CleanLeachate

"Combined anode and cathode process to treat landfill leachate"

PUBLISHABLE SUMMARY
OF FINAL REPORT

Grant Agreement Number: 262335 (FP7-SME-2010-1)
Research for the benefit of SMEs

CleanLeachate

Combined anode and cathode process to treat landfill leachate

Project coordinator name   Siegfried Egner

Project coordinator organisation name   Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung E.V

Executive summary

Waste disposed of on landfill sites degrades over time and produces a liquid waste stream called landfill leachate. The volume of produced leachate is increased by rainfall. It cannot be directly discharged to water courses as it contains many hazardous pollutants and therefore must be retained for treatment. With over 150,000 landfill sites across Europe, and an estimated annual spend of € 10-17 billion on leachate treatment, there is already a large market available. It is expected that leachate treatment will become a bigger industry as environmental Directives, aimed at improving the quality of EU water, are implemented.

The technological concept of CleanLeachate is a treatment system for the removal of refractory organic substances and ammonium by oxidation processes without chemical additives using reactions at both the anode and the cathode of an electrolytic cell.

In scope of the CleanLeachte project this process was researched and optimized by testing several electrode materials as well as different process parameters. An automated and mobile treatment system was developed.

The system has been tested successfully on a landfill site in the Czech Republic.

The SME partnership is a complete supply chain for the CleanLeachate system.

The component manufacturers are:
- Magneto Special Anodes BV (the Netherlands): Anodes
- Eilenburger Elektrolyse- und Umwelttechnik GmbH (Germany): Electrolytic cells
- ASIO spol s r.o. (Czech Republic): Structural elements

Initial Projects limited (UK) is responsible of sales and marketing while Eilenburger Elektrolyse- und Umwelttechnik GmbH (Germany) and ASIO spol s r.o. (Czech Republic) also sell complete systems to their home markets.

Landfill leachate producers are not the only waste stream producers that can benefit from our apparatus. Other industries such as food production, pharmaceutical und petro-chemistry are also able to see financial and environmental benefits of treating their waste streams using the technology developed in the CleanLeachate project.

Summary description of project context and objectives

Landfilling of municipal waste is still a very important issue for waste management across Europe and the rest of the world. Evidence that this issue is being taken seriously is reflected in predictions that the production of biodegradable municipal waste is expected to be reduced to 75% by weight of 1995 levels by 2010. Whilst alternative disposal methods such as recycling, composting and incineration are being encouraged, incinerations create residue of approximately 10– 20% that will ultimately become landfill. At present, modern landfills are highly engineered facilities designed to eliminate or minimize the adverse impact of the waste on the surrounding environment. However, the generation of contaminated leachate remains an inevitable consequence of the existing waste disposal practice and will remain so for future landfills. After being landfilled the refuse decomposes through a series of combined physico-chemical and biological processes, this may take more than 50 years. During the degradation process, one tonne of landfilled solid waste will generate about 0.2 m³ of highly contaminated wastewater, called leachate, depending on the type of waste and seasonal climate. This wastewater primarily results from the degradation of the organic portion of the waste in combination with percolating rainwater and moisture that leaches out of organic and inorganic constituents through the waste layer in the landfill. Whilst modern landfill sites are lined, with clay or asphalt for example, this lining is only able to prevent contamination of the underlying water table with leachate if the levels are controlled.

The common features of raw leachate from landfill are its high concentrations of ammonia nitrogen (NH_3-N) (1,000-5,000 mg/L) and high content of recalcitrant compounds, as reflected by its COD value (1,000-20,000 mg/L). Of the toxic pollutants that are present in landfill leachate, NH_3-N, which is stable under anaerobic conditions and therefore typically accumulates in the leachate, has been identified not only as a major long-term pollutant but also as the primary cause of acute toxicity. When present at a concentration higher than 100 mg/L, untreated NH_3-N is highly toxic to aquatic organisms.

Since the first European Directive in 1975 (Surface water 1975/440/EEC), significant progress has been made in tracking sources of aquatic ecosystem contamination. Consequently, landfill effluents need to be pre-treated on site to meet the standards for discharge into the sewer or for direct disposal into surface water. In the EU countries the problem of leachate treatment has existed for some time, but a universal solution has not been found. Unless properly treated, leachate that seeps from a landfill can infiltrate and contaminate the underlying groundwater. Once the leachate escapes to the groundwater, it will be difficult and expensive to control and to clean it, thus posing potentially serious hazards not only to living organisms, but also to long-term public health. In most cases it is extremely difficult to restore the polluted groundwater to its former state. For this reason, in recent years, the risk of groundwater pollution due to leachate seeping has become a major environmental concern worldwide.

As a result of the above issues there are a large number of landfill operators, both within Europe and worldwide, who would benefit greatly from an efficient and cost effective method of treating leachate prior to disposal into the municipal sewage system. It is the aim of the CleanLeachate project to be able to offer, as a minimum, this method of disposal through the development of our electrolytic cell, and in so doing provide additional benefit both to the SMEs directly involved in this project and also to those SMEs who are further down the supply chain.

