

**THE 16th INTERNATIONAL SYMPOSIUM
ON ELECTROKINETIC REMEDIATION
BOOK OF ABSTRACTS**



**6-8 August, 2018
Canakkale, Türkiye**





XVI. International Symposium on Electrokinetic Remediation
Çanakkale, Turkey, August 6-8, 2018



Book of Abstracts

The 16th International Symposium on Electrokinetic Remediation

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PREFACE

The symposia on Electrokinetic Remediation (EREM) have been held for two decades. The first symposium was held in Albi (France) in 1997, followed by subsequent editions around the world (Denmark, Germany, Belgium, Italy, Spain, South Korea, Portugal, Taiwan, The Netherlands, Japan, USA, Spain, UAE and Canada). The 16th edition of this conference (EREM 2018) has been organized by Çanakkale Onsekiz Mart University, Department of Geological Engineering, Canakkale-TURKEY.

This book includes the abstracts of the communications presented at the XVIth International Symposium on Electrokinetic Remediation (EREM 2018) August 6-8, 2018. EREM 2018 has attracted a large and diverse audience from engineering and scientific communities from around the world. There were two interesting keynote lectures and many communications about the electrokinetic applications to various materials, including soil, sediments, tailings, as well as industrial and municipal sludge. Applications of electrokinetic techniques to water treatment, wastewater treatment, mining, etc. were among the innovative use of electrokinetics in environmental applications. Overall, EREM 2018 conference has been very successful in bringing the cutting edge research in electrokinetics to the fore.

Abstracts were organized according to the symposium topics. Note that the authors are solely responsible for the content of their manuscripts and the opinions expressed.

Scientific Committee members were selected from well-known, productive and representative researchers from different countries. We are grateful to the scientific committee members of EREM 2018.

Our sincere thanks goes to the invited speaker Prof. Krishna R. REDDY from the University of Illinois at Chicago, USA and Prof. Maria ELEKTOROWICZ from Concordia University, Canada, for their interesting lectures. We also would like to thank all the contributors and attendees from more than 16 different countries for their interests and contributions. We were honored by your support and participation to the EREM 2018.

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We would like to thank the Session Chairs for their valuable contributions during the 16th International Symposium on Electrokinetic Remediation held in Çanakkale, Turkey, 6-8 August 2018.

Ahmed Benamar

Cetin Kantar

Yeliz Yükselen Aksoy

Anil K. Haritash

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Keynote Lecture 1:

Framework for Integrating Sustainability into Electrokinetic Remediation Projects

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Abstract

Soil and groundwater contamination is one of the major environmental pollution concerns in the world today. Several in-situ and ex-situ remediation technologies have been developed over the years to remediate the sites with contaminated soils and groundwater. Electrokinetic remediation (EKR) is one of the effective in-situ technologies for remediation of contaminated sites with inorganic contaminants, organic contaminants, or combination of them (mixed contaminants). EKR involves applying an electric potential across the contaminated zone through a series of electrodes (anodes and cathodes). Due to a variety of electro-chemical and chemical processes within the soil, the contaminants are driven towards respective electrodes and the contaminant-laden liquids are then removed from the electrodes. Electrokinetic remediation may be combined with other technologies such as chemical oxidation/reduction and bioremediation to make the overall process effective and economical. Although the principle used is simple, the dynamic physico-chemical conditions induced within the soils significantly affect the effectiveness of the EKR system. There has been considerable research to understand, optimize, and enhance the efficiency of contaminant remediation using EKR system. However, the broader environmental, economic and social benefits/impacts of the use of EKR as an alternative to other potential remedial technologies are unclear. Thus, there is a need for a general framework for assessing the triple bottom line sustainability of remediation alternatives to identify the most suitable option for the remediation of the site. This study presents a quantitative framework for integrating the sustainability assessment into the remediation projects. The proposed framework integrates the life cycle assessment concept for environmental sustainability assessment, the life cycle direct and indirect cost analysis for economic sustainability assessment, and a stakeholder survey-based project specific social sustainability assessment to collectively evaluate the overall sustainability index of potential remedial options identified for the remediation project. A detailed explanation of the concepts involved in the proposed sustainability assessment framework is presented. In addition, the applicability of the proposed framework is demonstrated through a case study involving the quantitative sustainability assessment of EKR and other potential remedial options for a contaminated site remediation project.

Keywords: Electrokinetic Remediation; Contaminated Site; Sustainability; Life Cycle Assessment; Multi-Criteria Decision Analysis



Keynote Lecture 2:

Application of Electrokinetics to Various Colloidal Environmental Systems

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Abstract

The application of electrokinetic phenomena to variety of environmental systems open an excellent possibility for development of new processes; most of them, are related to new treatment methods. The most difficult matrix to treat in environmental engineering domain are colloidal materials, stable suspensions, and multi-component polluted residues. Fortunately, such matrices are well responding to the application of electrokinetic phenomena.

Industrial sludge has very often characteristics of a stable suspension which is difficult to treat by any conventional method. However, the application of an adequate electrical field permits on its demulsification and subsequent separation of components, which might be recovered for further use. This might be a case of petroleum sludge.

Management of municipal sludge presents 60% of wastewater treatment plant's costs. Such matrix contains organic colloidal and biological fractions as well as mineral phase, metals, and other impurities. Moreover, an important amount of water, having affinity to sludge flocs does not respond to free drainage or conventional dewatering processes. Electrokinetics changes properties of sludge permitting on its dewatering, but also on its disinfection and the removal of different impurities, i.e. transforming wasted material into a valuable fertile soil amendment. Advanced BioElectro system can even sterilise complex materials (including all types of sludge) by taking an advantage of electroporation phenomena.

Treatment of soil, sludge and sediments contaminated with mixture of pollutants represents the most challenging task in environmental engineering. Usually, separated operation units are applied to address each type of pollutant. Electrokinetic can overcome this challenge and can perform simultaneous treatment of all pollutants in-situ or ex-situ.

