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Belgrade School of Electrochemistry*

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Abstract: Belgrade School of Electrochemistry is not made of institutions, building, not even the community. It is made of people and their knowledge, achievements and results. It has no date of establishment nor defined start, and we hope it also won't have an end. It was created as a result of several decades of scientists' efforts to accumulate knowledge and pass it on to future generations, to contribute with their research and results, to conquer new knowledge and advance the society as a whole. Its initiators and founders were not aware that they are starting something that will become recognised on a global level in the field of electrochemical science, they even didn't want that — they were simply devoted to their science and they tried to pass that devotion on to the future generations. The name Belgrade School of Electrochemistry appeared in the global electrochemical community even before we ourselves became aware of it, as a term which, first of all, defines one of the most important centres of electrochemical science in the world, and most definitely, the largest and the most developed in this part of Europe. It equally relates to the system of education and the importance and influence of the results and achieved knowledge of the scientists who originated from the Belgrade University on the world of electrochemistry.

Keywords: Tutundžić; Despić; Dražić; TMF; FFH; IHTM.

FROM THE FIRST EXPERIMENTS TO THE IMPORTANT PLACE ON THE ELECTROCHEMICAL MAP OF THE WORLD

Forerunner of the Belgrade School of Electrochemistry was academician Sima Lozanić (1847–1935), professor and the first Dean of the Belgrade University, one of the founders and the chairman of the Serbian Chemical Society. He performed scientific and professional work in almost all areas of chemistry, and his research in the field of electrosynthesis under the influence of silent

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electrical discharge holds a permanent value. Ložanić subjected various classes of compounds to electrosynthesis, thus obtaining a large number of new complex organic products. Even though those were not electrochemical experiments, they were the first in which reactions under the influence of electricity were studied, and they were published in late 19th century.

Documented beginning of electrochemical education in Serbia happened in 1903, when Dr Miloje Stojiljković, Geneva student, founded one of the oldest Departments of Physical Chemistry in Europe, at the Belgrade Grand School. He was also the first teacher of physical chemistry and his curriculum also included *Chemical statistic with electrochemistry*. Soon after the Grand School evolved into a University in 1905, at the newly formed Faculty of Philosophy, Institute of Physical Chemistry was established in 1908, and professor Stojiljković was its Head until 1948. Between two wars, the number of students that took physical chemistry as their main subject was small, even when in 1924, Department of History and Philology and Department of Natural and Mathematical Sciences were established at the Faculty of Philosophy. Those few students included Pavle Savić (1909–1993) and Slobodan Ristić (1912–1994), later professors of Physical Chemistry, who, each in his own way, left a strong mark on its development. After the Second World War, in 1947, Faculty of Philosophy was separated into Faculty of Philosophy and Faculty of Natural and Mathematical Sciences (PMF), which included Department of Physical Chemistry and Institute for Physical Chemistry, headed by Pavle Savić, after the retirement of professor Stojiljković in 1948.

On the other hand, in 1920, when professor Nikola Pušin (1875–1947) was elected honorary teacher of electrochemistry and electrometallurgy at the Department of Machine Engineering of the Technical Faculty, narrow professional electrochemical education appeared in Serbia for the first time. However, since he transferred to Zagreb in 1921, unsatisfied with the conditions for research work, there is no confirmation that that kind of classes ever took place. Still, in 1923, when Department of Technology was established, in the addition to the two existing departments at the Department of Machine and Electrical Engineering, electrochemistry appeared in the curriculum with 3+0 classes per week, but up until 1925, when Department of Technology evolved into a separate department, the classes did not take place. Then, with the election of young Panta Tutundžić as assistant professor, the classes for subjects Physical Chemistry with Thermodynamics (4+0, 5th semester) and Physical Chemistry with Electrochemistry (4+0, 6th semester) began. Already the following year, he managed to organise a Laboratory for Physical Chemistry and Electrochemistry within the Institute for Chemistry and Technology, and less than two years later, with the help of his younger colleagues M. Pajović and S. Rašajski (both of which later became professors at the Faculty of Technology), he introduced basic practical classes and began scientific work. When Faculty of Technology got a new building in 1930,

at the Kralja Aleksandra Boulevard, the Laboratory evolved into an Institute and Nikola Pušin, who was elected full professor after his return to Belgrade a year before, became its Head. This new, well-equipped space offered great conditions for practical classes for up to 25 students, as well as scientific work by professors and assistants. Professor Pušin found excellent collaborators in assistant professor Tutundžić and a few other young assistants, and together with them, until the outbreak of the Second World War, he improved the education, wrote the first textbooks in Serbian in the fields of physical chemistry and electrochemistry and successfully performed scientific work, first of all, in the areas of non-aqueous solutions, alloys and diagrams of multicomponent system state.

