Membrane Separation Technology

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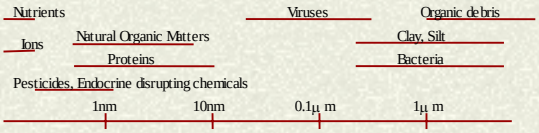
Tokyo Institute of Technology

Solute size and Separation size

Q: Please give appropriate sizes of ….

Bacteria	Sand
Virus	Silt
Nutrient	Clay

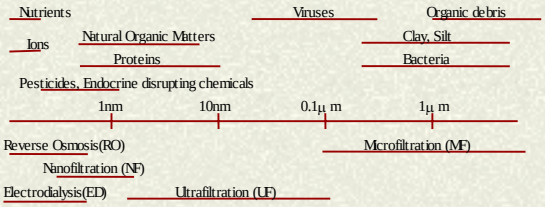
Solute size and Separation size



Please give appropriate separation sizes of …

Reverse Osmosis, Ultrafiltration, Microfiltration, Filter Papers

Solute size and Separation size



Categories of Membrane Processes

Pressure Driven Processes

-Reverse Osomosis, Ultrafiltration, Microfiltration

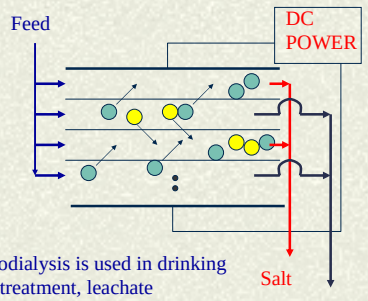
Other Processes

-Dialysis, Electrodialysis

Driving force is concentration difference

Driving force is electric potential difference

Electrodialysis



Electrodialysis is used in drinking water treatment, leachate treatment and other applications.

Membranes

- Porous vs Non Porous
- Hydrophilic vs Hydrophobic
- Charged vs Neutral
- Polymeric vs Inorganic

Membrane types

- Dense(Non porous)

RO, NF

Skin

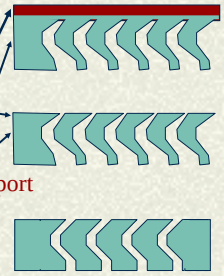
- Porous Asymmetric

UF, MF

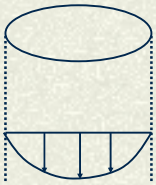
Support

- Porous Symmetric

MF



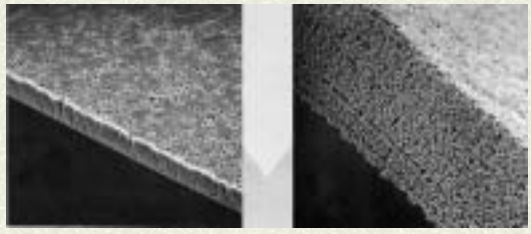
Model on flow in membrane pores



$$J_v = \frac{A_k \Delta P d_p^2}{32 \mu \Delta z}$$

J_v : Volume Flux
A_k : Pore Open Ratio
ΔP : Applied Pressure
d_p : Pore Diameter
μ : Viscosity
Δz : Membrane Thickness

