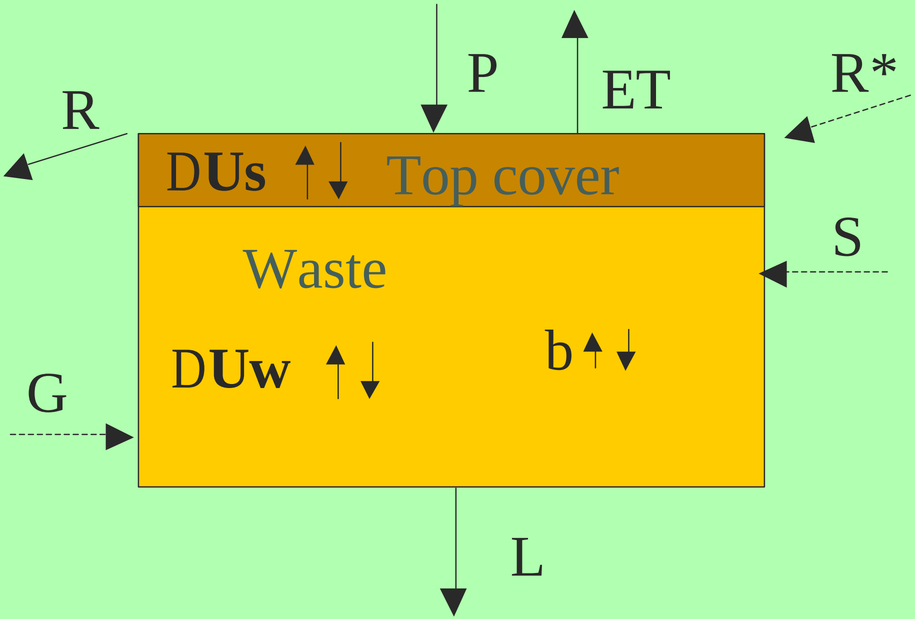
LEACHATE GENERATION, COLLECTION, AND TREATMENT

Prof. Raffaello Cossu, Dr. Roberto Raga

IMAGE Department – University of Padova, Italy

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

LEACHATE PRODUCTION



$L = P + S + G + R^* - R + \Delta U_s + \Delta U_w - ET + b$

L = Leachate generated

P = Precipitation (actually plus recirculated leachate and surface input)

S, G = infiltration from surface water or groundwater

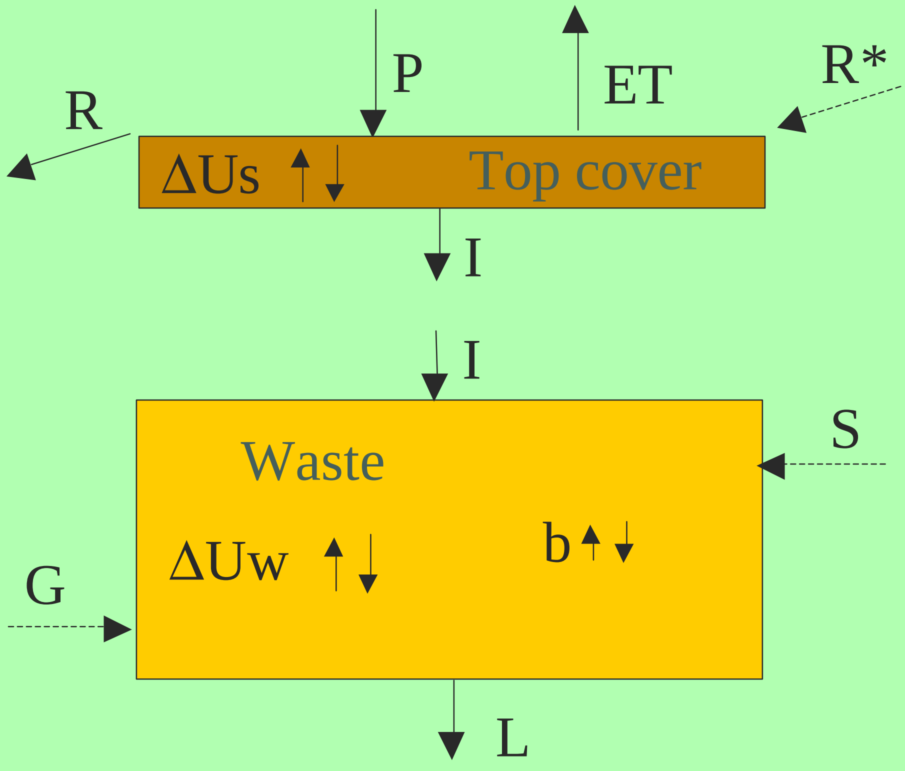
ΔU_s = Change in moisture storage in top cover

ET = Actual evapotranspiration

R, R* = Surface runoff

ΔU_w = Change in moisture content of refuse

b = biochemical water production or consumption



$I = P + R^* - R + \Delta U_s - ET$

SURFACE RUNOFF

$R = C \cdot P$

R = surface runoff (mm/d)

C = runoff coefficient

P = rainfall (mm/d)

$C = a \cdot b_i$

a – depends on the presence of the final cover, on the kind of materials used and on the slope.

b – depends on soil moisture content in the different months

RUNOFF COEFFICIENT $C = a \cdot b_i$

Empirical values for “a”

Landfill	type of soil	slope		
		<5%	5-10%	>100%
closed	sandy	0,05-0,10	0,10-0,15	0,15-0,20
	clayey	0,13-0,17	0,18-0,22	0,25-0,35
in operation	sandy	0,08-0,13	0,13-0,18	0,18-0,25
	clayey	0,16-0,20	0,21-0,25	0,27-0,38

Empirical values of “b” for Italy

Month	(b_i)	Month	(b_i)
January	1,60	July	0,29
February	1,80	August	0,29
March	1,43	September	0,46
April	0,97	October	1,20
May	0,89	November	1,40
June	0,37	December	1,60

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e Geotecnica
IMAGE

Evapotranspiration (ET)

- Potential ET (ET_{p}): Maximal ET from surface covered with a homogeneous, green crop with optimal water supply
- Governing factors:
  - Meteorological factors: Wind, Temperature, Relative humidity
  - Soil and plant factors: Type/state of crop, Soil type

Actual evapotranspiration

$$ET = ET_p \cdot U/FC$$

U actual moisture content
FC field capacity

POTENTIAL EVAPOTRANSPIRATION

Thorntwaite Formula:

$$PE_i = 16\left(\frac{10T_i}{I_T}\right)^a \cdot C_i$$

- PE_i = potential evapotranspiration of the i-month (mm/month)

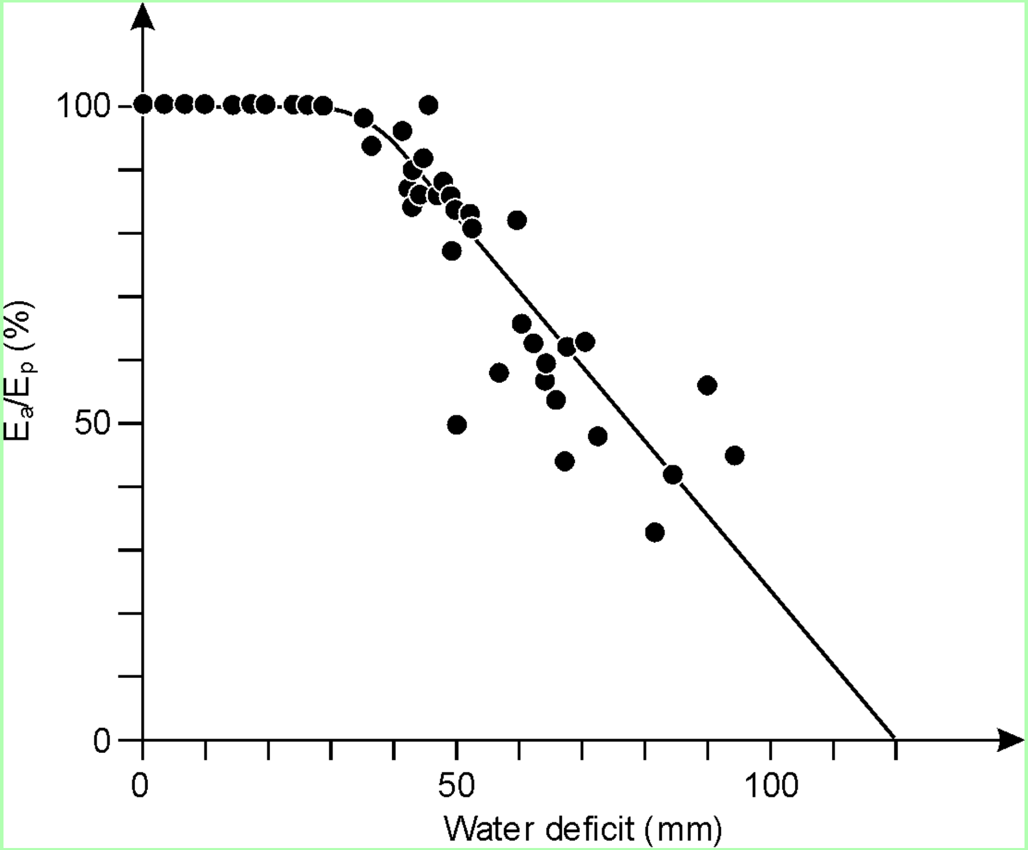
  T_i = monthly average temperature (°C)

$$I_T = \sum_{i01}^{12}\left(\frac{T_i}{5}\right)^{1,514}$$ = annual thermal index

$$a = 6,75\ 10^{-7}\ I_T^3 - 7,71\ 10^{-5}\ I_T^2 + 1,79\ 10^{-2}\ I_T + 0,49239$$

Ci = depends on hours of sunlight and on latitude

Actual evapotranspiration



Estimation of Leachate Volume

A rough estimation of leachate production may be given as a percentage of rainfall, as a function of waste density in landfill

low compacted landfill: 25 - 50 % of rainfall

high compacted landfill: 15 - 25 % of rainfall

As a consequence, for an average precipitation of 700 mm/y the leachate production expected is:

- low compacted landfill : 5 - 10 $m^3 / (ha \cdot d)$
- high compacted landfill : 4 - 5 $m^3 / (ha \cdot d)$

Leachate production and composition

Leachate production depends on:

Climate

Morphology of the underground

Composition and quality of waste

Landfill operation (daily cover, final closure)

Leachate Composition depends on

Composition and quality of waste

Emplacement technology

Emplacement speed

Water balance

Measures to be taken

Minimisation of leachate production (???)

