



Development of electrochemistry in Bosnia and Herzegovina — historical perspective

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Abstract

The aim of this paper is considering a brief historical perspective and overview of recent ideas and directions in electrochemistry in Bosnia and Herzegovina. Since the 1950s, dozens of researchers worked and are still working on the study of electrochemistry. The research evolved from polarography in the beginning to electrochemical deposition and/or dissolution of metals, alloys, polymers, nanocomposites and deposition of metal powders, corrosion mechanisms and corrosion protection, different catalysts and energy storage and conversion. Since the electrochemical and chemical industry was developed on the territory of today's Bosnia and Herzegovina in the period from 1950 to the 1980s, researchers and professors were focused on the problems and challenges in the industry, not on publications. The industry was destroyed after the breakup of Yugoslavia, and names of the important researchers are very difficult to find today. That is why only a few individuals can be found on scientific databases in this period. The important validations of electrochemistry schools in Bosnia and Herzegovina are former students who are successful people in the industry or academia worldwide.

Introduction

Electrochemistry is a very important branch of science and technology and examines electrochemical energy transfer. The discovery of the first battery (the voltaic pile) by Alessandro Volta in 1800 can be considered the beginning of electrochemistry. Electrochemistry is a very developed science now and has found wide application in various interdisciplinary fields of the chemistry of chemical industry, metallurgy, pharmacy, medicine, biochemistry, synthesis of new materials and nanochemistry. Modern life is unimaginable without electrochemistry, starting from batteries in our phones, laptops and electric vehicles to health-related devices. The main perspective of electrochemistry lies in the omnipresence of its application. This paper aims to give a brief historical perspective and overview of electrochemistry development in Bosnia and Herzegovina. After the civil war and the disintegration of the Socialist Federal Republic of Yugoslavia (SFRJ) in 1992, Bosnia exists as an independent state which is constituted of two entities: the Republic of Srpska and the Federation of Bosnia and Herzegovina.

Bosnia and Herzegovina today has eight universities: the University of East Sarajevo, the University of Sarajevo, the University of Banja Luka, the University of Tuzla, the University Džemal Bijedić Mostar, the University of Mostar, the University of Zenica and the University of Bihać.

Electrochemical engineering in Bosnia and Herzegovina

The tumultuous history of the area of today's state of Bosnia and Herzegovina and the many centuries spent under the Ottoman Empire left a mark on the development and culture of this country. Before Second World War, “Elektrobosna” in Jajce (1897) was the only electrochemical industry in Bosnia and Herzegovina. This company produced carbides, in addition to electrolytic caustic soda and chlorine. As the demand for carbides on the world market was declining, the production of ferrosilicon began in “Elektrobosna”. The company was devastated in the Second World War, but it was rebuilt later. More significant development of the chemical industry in today's Bosnia and Herzegovina took place after the Second World War. From the electrochemical industry at that time, the most important were “Hlor alkalni kombinat” HAK 1 and HAK 2 in Tuzla (chlorine production), “Aluminij” Mostar

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(aluminium production) and “Rudi Čajavec” in Banja Luka, which had facilities for galvanization. As part of the “Energoinvest Sarajevo combine”, there were several galvanizing plants in Bosnia and Herzegovina. Unfortunately, all these factories, except “Aluminij”, did not survive the civil war and privatization i.e. they no longer exist or went into bankrupt (in the phase of liquidation). Since “Aluminij” still exists, the brief history of this company follows. The history of “Aluminij” began in the first years of the twentieth century, with the discovery of bauxite ore deposits in Bosnia and Herzegovina and the subsequent exploitation of the resource. After the end of World War II in 1945, a new company was created, “Bauxite Mines Mostar”, to explore, exploit and transport bauxite commercially. In 1969, the “Bauxite Mines Mostar” company merged with “Energoinvest Sarajevo” to form a new organization focused on aluminium production. The Government of the Socialist Republic of Bosnia and Herzegovina tasked the group with maximizing the potential of the resources in the region and developing a new facility that would turn Mostar into a global aluminium producer. This was achieved by 1975, as an aluminium production began in the new “Alumina Factory”. The “Alumina” and “Bauxite mines” merged to form a new company in 1977, becoming “Aluminij”, and the blueprint for the company as it is known today. With government control, between 1981 and 1990, the company went through several structural and name changes, reflecting the economic and political situations of the time. In 1990, “Aluminij” was separated from “Energoinvest”, keeping its name that by this time had become a well-recognized brand with a pristine reputation. Since that separation, “Aluminij” has become the leading aluminium producer of Bosnia and Herzegovina, and a core driver of the economy, providing employment and investment that has shaped life in the Herzegovina, Bosnia and Dalmatian Region. The factory stopped working in 2019 completely. Today, it is a part of the M.T. Abraham Group [1]. The company produces inglots, billets, slabs and anodes of aluminium, but electrolysis is not working.

