Use of Advanced Oxidation Processes to Improve the Biodegradability of Landfill Leachates

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- Landfill leachates characteristics
- Biological treatments
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- Integrated advanced oxidation process and biological treatments
- Conclusions and futures perspectives

Landfill leachate entering retention ponds for treatment.

Context

- Leachates are defined as the **aqueous effluent** generated as a consequence of **rainwater percolation** through wastes, **biochemical processes** in waste's cells and the inherent **water content of wastes** themselves.
- Leachates may contain **large amounts of organic matter** (biodegradable, but also refractory to biodegradation), where humic-type constituents consist an important group, as well as **ammonia-nitrogen**, **heavy metals**, **chlorinated organic** and **inorganic salts**.

Context

- The removal of organic material based on
  - chemical oxygen demand (COD),
  - biological oxygen demand (BOD)
- and
  - ammonium

=> usual prerequisite before discharging the leachates into natural waters.

- **Toxicity analysis carried out** using various test organisms (*Vibrio fisheri, Daphnia similes, Artemia salina, Brachydanio rerio* …) **have confirmed the potential dangers of landfill leachates** and the **necessity to treat** it so as **to meet the standards for discharge in receiving waters**.

Thomas et al., 2009, Journal of Toxicology and Environmental Health, Part B, 12:83-105

Landfill leachates characteristics

Parameters	Young leachate	Stabilized leachate
Age	<5 years	>10 years
Composition	Low molecular weight compounds such as VFAs (acetic acid, propionic acid and butyric acid)	High molecular weight compounds such as humic acid and fulvic acid
pH	4.5–6.5	7.5–9.0
NH_3–N/mg L^{-1}	500–2000	400–5000
BOD/mg L^{-1}	4000–13 000	20–1000
COD/mg L^{-1}	6000–60 000	5000–20 000
BOD_5/COD	0.4–0.7	< 0.1
COD/TOC	>2.8	< 2.0
Total (Kjehldal) nitrogen/g L^{-1}	0.1–2	NA
Heavy metals/mg L^{-1}	>2	<2

Low effluent biodegradability

From Kurniawan et al. (2010) J. Environ. Monit., 2010, 12, 2032-2047

Landfill leachates characteristics

Organic compound	CAS n°	Concentration in µg/l
p-Cymene	99-87-6	199
Toluene	108-88-3	71
Ethylbenzene	100-41-4	30
o-Xylene	95-47-6	21
p-Dichlorobenzene	106-46-7	14
Naphthalene	91-20-3	9
Isopropylbenzene	98-82-8	8
1,2,4-Trimethylbenzene	95-63-6	7
1,2-Dichlorobenzene	95-50-1	6
1,3,5-Trimethylbenzene	108-67-8	3
Styrene	100-42-5	3
Chlorobenzene	108-90-7	2
Dioctyl phthalate	117-84-0	2
Tetrachloroethylene	127-18-4	2
4-Nitrophenol	100-02-7	1,547
Phenanthrene	85-01-8	1,464
2-methylnaphthalene	91-57-6	1,359
1-Methylnaphthalene	90-12-0	0,948

Organic compound	CAS n°	Concentration in µg/l
Fluorene	86-73-7	0,926
Fluoranthene	206-44-0	0,742
1,3-Dichlorobenzene	541-73-1	0,7
Diethyl phthalate	84-66-2	0,7
Acenaphthene	83-32-9	0,602
Pyrene	129-00-0	0,539
p-tert-Octylphenol	140-66-9	0,512
4-Nonylphenolmonoethoxylate	104-35-8	0,43

Organic micropollutants concentration from the mixed landfill leachates solutions
From **µg/l to ng/L concentration range**

Landfill leachates characteristics

Organic compounds	CAS n°	Concentration in µg/l
4 Nonylphenol diethoxylate	20427-84-3	0,346
2-Methylphenanthrene	2531-84-2	0,174
Anthracene	120-12-7	0,208
2-Methylphenanthrene	2531-84-2	0,174
diisobutyl phthalate	84-69-5	0,2
PCB 8	34883-43-7	0,172
PCB 66	32598-10-0	0,168
3-Methylphenanthrene	832-71-3	0,148
PCB-52	35693-99-3	0,146
PCB 29	15862-07-4	0,14
Dibenzothiophene	132-65-0	0,13
PCB 18	37680-65-2	0,115
Benz[a]anthracene	56-55-3	0,113
1-Methylphenanthrene	832-69-9	0,101
PCB 101	37680-73-2	0,092

Organic compounds	CAS n°	Concentration in µg/l
4-methyl-dibenzothiophene	7372-88-5	0,078
Dibutyl phthalate	84-74-2	0,07
PCB 44	41464-39-5	0,062
PCB 118	31508-00-6	0,049
Heptachlor	76-44-8	0,048
1-methyl-dibenzothiophene	31317-07-4	0,043
PCB 105	32598-14-4	0,041

Organic micropollutants concentration from a mixed landfill leachates solutions

Main compounds: Chlorinated compounds, PAH, sulfur compounds, phenols and alkylated phenols, phthalate esters

Landfill leachates characteristics

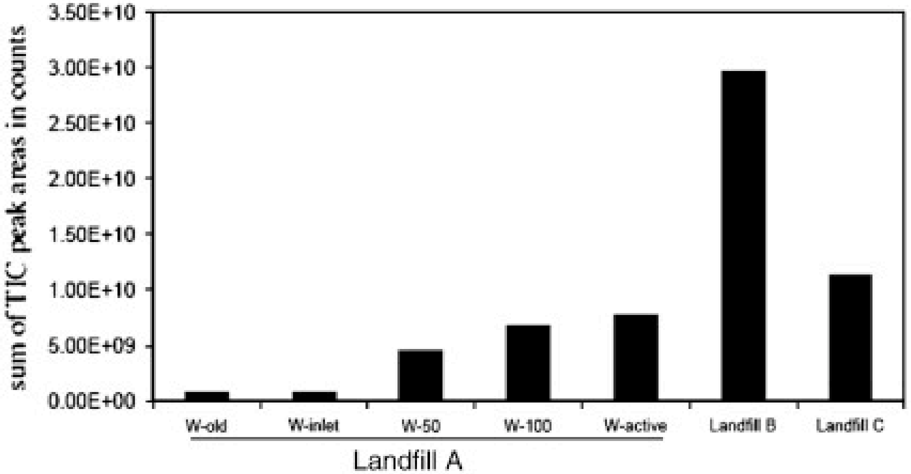
- **Municipal landfill leachates: A significant source for new and emerging pollutants ?**