After the Second World War, in new social circumstances and after the University began operating again, in 1948, Technical Faculty separated from the Belgrade University and became an independent Technical Grand School, while its Department of Technology became one of its faculties with two departments – Department of Technology and Department of Metallurgy. However, already in 1954, the School was cancelled and all its faculties, including the Faculty of Technology, once again became a part of the Belgrade University. Since 1966, the Faculty has been carrying its current name – Faculty of Technology and Metallurgy, TMF.

Panta Tutundžić, the true initiator of what was to become the Belgrade School of Electrochemistry in the 1970s, was elected the first Dean of the Faculty of Technology. He was the founder and the first Head of the Department of Physical Chemistry and Electrochemistry of the Faculty of Technology. Apart from his great contribution to science in the field of analytical chemistry and electroanalytics, he also established at the time unique curriculum for electrochemical education within the undergraduate studies, which today makes the Faculty of Technology and Metallurgy one of the rare institutions of high education in the world that has such a comprehensive and high-quality education in undergraduate studies. He also shared his knowledge and experiences with the students at the Faculty of Natural and Mathematical Sciences, where, from 1952 to 1957, he was an honorary full professor of electrochemistry for the subject Physical Chemistry, and since 1957, holding the same title, at the Faculty of Electrical Engineering.

His contribution to the development of scientific and research activities can also be seen in the management and establishment of several important institutions. In 1952, he became the Head of the Institute of Chemistry at the Serbian Academy of Sciences and Arts, which evolved four years earlier from the State Chemical Laboratory. He remained at the head of that Institute after it transformed into the Institute of Chemistry of the National Republic of Serbia in 1954. By reorganisation in 1961, it became the Institute for Chemical and Technical Research, nowadays, Institute of Chemistry, Technology and Metallurgy – IHTM, within which Panta Tutundžić established a Department, later an Institute,

and today the Centre for Electrochemistry – CEH, which he managed as its Head until his death in 1964. Since the seat of IHTM was at the building of the first State Chemical Laboratory (established in 1859), built in 1882, most of the associates of the Department of Electrochemistry had their laboratories in the newly constructed building of the Faculty of Technology (1960, primarily thanks to the efforts of Panta Tutundžić), which enabled almost all of the research to be executed by joint teams from the Faculty and the Department, the practice which has continued until today. Part of the researchers from the Department of Electrochemistry, headed by Petar Rakin and Lazar Vorkapić, established a new Institute for Chemical Power Sources – IHIS, in 1971. After a series of transformations, first into a company, then a holding, in 2005 IHIS was reorganised and became IHIS Scientific-Technology Park Zemun, whose central unit is still IHIS Techno Experts, a development-research centre in the field of chemical power sources and development of new electrode materials.

Over the years, new research and education institutions have developed in Serbia, as a consequence of the strong development of science, and some of them also developed strong centres of electrochemistry. That is how, within the Serbian Academy of Sciences and Arts, Institute for Technical Sciences was established in 1969 and within it, in 1973, a Bureau for Autonomous Electrical Vehicles, headed by Aleksandar Despić. Later, that Bureau was transformed into today's Centre for New Materials and Nanotechnologies. Associates of the Bureau and the Centre also have their laboratories in the building of the Faculty of Technology and Metallurgy, and ever since then, they have been participating in the joint research and projects with the researchers from TMF and CEH.

Aware of the fact that development of modern science requires narrow professional education, in 1970, University of Belgrade established the first graduate school in Central and Eastern Europe – Centre for Multidisciplinary Studies. Through a series of flexible educational programs, encouragement and development of multidisciplinary research, for the past 50 years, the Centre has been offering unique possibilities, first of all, to young scientists. Development of this kind of education at the faculties has made the educational role of the Centre redundant, so in 2007, it was reorganised into a scientific research institution called Institute for Multidisciplinary Research (IMSI). From the very beginning, perhaps the most important area of education and research at the Centre has been conversion and storage of energy. A great number of researchers who deal with this issue around the world have gained their basic knowledge in this school. Lecturers at the Centre are the most distinguished scientists and professors from various faculties, so majority of students did their master and doctoral dissertations, many of them their further research as well, at those faculties, most often as part of the previously mentioned teams at the laboratories at the Faculty of Technology and Metallurgy.

