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# Cyclic Voltammetry and Its Applications

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## Abstract

Cyclic voltammetry is a versatile method for scientific investigation and innovation due to the fact that most processes involve electron transfer, which makes them be able to be monitored by this technique. Its uses cover characterization, synthesis, mechanisms, and analysis. In all applications, the technique can work well with a large variety of compounds including organic, inorganic, polymer, films, and semiconductors, among others. Furthermore, the method operates satisfactorily whether in a direct or an indirect approach. It can be considered to be an essential part at the very beginning that leads further to the grand project. As an analytical tool, it plays an important role in not only chemistry but also other involving areas. This review sheds the light on the way the technique proves to become one of the important instruments in research, development, and application labs.

**Keywords:** cyclic voltammetry, electrochemistry, electrochemical applications, characterizations, analysis

## 1. Introduction

Cyclic voltammetry has long been well known for its versatile applications in a number of areas involving electron transfer process, both directly and indirectly. It should be recognized at first that the techniques are normally not the main or the most important one in the research. Rather, their data are really useful in fulfilling the work as an essential complementary technique. It has been well applied in monitoring electrochemical behavior of a great variety of substances due to the fact that it can provide the insights into the relationship of structure, potential, and characteristic activities. The technique is prominent with its advantages of simplicity, sensitivity, speed, and low costs, among others, which results in a wide range of applications so far. Only important cases of previous studies are presented. Brief information for examples of recent applications is focused here along with corresponding references for further studies in specific area of interest. Furthermore, due to the fact that there have been a large variety of applications, it is not easy to categorize. Therefore, the content has been arranged to suit its further use, vision extension, and initiation of new research. Finally, it has to be emphasized that at this point, readers are supposed to be familiar with basics of this technique as well as involving theories (for example, ref. [29] and [30]). If not, available pertaining literature can be very useful. In discussing the application of cyclic voltammetry, we are going to talk about the three main uses of cyclic voltammetry first for different types of compounds, then continue with involving areas that cyclic voltammetry is considered useful. CV is used starting from here instead of cyclic voltammetry for convenience.

## 2. Classifications of usage

### 2.1 Characterization and synthesis

General concepts on using CV for the characterization of polymers as well as inorganic materials can be found elsewhere [1].

#### 2.1.1 Organic compounds and polymers

CV has been proved to be helpful in characterizing xanthone, a bioactive compound, revealing that catechol is the key moiety to make it an effective scavenger for reactive species [2]. CV in methanol of antibiotic named amoxicillin revealed quasi reversible behavior and the change of redox potential upon the interactions with both metal ions and amino acids, which helps guiding in prescribing the medicine that they should not to be used together with the antibiotic [3–5]. Electrochemical behavior of ibuprofen and its degradation could be monitored closely by CV and found to be different for various types of electrode; for example, adsorption was observed on silver composite electrode, providing the insights into selecting the suitable electrode for removing this pollutant [6]. Together with EIS, CV is also found to be very useful in characterizing redox designing biosensors their behaviors depend on diffusion and capacitance, which might well shed the light on designing biosensors [7]. N-dodecylacrylamide (DDA) can form copolymer well with ferrocene derivatives on ITO to be applicable in the catalytic and sensor devices [8]. Its electron transfer characteristic is determined by the formation of monolayer or multilayer on the surface. A polymer-modified electrode namely poly(vinylferrocenium) on Pt was investigated and developed successfully by CV technique to make it applicable in analyzing organic compounds such as adenine [9]. The film of ruthenium complex can be synthesized via electropolymerization and then modified onto Pt electrode as a sensor for hydrazine with the characterization by CV [10]. Due to the fact that pyrrole is electroactive, the behavior of various types of polypyrrole can be conveniently followed by electrochemical methods, especially CV, and they were widely investigated in the 1990s and beyond [11–14]. CV could also be applied well in characterizing polyaniline to get suggestion in film preparations that its kinetic behaviors have the influence from the dopant acid [15]. Our work has also proved that CV can be used in electrografting born-doped diamond (BDD) surface via CV cycling without the use of reducing agent to prepare ex-situ working electrode for Cd determination [16]. With its advantage of speed, fast scan CV has been used to recommend the use of paraffin wax as a sealant instead of epoxy in making electrode for both in vivo and in vitro applications [17]. For natural polymers, CV has paved its way in analyzing specific electroactive compounds such as quinones in natural rubbers, which is very helpful in understanding their properties [18]. It is therefore clear that CV will still be greatly used for organic synthesis and characterizations for a number of years to come.