Leachate collection at landfill base

Leachate discharge from landfill body to treatment plant

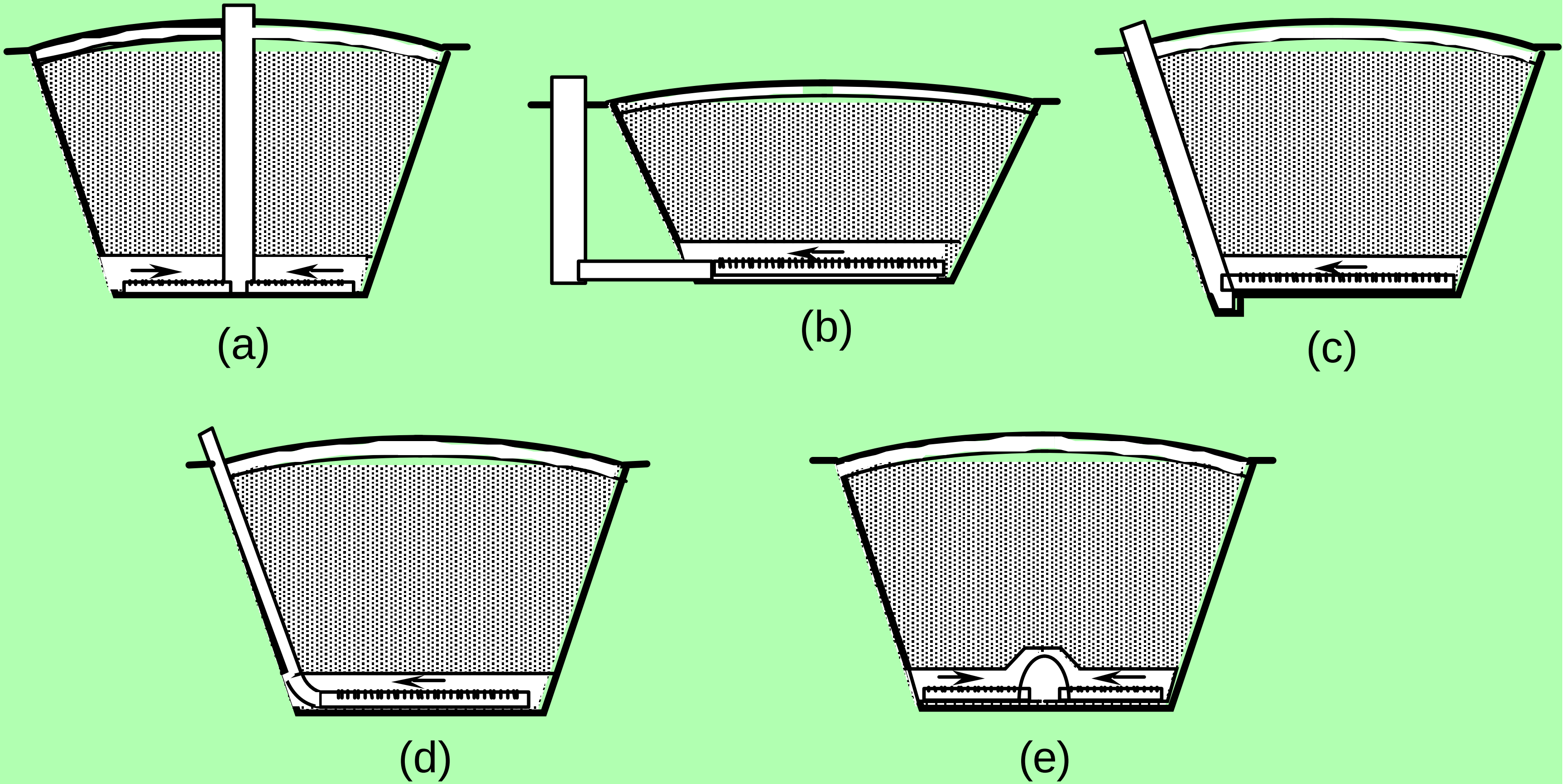
Minimization of the leachate head in the landfill body

Ramke: „Sickerwassersammlung und -ableitung“ in MHB, KZ 4545, 1998

LEACHATE COLLECTION

- Design strategies are addressed to minimize the transport of contaminants through the barriers to the environment.
- Drainage and collection systems are essential components in a containment landfill and can be considered as a barrier.
- When efficient they prevent leachate buildup and consequently decrease potential leakage to groundwater through the low permeability bottom liner.

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
I M A G E



Different possible configurations for leachate extraction wells: a = Central internal shaft; b= Lateral out-site well; c = Lateral slope internal shaft; d = Draining pipe - shaft; e = Tunnel

Dipartimento di Ingegneria Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

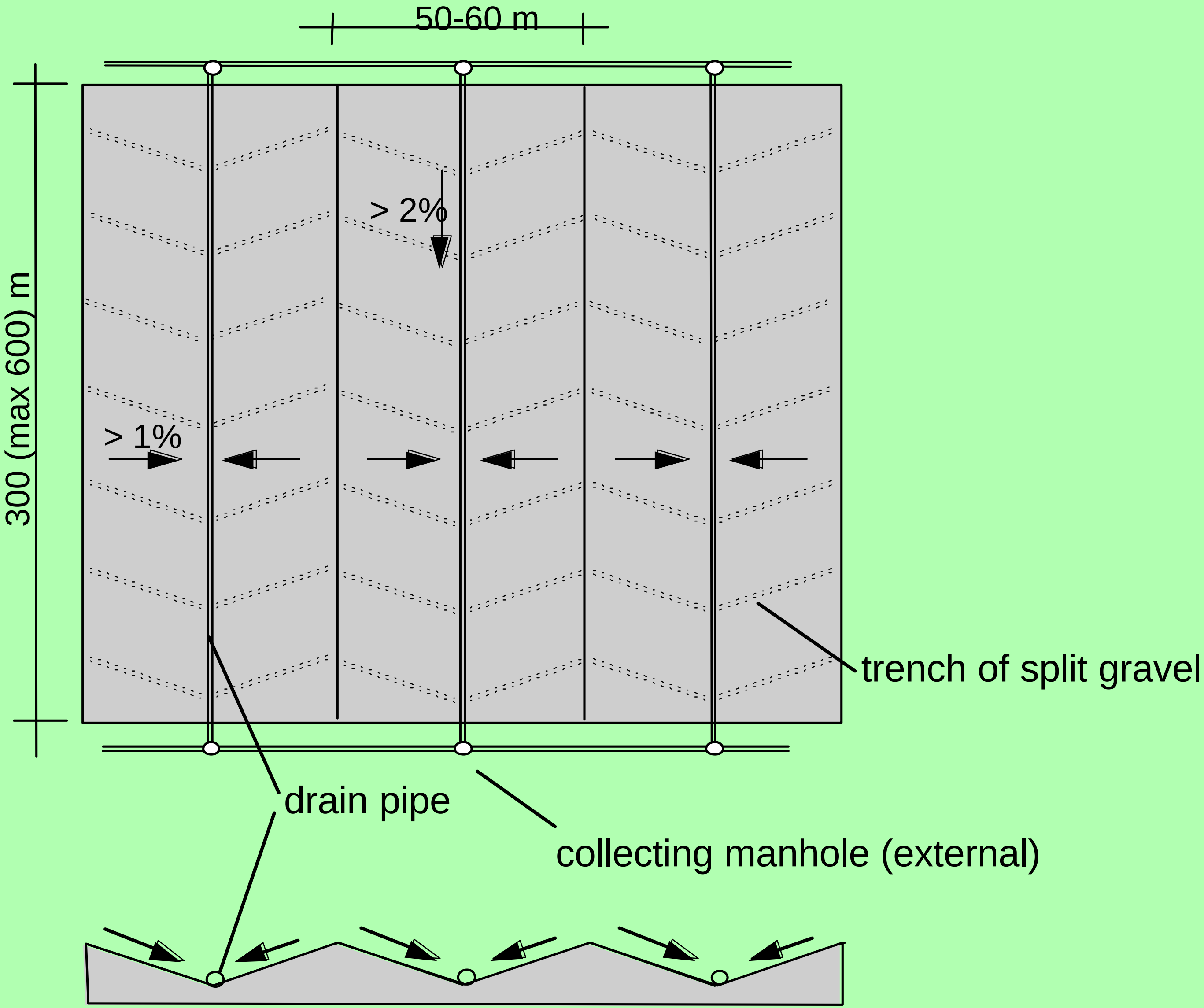
Engineering options to be employed for leachate collection
a) Drainage

- saw tooth configuration for the landfill bottom
- good longitudinal slope (> 2%)
- minimum cross slope of 1% (23% is desirable)
- use, at least for MSW landfills, of only granular material (gravel)
- high porosity of drainage layer
- thickness of the drainage layer > 50 cm
- clean gravel, possibly round shaped
- high grain size which is compatible with filter stability
- aerial distribution of the drainage. The filter should cover the entire area of the landfill bottom and slope
- split gravel trenches suitable for a drainage layer of fine material should be placed at a distance of 15 - 20 m and should have a minimum width of 2m
- avoidance of the use of any filter material (such as geotextiles) to "protect" the drainage from clogging They actually protect the filter too well!

