Overview

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An Overview of the Mexican Industrial Electrochemistry

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This work is dedicated to the emeritus professors in Electrochemistry for their teachings, for being our paragon, and for cherishing our friendship.

Abstract. This study provides an in-depth analysis of the electrochemical industry in Mexico by examining the geographic distribution of the companies, the economic sectors they belong to, the products they manufacture, and the electrochemical processes they utilize. The data were collected from 805 Mexican manufacturing companies in the electrochemical industry and analyzed using data mining techniques, revealing that Mexico's electrochemical industry is concentrated in regions with high economic development, such as Mexico City, Monterrey, and Guadalajara, which are also traditional suppliers of the automotive industry. Furthermore, 91.2 % of the industry is focused on the electrodeposition process, with zinc coatings and nickel being the most commonly produced products. The metal-mechanical sector is the most dominant economic sector, accounting for 89 % of the companies. In addition, this study highlights the potential for collaboration between the industry and academia, as there are numerous research groups and institutions throughout the country dedicated to electrochemistry research and development. Despite this, the industry has yet to fully integrate academic knowledge and expertise to address industry problems. Overall, the manufacturing sector in Mexico is diverse, with the electrochemical industry continuing to provide employment opportunities for thousands of people but there is room for growth and development in advanced electrochemical technologies beyond traditional galvanization processes.
Keywords: Electrochemical engineering; electroplating; companies; data mining; Mexican industrial electrochemistry.

Resumen. Este trabajo presenta un análisis detallado del sector electroquímico en México, proporcionando información sobre las regiones con mayor desarrollo en tecnologías electroquímicas, los sectores económicos en los que se desempeñan las empresas, los productos que comercializan y los procesos electroquímicos utilizados en su fabricación. Los resultados obtenidos demuestran que, aunque la galvanización representa el 80 % de las empresas electroquímicas, existe una pequeña parte que utiliza tecnologías avanzadas. Asimismo, se ha identificado que la mayoría de las empresas se ubican en regiones con alto desarrollo económico, con una tradición en el uso de la electroquímica y donde las empresas son parte de los proveedores de la industria automotriz. Además, se ha identificado que la academia ha florecido en este campo, con numerosos grupos de investigación e instituciones dedicadas a la investigación y el desarrollo en electroquímica en todo el país. Este

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estudio resalta la importancia de la colaboración entre la industria y la academia para impulsar el desarrollo de la industria electroquímica en México.
Palabras clave: Ingeniería electroquímica; galvanoplastia; empresas; minería de datos; electroquímica industrial mexicana.

Introduction

This study aimed to present an analysis of the electrochemical industry data in Mexico. As recognized electrochemists who were honored in this issue collaborated in some industry projects, it was considered of high importance to analyze the circumstances in which they conducted their research. It is well known that the use of electrochemistry in industry, including in developed countries, is lagging mainly because of the need for trained chemists and engineers in electrochemistry [1]. Therefore, knowing the characteristics of electrochemical companies, such as their size and economic activity, type of processes and products, and thus understanding the current scenario of this sector is useful to help other scientists to approach the industry and collaborate in the development of electrochemical applications.

The first widely used commercially marketed electrochemical systems were Volta's pile, such as the 600 voltaic piles installed by William Hyde Wollaston [2] at the Royal Institution in London in the early 19th century. In 1873, the first industrial electrochemistry applications were established with nickel plating in New York. Subsequently, the first electrolysis applications were developed in chlorine-alkali production in the United States and France in 1886 [3], while the first industrial application of electrodialysis was implemented in 1930 [4].

The use of industrial electrochemical technologies led to the establishment of the newly coined "Electrochemical Engineering" scope, which was introduced in Advances in Electrochemistry and Electrochemical Engineering in 1962 by Carl Wagner. These technologies have been employed in various industrial processes, such as the electrorecovery of metals, corrosion, electroremediation, batteries, and coatings [5]. Although the term "electrochemical engineering" [6] was first used by Mantell in his book entitled "Electrochemical Engineering" [7], in which he described some processes to produce particular electrochemical products, many electrochemical processes were incorporated for the production of several products in the 1950s. Wagner (1962), who is considered the founder of electrochemical engineering science [8], published his book "The Scope of Electrochemical Engineering" [9], in which he presented and solved some of the problems related to mass transport and current distribution. He placed special emphasis on mining applications, and through the development of chemical engineering and its foundations, electrochemical engineering took on the same meaning [6].

