Is One of the *E*'s in IEEE for *E*nvironmental?

No, but maybe it should be, although IEEEE might be too much!

by James M. Fenton

Every year the Industrial Electrolysis and Electrochemical Engineering (IEEE) Division of ECS sponsors a Report of the Electrolytic Industries for the past year (1-4). Even as far back as 1980, either in a footnote or later as the first paragraph in the report, it states that, "environmental aspects in the electrolytic and related industries" also are summarized. Each year environmental aspects appeared under appropriate sections of the report for the particular chemical, metal, or energy technology industry. In the Report for the Year 1984 (6) a separate section at the end of the report entitled "Environmental issues" first appeared. The first paragraph of that section reads, "Despite pressure from environmental groups, no clear consensus emerged on what actions should be taken to reduce acid rain and CO_2 emissions. Indeed, disagreement remained over both the causes and the seriousness of the problem."

In the Report for the Year 1992 (7) under this same section, "Some of the electrochemical processes for environmental application under development or presently in use are discussed in this section of the report. Many of the applications are in waste water treatment, metal recovery, destruction of organic pollutants, and on-site production of chemicals to reduce incidents from transporting chemicals."

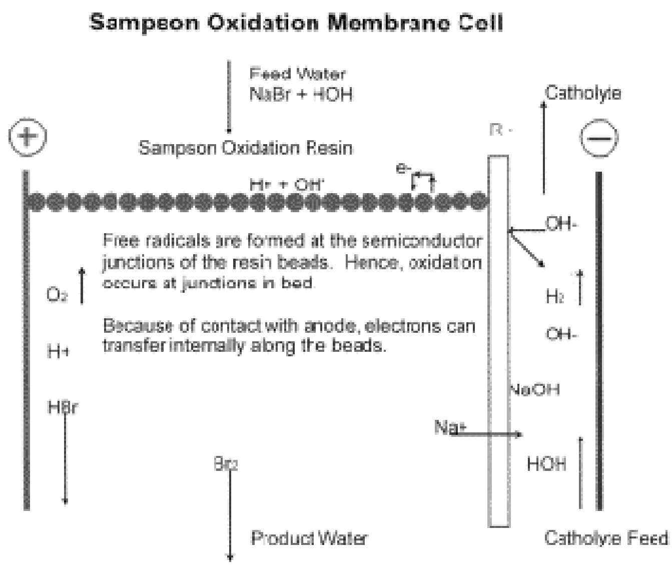

FIG. 1. Sampson Oxidation Membrane Cell. Depicts bromine production although chlorine dioxide is generated in a similar manner. Figure courtesy of Halox Technologies Corporation (Bridgeport, CT).

At about this same time, at the Spring Meetings of the Electrochemical Society, the IEEE Division started to sponsor environmentally related symposia. The Division has been the lead division for several symposia which have clear environmental themes.

With federal legislation emphasizing what to do for pollution control, rather than how to do it, electrolytic industries are finding economic ways to reduce wastes and emissions. Several staff members of the EPA's Pollution Prevention Research Branch at the Risk Reduction Engineering Laboratory prepared a critical review of industrial pollution prevention (8) showing EPA's encouragement of the pollution prevention ethic. In the Pollution Prevention Act, the EPA defines its multimedia waste management strategy aimed at preventing or reducing pollution at the source. At the top of the strategy list is source reduction, followed by recycling, treatment, and as a last resort, disposal. Pollution prevention at an industrial electrolytic manufacturing plant includes all activities that lessen or eliminate waste generation and the release of pollutants to the environment. Pollution prevention can be accomplished through increased efficiencies in the use of raw materials, energy, water, or other resources, or through conservation. These objectives can be met through changes in equipment or technology; process or procedural changes; reformulation or redesign of products; raw material substitutions; or operational improvements in housekeeping, maintenance, training, or inventory control.

Electrolysis for production of useful chemicals and materials, energy producing electrochemical reactions and electrochemical methods for destruction

celebrating 5 years of interface

of toxic or hazardous materials are environmentally-friendly processes. If these electrochemical processes are properly designed, they are energy efficient, need not produce unwanted effluents or undesired reaction co-products, nor use toxic or hazardous materials. Electrochemical technologies are providing solutions to pollution problems through treatment and recovery, as well as being used in manufacturing processes for pollution prevention. Often the use of electrochemical technologies for pollution prevention leads to profits by reclaiming valuable chemicals and materials from product and/or waste streams.

