This page intentionally left blank
Electrochemical Water Processing
Electrochemical Water Processing

Ralph Zito
Contents

Preface xi
Acknowledgements xvii
Introduction xix

1. Water Contaminants and Their Removal 1
   1.1 Introduction 1
   1.2 Technology, History, and Background 9
   1.3 Application Areas: Electrochemical Technology Water Processing 10

2. Basic Electrochemical and Physical Principles 15
   2.1 Introduction 15
   2.2 Acidity and Alkalinity, pH 17
   2.3 Activity and Activity Coefficients 19
   2.4 Equilibrium and Dissociation Constants 19
       2.4.1 Degree or Percentage Dissociation 20
   2.5 Electrode, or Half Cell Potential 20
   2.6 Chemical Potential Definition 21
   2.7 Concentration Potential 22
   2.8 Equivalent Conductance 23
   2.9 Free Energy and Equilibrium 23
   2.10 Dissociation Constants 24
   2.11 Ionic Conductance and Mobility 24
   2.12 Osmotic Pressure 26
   2.13 Diffusion (Flick’s Law) 26

3. Systems Description: General Outlines of Basic Approaches 29
   3.1 Electrodialysis 29
       3.1.1 Performance Characteristics 31
       3.1.2 General Purpose Processor 33
       3.1.3 Additional Details for Appropriate Application - Desalinator for Small Boats 36
3.2 pH Control: Analytic Development
   3.2.1 Introduction 39
   3.2.2 Some Technical Background 39
   3.2.3 Sample Processes for pH Control 42
   3.2.4 Application Possibilities 45
      3.2.4.1 Swimming Pool Water 46
      3.2.4.2 Cooling Towers 46
      3.2.4.3 Regeneration of Ion Exchange Resins 46
   3.2.5 Current and Electrical Energy Requirements 50
   3.2.6 Shielded (Limited Ion Access) Positive Electrode Operation 51
      3.2.6.1 Double Barrier 51
      3.2.6.2 Close Spacing 52
      3.2.6.3 Porous Barrier Design 52
      3.2.6.4 Etched Electrode Surfaces 52
3.3 Biociding Technology 55
   3.3.1 Electrolytic Production of Free Halogens 55
   3.3.2 Chlorination Process Description 57
   3.3.3 Bromination Process Description 61
3.4 Ion Exchange Resin Regeneration System 62
   3.4.1 General 62
      3.4.1.1 Present Regeneration Methods 63
      3.4.1.2 Electrochemical Regeneration Method 65
   3.4.2 Equipment Comparison 65
      3.4.2.1 Performance Characteristics Comparisons 66
3.5 Metals Reclamation 71
   3.5.1 Electrochemical Process for the Removal of Iron in Acid Baths 71
   3.5.2 Technical Approaches 72
   3.5.3 Technical Approaches 73
   3.5.4 Laboratory Feasibility & Data Study Suggestions 76
## Contents

3.5.5 Experimental Methods 76  
3.5.5.1 Approach B Tests 79  
3.5.5.2 Approach A 81  
3.5.6 Conclusions & Recommendations 91