Project objectives

Since the beginning of the project the consortium formed a team of researchers, scientists, and marketing representatives of the partner companies, which established a multi-national network for mutual benefit. The team confirmed the technological concept of the CleanLeachate project to be a wastewater treatment system for the removal of refractory (not biologically degradable) organic pollutants and ammonium by oxidation processes without chemical additives using reactions at both the anode and the cathode of an electrolytic cell.

The scientific objectives defined in the project included:

S1   Characterization and clustering of the composition of the sourced leachate including parameters such as the viscosity, chemical oxygen demand, biological oxygen demand and pH.
S2   Quantification of anode reactions in targeted landfill leachate solutions.
S3   Quantification of cathode reactions in targeted landfill leachate solutions.

Achievements:

S1   Sourced leachate was analysed. Furthermore a literature review on the composition of landfill leachate was done. The extent of the pollution of leachate strongly depends on the kind of the disposed waste, on the age of the landfill and the climate. Results of the analysis of the sourced leachate and of the literature review on the leachate composition are in Deliverable 1.2.
S2   Experiments were carried out to quantify anode reactions in synthetic leachate and in real leachate. Different anode materials were used. The influence of different parameters (e.g. current density, pH, flow rate, chloride concentration) was investigated. The results are documented in Deliverables 2.1, 4.1 and 5.2.
S3   Experiments were carried out to quantify cathode reactions in leachate. The reduction of AOX at two cathodes with different geometries was investigated. The results are documented in Deliverables 2.1 and 5.2.

The technological objectives defined in the project included:

T1   Design of the prototype electrolytic cell in such a way that it can be scaled up.
T2   Lifetime of the membrane and electrodes of a minimum of 3 years, and the structural elements of the system with minimum lifetime of 10 years.
T3   Automation of the electrolytic cell apparatus to allow a Process Control with an internal feedback loop.
T4   Demonstration and validation of the performance of the unit on site.

Achievements:

T1   Simulations of fluid dynamics were performed to achieve a uniform leachate flow over the electrodes and thus to upscale the electrolytic cell for the prototype. Experimental results showed that the degradation efficiency is proportional to the electrode area. This fact allows simple upscaling of the electrolytic cell. Another opportunity for upscaling is the parallel use of several electrolytic cells..
Simulations are documented in Deliverable 2.1.

T2   The electrode stability was investigated. The loading of the electrode coatings was measured before and after usage of the electrodes.

The results of these measurements for the electrodes used in Lab cell 1 are documented in Deliverable 2.3. A slight decrease in the loadings of the coatings was measured. But this did not result in significant changes in ammonium and COD degradation.

To determine the electrode stability over a longer period the electrode used for Lab Cell 2 and the field trial unit was investigated. The remaining loading of the coating was 78% which is documented in Deliverable 5.2.

It should be considered that the lifetime is depending on different parameters like leachate characteristics and current density.

T3   A control system was developed to guarantee an efficient and safe operation of the process. The sensors and actuators were selected taking into account the process specifications and the control system was designed in such a way that it provided a high flexibility, allowing adaptation to Lab Cell 2 and to the final field test trial unit. The control system has been successfully implemented and operated in both, Lab Cell 2 and final field test trial unit. A detailed description of the control system is in Deliverable 3.1.

T4   A landfill site in Šlapanice near Brno/Czech Republic was selected as field trial site. Two different leachates from this landfill were treated with the field trial unit (raw leachate and chemically pre-treated leachate). The process worked reliably and target pollutant reduction was achieved.

The results of the field trials are presented in Deliverable 5.2.

Description of the main S&T results/foregrounds

Electrode reactions with target pollutants (Work package 1)

In the first work package RTD performers sought and merged the expertise of the SME-partners in their respective fields with the latest technology research resulting from a detailed literature search and constructive technical discussions in the consortium.

Literature research on electrochemical reaction mechanisms

Electrochemical waste water treatment is a water phase treatment with decomposition of water to oxygen O_2 and hydrogen H_2 as competitive reactions to the electrochemical degradation of pollutants.

There are two different mechanisms for anodic oxidation of pollutants: The direct oxidation which takes place directly on the anode surface and the indirect oxidation via a mediator species. The schematic mechanisms are shown in Figure 1.
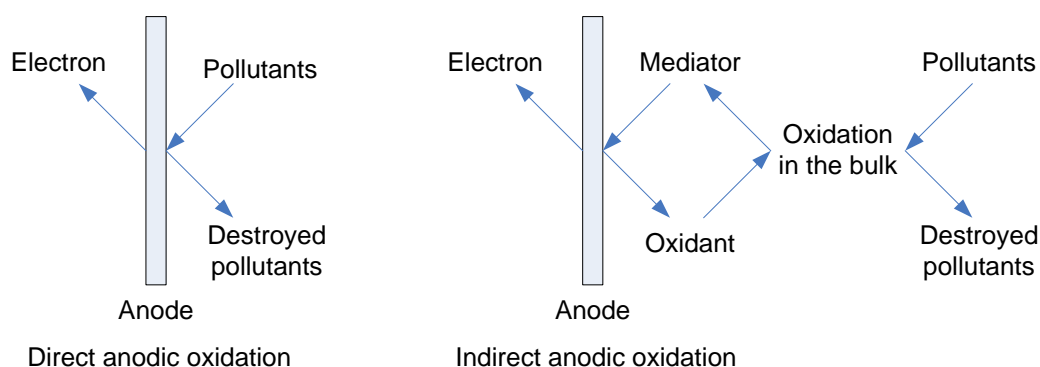