#### 2.1.2 Metals, metal complexes, and inorganic compounds

Due to the fact that complex formation involves electron transfer, understanding the behavior of metal-ligand interaction can be studied well by CV and proven satisfactorily for simulations for both higher and lower ligand concentrations as well as for obtaining overall formation constants [19]. Our contribution has shown the use of CV to support the results from X-ray crystallography to explain the behavior of copper-thiourea-halide complexes [20]. Redox potential and reversibility obtained by CV have been proved to be useful in studying metalloenzymes with cofactor of molybdenum complexes as a model to describe its physiological role [21]. The characterizations of metal complexes have also been indicated to help investigate the catalytic activities

of complexes for the removal of toxic phenolic substances, especially dyes [22]. At quantum level, redox potentials from CV can be used in calculating LUMO and HOMO as well as the gaps of new organic semiconductors, which are applicable in everyday life [23]. CV has been proved to be advantageous in characterizing quantum dots (QDs), particularly in terms of their stabilities *in vivo* [24]. CV has been shown to be effective in following molecular imprinting of copper complexes [25]. CV can also be used in tracing activated iridium oxide film (AIROF) microelectrode via the variation of scan rate during the steps of fabrications and animal implantation [26]. In particular, CV from gold rotating disk electrode (Au RDE) has also been proved to be useful in determining surface coverage of silica microparticle monolayer and revealing that the adsorption is stronger with increasing diameter and surface coverage, which sheds the light on the deposition of a variety of particles onto the surface [27]. In terms of fuel cells, CV has been used to characterize the synthesized Pt-Ru catalysts and their catalytic activities [28]. CV has been used in the characterization of metal hydride. Using NaOH instead of KOH reduces hydrogen adsorption/desorption, resulting in better performance of nickel-metal hydride batteries [29].

## 2.2 Mechanism

Generally, CV has been widely recognized to be able to identify the mechanism of coupled chemical reaction [30–32]. For recent applications, cyclic voltammetry was applied together with voltabsorptometry in understanding the reaction of luma-zine [33]. Special technique of fast Fourier transform continuous cyclic voltammetry was developed to be used well in investigating the mechanism of 4-nitrocatechol and its electrochemical synthesis [34]. This technique is also used in investigating proteolysis of milk protein by the research group in the same country [35]. The nontriangular waveform of CV has also been adopted with the advantage of convenient determination of transfer coefficient and electron transfer rate constant [36]. Additionally, staircase was compared with linear scan to assist in investigating adsorbed species [37]. Surprisingly, CV can also be used in studying the mechanism of surface coating [38]. Cyclic voltammetry was used together with potentiometry in understanding interactions between nicotine and metal ions [39]. The mechanism of electropolymerization and catalytic reaction of phenol red can be explained well by CV in order to analyze acetaminophen and dopamine [40]. The technique is also helpful in interpreting Ni electrodeposition for extending methanol oxidation [41]. Additionally, it can be used in understanding the mechanism of synthesizing graphene-coated graphene-coated electrode conveniently and fast in only one step [42]. The technique has been proved to be a helpful tool for mechanistic modeling for biosensors [43].

## 2.3 Analysis

CV can be used extensively for a wide range of both inorganic and organic compounds. In addition, it can be applied indirectly to analyze other types of characteristics, for example, microorganisms or antioxidant properties. Here the focus is on recent examples for analysis applications.

### 2.3.1 Organic compounds

For the analysis of organic compounds, cyclic voltammetry can be considered versatile in terms of a great variety of compounds. The technique has been used in the detection of glucose with graphene modified electrode [44]. Due to the overlapping of redox peaks in cyclic voltammetry, mathematical operation such as deconvolution has been applied in analyzing electroactive species including explosives, especially nitro



compounds. With modern technology in data analysis, the techniques can be used in the determination of pesticides [45]. Separation technology, for example, electromembrane is also helpful in eliminating interferences in diclofenac analysis [46]. Carbon black-modified GCE was used in estradiol by voltammetry in cooperation with FIA and amperometry [47]. Another important natural compound that has been widely used is curcumin, and its characteristics from CV can shed the light for its analysis in various corresponding products [48, 49]. CV was also proved to be supersensitive for hydrazine sensing [50]. Boron-doped diamond also exhibits its performance as an electrode with superb sensitivity for metronidazole in the analysis by CV [51], whereas bismuth electrode proved its specific characteristic in monitoring thiol content in fossil fuel [52]. The determination of 2,4,6-trichloroanisole in cork stoppers to reduce the wine defect can be accomplished satisfactorily with CV [53]. Recently, CV has played very important role in the analysis of juice [54] and wine [55] with particular analytes such as phenolic compounds. The analysis by CV helps in investigating perspective ionic liquids (ILs) to be used as solvents and electrolytes with their specific properties of cation and anion dependence [56]. It is also important to state here that CV can be used in analysis with the increase or decrease of the current signals of indicator compounds such as quinones [57] or ferricyanide [58]. Analyses of organic compounds by CV are sure to appear extensively in the near future in the analytical literature.