4. Mathematical Analysis & Modeling  
Electrodialysis Systems 95  
4.1 Electrodialysis: Descriptions and Definitions 95  
4.2 Basic Assumptions and Operating Parameters 102  
4.2.1 Electrolytic Conductivity 102  
4.2.2 Solute Concentration & Electrical Conduction 106  
4.2.3 Electric Charge Equivalence 108  
4.2.4 Coulombic Efficiency 109  
4.2.5 Coefficients of Performance 109  
4.3 Parametric Analysis: Flow-Through Configuration 110  
4.3.1 Performance Analysis of Electro-dialytic Systems, Part I 110  
4.3.1.1 First Approximation 110  
4.3.1.2 Design Assumptions 111  
4.3.1.3 Equation Development 111  
4.3.1.4 Resistance of a Cell 112  
4.3.2 Further Definition of Terms 114  
4.3.2.1 Average Current Density 114  
4.3.2.2 Entrance & Exit Current Densities 115  
4.3.2.3 Water Flow Rate in Processed Chamber 115  
4.3.2.4 Solute Concentration Along the Length of the Cell 116  
4.3.2.5 Figure of Merit 121  
4.3.3 Numerical Evaluation Program 122  
4.3.3.1 Second Approximation, Part II 123  
4.3.4 Multiple Cells in Parallel 127
4.3.5 General Characteristics 127
4.3.6 Total Electric Current through the Electrodes and Membranes 127
4.3.7 Coulombic Efficiency Variation 130
4.3.8 Further Considerations 138
4.4 Flow-Through Design Exercises 138
4.4.1 Exercise #1 140
4.4.2 Exercise #2 142
4.4.2.1 Predetermined Independent Variables 142
4.4.3 Exercise #3 144
4.4.4 TDS Removal Rate Capacity 145
4.4.5 Stacked Cell Configuration 146
4.4.6 Expanded Analysis 146
4.5 Batch Process Analysis: Re-Circulating or Static Water Processing System 149
4.5.1 Coulombic Efficiency 154
4.5.2 Single Cell Analysis 155
4.5.3 Single Cell - Special Case 157
4.5.3.1 Ohmic Energy loss and Water Temperature Rise 158
4.6 Design Exercises for Water Re-Circulation Systems 160
4.6.1 Exercise #1 161
4.6.2 Exercise #2 162
4.7 Cell Potential and Membrane Resistance Contributions 163
4.7.1 Membranes 164
4.7.2 Electrodes 164
4.7.3 Opposing Voltages 169
4.8 Diffusion Losses of Ions and Molecules Across Membranes 171

5. System Design Exercises & Examples 177
5.1 Electrolytic Generation of Bromine and Chlorine: Design Procedures 177
5.1.1 Design Geometry Comments 184
5.1.1.1 Example 188
5.2 Simple Estimate of Capital Equipment and Operating Cost of Electrochemical Desalination Apparatus
5.3 Cost Estimates Outline for an Electrodialysis De-ionizing System

6. Applications Discussion
   6.1 Demineralizer: Electrodialysis
      6.1.1 Advantages of Electrodialysis
            6.1.1.1 General Characteristics
      6.1.2 Desalination System - Module Specifications
      6.1.3 Performance Characteristics
      6.1.4 Cost Factors
   6.2 Residential Water Softener
      6.2.1 Product Design Description
      6.2.2 Physical Description of the System
      6.2.3 Operation
      6.2.4 Design Example
      6.2.5 Competitive Methods
   6.3 Electrical Water Processor Portable Design
      6.3.1 Present Solutions
      6.3.2 Operation of an ED System
      6.3.3 Design Prototype
      6.3.4 Description

Appendix A: Some Physical Constants and Conversion Factors

Appendix B: Conductance and Solubility
   B.1 KCl Ionization Constants

Appendix C: Feeder Tube and Common Manifolding Losses

Appendix D: Variable Current Density
   D.1 Current Density Variation
Appendix E: Mathematical Analysis: Water pH
Control Cell and Ion Exchange Resin
Regeneration 235
E.1 Analytic Approach 238
E.2 Special Case Evaluation - No Resins Present in System 248
E.2.1 Non-Constant Electrochemical Generation Rates for H⁺ and OH⁻ 250
E.2.2 Dimensions and Units 254
E.2.3 Variable Electric Current Densities 256
E.3 Estimation of Resin Constants 257
E.4 Electrolytic Resistance of the System Water 261
E.5 Solution of the Simultaneous System Equations 263
E.6 Sample Solution of Operating System 268

Appendix F: Industrial Chlorination and Bromination Equipment
Cost Estimates 271
F.1 Bromination Equipment List 275
F.2 Capital Cost Analysis 277
F.3 Operating Cost Analysis 280
F.4 Conclusions and Comments 281