Porous Symmetric Membranes

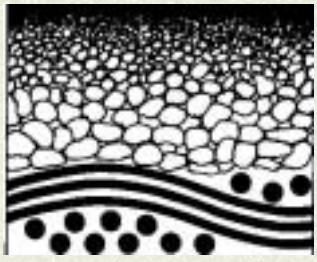


Nuclepore Membrane

Cellulose Membrane

From Catalog of Nuclepore

Asymmetric Membranes



Dense Layer

Porous support

Fiber Support

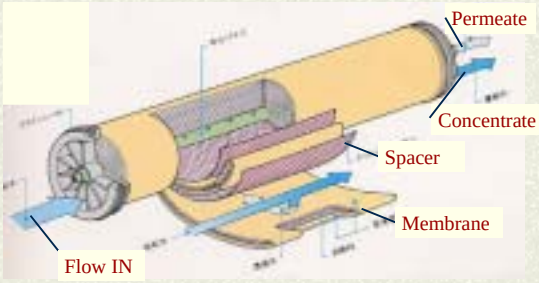
From Catalog of Toray

Modules

- Flat Sheet
- Spiral Wound
- Tubular
- Hollow Fiber

Contained vs Submerged

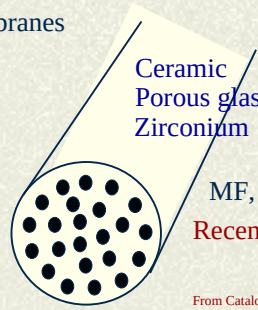
Spiral-Wound Module



From Catalog of Toray

Monolith

Inorganic Membranes

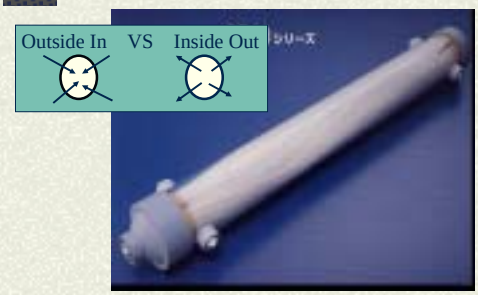


MF, UF

Recently NF

From Catalog of NGK

Hollow Fiber



From Catalog of Toray

Plate and Frame Module

UF

Polyacrylo nitrile(PAN)

Polyvinylidene fluoride(PVF)

Polysulfone(PS)

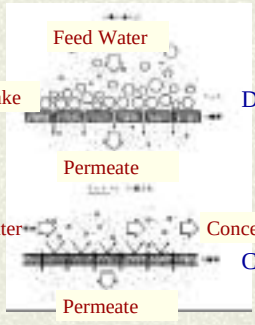
Sulfonated Polysulfone(SPS)

Building scale wastewater reclamation

Food processing

From Catalog of Mitsui Petrochemical

Crossflow and Deadend



Deadend Filtration

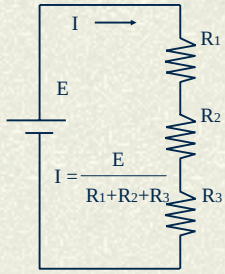
Suitable for low SS

Periodical Flushing

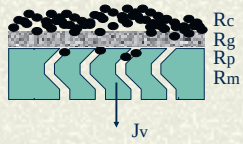
Crossflow Filtration

Continuous Operation

Resistance-in-Series Model



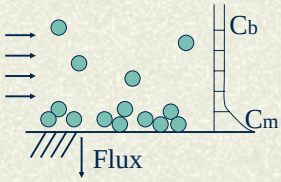
$$I = \frac{E}{R_1+R_2+R_3}$$



$$Jv = \frac{\Delta P}{\mu(R_c+R_g+R_p+R_m)}$$

Separation of resistance factors to Cake, Gel, Plugging, Membrane.

Concept of Film Theory



Difference in concentration between Cb and Cm is called concentration polarization

$$Jv = k \ln\left(\frac{Cm}{Cb}\right)$$

k: Mass transfer coefficient

Mass Transfer Coefficient

$$k = \frac{D\ (\text{Diffusion coefficient})}{\delta(\text{Thickness of polarization layer})}$$

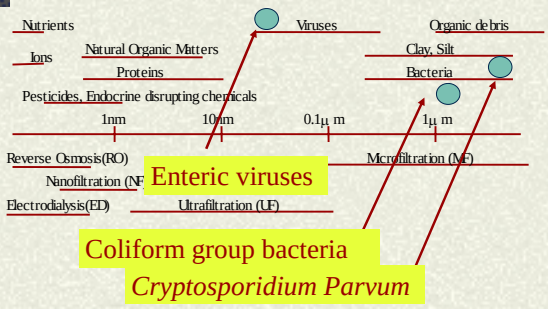
Laminar

$$Sh = 1.62\ Re^{0.33}\ Sc^{0.33}\left(\frac{dh}{L}\right)^{0.33}$$

Turbulent

$$Sh = 0.023\ Re^{0.8}\ Sc^{0.33}$$

Pathogenic Protozoa, Bacteria and Viruses



Pathogen removal

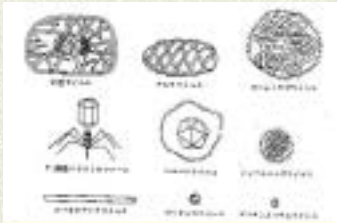
- Complete removal is expected for coliform group bacteria and for *Cryptosporidium* by membrane separation processes including MF, UF, and RO.
- This completeness of membrane processes is a great advantage for Membrane Processes.