Combining electrokinetics with other processes, gives infinite possibility for development of various new technologies. Electro-Fenton method permits on an advanced treatment of soil, sediments, sludge and groundwater. Bioelectro-phytoremediation accelerate the soil remediation in-situ.

Electrokinetics combined with membrane filtration and biological processes advances wastewater treatment to the point that drinking water can be recovered from wastewater using one operation unit only. In such case, until five different operation conventional units can be substituted by one electrokinetic compacted system, leading to decrease of energy, footprint and free emission of greenhouse gases.

Electrokinetics can be sometimes only solution for complex systems, e.g. loam-clayey polluted soils. Formation of a sub-surface barriers to protect groundwater can be done by electro-grouting only. On other hand, a multi-step grouting in oil contaminated soil can be conducted by one electrokinetic system.

The presentation will include lab and pilot applications of the above mentioned methods.

Keywords: Electrokinetics, electro-membrane bioreactors, BioElectro disinfection, electro-grouting, Electro-Fenton, treatment of colloidal matrices, multiple pollution



Effect of Temperature and pH on the Efficiency of PCB Removal from Glacial Till with Persulfate Oxidation Method

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Abstract

PCBs tend to persist in the environment due to their hydrophobic nature and low water solubility. They can become rapidly associated with sediments and soils. In situ oxidation can be enhanced by integrating electrokinetic and electrochemical processes with the use of chemical oxidants such as persulphates or hydrogen peroxide. In situ chemical oxidation is a process of injecting chemical oxidants into contaminated soil and groundwater to oxidize the contaminants. As most of the contaminants are degraded completely within the soil, it eliminates the collection of such contaminants in the effluents and thereby reducing the costs and efforts of treatment. Persulfate is a strong oxidant, however the kinetics of direct oxidation by persulfate are generally slow that reason needs to be activated. There are four primary methods that activate the persulfate. These are heat, metal chelates, hydrogen peroxide or high pH. The aim of this experimental investigation was to assess the feasibility of using chemical oxidation to degrade 2, 2', 3, 5' tetrachlorobiphenyl (#44) from artificially contaminated glacial till. For this purpose, several batch tests were performed with the sodium persulfate. The effect of temperature, pH and their combinations on the degradation were evaluated. It is more difficult to remediate glacial till, because of its non-homogenous constituents and high organic content. The initial total PCB concentration in glacial till samples was about 50 mg/kg. The PCB degradation increased with increasing temperature. The highest PCB degradation was obtained at 45°C after 24 hours and it was 62.3%. As temperature increased from 23°C to 45°C, the PCB degradation increased from 10% to 62.3%. PCB degradation was greater for pH 2 than for pH 4, 7, and 9 because persulfate was active at pH values less than 3. PCB degradation was significantly greater for pH higher than 10. PCB degradation for pH-activated persulfate oxidation was significantly lower as compared to PCB degradation with temperature activated persulfate oxidation, indicating that activation of persulfate oxidation with higher temperatures was more effectively than activation with high pH. When the temperature was 23°C, the final pH values were very close to the adjusted initial pH values. However, when the temperature was 45°C, the final pH values decreased significantly. The results show that, as the persulfate reaction proceeded, the pH of the solution decreased. However, the final pH values were high for glacial till due to the buffering capacity of glacial till. The pH decreased from 12.0 to 4.0 for glacial till at the end of the reaction period. In order to evaluate maximum removal efficiency, elevated temperature and high pH activators were used together. The tests were done at 45°C and pH 12, with 30% Na-persulfate dosage and reaction time of one day. When these two activators were used together degradation values was 24.5% for glacial till. When these results were compared with only temperature activation results, glacial till had higher (62.3%) degradation with elevated temperature activation of persulfate. Furthermore, with only high pH activation (pH 12) and at room temperature (23°C), PCB degraded 34.2% at glacial till. According to these results, the oxidation of PCB can be enhanced by temperature activation effectively.

Keywords: Glacial till, pH, Persulfate oxidation, Temperature



Enhancing Free Radical Production from Spent Pd Catalyst used in Electro-Fenton's Process

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Abstract

The production of free radical based on Palladium (Pd) catalysts is enhanced for remediation of hydrocarbon's wastewater with electro-Fenton reaction. However, spent catalysts have been produced as a reaction time consumed. This paper develops regeneration techniques with bases for deactivation of sulfide's poison with aqueous solutions. The proof of concept was established comprehensively using SEM, EDAX and optical imaging analysis. The effects of pH on a regenerated Pd were investigated for hydrocarbons dehalogenation (Trichloroethylene (TCE) and Chlorobenzene (CB)). Regeneration of a spent catalyst was done using NaOH and NH₄OH. The regeneration capacity was tested in removal % of TCE and CB with catalyst containing 0.5% Pd supported on alumina. The NH₄OH showed more active than NaOH for enhancing free radical production.





Treatment of Actual Wastewater from a Pharmaceutical Industry with Modified Pyrite-Fenton Process

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Abstract

Wastewater from pharmaceutical industries usually contains substances that are highly toxic to microorganisms. Fenton process using cost effective catalysts such as pyrite offers a cost effective and highly efficient solution to the treatment or pre-treatment of such toxic wastewaters. Here, column experiments were carried out to determine the applicability of pyrite Fenton process to the treatment of a wastewater from a pharmaceutical industry located in Turkey under variable chemical conditions (e.g., pH, citrate concentration). The wastewater used in the experiments contained a diclofenac concentration upto 20 mg/L with minor concentrations of some chlorophenolic compounds (e.g., 2-chrophenol). The wastewater had a solution pH of 7.1 with TOC and COD concentrations of ~180 mg/L and ~600 mg/L, respectively. Our results show that pyrite-Fenton process was very effective in removing diclofenac from actual wastewater. The process efficiency increased with decreasing solution pH. The addition of an organic ligand, citrate had a positive impact on process efficiency, and highly extended life span of pyrite-packed columns relative to non-ligand containing systems.