Figure 1: Scheme for pollutant removal pathways in electrochemical oxidation process (Chiang, Chang et al. 1995)

Anodes can be classified into two groups (Panizza 2009):
- "active anodes": they have a low O_2-overpotential hence they are good electro-catalysts for oxygen production. Active anodes are for example platinum-based anodes, iridium-based oxides and ruthenium-based oxides.
- "non-active anodes": these electrodes have a high O_2-overpotential and have low electrocatalytic activity for the oxygen evolution, e.g. antimony-doped tin oxide, lead dioxide and boron-doped diamond.

Electrochemical oxidation of ammonium

For electrochemical ammonium oxidation both the direct and the indirect pathway are possible.
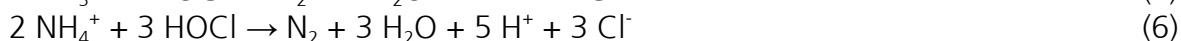
Ammonium is oxidised directly as ammonia around pH 8: The reaction follows the chemical equation (1) (Kim, Kim et al. 2005; Kapalka, Joss et al. 2010).

$$2\,NH_3 \rightarrow N_2 + 6\,H^+ + 6\,e^- \hspace{4cm} (1)$$

The indirect anodic oxidation proceeds through active chlorine or OH-radicals. Active chlorine is a collective term for the strong oxidants chlorine (Cl_2), hypochlorous acid (HOCl) and hypochlorite (OCl^-) (Mortimer and Müller 2003). These species are interdependent by the pH. Chlorine is electrochemically formed by oxidation of chloride ions.

$$2\ Cl^- \rightarrow Cl_2 + 2\ e^- \tag{2}$$
$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^- \tag{3}$$
$$HOCl \leftrightarrow OCl^- + H^+ \tag{4}$$

Electrochemically produced active chlorine degrades ammonium to nitrogen similar to breakpoint chlorination shown in the following equations (Li and Liu 2009):

$$2\ NH_3 + 3\ HOCl \rightarrow N_2 + 3\ H_2O + 3\ H^+ + 3\ Cl^- \tag{5}$$
$$2\ NH_4^+ + 3\ HOCl \rightarrow N_2 + 3\ H_2O + 5\ H^+ + 3\ Cl^- \tag{6}$$

Instead of nitrogen nitrate and nitrite can be formed (Kim, Kim et al. 2006):

$$NH_4^+ + 4\ HOCl \rightarrow NO_3^- + H_2O + 6\ H^+ + 4\ Cl^- \tag{7}$$
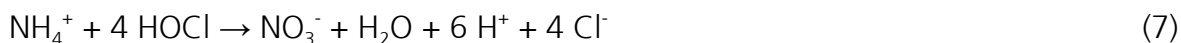
The reactions between active chlorine, especially hypochlorous acid and hypochlorite, and ammonium are very fast (Kapalka, Joss et al. 2010).
The indirect pathway via OH-radicals mainly takes place in neutral and acidic environment. The OH-radicals are produced at the anode surface and degrade ammonium to nitrogen (Kim, Kim et al. 2006).
The most important way to degrade ammonium is the pathway via active chlorine (Kim, Kim et al. 2006).
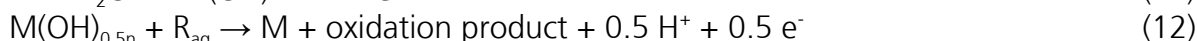
Electrochemical oxidation of COD

For the anodic oxidation of COD the direct pathway goes via adsorption of the organics at the anode surface. There the substances are oxidised by gradual electron transfer (Rajeshwar, Ibanez et al. 1994; Schmidt 2003; Rajkumar and Palanivelu 2004).

$$Org_{ads} \rightarrow CO_2 + H_2O \tag{8}$$

At metal oxide anodes direct oxidation of organic (RH) follows equation (9) and (10).

$$RH \rightarrow CO_2 + n\ H^+ + n\ e^- \tag{9}$$
$$RH \rightarrow R_2 + m\ H^+ + m\ e^- \tag{10}$$

The indirect oxidation proceeds mainly through OH-radicals or other strong oxidants. The OH-radicals mechanism at an electrode (M) is shown in equations (11) to (13) (Kapalka, Fóti et al. 2009).

$$M + H_2O \rightarrow M(OH) + H^+ + e^- \tag{11}$$
$$M(OH)_{0.5n} + R_{aq} \rightarrow M + \text{oxidation product} + 0.5\ H^+ + 0.5\ e^- \tag{12}$$
$$M(OH) \rightarrow M + 0.5\ O_2 + H^+ + e^- \tag{13}$$

First the OH-radicals are produced through the oxidation of water. The radicals remain adsorbed on the anode surface. In the vicinity of the electrode surface they react with the organics (R_{aq}). As unwanted side reaction oxygen production occurs.

