EQUIFILL: INORGANIC WASTE LANDFILL MEETING EU LANDFILL CRITERIA

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SUMMARY: The EU council has set criteria for leaching limit values for waste to be accepted at landfills for inert wastes. Apart from a geological barrier such landfills do not require further isolation measures or aftercare. The predominantly inorganic waste landfill concept (Equifill) aims at creating a biogeochemical equilibrium in a landfill with the environment within a period of 30 years. Waste mixture leaching tests and pilot leachate data show a good agreement. This indicates that in spite of an apparently very heterogeneous mix of materials, leaching is governed by well-defined solubility controls for many constituents. A comparison of release as observed on the waste mix of the pilot shows that for all critical parameters the inert EU landfill criteria are met. It could be argued that the conditions for ending maintenance on isolation measures and ending aftercare are achieved.

1. INTRODUCTION

The EU Council Decision on criteria for the acceptance of waste (Anonymous, 2003) specifies leaching limit values for waste to be accepted at landfills for inert waste. Such landfills according to EU regulations do not require isolation measures or aftercare. It can therefore be assumed that the related leaching is considered an acceptable emission to the environment.

The predominantly inorganic waste landfill concept (Equifill) aims at creating a biogeochemical equilibrium in a landfill with the environment within a period of 30 years in order to reduce the long-term risk and the aftercare needs. This goal is reached by constructing a landfill that will exhibit favourable properties with respect to the leaching of contaminants. This can be achieved with neutral pH, slightly reducing conditions, low organic matter content and relatively low salt loads. Measures are to be taken to develop more sophisticated acceptance criteria, pre-treatment of waste materials before disposal and also actions during the operational phase of the landfill.

This study integrates testing at laboratory- and pilot scale with modelling of long-term release of contaminants. Emphasis has been placed on understanding the processes within the landfill as the mutual interaction of individual wastes determines the ultimate long-term quality of leachate. Understanding the physical/chemical processes in a landfill allows one to predict the long-term emissions based on geochemical modelling. The anticipated outcome is a disposal practice through waste acceptance that will reduce the contaminant emissions to acceptable levels on the long-term; thus reducing the need for long-term aftercare. Modelling, laboratory

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Figure 1. First batch of waste in the 12,000 m³ pilot cell

and lysimeter tests are described in other papers (Sloot et al., 2002 & 2003; Zomeren et al., 2005). This paper focuses on the results observed in the field scale pilot project.

2. MATERIALS AND METHOD

2.1. Laboratory and lysimeter experiments

In the framework of the predominantly inorganic waste landfill project, laboratory experiments (percolation test – PrEN 14405, 2002; pH dependence test – PrEN 14429, 2002) were carried out in conjunction with chemical speciation modelling and release modelling (Sloot, 2003; Zomeren 2005).

2.2. Pilot

The pilot cell of 12,000 m^3 is isolated from the rest of the landfill site by a HDPE membrane of 2 mm thickness. In order to prevent subsidence of waste at the slopes, a geogrid was installed. The geogrid has fine mazes that increases the resistance between waste and HDPE membrane. Furthermore a layer of 0.5 m of sand was brought up on top of the bottom liner and drainage pipes were placed as shown in figure 2. The drainage system was connected to a pumping system and flow meters were installed for monitoring purposes.

Before suitable waste batches were landfilled according to Equifill protocol, quality control measurements were carried out. Samples were taken from all waste batches deposited at the side

Figure 2. Drainage system at pilot Nauerna

of the cell and examined in the lab at Nauerna landfill. The quality control measurements consisted of short on-site leaching tests with a maximum duration of 4 hours.

The dry weight of a sample from each batch of waste was determined with an IR dryer. Then the volume of demineralised water was calculated in order to perform a leaching test at a Liquid to Solid ratio (L/S) = 2. The waste and demineralised water mixture were put into a 1 litre PE flask and brought into suspension with a roller bench. The mixture was equilibrated for 1 hour.