### 2.3.2 Inorganic compounds

Cyclic voltammetry can be used well with numerous inorganic compounds. It is normally applied to simple inorganic compounds probably because their electrochemical behavior is less complicated. It is worth mentioning here that metal ions are normally monitored by stripping voltammetry, so it is not going to delve into details here. Certainly, voltammetry is sensitive to metal ions, but its specificity can be enhanced by electrode modifications and stripping potential. Those who are interested in this area are suggested to get more details elsewhere [59–61]. An example of application of cyclic voltammetry to complicated inorganic compounds is the case of nanostructured iron oxides [62]. Additionally, corrosive impurities can be monitored closely in molten chloride by CV, which is very useful for energy storage [63]. With the use of chitosan and silver nanocomposite modified electrode, hydrogen peroxide can be detected [64], and this can be further extended to the determination of other compounds involving hydrogen peroxide such as glucose.

### 2.3.3 Other aspects of analysis

With electrochemical characteristics of CV, various analytical aspects of applications in analysis can be achieved as well. It was used in the valuation of antioxidant potential, which is very important in making wine [65]. The technique, along with EIS, CV can be used in assessing emulsion stability [66]. Furthermore, CV can be used in determining HOMO and LUMO levels with an acceptable accuracy [67]. Surprisingly, it can be applied in monitoring the formation of biofilms [68]. With its sensitivity for antioxidant, CV can be used in classifying black tea [69]. It is clear that indirect uses of CV can be used in the future in a variety of applications.

## 3. Areas of applications

### 3.1 Chemistry

Electron transfer definitely plays an important role in all reactions; therefore, electrochemistry and CV in particular have an essential part in all aspects of

Areas of chemistry	Typical applications
Analytical chemistry	Preparation and synthesis
	Analysis
	Mechanism
Inorganic chemistry	Metal interactions and reactions
	Structure characterizations
	Analysis
Organic chemistry	Synthesis
	Analysis
	Characterization
	Mechanism
Physical chemistry	Thermodynamic studies
	Kinetic studies
	Theoretical equations
	Surface and adsorption
	Analysis
	Mechanism
Biochemistry (and biology)	Metabolic processes
	Continuous monitoring
	In vivo and in vitro analysis
	Kinetic of enzymes
	Biosensors

**Table 1.**  
*Summary of the main uses of CV in chemistry.*

chemistry as summarized in **Table 1**. Typical examples have already been mentioned in the previous text.

**3.2 Other areas**

Due to the fact that CV provides essential information for better understanding and the instrument is quite cost-effective now, thanks to modern technology, not to mention the way that it is easy to access, cyclic voltammograph in the form of potentiostat and specific programs is a must in most research and development labs. **Table 2** summarizes the use of CV in other areas besides chemistry.

**4. Conclusive remarks**

Cyclic voltammetry has long provided essential information in a number of areas and obviously will continue to facilitate research work as an analytical tool. The technique gives researchers an insight into the systems they are working on. For chemistry, the technique has shed the light on the mechanism of electron transfer reactions as well as their quantitative and synthetic relevance. The way that the electron transfer responses to the parameters of the surrounding environment leads scientists to be able to follow the behavior of target substances and therefore supports their characterizations. With smaller and cheaper instruments in addition

Areas	Reference for typical example
Paint	[70]
Medical	[71]
Engineering	[72]
Pharmaceutical sciences	[73–75]
Polymer and polymer films	[76]
Material sciences	[77]
• microporous materials	
• semiconductors	
Surface science and interface	[78]
Corrosion	[79]
Energy	[80]
Battery	[81]
Fuel	[82]
Fuel cell and microbial fuel cell	[41]
Processing and production	[83]
Flow detection	[84]
Food	[85]
• wine product	
• antioxidant	
• preservation	
Environment	[86]
Catalysis	[87]
Forensics	[88]

**Table 2.**  
*Summary of the main uses of CV in other areas besides chemistry.*

to the ease the ease to operate, the technique can be available anywhere to serve all types of needs. The given examples are just only a handful of its usefulness in applications to initiate the understanding and further search. It is hoped that this review can form fundamental database to be implemented for further uses in the areas of individual interest. The opportunity is still there to investigate as well as to develop beneficial innovations. The more newly things are discovered and invented, the greater role the CV data play in feeding the world with much more meaningful scientific prosperity.