The reactivity of the OH-radicals depends on the strength of adsorption forces. The weaker these forces are the more reactive are the OH-radicals. At BDD they are quasi-free and very effective for the oxidation of organics (Kapalka, Fóti et al. 2009).

The oxidation pathway via active chlorine is also possible but here the production of toxic chlorinated organics takes place (Simonsson 1997).

Electrochemical reduction of AOX

Electroreduction is an effective way to remove the halogen group from an AOX-molecule. By dissociative electron transfer the C-X (X= F, Cl, Br, I) bond is split.

There are two ways of the C-X cleavage of halogenated organic molecules (RX). One mechanism goes via a mediator radical ($RX^{\bullet-}$):

$$RX + e^- \leftrightarrow RX^{\cdot-} \tag{14}$$
$$RX^{\cdot-} \rightarrow R^{\cdot} + X^- \tag{15}$$

The other mechanism is the simultaneous electron transfer and the C-X cleavage:

$$RX + e^- \rightarrow R^{\cdot} + X^- \tag{16}$$
$$R^{\cdot} + e^- \rightarrow R^- \tag{17}$$
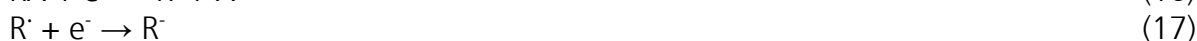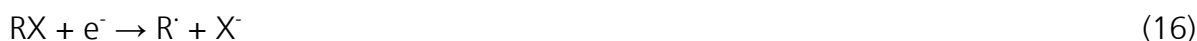
Both the anion (R^-) and the radical ($RX^{\bullet-}$) react with other RX molecules. This produces dimers and hydrodehalogenated substances.

The indirect dehalogenation through electrochemical produced atomic hydrogen is another way. This mechanism mainly takes place on cathodes activated with noble metals (Rondinini and Vertova 2010).

Experimental work: Setup

Experiments were carried out with a laboratory unit for electrolytic leachate treatment.

The electrolytic cell for leachate treatment (so called Lab Cell 1, see Figure 2) was built by Eilenburger Elektrolyse- und Umwelttechnik GmbH (EUT). It is built as a divided electrolytic flow-through cell. An anion-exchange membrane (Ralex AMH5E-HD by MEGA a.s.) separates the cell into an anode and a cathode compartment.
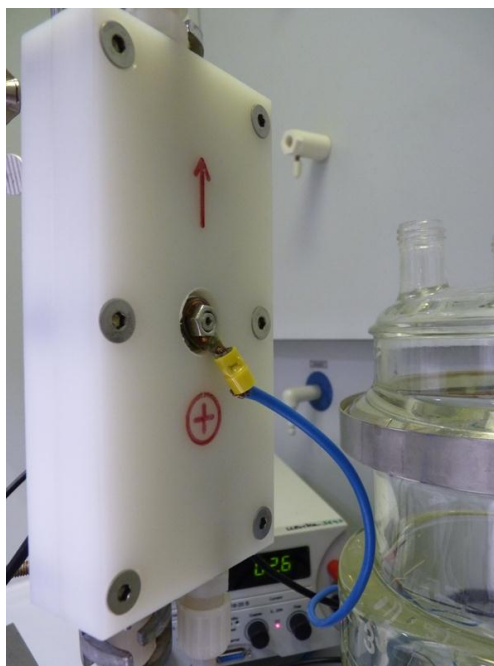
Figure 2: Lab Cell 1

Six different anode materials were used in Lab Cell 1:
– Ruthenium oxide/Iridium oxide (Ru/Ir)
– Platinum/Iridium oxide (Pt/Ir)
– Platinum (Pt)
– Lead dioxide (PbO_2)
– Tin dioxide (Sb-doped SnO_2)
– Boron-doped diamond (BDD)

All anodes were manufactured by MAGNETO SPECIAL ANODES BV, except for the boron-doped diamond anode (BDD), which was supplied by CONDIAS GmbH.
A stainless steel mesh was used as cathode.

First the leachate was treated by recirculating through the anode compartment to oxidise ammonium and organic pollutants. Then the leachate was transferred to the catholyte tank treated by recirculating through the cathode compartment to dehalogenate AOX that were formed during oxidation in the anode compartment.

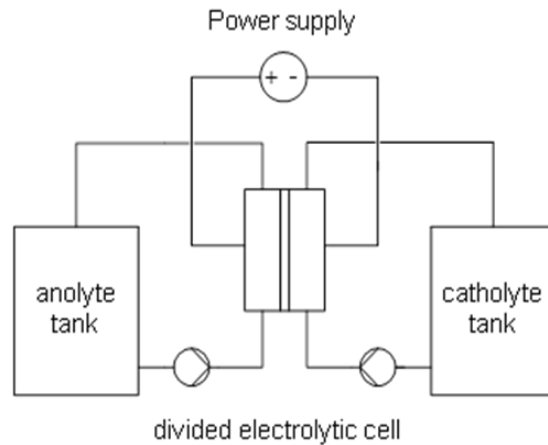The setup of the laboratory unit is depicted in the Figure 3.