Keywords: Fenton, diclofenac, wastewater, treatment, pharmaceuticals





Comparison of Conventional and Electrofenton Pretreatment Methods for Olive Mill Wastewater

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Abstract

The type of pre-treatment method for olive mill wastewater (OMW), which is one of the most problematic industrial wastewaters, has a very important role in the success of the whole treatment scheme. Therefore, in this study, several physico-chemical processes (coagulation, fenton and electrofenton) were investigated for the removal of pollutants from OMW. Optimum conditions were determined for all pretreatment methods and the results are compared according to pollutant removal efficiencies. Based on the comparison, the most efficient pretreatment method was selected. For coagulation, at optimum alum dose of 5000 mg/L; 22% turbidity, 17% TSS, 15% COD and 9% sCOD removal efficiencies were obtained. In the fenton process; 20:1 H₂O₂/FeSO₄ molar ratio was selected as optimum ratio, and 71% turbidity, 70% TSS, 33% COD and 14% sCOD removal efficiencies were found. In the electrofenton process, optimum conditions were determined as pH 3, 20:1 H₂O₂/FeSO₄ molar ratio and 10 V direct current. After four hours, 93% turbidity, 91% TSS, 44% COD and 19% sCOD efficiencies were achieved. Economic analysis of the methods were also compared. Overall results indicated that electrofenton is the best pretreatment option for OMW in terms of both pollutant removal efficiencies and economic feasibility among the other pretreatment methods investigated.

Keywords: Olive mill wastewater, Coagulation, Fenton, Electrofenton, Pollutant



Isolation of Bacterial Strains and Mitigation of Agricultural Soil Using Solar-Powered Bioelectrokinetic

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Abstract

The present study investigated bioelectrokinetic of soil contaminated with petroleum hydrocarbons. Dozens of bacterial strains have been isolated from agricultural soil and characterized according to their ability to degrade diesel fuel. Forty five strains were identified to be able to use diesel fuel as sole carbon source. Bacterial genes that involve in diesel degradation were found to be expressed in three distinct strains, designated as AC16, SM155 and SB53. These strains have been subjected to further investigation, including identifying functional genes, ability to grow in liquid medium with different diesel fuel concentrations and at different pH's and temperatures. The experimental program involved outdoors tests in which a new electrode configuration technique was used to stabilize the pH during the bioelectrokinetic treatment. The new technique employs an anode and a cathode in the same compartment (ACC) placed side by side at each end of the soil under treatment. The hypothesis was that the coexistence of an anode and a cathode in the same water compartment would result in the hydroxyl ions generated at the cathode neutralizing the hydrogen ions produced at the anode and thereby forming water. The power for bioelectrokinetic was provided by a solar photovoltaic panel. The use of solar power in bioelectrokinetic will advance the understanding of hybrid solar-bioelectrokinetic applications and initiate steps of deploying this new treatment technology in particular for sites without power lines.

The tests were conducted using six electrokinetic cells placed inside steel cabinets located in an open to sky yard for 60 days with no temperature control. The soil temperature in the cells were monitored and recorded regularly during the test using real time data acquisition systems and compared with the minimum, median, and maximum ambient temperatures obtained from local weather station. The voltage gradient and the electrical current running through electrokinetic cells were monitored and recorded during the test. After the tests, soil sample in each cell was recovered and divided into four sections between the anode and the cathode and water content, pH, nutrients, and diesel fuel concentration was determined in each section.

The results showed that the electrical currents in the cells during the tests varied between 0.23 A and 0.12 A. The differences between the current values in the cells can be attributed to the initial constituents of the matrix in the cells. The temperature results show a significant difference (18 to 20°C) between the maximum temperature in the electrokinetic cells and the maximum ambient temperature. The results show direct correlation between the current and the temperature. The results from this study provide evidence that the application of electric current in electrokinetics can cause an increase in soil temperature. The increase in temperature can stimulate the growth and metabolism of bacteria. The results show that the application of electrokinetic bioremediation resulted in an increase in diesel fuel degradation between 83% and 127% compared to the control. The results may also suggest that the increase in current increased the diesel fuel degradation as the increase in current increased the temperature in the cell.

Keywords: Electrokinetic, Bioremediation, Solar power, pH stabilization, Bacterial strains



Soil Response to the Application of a DC Electric Field in Phytoremediation

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Abstract

Phytoremediation is a technology designed for the restoration of contaminated soils and groundwater. The remediation is carried out by plants growing up directly in the contaminated soils. This is a versatile technology that can deal with heavy metals or organic contaminants. It has been demonstrated that the remediation capacity of the plants can be enhanced by the direct application to the soil of low intensity electric fields. The electricity mobilizes contaminants and nutrients that are more bioavailable for plants. However, the electric current in the soil tend to create pH gradients due to the electrochemical decomposition of water on the electrodes. Significant pH changes in the soil are going to affect the growth and survival of the plans. This study deals with the effect of the electric field in the properties of the soil, paying special attention to soil pH and electric conductivity. The objective is to determine the response of the soil to the application of a DC electric field along the time. Thus, a system for the application of the electric field to the soil could be designed avoiding dramatic changes in soil pH. Three different soils were tested in this study: clayey soil, agricultural soil with organic matter, and topsoil. The clayey soil showed the highest resistance to pH changes. This soil was selected to grow plant species with remedial capacity: *Phalaris Canariensis*, *Brassica Rapa* and *Zea Mays*. *B. rapa* showed the fast growing in the presence of a constant electric potential gradient of 1 DCV/cm.

