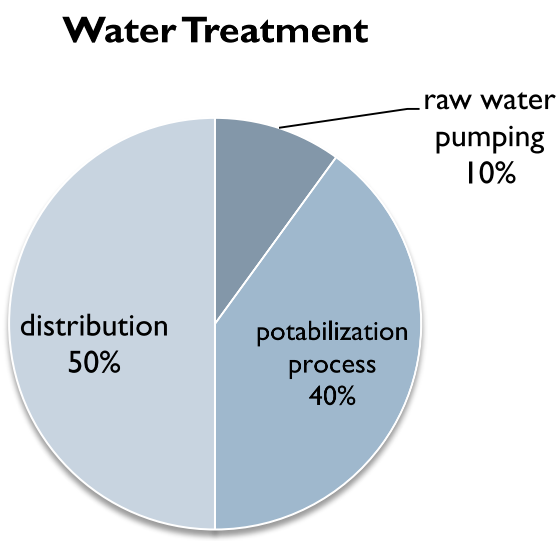
Thermal treatment:

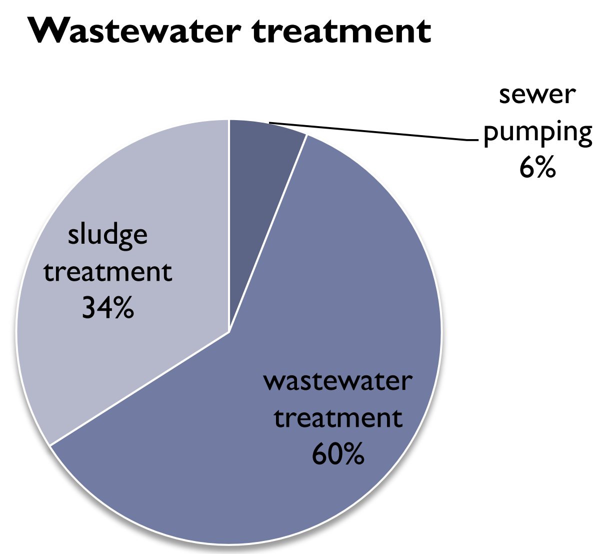
- Co-incineration with MSW
- Co-incineration in high energy demand plants
- incineration: large WWT plants
  costs evaluation
  environmental impact

Sludge Incineration: fluid bed reactor, atmospheric pressure



WT and WWT processes: energy demand





WT and WWT processes: energy efficiency

		max Energy savings:
General intervents:	maintenance optimization	5-10%
	optimization of buildings cooling/heating/lighting	10%
WT plants:	inverters on pumps	15-33%
	optimization of coagulant dose	5-35%
WWTPs:	inverters on pumps	<30%
	enhanced SS, COD, BOD removal in primary settling (+ coagulants)	25%
	high efficiency aeration devices	25%
	optimization of oxygen demand	15%
	control of process parameters (D.O., NH_4^+, NO_3^-)	20-30%
	optimization of mixed liquor recirculating flow rate	16%

- (Foladori, 2013)