Engineering options to be employed for leachate collection
a) Drain pipes

- short space between drain pipes (50 - 60 m)
- parallel straight line layout of drain pipes
- pipes should be accessible from outside the waste deposit
- pipe diameter should be larger than 200 mm
- pipeline should be designed according to a good pressure distribution under the given conditions
- reinforced drain pipe should be consequently adopted
- drain pipes should be controlled by a videocamera immediatly after implacement of the first waste lift. Mechanical failure caused by compaction can be easily repaired at this stage.
- regular flushing of drain pipes shoul be carried out as soon as possible as clogging deposits can be removed before concreting
- process enhancement, as discussed earlier, has a positive effect on the efficiency of drainage layer as the methanogenic leachate proved to be less clogging (Ramke,1989; McBean *et al.*,1993).

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e Geotecnica
I M A G E



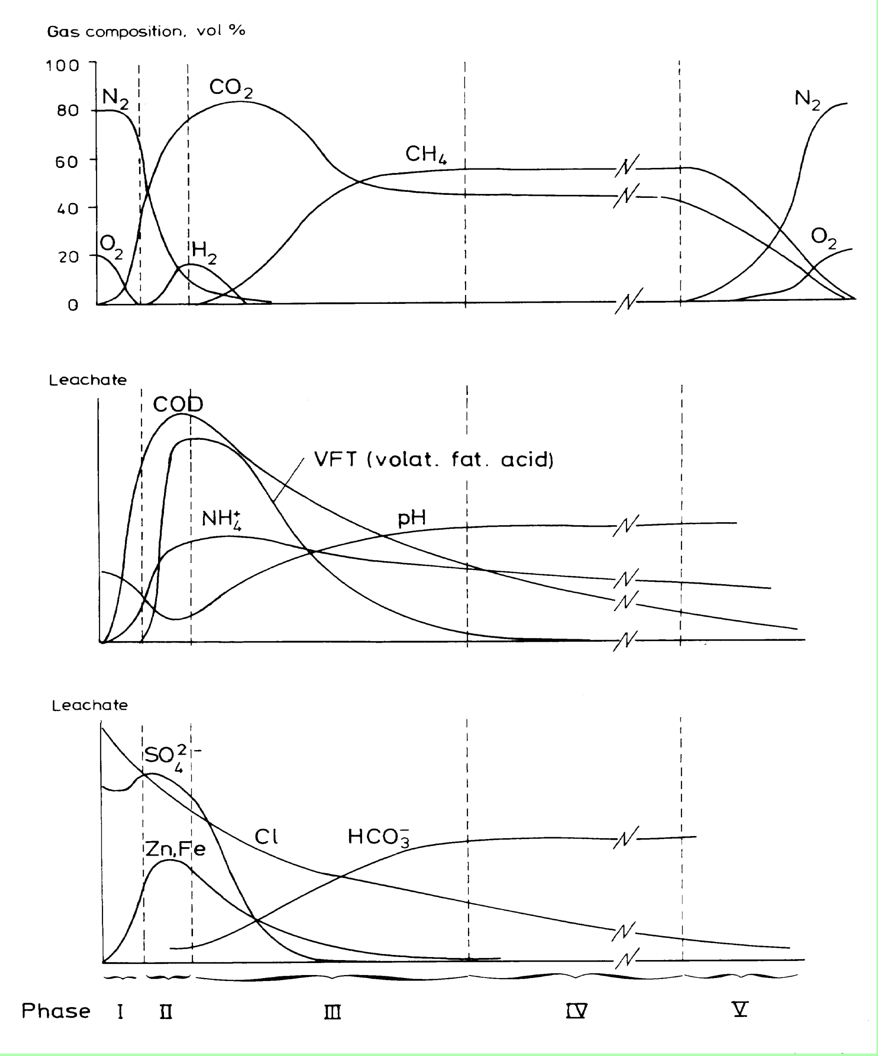
Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

LEACHATE QUALITY

Leachate and gas evolution in a landfill

(Kristensen & Kjeldsen (1989)

Phase I:
Aerobic phase
Phase II:
Acid phase
Phase III:
Intermediate methanogenic phase
Phase IV:
Stabilized methanogenic phase
Phase V:
Final aerobic phase

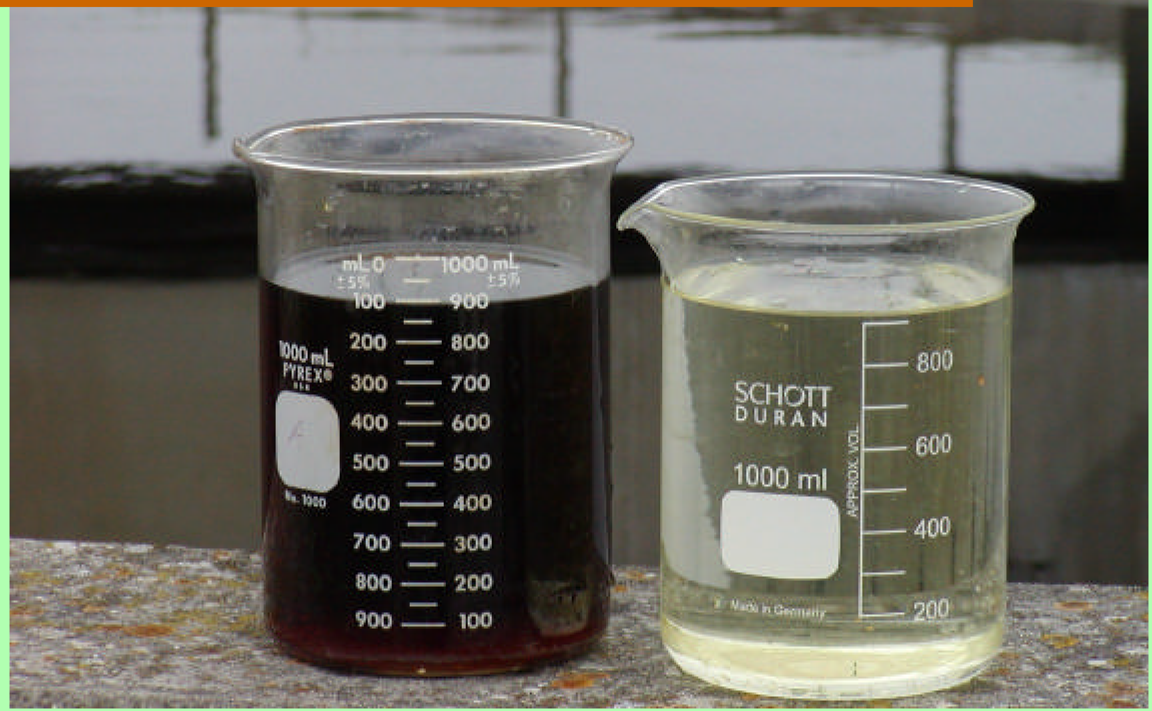


Dipartimento di Ingegneria Idraulica, Marittima, Ambientale e Geotecnica
I M A G E

Constituents in leachate (Ehrig 1990)

Parameter	Unit	Leachate from MSW landfills	
		Acid phase Range	Methanogenic phase Range
pH-value	-	4,5 - 7	7,5 - 9
COD	mg/l	6.000 - 60.000	500 - 4.500
BOD_5	mg/l	4.000 - 40.000	20 - 550
TOC	mg/l	1.500 - 25.000	200 - 5.000
AOX	µg/l	540 - 3.450	524 - 2.010
org. N[1)]	mg/l	10 - 4.250	10 - 4.250
NH_4-N[1)]	mg/l	30 - 3.000	30 - 3.000
TKN[1)]	mg/l	40 - 3.425	40 - 3.425
NO_2-N[1)]	mg/l	0 - 25	0 - 25 0
NO_3-N[1)]	mg/l	0,1 - 50	0,1 - 50
SO_4	mg/l	70 - 1.750	10 - 420
Cl	mg/l	100 - 5.000	100 - 5.000

LEACHATE TREATMENT



Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

LEACHATE TREATMENT

- Leachate treatment is a complex task because:
  - every landfill have different characteristics
  - flow rates and pollutant concentrations are variable with time and with the position
  - concentrations of some compounds might be very high
  - the nature of the contaminants may prevent the application of biological processes
- Treatment options:
  - on site treatment plant
  - combined treatment with sewage
  - leachate recirculation

LEACHATE TREATMENT

Treatment Methods

- Biological treatments (aerobic, anaerobic)
- Adsorption
- Chemical oxidation
- Membrane technology
- Evaporation
- Desiccation
- Stripping
- Flocculation / precipitation
- Filtration
- Sedimentation

Biological treatment

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
I M A G E

Biological treatment

- Objectives:
  - reduction of organic load
  - nitrification and denitrification
- Main control parameters: COD, BOD, ammonia nitrogen, heavy metals
- Need of flexible solutions due the variations of leachate quality and quantity.
- Less expensive than chemico-physical treatment processes, however the law limits cannot be reached when used as unique step
- No residues production except the biomass

ANAEROBIC TREATMENT

- Usually applied for young leachate and as pretreatment before aerobic treatment, as less sensitive to flow rate and load variation.
- Advantages:
  - methane production;
  - no need for aeration, limited energy required;
  - low sludge production
- Disadvantages:
  - sensitivity to pH, metals, phenols…
  - BOD, COD, and N-NH4 residual concentrations still too high
- The efficiency depends on volumetric load and temperature

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

Some important reactions for four groups of bacteria involved in anaerobic waste degradation