In the 1960s, the use of electrochemical technologies was mainly focused on the electrolytic production of chlorine-alkali, the synthesis of hypochlorite and chlorate, the electrodeposition of aluminum and magnesium from molten salt electrolytes, the electrolytic extraction of zinc and refining of copper, as well as small-scale processes such as the production of MnO_2 [6]. Subsequently, electrochemical engineering began to grow until the 1990s with the development, modeling, and simulation of electrochemical reactors, the understanding of electrochemical processes, the creation of new sub-disciplines of electrochemistry and chemical engineering; and the formation of more electrochemical specialists in schools [8].

In 1970, Electrochemical Engineering was recognized in Mexico as a part of the development of Chemical Engineering [10], with Wendt [11] emphasizing the importance of compiling knowledge on Electrochemical Engineering In 1977, which was achieved through the work of Von D. J. Pickett entitled "Electrochemical Reactor Design" [12], which presented all the information needed to understand electrochemical processes. However, Wendt also mentioned that the book lacked a connection with the electrochemical industry [11].

In 1982, Derek Pletcher and Frank C. Walsh published the book "Industrial Electrochemistry" [13] and Fumio Hine published "Electrode Processes and Electrochemical Engineering" in 1985 [14]. Both provide a comprehensive reference for engineers, researchers, practitioners, and students alike who are interested in applying electrochemistry in engineering applications. The books offer both theoretical and practical insights

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into the subject matter, making them an indispensable resource to design and optimize electrochemical systems for a wide range of applications, including electroplating, corrosion protection, and battery technology.

Meanwhile, in the 1990s, multipurpose press filters, mono and bipolar electrode arrays, reactors for the synthesis of organic compounds, and rotary cylinders among others were developed. New materials were also being used for the construction of electrodes. The main applications of electrochemical processes and technologies were in the recovery of metals, corrosion control, and the treatment of contaminated effluents. Additionally, other applications, such as the development of electrochemical sensors, catalysis, and ionic liquids, were gaining more attention and showing great potential benefits [8,15].

Electrochemistry was a mature scientific field, however, its technological applications were in a continuous process of growth and maturity [10] because many of the applications were due to the study of the fundamentals and the great potential for the production of numerous chemical compounds and the diversity of applications [15]. More recently, the first technological development in electrochemical technology was the battery as an energy source in electrolysis, with electrochemical industrial applications remaining pioneering in electroplating.

In Mexico, companies such as "Acumuladores Omega" was created around 1940 in Pesquería N.L., and "Sosa Texcoco" founded in 1942 in the State of Mexico through the efforts and ingenuity of Antonio Madinaveitia became the largest alkali industry in Latin America. The company produced 100 tons of alkalis per day in 1948 but due to a strike in 1993, it ceased operations. In addition, table salt was produced as a byproduct that could be used in the industrial electrolytic production of alkalis [16,17].

In addition, other companies in Mexico contributed to the growth of the electrochemical industry, such as "Acumuladores Anáhuac" (1965) in Xalostoc, Edo. Mex., "Galvanoplastía Mexicana" (1981) in Mexico City, "Electro Química Mexicana" (producer of hydrogen peroxide, founded in 1948), "Productos Químicos Mexicanos, Inmermek" in the State of Mexico since 1987, "Galvanoquímica Mexicana" since 1981, "Recubrimientos Metálicos de México" since 1954, "Galvanolyte" (1951), prominent in water treatment by electrolysis since 1960, "Plásticos Especializados Mexicanos" (1971), "Artículos Metálicos Peréa" (1992), "Karati" (1988), "Galvano Depósitos" (1972), "Galvanizadora CABE-RI" since 1974, and "Galvano Depósitos (GADESA)" since 1972.

In 1976, Pennwalt was established in Mexico, which was later acquired in 1984 by Antonio del Valle and became Mexichem which mainly produces electrolysis-based caustic soda and recovers metals such as electrolytic copper. Other companies in Mexico include "Aleamex" since 1982, "Grupo GISA" since 1978, and "Cromadora Campos", all of them located in Mexico City. "Ecoplating" is based in the State of Mexico (founded in 1942), "Galvanizadora Tijuana" in the State of Baja California Norte since 1986, "Galvanoplastia y Servicios Industriales" in Puebla since 1998, Mexicana de Cobre SA de CV founded in 1968, "Rot Química" founded in 1977 in Monterrey to produce chlorine, and the electrowinning of Metalúrgica Mexicana Peñoles since 1887 in Torreón, Coahuila.