Size of Viruses

Water-borne Diseases

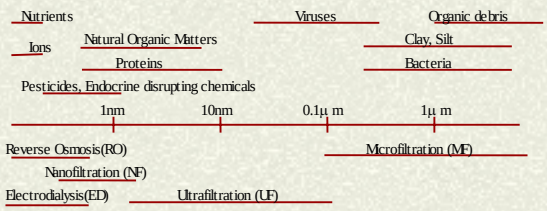
Enteric Virus

0.025μm

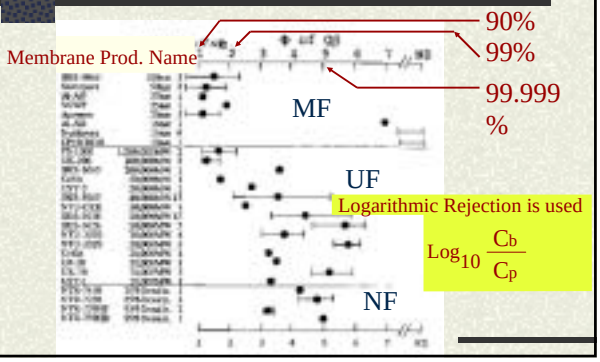


1μm

Solute size and Separation size



Our results:
Rejection of Qβ viruses (0.025μm)



Virus Rejection by Membranes

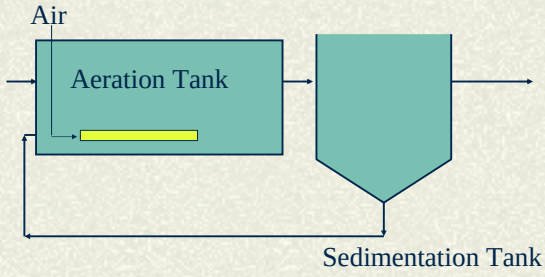
- Complete removal is difficult for viruses not only by MF, but by UF and RO.
- Possible reasons are:

  Pore size distribution

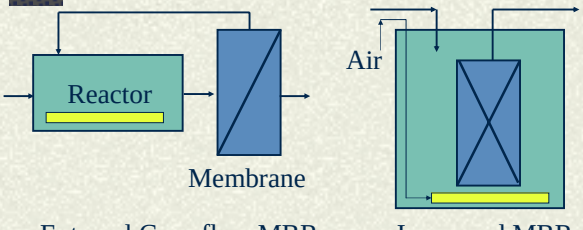
  Membrane defects
- Complete removal is also difficult for HPC bacteria (Normal bacteria) by membrane separation.

Application of membrane bioreactor to wastewater treatment

Conventional Activated Sludge Process



External Crossflow or immersed MBR



External Crossflow MBR Immersed MBR

Comparison Crossflow vs Immersed

	Flat Plate external crossflow	Tubular external crossflow	Immersed flat plate	Immersed hollow fiber
Packing Density	Moderate	Low	Moderate	High
Energy Consumption	Moderate	High	Low	Low
Fouling	Moderate	Good	Moderate	Poor
Cleaning		Good Sponge ball		Backwash

Recent applications

General Trends

UF tubular ⟶ Immersed MF
(External crossflow)

1980s Building Scale wastewater reclamation
1990s Night soil treatment
Drinking Water Treatment
2000s On site wastewater treatment
2005 ? Municipal wastewater treatment

Kubota Flat Sheet Membrane

Success in the business in UK

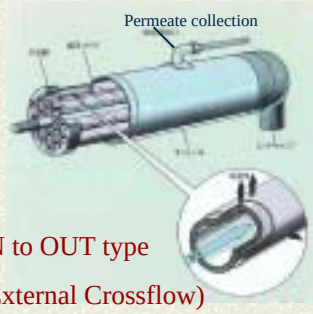
No suction pump but use of gravity force.

Low energy consumption
0.5 to 1 kWh/m^3

No need for further disinfection

From Kubota catalog

Kubota Tubular Membrane



OUT to IN type
(Immersed)

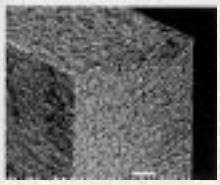
IN to OUT type
(External Crossflow)

Mitsubishi Rayon Hollow Fiber

Applications can be seen in food industries.

