

Perspective Article

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Received January 26th, 2023; Accepted May 24th, 2023.

DOI: <http://dx.doi.org/10.29356/jmcs.v67i4.1954>

Abstract. A bird's eye view of some qualitative aspects of the state of Electrochemistry in Mexico in the 80's and that of now is given. My initial steps in the field were very encouraging and I have continued in it for 4 decades, of which an overview is given with emphasis in Environmental Electrochemistry and Electrochemistry and Corrosion Education.

Keywords: Electrochemistry education; environmental electrochemistry; electrochemistry in Mexico; distance learning.

Resumen. Se da una vista panorámica de algunos aspectos cualitativos del estado de la Electroquímica en México en los años 80 y el de ahora. Mis primeros pasos en el campo fueron muy alentadores y he continuado en él durante 4 décadas, de las cuales doy una visión general con énfasis en Electroquímica Ambiental y en Educación en Electroquímica y Corrosión.

Palabras clave: Educación en electroquímica; electroquímica ambiental; electroquímica en México; enseñanza a distancia.

Introduction

I begin this brief article with a deep thanks to the editors of the JMCS (especially Bernardo Frontana) for their initiative to publish a special issue commemorating the appointment of five members of the Mexican Society of Electrochemistry (SMEQ) as National Emeritus Researchers. Following the editorial recommendations, I will make a brief overview of how I see the development of electrochemistry in our country in the last four decades, as well as the simple but intense contributions I have made in the field. I have published articles, chapters, patents, and books with more than a hundred coauthors, so I offer an apology if I do not mention all of them because it would be a cumbersome job to do so. But this paragraph serves as a huge thank you, because without them I would not have been able to achieve anything of what I tell below. Also, in this article I will mention only some examples of the published works.

My beginnings

When I was a chemical engineering senior student at ITESO (the Jesuit university) in Guadalajara, the one who had been our professor of organic chemistry for several years became ill. He was a Jesuit, Fr. Luis Hernández Prieto, S.J. who had received his doctorate in the United States. Our departmental chair, Salvador

Santoyo invited me to teach his classes to my sophomore and junior classmates while "The Priest" healed, which never happened because he died a few days later... leaving me a giant position to fill. I ended up with difficulty teaching his courses that semester and the next, and it became clear to me that I was not ready to train students with the level that was required. That is why I asked for help from my friend Jorge Ayala Padilla, the eventual departmental chair, who connected me with Dr. Wayne Wentworth of the University of Houston that kindly received me and awarded me a scholarship to do a PhD in physical chemistry (with the theme: chemical storage of thermal energy). Upon finishing it, I asked Dr. Ralph Becker (from the same university) to accept me to do a postdoc in semiconductor electrochemistry and I did. There we studied many redox pairs with a view to protecting semiconductors from photocorrosion [1]. This marked my introduction to electrochemistry, plus a graduate course with Dr. Karl Kadish, and I became fascinated by the field. At a later time, I went to the University of Texas at Austin with Dr. Adam Heller to work on electrochemical glucose enzyme sensors – so I could see concrete applications of electrochemistry for social benefit [2]. There I also had the opportunity to take Dr. Allen Bard's graduate course and participate in his weekly seminars.

The return to Mexico

My wife Uqui (Luz Teresa Velasco-Lafarga) and I decided to return to Mexico, for which I joined CINVSTAV-IPN as a professor and researcher thanks to Rosalinda Contreras. There we continued the study of redox pairs and the deposit of metals on semiconductors [3]. Soon I was lucky enough to attend the national congress of electrochemistry (in 1984) – where I realized the status of electrochemistry in our country – and I was fortunate to meet friends and dear colleagues that I keep to date (Ignacio González, Alberto Rojas, Tere Ramírez, Joan Genescá, Elsa Arce, Yunny Meas, among others). The warm welcome that SMEQ gave me was the beginning of many interactions with this society and its members. I definitely recommend all faculty who start their career to look for a professional group like this to develop in their midst. There I could see how the different fields of electrochemistry were brewing in our country, and I was interested in collaborating as much as possible to help these groups flourish.