Fermentative processes	
$C_6H_{12}O_6 + 2H_2O$	$2CH_3COOH + H_2 + 2CO_2$
$C_6H_{12}O_6$	$CH_3C_2H_4COOH + 2H_2 + 2CO_2$
$C_6H_{12}O_6$	$2CH_3CH_2OH + 2CO_2$
Acetogenic processes	
$CH_3CH_2COOH + 2H_2O$	$CH_3COOH + 3H_2 + CO_2$
$CH_3C_2H_4COOH + 2H_2O$	$2CH_3COOH + 2H_2$
$CH_3CH_2OH + H_2O$	$CH_3COOH + 2H_2$
$C_6H_5COOH + 4H_2O$	$CH_3COOH + H_2$
Methanogenic processes	
$4H_2 + CO_2$	$CH_4 + 2H_2O$
CH_3COOH	$CH_4 + CO_2$
$HCOOH + 3H_2$	$CH_4 + 2H_2O$
$CH_3OH + H_2$	$CH_4 + H_2O$
Sulphate reducing processes	
$4H_2 + SO_4^{2-} + H^+$	$HS^- + 4H_2O$
$CH_3COOH + SO_4^{2-}$	$CO_2 + HS^- + HCO_3^- + H_2O$
$CH_3C_2H_4COOH + SO_4^{2-} + H^+$	$4CH_3COOH + HS^-$

$HCOOH$: formic acid,
CH_3COOH: acetic acid,
CH_3CH_2COOH: propionic acid,
$CH_3C_2H_4COOH$: butyric acid,
$C_6H_{12}O_6$: glicose,
CH_3OH: methanol,
CH_3CH_2OH: ethanol,
C_6H_5COOH: benzoic acid,
CH_4: methane,
CO_2: carbon dioxide,
H_2: hydrogen,
SO_4^{2-}: sulphate,
HS^-: hydrogen sulphide,
HCO_3^-: hydrogen carbonate,
H^+: proton,
H_2O: water.

(Kristensen & Kjeldsen (1989))

Dipartimento di Ingegneria Idraulica, Marittima, Ambientale e GEotecnica
I M A G E

Anaerobic treatment

•DIGESTORS:

Closed reactors continuously mixed by means of injection of the produced biogas; the temperature is kept above 20°C.

Higher efficiency in comparison to lagoons, but higher costs.

The efficiency of BOD and COD removal is about 80-90% in case of volumetric loads of about 1 kg COD/m^3d and for T=25-30 °C.

The precipitation of metals as sulphides may reach an efficiency of 90%.

Residence time:

- Digestors: 12-15 d
- Lagoons: 20-40 d

Anaerobic treatment

•UASB Reactors:
Leachate is pumped from the bottom of the reactor, through a filter of porous media with high specific surface, where the biomass is attached.

Advantages: higher biomass concentration and thus treatment of leachate with higher organic volumetric load (up to 4 kgCOD/$m^3 \cdot d$), lower retention times, lower volumes and higher biogas production (about 6 liters of biogas per liter of leachate).

Disadvantages: higher costs for plant installation, partly offset by energy recovery from the biogas.

Dipartimento di Ingegneria Idraulica, Marittima, Ambientale e GEotecnica
I M A G E

APPLICATION OF REMOVAL KINETICS

COD removal was found to follow a first order rate equation such that removal rate was independent of the initial COD concentration.

$-d[COD]/dt = K[COD]$

where
[COD] = initial COD concentration (mg/litre)
t = retention time (days)
K = reaction constant (day-1)

Integrating eqn (1) between the initial time (to) and time t yields

$\ln[CODt/[COD]o = -Kt$

Experimental values

$k\ 25° = 0{,}0317\ d^{-1}$
$k\ 10° = 0{,}0083\ d^{-1}$
$k\ 4° = 0{,}0012\ d^{-1}$

Using the relationships described above, an expression can be derived linking the mean operating temperature and the target percentage COD removal (ηCOD) to the volume of a suitable anaerobic lagoon

$\eta COD = [COD]o - [COD]t/[COD]o$

$\eta COD = 1 - e^{-Kt}$

If Q equals the daily leachate flow (m3/day) and V is the volume of the anaerobic lagoon, then rearranging and substituting V/Q for t:

$V = Q \ln(1 - \eta COD)/K$

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

$$V = Q \ln (1 - \eta COD)/K$$

Mean daily flow from a hypothetical landfill receiving a mean annual rainfall of about 700 mm/year has been estimated to be approximately 3 m3/ha day (Ehrig). Extrapolating this figure to a 10-ha site, daily flow would be around 30 m^3. A relationship between leachate temperature and lagoon volume for a range of treatment efficiencies is shown.

Estimates of lagoon volume for a 30 m3/day leachate flow under different temperature conditions for a range of treatment efficiencies

Target COD removal (%)	**Lagoon volume ($m^3 \times 10^3$)**		
	4 °C	**10 °C**	**25 °C**
10	2.63	0.38	0.01
25	7.19	1.04	0.27
50	17.3	2.51	0.66
75	34.7	5.01	1.31
90	57.6	8.32	2.18

AEROBIC TREATMENT

- Suitable for the treatment of young leachate.
- The processes are more rapid than anaerobic ones but more expensive, due to the need of providing aeration.
- Less sensitive than anaerobic ones to the presence of inhibitors such as heavy metals, phenols, sulphides, ammonia…
- Much sensitive to load fluctuations.
- Removal efficiency for COD e BOD: 98-99%; ammonia nitrogen: 90% when NH_4 in the leachate is below 100-200 mg/l and 80% when above 500 mg/l.

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e Geotecnica
IMAGE

Aerobic degradation reactions

aerobic degradation

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

Nitrification

$$NH_4^+ + 2\ O_2 + 2\ HCO_3^- \rightarrow NO_3^- + 2\ H_2CO_3 + H_2O$$

Denitrification

$$5\ C_6H_{12}O_6 + 24\ NO_3^- \rightarrow 30\ CO_2 + 18\ H_2O + 24\ OH^- + 12\ N_2$$

Albers, Ehrig, Mennerich : Sickerwasserreinigung. Müll-Handbuch. 4588. Lfg. 1/91. Erich Schmidt Verlag. Berlin

Aerated Lagoons

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
I M A G E

AEROBIC TREATMENT
Aerated Lagoons

Depht: 2-6 m

Aerobic conditions obtained by means of turbines.

No recirculation, the volume has to guarantee retention times high enough for biomass growth.

Very high efficiency for BOD/COD>0,4; T>20°C; 20-30 day retention time; volumetric load 1-1,5 kgCOD/m^3d

The efficiency depends on temperature, on volumetric load and retention time (t).

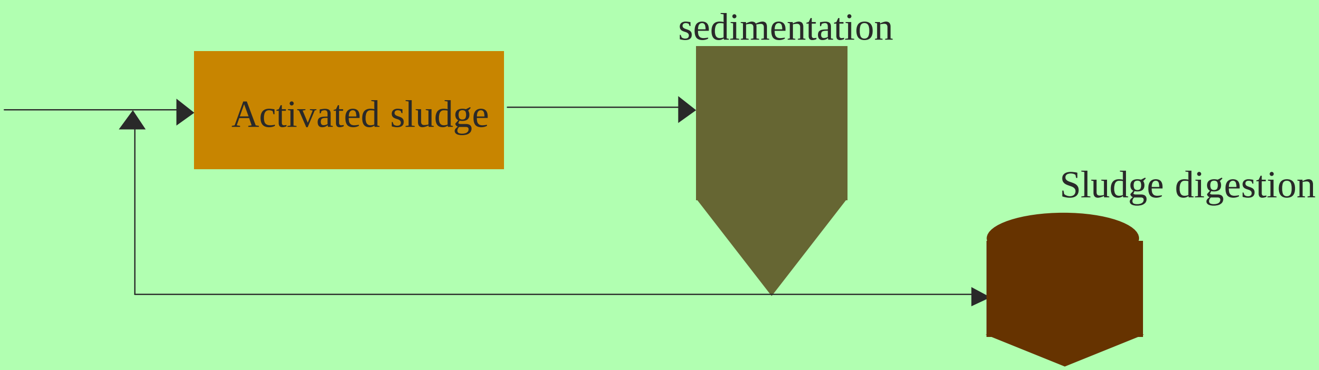
High efficiency for nitrification for retention times > 20 d

Metal removal due to precipitation as hydroxides.

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e Geotecnica
I M A G E

Activated sludge processes

Detention time considerably shorter than in aerated lagoons as the sludge content can be controlled and is 3-5 times higher. This is achieved by installing a settling tank and recirculating the sludge back into the activated sludge tank.