From Eggen et al., 2010, Science of the Total Environment, 408 (21) 5147-5157

Landfill leachates characteristics

Total content of organic compounds

(A)

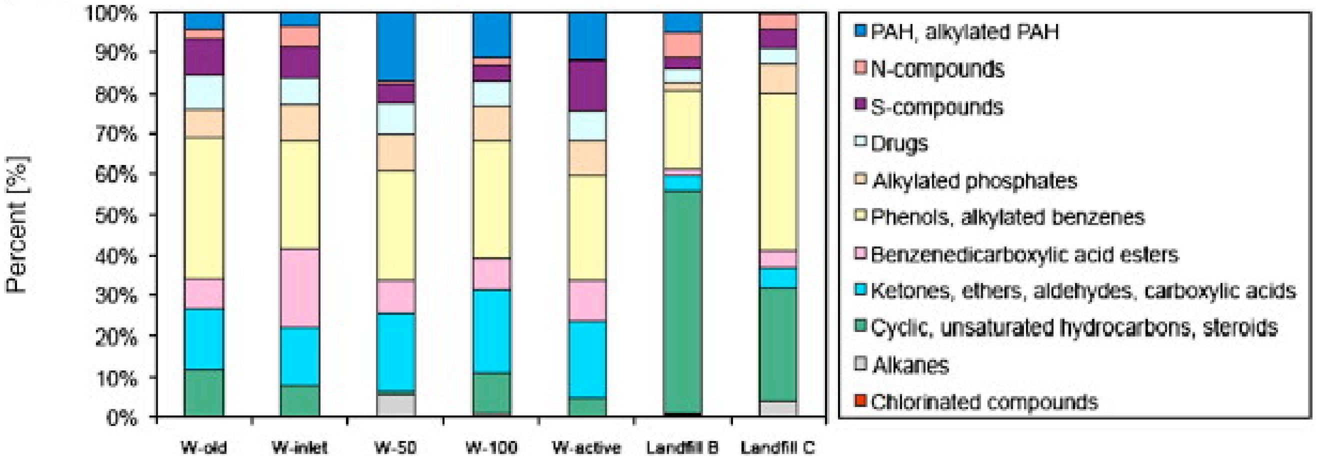


Based on GC peak areas of the GC-MS full scan analysis

From Eggen et al., 2010, Science of the Total Environment, 408 (21) 5147-5157

Relative distribution of compound groups

(B)



Landfill leachates characteristics

- **Municipal landfill leachates: A significant source for new and emerging pollutants ?**
  - Emerging compounds identified in untreated leachates samples at nanogram or microgram par liter levels
    - Chlorinated alkylphosphates
    - Carcinogenic flame retardant (TCPP)
    - Neurotoxin plasticizer (NBBS)
    - Insect repellent (DEET)
    - PFC's
    - Pharmaceuticals
    - Personal care products such as NSAIDs (ibuprofen and naproxen)
    - Polycyclic musk compounds

From Eggen et al., (2010) Science of the Total Environment, 408 (21) 5147-5157

Landfill leachates characteristics

- Many emerging compounds are identified at **higher levels in the water phase then in the particles phase**.
- Since they also seem to be **rather persistent**, they might be pose significant removal challenge in treatment processes.

- Therefore, Eggen *et al.* (2010) have shown that municipal landfill leachates may represent a significant source of concern for legacy, new and emerging chemicals in groundwater.

- => Additional knowledge about the environmental fate and toxicology of emerging compounds is necessary in order to address the need for **improved treatment technologies** for sustainable and efficient removal of these compounds.

Conventional treatments

- Conventional landfill leachate treatments can be classified into three major groups:
  - (a) leachate transfer: recycling and combined treatment with domestic sewage,
  - (b) **biodegradation**: aerobic and anaerobic processes
  - (c) **chemical and physical methods**: chemical oxidation, adsorption, chemical precipitation, coagulation/flocculation, sedimentation/flotation and air stripping.

Biological treatments

- Due to its reliability, simplicity and high cost-effectiveness, biological treatment (suspended/attached growth) is commonly used for the removal of high concentrations of BOD.
- Biodegradation is carried out by microorganisms, which can degrade organics compounds to carbon dioxide and sludge under **aerobic conditions** and to biogas (a mixture comprising chiefly CO_2 and CH_4) under **anaerobic conditions**.
- Biological processes have been shown to be very effective in removing organic and nitrogenous matter from immature leachate when the **BOD/COD** ratio has a high value (>0.5).
- With time, the major **presence of refractory compounds** (mainly humic and fulvic acids) **tends to limit process's effectiveness**.

Biological treatments

- Among the biological treatments, AS, **SBR** and **UASB** are the most frequently applied.
- These treatments are effective to
  - remove over 90% of COD with a concentration ranging from 3500–26 000 mg.L^{-1},
  - to achieve 80% of NH_3–N removal with a concentration ranging from 100–1000 mg.L^{-1}.