After equilibration a visual inspection of the waste-water mixture took place (i.e. for mineral oil). Conductivity, pH and redox of the mixture were measured with an Eijkelkamp multimeter.

If in situ pH was over 8.5 or below 6.5 the acid or base neutralisation capacity (ANC or BNC) was determined. In case of a pH over 8.5, 1M of HNO_3 was used for titration of the waste – water mixture until a pH between 7.3 – 7.7 was reached. When a pH lower than 6.5 was observed then 1M of NaOH was used for titration.

In order to measure Cl and DOC concentrations, the waste-water mixture was filtered with a Büchner funnel and 45 µm paper filter. Then the leachate was filtered with a 0.2 µm filter. The sample was then used for spectrophotometric analysis of Cl and DOC. A Dr Lange ISIS9000 spectrophotometer was used in combination with Dr Lange Cl (LCK311) and DOC (LCK385) analytical kits.

The waste input to the pilot cell is controlled by more stringent acceptance criteria than currently required by regulation. To determine whether waste batches could be accepted for the pilot, following acceptance criteria were drawn up and given in table 1.

Only after compliance with the acceptance criteria was established, the batches were processed in layers in the pilot cell. Filling of the pilot cell started in the spring of 2000. The weight of each batch was recorded by means of the weighbridge data and computer system.

Table 1. Acceptance criteria Equifill

Parameter	Threshold (mg/kg)
Cl	4000
DOC	1500
ANC/BNC	0.20

Figure 3. Final situation Equifill full scale pilot.

From all waste samples collected, an integrated waste mix was prepared by taking the mass of each batch of waste into account.

The mix prepared from the samples was used for the laboratory testing (column batch test) and for filling three lysimeters with a representative waste mixture. The studies at field, lysimeter and laboratory scale represent different time scales through the liquid to solid ratio, to which the waste was exposed. The different times scales are used for extrapolation in another study (Zomeren, 2005).

After filling the pilot cell was capped with a 0.8 m thick layer of soil (figure 3). The cap is sloped resulting in a considerable amount of run-off and a reduced amount of leachate. After depositing the first batch of waste samples of the leachate were taken on a regular basis. Leachate is collected and the amount of leachate pumped out of the test cell is measured. Leachate samples were send to a qualified independent laboratory and analysed on a list of parameters. The parameters and the techniques of measurements and corresponding detection limits are given in table 2.

Table 2. Analyses performed on leachate by independent laboratory

Parameter	Method	Technique	Detection limit
pH	NEN 6411	Potentiometric	-
Conductivity	NEN-ISO 7888	Conductometric	2 $\mu S.cm^{-1}$
BOD	NEN 6634	Potentiometric	5 $mg.l^{-1}$
COD	NEN 6633	Titrimetric	5 $mg.l^{-1}$
DOC	NPR 6622 NEN-EN-1484	High temperature combustion	
$N\text{-}NH_4$	NEN 6472	Spectrophotometric	
N-Kj	NEN 6481	Titrimetric	
$N\text{-}NO_3$	NEN-EN ISO 10304	Ion chromatography	
$N\text{-}NO_2$	NEN-EN ISO 10304	Ion chromatography	
SO_4	NEN-EN ISO 10304	Ion chromatography	
SO_2 (aquatic)	NEN 6608	Spectrophotometric	
PO_4	NEN 6663		
Br	NEN-EN ISO 10304	Ion chromatography	
Cl	NEN-EN ISO 10304	Ion chromatography	
Al	NEN 6426	ICP AES	
Sb	NEN 6426	AAS hydride	2 $\mu g.l^{-1}$
As	NEN 6426	ICP AES	2 $\mu g.l^{-1}$
Ba	NEN 6426	ICP AES	5 $\mu g.l^{-1}$
Ca	NEN 6426	ICP AES	
Cd	NEN 6426	ICP AES	0.4 $\mu g.l^{-1}$
Co	NEN 6426	ICP AES	
Cr	NEN 6426	ICP AES	1 $\mu g.l^{-1}$
K	NEN 6426	ICP AES	0.1 $mg.l^{-1}$
Cu	NEN 6426	ICP AES	2 $\mu g.l^{-1}$
Hg	NEN 6426	AAS cold vapour	0.03 $\mu g.l^{-1}$
Li	NEN 6426	ICP AES	
Pb	NEN 6426	ICP AES	5 $\mu g.l^{-1}$
Mg	NEN 6437	ICP AES	5 $\mu g.l^{-1}$
Mn	NEN-EN ISO 10304	Ion chromatography	0.5 $mg.l^{-1}$
Mo	NEN 6462	ICP AES	5 $\mu g.l^{-1}$
Na	NEN 6424	ICP AES	0.5 $mg.l^{-1}$
Ni	NEN 6426	ICP AES	5 $\mu g.l^{-1}$
Se	NEN 6424	AAS hydride	2 $\mu g.l^{-1}$
Sn	NEN 6434	ICP AES	
Fe	NEN 6426	ICP AES	0.03 $\mu g.l^{-1}$
V	NEN 6426	ICP AES	
W	NEN 6426	ICP AES	
Zn	NEN 6426	ICP AES	5 $\mu g.l^{-1}$
BTEX + chlorinated hydrocarbons	VPR C85-10		0.2 $\mu g.l^{-1}$
EOX	NEN 6402	Microcoulometric	1 $\mu g.l^{-1}$
PAC	EPA		0.1-0.01 $\mu g.l^{-1}$
CN	EPA		0.2 $meq.l^{-1}$
Phenol index			
Organic chlorinated pesticides + PCB			