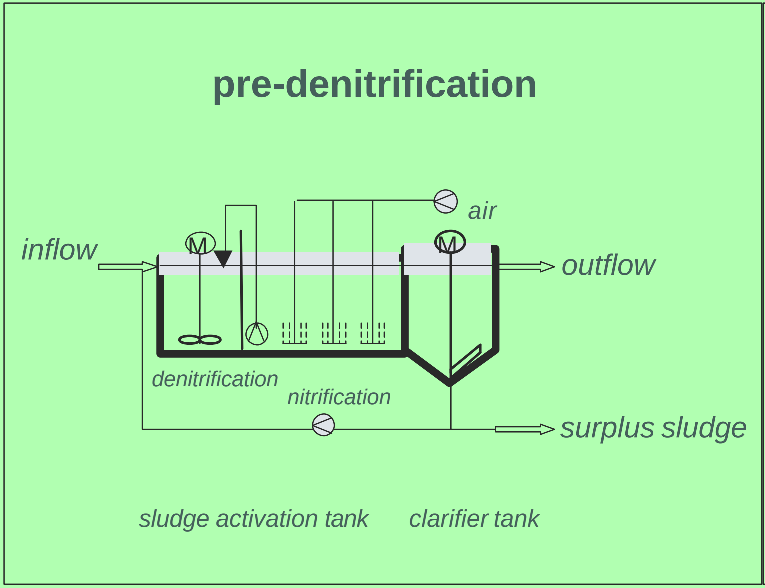
F/M = 0.02 – 0.05 kg BOD_5/kgMLSS·d

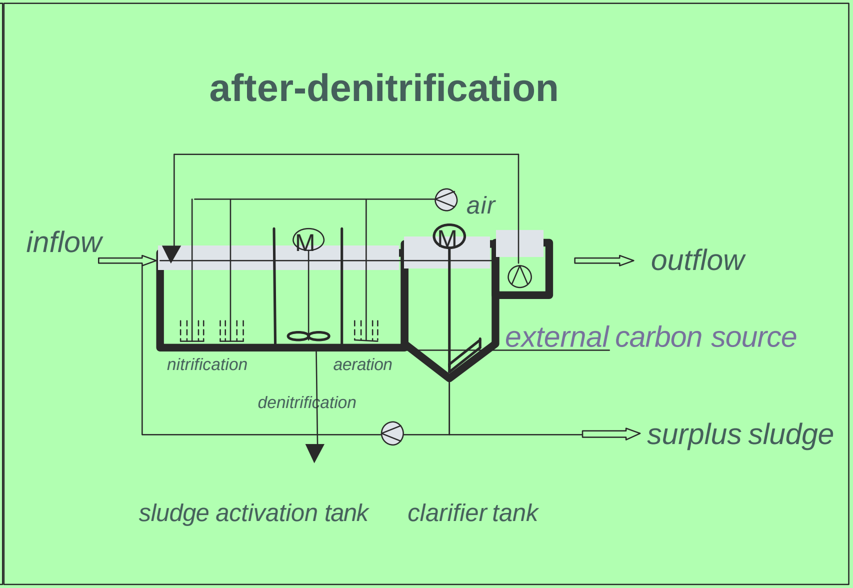
Volumetric Load: 0.2 – 0.6 kg $BOD_5/m^3\cdot d$

Effluent: $BOD_5 < 25$ mg/l

Activated sludge processes

NITRIFICATION OF AMMONIA





In general, complete nitrification can be observed at N-loading rates lower than 0,03 kgN/kg MLSS·d. A denitrification step is necessary also.

Aerobic treatment

Rotating biological contactors (RBC):

This process differs form the activated sludge process in so far as the bacteria are attached to the rotating contactors. The air supply takes place naturally, i.e. the rotating contactor is partly in the air and partly in the water.
Low amount of energy required.

Main advantage: high efficiency (up to 95%) for nitrification.

In order to avoid toxic nitrite concentrations, the nitrogen loading should not exceed 2g $N/m^2 \cdot d$

Some authors report that about 95% of ammonium concentrations are oxidized also when high loading rates are present (> 10 g $N/m^2 \cdot d$).

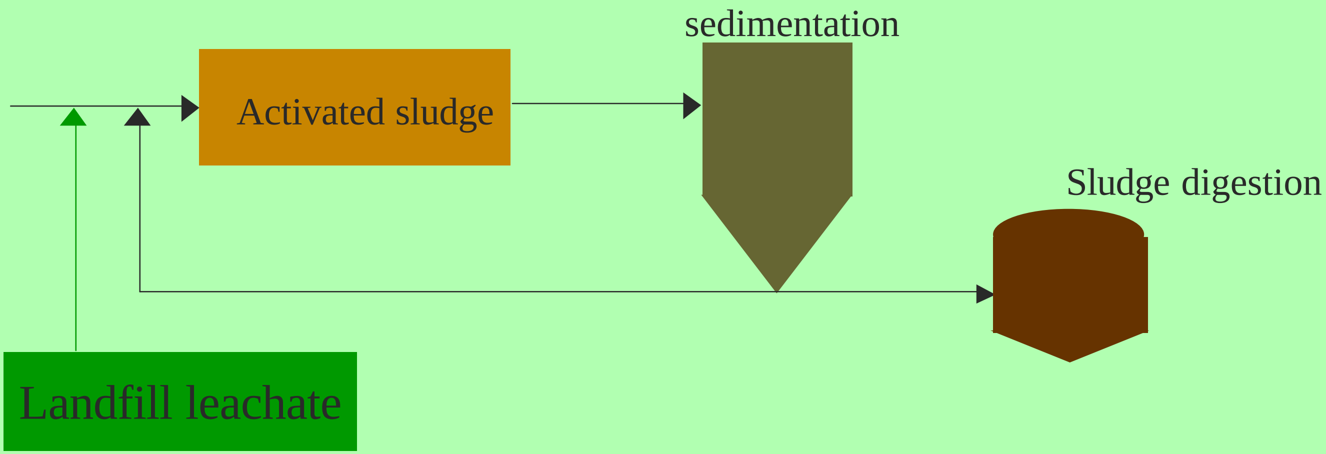
Aerobic treatment
Trickling filters

In trickling filters air vents from the bottom to the top through a filter of porous media with high specific surface, where the biomass is attached. Leachate is sprinkled on the surface and the treatment occurs during the percolation through the filter material. When treating highly organically-polluted leachate, clogging by inorganic precipitates or produced biomass may occur.

Good efficiency of nitrification (up to 95%), proved for leachate with the following characteristics:

Ammonia nitrogen: 200-600 mg/l;
BOD: 80-250 mg/l;
COD: 850-1350 mg/l;

CO-TREATMENT IN DOMESTIC SEWAGE FACILITY

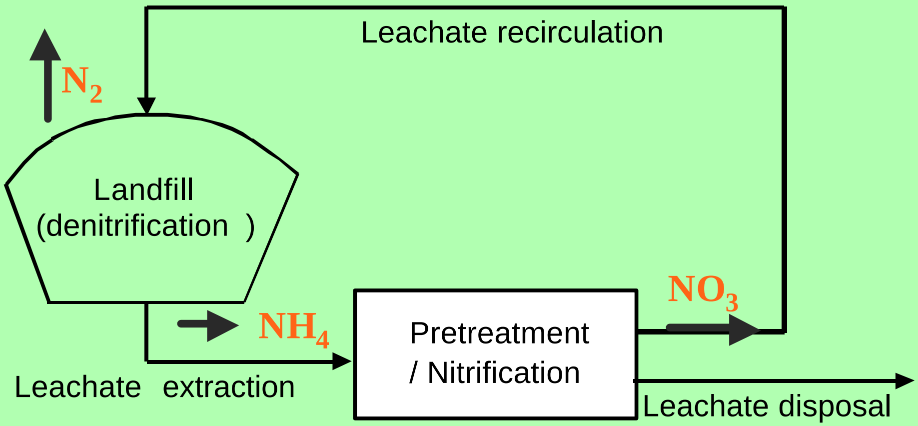


Problems:

Organic load
Dilutions of metals and AOX
Nitrogen and Phosphorous

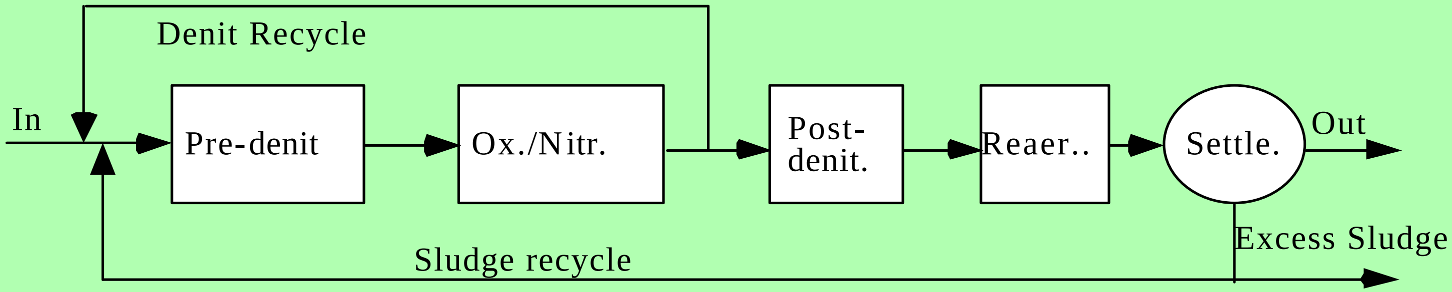
LEACHATE RECIRCULATION

- Reduction of the amount of leachate to be treated by increasing evapotranspiration
- Reduction of the organic content of leachate and of the cost for treatment
- Enhancement of degradation processes by increasing water content and supply and distribution of nutrients and biomass
- Dilution of locally high concentrations of inhibitors
- Possible recirculation after nitrification