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## References

- [1] Bocasly AB. Cyclic voltammetry, electrochemical technique. In: Characterization of Materials. 2nd ed. Wiley; 2012. DOI: 10.1002/0471266965.com050.pub2
- [2] Santos CMM, Garcia MBQ, Silva AMS, Santos R, Morlière P, Fernandes E. Electrochemical characterization of bioactive hydroxyxanthenes by cyclic voltammetry. *Tetrahedron Letters*. 2013;**54**:85-90
- [3] Auguste AFT, Quand-Meme GC, Ollo K, Berté Mohamed B, Sahi placide S, Ibrahima S, et al. Electrochemical oxidation of amoxicillin in its commercial formulation on thermally prepared RuO<sub>2</sub>/Ti. *Journal of Electrochemical Science and Technology*. 2016;**7**:82-89
- [4] Quand-Même GC, Auguste AFT, Hélène LEM, Ibrahima S, Ouattara Lassine O. Electrochemical oxidation of amoxicillin in its pharmaceutical formulation at boron doped diamond (BDD) electrode. *Journal of Electrochemical Science and Engineering*. 2015;**5**:129-143. DOI: 10.5599/jese.186
- [5] Orata D, Amir Y, Nineza C, Mukabi M. Electrochemical characterization of amoxycillin, a broad spectrum antibiotic on a bentonite host matrix, using cyclic voltammetry. *IOSR Journal of Applied Chemistry*. 2015;**7**:50-58
- [6] Remes A, Ihos M, Manea F. Electrochemical characterization of some electrode materials for pharmaceutically active compounds degradation. *Chemical Bulletin of Politehnica University of Timisoara*. 2010;**55**(2):152-155
- [7] Bott AW. Electrochemical techniques for the characterization of redox polymers. *Current Separations*. 2001;**19**:3
- [8] Aoki A, Miyashita T. Electrochemical characterization of redox polymer Langmuir–Blodgett films containing ferrocene derivatives. *Macromolecules*. 1996;**29**:4662-4667
- [9] Kuralay F, Erdem A, Abacı S, Ozyörük H. Electrochemical characterization of redox polymer modified electrode developed for monitoring of adenine. *Colloids and Surfaces. B, Biointerfaces*. 2013;**105**:1-6. DOI: 10.1016/j.colsurfb.2012.12.049
- [10] Brown KL, Hou X, Banks O, Krueger KA, Hinson J, Peaslee GF, et al. Characterization of tris (5-amino-1,10-phenanthroline) ruthenium(II/III) polymer films using cyclic voltammetry and Rutherford backscattering spectrometry. *International Journal of Chemistry*. 2011;**3**:12-19
- [11] Zoppi RA, De Paoli M-A. Electrochemical characterization of polypyrrole and poly pyrrole/EPDM rubber blends by cyclic voltammetry and impedancimetry. *Journal of the Brazilian Chemical Society*. 1994;**5**:197-201
- [12] Walton DJ, Hall CE, Chyla A. Characterization of poly(pyrroles) by cyclic voltammetry. *The Analyst*. 1992;**117**:1305-1311
- [13] Yeu T, Yin K-M, Carbajal J, White RE. Electrochemical characterization of electronically conductive polypyrrole on cyclic voltammograms. *Journal of The Electrochemical Society*. 1991;**138**:2869-2877
- [14] Sharma PK, Gupta G, Singh VV, Tripathi BK, Pandey P, Boopathi M, et al. Synthesis and characterization of polypyrrole by cyclic voltammetry at different scan rate and its use in electrochemical reduction of the simulant of nerve agents. *Synthetic Metals*. 2010;**160**:2631-2637