3. RESULTS AND DISCUSSION

3.1. Quality control measurements

The EU Landfill Directive (Anonymous, 1999) requires waste to be (pre)treated prior to landfill. In accordance with this principle the waste processed in the pilot cell consisted of residues arising from recycling and treatment processes.

The most important processes were soil separation and cleaning, dredging sludge treatment and construction and demolition waste sorting and recycling. Table 3 gives an representation of waste composition of the full scale Equifill pilot at Nauerna. It should be noted that the pilot cell was filled before the European Waste Catalogue (EWC) (Anonymous, 2000), Landfill Directive and the strict separation of hazardous and non-hazardous waste were implemented into national legislation.

Table 3. Waste composition pilot Equifill

EWC-code	Type of waste	Tonnes	Percentage
	Non-hazardous waste		
01 05 08	Chloride containing drilling muds	467	2,7%
07 05 12	Sludges from on-site effluent treatment	15	0,1%
08 04 12	Adhesive and sealant sludges	3	0,0%
10 09 08	Casting cores and moulds	90	0,5%
12 01 17	Waste blasting material	7	0,0%
15 01 04	Metalic packaging	12	0,1%
16 03 06	Organic waste other than 16 03 05	26	0,2%
17 01 07	Mixtures of concrete, bricks, tiles and ceramics	53	0,3%
17 03 02	Bituminous mixtures other than 17 03 01	4	0,0%
17 05 04	Soil and stones other than 17 05 03	268	1,6%
17 09 04	Mixed construction and demolition wastes	55	0,3%
19 05 01	Non-composted fraction of MSW and similar	9	0,1%
19 10 04	Fluff light fraction and dust other than 19 10 03	21	0,1%
19 12 09	Soil and dredging sludge treatment residues	11.374	66,8%
19 12 12	Waste from mechanical treatment of waste	1.401	8,2%
19 13 02	Solid wastes from soil remediation	145	0,9%
20 03 03	Street cleaning residues	75	0,4%
	subtotal	14.025	82,4%
	Hazardous waste		
12 01 16*	Waste blasting material containing dangerous substances	289	1,7%
12 01 14*	Machining sludges containing dangerous materials	1.728	10,1%
17 05 03*	Soil and stones containing dangerous substances	950	5,6%
19 10 05*	Other fractions containing dangerous substances	36	0,2%
	subtotal	3.003	17,6%
	total	17.028	100,0%