In 1957, Milenko Šušić, one of Panta Tutundžić's students at the Department of Physical Chemistry at PMF, already recognised for his papers on polarographic determination of uranium, became the first elected lecturer for the subject of Electrochemistry at the Department, which he took over from his teacher, developed it and managed until he retired in 1990. That was, practically speaking, the start of the second centre of the Belgrade School of Electrochemistry, which originated from the same source. After Pavle Savić retired in 1966, professor Šušić became the Head of the Department and Head of the Institute for Physical Chemistry. Over the years, PMF has gone through a series of reorganisations – departments, institutes, new departments, new subjects have been established, postgraduate studies have been organised, and in 1990, it was separated into six independent faculties, which included today's Faculty of Physical Chemistry.

Due to a confluence of circumstances, partly because of the spatial separation and partly due to occasional disagreements between the two centres of the Belgrade School of Electrochemistry at FFH and TMF, their cooperation has been far smaller than it should and could have been. Still, it never ceased, it only occasionally changed intensity and form, and it was more often personal than institutional. This is also testified by fact that Belgrade School of Chemistry has been recognised in the world as a unique centre, a unique source of excellent scientists and great ideas and achievements. This will also be demonstrated by the following lines that mention the most important areas of its activities, its most significant achievements and the most distinguished names.

Out of the enormous number of students and associates, two of Panta Tutundžić's pupils, later professors at the Faculty of Technology and Metallurgy, Aleksandar Despić and Dragutin Dražić, together with a handful of their colleagues, also Panta Tutundžić's students, were the carriers and it can be said, the true founders of the Belgrade School of Electrochemistry since the early 1960s. Their research and knowledge, largely acquired during several short- and long-term visits to numerous universities in Europe and USA, as well as through cooperation with great electrochemists of their time, such as John O'Mara Bockris, Graham Hills, Alexander Frumkin, Kurt Schwabe, Jakov Kolotirkin, Roger Parsons, Lev Krishtalik, Evgeni Budevski, Brayan Conway, Sergio Trasatti, Erika Kalman, *etc.*, as well as their desire to pass on the acquired knowledge and experience to new generations of their students and young associates, enabled Belgrade to become an important place on the electrochemical map of the world. Up until the early 1990s, electrochemical science in Belgrade had been developing quickly and the number of researchers continued to grow, while the results of those research were among the most significant findings in the electrochemistry of that time. That was possible thanks to excellent equipment (in mid-1980s, Belgrade electrochemical laboratories were among the best-equipped in the world), continuous contacts and cooperation with electrochemists all around the world,

stable and secure funding of research and participation in international electrochemical conventions, as well as researchers' great dedication. There were only a few important names in the world electrochemistry that didn't visit Belgrade and that passed on the opportunity to exchange their experiences with professors Despić and Dražić and their associates.

The intensive development of electrochemistry in Belgrade resulted in the establishment of Electrochemical Division at the Serbian Chemical Society in 1968. Since its foundation, it has been one of the most active and the most organised section of the Society. Bearing in mind that in the 1960s, centres of electrochemistry also developed in other university centres in Yugoslavia, albeit not as great nor strong, the Section was the initiator of establishing Yugoslav Symposium on Electrochemistry. The first was held in Belgrade in 1968, and then, in the following years, the symposiums became a place for presentation of the latest results, discussions and making agreements on joint research and initiatives. The symposiums' guests and plenary lecturers were many of the previously mentioned names from the global electrochemical community and the Symposium held an important place in the annual calendar of electrochemical events for many years. Members of the Belgrade School of Electrochemistry were almost regularly the most numerous participants with the greatest number of presentations. Most of the symposia were held in Dubrovnik, but also at Ohrid Lake, in Bečići and Rovinj, while the last one (the twelfth in total), which gathered all the electrochemists in the former state, was held in June 1991 at Igman. After the break-up of Yugoslavia, the tradition of these gatherings under the same name, was continued by electrochemists from the Federal Republic of Yugoslavia, in an unproportionally smaller scope by both the number of participants and the quality, and the last one was held in June 2003 under the name of 14th Symposium of Electrochemistry of Serbia and Montenegro, with only about 20 participants.