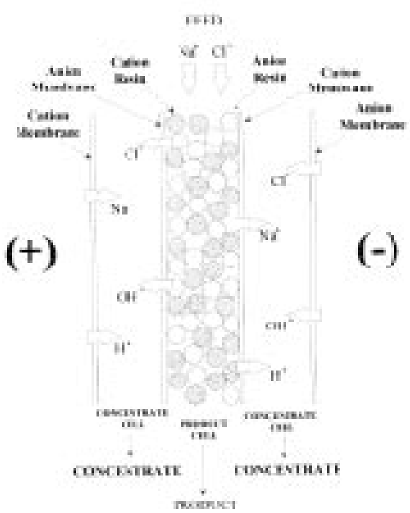

FIG. 2. Schematic of plate and frame electrodeionization cell. Softened water is removed of Na^+ and Cl^- to make high purity water. Courtesy of US Filter (Lowell, MA.)

Electrolytic technologies have definite advantages over the traditionally used physicochemical processes. The primary benefit is that chemical change in an electrochemical process is brought about by the ability to add or remove electrons, a nonpolluting reagent, from the chemical reactant or from a chemical species to be treated. This eliminates the use of redox agents to carry out oxidations or reductions and also removes the need to treat spent redox streams. Other important benefits of electrochemical processes include: close control of reactions through control of the applied potential or current; lower operating temperatures and, hence, lower costs; increased possibility of on-site treatment or production of chemicals, especially in small scale use; possible simultaneous use of the anode and cathode for waste minimization; and the ability to recover and recycle valuable chemicals and/or metals from waste streams, thereby preventing pollution.

Contributions that electrochemical technology can make to a better environment include:

Cleaner generation of energy.—Fuel cells are clean, efficient, and noiseless. Fuel cells are powered by hydrogen or fuels such as methanol, ethanol, and natural gas (landfill gas has also been used as a fuel). An electrochemical reaction produces electricity without combustion when the hydrogen in the fuel is combined with oxygen to form water. In addition, pollutants such as NO_x, carbon monoxide, and hydrocarbons are reduced by a factor of 10 or more over power sources that rely on combustion. Batteries are not a primary source of energy, but are continuing to have a more important role in our "mobile lifestyle."

Cleaner, "greener," and more selective synthesis.—Electrolysis for the synthesis of both organic and inorganic chemicals, while not widely subscribed, does replace toxic, hazardous reagents, avoids difficult effluents and almost always uses mild conditions. In many cases it can also be selective, through either careful potential or current control.

On-site generation of chemicals.—Electrolysis can conveniently be carried out on a wide range of scales. This allows the design of small units suitable for the on-site generation of chemicals, avoiding the hazards of transporting chemicals such as chlorine and hydrogen peroxide. FIGURE 1 shows a recently patented cell for the on-site production of oxidizing agents such as bromine and chlorine dioxide for killing bacteria in industrial and municipal water.

Improving water quality.—Electrochemical processes exist for the removal of salts from water as well as removal of bacteria (e.g. based on ClO^-, O_3), organics, and metal ions. FIGURE 2 shows such a process for the production of high purity water, which combines features of ion exchange, membranes, electrodialysis, and acid/base generation.

Recycling process streams.—Electrochemical technologies are used to regenerate redox agents, recover acid and base from salts, or to remove metal ions and/or organics from a process stream; "electrolysis can be expected to contribute greatly to the design of the zero effluent plant of the future." FIGURE 3 shows both the treatment and regeneration steps in using a modulated current electrochemical and an integrated ion exchange cell for recovery of plating effluents for recycle and re-use.

Effluent treatment.—Many types of cells and systems for the removal of metal ions, organics, and metal particles from effluent prior to discharge are available. An electrocoagulation process for removing mercury amalgam from dental wastewater is depicted in FIG. 4.

Improving atmospheres.—Again several types of electrochemical systems are available, e.g., for the removal of acid gases from flue gas discharges or organics from enclosed atmospheres.

Sensors.—Electrochemical devices are particularly well suited to on-line monitoring and field-work analysis.