Figure 3: Schematic drawing of laboratory unit

Experimental work: Results

Influence of different parameters on the anodic oxidation of ammonium

To investigate the influence of different parameters on the anodic oxidation of ammonium BDD was used as anode. The model wastewater had an ammonium concentration of 775 mg/L and a chloride concentration of 2000 mg/L. Both concentrations are equivalent to the concentrations in real leachate. The pH value of the anolyte was adjusted to 8 by adding NaOH. Experiments were carried out at a current density of 86 mA/cm² and a recirculation flow rate of 10 L/h.

The influence of chloride ions, pH, flow rate, and current density on the oxidation of ammonium was investigated.

Influence of chloride ions

When no chloride ions were present in the model wastewater, the ammonium was degraded only slightly. By adding chloride ions the degradation of ammonium was significantly improved from 17% to 59%. Chloride ions are oxidised to active chlorine at the anode. Depending on the pH chlorine, hypochlorite or hypochlorous acid is formed. These substances are strong oxidants that react with ammonium. Thus the ammonium concentration decreased quite fast when chloride ions were present in the solution. Furthermore the ORP is approximately 200 mV higher (800 mV instead of 600 mV) when chloride ions are added which confirms the presence of strong oxidants.

Influence of pH

By adjusting pH to a value of 8 the ammonium oxidation was improved from 37% to 59%. A reason for this is the equilibrium between ammonium and ammonia which is depending on pH. At a pH of 8 ammonium is partly present as ammonia. Ammonia can be absorbed at the surface of the anode. Thus it is directly oxidised.
Furthermore active chlorine is present as hypochlorite and hypochlorous acid under alkaline conditions. These substances are important oxidants for the indirect oxidation of ammonium and ammonia.

Influence of current density

Experiments were carried out at current densities of 80 mA/cm², 86 mA/cm² and 100 mA/cm² to investigate the influence of the current density on the ammonium degradation.
In this range the current density had no significant effect on the ammonium degradation.

Influence of flow rate

To investigate the influence of the flow rate on ammonium degradation experiments were carried out with recirculation flow rates of 10 L/h, 30 L/h and 50 L/h.
There was no significant effect of the flow rate on the ammonium degradation.

Experimental results with landfill leachate

The investigated landfill leachate originated from a municipal waste landfill site near Stuttgart, Germany. The landfill is already closed and is producing methanogenic phase leachate. The raw leachate properties are given in Table 1.

Table 1: Physico-chemical properties of the leachate

parameter	unit	value
COD	mgO_2/L	1360
BOD_5	mgO_2/L	120
BOD_5 / COD	-	0,09
AOX	mg/L	0,56
NH_4-N	mg/L	1000
NO_3-N	mg/L	6
N_{total}	mg/L	1200
Cl^-	mg/L	1100
ORP	mV	108
pH	-	8,39
conductivity	mS/cm	13

Experiments were carried out at a current density of 86 mA/cm². Six anode materials were tested (Pt, Pt/Ir, Ru/Ir, PbO_2, Sb-doped SnO_2, BDD). The decrease of COD and ammonium in the anolyte was determined. Furthermore the increase of nitrate in the anolyte was investigated.

COD degradation

On every examined anode material COD decreased. The extent of degradation depended on the anode material and varied between 15% and 52%. A sufficient decrease was observed at anode materials with a strong formation of OH-radicals that are weakly absorbed to the electrode surface. These radicals destroy organic substances very effectively. Anode materials that produce a lot of active chlorine were not sufficient for COD degradation.

Ammonium degradation

On every examined anode material the ammonium concentration decreased. The extent of degradation depended on the anode material and varied between 19% and 64%. The highest degradation of ammonium is obtained at anode materials that produce a lot of active chlorine. According to literature the ammonium degradation is mainly caused by the indirect oxidation through the electrochemical evolution of active chlorine. Therefore the degradation rate for ammonium correlates to the electrocatalytic activity of the anode materials toward the evolution of active chlorine.

Nitrate generation

During the electrochemical treatment of ammonium at different anode materials nitrate was formed. The extent of nitrate formation is influenced by the anode material. Lower nitrate formation was investigated at anode materials with a high electrocatalytic activity toward the evolution of active chlorine.
The reduction of nitrate into nitrogen in the cathode chamber was observed.
Nitrite could not be detected in the anolyte.

AOX reduction

AOX reduction in the catholyte was determined. AOX concentration decreased to a large extent but it was not removed completely.

Electrolytic cell research and development (Work package 2)

In the second work package simulations of fluid dynamics and gas bubble generation were performed to optimize and to upscale the design of the electrolytic cell. All simulations were performed with Ansys ®, an engineering simulation software.

The fluid dynamics of the electrolytic cell used in word package 1 (Lab Cell 1) were simulated. Furthermore simulations of gas formation on the electrodes were performed. For this purpose the inlet and outlet conditions were defined (e.g. density, temperature, velocity). The gas formation at the electrodes was simulated as particle wall injection.
The simulation results showed that flow velocity over the electrode was quite uniform. There was a considerable lower velocity on the sides and slight bubble stagnation at the outlet of the electrolytic cell.