A little later, as a result of the same trends, in 1989, Serbian Society of Physical Chemists – DFS, was established, which, since the inception, dedicated a large part of its activities to electrochemistry, which in 2000 led to the formation of Section for Electrochemistry. According to the themes that the members of the Section were most interested in, since 2014, as a satellite event of its international conference *Fundamental and Applied Aspects of Physical Chemistry*, DFS has been organising *Meeting on Materials Science for Energy Related Applications*, an increasingly respected international conference that gathers mostly electrochemists, largely from the region. In 2020, the 15th Conference will be followed by the fourth meeting on materials in the field of energy.

Since electrochemistry at the Department for Physical Chemistry of the Faculty of Natural and Mathematical Sciences has been studied as part of numerous complicated subjects, such as mathematics, physics, chemical thermodynamics, atomistics, chemical kinetics, atomic and molecular spectral chemistry, the

emphasis was on its fundamental side in correlation with the previously mentioned complementary subjects – study of transport of ions in electrolytes, theory of double electrical layer formation, thermodynamic aspect of electromotive force and kinetic aspect of reaction at the metal/electrolyte interface. The issue at first was inadequate and modest equipment. It wasn't until 1970s that the procurement of at the time modern electrochemical instrumentation began, which was supplemented by even more modern one in 1987. But despite that, thanks to the favourable surroundings for fundamental research, the researchers from PMF have managed to keep up with the modern trends in the development of electrochemistry. That is how in the 1970s, they began studying salt dissolution with its importance for production of alkaline and hard-to-melt strategically important metals. A few years later, they introduced study of solid electrolytes, in relation to at the time topical discovery of superionic conductors based on highly movable ions through a solid phase, and long-term lithium batteries for pacemakers that were based on them. At the time of commercialisation of metal-hydride batteries, in the 1980s, they also began research of thermodynamics and kinetics of metal and alloy hydration, and at the start of the new millennium, also the study of conductivity of aprotic electrolyte solutions and kinetics of intercalation reactions, in relation to at the time topical commercialisation of Li-ion batteries with organic electrolyte solvents. Later, the same research has expanded to other ions, besides lithium, of alkaline and non-alkaline earth elements, not just in aprotic but in aqueous solutions as well. In parallel, catalytically active materials for reactions of oxygen and hydrogen electrode in aqueous solutions were also studied, because of the possibility for the hydrogen-air energetics to compete with the fossil fuels in the field of transportation. A special contribution has been achieved in the development of carbonised polyanilines of doped heteroatoms, of high electrocatalytic activity and high capacity of double electrochemical layer. In the last ten years, research into phenomena on the metal/electrolyte Interface have also been performed using theoretical DFT method.

Although they were mostly oriented towards fundamental research, several practical solutions have originated from the Faculty of Physical Chemistry, such as improvement of technology for production of tantalum capacitors or technology of alkaline iodate synthesis for anti-hail reagents, as well as a series of registered patents that are still awaiting practical application.

Unfortunately, unfortunate events in the 1990s and the lack of conditions for good-quality scientific research have slowed down the development of electrochemistry in Belgrade, but not the Belgrade School of Electrochemistry. Taking refuge from the unfortunes in their own country, in search of better conditions for research and safer existence, great number of professors Despić, Dražić and Šušić's students left the country in the late 1980s and 1990s, and after that as well, and with them carried their knowledge and achievements acquired in Bel-

grade. We will mention only some of the most successful and famous among them: Radoslav Adžić, Nenad Marković, Radoslav Atanasoski, Nikola Anastasi-jević, Vojislav Stamenković, Stanko Branković, Nebojša Marinković, Aleksan-dar Žerađanin, Tanja Vidaković Koch, Srećko Stopić *etc.* None of them, when speaking to the electrochemical public, fails to mention that their successful sci-entific career and achieved results are largely based on what they have learned and accomplished in Belgrade. The size of the Belgrade School of Electrochem-istry can also be seen in the fact that after over a decade of stagnation, modest presence in the main streams of newly launched research, shortages, outdated equipment, at the start of the new millennium, it began producing a new gener-ation of successful scientists.