Appendix G: Design Mathematics in Computer Format 285
G.1 Case A 286
G.2 Case B 294
G.3 Case C 299

Appendix H: Mathematics for Simple Electrochemical Biociding 303

Bibliography 309
Index 311
Also of Interest 313
Preface

In recent years, the awareness of water needs and processing requirement has become an increasingly important topic. As the earth's population increases the demand for "clean" water has become an even larger factor in residential as well as industrial and commercial costs. There are now almost no natural water sources that do not require some purification of one form or another to render them potable sources.

If the water impurities are ionic in nature, i.e., inorganic salts such as sodium chloride, calcium chloride, or iron sulfate, or inorganic acids such as sulfuric and hydrochloric etc., then the most effective method of moving these components about is by electrochemical means. Most substances dissolved in water do not lend themselves to be removed by filtration, as usually such ionic materials have been leached out of the ground supply. If the contaminants are non-ionized organic substances in solution, then there must be other means for their removal, and we will not treat the subject of their removal by chemical, distillation or filtration means.

The technology that will be described here is well known but it is hoped that some of the quantitative and systems fabrication aspects covered here will contribute to the increasing practicality of electrochemical methods in water treatment applications. Much of the methods discussed here are a direct outgrowth of our research and development work in energy storage. Electrode design and construction methods for single and multiple cell devices were first addressed in the development of energy storage cells and multi-cell modules.
As the title of this book indicates, the following pages represent a summary of the results of a number of years of R&D effort directed to a better understanding of some basic processes for water treatment as well as the development of practical methods for design of useful hardware. The information contained herein is presented in an informal manner, in much the same fashion that it was generated in the laboratory studies. It is sincerely hoped that this compendium of technical notes will add meaningfully to the body of information associated with electrochemical approaches to water treatment, and will encourage others to pursue these avenues more intensively.

Except for the review of some very basic mathematical relationships associated with chemical and physical processes, involving electric potential, molecular diffusion and solution pH, all of the material presented in this book is original.

The major purpose of this book is the presentation of a body of analytical and design information that the reader may find useful in the exploration of electrochemical technology as applied to water processing. Hopefully, the contents of this text will encourage and promote further development of electrochemical processing systems for consumer as well as industrial and commercial applications.

In our attempt to accomplish this end, the book has been organized into three main sections. They are:

1. General description of electrochemical processing and their application areas
2. Mathematical analysis of operating systems for design and optimization purposes
3. Design examples and procedures.

Most of the experimental work on various water treatment projects was done at GEL/TRL during the period between 1978 and 1988.

A short introduction to some very important and basic concepts is included at the beginning of the book and
in Chapter 2 as a convenient review for the reader. The Appendices are also offered for some additional analytical and ancillary application information, without disrupting the arguments and descriptions in the main portion of the text.

The thread of the discussions to follow is to first identify the nature of the technology and to describe its various formats and uses. Then the book proceeds to develop an approach to mathematically treat the essential parameters associated with the principle mechanisms of ionic transport, electrolysis and diffusion. These developed mathematical tools are then applied to the preliminary design of a number of systems, serving as exercises for those that wish to carry on with their application in practical water processing problem-solving.

The fundamental equations that evolve in the analyses are listed in a reasonably convenient and accessible form so that the reader can place them into appropriate computer software programs for easy solution and graphing of data. I have tried to establish an obvious rationale throughout the book to minimize confusion and the obscuring of direction and purpose.

The Technology Research Laboratories, Inc. sponsored most of the analytical and experimental developments presented in the following pages. Some of the laboratory hardware and prototype systems were part of development projects funded by other industrial organizations for evaluation purposes.

Our purpose in writing this book is to present sufficient basic applications and information about electrodialysis so that the reader is able to develop his own designs and approaches to solving water management problems. We will treat a number of forms of electrochemical water treatment from pH control to desalination along with their many application potentials.