On the other hand, it is crucial to acknowledge the distinguished researchers who have played a pivotal role in advancing electrochemical technologies in Mexico. Dr. Ignacio González is renowned for his expertise in hydrometallurgical processes and developing alternatives to cyanide in gold and silver extraction. Dr. Omar Solorza Feria has made notable contributions with his prototypes of solar-hydrogen fuel cells. Dr. Jorge Ibañez Cornejo focuses on environmentally friendly processes, while Dr. Joan Genescá has made significant strides in corrosion research. Dr. Yunni Meas has dedicated his research to electrochemistry and environmental sciences, particularly in wastewater treatment. Lastly, Dr. Elsa Arce, renowned in the field of electrochemistry, has conducted groundbreaking research and made significant contributions to the training and professional development of industry personnel. All of them, who have been awarded and recognized as emeritus professors of the National System of Researchers.

Understanding the market for products manufactured through electrochemical processes is equally vital. Compiling information from company databases allows for a comprehensive assessment of the electrochemical industry, including its size, sectors, regions of significant development, and primary products. This understanding enables companies to make informed decisions regarding production and investment in research and development. Furthermore, policymakers and regulators can utilize this information to make well-informed decisions regarding the development and regulation of the electrochemical industry.

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Analysis setting

Data mining was performed using the Octoparse version 8.0 program to access various databases on the internet and considered search elements such as name, city, state, type of electrochemical process, business activity, product, phone, email, and website. The NCSS 5.0 program was used to perform the descriptive statistics using a normalized distribution model of the frequency raised to ⅓. The data collected from 804 companies in the electrochemical sector were used to create distribution and Pareto charts using Microsoft Excel and Origin Pro.

To ascertain the Production and Market Value of the primary electrochemical products manufactured in Mexico, we consulted the findings of the monthly survey conducted by the Economic Information Bank (BIE) of INEGI.

Results and discussion

After analyzing the data gathered from the data mining process, a total of 805 companies were identified, including 756 addresses, 754 websites, and 745 phone numbers. However, it should be noted that this figure only represents 0.1 % of the total number of manufacturing companies in Mexico as reported by the Economic Census of INEGI [18]. These findings highlight the untapped potential of electrochemical technologies in promoting entrepreneurship in Mexico.

The study revealed the regional distribution of the highest density of electrochemical companies in Mexico (Fig. 1), showing that most companies were concentrated in Mexico City, Monterrey, and Guadalajara, along with their metropolitan areas, Bajío, the border region, the Gulf, and the Pacific. The municipalities with the most significant number of registered companies were Guadalajara, Ecatepec, Gustavo A. Madero, Monterrey, Cuauhtémoc, Tijuana, Querétaro, San Nicolás de Los Garza, San Luis Potosí, Mexicali, Iztapalapa, Puebla, Aguascalientes, Escobedo, Azcapotzalco, Matamoros, Tlalnepantla, and Tlaquepaque, which accounted for 50 % of the total number of companies in the country.

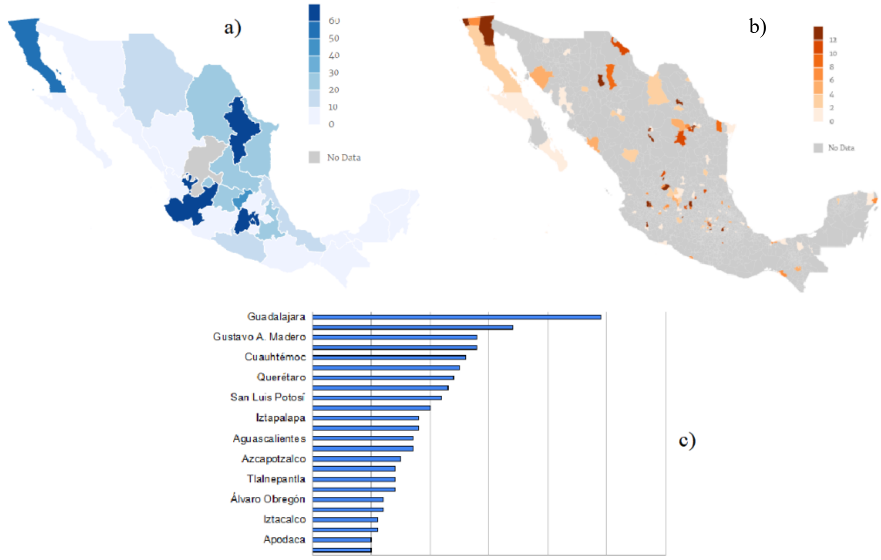

Fig. 1. The geographical distribution of the Mexican electrochemical industry with **(a)** a map displaying the distribution of companies by state, **(b)** a zoomed-in map displaying the distribution of companies by municipality, and **(c)** a frequency histogram showing the municipalities with the highest number of companies.