Biological treatments

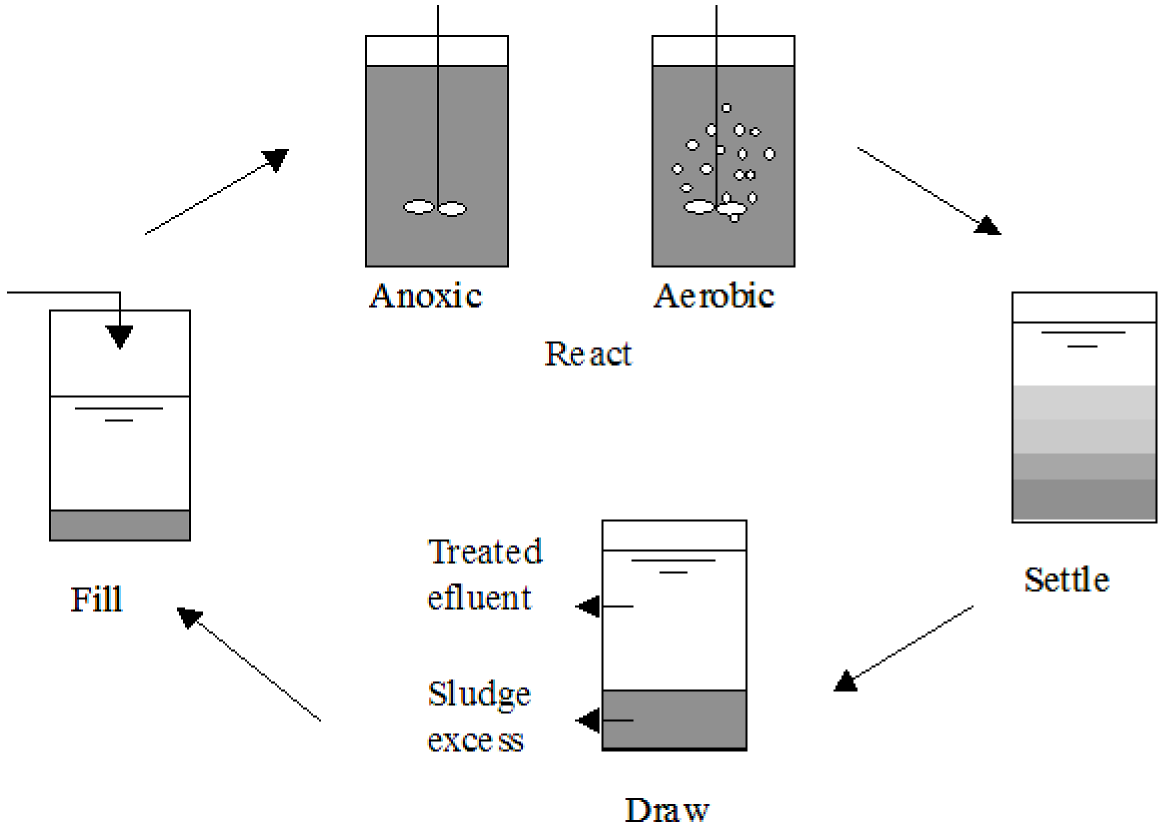
- **Aerobic treatment**
- In aerobic treatments, microbes consume organic materials as their energy sources in the presence of oxygen.
- In addition, an aerobic process oxidizes NH_3–N into nitrate or biomass.
- The most common aerobic biological treatments are AS, **SBR**, AL and RBC .

Biological treatments

- **SBR**
- Recently SBR has been widely employed as one of the most promising options for the biological treatment of leachate.
- Basically SBR is an activated sludge treatment in a reactor.
- This technique can capture solids and remove organic compounds in a vessel, eliminating the need for a clarifier.

Biological treatments

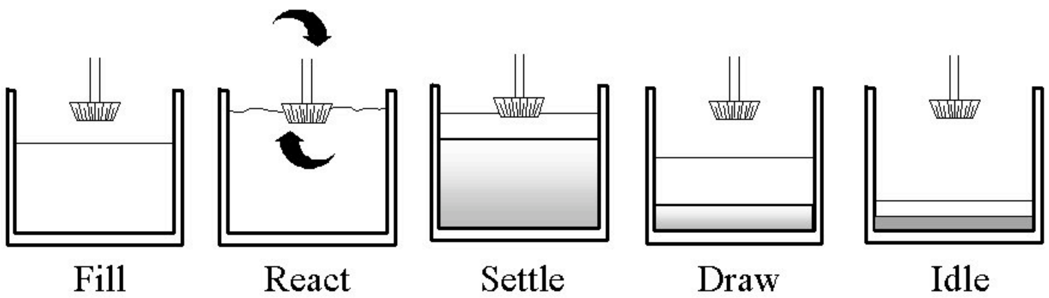
- **SBR**
- There are five operating phases in an SBR system:
  - filling,
  - reacting,
  - settling,
  - Drawing
  - idling.



the SBR process

Biological treatments

- **SBR**
- This reactor design is ideally suited to **nitrification–denitrification or nitritation-anammox** studies, as it provides an operational regime compatible with a concurrent nitrification and the oxidation of organic carbon.
- Between the filling and drawing phases, the operating conditions could be controlled by a periodical change of the concentration of O_2, substrate and inorganic nutrients.



Biological treatments

- **SBR**

Location	HRT/day	Volume of reactor/L	Initial concentration in leachate/mg L^{-1}		Loading rate/ kg m^{-3} day^{-1}		BOD_5/COD	COD/TOC	Optimum pH	Removal efficiency (%)	
			COD	NH_3–N	COD	NH_3–N				COD	NH_3–N
NA	0.5	NA	5295	872	NA	NA	0.4–0.5	NA	9.1	68	NA
NA	1	NA	100–150	100–330	0.1	NA	NA	NA	NA	38	99
Canada	3.2	NA	12 760	179	0.6	NA	0.46	NA	7.1	97	99
Istanbul (Turkey)	1.0	5	26 000	1000	NA	120	0.58	NA	7.5	97	99
Izmir (Turkey)	0.29	4	10 000	1590	NA	NA	NA	NA	8.6	64	23
	2.0	2.75	14 900	2780	0.8	NA	0.63	3.27	7.52	74	NA
Thesaloniki (Greece)	20	8	5000	1800	NA	NA	0.20	NA	7.5	90	NA
	20	8	15 000	1800	NA	NA	0.37	NA	7.5	75	70
Sobuckzyna (Poland)	NA	5	3500	800	NA	NA	NA	NA	8.3	90	70
Wysieka (Poland)	12	0.5	1348	NA	NA	NA	0.38	3.57	NA	83	NA
Chandler (Australia)	0.25	6	1100	900	NA	5.9	0.05	NA	7	NA	100

[a] NA: not available.

From Kurniawan et al. (2010) J. Environ. Monit., 2010, 12, 2032-2047

COD removal from 38 to 97 %
NH_3-N removal from 23 to 100 %

Biological treatments

- **SBR**
- There are various advantages in using SBR for leachate treatment such as:
  - the ease of operation and maintenance,
  - its ability to treat a wide range of contaminant loading in a single reactor,
  - less sludge bulking,
  - tolerance to shock loading
  - no separate clarifiers required, thus reducing operational costs.