This book is concerned with the development of the basic principles and engineering design aspects of electrochemical
water processing. The intent in writing this volume is to serve as handbooks for the further development of related products. It should provide most of the necessary physical and chemical background to enable the reader to proceed with his own mathematical computations and engineering designs and mathematical computations. He should be able to arrive at sizes, performance characteristics and some preliminary cost factors on the basis of the information presented in this volume.

No attempt is made in this book at covering the entire field of water treatment or reviewing the various competitive technologies associated with these methods. There are many excellent texts that have treated these subjects extensively, and have reviewed and summarized the work of numerous other investigators. There have been many texts that present excellent reviews of the state of the art in electrodialysis, reverse osmosis, filtration and distillation systems.

Some of the specific terms and physical constants employed in the analytic approaches are covered in Chapter 2. However, it is assumed that the reader is familiar with the basic concepts of physical chemistry and elementary inorganic chemistry. For those who are not so well versed in these scientific disciplines, the resultant equations developed in Chapter 4 and elsewhere in the book are still useable for purposes of calculating the design parameters for the water processing devices under discussion.

TRL, Inc. has performed the background work, a portion of which is covered by this book, over a ten-year period. The author, with over 35 years of research and development experience in related technical areas, has been principle investigator in most of the work represented in these pages.

Water treatment with the minimal use of chemical reagents will increasingly become the goal of most systems in the future. In some instances, the elimination entirely of chemical agents is possible.
A family of systems that provide means for controlling pH, biocide level and dissolved solids concentration in water have been studied as a result of the many years of electrochemical developments in the energy storage area at TRL. A larger portion of our attention here is devoted to the direct removal of dissolved, ionized materials in water via electrochemical (electrodialysis) separation.

As a final comment, it is important to note that this book is concerned primarily with methodology rather than the specifics of any one design or system configuration. Very little empirical data or materials' properties information is contained herein. The specifics of component characteristics such as membranes, electrodes, and materials properties will be treated in another reference that is presently in preparation. This future text will also contain some empirical data on system performance as well as design and fabrication methods.

Many application possibilities are still available that are eminently suitable to electrochemical techniques.

I would like to express my sincere appreciation to Donald Morris, who performed many of the experiments and prototype design and fabrication, and for his invaluable assistance in organizing this information. Much of the discussion on biociding processes, and especially the sections that treat large-scale industrial water cooling systems was prepared by Catherine Middelberg as part of an application study at TRL, Inc.

Special gratitude is due to my wife, Min, for her encouragement and endurance with the labors of organizing the technical material for these volumes.

Ralph Zito
Port Orange, FL
January, 2011
This page intentionally left blank
Acknowledgements

The work represented as a summary of laboratory investigations, as well as the design, building and field testing of potentially viable and useful water treatment products took place over a period of a few years at TRL, Inc. in Durham, NC.

A number of different talents of various individuals participated in critical manners to bring about the net results contained in this book. Only a few of these people can be credited here. It required not only some scientific perceptivity, but also engineering and fabrication know-how to persistently pursue these projects. It is hoped that some of these developments and knowledge gained by the activities of these people will be useful to others in the commercializing of systems in the future. Generally, water must be treated in some manner due to the many problems that beset its use in applications where “uncontaminated water” is critical to our civilization.

Among the numerous contributors to this project, I would like to particularly cite Dale Jones for his steadfast support in overcoming some difficult situations, Don Morris for his unparalleled contributions to design and hardware fabrication. And many thanks to Patricia Pearson and Sara Tortora who provided order to the laboratory; orderly enough to maintain the necessary continuity for any work to succeed with a staff of usually over a dozen individual contributors. Also, without their imposed discipline and encouragement we almost certainly would not have completed these tasks.
This page intentionally left blank
Introduction

Water has been in plentiful supply on this planet since it long ago cooled down and the oceans were formed. Despite the fact that over 70% of the Earth’s surface is covered by water, the water needed for various life sustaining purposes is either unavailable at the required locations, or it is too contaminated for practical use.