Keywords: Phytoremediation; Electric Field; *Brassica rapa*; Soil Physicochemical Properties



Electro-Phytoremediation of Mixed Contaminated Soil with *Brassica rapa*

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Abstract

Phytoremediation is a sustainable process in which green plants are used for the removal or elimination of contaminants in soils. Both organic and inorganic contaminants can be removed or degraded by growing plants by several mechanisms, namely phytoaccumulation, phytostabilization, phytodegradation, rhizofiltration and rhizodegradation. Phytoremediation has several advantages: it can be applied in situ over large areas, the cost is low, and the soil does not undergo significant damages. However, the restoration of a contaminated site by phytoremediation requires a long treatment time since the remediation depends on the growth and the biological cycles of the plant. It is only applicable for shallow depths within the reach of the roots, and the remediation efficiency largely depends on the physicochemical properties of the soil and the bioavailability of the contaminants. The combination of phytoremediation and electrokinetics has been proposed in an attempt to avoid, in part, the limitations of phytoremediation. The coupled phytoremediation–electrokinetic technology consists of the application of a low intensity electric field to the contaminated soil in the vicinity of growing plants. The electric field may enhance the removal of the contaminants by increasing the bioavailability of the contaminants. Variables that affect the coupled technology are: the use of AC or DC current, voltage level and mode of voltage application (continuous or periodic), soil pH evolution, and the addition of facilitating agents to enhance the mobility and bioavailability of the contaminants.

This work study the effect of the electric field in the plant growing and development and in the simultaneous capacity of the plant in the removal/degradation of heavy metals and organic contaminants. The soil used in this study was contaminated with heavy metals (Cd, Pb and Cr) and PAH (anthracene and phenathrene). *Brassica rapa* was selected as a plant with promising phytoremediation capacity. The plants from genus *Brassica* are well-known as their capacity in phytoremediation and *B. rapa* is a species very well adapted to the local climate and soil conditions in this study, this plant shows a rapid growth and does not demand specific conditions. This study try to evaluate the capacity of *B. rapa* in the phytoremediation of a mixed contaminated soil and the possible enhancing or detrimental effects of the electric filed applied to the soil around the growing plants. The influence of AC and DC electric fields and various modes of operation were tested. *B. rapa* was not negatively affected by the presence of the electric field and significant enhancement in the remedial capacity was observed compared to the control tests without plant or electric current. The periodic application of 1 DCV/cm yield the best remediation results.

Keywords: Phytoremediation; *Brassica rapa*; Heavy Metals; PAH.



Physicochemical and microstructural changes in clay soils due to electroosmosis

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Abstract

Treatment of soils from the hazardous contaminants is one of the most important ecological challenges. From this point of view, electrokinetic treatment of clayey soils is a promising and very efficient method, and the rate of its efficiency depends not only on technological aspects but also on contaminant properties and physicochemical parameters of the treated soil greatly. Meanwhile, soil properties are changed due to an electrokinetic treatment. Particularly, in some cases the values of electrokinetic potential of clay particles, which effects on soil structure, its adsorptive and filtration properties, are changed. Consequently, the purpose of the present study was to study a change of clay particle electrokinetic potential in the course of electrokinetic treatment of clayey soil and to estimate a related change in soil physicochemical properties that are significant for the efficient pollutant treatment. The mantled loam (80% quartz, 20% clay minerals) and kaoline were chosen as objects of the investigation. The studied samples were artificially made by mixing dry soil matter with 0.01 M CaCl₂ solution up to the moisture corresponding to liquid limit (w_L). Electroosmotic treatment was conducted in the one-compartment open type cell at the constant current strength of 10 mA until the electroosmotic flow had ceased. Each specimen after the treatment was divided into 5 parts along their length. The samples were taken from each part to measure the moisture and the density and to prepare suspensions. Electrokinetic potential values (ζ) were determined in the suspensions under different pH at a constant solution ionic strength of 0.03 M. The ζ -potential values were determined by the laser analyzer Horiba SZ-100, pH was controlled by the instrument pH 150-M, total dissolved solids were defined by the conductometer HM Digital COM-80. In addition, samples for a scanning electronic microscopy (SEM) were taken from the initial specimen and after its electrokinetic treatment from anodic and cathodic parts to study microstructural transformations caused by electroosmosis. Ions redistribution, pH and ζ -potential change by the length of the specimen was studied as a function of a relative distance from the anode (L/L_0). Electrokinetic treatment results in the change of pore solution pH and clay particles ζ -potential values. For a sample of the mantle loam an alkaline medium about pH=11 was generated in the cathode part ($L/L_0=0.9$) while changes in ζ -potential here are negligible: from -31.5 mV at pH=6.5 for initial specimen to -34.0 mV at pH=11 after the treatment in the case of a constant ionic strength of the pore solution. On the contrary, medium near the anode part ($L/L_0=0.3$) becomes acidic (pH=4) that results in a recharge of clay particles. In this way the clay particles have positive ζ -potential values (+24.0 mV) whereas in a highly acidic medium in the anodic part ($L/L_0=0.1$) at pH=1.7, $\zeta=+3.5$ mV, so here ζ -potential values are lower than in a weak acidic medium due to the contraction of double electric layer (DEL) envelopes. The point of the change in ζ -potential sign is shifted to the anode direction and is located at $L/L_0\approx 0.4$, pH value of point of zero charge is 4.8. Thus, electroosmosis and the influence of a direct current result in a redistribution of the ions along the length of a clayey soil specimen and in a formation of the pH and ζ -potential gradients that limit electroosmotic process. This work was supported in part by "M.V. Lomonosov Moscow State University Program of Development".