Today, there are no such powerful factories in the electrochemical industry. Company “ORAO” in Bijeljina is worth mentioning due to the galvanization process. The main activity of this company is the overhaul of airplane engines. There is a galvanic-chemical protection process that is an important technological link in the chain of activities in the overhaul process of turbojet engines. The investment cycle started in the middle of 2011 allowed “ORAO” to acquire a modern facility for reparation technologies in 2012 and thereby round off the overhaul and production process at the location in Bijeljina. The facility for reparation technologies, which houses a completely new galvanization facility consisting of seven independent lines [2]:

1. mechanized line of anodization and chromatization (anodization in sulphuric or chromic acid, hard anodization and chromatization of alloys based on Mg and Al),
2. mechanized zinc – cadmium line,
3. mechanized line of nickel plating (Watt’s nickel) and passivation of stainless steel,
4. mechanized hard chrome line,
5. mechanized silver – copper line (silver plating and copper plating),
6. hand line and rotor silvering,
7. mechanized phosphating and burnishing line (burnishing and phosphating – Zn-phosphate).

Besides “ORAO”, there is the company “SJJAJ” in Konjic and a couple of smaller companies for electroplating, which do not have a significant impact on the development of the economy in Bosnia and Herzegovina.

Electrochemists in Bosnia and Herzegovina

Up to the author’s knowledge, the first published experimental research in electrochemistry in Bosnia and Herzegovina was *Polarographic investigation of autoxidation of vitamin C and the problem of its stabilization* (1953) by Deželić et al. [3]. Academician, Prof. Dr. Mladen Deželić was a chemist and a very important person for science in Bosnia and Herzegovina. From the beginning of his education, he wanted to be a specialist in organic chemistry. That is why as a student, in 1920, he went to Fresenius laboratory in Wiesbaden for a 2-month-long summer course in organic chemistry. On that occasion, he attended a congress of chemists in Leipzig where he listened to lectures by prominent chemists, and Nobel prize winners in chemistry: Svante Arrhenius, Wilhelm Ostwald and Walther Nernst [4]. He specialized in physical chemistry in 1935 at the persuasion of Hans Fischer “because it is the chemistry of the future” [4]. Prof. Dr. Mladen Deželić was one of the founders of the Faculty of Philosophy and Faculty of Science at the University of Sarajevo and the Institute for Chemistry and Physics in Sarajevo.

Another great name in electrochemistry in Bosnia and Herzegovina is Prof. Dr. Tihomil Marković. Prof. Marković was associate professor, dean of the Faculty of Technology, and first rector of the University of Tuzla. Also, he was a UNESCO expert and visiting professor at the IPN University in Mexico. He founded The Department of Physical Chemistry and Electrochemistry at the Faculty of Technology in the academic year 1961/62. Prof. Marković’s scientific field was corrosion and thermodynamics of metal – solution systems. Some of the papers published in 1954 in Materials and corrosion journal are *The Dissolution of Various Metals when in Contact with Rotating Platinum Electrodes* [5], *The Influence of the condition of the Surface of Iron*

upon the Rapidity of Corrosion when buried in Soil [6] and The Decomposition of Hydrogen, Peroxide on Metallic Copper [7]. Besides the research papers, he published several books and chapters in German and English languages. Prof. Marković founded the first postgraduate study program in Bosnia and Herzegovina in 1964 in the field of Theoretical and Applied Electrochemistry. In 1966, the scientific field of Physical Chemistry and Electrochemistry had its first master's degrees from the first generation of enrolled students. Several doctoral dissertations were then completed under the supervision of Prof. Marković. His doctoral students Mahmud Ahmedbašić, Nusreta Đonlagić, Zlata Pavlović and Ranko Babić later spent their entire working life working in the narrower scientific field of physical chemistry and electrochemistry. The most cited paper written by N. Đonlagić is *Distribution and chemical speciation of arsenic and heavy metals in highly contaminated waters used for health care purposes (Srebrenica, Bosnia and Herzegovina)* published in Science of the Total Environment journal [8].