Electrochemistry in Mexico: then and now

With enormous strength, the members of the SMEQ at that time initiated research in very different areas, although all more or less incipient. We didn't have the modern tools to propel a big development. Do not dream of having an ESCA to analyze the elements on surfaces, or an AFM to observe their morphologies, or an EPR to detect radicals generated during reactions. But there were potentiostats (many of them made by Mexicans like Álvaro García, from the University of Guanajuato), so with a lot of desire and little equipment things were achieved. Seeing colleagues at least once every year since then at the SMEQ congresses has led to a gigantic exchange of ideas, collaborations in projects, loan of facilities and equipment for collaborative research, promotion of mutual stays for students and researchers, the facilitation of contacts abroad, and above all, the mutual ability to get excited and encouraged by what everyone does. The long nights working together or listening to our practice presentations in the hotel rooms where the congresses were held were historic. In my opinion, the SMEQ has been much more a breeding ground than a boxing ring or a legal trial where your mistakes are evidenced, and a sentence is imposed on you. For example, it was quite an event for me to learn that the behavior of species in aqueous media could be generalized through relatively simple equations with a method developed by Tere Ramírez, Alberto Rojas and Nacho González of the UAM-I. They were kind enough to teach me their method in long and very pleasant sessions in our different houses and allowed me to collaborate in some works [4].

Foray into environmental electrochemistry

At a certain point, I decided to change institutions from CINVESTAV to the Universidad Iberoamericana, because coming from ITESO I would surely feel more at home. And so it was. The great freedom of research and humanism promoted by Ibero allowed me to open some fields of research such as semiconductor chemistry and electrochemistry, education in electrochemistry, and later the environmental applications of electrochemistry. Thanks to a contact I established with Dr. Krishnan Rajeshwar of the University of Texas at Arlington, I began trying to understand what electrochemistry can do for our common home. First, we took on the task of synthesizing 250 articles on the subject, which greatly opened up for me the global panorama [5]. And already entered in the matter, we decided to make one of the first books internationally on the subject entitled *Environmental Electrochemistry*, which was published in the USA by Academic Press [6]. I elaborated on a number of problems for this book, but my co-author felt that the book was not suitable for their inclusion. Fortunately, Dr. Carlos Mauricio Castro of UNAM connected me with Dr. John Bockris of Texas A&M University, who was interested in including them in the new edition of his famous textbook [7]. I remember with pleasure that he even gave me enough money to buy my round plane ticket to College Station, Texas to discuss my problems in his home and check them out.

Subsequently, we elaborated several reviews on electrochemistry and the environment, including one with Alanah Fitch (de Loyola, U.–Chicago) on its complementation with other physical, biological, chemical and electrochemical techniques [8]. During my research, at some point we got involved in the direct and indirect reduction of chromate ions by a conductive polymer, and – for something that can be attributed to serendipity – we achieved a patent [9]. We also published several works on the subject thanks to a collaboration with Nikola Batina of the UAM-I, Arturo Fregoso of Ibero, as well as Silvia Gutiérrez, Alejandro Alatorre, Ulises Páramo, Javier Guzmán and Francisco Rodríguez of the University of Guanajuato, in addition to several students [10,11]. With the same Alejandro Alatorre and collaborators, we later developed our idea of evaluating the possibility of using Ag(III) compounds for remediation purposes as it is a powerful oxidant [12]. At times we also worked with Alejandro Baeza (UNAM), Rodrigo Mayén (Ibero), Teresita Oropeza (Tec de Tijuana), Gerardo Salinas (now in Europe), and the group of the University of Guadalajara (Norberto Casillas, Max Bárcena, Ale Carreón et al.) in the analysis of samples – some of environmental importance and others of industrial significance [13-15]. We also realized the importance of electrocoagulation [16] and developed with ITESO an idea to carry out a magnetic separation of the waste generated during the process [17].

The collaboration of many years with Rubén Vásquez of Ibero led us to a large number of works in the waste treatment arena [18]. Fundamental for this was the collaboration with the CIRA group formed by Ivonne Linares, Verónica Martínez, Alejandra Teutli et al. [19]. We also emphasized in several investigations with Bernardo Frontana the importance of using green electrochemistry [20], conductive polymers [21], and the idea of using coupled processes for different objectives [22]. Thus, we achieved for the first time the simultaneous synthesis of chlorine dioxide [23], and the simultaneous electroluminescence of luminol (with Daniel Zavala, Claudia Camacho, several students, and Michael Tausch and his group at the University of Wuppertal) [24]. With this work we made the cover of one of the issues of the Journal of the Chinese Chemical Society [25].

We were also pioneers in testing the simultaneous destruction of pollutants [26], and with another group from the UAEMex (Patricia Balderas, Gabriela Roa et al.) we worked on simultaneous electrocoagulation processes that involved the production of hydrogen [27], as well as the substitution of reagents to achieve greener analyses [28]. There are a very important number of groups in Mexico dedicated to environmental electrochemistry, which is definitely encouraging. It would be a titanic task to describe them. One can get an idea by taking a look at any SMEQ congress report (www.SMEQ.org.mx). As we discussed in the book and in the reviews mentioned earlier, the competitive advantages of electrochemistry over other technologies make it in many cases the most desirable alternative.