Keywords: Electroosmosis, ζ -potential, Clay soil, Point of zero charge



A Solid-State Sensor Based on Poly(2,4,6-triaminopyrimidine) Grafted with Electrochemically Reduced Graphene Oxide for Pharmaceutical Applications

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Abstract

A catalytic surface made by incorporation of electrochemically reduced graphene oxide (ERGO) on poly(2,4,6-triaminopyrimidine) (Ptap) film modified glassy carbon electrode. The surface morphology of the constructed electrode (ERGO.Ptap/GCE) was characterized by electrochemical and surface scanning techniques such as Cyclic Voltammetry (CV), Electrochemical Impedance Spectroscopy (EIS), X-ray Photoelectrons Spectroscopy (XPS), Fourier Transform Infrared Spectroscopy (FTIR), and Spin Electron Microscopy (SEM). The synergistic effect of surface materials promotes the catalytic efficiency of the developed sensor for the detection of pharmaceutical drug composed of ephedrine (EPH) and paracetamol (PARA) constituents. The heterogeneous rate constant of the surface materials was $1.63 \times 10^{-2} \text{ cm.s}^{-1}$ evaluated by Nicholson method. The diffusion coefficient of ephedrine was also evaluated using theoretical electrochemical approach equal to $1.59 \times 10^{-6} \text{ cm}^2.\text{s}^{-1}$. The detection limit for the selective determination of PARA and EPH were 0.15 and 5 ppm, respectively. The analytical performance of the sensor was successfully applied for real drug sample with acceptable analytical recovery percentage.

Keywords: Reduced graphene oxide, Polypyrimidine film, Ephedrine

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Electrokinetic Demulsification of Water-in-oil Suspensions by Implementing Various Additives

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Abstract

A huge amount of various oily suspensions, is produced per day in the upstream and downstream of petroleum industries which requires to be managed in an appropriate way. Since these suspensions show often properties of stable emulsions, their treatment for a safe disposal is not an easy task. Furthermore, very often such suspensions are considered potentially harmful to the environment, then, their disposal requires a particular attention. Current treatment processes including separation of phases by centrifuge, result in a decrease in the disposal volume of sludge and also extraction of water; however, an extra procedure is required, particularly when such suspension is a water-in-oil emulsion. Therefore, electrokinetic method for the oil-water separation came into consideration for enhancement of the quality of separated products. Subsequently, introducing additives into the electrokinetic system was considered for accelerated demulsification and achieving better water clarity at lab scale. This paper discusses impacts of several additives, namely, ferric chloride, alum, cationic polymer, clay, and a mixture of clay and a cationic polymer on electrokinetic treatment of suspensions. The tests were conducted at small, medium and large lab scale using arrays of steel electrodes and an evacuation system which mimicked full scale conditions. The results showed improvement of the system conductivity by introducing additives as well as a better phase separation process. Furthermore, an excellent clarity of extracted water was achieved by using ferric chloride. The results from this study are ready to be implemented at a pilot scale.

Keywords: Oily sludge, Electrokinetics, Oil-water separation, Demulsification, Additives



Treatment of End-Waste Effluent from the Electrokinetic Reactivation of Activated Carbon

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Abstract

The electrochemical regeneration of spent activated carbon has been proposed as an efficient and sustainable alternative to the classical reactivation methods (thermal, chemical, ...). The electrochemical treatment consumes less energy and produce less CO₂ than the traditional thermal activation. The electrochemical regeneration of activated carbon uses a DC electric current directly applied to the carbon specimen through an anode and cathode. The electric current desorbs and mobilizes the contaminants retained in the activated carbon. The contaminants include organics compounds and inorganic ions. These contaminants remain dissolved in the catholyte and anolyte. At the end of the regeneration process, the electrode solutions (anolyte and catholyte) are the wastewaters that contains the concentrated contaminants retained in the carbon. This work proposes a combination of various advanced oxidation processes (electrochemical, photochemical and chemical oxidation) for the removal of the organics in the wastewaters with the objective of recycling the electrode solutions to the regeneration process.

Keywords: Activated Carbon; Electrochemical Regeneration; Advanced Oxidation Processes

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Fine-grained soils remediation by electrokinetic process

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Abstract

Electrokinetic process is an effective technology for treating fine-grained soils. The removal of various contaminants from soil and its improvement can be achieved by electrochemical processes involved by a continuous fixed potential voltage which induces the migration of chemical species toward opposite electrodes (electro-migration). In addition to this process, the electric field stimulates a net flow of water from the anode to the cathode, namely electroosmosis. This is a key phenomenon that moves contaminants in the soil and therefore leads to the extraction of pollutants. The present work aims to study the performance of electrokinetics on species transfer in a silty soil collected from Ain Nouissy (Mostaganem, Algeria), as an innovative in situ and ex situ treatment technology. A test cell was developed at the laboratory scale where electric current, effluent flow, pH, and voltage and water content were measured at different positions along the sample, when different voltages were applied. The results obtained from the tests showed electro-osmotic flow increases with increasing voltage till an asymptotic value. The remarkable reduction in moisture content in the soil sample was also measured during the electroosmosis process, showing the process ability to consolidate the soil. Soil heating was investigated through the surface temperature, indicating a relative loss energy by heating when the voltage gradient exceeds an optimal value.

Keywords: Electro-migration, Direct current, pH, Electroosmosis, Clay, Cathodic effluent.