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The concentration of electrochemical companies is primarily influenced by growth centers including large cities and conurbations. In addition, regions with a significant history in electroplating serve as suppliers to the automotive industry, as observed in the Bajío and the border zone.

The statistical results were organized in quartiles based on the number of registered companies (Fig. 2). The first quartile (Q1) includes states with 27 to 139 registered companies, such as Coahuila, Puebla, Querétaro, Baja California Norte, Jalisco, Nuevo León, State of México, and Mexico City (CDMX), accounting for 76.1 % of the industry. The second quartile (Q2) includes Sonora, Veracruz, Guerrero, Chihuahua, Aguascalientes, Guanajuato, San Luis Potosí (SLP), and Tamaulipas, containing 19.5 % of the national industry. The third quartile (Q3) comprises the states of Yucatán, Michoacán, Sinaloa, Tlaxcala, Chiapas, Durango, Morelos, and Hidalgo, which account for 3% of the industry. The fourth quartile (Q4) includes Baja California Sur, Campeche, Colima, Nayarit, Oaxaca, Quintana Roo, Sinaloa, and Tabasco, with only 1 % of the national electrochemical industry.

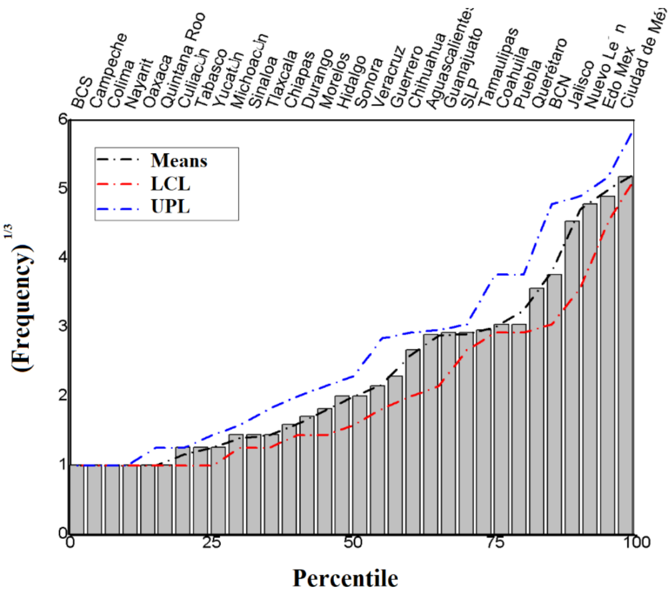

Fig. 2. Statistical distribution by quartile of the states with the highest number of companies in the electrochemical sector, depicting the average value (black line) and the lower (red LCL line) and upper (blue UCL line) control limits.

The states in Q2 present a high potential for the development of electrochemical companies, as the presence of such companies indicates a market demand. Moreover, it is of note that these states are located in different regions, suggesting a diversified market.

The distribution of the electrochemical processes (Fig. 3**(a)**) indicates that 91.2 % of the companies focus on electrodeposition, while energy storage and metal electro-recovery account for only 2.4 % and 2.1 %, respectively. Additionally, 1.9 % of companies act as suppliers with only 0.7 % providing corrosion services. The remaining processes such as electro-remediation, electrosynthesis, and synthesis processes are limited, accounting for 0.4 %, 0.4 %, and 0.3 %, respectively. These results suggest that the industry's expertise is primarily focused on electroplating, with limited experience in the production of batteries and accumulators.

The industry's extensive experience in electrodeposition is evident in the types of products it promotes, with metallic coatings being the most prevalent at 79 %, mainly zinc and nickel coatings, followed by other coating products, such as chrome (10 %) and manufacture of accumulators (3 %). Anodized coating, metallurgical products, and plating processes each account for 2 %, with only 2 % of companies installing technological processes, such as the remediation of effluents, while only 1 % of companies perform chemical synthesis processes.