Although the name Belgrade School of Electrochemistry is not as recognis-able anymore, the heirs to the founders are returning its good reputation in the world, intensively continue research in the traditional areas, but also conquer new ones, restore the old and make new contacts and cooperate with their colleagues in the world. An indicator of those efforts is the establishment of Regional Symposium on Electrochemistry, which was created on the tradition of former Yugoslav Symposiums on Electrochemistry. Upon the initiative of a group of electrochemists from Belgrade, with the support of their colleagues from Croatia, the first Regional Symposium on Electrochemistry of South-East Europe, was organised in 2008 in Rovinj, Croatia. So far, there have been seven symposiums (apart from Croatia, in Serbia, Romania, Slovenia, Bulgaria and Hungary), each time with around 200 participants, and the next, eight, will be held in 2021 in Austria. The best confirmation to the electrochemists in Belgrade that they are on the right track is the fact that they were chosen to be the hosts of the 71st Annual Meeting of the International Society of Electrochemistry, from August 30 to September 4, 2020, the largest global gathering in this field. Using that great scientific event and with the aim of promoting electrochemical science, motiv-ating the young and also getting the wider community to get acquainted with this science and its achievements, 13 scientific institutions and societies have dec-lared this year, 2020, the Year of Electrochemistry in Serbia. The celebration shall include numerous activities: 3 cycles of public lectures, several workshops for pupils and students, promotion of electrochemistry in several scientific con-ventions, as well as this exhibition as a comprehensive introduction to electro-chemistry through the establishment, development and activities of the Belgrade School of Electrochemistry.

FROM IODOMETRY TO LITHIUM-ION BATTERIES

From development and improvement of electroanalytical methods, first of all, coulometry, iodometry, metallometry, permanganometry, bichromatometry, indirect coulometric titration of multicomponent system, *etc.*, which were the

focus of Panta Tutundžić's work, the Belgrade electrochemists' area of research has expanded over time. In late 1950s (1957–1959), during his stay with John Bockris, Aleksandar Despić began working on the problems of kinetics of electrode processes, and that subject, especially the issues of electrochemical deposition and dissolution of metal, remained one of the most important areas that Belgrade School of Electrochemistry has been known for. After Despić, Dragutin Dražić also spent two years (1959–1961) with professor Bockris, where he also had the opportunity to meet and collaborate with the most distinguished electrochemists of that time, including also Alexander Frumkin. Collaboration and contacts that were then established by Despić and Dražić have continued for decades, until today, and it is quite likely that it was them that enabled electrochemistry in Belgrade to rise up to planetary recognisable Belgrade School of Electrochemistry. Mechanism of deposition and dissolution of iron, which was established in 1961 in a joint research by Bockris, Despić and Dražić, today known after the initials of its authors as BDD mechanism,¹ was the first great result that announced the creation of Belgrade School of Electrochemistry. Over the past 60 years, dozens of researchers worked and are still working on the study of electrochemical deposition and dissolution of metals, alloys and composite (multi-layered) materials, deposition of metal and alloy powder, and various catalysers for industrial electrolysis, including research of mechanisms of various forms of corrosion and development of corrosion protection. Among the numerous achievements in this area, we will mention a few.

At the time when computers were still taking up entire rooms, a program has been created that made it possible to generate all possible ways in which a certain (electro)chemical reaction can take place. It turned out that in some reactions, for example in oxygen reduction, the number of possible pathways is enormous and that there can be countless others, which researchers at the time couldn't even dream of.

For decades, a large group of researchers from the Belgrade School of Electrochemistry has been working on problems of metal electrocrystallisation, *i.e.*, morphology of metal deposits that stem from it. The phenomenon of dendric growth has been especially researched and the result was a theory that shows that it is conditioned by the relationship between activation and transport control of the ion discharge process. A contribution was also given to the knowledge about the process of metal grain nucleation on an unrelated surface, while the existence of exclusion zone around the already formed nucleus where no new nucleation may occur has been experimentally proven, as well as the existence of nucleation rings that spread around the growing crystal.

As a result of the research on electrochemical qualities of various alloys and techniques for obtaining them by cathode deposition, an excellent method for determination of phase composition of alloys has also been discovered, which is

simpler and faster than all the others that were previously known. The method in question is the method of anodic linear sweep voltammetry (ALSV), whose answers are like fingerprints, characteristic for each alloy, and which also give qualitative and quantitative data on the phases of the alloy.