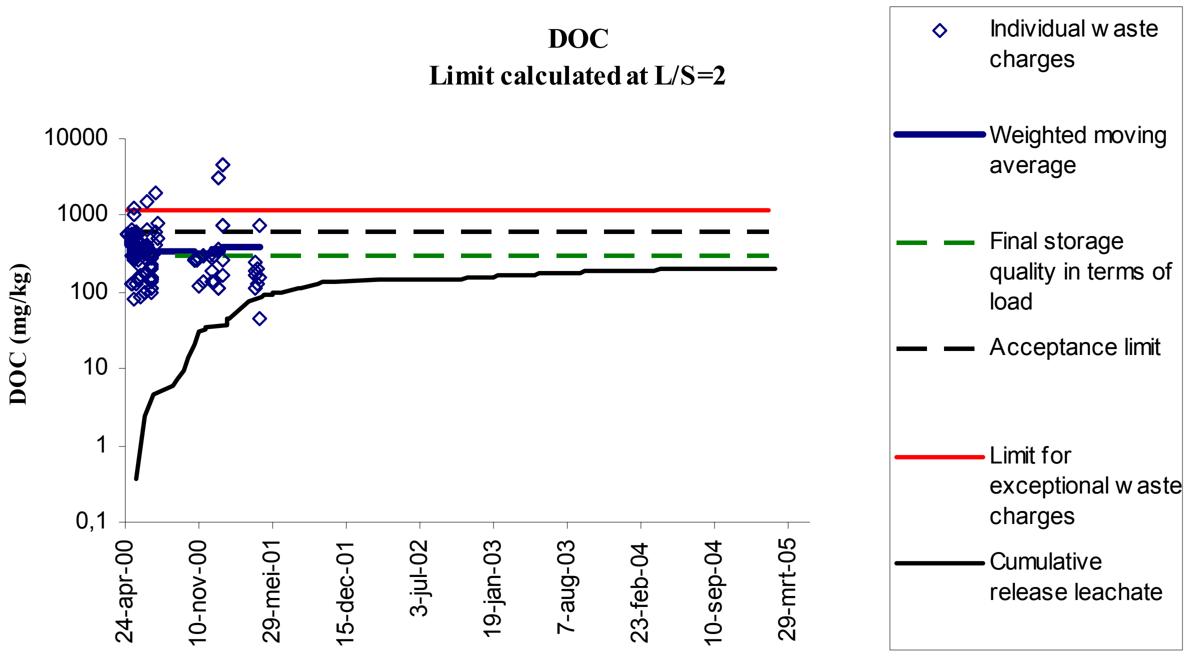

Figure 3. Quality control measurements DOC. DOC concentrations were obtained by the LCK385 Dr Lange kit. Compared to the Shimadzu TOC analyser the relative error is larger. Therefore a slightly higher DOC value is calculated in figure 3 compared to the DOC value stated in table 4.