From Mitsubishi Rayon Catalog

Mitsubishi Rayon Hollow Fiber

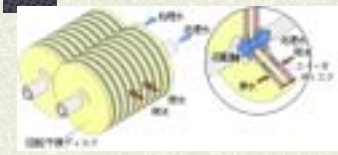


Pore size 0.4μm

Cross section

From Mitsubishi Rayon Catalog

Hitachi Plant Rotating Disk Membrane



High sheer rate

↓

Suitable for high concentration suspension

Zenon membrane

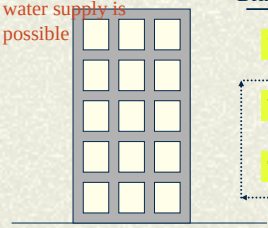
Zenon membrane

High Strength

From Nishihara Eisei Catalog

Building Scale Wastewater Reclamation

50% reduction in water supply is possible



Drinking Water

Used in Restaurants, Other Taps

Wastewater reclamation — By Membranes

Toilet flushing

Discharge to Sewer

Tokyo Metropolitan government and Fukuoka prefectural government set up a regulation that the building constructor should install wastewater reclamation

Possible process for Building Scale Wastewater Reclamation

Contact Aeration → UF → Activated Carbon

Membrane Bioreactor with External UF

Oil

Activated Sludge → Sand Filtration → Activated Carbon

Influent is usually restaurant wastewater and other wastewater

If influent contains toilet flush wastewater, color removal (ozonation etc.) is necessary to avoid unhappy appearance of the reclaimed water, even if it is used for toilet flushing.

Sanitation in Japan

Approximate population ratio in service in Japan

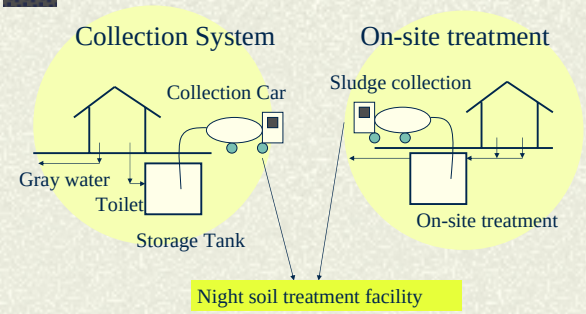
60% Public Sewerage System — Urban Cities

10% Community Plants

20% On-site Domestic wastewater treatment

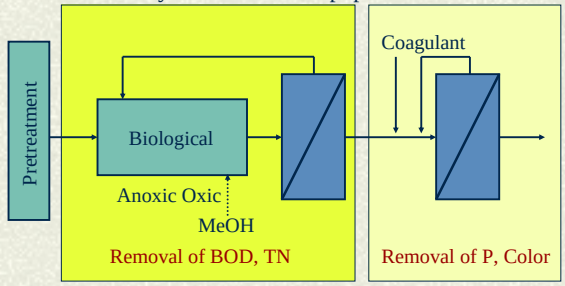
10% Storage and Collection — Rural area

Sanitation in rural area in Japan



Night Soil Treatment

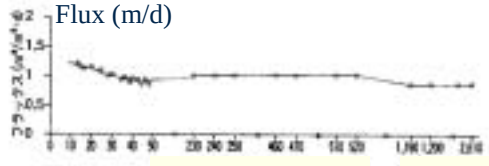
Membrane system is the most popular in the market.



Water quality in night soil treatment

	Raw Collected Human Excreta	Typical Effluent using membranes
BOD(mg/L)	5,000	1
COD(mg/L)	3,500(COD_{Mn})	50
SS(mg/L)	8,000	ND
TN(mg/L)	1,000	10
TP(mg/L)	140	0.5

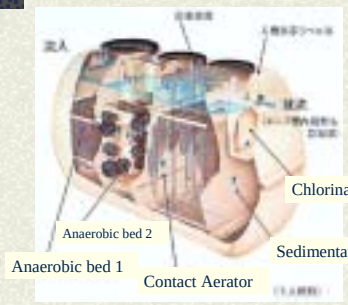
7 years operation in night soil treatment



Sponge ball cleaning and chemical cleaning is carried out.

From Fujise *et al*.

