Project ID: **55119**

Project Title: **Phase Equilibria Modification by Electric Fields**

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Progress Report

RESEARCH OBJECTIVE

The objective of this project is to use electric fields to favorably manipulate the thermodynamic and transport properties of mixtures so that higher separation efficiencies can be achieved. The main focus is to understand and quantify the influence of electric fields on vapor-liquid, liquid-liquid, and solid-liquid systems. This program will lead to greater separation efficiency in a wide range of environmental treatment processes, including solvent extraction, sorption, distillation, and stripping. Such processes are widely used by DOE for treatment of wastes and sites contaminated with heavy metals, radionuclides, and organic solvents. Particular examples of applications of vapor-liquid-equilibria modification can be found in the separation of volatile organic compounds by either stripping or distillation. Improvements can also be made in liquid-liquid-extraction processes of TRU, Sr, Tc, and Cs by both thermodynamic and transport enhancements. Separations of metal ions by electrosorption can be used to remove such metal ions as Cs, Sr, Co, Pu, Cr, Cd, and Hg.

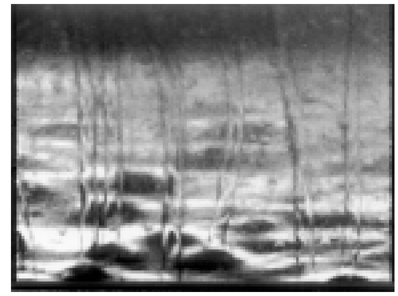
RESEARCH PROGRESS AND IMPLICATIONS

Following is a summary of the work after 2 and 2/3 years of a 3-year project:

Vapor-Liquid Equilibria: Experimental studies of electric-field effects on vapor-liquid equilibria have been completed and the results have been summarized in two peer-reviewed papers (Blankenship et al., 1999a and b) and a Masters thesis (Blankenship, 1999). It has been found that an electric field can be used to alter the vapor-liquid concentration of a binary mixture that involves at least one polar component. The mechanism has been investigated by Raman and FTIR spectroscopy. It was concluded that concentration changes in the vapor phase are caused by charge accumulation on the interface. In addition, transport effects of electric fields in distillation have been examined. It was found that electric fields can be used in distillation columns to decrease the bubble diameter and enhance mass transport rates.

Liquid-Liquid Studies:
A new phenomenon of "tornado" formation at a liquid-liquid interface under electric fields has been uncovered. The figure below shows a typical image of liquid tornadoes rising from the toluene/isopropanol/water interface under an electric field applied across the interface. Tornadoes are formed, grow in diameter and height, and then become unstable forming droplets. However, the total population of the tornadoes is relatively stable when the

operating conditions are well maintained. The population, intensity and size distribution of the tornadoes have been found to depend on the strength of the electric field, physical properties of the LL system, and the geometry of the experimental apparatus. *(More on liquid-liquid studies are described in the Optional Proprietary Information section)*.



Tornadoes formed at the interface of toluene/ isopropanol/water under an electric field

Solid-Liquid Equilibria: Solid-liquid equilibria studies under electric fields have been conducted in an electrosorption apparatus, where the metal ion concentration in an aqueous solution was monitored as a function of an applied electric field between two parallel electrodes made of carbon aerogel. Unlike ion exchange, no additional chemicals are required for regeneration of the electrosorbent carbon aerogel in the system. Experiments were conducted to investigate the effects of solution concentration, electric field strength, and type of anion on electrosorption equilibrium. It was found that the mechanism of electrosorption is mainly based upon the electrical double layer formed on the electrode surfaces. Both the zeta potential of the electrode surface and the valence of removed ions influence the electrosorption capacity of the electrodes. A mechanistic model has been developed, incorporating both chemisorption and electrosorption, to predict the sorption capacity of electrodes as a function of the controlling parameters, including electrical potential and metal ion concentration. The overlapping effect of the electrical double layer is also considered because such an effect is inevitable in the pores of the carbon aerogel material, because of their broad pore size distribution. To demonstrate the importance of pore size on the removal of ions using electrosorption, the pore size distribution of carbon aerogel is incorporated in the modeling of the electrical double layer.