Enhanced Electrokinetic Remediation of Dredged Harbor Sediment Co-Contaminated by Heavy Metals and Polycyclic Aromatic Hydrocarbons (PAHs)

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Abstract

The maintenance of harbor waterways generates large amounts of dredged sediments which contain organic and inorganic contaminants. Electrokinetic (EK) remediation is often developed for metal decontamination but shows limitations for polycyclic aromatic hydrocarbons (PAHs) which involve low aqueous solubility. Laboratory studies were devoted to the investigation of EK efficiency on the mobility and the removal of metals (As, Cd, Cr, Cu, Ni, Pb and Zn) and PAHs from contaminated sediments. Many samples of dredged sediments collected from different deposits which are managed by a French harbor, were subjected to enhanced electrokinetic treatments, using mixtures of chelating agents (citric acid CA, ethylenediaminetetraacetic acid EDTA, ethylenediaminedisuccinic acid EDDS, nitrilotriacetic acid NTA) and surfactants (Tween 20 (TW20), rhamnolipid, saponine, original biosurfactants) as additives in the processing fluids. Various testing conditions were investigated: different voltage gradients, different CA concentrations, applied intermittent voltage gradient. Results showed that increasing CA concentration was favorable for both metal and PAH removal. Applying intermittent voltage gradient associated to a low concentration of CA and TW20 provided the best results for Zn, Cd and Pb removal and also for removal of the 16 priority PAHs. Promising results were obtained with solutions containing rhamnolipids (0.028%) and a viscosin-like biosurfactant produced by *Pseudomonas fluorescens* Pfa7B (0.025%), associated to a intermittent voltage gradient. Although the rhamnolipid and the viscosin-like compounds involved a higher electrical current than TW20, metals were less removed from the sediment. The electroosmotic flow was lower when we used biosurfactants, hence a less effective effect on PAH removal was obtained. The results showed that, for the same concentration of chelating agent (0.1 mol L⁻¹), EDTA was more suitable to enhance removal of Ni (52.8 %), Pb (60.1 %) and Zn (34.9 %). EDDS provided effectiveness to increase Cu removal efficiency (52 %), while EDTA and EDDS had a similar enhancement removal effect on As EK remediation. The harbor sediment was highly resistant to metal and organics mobilization and transport because of an aged contamination, a high buffering capacity, a very low hydraulic permeability and a high organic matter content. The effect of EK process on sediment was also assessed by measuring the acute toxicity of the EK-treated sediment on *E.affinis* copepods exposed to sediment elutriates. It appeared that the variability of removal results was due to the ageing effect on deposited sediments, showing more ability of EK remediation for sediments involving low organic matter and carbonate contents.

Keywords: Electrokinetic remediation, dredged sediments, PAHs, trace metals, Chelates, Biosurfactant



Enhanced Electrokinetic Remediation of Multi-Contaminated Dredged Sediment and Induced Effect on their Toxicity

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Abstract

The maintenance of harbor waterways generates large amounts of dredged sediments which contain organic and inorganic contaminants. Electrokinetic (EK) remediation is often developed for metal decontamination but shows limitations for polycyclic aromatic hydrocarbons (PAHs) and polychlorobiphenyles (PCBs) which are nonionic and involve low aqueous solubility. Laboratory studies were devoted to the investigation of EK efficiency on the mobility and the removal of metals (Cd, Cr, Cu, Pb and Zn), PAHs and PCBs from contaminated sediments. Fresh dredged sediments were collected from the old lock of the Tancarville (France) canal managed by Le Havre port authority, and were subjected to enhanced electrokinetic treatments, using mixtures of chelating agents (citric acid CA or ethylenediaminedisuccinic acid EDDS) and surfactants (synthetic Tween 20 TW20 or biosurfactants) as additives in the processing fluids. Results showed that increasing CA concentration was favorable for both metal and PAH removal. Applying a periodic voltage gradient associated to a low concentration of CA and TW20 provided the best results for Zn, Cd and Pb removal and also for the removal of the 16 priority PAHs. Promising results were obtained with solutions containing rhamnolipids (0.028%) and a viscosin-like biosurfactant produced by *Pseudomonas fluorescens* Pfa7B (0.025%), associated to a periodic voltage gradient. Although the rhamnolipid and the viscosin-like additives involved a higher electrical current than TW20, metals were less removed from the sediment. The electroosmotic flow was lower when we used biosurfactants, hence a less effective effect on PAH removal was obtained. The harbor sediment was highly resistant to metal and organics mobilization and transport because of an aged contamination, a high buffering capacity, a very low hydraulic permeability and a high organic matter content. The variability of removal results was also due to the surface aeration of the deposited sediments. EK remediation was more efficient for sediments involving low organic matter and carbonate contents, but also oxidation of the material. A negative redox potential of the sediment was not favorable for the mobilization of metals. The efficiency of the EK process was also assessed by measuring the acute toxicity of the EK-treated sediment on *Eurytemora affinis* copepods exposed to sediment elutriates. Fortunately, the use of CA and biosurfactants did not significantly impact on sediment toxicity. It was also the case with the use of TW20 as enhancing agent. More particularly, *E. affinis* copepods were significantly sensitive to low pH values and oxidative conditions obtained after the EK-treatment, but also to Cu, and to a lesser extent to Pb amounts.



Effect of the Imposed Electrical Gradient on Reclaiming Fine Grained Saline Soil During the Electrokinetic Process

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Abstract

During the last years, soil salinity has been found as the main reason of land degradation and a large scale threat, affecting thus many areas around the world. This scourge is primary due to the excessive accumulation of salts within the soil porous medium, leading to increase the osmotic pressure, disturbing hence the environmental biodiversity as well as civil engineering facilities. This hazard is farther aggravated mainly when dealing with fine grained soils, owing to their low permeability as well as their mineralogical complexity, making remediation of such soils a real challenge and a very hard task. Several conventional techniques are commonly used in restoration of these soils. However, it has been found that they are inadequate, expensive and mostly ineffective. This creates an urgent need to develop an effective reclaiming technique such as the electrokinetic treatment. In this process, the imposed electrical gradient, facilitate the movement and the migration of ionic species, leading thereby to a better removal of contaminants within the soil matrix. This research aims to investigate the feasibility of the electrokinetic process in remediation of saline silty clay soil located in the region of Çanakkale-Dardanos Campus, north western of Turkey. To highlight this, a set of experiments were carried out on a laboratory cell using graphite electrodes. The target pollutants include sodium, potassium and calcium contents, as a function of processing time under a various applied voltage gradient of 1; 1,5 and 2 V/cm.