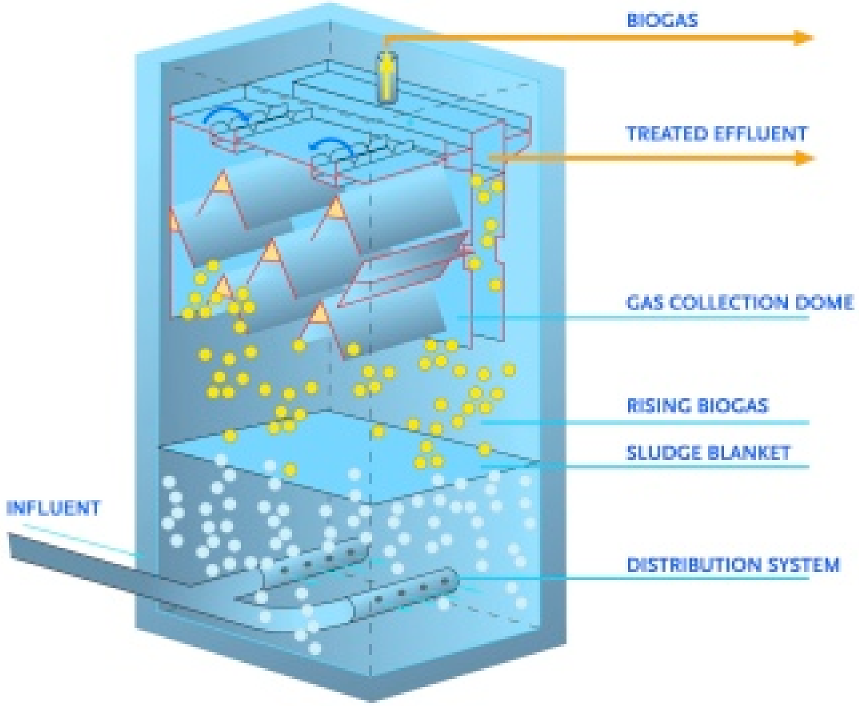
- In spite of its advantages, SBR has a variety of drawbacks such as:
  - odor generation,
  - excess sludge production, as well as high energy consumption.

Biological treatments

- **Anaerobic process.**
- In the anaerobic process, microbes are cultivated in the absence of oxygen, while organics are converted by methanogenic bacteria to CO_2, CH_4 and other metabolite products as the end products.
- This treatment is preferable to **provide energy**, while simultaneously **reducing greenhouse gas emissions**.
- Due to the substantial amount of readily biodegradable VFA compounds, anaerobic treatment is suitable for **young leachate**.
- Therefore, the most extensively applied anaerobic process for leachate treatment is UASB.

Biological treatments

- **Anaerobic process.**



The UASB process was initially developed in The Netherlands in 1970-80 with the following basic concepts: (i) the separation of the solid and gas phases from the liquid and (ii) the conversion of organic matter in the leachate into methane as bioenergy.

Biological treatments

- **Uflow anaerobic sludge blanket (UASB).**
- In recent years, the UASB reactor has gained global acceptance to treat leachate with a COD concentration higher than 10000 $mg.L^{-1}$.

- Basically, an anaerobic process requires a reactor containing waste and bacteria responsible for the digestion process.
- When the waste enters the bottom of the reactor and flows upward through a blanket of biologically formed granules, the microbes in the reactor form granules through self-immobilization of the bacteria cells.

- Concentrated waste in the form of sludge is then added into the reactor, where it is mixed with the reactor's contents to produce biogas as presented in the following reaction:
- $(C_6H_{10}O_5)_n + nH_2O \rightarrow 3nCO_2 + 3nCH_4$

  – where n represents the coefficient of reaction of each molecule.

Biological treatments

- **Uflow anaerobic sludge blanket (UASB).**
- Various parameters play major roles in enhancing the effectiveness of a UASB reactor for leachate treatment.
  - (i) the operating conditions (**temperature**, organic loading rate, hydraulic retention time and the upflow velocity),
  - (ii) the influent characteristics (strength of leachate, molecular size distribution),
  - (iii) the treatment system (reactor configuration, control system),
  - (iv) the sludge bed characteristics.

Biological treatments

Location	HRT/day	Volume of leachate in the reactor/L	Initial concentration in leachate/mg L^{-1}		Loading rate/ kg m^{-3} day^{-1}		Concentration of CH_4 (%) (v/w)	Biogas production/ L kg^{-1} (COD)	Optimum pH	Removal efficiency (%)	
			COD	NH_3–N	COD	NH_3–N				COD	NH_3–N
Izmir (Turkey)	4.5	2.5	20 000	679	16	16	62	9.5	7.0–7.3	98	NA
Komurcuoda (Turkey)	2	7.85	47 800	2690	8.2	NA	NA	NA	NA	90	NA
Komurcuoda (Turkey)	2.0	NA	47 800	2680	23.5	NA	NA	NA	8.3	80	NA
Harmandali (Turkey)	0.42	10	9400	2500	9.4	NA	72	0.18	7.3–7.8	85	NA
Harmandali (Turkey)	2.8	10.35	25 000	NA	10	NA	90	440	7.3–7.8	94	NA
Odayeri (Turkey)	1	13	50 000	2350	2.5	NA	75	515	7.5–8.0	90	NA
La Zoreda (Spain)	9	9	19 400	61	NA	NA	73	110	7.0	87	NA
Meruelo (Spain)	0.1	NA	64 000	1991	21.4	NA	NA	370	8.6	91	NA
Asturias (Spain)	9	NA	4980	2670	2.3	NA	75	290	8	87	NA
(Spain)	0.5	NA	7000	NA	5	NA	NA	NA	7–7.5	70	NA
Hong Kong SAR	6.6	2.8	15 700	2260	2.4	NA	92.5	NA	7.1–8.5	90	NA
Taichung (Taiwan)	1.5	13.5	12 050	424	6.7	NA	52	187	7.2	68	NA
Ammassuo (Finland)	3	NA	32 000	NA	4.0	NA	NA	0.32	6.5–7.0	75	NA
Ammassuo (Finland)	0.45	0.38	4000	160	10	NA	90	0.32	6.8–7.6	75	80
Korea	3.9	41	7000	NA	15.8	NA	81	5.5	7.5	96	NA
Korea	6	0.75	7000	NA	4.2	NA	NA	NA	8–9	80	NA
Nepean (Canada)	1	1.40	9190	NA	19.7	NA	NA	340	7–9	91	NA
Sweden	2.9	0.84	20 000	NA	4.7	NA	65	230	6	98	NA
Kohtla-Jarve (Estonia)	2.1	0.2	1800	NA	0.8	NA	NA	NA	7	95	NA
Thessaloniki (Greece)	NA	2	12 000	920	NA	NA	NA	NA	NA	98	50
Bavel (The Netherlands)	12	NA	35 000	1600	25	NA	NA	NA	6.8	85	NA

[a] NA: not available.