In the 1960s, the professors Tibor Škerlak and Vladimir Milićević must be mentioned. They were physicochemists, but they had a significant research focus on electrochemistry. Prof. Dr. Tibor Škerlak is one of the founders of the Department of Physical Chemistry at the Faculty of Science at the University of Sarajevo, and Vladimir Čiko Milićević was one of the most famous professors from this Faculty. The most cited paper written by T. Škerlak is *Concentration profile of copper in a solid-supported copper-transporting liquid membrane* in Journal of Physical Chemistry [9] and paper *Amperometric sensor for L-ascorbic acid determination based on MnO₂ bulk modified screen printed electrode* in Fresenius' Journal of Analytical Chemistry [10] is the most cited paper written by V. Milićević. Prof. Dr. Branko Škundrić started his carrier in the Department of Physical Chemistry at the Faculty of Natural Science at the University of Sarajevo. He is member of Academy of Sciences and Arts of the Republic of Srpska and full professor of Physical Chemistry at the University of Banja Luka in retirement. He has published six books and several scientific papers and presented reports at numerous scientific meetings. The most cited paper, according to Scopus, is *Stability of tris-1, 10-phenanthroline iron(II) complex in different composites* published in Chemical Industry and Chemical Engineering Quarterly journal [11]. Prof. Dr. Merzuk Cacan and Dr. Vjeročka Šišlov had publications in electrochemistry, mainly related to corrosion and galvanization, for example, *Investigation of pitting corrosion on orthopedic implant in physiological solutions* by Cacan [12].

Bosnia and Herzegovina has a worldwide known scientist – Professor Ibro Tabaković. Ibro Tabaković was born on 31 August 1942 in Banja Luka. In 1967, he was hired at the JNA College of Technology in Zagreb as a tenured teaching assistant and, in 1973, as an assistant professor. In 1974, he

attended postdoctoral studies at the University of Southampton, and in late 1975, he was in specialization at the University of Aarhus. He was elected as an assistant professor, associate professor and full professor at the Faculty of Technology at the University of Banja Luka (scientific fields: organic electrochemistry, organic synthesis and biochemistry). He was an internationally renowned chemist, having given numerous lectures upon the invitation of prestigious universities across the world, such as the University of California, the University of Copenhagen, University of Minnesota as well as other universities in France, England and Germany. He held 85 presentations at scientific congresses in Yugoslavia and around 100 at international conferences, including seven plenary lectures. He was also the chairman of the Presidency of the Union of Universities of Bosnia and Herzegovina and a member of the binational American and Yugoslav committee (the Fulbright program). He published 92 original scientific papers, seven reviews, three books and three chapters in scientific monographs. The greatness and significance of professor Tabaković's scientific contribution are also supported by a very high citation frequency, even including papers from the 1970s (1671 citations). From 1977 to 1979, he served as a vice-rector of the University. He was elected as rector of the University at the age of 37, becoming the youngest rector in the history of the University, a record which he still holds. From 1986 to 1989, he served as Minister in the Yugoslav Government. In the Government, Prof. Tabaković carried out activities on the development of economic, political and scientific cooperation with non-aligned countries. He was appointed as chairman of the Steering Board of the Solidarity Fund of the SFRY for Developing Non-Aligned Countries. He left for the USA in 1993, where he started the life from zero. He worked incredibly hard to start over the work in the field where he belongs – in science. In late 1997, he completely changed his career and went to work as an engineer at Seagate Technology in research and development for disc-drive writer materials, which are most efficiently produced via electrodeposition. In the following 16 years, Prof. Tabaković was promoted five times for his scientific contribution. Before long, he became Seagate's chief Technologist and Research Leader in electrodeposition. He entered the Seagate Technology Hall of Fame in 2012. He authored 40 US patents and 34 Seagate's trade secrets. Two products – writer materials, specifically 1.8 T CoFeNi and 2.4 T CoFe, developed by Prof. Tabaković's group was installed in over 2.2 billion computers sold in the world. In 2013, professor Tabaković was again hired as a professor at the University of Minnesota (Department of Electrical and Computer Engineering) from where he retired on 1 January 2019 [13]. Prof. Tabaković's most cited paper is *Composition, structure, stress, and coercivity of electrodeposited soft magnetic CoNiFe films: thickness and substrate dependence* published in the Journal of The Electrochemical Society [14].