Based on these fundamental research, numerous procedures have been developed and practically applied, facilities have been constructed and patents were registered and realised.

Equally important and for the Belgrade School of Electrochemistry recognisable is the area of electrocatalysis, study and development of new electrocatalytic materials for various purposes. Although electrocatalysis has been studied in Belgrade since the 1950s, in early 1980s, with the discovery of selectivity of the noble metal monocrystal catalytic activity in the function of crystallographic orientation, intensive research into the application of noble metals, various alloys and carbon based composites, as catalysts for low-temperature fuel cells, superconductors, lithium-ion batteries, as well as numerous other processes, began. The focus of this research were the processes of cathodic reduction of hydrogen ions and oxygen, as well as oxidation of organic molecules that represent potential fuels in galvanic fuel cells. A special contribution has been given by the study of catalytic activity of well-defined crystal planes. A technique has been developed for cutting of platinum and gold monocrystals so that on their different surface, both low-index and high-index planes, are exposed to the solution, which represents various relations of flat surfaces and steps. Significant differences in catalytic activity of such surfaces on electrochemical reactions have been demonstrated. Special attention was given to understanding of surface processes on the metal-solution interface. Using various *ex situ* (AES, LEED, UPS, XPS) and *in situ* (SXS, STM/AFM) surface sensitive techniques in combination with vibrational spectroscopy (FTIR, ATR) and classic electrochemical methods, relations have been established between the microscopic atomic (electron) structure of monocrystal surfaces and the macroscopic kinetic rate of electrochemical and/or chemical reactions. This led to understanding of the activity of metal nanoparticles in energy conversion and storage systems, by establishing relations between the reaction rate, selectivity and stability and characteristic dimensions of metal catalysts. When in early 1990s, a large part of the team left for USA, centre of this research moved across the ocean, but even then, in increasingly more modest conditions, this research has continued in Belgrade, with continuous and interchangeably intense and modest cooperation with the colleagues in the USA. Still today, there is a significant group of researchers in Belgrade who are dedicated to these topics and a new generation of scientists has come of age which is on its way to return the good reputation that Belgrade once had in this field.

Perhaps one of the most original practical results of the Belgrade School of Electrochemistry is creation of a primary chemical source of electricity or an

electric accumulator with mechanical loading, using aluminium-air system with neutral aqueous solution of sodium-chloride as electrolyte. Under the management of professor Despić, for the first time in the world, high energy potential of a low-alloy electroactive aluminium was used in combination with oxygen from air as oxidant and a solution of table salt as a source of electric energy of high specific capacity. That is how they have created **Metal Candle**, ecologically impeccable chemical electricity source, because the products of its potential disintegration are aluminium oxide and saline water. All it takes is a glass of water and a little bit of table salt to get a lot of hours of good lighting whenever it is necessary. The first prototype was made and patented in the early 1980s, but the problems with collector corrosion and hydrophobicity of the air electrode on the side of air, as well as generation of aluminium hydroxide gel, prevented its commercialisation. Although the research on overcoming its shortcomings lasted for years and by the end of the last millennium, a comprehensive project for establishment of the procedure for commercial production was produced, an acceptable solution was never reached. The project was never realised for numerous reasons, but the fact that metal/air batteries are a good potential source of energy is also being demonstrated by numerous current studies and belief that they are one of the candidates for powering electrical vehicles.

One of the more important achievements in the practical application of knowledge and results of the basic research is the field of chlorin-alkaline electrolysis. In early 1970s, a group of researchers began studying development of catalytic coatings based on noble metals, first of all ruthenium, on titanium, as electrodes in the production of chlorine and chlorates. The result of these studies was the development of construction and reparation procedure for this type of anodes, which have been supplied for almost two decades to all facilities for chlorine-alkaline electrolysis in Yugoslavia. Apart from the development of anodes, the research team also had a task to resolve all, not just technical and technological, demands of the chlorine manufacturers. Among other things, it drove the projects of improvement and reconstruction of technological procedures and introduction of new membrane technology in production. One of the results of this research was also the development of highly automatized water disinfection technique, which has been commercialised in the so-called *Hlorogen* facilities. The first facility was produced in 1996 at the Sigma Company, Kula, and today more than ten different models with various capacities are being produced for various purposes — from stationary, containers to mobile.