From Kurniawan et al. (2010) J. Environ. Monit., 2010, 12, 2032-2047

Biological treatments

- **Uflow anaerobic sludge blanket (UASB).**
- The UASB process for leachate treatment has several advantages.
  - This technique enables the **liquid, gas and solid phases** in the waste to be **separated in one vessel** without requiring a separate mechanical mixing and an additional settling unit.
  - Unlike other biological processes, UASB has many competitive advantages in terms of its **ability to treat the varying strength and composition of leachate**.
  - In addition, the **sludge** generated from the UASB process has **good settling characteristics**, provided that the sludge is not exposed to heavy mechanical agitation.
  - Moreover, methane as the biogas produced under the anaerobic condition is a **new resource of energy**.
- In spite of its benefits,
  - UASB can not cope with high loading rate variation.
  - In addition, it requires a long starting up period (2–8 months) for the development of anaerobic granules and acclimatization.
  - These drawbacks may limit its application for leachate treatment.

Biological treatments

No.	Type of treatment	Target of removal	Initial concentration range in leachate/mg L^{-1} COD	Initial concentration range in leachate/mg L^{-1} NH_3–N	Removal efficiency (%) COD	Removal efficiency (%) NH_3–N	Advantages	Disadvantages
A. Aerobic								
1.	Activated sludge	Unsettleable organic material and NH_3–N	1000–24 000	115–800	95–98%	90–99	Can be combined with nitrification process; sludge may be used as fertilizer; can remove suspended solid, BOD_5, COD	Long retention time, O&M cost is high; system depends on varying organic loading rate; sludge production; high energy cost; sensitive to hydraulic overloads
2	SBR	Organic compounds and NH_3–N	3500–26 000	100–1000	90–97	99–100	A clarifier is not required	Sludge and odor generation; high energy consumption
3	Nitrification	Nitrogen compounds only	1000–2116	270–535	30–55	90	High nitrification rates during summer; less sludge production; low O&M cost	Inhibition if NH_3–N concentration is high; high energy consumption
4.	Aerated lagoon	Organic compounds and NH_3–N	1733–34 000	104–175	83–98	>99	Low O&M cost; can operate in the fluctuating organic concentrations	Long retention time; excessive algal growth; odor gene-ration; high energy consumption
B. Anaerobic								
1.	UASB	Organic compounds and NH_3–N	1800–64 000	160–920	91–98	50–80	Produces methane gas as an energy; requires no separate mechanical mixing; liquid, gas and solid phases can be separated in one vessel; Sludge has good settling properties	A long starting up period; a narrow pH range is required; ammonia toxicity; inhibition by heavy metals

From Kurniawan et al. (2010) J. Environ. Monit., 2010, 12, 2032-2047

Physicochemical treatments

- Physical and chemical processes include reduction of suspended solids, colloidal particles, floating material, color, and toxic compounds by :
  - either flotation, coagulation/flocculation, adsorption, chemical oxidation and air stripping.
- Physical/chemical treatments for the landfill leachate are used in addition at the treatment line (pre-treatment or last purification) or to treat a specific pollutant (stripping for ammonia).

Advanced oxidation processes

Presentation of AOP's

- Chemical oxidation is a widely studied method for the **treatment of effluents containing refractory compounds** such as landfill leachate. Growing interest has been recently focused on advanced oxidation processes (AOP).
- Most of them, except simple ozonation (O_3), use a combination of strong oxidants, e.g. O_3 and H_2O_2, irradiation, e.g. ultraviolet (UV), ultrasound (US) or electron beam (EB), and catalysts, e.g. transition metal ions or photocatalyst.

Why AOP's?

- AOP, adapted to old or well-stabilized leachate, are applied to:
  - oxidize organics substances to their highest stable oxidation states being carbon dioxide and water (i.e., to **reach complete mineralization**),
  - **improve the biodegradability** of recalcitrant organic pollutants up to a value compatible with subsequent economical biological treatment.

Advanced oxidation processes

List of typical AOP systems

with irradiation	*without irradiation*
Homogeneous System	
O_3/ultraviolet (UV)	O_3/ H_2O_2
H_2O_2/UV	O_3/OH^-
electron beam	H_2O_2/Fe^{-2} (Fenton's)
ultrasound (US)	
H_2O_2/US	
UV/US	
H_2O_2/Fe^{-2}/UV (photo-Fenton's)	
Heterogeneous Systems	
TiO_2/ O_2/UV	electro-Fenton
TiO_2/ H_2O_2/UV	