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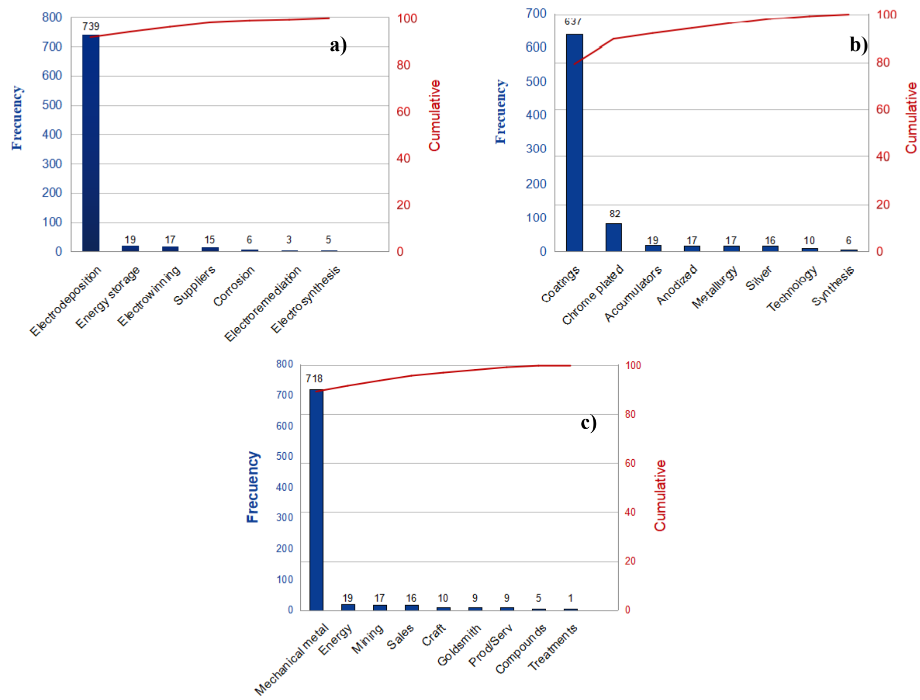

Fig. 3. Pareto charts depicting the distribution of registered companies based on **(a)** the type of electrochemical process used, **(b)** marketed products, and **(c)** the economic sector classification of the companies.

The data shows that most companies (89 %) belong to the metal-mechanical industry, followed by energy, mining, and sales (2%). Other economic sectors such as crafts, jewelry, products and services, chemical compounds, and treatments only account for 1 % each.

Currently, most companies concentrate on electrodeposition processes used in the metal-mechanical sector to manufacture coatings. This can be attributed to the crucial role played by the automotive industry in Mexico, which demands electroplating in many of its supply chains for producing automotive parts. However, compared to the global industry, it is evident that, in addition to coatings, there is also a focus on the development of chemical sensors for monitoring manufacturing processes and analyzing clinical parameters relevant to the control of chronic diseases, such as diabetes or cholesterol. Additionally, the industry is involved in the synthesis of chemical products for raw materials used in other sectors such as pharmaceuticals or food. Furthermore, energy storage has emerged as a sector of great importance, with many countries focusing on developing more advanced batteries. Other electrochemical technologies that can be employed include corrosion control through the development of inhibitors and the implementation of current printing systems.

Companies currently involved in electrochemical unit operations can leverage their existing knowledge and infrastructure to explore other markets by adopting new technologies. Electroplating companies could benefit from the adoption of other technologies such as electrosynthesis, metal electro-recovery, or energy storage. While some equipment, personnel, and experience may be transferable, additional investment in infrastructure, scientific knowledge, research, and technological development is necessary to implement a new production line using electrochemistry.

Electrochemical presence in the Mexican academy

In contrast to the electrochemical industry in Mexico, the academic sector has flourished in many higher education institutions and research centers, as evidenced by the significant growth of the Sociedad Mexicana de Electroquímica A.C. (SMEQ) in recent decades and the vast array of research groups and topics in various areas of electrochemistry throughout the country.