Keywords: Electrokinetic remediation; Electro-migration; Salinity; Salts removal; Electrical gradient.



Removal of Toxic Metals and Arsenic from Acid Pond Sediment in a Mining Area: Gonen-Balikesir (Turkey)

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Abstract

Mining activities generate an important impact in soil and water quality and the surrounding ecosystems due to the uncontrolled release of acid drainage loaded with toxic metals. The main source of contamination is the mine tailings. In the Çanakkale and Balıkesir region (Turkey) various mines, abandoned or in exploitation, generates a huge environmental impact in rivers and soil due to the acid mine drainage loaded with toxic elements such as Al, Fe, Mn and As.

The aim of this study is primarily to investigate the physical and chemical properties of lake sediments in an abandoned mining area in Gonen (Balıkesir, Turkey). Metal content and speciation in the sediments have been examined in detail. Mine pond sediment was sampled to identify the concentration of toxic elements and to test electrokinetic technology for the removal of the contaminants. The results showed that sediment in the study area were acidic (pH=3.35) and electrical conductivities were high (2427 $\mu\text{S}/\text{cm}$). The sediment contains Al (6.67%), Fe (5.68%), As (1030 ppm) and Mn (751 ppm). The column leaching tests proved that Al, Fe and Mn can be removed flushing DI (deionized) water. The electrokinetic treatment was able to transport the metals in the sediment specimen, but the total removal from the soil matrix was very low. Arsenic (As) was removed by 9%, mainly in the anode. Al, Fe and Mn were transported towards the cathode with a minor removal in the catholyte. The addition of facilitating agents and the extent of the treatment time will result in higher metal removal.

Keywords: Mine pond, sediment, arsenic, heavy metal, electrokinetic remediation

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Removal of Pb and Cd from Contaminated Soil Using a Combined Continuous Flow Treatment System

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Abstract

In this study a combined system was designed for remove Pb and Cd from from heavily contaminated mine tailing soils. 0.05M Na₂EDTA was used as chelating agent to remove Pb ve Cd metals from the polluted soil with heavy metals which taken from nearby of Kayseri ÇİNKUR. Initial concentrations of Pb and Cd were 16381 and 34347 mg/kg, respectively. Electrochemical treatment process was applied to the washing solution which is secondary polluting appeared by upward flow extraction of Pb and Cd from the soil column. Metal ions were transformed to metallic form by applying electrochemical treatment process to washing solution which contains Pb²⁺ and Cd²⁺. At the end of the extraction experiment which done with the 50 g soil sample in the column system metal ions concentrations (Ce) moved from soil to solution for Pb and Cd were 1486 mg/L and 1786 mg/L at 0.3 mL/min flow rate. At the end of extraction process in the soil column, Pb and Cd removal efficiencies from soil were 40% and 41%, respectively. Then, the soil column solution was subjected to electrodeposition through period 48 h at 10 V. Electrochemical removal efficiency of ions moved from column to solution was 85% for Pb and 59% for Cd.

Keywords: Heavy Metal, Soil Washing, Electrochemical Treatment, EDTA, Combined treatment system

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Removal of Phosphorous and Nitrogen from Wastewater in A Sub-Surface Horizontal-Flow Tropical Wetland planted with *Brachiaria mutica*

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Abstract

To combat eutrophication of water bodies, sustainable treatment technologies like constructed wetlands have become a promising alternative for nutrient removal and wastewater treatment. This rare study assessed the potential of a sub-surface horizontal-flow constructed wetland planted with *Brachiaria mutica* for the removal of phosphorous and nitrogen during different seasons in a tropical region. A wetland cell that was operated during the study could efficiently remove phosphate under varying seasonal conditions and influent phosphate concentrations. Average seasonal removal of total phosphate (TP) was 55.2% in winter, 78.5% in spring, 80.7% in autumn and 85.6% in summer. The maximum average removal rate was 384.4 mg/m²/day of TP during summer. Variations of ambient temperature during different seasons were observed to be the dominant influence in TP removal. Evapo-transpiration influenced the nutrient uptake. Soluble orthophosphate (available phosphate) was removed well due to its high bioavailability. Based on variations of influent phosphate concentration (5 to 20 mg/l), it was observed that the removal efficiency of *B. mutica* increased with an increasing influent phosphate concentration, if supplemented with nitrogen at a nitrogen to phosphate ratio of 5:1. Substantial removal of nitrogen (as total Kjeldahl's nitrogen (TKN); 75.6–84.6%) was observed during the study. Statistical analysis (Student-t test and principal component analysis (PCA)) revealed significant seasonal variations for phosphate removal, primarily governed by temperature and nitrogen. The study concluded that the *B. mutica*-based wetland could serve a dual purpose of nutrient removal (wastewater treatment) and production of fodder for livestock, supporting particularly rural communities in tropical and subtropical regions.

Keywords: Nutrient removal, Phytoremediation, Constructed Wetland, *B. mutica*



Investigation of the Effects of Ultrasound and Electrohydrolysis Processes on Anaerobic Treatability of Olive Mill Wastewater

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Abstract

Approximately 90% of the produced olives are used in the production of olive oil in Turkey which is one of the biggest olive producer countries in the world. Treatment of olive mill wastewater (OMW) which is produced during the oil production is problematic due to its complex character and can be only accomplished at high cost. Anaerobic treatment methods, which have significant environmental and economic benefits such as energy production and low sludge production, have been proposed for OMW treatment. However, there are some limitation in the application of anaerobic processes to OMW due to possible detrimental effect of complex compounds present in the wastewaters on both microbial community and their activity. Therefore, it has been proposed that an effective pre-treatment unit should be integrated to biological treatment processes for OMW. There is a growing interest to new alternative methods which can treat this type of wastewater with a low sludge production. Therefore, the aim of this study is to perform anaerobic batch tests for OMW which is pretreated both by ultrasound and electrohydrolysis. Thus, the pretreatment effects of these processes on anaerobic treatment can be determined. Electrohydrolysis and ultrasound treated OMW samples were fed to anaerobic batch reactors based on total COD concentrations. COD removal efficiency was found to be as 70% during anaerobic treatment fed with electrohydrolysis-pretreated wastewater, In anaerobic reactors fed with ultrasound pretreated wastewater, COD removal efficiency was found to be as 77%. Therefore it can be concluded that these processes can be effectively used as a pretreatment step for anaerobic treatment of OMW.