Electrochemistry education

I now want to focus on the importance and development of electrochemistry education. In the early 80's, the emphasis was on teaching traditional topics in electrochemical thermodynamics and kinetics, including corrosion. I have seen over the last 4 decades a transition to more modern and global ways of looking at electrochemistry. A myriad of more powerful and sensitive instrumental methods of analysis have been integrated, the vision of fundamental processes has been complemented with theoretical chemistry, the possibility of scaling the processes developed in laboratories has been opened more...and an electrochemical engineering that goes from the figures of merit to the modern design of reactors using simulators and modeling has been established with more aplomb, supported by mathematical and computational tools.

On the occasion of the 30th. anniversary of the SMEQ we wrote an article on education in electrochemistry [29]. In addition, The Electrochemical Society compiled a series of interesting didactic supports [30], and so did Coe College at the time [31]. In a more modern version, the University of Oregon has online a series of videos and folders containing electrochemistry teaching materials [32]. There are other current reviews on the subject [33-35], which show its dynamism.

However, I must also recognize that a better motivational strategy is needed in initial education in order to encourage students to start off on the right foot and with the necessary enthusiasm. From my perspective, opening courses with simple experiments is highly motivating. That is why we have dedicated ourselves for a long time to the development of basic experiences, using accessible and inexpensive materials available to any high school or university (of course when there are no potentiostats or galvanostats, or more sophisticated things). Not because these latter instruments are not useful – they are in fact very useful and give a more complete picture – but because one has to start from the bottom. In addition, we have done so keeping in mind the care of the environment through the use of microscale (or small-scale) techniques, as we have found innumerable advantages from the environmental, economic, safety, time, social acceptance, accessibility, legal, storage, etc. perspectives. [36]. After the initial impulse given by the National Microscale Chemistry Center (Merrimack College, USA) to our group of the Mexican Center for Green Chemistry and Microscale that we formed at Ibero in 1990, we have collaborated with many national and foreign institutions to impact more than 50 countries on the 5 continents [37-39]. Our book on *Environmental Chemistry* and its *Handbook of Experiments* have served as texts in many institutions around the world [40,41]. During the COVID-19 pandemic we ventured into designing real experiments remotely, and assembled and shipped an electrochemistry and corrosion kit to each student's home for two semesters. This allowed us to perform up to 30 experiments per semester, several of which we published in journals in the USA (e.g. [42]) and Europe (e.g. [43]). There is much to be done in the line of improving and giving greater relevance to experimental teaching, and surely the new generations will benefit from these impulses.

Final thoughts

Electrochemistry in Mexico has reached a commendable level of development, thanks to so many teachers, researchers, and students who have committed themselves to this trench of science and technology. When some politicians criticize science in Mexico, we should put them to work in the conditions in which many of us have worked so that they realize what has been achieved with an investment that leaves much to be desired. Despite the difficulties and the social environment in which we are living, I can gladly say that not a single day of my life have I regretted having returned to Mexico from the USA. I love my country, my people, and I want to be a bearer of hope. I trust that the (approximately) 10,000 students and teachers that I have contributed to train are to some extent agents of change.

In the humanistic field, in addition to my forays into the area of education, I was able to share knowledge with visually impaired people through workshops and the writing of a manual in Braille [44]. I was also honored to be invited by the OPCW (Organization for the Prohibition of Chemical Weapons) – winner of the Nobel Peace Prize in 2013 – to its headquarters in The Hague. There, I participated in the drafting of the Guide for the Ethical Use of Chemical Substances [45]. I have also been interested in promoting the dialogue

between science and transcendence through conferences, radio capsules, and the translation of two books on the subject [46,47], in addition to having completed a European diploma in this field.

Undoubtedly, with my retirement, many things remained in the pipeline. When it became clear that I would no longer have time to develop various ideas that I kept for decades, I got rid of the equivalent of 8 large containers of paper for recycling. However, I do not feel the slightest frustration for it, because the feeling of gratitude for everything achieved prevails far above. I have been immensely blessed with my family, my friends, my colleagues, my institutions, my collaborations, my students, my stays, my travels. (I never thought that as a professor of Chemistry I would visit countries on the 5 continents, and that IUPAC would invite me several times as a plenarist of its congresses)! And also, having been able to play soccer for three decades with the same team of teachers, and participate in volleyball and table tennis championships, ... and even in college dance contests! Being a teacher-researcher has to go hand in hand with a harmonious development of our personal, family, physical, emotional, relational, spiritual, cultural spheres... So it is essential to optimize our times and movements to accommodate them. I don't know to what extent I achieved it during my career, but I certainly enjoyed myself to the fullest and I hope that in the process I have contributed to a better society with my grain of sand.

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