PLANNED ACTIVITIES

A no-cost extension has been requested to complete this project by March 31, 2000. The following activities are planned for the remaining time: (i) Experiments will be conducted to investigate the effect of electric fields and phase inversion on mass transfer. (ii) Modeling studies of electrosorption will be completed. The following articles are in preparation to be submitted for publication in peer-review journals.

Phase Inversion of Liquid-Liquid Dispersions in the Presence of Electric Fields
Tornado Formation at a Liquid-Liquid Interface Due to an Electric Field
Electrosorption of Metal Ions from Aqueous Solutions
Distillation in the Presence of Electric Fields

INFORMATION ACCESS

Shin, W-.T., S. Yiacoumi, and C. Tsouris, "Experiments on Electrostatic Dispersion of Air in Water," Industrial and Engineering Chemistry Research, **36**, 3647-3655 (1997).

Norato, M.A., C. Tsouris, and L.L. Tavlarides, "Phase Inversion Studies in Liquid-Liquid Dispersions," The Canadian Journal of Chemical Engineers, **76**, 486-494 (1998).

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Blankenship, K.D., D.W. DePaoli, J.O. Hylton, and C. Tsouris "Effect of Electrode Configurations on Phase Equilibria with Electric Fields," Separation and Purification Technology, **15**, 283-294 (1999a).

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Tsouris, C., A.P. Borole, and E.N. Kaufman, D.W. DePaoli "An Electrically Driven Gas-Liquid-Liquid Contactor for Bioreactor and Other Applications," Industrial and Engineering Chemistry Research, **38**, 1877-1883 (1999).

Tsouris, C., D.W. DePaoli, J.T. Shor, M.Z.-C. Hu, and T.-Y. Ying, "Electrocoagulation for Magnetic Seeding of Colloidal Particles," submitted for publication in Colloids and Surfaces, September 1998.

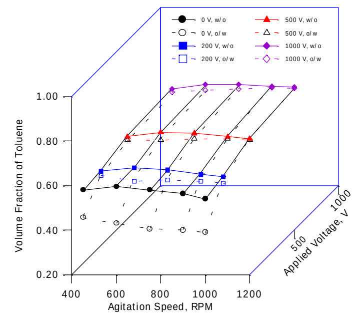
Tsouris, C., and J. Dong, "Effects of Electric Fields on Phase Inversion of Liquid-Liquid Dispersions," submitted for publication in Chemical Engineering Science, March 1999.

Tsouris, C., W.-T. Shin, S. Yiacoumi, and D.W. DePaoli, "Effects of Electric Fields on Bubble and Particle Velocities in Water and Alcohols," submitted for publication in Journal of Colloid and Interface Science, May 1999.

Blankenship, K.D., "Distillation with Applied Electric Fields," Master Thesis, Department of Chemical Engineering, University of Tennessee, April 1999.

OPTIONAL PROPRIETARY INFORMATION

Effects of electric fields on liquid-liquid (LL) dispersions have been investigated. Based on our results, a new method for modification and control of LL dispersions has been demonstrated. By applying an electric field, a LL dispersion of water-in-organic could be inverted to organic-in-water and re-inverted to water-in-organic again by simply turning off the electric field. The effect of electric fields on the ambivalence regime of a toluene/water dispersion system was also investigated (see Figure below). The ambivalence regime is defined as the range of organic-phase volume fraction in which either phase can be continuous or dispersed. Above and below the ambivalence regime, only one phase can be continuous and the other dispersed. It is clear in the figure that an electric field can be used to modify the ambivalence regime. The new method of controlling phase inversion by means of electric fields may have the following impact: (i) It can be used to ensure that the aqueous phase remains the continuous phase, even at a high volume fraction of the organic phase. (ii) It can be used to increase the volume fraction of a dispersed organic phase without causing phase inversion. (iii) It can be used to enhance mass-transfer rates from one phase to the other by inducing phase inversion. (iv) It can be used to correct a phase inversion, which is currently considered a catastrophic event, without having to shut down the process. Experiments have been conducted to better understand the phenomenon of phase inversion in LL dispersions under applied electric fields. The parameters studied include energy input, applied voltage, interfacial tension, viscosity, conductivity, and surface charge. More experiments are currently conducted to investigate the effect of induced phase inversion on interfacial mass transfer. A subject invention disclosure has been prepared for application of this concept, which could have wide-ranging impact on solvent-extraction applications.



Phase inversion of toluene/water dispersion under electric fields