- [15] Pruneanu S, Veress E, Marian I, Oniciu L. Characterization of polyaniline by cyclic voltammetry and UV-vis absorption spectroscopy. *Journal of Materials Science*. 1999;**34**:2733-2739
- [16] Innuphat C, Chooto P. Determination of trace levels of Cd(II) in tap water samples by anodic stripping voltammetry with an electrografted boron-doped diamond electrode. *ScienceAsia*. 2017;**43**:33-41
- [17] Ramsson ES, Cholger D, Dionise A, Poirier N, Andrus A, Curtiss R. Characterization of fast-scan cyclic voltammetric electrodes using paraffin as an effective sealant with in vitro and in vivo applications. *PLoS One*. 2015;**10**(10):e0141340. DOI: 10.1371/journal.pone.0141340
- [18] Cabral MF, Pedrosa VA, Suffredini HB, Moreno RMB, Mattoso LHC, Goncalves PS, et al. Characterization of conductive natural rubber by cyclic voltammetry and electrochemical impedance spectroscopy. *Zaštita Materijala*. 2006;**47**:41-45
- [19] Killa HM, Mercer EE, Philp RH. Applications of cyclic voltammetry in the characterization of complexes at low ligand concentration. *Analytical Chemistry*. 1984;**56**:2401-2405
- [20] Chuaysong R, Chooto P, Pakawatchai C. Electrochemical properties of copper(I) halides and substituted thiourea complexes. *ScienceAsia*. 2008;**34**:440-442. DOI: 10.2306/scienceasia1513-1874.2008.34.440
- [21] Knittl ET, Rusakov DA, Korotkova EI, Dorozhko EV, Voronova OA, Plotnikov EV, et al. Characterization of a novel dioxomolybdenum complex by cyclic voltammetry. *Analytical Letters*. 2015;**48**:2369-2379
- [22] Abdou SN, Faheim AA, Alaghaz A-NMA. Synthesis, spectral characterization, cyclic voltammetry, molecular modeling and catalytic activity of sulfa-drug divalent metal complexes. *Current Synthetic and Systems Biology*. 2013;**2**:112. DOI: 10.4172/2332-0737.1000112
- [23] Mandadapu G. Characterization of Organic Semiconductors Using Cyclic Voltammetry. Kingsville: Texas A&M University, ProQuest Dissertations Publishing; 2015. p. 10020622
- [24] Sobrova P, Ryvolova M, Hubalek J, Adam V, Kizek R. Voltammetry as a tool for characterization of CdTe quantum dots. *International Journal of Molecular Sciences*. 2013;**14**:13497-13510. DOI: 10.3390/ijms140713497
- [25] Zeng YN, Zheng N, Osborne PG, Li YZ, WB C, Wen MJ. Cyclic voltammetry characterization of metal complex imprinted polymer. *Journal of Molecular Recognition*. 2002;**15**: 204-208. DOI: 10.1002/jmr.578
- [26] Hu Z, Troyk P, Cogan S. Comprehensive cyclic voltammetry characterization of AIROF microelectrodes. Conference Proceedings: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2005;**5**:5246-5249
- [27] Nosek M, Batys P, Skoczek M, Weroni P. Cyclic voltammetry characterization of microparticle monolayers. *Electrochimica Acta*. 2014;**133**:241-246
- [28] Rotha C, Martz N, Hahn F, Léger J-M, Lamy C, Fuess H. Characterization of differently synthesized Pt-Ru fuel cell catalysts by cyclic voltammetry, FTIR spectroscopy, and in single cells. *Journal of The Electrochemical Society*. 2002;**149**:E433-E439. DOI: 10.1149/1.1511191
- [29] Li X, Dong H, Zhang A, Wei Y. Electrochemical impedance and cyclic voltammetry characterization of a

metal hydride electrode in alkaline electrolytes. *Journal of Alloys and Compounds*. 2006;**426**:93-96

[30] Mabbott GA. An introduction to cyclic voltammetry. *Journal of Chemical Education*. 1983;**60**:697-701

[31] Bard AJ, Faulkner LR. *Electrochemical Methods: Fundamentals and Applications*. 2nd ed. New York: John Wiley & Sons; 2001

[32] Bott AW. Characterization of chemical reactions coupled to electron transfer reactions using cyclic voltammetry. *Current Separations*. 1999;**18**:9-16

[33] He R-X, Da-Wei Zha D-W. Cyclic voltammetry and voltabsorptometry studies of redox mechanism of lumazine. *Journal of Electroanalytical Chemistry*. 2017;**791**:103-108

[34] Yazdani J, Norouzi P, Nematollahi D, Ganjali RM. Online monitoring of electrochemical synthesis of 4-nitrocatechol using fast Fourier transform continuous cyclic voltammetry (FFTCCV) in flow system. *Electrochimica Acta*. 2018;**259**: 694-701

[35] Shayeh JS, Sefidbakht Y, Siadat SOR, Niknam K. Continuous fast Fourier transforms cyclic voltammetry as a new approach for investigation of skim milk k-casein proteolysis, a comparative study. *International Journal of Biological Macromolecules*. 2017;**103**:972-977

[36] Uchida Y, Kätelhön E, Compton RG. Cyclic voltammetry with non-triangular waveforms: Electrochemically irreversible and quasi-reversible systems. *Journal of Electroanalytical Chemistry*. 2018;**810**:135-144

[37] Montella C. Further investigation of the equivalence of staircase and linear scan voltammograms.