The chemical industry was very developed in Bosnia and Herzegovina at that time (in the period from 1950 to the 1980s); therefore, researchers were almost completely focused on the problems in the industry and the development of new processes, so very few things were published in scientific journals. Thus, there were undoubtedly more electrochemists in that period, but their names are now very difficult to find.

In the 1990s, the Faculty of Technology in Zvornik was founded (1992). Dr. Miomir Pavlović became a professor of Electrochemistry and Corrosion in 1997. Prof. Dr. Pavlović defended his doctoral dissertation in the Faculty of Technology and Metallurgy in Belgrade in 1982. He was a researcher in the ICTM-Department of electrochemistry in Belgrade before starting his career as a professor at the Faculty of Technology Zvornik. Prof. Pavlović has been actually one of successors of the famous Belgrade school of electrochemistry. He connected the two schools of electrochemistry (Belgrade and Zvornik) and that connection has still been preserved today through collaboration and projects. Prof. Dr. Miomir Pavlović's research fields are electrochemical deposition and dissolution of metals and alloys, corrosion and material protection, electrochemical deposition of metal powders and electrochemical engineering. Validation of his enormous contribution to electrochemistry is 1958 citations and h/index 34. Prof. Pavlović is the most cited electrochemist in Bosnia and Herzegovina. He published 6 monographs of international importance; more than 250 scientific publications in the field of electrochemistry and electrochemical engineering; over 107 scientific papers, poster presentations, or short talks at electrochemistry meetings. Prof. Pavlović's monographs are published in *Modern Aspects of Electrochemistry*, *Electrochemistry Encyclopedia* and *Electroanalytical Chemistry-Research Developments*. He has over 40 technical reports. Prof. Pavlović's innovative work has been awarded several times i.e. 2002 Reward from the Serbian Chamber of Commerce for the best invention: *Electrochemical deposition of copper powders of controlled characteristics using reversal current*; in 2007, Reward from the Serbian Chamber of Commerce for the best invention: *Device for microbiological disinfection of water – Eco Aqua Cleaner*; in 2011 and 2012 Rewards of the Ministry of Education and Science of the Republic of Serbia (II place) in the category of Realized inventions for the following works: *New technology for the synthesis of the new materials based on cellulose and lignin* and *Device for the microbiological disinfection of water by electrochemical means*. He was the coordinator of more than 10 international projects and numerous national research projects. Prof. Dr. Miomir Pavlović was head of the Department of Physical Chemistry, Electrochemical Engineering and Materials at the Faculty of Technology Zvornik, University of East Sarajevo until his retirement in 2021. His most cited article is *The effect of hydrogen codeposition on*

the morphology of copper electrodeposits. I. The concept of effective overpotential, published in the Journal of Electroanalytical Chemistry [15]. Besides Prof. Dr. Pavlović, a significant contribution to the development of electrochemistry in Bosnia and Herzegovina gave Prof. Dr. Dušan Stanojević and Prof. Dr. Dragan Tošković. Prof. Dr. Dušan Stanojević finished his doctoral studies at the Faculty of Technology and Metallurgy in Belgrade, and his research fields are electrodeposition and electroanalytical chemistry and analysis (selected article: *Extraction of useful metals from lead-silver cake in the process of hydrometallurgical zinc production by leaching in calcium-chloride solution* in Bulletin of Electrochemistry Journal [16]). Prof. Dr. Dragan Tošković finished his doctoral studies at the Faculty of Technology, the University of Tuzla in 1992. He is a full professor and head of the Department of Physical Chemistry, Electrochemical Engineering and Materials at the Faculty of Technology Zvornik, University of East Sarajevo. His teaching subject is Physical Chemistry, but he has a significant research focus on electrochemistry (selected article: *Study of corrosion resistance of chromium-nickel steel in calcium – hypochlorite solution part 1. Steels uranus b6* Journal of Mining and Metallurgy [17]). Prof. Dr. Dragan Tošković research fields are electrochemical deposition, metal dissolution, corrosion and water treatment. He published 3 books. Prof. Tošković coordinated several research projects and gave numerous technical reports for the industry. Also, at this time, Prof. Dr. Jovo Mandić from the University of Banja Luka was doing research in the field of electrochemical engineering (selected article: *Impact of electrode material on the anodic oxidation of cyanide wastewater* Gazette of Chemists, Technologists and Environmentalists of Republic of Srpska [18]).