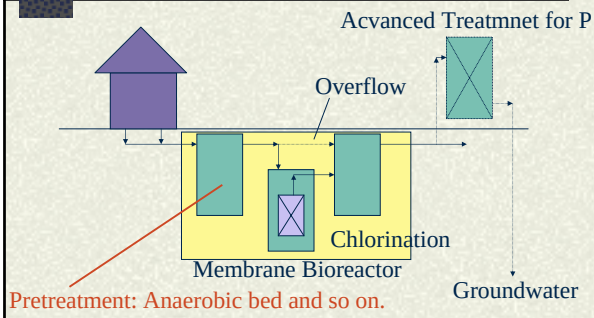
On-site domestic wastewater treatment



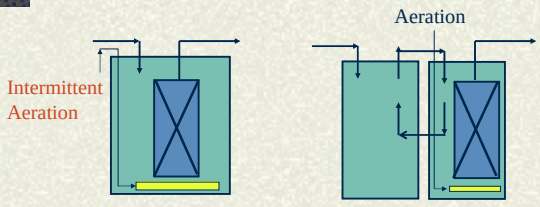
Anaerobic contactor - aerobic contactor system is the standard.

From Kubota catalog

On-site membrane wastewater treatment (Developing)



Nitrogen Removal



Removal of nitrogen is preferable for small scale treatment because we can discharge the treated wastewater to underground.

Nitrogen Removal 2

Membrane processes are used for small scale treatment because of low maintenance frequency.

In small scale treatment

Change in Water Quantity, Water Quality, and Water temperature is so large.

Stable nitrogen removal is difficult.

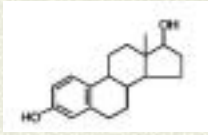
Reliable DO sensor without maintenance free and intelligent aeration control is necessary.

Removal of Endocrine Disrupting Chemicals

- MBR is suitable for treatment of biodegradable matter.

↓

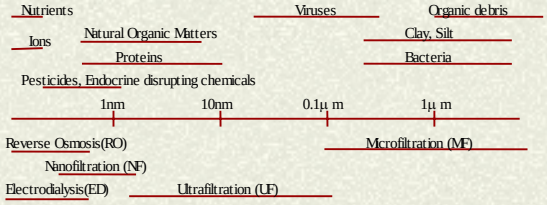
Does MBR show better performance for persistent organic compounds and endocrine disrupting chemicals ?



17β-estradiol

MF itself dose not reject EDCs.

Solute size and Separation size



Removal of Endocrine Disrupting Chemicals

- Better results will be expected by using membrane separation

Because

1. No SS in the effluent → Some of EDCs are adsorbed on sludge surface.
2. Formation of deposit layer → Change from MF to biofilm filtration
3. Long SRT → Retain microorganism with special functions

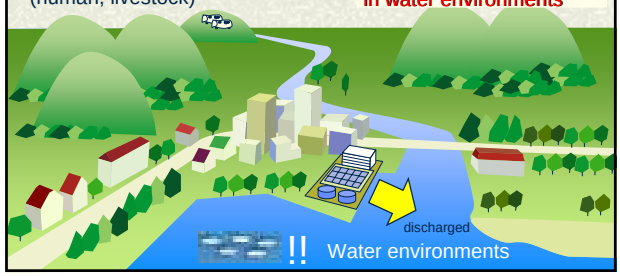
Confirmation is necessary

Background

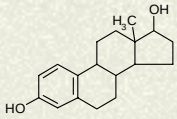
Female hormones contained in human's urine mainly contribute to disturbance of ecosystem in water environments

Female hormones

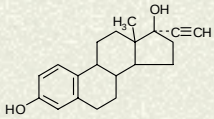
(human, livestock)



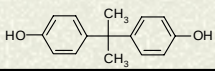
Target solutes



17β Estradiol(E2)
- Female hormone
- Strongest estrogenic activity



17α Ethynyl Estradiol(EE2)
- Synthetic female hormone
- Oral contraceptive (Pill)



Bis Phenol A(BPA)
- Typical artificial endocrine disrupters
- Raw material of polycarbonate plastic