III-averaged-current staircase voltammetry applied to electrochemical reactions involving adsorbed species. *Journal of Electroanalytical Chemistry*. 2018;**808**:348-361

[38] Shbeh M, Yerokhin A, Goodall R. Cyclic voltammetry study of PEO processing of porous Ti and resulting coatings. *Applied Surface Science*. 2018, In press

[39] Fazary AE, Ju Y-H, Fawy KF, Al-Shihri AS, Bani-Fwaz MZ, Alfaifi MY, et al. Nicotine—metal ion interactions in solutions: Potentiometric, cyclic voltammetry investigations and quantum chemical calculations. *The Journal of Chemical Thermodynamics*. 2017;**112**:283-292

[40] Hsieh M-T, Whang T-J. Mechanistic investigation on the electropolymerization of phenol red by cyclic voltammetry and the catalytic reactions toward acetaminophen and dopamine using poly(phenol red)-modified GCE. *Journal of Electroanalytical Chemistry*. 2017;**795**:130-140

[41] Cheshideh H, Nasirpouri F. Cyclic voltammetry deposition of nickel nanoparticles on TiO<sub>2</sub> nanotubes and their enhanced properties for electro-oxidation of methanol. *Journal of Electroanalytical Chemistry*. 2017;**797**:121-133

[42] Gürsu H, Gençten M, Şahin Y. One-step electrochemical preparation of graphene-coated pencil graphite electrodes by cyclic voltammetry and their application in vanadium redox batteries. *Electrochimica Acta*. 2017;**243**:239-249

[43] Semenova D, Zubov A, Silina YE, Micheli L, Gernaey KV. Mechanistic modeling of cyclic voltammetry: A helpful tool for understanding biosensor principles and supporting design optimization.



Sensors and Actuators B: Chemical. 2018;**259**:945-955

[44] Ji D, Liu L, Li S, Chen C, Lu Y, Wu J, et al. Smartphone-based cyclic voltammetry system with graphene modified screen printed electrodes for glucose detection. *Biosensors & Bioelectronics*. 2017;**98**:449-456

[45] Chen J, Chen C. A new data analysis method to determine pesticide concentrations by cyclic voltammetry. *Measurement*. 2013;**46**:1828-1833

[46] Mofidi Z, Norouzi P, Seidi S, Ganjali MR. Determination of diclofenac using electromembrane extraction coupled with stripping FFT continuous cyclic voltammetry. *Analytica Chimica Acta*. 2017;**972**:38-45. DOI: 10.1016/j.aca.2017.04.011

[47] Smajdor J, Piech R, Ławrywianiec M, Paczosa-Bator B. Glassy carbon electrode modified with carbon black for sensitive estradiol determination by means of voltammetry and flow injection analysis with amperometric detection. *Analytical Biochemistry*. 2018;**544**:7-12

[48] Masek A, Chrzescijanska E, Zaborski M. Characteristics of curcumin using cyclic voltammetry, UV-vis, fluorescence and thermogravimetric analysis. *Electrochimica Acta*. 2013;**107**:441-447

[49] Phongarthit K, Wongnawa M, Chooto P, Wongnawa S. Spectrophotometric study of complex formation between curcumin and Cr(III) ion: A case of heavily overlapping absorption peaks. *Journal of Solution Chemistry*. 2016;**45**:1468-1478. DOI: 10.1007/s10953-016-0512-8

[50] Heydari H, Gholivand MB, Abdolmaleki A. Cyclic voltammetry deposition of copper nanostructure on MWCNTs modified pencil graphite electrode: An ultra-sensitive

hydrazine sensor. *Materials Science and Engineering: C*. 2016;**66**:16-24

[51] Ammar HB, Brahim MB, Abdelhédi R, Samet Y. Boron doped diamond sensor for sensitive determination of metronidazole: Mechanistic and analytical study by cyclic voltammetry and square wave voltammetry. *Materials Science and Engineering: C*. 2016;**59**:604-610

[52] Kong D, Kong W, Khan ZUH, Wan P, Chen Y, Yang M. Determination of thiol content in fossil fuel by cyclic voltammetry using in situ bismuth film electrode. *Fuel*. 2016;**182**:266-271