Obtaining fresh water is almost invariably a costly endeavor. The natural pools and lakes have gone to a great extent, relatively free of contaminants, and scattered everywhere in the communities of this country. High population densities coupled with increased demands and pollution by industry and residents have left these idyllic scenes far behind us. Now, we must either transport water from a few remaining sources at higher elevations such as melting snow on mountains or lakes at or near mountaintops.

Roman cross country aqueduct.
The ancient Romans took advantage of such sources in Europe by building aqueducts (viaducts) to provide water to remote farms and villages by gravity feed. They spanned obstructions and valleys with gradually diminishing height to sustain the driving force of the mass of water being transported. There was little expense beyond the initial capital investment of the masonry, and of course, some continuing maintenance costs. These facilities were durable and had very long lives, as is evidenced by their existence today as functioning water lines.

Today, we must resort to other transportation mechanisms other than gravity. Now, pipelines with water pumps are more common, but trucking and shipping is even used in some areas where water is critical. Such means of provision are quite costly.

The only alternative to transporting water of good quality to other places of need is a purification or decontamination process of some sort. These methods, too, are costly depending upon the extent of processing necessary and the source of materials and energy. As in the case of transportation, energy for separation is necessary to produce useable water from contaminated sources. There are only a limited number of mechanisms that can be employed to remove unwanted substances from water, whether they are dissolved or simply as particulate matter in suspension. In the latter case, filtration of one form or another or sedimentation can solve these problems.

For those materials that are in solution, other methods must be employed, such as reverse osmosis, electrodialysis, or the old standby, distillation. Both distillation and RO will remove all solid matter in solution regardless of whether they are organic in nature, or inorganic, ionic materials. Distillation is the oldest method in existence, but it can be quite inefficient in terms of energy required per unit quantity of condensed water produced. Maintenance of boilers and evaporators can also be costly because of the solids left behind. The same is
true for ED systems whose micro-porous membranes can become clogged with solid matter.

ED is a cleaner system in the sense that no solids are collected as such, but the process will only remove substances that produce ions when dissolved so that they will respond to electrical forces for the separation process. Hence, ED is limited to removing only inorganic materials. Depending upon the nature of the situation one or more of these systems might be employed in treating a single body of water.

It should be kept in mind that a minimum amount of energy is required to extract dissolved materials at the very least equivalent to their heats of solution. However, in practical systems that amount of energy is usually quite small compared to the dissipative factors of electrical resistance in ED devices, and mechanical resistances of RO devices. Desalination of seawater presents the greatest of all problems because of the very high concentrations of salt involved. Depending upon the form of energy available at a particular location where the fresh water supply is a problem, one of the preceding approaches is usually employed. If, for example, solar energy or cheap fuels are in great supply, distillation may very well be the method used in that location. Desalination should be receiving greater attention as a means of providing "fresh water" especially because seawater is so plentiful, and the demands are increasing so rapidly. The future will undoubtedly bring more conservation measures, but we may still be hard-pressed for better solutions to this ever-increasing problem.

In recent years, especially, many devices and gadgets have been offered for sale on the open market, claiming to be capable of "purifying" water for drinking and cooking purposes. Some of these offered products are, indeed, genuine and perform as advertised. Products such as those based upon the use of ion exchange resins and distillation are based upon real science.
However, numerous electrical devices on the market do not perform the tasks of which vendors claim they are capable. For example, ineffective devices include those that supposedly operate on the basis of some sort of magnetic field imposed on the water system via coils of wires that "polarize" or otherwise change the character of ionic species. These products are not based upon any known mechanism that would, in fact, separate unwanted materials in the water supply, or prevent mineral deposits from accumulating on the insides of pipes or hot water tanks in home or industrial water systems.