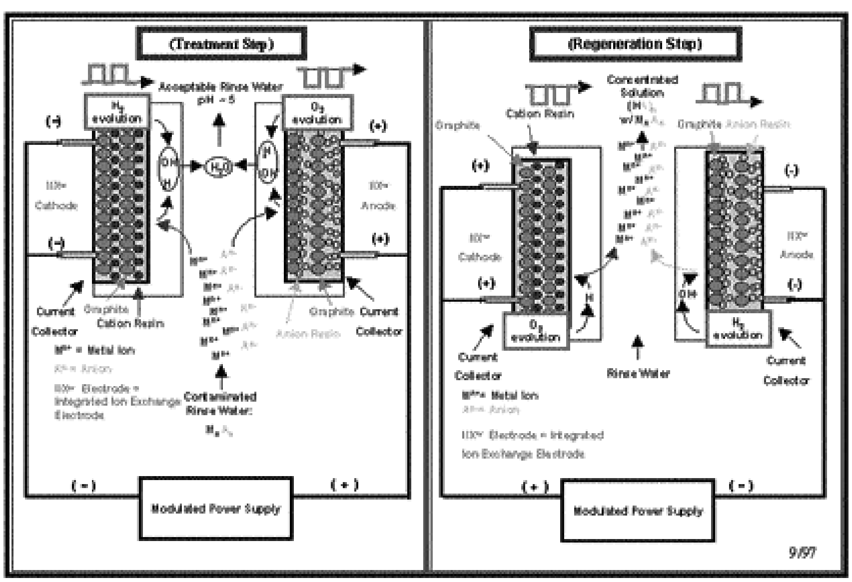

FIG. 3. In-process recycling system which integrates electrowinning and ion-exchange into one system, combining the benefits of both. Figure courtesy of Faraday Technology, Inc. (Clayton, Ohio).

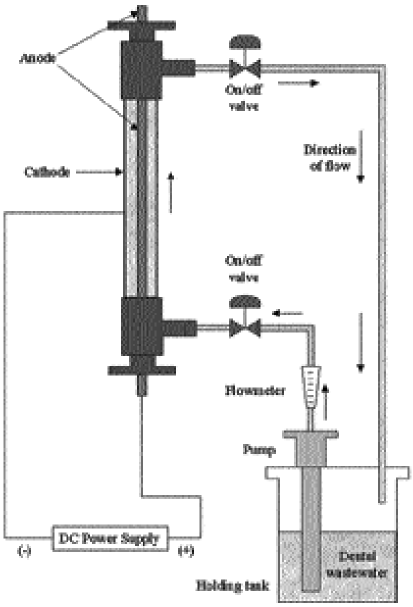

FIG. 4. Electrocoagulation process for removing mercury amalgam from dental wastewater.

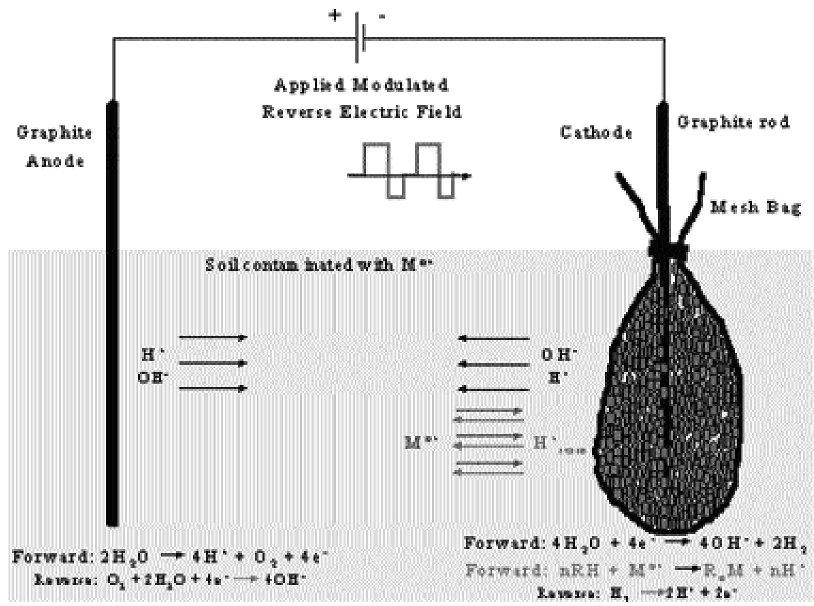

FIG. 5. Enhanced electrokinetic system. pH front is eliminated so metal cations transport to the cathode and are collected in the ion-exchange resin. Figures 4 and 5 courtesy of Faraday Technology, Inc. (Clayton, Ohio),.