Keywords: Olive mill wastewater, Electrohydrolysis, Pretreatment, Pollutant, Ultrasound



Simultaneous Hydrogen Production and Pollutant Removal from Olive Mill Wastewaters Using Electrohydrolysis Process

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Abstract

Management of olive mill wastewaters is one of the most challenging environmental issue in Mediterranean countries due to its high organic load and color, presence of phenolic compounds which resist biological degradation and need for high energy cost for meeting discharge standards with conventional treatment options. Performance of electrohydrolysis (EH) process in terms of removal of organic compounds, detoxification and discoloration of olive mill wastewater (OMW) with simultaneous energy production in the hydrogen gas form has been investigated using aluminium electrodes. Different operating parameters in terms of reaction times and DC voltages have been tested in order to define the most effective conditions for removal of pollutants such as total chemical oxygen demand (tCOD), suspended solids, colour and phenol. The optimum reaction time and current were determined as 8 hours and 8V, respectively. Under these conditions, removal efficiencies for tCOD, suspended solids, colour and phenol were obtained as 73%, 84%, 91% and 75%, respectively. At the end of the operating period of 8 hours, 1037 ml hydrogen gas was obtained. The results show that electrohydrolysis process can be effectively used as an alternative solution for the management of OMW and the process can be upgraded with a better reactor design or combined with different treatment processes to achieve a better effluent quality to meet discharge standards.

Keywords: Color removal, electrocoagulation, electrohydrolysis, hydrogen gas, olive mill wastewater, organic matter removal



Hydrogen Production from Municipal Wastewaters via Electrohydrolysis Process

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Abstract

Nowadays, studies investigating economic treatment processes of domestic wastewater in order to meet effluent discharge standards have gained momentum. Rather than using conventional treatment plants using energy and high amount of chemicals in order to treat wastewaters, it is a viable option to get energy with alternative methods. Therefore, there is a growing interest to produce clean energy from wastewaters/wastes in the form of methane or hydrogen. The aim of this study is to investigate the effect of electrohydrolysis process on domestic wastewater treatability and energy potential in terms of hydrogen. Copper and aluminum electrodes were compared to determine the effect of electrode types on hydrogen gas production. During the experiments, hydrogen production has been found to be higher for aluminum electrodes than copper ones. Various DC voltages (4, 6, 8 and 10 V) were investigated for domestic wastewater in order to determine the optimum DC voltage. Maximum hydrogen production (485 ml) was obtained from 8 V DC for 4 hours reaction time. Under optimum conditions (8 V DC and 4 hours operation time), 82% turbidity, 75% color, 86% TSS, 84% COD, 82% sCOD, 75% BOD, 38% oil and grease and 40% total coliform removal efficiencies were achieved, respectively. Electrohydrolysis experiments were carried out at different time periods (1, 2 and 4 hours) in order to determine the effect of reaction time on hydrogen production and pollutant removal efficiencies. Optimum operation time in terms of both hydrogen production and pollutant removal efficiencies was determined as 4 hours. It is a huge advantage to treat domestic wastewater in order to meet effluent discharge standards in such a short time (4 hours). It has been shown that with the operation of electrohydrolysis, sustainable clean energy production and simultaneous pollution reduction can be achieved.

Keywords: Domestic wastewater, electrohydrolysis, pollutants, hydrogen production



A New Electrically-Assisted System for Rapid Anammox Entrenchment Dedicated to Treatment of Low-Strength Ammonium

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Abstract

The anammox-based treatment is an advanced nitrogen removal leading to significant economic-savings. Nevertheless, long start-up time of such process caused by slow activity and growth rate of anaerobic ammonia oxidation (anammox) bacteria does hinder its engineering application. Likewise, the implementation of anammox related technologies at mainstream of municipal wastewater is still a huge challenge and needs to be confirmed due to lower ammonium concentrations and colder operating temperatures of mainstream conditions. The aim of this work was to investigate start-up period and activity of anammox bioprocess operating at low ammonium concentrations in one-stage electrically enhanced bioreactor towards complete autotrophic nitrogen removal. Continuous flow electro-bioreactor was fed with synthetic wastewater comprising essentially of nitrite and ammonium at a molar ratio of 1:1. A steady-state condition was attained after 3 months of operation, while the same reactor without electrical system needed over 6 months to achieve an adequate anammox growth. The results indicate that the electro-bioreactor with a DC electric field being alternatively operated achieved almost 90% removal efficiency for both $\text{NH}_3^+ - \text{N}$ and $\text{NO}_2^- - \text{N}$. Besides, the established electro-bioreactor was robust and accelerated anammox metabolism leading to nearly 50% reduction in the start-up period of anammox process compared to the control reactor. Thus, the submerged membrane electro-bioreactor (SMEBR) is able to speed up anammox reaction and remove nitrogen species with a minimum cost and space requirement. Such new system can be applied to mainstream wastewater treatment by integrating ammonium oxidizing bacteria (AOB) and anammox through a smart application of electrical field.

Keywords: Municipal wastewater treatment, Mainstream processes, Anammox, Autotrophic nitrogen removal, Submerged membrane electro-bioreactor (SMEBR), Sustainable design.