[53] Freitas P, Dias LG, Peres AM, Castro LM, Veloso ACA. Determination of 2,4,6-trichloroanisole by cyclic voltammetry. *Procedia Engineering*. 2012;**47**:1125-1128

[54] Makhotkina O, Paul A, Kilmartin PA. The phenolic composition of Sauvignon blanc juice profiled by cyclic voltammetry. *Electrochimica Acta*. 2012;**83**:188-195

[55] Makhotkina O, Kilmartin PA. The use of cyclic voltammetry for wine analysis: Determination of polyphenols and free sulfur dioxide. *Analytica Chimica Acta*. 2010;**668**:155-165

[56] Ni W, Liu S, Fei Y, He Y, Ma X, Lu L, et al. The determination of 1-methylimidazole in room temperature ionic liquids based on imidazolium cation by cyclic voltammetry. *Journal of Electroanalytical Chemistry*. 2017;**787**:139-144

[57] Cao X, Xu H, Ding S, Ye Y, Ge X, Yu L. Electrochemical determination of sulfide in fruits using alizarin-reduced graphene oxide nanosheets modified electrode. *Food Chemistry*. 2016;**194**:1224-1229.

[58] Cui L, Hu J, Li C, Wang C, Zhang C. An electrochemical biosensor based

on the enhanced quasi-reversible redox signal of prussian blue generated by self-sacrificial label of iron metal-organic framework. *Biosensors and Bioelectronics*. 2018;**122**:168-174

[59] Chooto C. Modified electrodes for determining trace metal ions. In: Stoytcheva M, Zlatev R, editors. *Application of the Voltammetry*. Rijeka, Croatia: InTech; 2017

[60] Lu Y, Liang X, Niyungeko C, Zhou J, Xu J, Tian G. A review of the identification and detection of heavy metal ions in the environment by voltammetry. *Talanta*. 2018;**178**: 324-338

[61] March G, Nguyen TD, Piro B. Modified electrodes used for electrochemical detection of metal ions in environmental analysis. *Biosensors*. 2015;**5**:241-275. DOI: 10.3390/bios5020241

[62] Santos CMM, Garcia M, BQG SAMS, Santos R, Fernandes E. Electrochemical analysis of nanostructured iron oxides using cyclic voltammetry and scanning electrochemical microscopy. *Electrochimica Acta*. 2016;**222**:1326-1334

[63] Ding W, Bonk A, Gussone J, Bauer T. Cyclic voltammetry for monitoring corrosive impurities in molten chlorides for thermal energy storage. *Energy Procedia*. 2017;**135**:82-91

[64] Tran HV, Huynh CD, Tran HV, Piro B. Cyclic voltammetry, square wave voltammetry, electrochemical impedance spectroscopy and colorimetric method for hydrogen peroxide detection based on chitosan/silver nanocomposite. *Arabian Journal of Chemistry*. 2016, In press

[65] Jara-Palacios MJ, Escudero-Gilete ML, Hernández-Hierro JM, Heredia FJ, Hernanz D. Cyclic voltammetry

to evaluate the antioxidant potential in winemaking by-products. *Talanta*. 2017;**165**:211-215

[66] Roldan-Cruz C, Vernon-Carter EJ, Alvarez-Ramirez J. Assessing the stability of tween 80-based O/W emulsions with cyclic voltammetry and electrical impedance spectroscopy. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2016;**511**:145-152

[67] Lucia LL, Sbarcea G, Ioan VBIV. Cyclic voltammetry for energy level estimation of organic materials. *UPB Scientific Bulletin, Series B*. 2013;**75**:111-118

[68] Kang J, Kim T, Tak Y, Lee J-H, Yoon J. Cyclic voltammetry for monitoring bacterial attachment and biofilm formation. *Journal of Industrial and Engineering Chemistry*. 2012;**18**: 800-807

[69] Bhattacharyya R, Tudu B, Das SC, Bhattacharyya N, Bandyopadhyay R, Pramanik P. Classification of black tea liquor using cyclic voltammetry. *Journal of Food Engineering*. 2012;**109**:120-126

[70] Bowman L, Spencer D, Muntele C, Muntele I, Ila D. Cyclic voltammetry and RBS study of paint components. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*. 2007;**261**:557-560

[71] de Abreu FC, Ferraz PAL, Goulart MOF. Some applications of electrochemistry in biomedical chemistry. Emphasis on the correlation of electrochemical and bioactive properties. *Journal of the Brazilian Chemical Society*. 2002;**13**:19-35. DOI: 10.1590/S0103-50532002000100004