Experiments

Artificial wastewater with E2,EE2,BPA were fed at t=0

Volume 20L

Sampling of mixed liquor

↓ Centrifugal separation

Conc. ↑ E2,E1, EE2,BPA, DOC

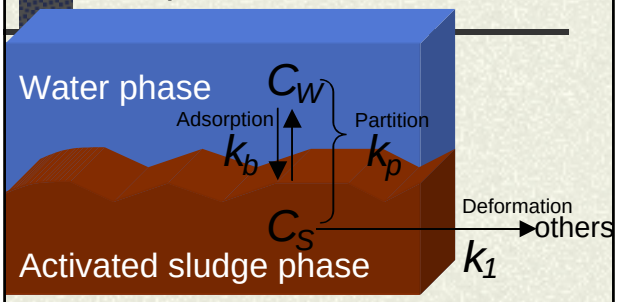
Time →

Separate measurement of water phase and activated sludge phase

Water Temperature : 15ºC

Measurements : dimethyl derivatization → GC/MS

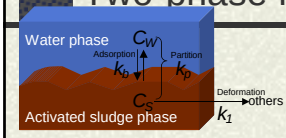
Two-phase fate model



C_W : Conc. in water phase

C_S : Conc. in activated sludge phase

Two-phase fate model



Reaction kinetics was considered

X : MLSS, β : Volume connection factor

Water phase

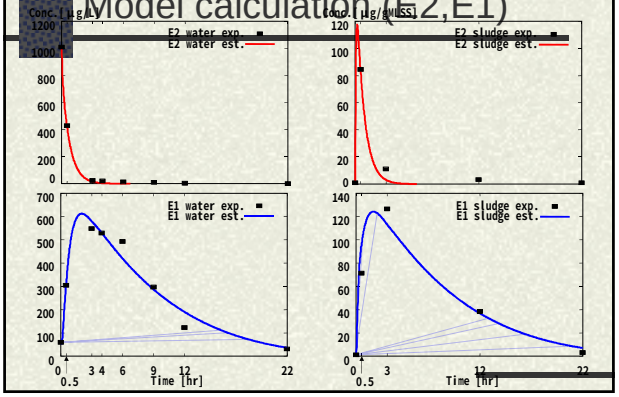
$$\frac{d(\beta C_W)}{dt} = -k_b(k_p C_W - C_S)X$$

Adsorption-desorption term | Degradation term

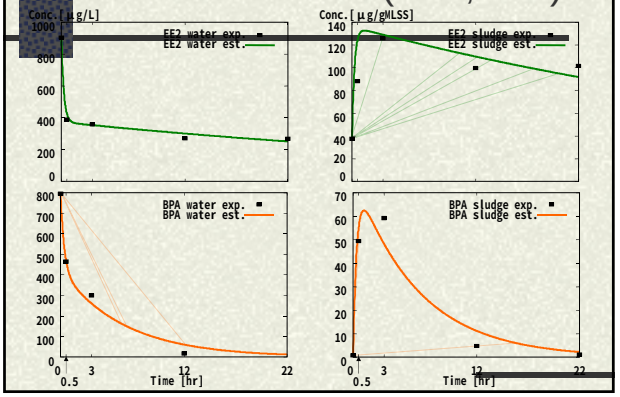
Activated sludge phase

$$\frac{d(C_S X)}{dt} = k_b(k_p C_W - C_S)X - k_1 C_S X$$

Model calculation (E2,E1)

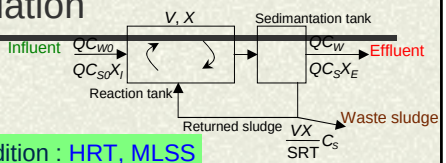


Model calculation (EE2,BPA)



Simulation

WTP modeling



Operating condition : HRT, MLSS

Water Phase

$$QC_{W0} - k_b(k_p C_W - C_S)XV = QC_W$$

$$HRT = V/Q$$

$$SRT = 1\Big/\left(\frac{YS_0}{X \cdot HRT} - k_d\right)$$

Activated sludge Phase

$$QC_{S0}X_I + k_b(k_p C_W - C_S)XV = k_1 C_S XV + (VX/SRT)C_S + QC_S X_E$$

Fate of E2

MLSS=1000mg/L

HRT=8hr

E2 100 → A S

E2	7.9	Water	
E1	26.3		
E2	0.1	Sludge	
E1	0.5		
Biodegradation	65.3		

Conclusion

- A two-phase model was successfully applied to the degradation of estrogens. Three parameters that are biodegradation constant, water-sludge partition constant and water-sludge transfer rate constant in this model were obtained for 17-beta-estradiol (E2), estrone (E1), 17-alpha-ethynylestradiol (EE2) and bisphenol A (BPA) by batch experiments.

Conclusion

- The simulation shows that the removal of E2 and of BPA increased with the increase in HRT and MLSS, though the removal of EE2 was less than 38% even at infinite SRT.
- The ratio of the compounds transferred to the excess sludge was low, because the target solutes have a relatively hydrophilic nature and tend to remain in the water phase.