To upscale the electrolytic cell fluid dynamics of three different cell geometries were simulated. The inlet and outlet conditions were defined (e.g. density, temperature, velocity).
The cell geometry with the most uniform flow velocity over the electrode was selected as so called Lab Cell 2.

Experimental automation of Lab Cell 2 (Work package 3)

The main goal of WP3 was the development of a control system to guarantee an efficient and safe operation of the process. The sensors and actuators were selected taking into account the process specifications and the control system was designed in such a way that it provided

a high flexibility, allowing adaptation to Lab Cell 2 and to the final field test trial unit. The control system has been successfully implemented and operated in both, Lab Cell 2 and final field test trial unit.

The control system is based on a distributed control strategy. A Programmable Logic Controller (Siemens S7-1200 PLC) is used to control the process, while a laptop computer serves as user interface and historical data base.
This strategy has several advantages over the use of a centralized control system: easy programming, autonomous operation, short response times and a great flexibility. The flexibility of a PLC is highly valued in a system like CleanLeachate, in which modifications may be identified during the performance of tests.

The pH value, ORP, conductivity and temperature were monitored in the anolyte tank of the Lab Cell 2 setup and pH and ORP in the catholyte tank. Furthermore flow rates through anode compartment and cathode compartment of the electrolytic cell were monitored. Dosing pumps for the pH adjustment in anolyte and catholyte as well as the power supply for the electrolytic cell were also connected to the control system.

The modular structure of the Siemens S7-1200 PLC allows for the implementation of additional modules if further parameters need to be monitored and controlled.

The integration of all control elements in a cabinet made transport of the control unit much easier. To further increase the flexibility of the system, the user interface was implemented in a laptop computer, making historical data management easier.

Figure 4: Switching carbinet

The control system was successfully implemented and operated in Lab Cell 2. Sensor performance and stability were successfully tested.

Construction and testing of automated field trial unit (Work package 4)

In work package 4 the field trial unit has been constructed to demonstrate the functionality and the efficiency for treating landfill leachate. The design and setup were based on results gathered within work packages 1 to 3.

The overall setup of the field trial unit is depicted in Figure 5.
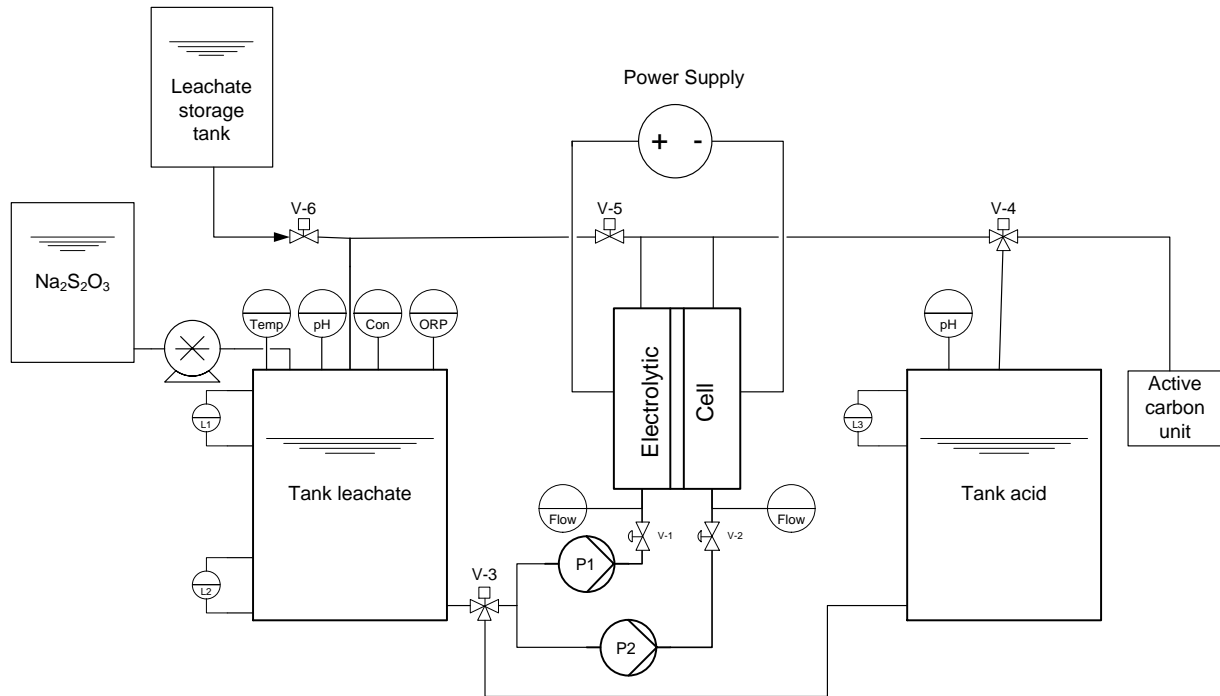

Figure 5: Overall setup of field trial unit

The field trial unit is operated in batch mode. As the first process step, the leachate tank is filled with leachate from a leachate storage tank that belongs to the landfill site. When the tank is full, the treatment begins. The anode compartment and the cathode compartment of the electrolytic cell are fed with landfill leachate from the same tank to avoid dosage of acid and base. After the treatment, the active chlorine that is formed in the anode compartment is removed by dosing with sodium thiosulfate solution. Then the treated leachate is discharged into a sewer. As the last process step, the electrolytic cell is cleaned with citric acid to remove calcium and magnesium precipitation that has formed on the cathode and on the membrane in the anode compartment.