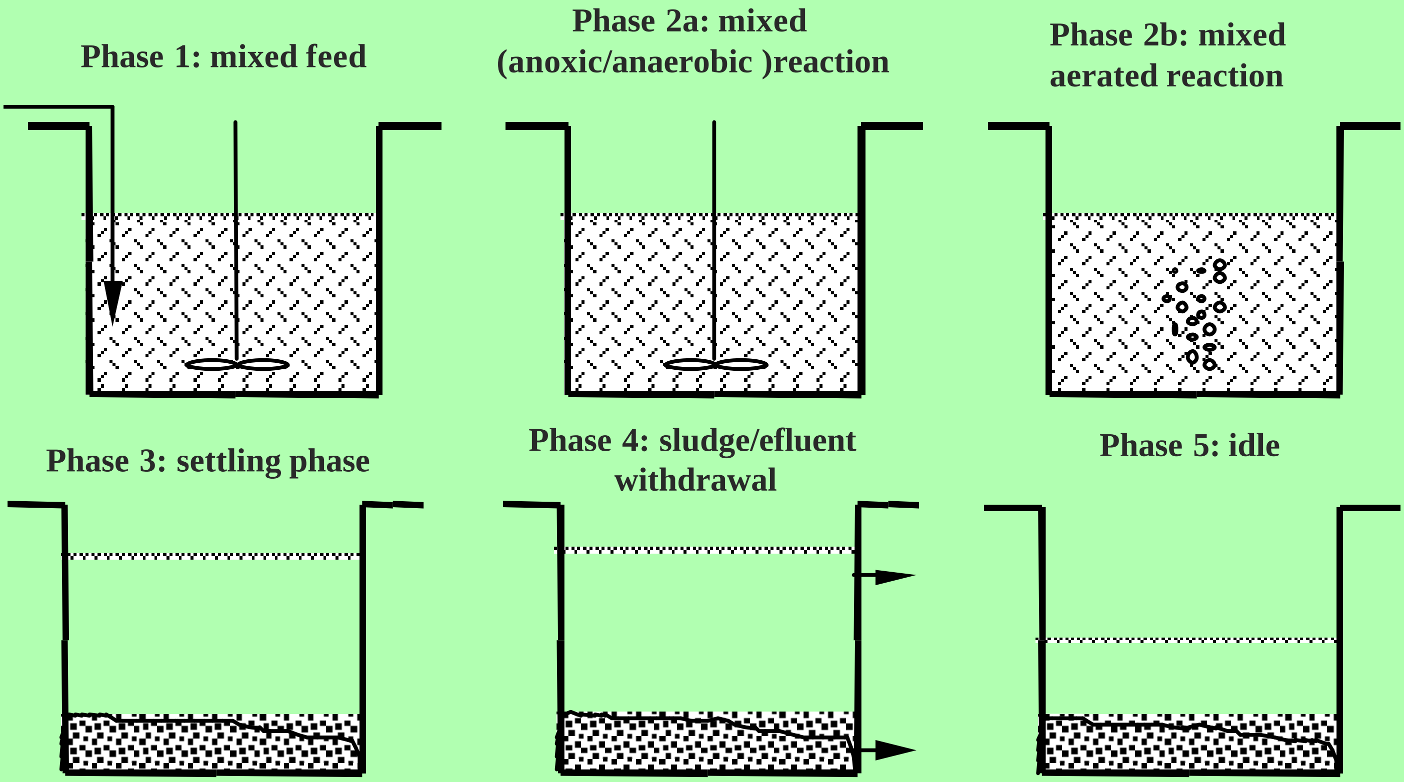


SBR

SBRs perform in a single reactor, during temporised cycles, the same reactions that the continuous flow treatment trains do in different reactors



SBR phases



Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

Plant under construction, showing the twin raw leachate balancing tanks, three large SBR tanks, and effluent balance tank and reed beds top right (Robinson, Sardinia 2003)

Effluent balance tank, and recently planted reed beds (Robinson, Proceedings Sardinia 2003)

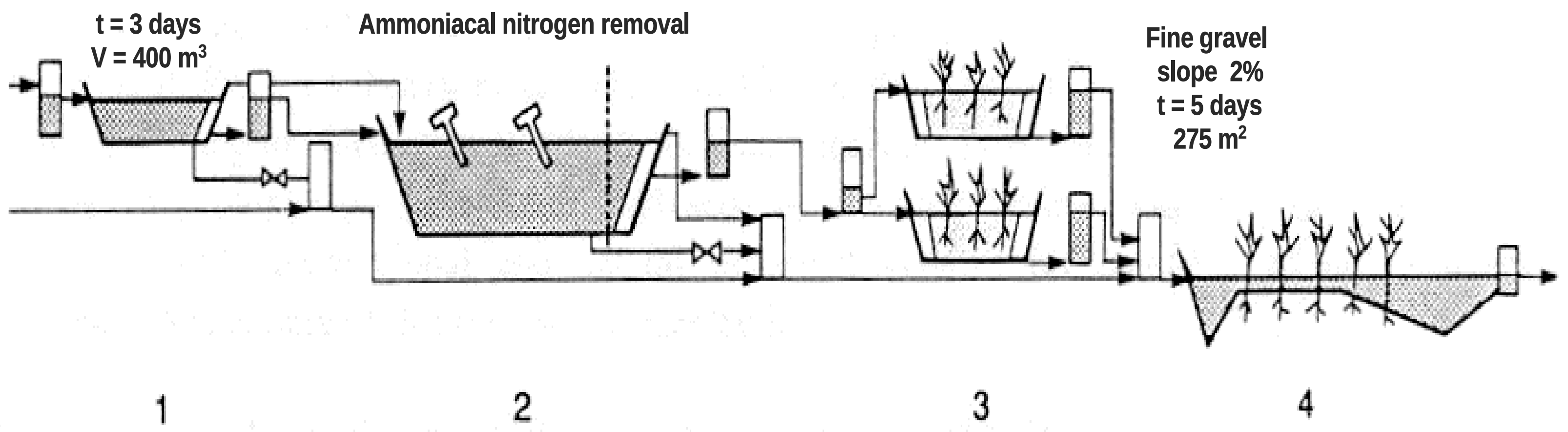
PLANT PERFORMANCE

Determinand	Influent leachate	Effluent
COD	4730 – 5990	1010
BOD_5	537 – 688	<1
ammoniacal-N	1240 - 1460	1.5

The effluent from the plant is polished by passage through a series of terraced reed beds, a wholly natural process in which the reed plant rhizomes provide additional treatment to high standards, before final effluent is discharged into the Mersey river at typical rates of 10 – 20 cubic metres per hour (Robinson, Sardinia 2003).

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e Geotecnica
IMAGE

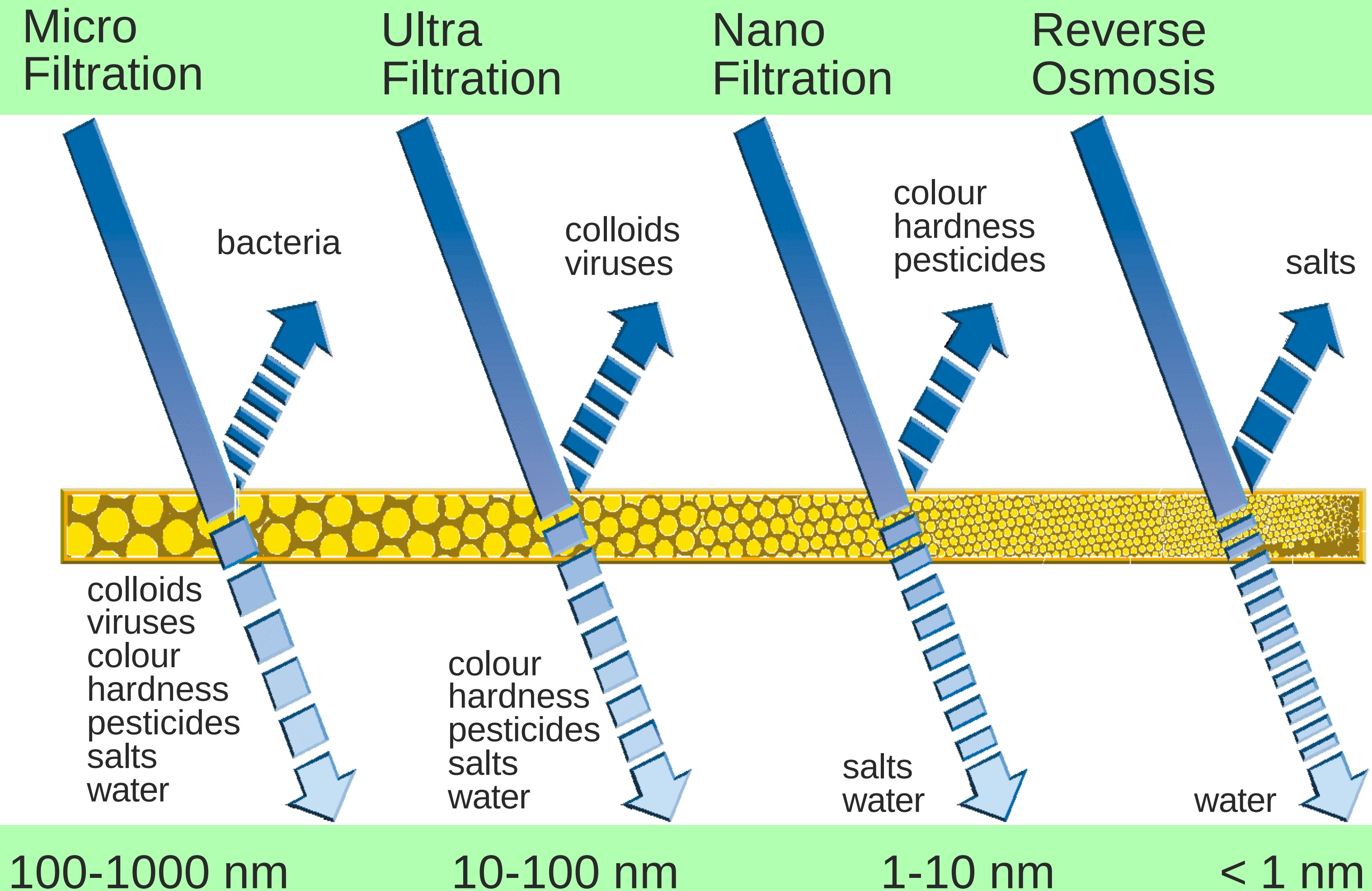
Leachate treatment plant of Esval



1 - anaerobic lagoon 2 - aerobic lagoon
3 - two parallel CWs wit subsurface flux 4 - terminal surface flux CW
Efficiency for BOD_5 and NH_3 is 60-90% depending on season (Maelun - 1995)