Advanced oxidation processes

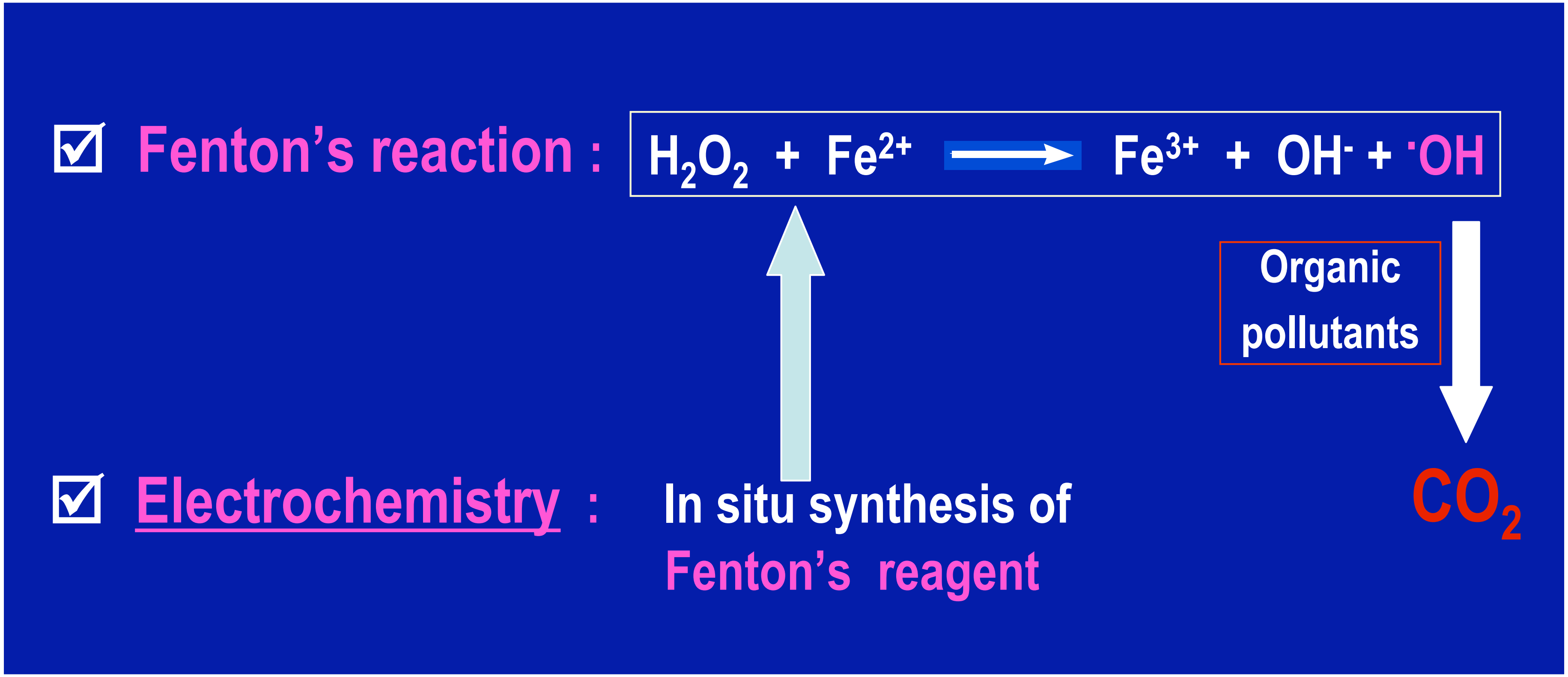
H_2O_2/UV, H_2O_2/Fe^{2+} and H_2O_2/Fe^{2+}/UV in leachates treatment (updated from Wang et al. [13])

COD ($mg\,L^{-1}$)	BOD ($mg\,L^{-1}$)	pH	COD removal (%)	BOD/COD after treatment	UV (W)	H_2O_2 ($g\,L^{-1}$)	Fe^{2+} ($mg\,L^{-1}$)
H_2O_2/UV							
760	–	–	22	–	150	3.4	
760	–	3	99	–	150	3.4	
1000–1200	<10	3.0–4.0	90	–	15	0.5	
1000–1000	<10	3.0–4.0	85	–	150	0.5	
1280	100	2	57	–	100	–	
1280	100	2	59	–	500	–	
430 TOC	–	–	42 TOC	–	300	–	
26,000	2920	3	79	0.37	1500	5.19	
26,000	2920	3	91	0.4	1500	13	
26,000	2920	3	96	0.45	1500	26	
H_2O_2/Fe^{2+}							
–	–	3	50	–		1.6	–
1050–2020	50–270	4	60	–		0.2	600–800
1200	–	–	63	0.15		–	–
1150	3–5	3	70	–		2.44	56
2000	87	3.5	69	0.58		1.5	120
330	<8	7.5	72	0.3		$10\,mL\,L^{-1}$	20
282–417 TOC	–	3	49–76 TOC	–		1	1250
–	–	3	55	–		2.2	–
1500	30	3.5	75	–		1.65	645
Old leachate	–	–	–	–		1	1000
1800	225	3	52	0.22		1.5	2000
1800	225	4.5	45	0.27		1.2	1500
1500	75	6	70	–		0.2	300
1500	75	8.5	14	–		0.2	300
10,540	2300	8.2	60	0.5		1	830
H_2O_2/Fe^{2+}/UV							
1150	3–5	3	70		500–1000	1.15	56
1150	–	3.2	70		UVA	1.15	72
440	–	2.7	78		UVA	0.44	30

From Renou et al., 2008

Advanced oxidation processes

- **Electro-Fenton**
- Fenton’s reaction assisted by electrochemistry
- Electrochemical advanced oxidation process
- In situ electrochemical generation of Fenton’s reagent (H_20_2 + Fe(II)) allowing the formation of $^{\bullet}OH$