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There are researchers and postgraduate students in various research groups across the Mexican Republic [19], including Baja California, Mexico City, Campeche, Coahuila, State of Mexico, Guanajuato, Hidalgo, Jalisco, Michoacán, Nuevo León, Querétaro, Quintana Roo, Sinaloa, Tabasco, Tamaulipas, Veracruz, and Zacatecas. It is important to note that the absence of research groups related to electrochemistry in some states does not necessarily mean that no such groups are working in those areas. Moreover, the "Centro de Investigación y Desarrollo Tecnológico en Electroquímica" (CIDETEQ) is a specialized research center in Mexico that focuses on electrochemistry and related technologies. Established in 1997, it was created as part of the Mexican government's initiative to promote the development of electrochemistry in the country [20].

The research groups in Mexico focus on various research topics related to electrochemistry, such as the development of new materials, batteries, supercapacitors, electrochemical processes, contaminant removal, metal recovery, sensors, and corrosion inhibition, among others. As shown in Fig. 4, there is a similarity in the geographic distribution of academic research groups with that observed in the industry (Fig. 1**(a)**). This can be attributed to the growth of development poles in the country, which are accompanied by the creation and growth of higher education institutions. While this may be related to the training of professionals who work in the industry, it does not necessarily translate into the resolution of industry problems with the support of academia. However, with both the industry and academia as two actors of the triple helix model, there is potential for the intervention of a third actor to generate greater development in the electrochemical industry.

Fig. 4. National distribution of research groups in Mexican universities specialized in electrochemistry, as registered in the Sociedad Mexicana de Electroquímica A.C. (SMEQ).

It is in these research groups where developments in electrochemical technologies have been generated and led by our award-winning and honored researchers. For example, Dr. Ignacio González has spearheaded numerous projects funded by CONACYT, PEMEX, the Trust for State Infrastructure, and Industries Peñoles. His work has involved developing electrochemical methodologies for the hydrometallurgical processes of leaching, cementation, and metal separation, as well as finding alternatives to cyanides in gold and silver extraction. Additionally, he has conducted studies on corrosion layers formed in reactors, which have led to improved effectiveness of chemical inhibitors. Dr. González has multiple national and international patents and has published over 140 original research articles, as well as authored over two dozen chapters in various books. In 2007, three of his patents for extracting gold and silver without generating toxic waste were implemented on an industrial scale, with the launch of a pilot plant created jointly by the Metropolitan Autonomous University-Iztapalapa (UAM-I) and Servicios Industriales Peñoles (SIPSA). This plant was the most significant result of a collaboration initiated in 2004, with an investment of 1.7 million pesos. The metals obtained are reused in industries such as jewelry, water treatment, cell phones, and electronics, or sold to the Bank of Mexico [21].

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Dr. Omar Solorza Feria, from CINVESTAV-IPN, has demonstrated the practical applications of his research and development work to society. He designed and built prototypes of solar-hydrogen fuel cells integrating a silicon photovoltaic module, and later built three 35-watt fuel cells and power electronics to operate a go-kart exhibited on the streets of Mexico City. He has also studied and compared the performance responses of various catalytic materials, including platinum used in the manufacture of membrane-electrode assemblies, which is the heart of fuel cells. These projects have been presented at various forums and television programs [22].

Dr. Joan Genescá, from FQ-UNAM, has made significant contributions to corrosion research. His work has focused on the development of new galvanic anodes for protecting underwater structures and improving the efficiency of Mg anodes for buried structures. He has also consulted for organizations such as the Pan American Health Organization and the Gulf of Mexico Corrosion Program. Dr. Genescá has directed the Corrosion Laboratory of the FQ since 1984 and has trained numerous corrosion experts. He also played a key role in the creation and development of the Mexican Institute of Corrosion Research, IMICORR, and designed the Corrosion and Protection Engineering Diploma to train specialized personnel in various companies [23].

Dr. Yunni Meas has contributed significantly to the fields of electrochemistry and environmental science for over thirty years. He founded the Center for Research and Technological Development in Electrochemistry (CIDETEQ) in 1991, and he currently serves as its Director of Technology. Dr. Meas has published over 120 articles and book chapters and co-authored 20 patents. His work has various practical applications in solving concrete problems such as water purification, pool disinfection, washing fruits and vegetables, and preventing material corrosion in different industries. Additionally, he has developed electrochemical processes for treating industrial wastewater, and he has patented the electrocoagulation process, which has been implemented in several companies, mainly in aeronautics in Querétaro for water treatment [24].