There are some simple rules that one can follow to determine whether these proffered products do indeed operate. One should consider the amount of energy required to remove a given quantity of materials, i.e., dissolved substances, from a given volume of water. Generally one can employ such simple estimates to determine the probability of successful operation. Most of these important issues are covered thoroughly in the text to follow.

There isn't much question about the importance of water in every facet of our lives, specifically the necessity for good quality water. The issues covered here are largely concerned with the removal of unwanted dissolved substances in water—substances that are ionic and are usually inorganic salts, acids and bases of soluble materials. The most common of these is salt, i.e. sodium chloride, because of its abundance and global availability. Various competing methods for removing materials of this nature are reviewed, but the main emphasis is electrochemical approaches such as electrodialysis. Much of the book is an analysis of the performance, efficiency and configurations of these types of systems. Some information is provided about the materials of construction, but the main theme of the book is analytic in format.
1

Water Contaminants and Their Removal

1.1 Introduction

This book is intended both as a tutorial presentation of basic principles of electrochemical water processing as well as a short working manual for the design and operation of electrochemical deposition cells and for electrodialysis devices.

Water quality for direct and indirect human uses has always been an important concern in the past, and continues on into the future. With the ever-increasing concentrations of population centers and the demands of the industry, that concern is growing continuously throughout the world.

The conditions that determine acceptable water quality are very dependent upon the use to which the water is intended. The factors involved are numerous, to say the least, and range from one high purity extreme to non-potable irrigation water. Water intended for farm
irrigation, for example, can contain a high level of foreign substances at the level of thousands of parts per million as long as these are not damaging to crops. At the other end of the water spectrum is the need for super pure, or “polished” demineralized water for pharmaceutical or semiconductor production uses.

Among the more common types of foreign materials present that determine the “purity level” of water are listed below. Their removal from the body of water for each type is identified.

1. Solid matter in agitation or suspension
   Removal by: filtration, decanting
2. Dissolved organic substances
   Removal by: distillation, adsorption
3. Dissolved inorganic, ionic substances
   Removal by: distillation, reverse osmosis (RO), ion exchange resins, electrodialysis (ED)
4. Bacteria and other living organism contaminants
   Removal by: reverse osmosis, chemical addition, heating
5. Gasses present, in solution or otherwise
   Removal by: heating, ED, RO, adsorption
6. Other liquids miscible or non-soluble
   Removal by: fractional distillation, adsorption, RO, ED

The removal method selected depends upon the economics of the situation for the intended applications, the specifics of the contaminants, and other unwanted substances present in the water.

In the future, water treatment with minimal use of chemical reagents will become the goal of most processing systems. This approach is stimulated by the desire to minimally disturb the existing chemical conditions in water, and to reduce the amount of chemical correction needed as one introduces a reagent to fix one problem, only creating
another problem. In some water conditioning instances, the elimination of all chemical agents is possible.

A family of systems is possible, which will provide means for controlling pH, biocide level and dissolved solids concentration in water. One such form of technology is the direct removal of dissolved, ionized materials in water via electrochemical, (electrodialysis), separation.

In the ensuing pages, one such class of processes will be described in some considerable engineering detail. In some instances the need to introduce bulk chemical agents to the water system can be eliminated entirely.

This system removes dissolved substances such as salts, mineral compounds, acids and alkalis through the application of an electric field impressed across an array of electrodes and ion selective membranes. An electric power source is only required as input to the water. No chemicals or consumable materials are introduced into the water system.

Dissolved substances that are removed from the main body or mainstream of water are carried over into a waste water stream and eventually discarded. A maximum of only a small percent of the incoming water is “wasted” in this manner, and no materials are put back into the drainage that were not present initially. The waste-water just has a higher concentration of the same dissolved materials than it had when first introduced into the systems.