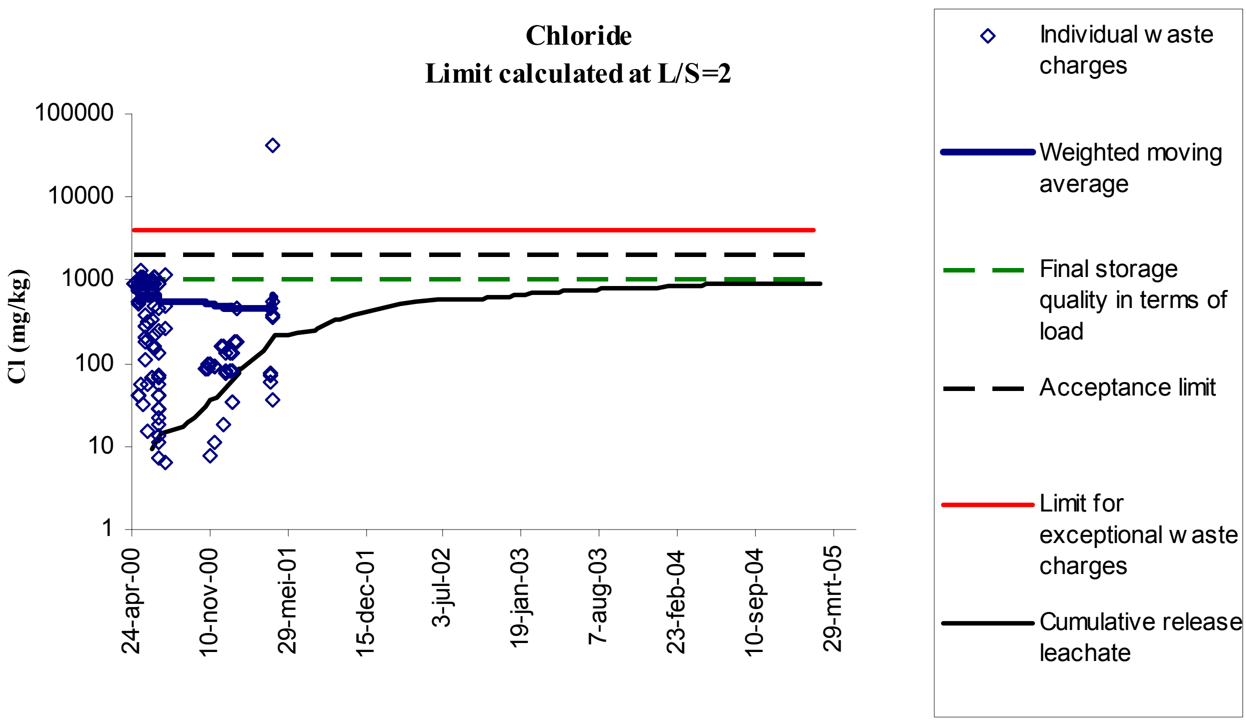

Figure 4. Quality control measurements Cl. The LCK311 Dr Lange analytical kit shows good agreement to other more sophisticated analytical techniques. The value calculated in figure 4 is comparable with the result stated in table 4.

Figures 3 and 4 show that individual waste batches have a very variable leaching behaviour for DOC and chloride. Almost all batches meet acceptance criteria as expressed in table 1. Only few waste batches surpass the limit for exceptional waste charges (upper line in figures 3 and 4).

Figure 3 and 4 show typical leaching behaviour of DOC and Chloride. Both components show that in time the contribution decreases. Chloride shows availability governed leaching, which is typical for chloride. For DOC a similar curvature is found.

3.2. Leachate quality measurements

In total 14.324 m^3 have been discharged from the pilot cell at Nauerna. The pilot cell has reached a L/S ratio of 0.9 within a period of 4 years. During the pilot no operational problems were observed apart from periodic maintenance of the pumping system.

Leachate quality data were combined with leachate quantities and resulted in the amounts leached from the Equifill pilot in five years. In Table 4 these amounts are compared to limit values for waste acceptable at landfills for inert, non-hazardous and hazardous waste expressed in the Annex II of the EU landfill directive. The Annex II states two L/S ratios for which limit values were determined (L/S = 2 and L/S = 10). Member States will finally determine which of the test methods and corresponding limit values should be used. As the L/S ratio of the pilot cell is 0.9 actual leachate quality is compared to Annex II limit values at L/S=2.

However results obtained at L/S = 0.9 and limit values obtained at L/S = 2 are rather hard to compare. Therefore the leachate quality obtained by column leaching tests at L/S = 2 is also given in table 4. The obtained leaching characteristics with column leaching tests for Annex II components enable better understanding and comparison of leaching behaviour of the pilot cell.

Table 4. Leaching data Equifill and limit values EU landfill Directive Annex II.