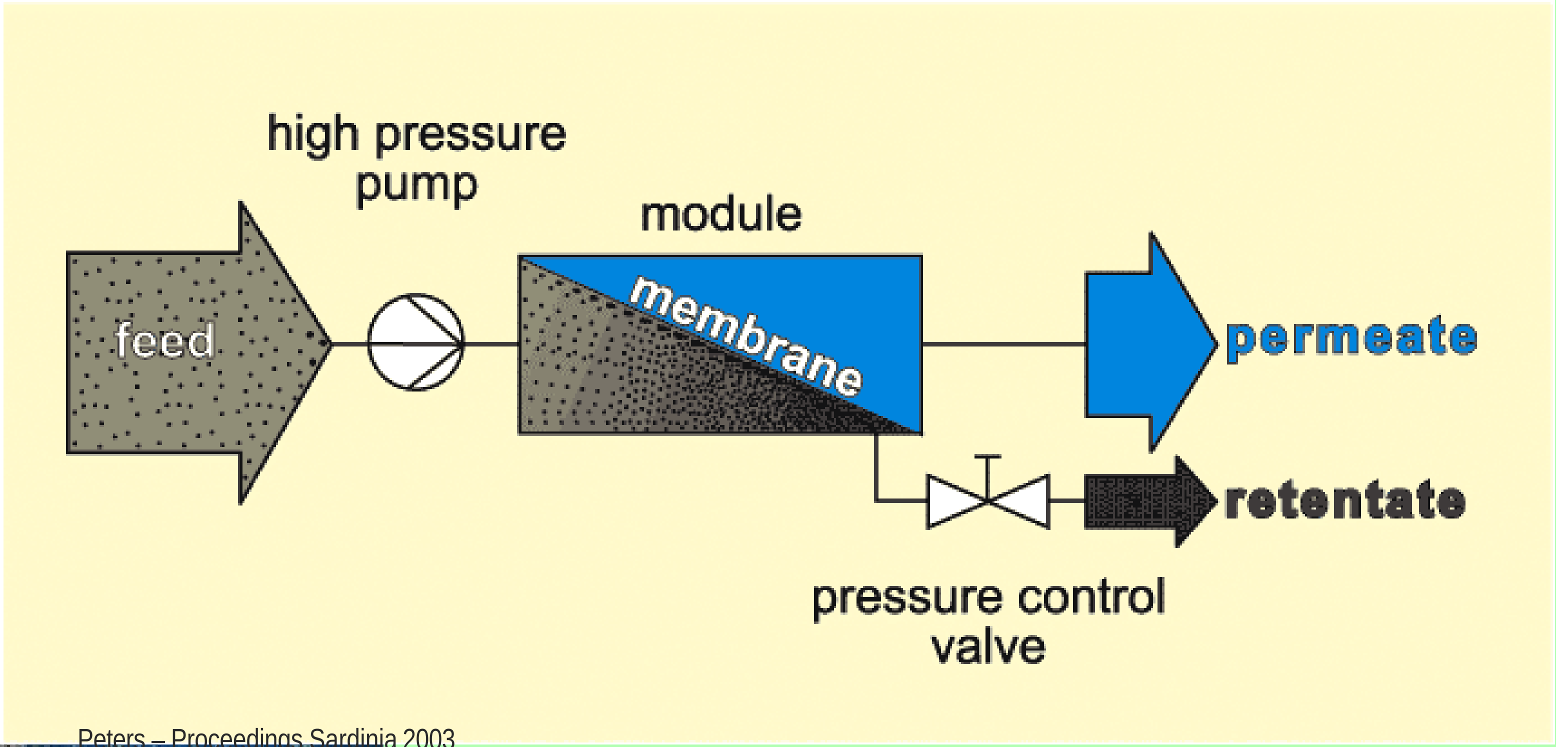
Dipartimento di Ingegneria Idraulica, Marittima, Ambientale e GEotecnica
I M A G E

FILTRATION TECHNIQUES



REVERSE OSMOSIS

The residual contaminants of biologically treated leachate might be concentrated by reverse osmosis and evaporation.
The overall treatment process and specially the residue discharge are expensive.



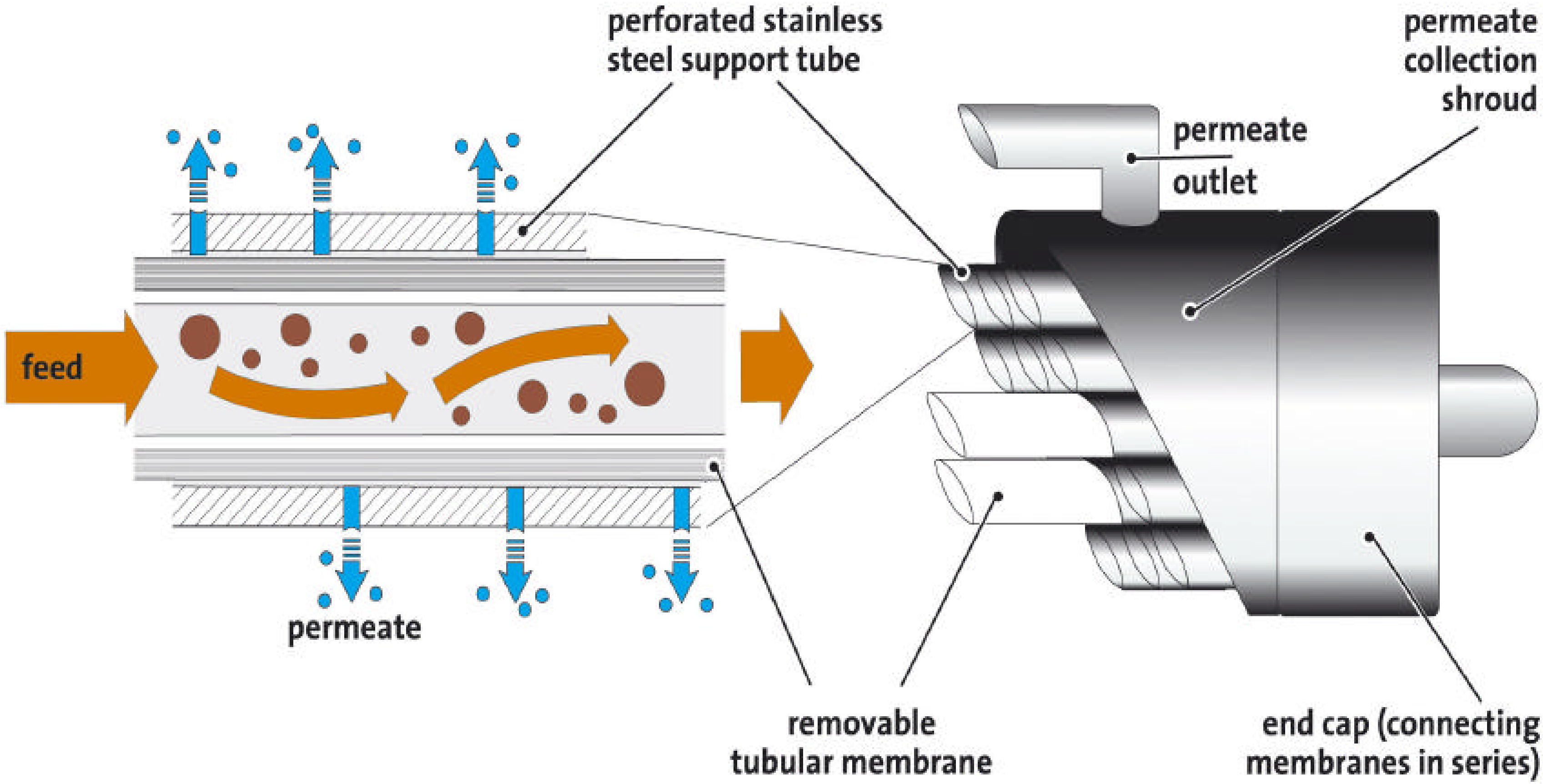
TYPICAL RO PLANT PERFORMANCE IN LEACHATE PURIFICATION

PARAMETER	leachate	permeate I	permeate II	rejection in%
pH-value	7.7	6.8	6.6	
el. conduct.*	17,250	382	20	99.9
COD in mgO_2/l	1,797	< 15	< 15	> 99.2
ammonium mg/l	366	9.8	0.66	99.9
chloride mg/l	2,830	48.4	1.9	99.9
sodium mg/l	4,180	55.9	2.5	99.9
heavy metals #	0.25	< 0.005	< 0.005	> 98

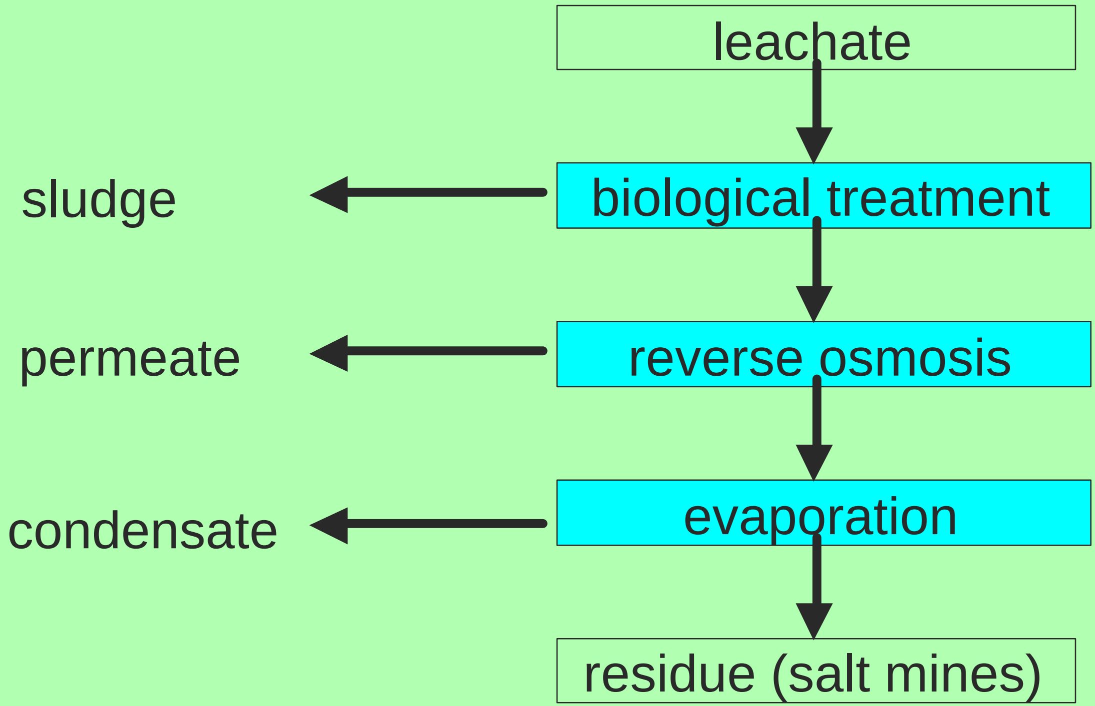
* = µS/cm   # = mg/l

Peters – Proceedings Sardinia 2003

TUBULAR MODULE



Scheme of the reverse osmosis – evaporation plant



Woelders – Proceedings Sardinia 2003

Dipartimento di Ingegneria Idraulica, Marittima, Ambientale e GEotecnica
I M A G E