Over time, the field of research has expanded to other applications of active coatings on titanium for various electrochemical processes (waste water treatment, chrome plating, production of sheet metal, copper refining, *etc.*), but also to other applications of oxides of noble and transition metals enabled by their properties: composite materials for energy conversion and storage, catalyst sup-

ports. Starting from the early 1980s, the expansion of the area of research has also led to the increase of the number of researches.

Belgrade's respected place on the map of the electrochemical world is also confirmed by the fact that despite modest capabilities, first of all financial, for the past 60 years, it has been the place that many scientists have come to for improvement and work. Whenever there was a chance, through various types of collaboration and international projects, dozens, first of all, young scientists, have come to Belgrade School of Electrochemistry to expand their knowledge, perfect their skills or participate in the realisation of important research. They were most often exchange students on PhD or postdoctoral studies (from Russia, Netherlands, Finland, Morocco, Belarus, Algeria, China, *etc.*), but there were experiences researchers as well. Among them, we shall mention only a few, which came to Belgrade as already distinguished and famous scientists: Boris Daniel Cahan, Case Western Reserve University, USA; I. Sabo, Hungarian Academy of Sciences; Chen Shen Hao, Shandong University, Jinan, China; Nikola Batina, professor at the *Universidad Autónoma Metropolitana-Iztapalapa* in Mexico; Peter Faguy, today, a program manager at the Department of Energy in Washington DC, USA; Andrzej Kowal, Institute of Catalysis and Surface Chemistry, Polish Academy of Science.

It would take a long time and a lot of space to present, apart from the ones already mentioned, all the other most important achievements of the Belgrade School of Electrochemistry, and even more to state the contributions of all the individuals that make up the School. Besides, those who have given their contributions in just one area are rare, since like all others, electrochemistry is also becoming an increasingly multidisciplinary science. Thus, electrochemical research permeates biology, medicine, environmental protection, materials science; it has always had unbreakable ties with physics, theoretical chemistry, pharmacy, *etc.* Therefore, at the end of this short review, we will mention only the areas that the researchers from the Belgrade School of Electrochemistry have worked and are still working on, and after that, we have provided names of the people that make up the School, no matter in what area they have left their mark. It is almost certain that there are some names missing, because half a century of the School's existence and a large number of researchers have made it impossible for the author to learn all of them.

Areas of main and applied research by the Belgrade School of Electrochemistry:

- Kinetics of electrode processes
- Electrochemical deposition and dissolution of metals and alloys and their powders
- Corrosion and corrosion protection
- Electroplating and coatings — protective, functional, decorative

- Electrocatalysis – development of catalysts and catalyst support
- Materials science
- Conversion and storage of energy – batteries, fuel cells, supercapacitors, hybrid energy sources
- Carbonaceous materials and composites based on carbon
- Chlor–alkali electrolysis
- Electroanalytics
- Electrochemical sensors
- Electrochemistry in medicine — biocompatible materials for implants and treatment, electrochemical diagnostic methods
- Electrochemical engineering
- Electrometallurgy
- Recycling of mining waste and flotation tailing dumps
- Wastewater treatment

Belgrade Scholl of Electrochemistry consists of (in an approximate chronological order)*:

Panta Tutundžić, Aleksandar Despić, Dragutin Dražić, Milenko Šušić, Paula Putanov, Sreten Mladenović, Ivan Doroslovački, Nada Jakovljević-Halai, Aleksandar Damjanović, Vera Dražić, Ozra Tatić-Janjić, Danka Jovanović, Spasoje Đorđević, Desanka Sužnjević, Dragica Minić, Momir Jovanović, Dragan Veselinović, Dragica Ovcin, Darko Šepa, Milan Vojinović, Petar Rakin, Igor Kadija, Gordana Savić Maglić, Konstantin Popov, Svetomir Hadži-Jordanov, Radoslav Atanasoski, Radoslav Adžić, Milan Jakšić, Branislav Nikolić, Amalija Tripković, Iva Justinijanović, Nenad Tomov, Ljiljana Vračar, Zvonko Stanković, Jovan Jovićević, Velizar Stanković, Ljiljana Atanososka, Miodrag Maksimović, Radojka Šimpraga, Luka Bjelica, Vukadin Leovac, Ljiljana Jovanović, Dragan Marković, Nikola Vukelić, Tibor Pastor, Tatjana Rakić, Milan Čekerevac, Aleksandar Đorđević, Dušan Keča, Strahinja Zečević, Predrag Despotov, Slavko Mentus, Nedeljko Krstajić, Anka Vorkapić, Miroslav Spasojević, Časlav Lačnjevac, Toma Grozdić, Vjekoslav Nakić, Rade Stanković, Katarina Jeremić, Milorad Atanacković, V. Jovančićević, Lazar Vorkapić, Mirjana Rajčević-Vujasinović, Nenad Marković, Nikola Anastasijević, Gordana Adžić, Vladimir Jović, Borka Jović, Milka Avramov Ilić, Stojan Đokić, Vladislava Jovanović, Ksenija Popović, Miomir Pavlović, Ljubica Pavlović, Vedrana Marinović, Milovan Purenović, Ljiljana Gajić Krstajić, Zoran Stević, Jovan Popić, Veliša Vešović, Nebojša Marinković, Vesna Mišković-Stanković, Tomislav Trišović, Rade Stevanović, Jasmina Stevanović, Svetlana Štrbac, Aleksandar Dekanski, Zoran Minevski, Nikola Cvetičanin, Ljiljana Minevski, Snežana Gojković, Branimir Jugović, Dragan Manojlović,

* At least a few names are missing. Despite the author's efforts to learn as many names as possible from his colleagues and friends, some were almost certainly omitted.

Dalibor Stanković, Ljubiša Ignjatović, Biljana Bobić, Branimir Grgur, Milica Popović, Bora Jegdić, Vojislav Stamenković, Jelena Bajat, Stanko Branković, Radenka Marić, Miomir Vukmirović, Vladimir Panić, Tanja Vidaković Koch, Nebojša Nikolić, Jelena Lović, Berislav Blizanac, Maja Obradović, Nataša Vasiljević, Sanja Stevanović, Vesna Grekulović, Biljana Šljukić Paunković, Nevenka Elezović, Goran Vljanić, Biljana Babić, Ivana Stojković-Simatović, Igor Pašti, Uroš Lačnjevac, Vladimir Tripković, Nemanja Gavrilov, Vesna Cvetković, Dušan Tripković, Nataša Vukićević, Sanja Eraković, Milica Vujković, Marija Mihailović, Milutin Smiljanić, Gavriilo Šekularac, Milica Košević, Marko Jonović, Sanja Martinović, Milica Vlahović, Sanja Šešlija, Branka Petković, Irina Srejović, Mila Krstajić Pajić, Miroslav Pavlović, Bojana Radojković, Ana Dobrota.

SUPPLEMENTARY MATERIAL

Short biographies of several important representatives of the Belgrade School of Electrochemistry are available electronically on the pages of journal website: <http://www.shd.org.rs/JSCS/>.

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ИЗВОД

БЕОГРАДСКА ШКОЛА ЕЛЕКТРОХЕМИЈЕ

АЛЕКСАНДАР ДЕКАНКИ

Универзитет у Београду, Институт за хемију, технологију и металургију, Институт од националног значаја за Републику Србију, Центар за електрохемију, Његишева 12, Београд, Србија

Београдска школа електрохемије није ни институција, ни грађевина, па ни заједница. Њу чине људи и њихова знања, достигнућа и резултати. Она нема датум оснивања нити дефинисан почетак, а надамо се да неће имати ни крај. Настала је као резултат напора неколико генерација научника да акумулирају знања и пренесу их на следеће генерације, да својим истраживањима и њиховим резултатима допринесу освајању нових знања и напретку целокупног друштва. Њени зачетници и оснивачи нису били свесни да започињу нешто што ће у електрохемијској науци постати светски препознато, чак то нису ни желели – они су само били посвећени науци којом су се бавили и трудили су се да ту своју посвећеност пренесу на следеће генерације. Име Београдска школа електрохемије се појавило у светској електрохемијској заједници и пре него што се код нас појавила свест о њој, као појам који пре свега означава један од најзначајнијих центара електрохемијске науке у свету, а свакако највећи и најразвијенији у овом делу Европе. Оно се подједнако односи и на систем образовања и на значај и утицајност резултата и сазнања научника потеклих са Београдског универзитета на светску електрохемију.

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