[72] Jittiarporn P, Sikong L, Kooptarnond K, Taweepreda W, Chooto P, Khangkhamano M. Synthesis of h-MoO<sub>3</sub> and (NH<sub>4</sub>)<sub>2</sub>Mo<sub>4</sub>O<sub>13</sub> using precipitation method at various

pH values and their photochromic properties. *Applied Mechanics and Materials*. 2016;**835**:34-41

[73] Ozkan SA, Kauffmann J-M, Zuman P. *Electroanalysis in Biomedical and Pharmaceutical Sciences: Voltammetry, Amperometry, Biosensors, Applications*. Berlin Heidelberg: Springer-Verlag; 2015

[74] Mekassa B, Tessema M, Chandravanshi BS, Baker PGL, Muya FN. Sensitive electrochemical determination of epinephrine at poly(L-aspartic acid)/electrochemically reduced graphene oxide modified electrode by square wave voltammetry in pharmaceuticals. *Journal of Electroanalytical Chemistry*. 2017;**807**:145-153

[75] El-Hady MNA, Gomaa EA, Al-Harazie AG. Cyclic voltammetry of bulk and nano CdCl<sub>2</sub> with ceftazidime drug and some DFT calculations. *Journal of Molecular Liquids*. 2018, In press

[76] Do J-S, Chang Y-H, Tsai M-L. Highly sensitive amperometric creatinine biosensor based on creatinine deiminase/Nafion®-nanostructured polyaniline composite sensing film prepared with cyclic voltammetry. *Materials Chemistry and Physics*. 2018;**219**:1-12

[77] Mei B-A, Pilon L. Three-dimensional cyclic voltammetry simulations of EDLC electrodes made of ordered carbon spheres. *Electrochimica Acta*. 2017;**255**:168-178

[78] Viada BN, Juárez AV, Gómez EMP, Fernández MA, Yudi LM. Determination of the critical micellar concentration of perfluorinated surfactants by cyclic voltammetry at liquid/liquid interfaces. *Electrochimica Acta*. 2018;**263**:499-507

[79] Chooto P, Manaboot S. Electrochemical, spectrochemical and

quantum chemical studies on dimedone as corrosion inhibitor for copper in acetonitrile. *Journal of Scientific Research and Reports*. 2017;**15**: 1-13

[80] Inoue M, Cedeño R. A dimeric tris(2,2'-bipyridine)ruthenium(II) system: Emission spectrum and cyclic voltammogram. *Inorganica Chimica Acta*. 1988;**145**:117-120

[81] Hansen S, Quiroga-González E, Carstensen J, Föll H. Size-dependent cyclic voltammetry study of silicon microwire anode for lithium ion batteries. *Electrochimica Acta*. 2016;**217**:283-291

[82] Nechaeva D, Shishov A, Ermakov S, Bulatov A. A paper-based analytical device for the determination of hydrogen sulfide in fuel oils based on headspace liquid-phase microextraction and cyclic voltammetry. *Talanta*. 2018;**183**:290-296

[83] Pouri SR, Manic M, Phongikaroon S. A novel framework for intelligent signal detection via artificial neural networks for cyclic voltammetry in pyroprocessing technology. *Annals of Nuclear Energy*. 2018;**111**:242-254

[84] Jiao Y, Kilmartin PA, Fan M, Quek SY. Assessment of phenolic contributors to antioxidant activity of new kiwifruit cultivars using cyclic voltammetry combined with HPLC. *Food Chemistry*. 2018;**268**:77-85

[85] Schneider M, Türke A, Fischer W-J, Kilmartin PA. Determination of the wine preservative sulphur dioxide with cyclic voltammetry using inkjet printed electrodes. *Food Chemistry*. 2014;**159**:428-432

[86] Massah J, Vakilian KA. An intelligent portable biosensor for fast and accurate nitrate determination using cyclic voltammetry. *Biosystems Engineering*. 2018, In press



[87] Surendra BS. Green engineered synthesis of Ag-doped  $\text{CuFe}_2\text{O}_4$ : Characterization, cyclic voltammetry and photocatalytic studies. *Journal of Science: Advanced Materials and Devices*. 2018;**3**:44-50

[88] Üzer A, Sağlam Ş, Tekdemir Y, Ustamehmetoğlu B, Apak R. Determination of nitroaromatic and nitramine type energetic materials in synthetic and real mixtures by cyclic voltammetry. *Talanta*. 2013;**115**:768-778