Dr. Jorge Ibañez Cornejo is a coordinator and researcher at the Mexican Center for Green Chemistry and Microscale at the Universidad Iberoamericana (CMQVM-UIA), which aims to teach chemistry on a small scale and conduct research on more environmentally friendly processes. Dr. Ibáñez's team has made significant strides in this field, having developed an eco-friendly disinfectant for contaminated water and a PET depolymerization system that could benefit paper mills and beverage producers. They have also been granted a European patent for reducing toxic chromates. While the CMQVM-UIA focuses primarily on educational workshops, some of their developments have practical industrial applications. Dr. Ibáñez emphasizes that microscale chemistry to reduce, recover, and recycle can result in up to 99% savings in costs and materials in laboratory research without sacrificing efficacy. The center's objective is to train teachers at all levels to work on green chemistry-related topics and create a ripple effect [25].

Mexican electrochemical products market

Electro-winning of zinc and electrolytic copper mining are two of the most traditional and productive industries in Mexico, with Grupo Mexico being the main representative with over 40 years of experience in the sector [26]. Basic industrial manufacturing (Fig. 5**(a)**) companies utilize this electrochemical process for smelting, refining, and electro-refining of blister and electrolytic copper, as well as for producing alloys. The production volume of copper (SCIAN 331411) is 40.1±2.1 thousand tons, with a market value of 2,455.7 ± 951 million pesos on average over the last ten years. Copper production has increased by 23.1 tons and approximately 5.9 million pesos per month, with 96.41 % of production by large companies [27, 28]. This sector employs 972 people for copper smelting and refining [28].

Another manufacturing industry that utilizes electrochemical processes is the production of metallic coatings and finishes (Fig. 5**(b)**). These companies specialize in coating metallic pieces using anodization, chroming, galvanization, precious metal plating, copper plating, painting, and other types of coatings. The production volume of coating companies (SCIAN 332810) is 179.3 ± 20.7 thousand tons of coatings, with a market value of 3,526.0 ± 763.8 million pesos on average over the last ten years. The manufacturing of coatings has increased by 524.3 tons and 42.3 million pesos per month [28] and employs 16,283 people for the manufacturing of coatings and metal finishes [28].

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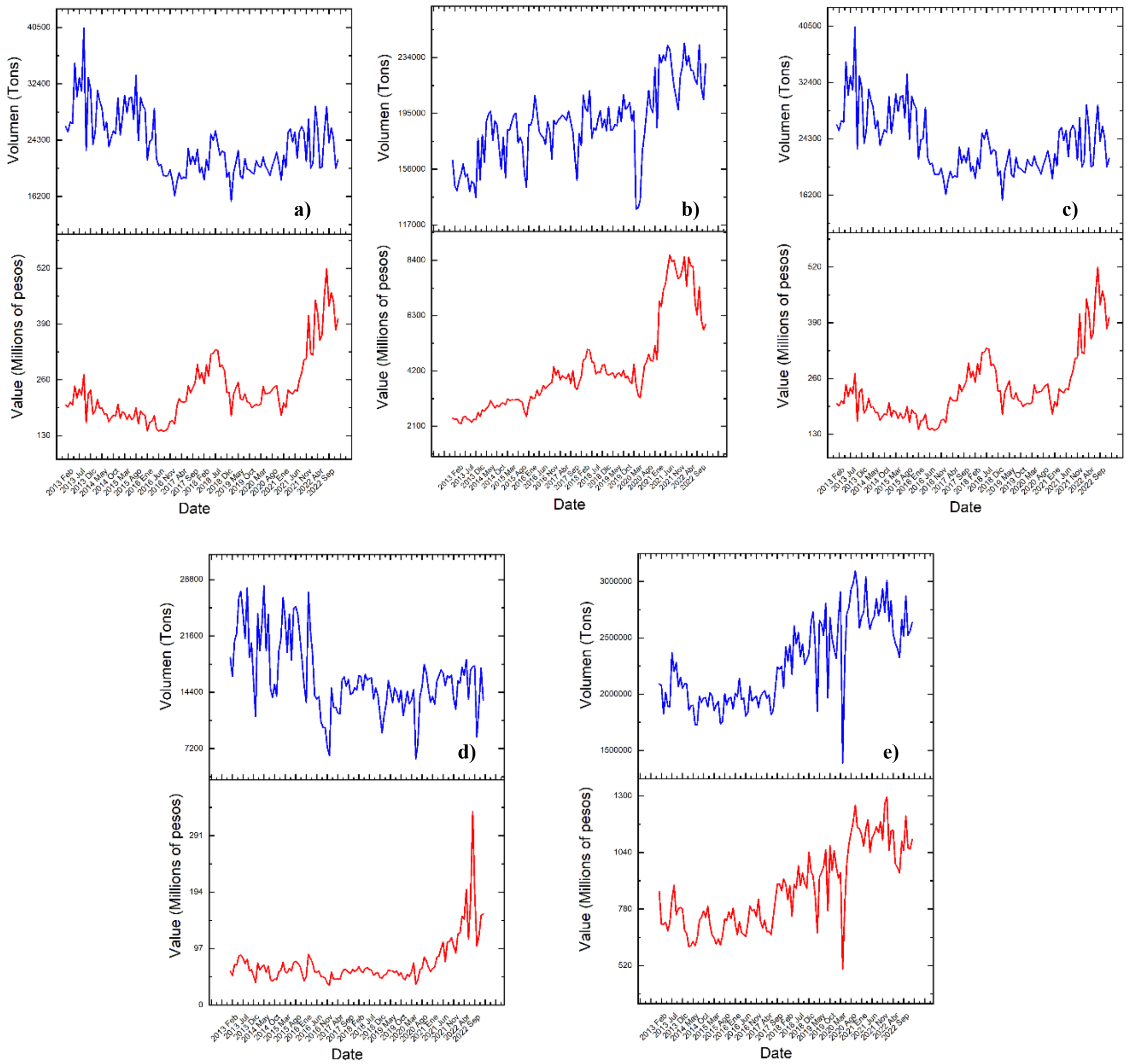