The operation of the field trial unit can be summarized in five process steps:
1. Filling
2. Treatment
3. Active chlorine removal
4. Discharging
5. Cleaning

All process steps have been implemented to the software. This allows the user to operate the process either in MANUAL or AUTO mode.

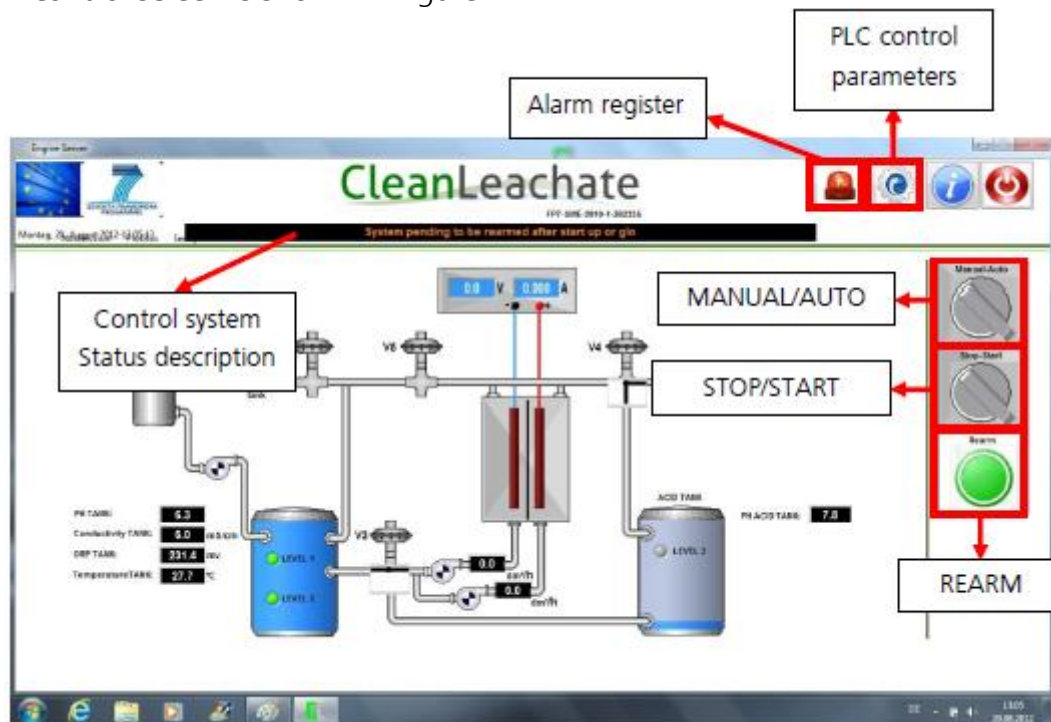The main control screen is shown in Figure 6.

Figure 6: Main control screen for the field trial unit

The manual mode allows the user to activate the different elements manually (e.g. pumps, valves).

When working in automatic mode, the user has to set the PLC control parameters (e.g. current set point, treatment time) in the PLC control parameters window, which can be accessed from the main control screen (see Figure 6). The process steps as described before are running automatically in succession.

Field trials (Work package 5)

A landfill site in Šlapanice near Brno/Czech Republic was selected as field trial site. Two different leachates from this landfill were treated with the field trial unit (raw leachate and chemically pre-treated leachate). Asio and Fraunhofer carried out the operation of the field trial unit.
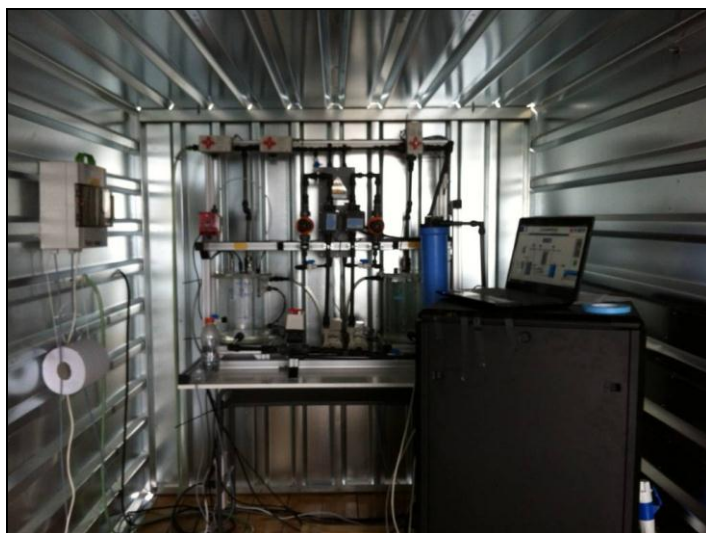
Figure 7: Field trial unit in Šlapanice/Czech Republic

Ammonium nitrogen was degraded almost completely from an initial concentration between 800 and 900 mg/L. Only a small amount of nitrate nitrogen was formed.