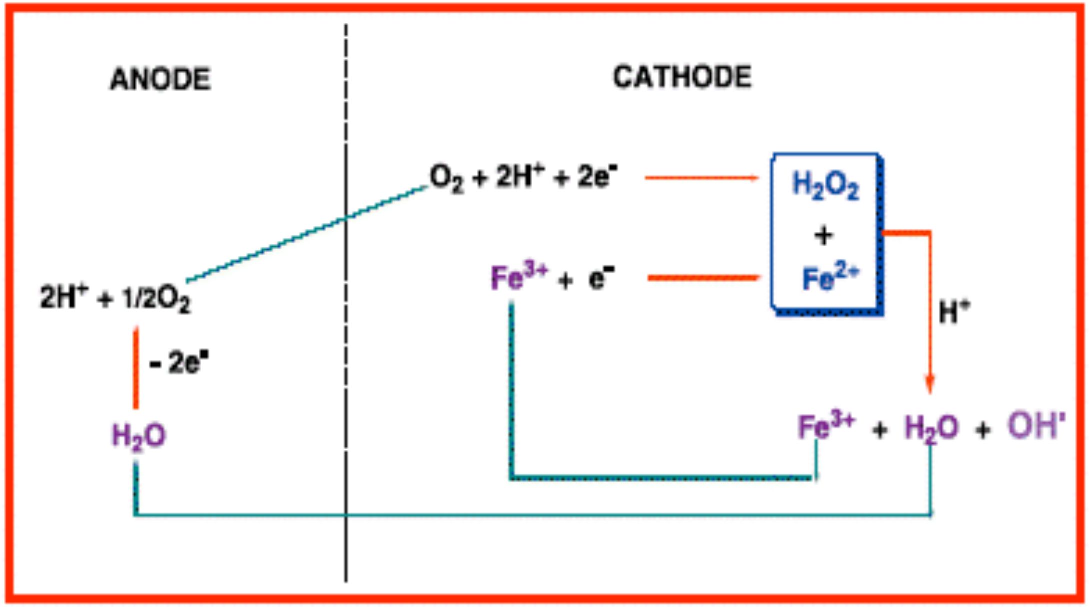


Advanced oxidation processes

Electrochemical reactor: Open, cylindrical and non divided

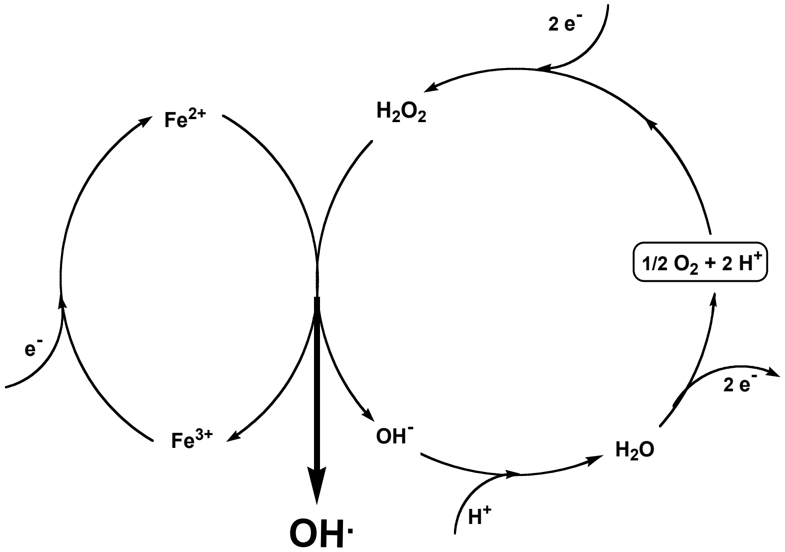
- Cathode:Carbon-felt
- Anode: Pt, BDD or mixed metal oxides

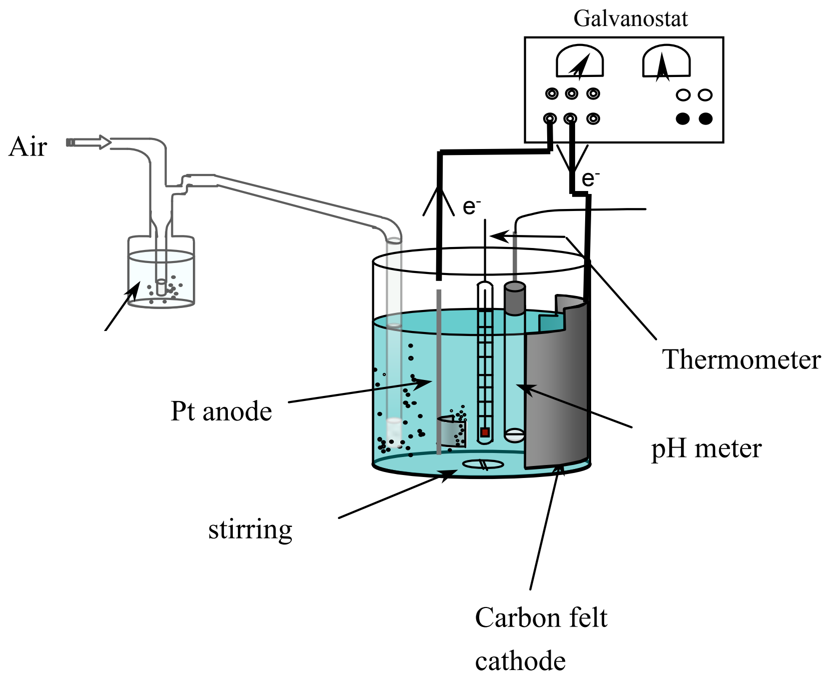
- Reagent : compressed air / O_2
- Catalyst : Fe^{3+} , Cu^{2+} , … (< 1 mM)



Advanced oxidation processes

Electro-Fenton: Electrocatalytic production of °OH



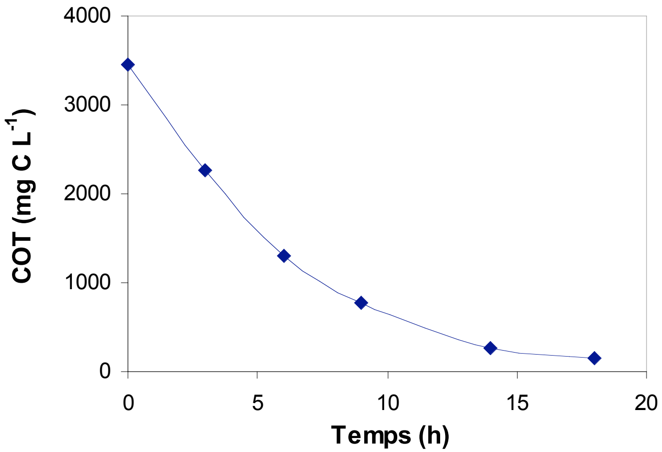


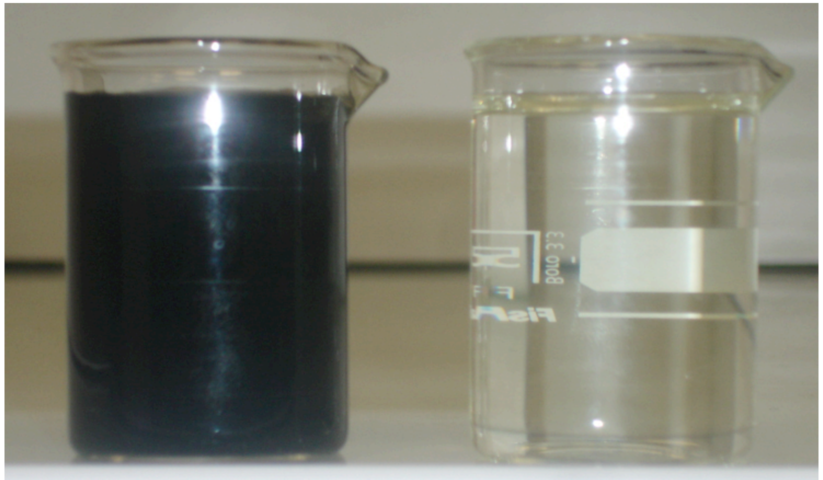
Oturan et al., J. Electroanal. Chem., 507 (2001) 96