Fig. 5. Production and market value of the main electrochemical products manufactured in Mexico: **(a)** Copper, **(b)** Coatings, **(c)** Soda, **(d)** Chlorine and **(e)** Accumulators.

The chemical manufacturing industry is not the only one to utilize long-standing processes in the production of inorganic chemical products such as caustic soda (Figure 5**(c)**) and chlorine (Figure 5**(d)**). Accumulators and batteries are another manufacturing industry that utilizes electrochemical processes (Figure 5**(e)**). For example, the production volume of accumulators (SCIAN 335910) averages 2.18 ± 0.34 million units, with an average market value of 813.4 ± 152.9 million pesos over the last ten years. The manufacturing of accumulators has increased by 8,102 units per month, with an increase in the market value of 4.3 million pesos per month and employs 2,142 people [28].

In addition, the metallurgy and jewelry-making industries specialize in the production of precious metal and stone jewelry (SCIAN 339912). The iron and steel manufacturing industry focuses on steel mills to produce electrolytic iron (SCIAN 331111). Furthermore, the chemical manufacturing industry produces other inorganic compounds (SCIAN 325180), such as hydrogen peroxide. The industry that produces measuring and

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control instruments, laboratory analysis, testing and detection equipment, electronic diagnostic medical equipment, and other implant devices (SCIAN 334410) also includes electrochemical sensors.

Other manufacturing industries are part of the supply chain, such as the production of electrical carbon and graphite products (SCIAN 335991) for the manufacture of carbon electrodes. Similarly, the manufacturing industry for electrical appliances and electric power generation equipment (SCIAN 335312) includes the production of electric power rectifiers. Companies that offer repair and maintenance services for industrial machinery and equipment also specialize in the repair of equipment for electroplating (SCIAN 811312).

Conclusions

Most electrochemical companies are located in Mexico City, Monterrey, and Guadalajara, while Coahuila, Puebla, Quintana Roo, Baja California Norte, Jalisco, Nuevo León, State of México, and Mexico City have the highest number of registered companies, with 76.1 % of the industry concentrated in these regions. The industry mainly focuses on electrodeposition, with metallic coatings, particularly zinc and nickel coatings, being most commonly produced. The metal-mechanical industry is the dominant economic sector, accounting for 89 % of companies primarily due to the significant importance of the automotive sector in Mexico. Nonetheless, there is a need for greater collaboration between industry and academia to drive industrial development. While the industry benefits from a thriving academic community with numerous research groups and institutions dedicated to electrochemistry research and development, further cooperation between industry and academia could accelerate innovation and growth in the sector.

In conclusion, electrochemical technologies hold significant potential for entrepreneurship in Mexico but successful implementation requires additional investment in infrastructure, scientific knowledge, research, and technological development. Collaborations between industry and academia could drive industrial development benefiting both the industry and the broader Mexican economy.

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