Organic compounds with higher molecular weight were degraded to organic compounds with lower organic weight (e.g. alcohols, ketons and aldehydes with a molecular weight < 350 g/mol).

Depending on the leachate and the current density the energy consumption of the electrolytic cell was between 7.23 kWh/m³ leachate and 51.61 kWh/m³ leachate.

Potential impact and main dissemination activities and exploitation of results

Through the adoption of the CleanLeachate apparatus there could be a significant societal benefit through the reduction of pollution from road transportation of raw leachate and through the improved treatment of leachate prior to discharge into sewage works. Some toxic organic compounds in landfill leachate are inhibitory to the biological processes at water treatment works. Raw leachate also contains recalcitrant organic substances that are not degraded during biological treatment at water treatment works.

The CleanLeachate process can be applied as final polishing step after biological treatment at leachate treatment works. The recalcitrant organic compounds will be removed reliably from the discharge, which will protect water bodies from pollution.
In case the leachate contains a lot of toxic substances, the treatment of leachate by the CleanLeachate process prior to release to the water treatment works will remove these toxic components so biological processes are not inhibited.

The CleanLeachate process is still more energy consuming compared to other leachate treatment processes. However, within the framework of the CleanLeachate project the process parameters were optimized and the energy consumption was reduced considerably. Furthermore the process was working reliably. It was shown that depending on the leachate and on the application (raw or pre-treated leachate) the CleanLeachate process can compete against other processes.

Dissemination activities included the project internet page http://www.cleanleachate.eu, created in December 2010. Furthermore Fraunhofer and ASIO have presented the project at different trade fairs in Germany and Eastern Europe (e.g. Hannover Messe 2012 in Hanover/Germany, IFAT Entsorga 2012 in Munich/Germany, MAJA 2012 in Riga/Latvia, EXPOAPA 2012 in Bucharest/Romania) by distributing flyers. The flyers are available in Bulgarian, Czech, English, Latvian, Romanian, Slovakian, and Ukrainian language.

Address of the project public website and relevant contact details

Christiane Chaumette
Physical Process Technology
Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Nobelstrasse 12
70569 Stuttgart
Germany

christiane.chaumette@igb.fraunhofer.de

A project website is available at:

http://www.cleanleachate.eu

and

http://www.cleanleachate.fraunhofer.de

References

Chiang, L.-C., J.-E. Chang, et al. (1995). "Indirect oxidation effect in electrochemical oxidation treatment of landfill leachate." Water Research **29**(2): 671-678.

Kapalka, A., G. Fóti, et al. (2009). Basic principles of the electrochemical mineralization of organic pollutants for wastewater treatment. Electrochemistry for the environment. C. Comninellis and G. Chen. New York, Springer**:** 1-24.

Kapalka, A., L. Joss, et al. (2010). "Direct and mediated electrochemical oxidation of ammonia on boron-doped diamond electrode." Electrochemistry Communications In Press, Corrected Proof.

Kim, K.-W., Y.-J. Kim, et al. (2005). "The electrolytic decomposition mechanism of ammonia to nitrogen at an IrO2 anode." Electrochimica Acta **50**(22): 4356-4364.

Kim, K.-W., Y.-J. Kim, et al. (2006). "Electrochemical conversion characteristics of ammonia to nitrogen." Water Research **40**(7): 1431-1441.

Li, L. and Y. Liu (2009). "Ammonia removal in electrochemical oxidation: Mechanism and pseudo-kinetics." Journal of Hazardous Materials **161**(2-3): 1010-1016.

Mortimer, C. E. and U. Müller (2003). Chemie : Das Basiswissen der Chemie. Stuttgart, Thieme.

Panizza, M. (2009). Importance of electrode material in the electrochemical treatment of wastewater containing organic pollutants. Electrochemistry for the environment. C. Comninellis and G. Chen. New York, Springer**:** 25-54.

Rajeshwar, K., J. G. Ibanez, et al. (1994). "Electrochemistry and the Environment." Journal of Applied Electrochemistry **24**(11): 1077-1091.

Rajkumar, D. and K. Palanivelu (2004). "Electrochemical treatment of industrial wastewater." Journal of Hazardous Materials **113**(1-3): 123-129.

Rondinini, S. and A. Vertova (2010). Electroreduction of Halogenated Organic Compounds. Electrochemistry for the Environment. C. Comninellis and G. Chen. New York, Springer**:** 279-306.

Schmidt, V. M. (2003). Elektrochemische Verfahrenstechnik : Grundlagen, Reaktionstechnik, Prozeßoptimierung. Weinheim, Wiley.

Simonsson, D. (1997). "Electrochemistry for a cleaner environment." Chemical Society Reviews **26**(3): 181-189.