Advanced oxidation processes

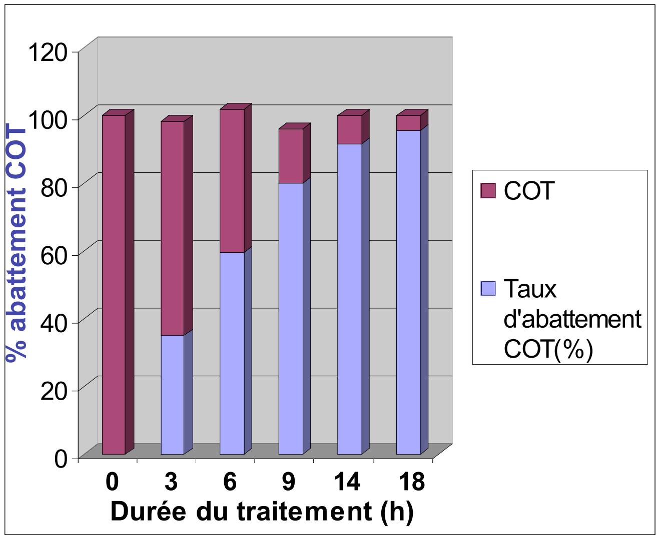
Mix of 8 French landfill leachates : mainly MSW, Industrial wastes

- ✓ No need to add (Fe^{3+})
- ✓ I = 1 A
- ✓ système EF : Carbon felt electrode / BDE





BEFORE **AFTER**



Advanced oxidation processes

Biodegradability improvement after Fenton and related processes.

Process	Initial BOD_5/COD	Final BOD_5/COD	References
Fenton	0.18	0.38	Guo et al. (2010)
Fenton	0.44	0.68	Goi et al. (2010)
Fenton	0.63	0.88	Kochany and Lipczynska-Kochany (2009)
Photo-Fenton	0.13	~0.4	De Morais and Zamora (2005)
Fenton	0.2	0.5	Lopez et al. (2004)
Fenton	–	0.5	Kim et al. (2001)
Electro-Fenton	0.1	0.3	Lin and Chang (2000)

From Umar et al., (2010) Waste Management 30, 2113-2121

Integrated advanced oxidation process (AOP) and biological treatments.

- In the past three decades (1976–2005), increasing scholarly interest has been shown in the application of AOP such as ozonation, Fenton's oxidation to **transform toxic pollutants into relatively harmless substances**.

- Among the AOPs reviewed, **ozonation and the Fenton's oxidation** are the most frequently investigated and commonly employed.
- However, other novel photo-oxidative technologies using UV LED as a light source or atomic layer deposit thin films as a photocatalyst are currently tested for its feasibility for leachate treatment.

- **A combination of AOP and biological process enhances its treatment performance for leachate.** An almost complete COD removal (98%) was attained by combining AS and Fenton's oxidation (COD: 7000 $mg.L^{-1}$) and/or the AS and wet air oxidation (COD: 4140 $mg.L^{-1}$).

Integrated advanced oxidation process (AOP) and biological treatments

Location of landfill	Type of combined treatment	Coagulant/ Adsorbent/ Oxidant	Dose/g L^{-1}	Ozone consumption/ mg O_3 per mg COD	Initial concentration in leachate/mg L^{-1} COD	Initial concentration in leachate/mg L^{-1} NH_3–N	BOD/ COD	COD/ TOC	pH	Removal efficiency (%) COD	Removal efficiency (%) NH_3–N
Taiwan	Coagulation + Electro-Fenton + SBR	Fe(II)SO_4/H_2O_2	0.75	—	1941	151	0.3	NA	4	95	81
Hong Kong	UASB + Ozonation	O_3	0.05	16	15 700	2260	0.06	NA	7-8	93	NA
Hong Kong	UASB + Ozonation + Fenton oxidation	O_3 Fe(II)SO_4/H_2O_2	0.05 0.3 0.2	25	15 700	2260	0.06	NA	5	99	NA
Kimpo (Korea)	Fenton oxidation + Activated sludge	Fe(II)SO_4/H_2O_2	0.9 0.9	NA	7000	1800	0.15	NA	3.5	98	89
Germany	Photochemical + Activated sludge	UV/H_2O_2	1 4	—	920	NA	0.005	NA	4.0	89	NA
Fossalta (Italia)	Wet oxidation + activated sludge	—	—	—	4140	998	0.46	NA	7.8	98	NA
Flanders (Belgium)	Ozone + activated sludge	O_3	2.8	3.7	895	626	0.05	NA	8.2	81	NA
—	Ozone + activated sludge	O_3	0.05	2.0	2800	250	0.54	NA	6	97	NA
Finland	Ozone + activated sludge	O_3	5.00	0.3	560	NA	0.06	2.80	9.5	95	NA
Teuftal (Switzerland)	Ozone + Nitrification	O_3	0.03	NA	1500	600	0.23	NA	7.0	98	NA

[a] NA: not available.

Conclusions and future perspectives

- Several treatment strategies may be designed
  - For mature landfill
    - AOP pre-treatment (enhance biodegradability) followed by UASB and/or SBR biological treatment
    - Biological treatment (SBR or UASB) followed by AOP post-treatment (removal of residual biorefractory COD) prior to release into sewer network or the environment
  - Residual organic micropollutants and toxicity should be evaluated prior discharges

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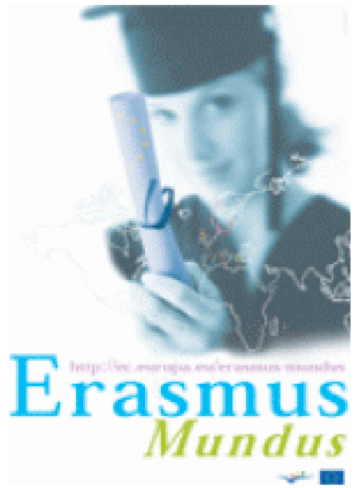
- Thank you for your attention



EMJD : Environmental Technologies for Contaminated Solids, Soils and Sediments (ETeCoS^3)

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