There is a generation of electrochemists that gave their scientific contribution to electrochemistry in the 2000s, and some of them will be mentioned below. Prof. Dr. Milorad Tomić, full professor of the Faculty of Technology, University of East Sarajevo is doing research in the field of electrodeposition of alloys and composites, electrodeposition of metal powders, catalysis, corrosion and electrochemical engineering. Prof. Tomić has published 21 scientific publications in the field of electrochemistry and electrochemical engineering and 170 scientific papers, poster presentations or short talks on electrochemistry meetings. The most cited article written by Tomić is *Morphology and growth of electrodeposited silver powder particles* published in Hydrometallurgy [19]. Also, Prof. Tomić coordinated several international projects and 10 national projects. Prof. Dr. Borislav Malinović, the dean of the Faculty of Technology, University of Banja Luka is doing research in the field of electrochemical engineering (wastewater treatment) (*Electrochemical removal of nitrate from wastewater using copper cathode* in Journal of Environmental Protection and Ecology [20]). Prof. Dr. Dijana Jelić, Faculty of Natural Sciences

and Mathematics, the University of Banja Luka and Prof. Dr. Amra Odošić, Prof. Dr. Amra Bratovčić, and Prof. Dr. Indira Šestan, University of Tuzla, are doing research in electroanalytical chemistry and catalysis. Selected articles are: Jelić *A kinetic study of copper (II) oxide powder reduction with hydrogen, based on thermogravimetry*, *Thermochimica Acta* [21]; Odošić *The advantages of the use of ion-selective potentiometry in relation to UV/VIS spectroscopy*, *Agriculturae Conspectus Scientificus* [22]; Bratovčić *Photocatalytic properties of sodium decatungstate supported on sol–gel silica in the oxidation of glycerol*, *Catalysis Today* [23]; Šestan *The effect of heat treatment on the physical–chemical properties of milk*, *Academia Journal of Environmental Science* [24]. Prof. Dr. Zora Pilić (selected article *A comparative study on the electrochemical behaviour of aluminium and 8090 Al–Li–Cu–Mg alloy in acid rain solution*, *International Journal of Electrochemical Science* [25]) and Prof. Dr. Ivana Martinović, University of Mostar (selected article *Electrochemical behaviour of stainless steel in acidic fluoride media*, *International Journal of Materials Research* [26]), Prof. Dr. Farzet Bikić, University of Zenica (selected article *Investigation of possibility for reducing AISI 303 stainless steel pitting corrosion by microalloying with boron or zirconium*, *Bulletin of the Chemists and Technologists of Bosnia and Herzegovina* [27]), Prof. Dr. Sead Čatić (selected article *Studying of corrosion behaviour of 316 l steel as a metallic biomaterial in the infusion solution*, *Technologica Acta* [28]), University of Tuzla are doing research in the field of corrosion.

Prof. Dr. Sanjin Gutić, Faculty of Science, University of Sarajevo published more than 14 scientific publications in the field of electrocatalysis, energy storage and conversion, and electrodeposition of polymers (193 citations). In 2014, Prof. Gutić started a project with the industry in which four cathode materials for a lithium-ion battery prototype were made. Currently, he is working on catalysts for hydrogen evolution. Also, he is part of several international projects and coordinated numerous national research projects. The most cited publication written by S. Gutić is *Improved catalysts for hydrogen evolution reaction in alkaline solutions through the electrochemical formation of nickel-reduced graphene oxide interface*, *Physical Chemistry Chemical Physics* [29].

The best validation of Bosnia and Herzegovina's school of electrochemistry is the students who are employed worldwide at leading positions in the electrochemical industry, and those who have successfully completed their doctoral studies abroad, like Blaženka Sušić (GABRIJEL Aluminium, Slovenia), Nađa Nalić (DV Power with headquarters Sweden), Saša Pljuco (EVA Fahrzeugtechnik GmbH, Germany), Dževad Kozlica (Jožef Stefan Institute, Slovenia), Dino Metarpi and Armin Hrnjić (National Institute of Chemistry, Slovenia).

Conclusions

After a brief historical perspective and overview of development in electrochemistry in Bosnia and Herzegovina, it can be concluded that it is evaluated from basic research and techniques, like polarography to electrochemical studies of catalysts, fuel cells for fossil fuel-free world and nanotechnology. Since the 1950s, dozens of researchers worked and are still working in the fields related to electrochemistry. The overall conclusion is that Bosnia and Herzegovina has people in electrochemical science, but they still have insufficient funds to realise their ideas. Investments in science in Bosnia and Herzegovina must be increased; otherwise new generations of electrochemists will never be internationally recognized in the world of industry and science, as we once were.

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