Electrochemical sensors are available for a wide range of gases in atmospheres (e.g. O_2, CO, CO_2, SO_2, NO_x, NH_3, anesthetics, nerve gases) as well as pH, gases, ions and organics in solution.

Electrokinetic Processing of Soils.—Electric fields as well as electron transfer processes have been used for the treatment of soils and groundwater containing organic or inorganic pollutants. The electrokinetic mechanisms include electro-osmosis, electrophoresis, streaming potential, and sedimentation potential. FIGURE 5 shows a system designed to eliminate the pH front associated with conventional D. C. based electrokinetic processes (18).

While electrochemical technology can and should be environmentally friendly, there have been environmental mistakes in the past. Fortunately, the electrolytic and battery industries have learned from these mistakes. The development of mercury-free cathode technology along with better housekeeping has eliminated mercury discharges from the chlor-alkali industry. Battery technologies are evolving from lead and cadmium to nickel-metal hydrides and lithium ion batteries and recycling of battering constituents is starting to occur throughout the world. Mercury has already been removed from most alkaline batteries.

There are a multitude of environmentally related papers representing all the divisions of the Society published in the **Journal** each year. Several of the IEEE led environmental symposia, as well as symposia which other divisions took the lead, are available as Proceedings of The Electrochemical Society (http://www.electrochem.org/books/pro_vol.html). Several other review articles, books and chapters are also recommended reading (9-16). ■

References

1. C.-P.Chen and M. Vreeke, *J. Electrochem. Soc.*, **144**, 3674 (1997).
2. G. Pillay and C.-P. Chen, *J. Electrochem. Soc.*, **143**, 3410 (1996).
3. D. W. Gibbons and G. Pillay, *J. Electrochem. Soc.*, **142**, 3597 (1995).
4. R. Gopal and D. W. Gibbons, *J. Electrochem. Soc.*, **141**, 2918 (1994).
5. K. E. Woodard, Jr. and E. J. Rudd, *J. Electrochem. Soc.*, **127**, 251C (1980).
6. D. E. Hall and E. Spore, *J. Electrochem. Soc.*, **132**, 253C (1985).
7. S. D. Fritts and R. Gopal, *J. Electrochem. Soc.*, **140**, 3337 (1993).
8. H. Freeman, T. Harten, J. Springer, P. Randall, M. A. Curran and K. Stone, *J. Air Waste Manage. Assoc.*, **42, 5**, pp 618-658 (1992).
9. J. M. Fenton, “Electrochemistry: Energy, Environment, Efficiency, and Economics.” *Interface*, **3,1**, 38 (1994).
10. *Environmental Oriented Electrochemistry*, C. A. C. Sequeira, ed., Elsevier, Amsterdam, The Netherlands (1994).
11. P. Tatapudi, and J. M. Fenton. in *Advances in Electrochemical Science and Engineering*, H. Gerischer and C. W. Tobias, eds., **4**, pp 363-417 (1995), VCH Publishers, New York.
12. D. Pletcher and N. L. Weinberg, *Chemical Engineering*, August 1992, pp 98-103.
13. D. Pletcher and N. L. Weinberg, *Chemical Engineering*, November 1992, pp 132 -141.
14. *Electrochemistry for a Cleaner Environment*, J. D. Genders, and N. L. Weinberg (Eds), Electrosynthesis Co., East Amherst, New York, (1992).
15. K. Rajeshwar, J. G. Ibanez, and G. M. Swain, *J. Applied Electrochem*., **24**, 1077 (1994).
16. K. Rajeshwar and J. Ibanez, *Environmental Electrochemistry*, Academic Press, Inc., San Diego, California (1997).
17. R. P. Renz, T. R. Shank, J. J. Sun, E. J. Taylor, and C. D. Zhou, *Proceedings of 19th AESF/EPA Week*, Orlando, FL (1998).
18. M. Inman, E. J. Taylor, D. L. Myers, M. K. Sunkara, and C. D. Zhou, *Proceedings of Emerging Technologies in Hazardous Waste Management IX*, ACS, I&E Division, Pittsburgh, PA (1997).

About the Author

James M. Fenton is an Associate Professor of Chemical Engineering and Director of the Pollution Prevention Research and Development Center at the University of Connecticut, Storrs, Connecticut.