REVERSE-OSMOSIS

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
I M A G E

EVAPORATION PLANT

Dipartimento di Ing...
Idraulica, Marittima, Ambientale e Geotecnica
IMAGE

COLORS

influent NF   effluent NF

parameter	*unit*	*cleaning efficiency [%]*		
		reverse osmosis		*nanofiltration*
		one-stage	*two-stage*	
ammonium	[mg / l]	86,0 – 94,0	98,0 – 99,6	ca. 5 – 40
nitrate	[mg / l]	86,0 – 90,0	98,0 – 99,0	ca. 5 – 40
conductivity	[µS / cm]	84,0 – 95,0	97,4 – 99,7	ca. 5 – 40
COD	[mg / l]	90,0 – 96,0	99,0 – 99,8	ca. 85 – 95
BOD	[mg / l]	90,0 – 96,0	99,0 – 99,8	ca. 80 – 90
AOX	[mg / l]	90,0 – 94,0	99,0 – 99,6	ca. 80 – 90
heavy metals	[mg / l]	86,0 – 90,0	98,0 – 99,0	ca. 80 – 95

Dahm, Kollbach, Gebel: „Sickerwasserreinigung", 1994

Adsorption

Treatment of old leachate or of biological pretreated leachate
Low efficiency with volatile acids due to polarity
Removal of low biodegradable compounds (Residual-COD and AOX)
Removal of heavy metals
High efficiency at low pH
Removal of fulvic acids (MW: 100-10000)
Difficult removal of humic acids due to too high MW

- powder or granular Activated Carbon
- Rotating Reactors
- Columns
- 500mg COD/g AC
- Regeneration of Loaded Activated Carbon is necessary

Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e GEotecnica
IMAGE

FLOCCULATION AND PRECIPITATION

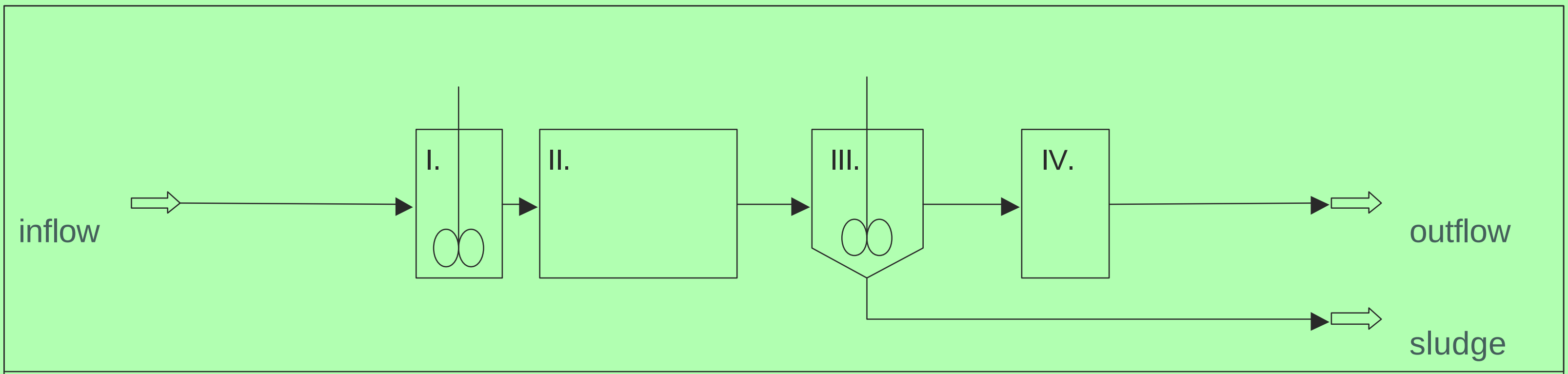
Precipitation: Formation of insoluble compounds by means of addition of auxiliary substances: the equilibrium is shifted towards the insoluble form

Removal of Metals

Flocculation: suspended, colloidal or emulsified substances become destabilized and precipitate

Removal of Organic Compounds

Up to 50% COD Reduction



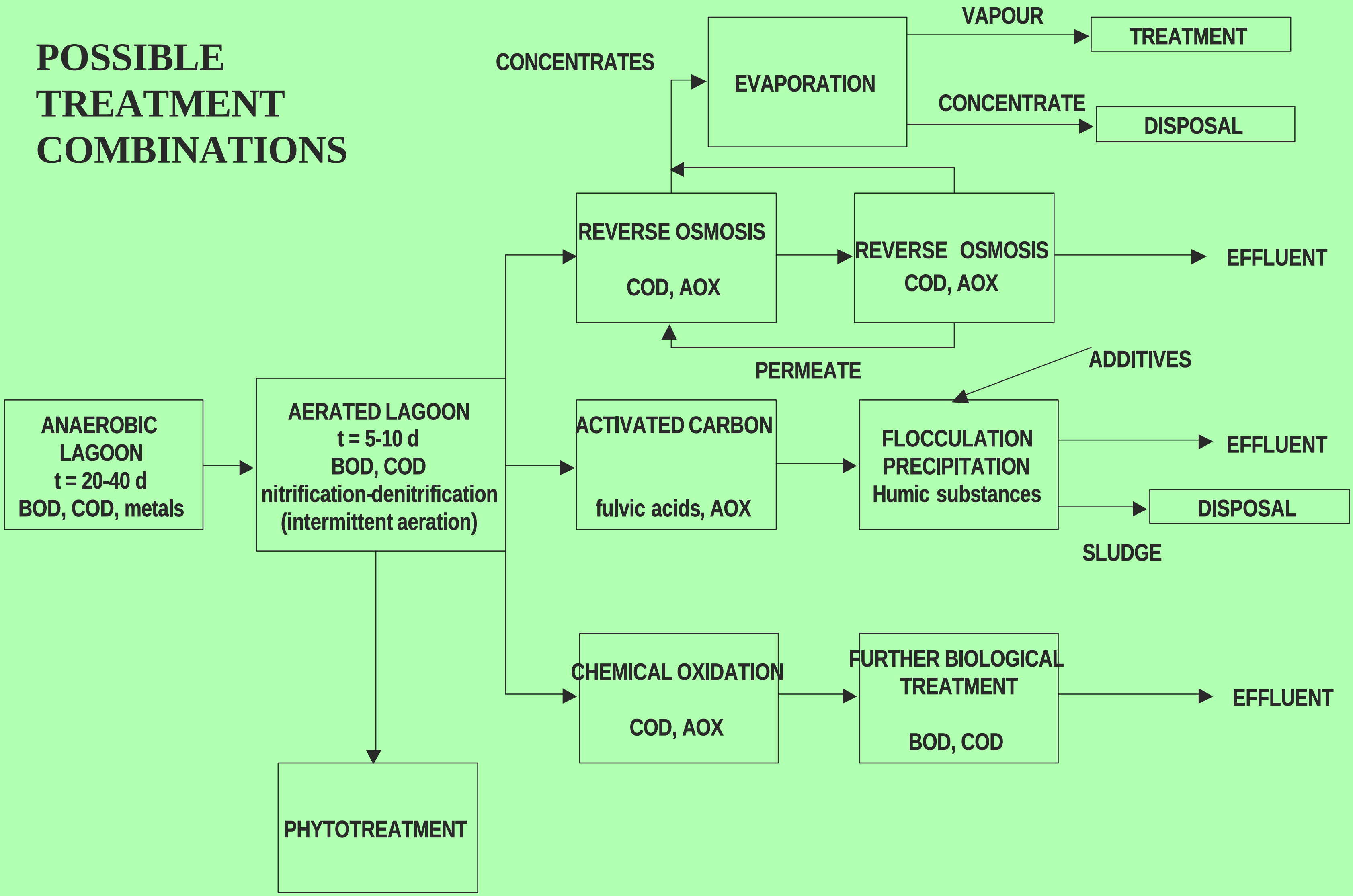
I. mixing tank, II. flocculation reactor, III. sedimentation tank, IV. neutralisation tank

nach Dahm, Kollbach, Gebel: „Sickerwasserreinigung“, 1994

ESTIMATIONS FOR COSTS OF COMBINATIONS FOR LEACHATE TREATMENT IN RELATION TO THE CAPACITY

<table>
<tr><th>Treatment (combination)</th><th>costs for small capacity (< 10m³/h) [€/m³]</th><th>costs for high capacity (> 10m³/h) [€/m³]</th></tr>
<tr><td>Biology + Membrane Sep.</td><td>9 - 30</td><td>7 - 15</td></tr>
<tr><td>Biology + Chemical Oxid.</td><td>18 - 50</td><td>9 - 30</td></tr>
<tr><td>Biology + Active Carbon</td><td>3 - 25</td><td>1 - 10</td></tr>
<tr><td>Biology + Flocc./Precip.</td><td>3 - 30</td><td>3 - 15</td></tr>
<tr><td>Biology + Reverse Osmos.</td><td>5 - 25</td><td>3 - 8</td></tr>
<tr><td>Evaporation</td><td colspan="2">6 - 24</td></tr>
</table>

POSSIBLE TREATMENT COMBINATIONS



Dipartimento di Ingegneria
Idraulica, Marittima, Ambientale e Geotecnica
I M A G E