Parameter	EQUIFILL L/S = 0,9 mg/kg	COLUMN TEST PrEN 14405 L/S = 2 mg/kg	INERT Landfill Directive L/S = 2 mg/kg	NON-HAZARDOUS Landfill Directive L/S = 2 mg/kg	HAZARDOUS Landfill Directive L/S = 2 mg/kg
As	0.01	0.012	0.1	0.4	6
Ba	0.17	0.11	7.0	30	100
Cd	0.001	0.02	0.03	0.6	3
Cl	901	3645	550	10000	17000
Cr	0.01	0.004	0.2	4	25
Cu	0.0005	0.003	0.9	25	50
DOC	105	179	240	380	480
Mo	0.01	0.014	0.3	5	20
Ni	0.03	0.1	0.2	5	20
Pb	0.01	0.06	0.2	5	25
SO_4	1144	3629	560	10000	25000
Sb	0.007	0.008	0.02	0.2	2
Se	0.014	0.011	0.06	0.3	4
Zn	0.018	0.5	2	25	90
F	0.220	-	4	60	200
TDS*	-	-	2500	40000	70000

*The value for TDS (total dissolved solids) can be used alternatively to the values for sulphate and chloride (Anonymous, 1999).

The Equifill leachate quality (L/S = 0.9) show that most components do not exceed EU Landfill Directive limit values for waste acceptable at landfills for inert wastes sofar. At first glance chloride and sulphate could be indicated as non complying components. The Annex II states that values for TDS (total dissolved solids) can be used alternatively to the values for chloride and sulphate. Since Ca leaching of the waste mixture amounts to 2,000 mg/kg at L/S=2 it can be expected that TDS will not provide a solution for non compliance with the Annex II criteria. To achieve compliance for these components two routes can be followed. Adequate pre-treatment measures like flushing of salts could be taken and stricter acceptation criteria must be set in order to comply to Annex II limit values for landfills accepting inert wastes. Or based on a risk assessment and the local groundwater conditions an exception is made for chloride and sulphate. When a risk assessment approach is taken, it can be argued that at the landfill site in question chloride and sulphate are irrelevant. The neighbouring Noordzeekanaal and the groundwater are brackish and contain concentrations of chloride and sulphate similar to the leachate. They vary between 2500 to 5000 mgCl/ l and 500 to 700 $mgSO_4$/l. The leachate of the pilot contains 1100 mgCl/ l and 1300 $mgSO_4$/l.

Column leaching tests provide additional information whether limit values will be exceeded when Equifill reaches L/S = 2 in time. Zomeren (2005) gives a good overview of both column tests and full scale pilot results for some of the components. The paper discusses if both systems correspond and whether prediction of long term leaching behaviour can be described by column leaching tests. When Equifill leachate quality and leachate quality obtained by column testing are compared slight variations can be indicated. One must keep in mind that during a column batch test a large part of the waste packed in the column interacts with percolating water or leachate. The interaction between waste and percolating water or leachate within the pilot cell is smaller. Hence, variations between leaching tests and pilot scale can be explained by the differences in mobile or immobile fractions.

4. CONCLUSIONS

In general there is a very good agreement between the leaching behaviour of the waste mixture prepared for lysimeters and laboratory experiments (Zomeren, 2005) and the leachate as obtained from the full-scale pilot demonstration cell. This indicates that in spite of an apparently very heterogeneous mix of materials, leaching is governed by well-defined solubility controls for many constituents. Key controlling factors for this predominantly inorganic waste disposal method are controls on the levels of dissolved organic carbon, mobile inorganic (e.g. chloride and sulphate) and water-soluble organic contaminants of the individual wastes.

A comparison of release as observed on the pilot Nauerna shows that for all critical parameters the inert EU landfill criteria are met. Chloride and sulphate form an exception. At Nauerna landfill this can be considered irrelevant as the surrounding brackish surface water and groundwater contain concentrations of chloride and sulphate similar to the leachate. In other situations more stringent acceptance criteria in combination with pre-treatment might supply a solution. These observations indicate that already an important goal has been achieved within five years. As inert waste does not require any form of lining according to the EU Landfill Directive, it could be argued that the conditions for ending maintenance on isolation measures and ending aftercare are achieved. This will however require acceptance of an approach that takes the entire instead of just individual batches of waste into account.

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