There are only a limited number of other methods, which can be employed to perform this task. They are:

1. Distillation
2. Reverse osmosis, RO
3. Ion exchange resin beds
   • Distillation is simply the evaporation of solvent from solids and other contaminants present in the original body of water. The disadvantages are the life of equipment, relatively high maintenance in cleaning residues
from evaporating surfaces (heat exchangers), and high temperatures and high-energy consumption.

- Ion exchange resins operate on the basis of the displacement of one ionic species for another as a function of relative concentrations. A mixed resin bed (cation and anion), regenerated in the hydrogen and hydroxide forms, respectively, will remove all other species of ions upon passing through the bed, and replace them with hydrogen and hydroxide (water as net product). High quality water can be obtained via this method. However, problems include high cost of regeneration and contamination. Usually this process is suitable for bringing good quality input water to high quality (polished, ultra pure) water for pharmaceutical and semiconductor uses.

- During osmosis, solvent passes through a semi-permeable membrane separating two solutions. Solvent—or water in this case—passes from the dilute solute side to the more concentrated side. This migration of solvent molecules to the concentrated side will continue until the solute concentrations are equal on both sides of the membrane. Reverse osmosis or migration of solvent to the dilute side can occur if a sufficiently large hydraulic pressure differential is established across the membrane in the appropriate direction (see Chapter-2, Section 2-12).

RO is a system in which the water (solvent) is forced through the membrane, leaving behind ionized solutes as well as solids and organic materials. This filtration aspect of the process is an advantage in terms of ridding the water of most of the unwanted contaminants. However, the problems of membrane damage and clogging or blocking and fouling are significantly increased.
The electrodialysis, (ED), method offers some distinct advantages over all three of the above alternative methods. A comparison of attributes shows these to be some of the distinct benefits in practical use.

Problem areas with Distillation

- a. Costly in energy consumption
- b. Small systems are usually very inefficient
- c. Maintenance and scale accumulation problems
- d. Low production rate of water

Problem areas with Reverse Osmosis

- a. Fouling of membranes
- b. High pressure requirements for high TDS differences and their potential hazards.
- c. Costly systems
- d. Large size systems for large water flow rates make them impractical for many consumer applications

Problem areas with Ion-Exchange Resins

- a. Resins are costly
- b. Need for regeneration is inconvenient and costly
- c. Two resin bed systems require use of hazardous acids and alkalis for regeneration
- d. Practical considerations of these de-ionize systems render them impractical for consumer and many commercial applications

Problems and Limitations of ED Methods

1. No filtration provided for particulate matter
2. ED will separate out only ionized chemical species, no organic
3. Possible corruption of membrane by crystallizing materials within the membrane structure
The ED system employs long-term, inexpensive electrodes in conjunction with durable membranes that make for a low capital cost apparatus. The equipment operates at standard conditions of temperature and pressure, and requires no special precautions regarding quality of incoming water. The system can be designed to handle a full flow of water on a "once through" basis or it can be made very small and used in conjunction with a storage tank as a batch processor.

Because the system is very simple in structure and operates through direct input of electric power, it can be made very small for portable applications.

Surprisingly, ED is not employed in many areas where its applicability has distinct advantages. For various reasons of cost, unavailability of durable ion exchange membranes, and perhaps complex manufacturing requirements in the past, ED is not as popular for desalination and demineralizing as reverse osmosis, RO, systems. In a similar fashion, RO and cation exchange resin bed methods have been preferred for performing the tasks of water softening.

Residential water softening presents an interesting example of a use where one method almost exclusively predominates the field. Cation resin bed devices have become the primary choice of the industry. RO and ED are competing systems that offer dramatic advantages with regard to the condition of the emergent, treated water over cation resins for softening water.

Neither RO nor ED requires the consumption of sodium chloride for its operation resulting in brine waste water effluents into the ground water table. Softening by cation resins results in virtually the same concentration of dissolved substances in the treated water, except that sodium ions have been substituted for the unwanted "hardening cations" such as calcium and iron.

RO and ED systems soften and demineralize input water by the removal of both cations and anions, thus