Iranian Journal of Analytical Chemistry
Volume 6, Issue 1, March 2019 (57-64)

مجله ایرانی شیمی تجزیه
دوره۶، شماره ۱، فروردین ماه ۱۳۹۸ (۶۴-۵۷)

تعیین حساس سیستئامین با استفاده از حسگر الکتروشیمیایی یکبار مصرف بر پایه الکترود صفحه چاپی اصلاح‌شده

سید ضیا محمدی*،۱، سمیه تاجیک۲، هادی بیت الهی۳، زهره بارانی۱

۱. بخش شیمی، دانشگاه پیام نور، صندوق پستی ۳۶۹۷-۱۹۳۹۵، تهران، ایران

۲. مرکز تحقیقاتی بیماریهای عفونی و گرمسیری، دانشگاه علوم پزشکی کرمان، کرمان، ایران

۳. پژوهشگاه علوم محیطی، دانشگاه تحصیلات تکمیلی صنعتی و فناوری پیشرفته، کرمان، ایران

تاریخ دریافت: ۷ بهمن ۱۳۹۷ تاریخ پذیرش: ۲۶ اسفند ۱۳۹۷

Sensitive Cysteamine Determination Using Disposable Electrochemical Sensor Based on Modified Screen Printed Electrode

Sayed Zia Mohammadi*,1, Somayeh Tajik2, Hadi Beitollahi3, Zohreh Barani1
1. Department of Chemistry, Payame Noor University, Tehran, Iran
2. Research Center of Tropical and Infectious Diseases, Kerman University of Medical Sciences, Kerman, Iran
3. Environment Department, Institute of Science and High Technology and EnvironmentalSciences, Graduate University of Advanced Technology, Kerman, Iran

Received: 27 January 2019 **Accepted:** 17 March 2019
DOI: 10.30473/ijac.2019.45800.1142

چکیده

در مطالعه حاضر، ویژگی‌های الکتروشیمیایی سیستئامین با استفاده از الکترود صفحه چاپی اصلاح‌شده با نانوکامپوزیت La_2O_3/Co_3O_4 ($La_2O_3/Co_3O_4/SPE$) بوسیله روشهای ولتامتری، کرونوآمپرومتری و ولتامتری پالس تفاضلی مورد بررسی قرار گرفت. کیفیت نانوکامپوزیت La_2O_3/Co_3O_4 سنتز شده بوسیله SEM، FT-IR و XRD مورد بررسی قرار گرفت. شاهکار الکترود صفحه چاپی اصلاح‌شده با نانوکامپوزیت La_2O_3/Co_3O_4 این است که سینتیک اکسیداسیون الکتروشیمیایی سیستئامین بوسیله کاهش پتانسیل اورولتاژ آندی بطور قابل ملاحظه‌ای بهبود پیدا می‌کند. بررسی های ولتامتری الکترود $La_2O_3/Co_3O_4/SPE$ حساسیت بالایی نسبت به سیستئامین نشان داد که در نتیجه یک حسگر فوق العاده مناسب برای تعیین مقادیر ناچیز سیستئامین می‌باشد. نتایج نشان داد که جریان پیک اکسایش الکتروشیمیایی سیستئامین با غلظت آن در گستره غلظتی ۱/۰ تا ۷۰۰/۰ میکرومولار با حد تشخیص ۰/۳ میکرومولار ارتباط دارد. در پایان الکترود $La_2O_3/Co_3O_4/SPE$ برای تعیین مقدار سیستئامین در نمونه‌های واقعی مورد استفاده قرار گرفت.

واژه‌های کلیدی

سیستئامین؛ الکترود صفحه چاپی؛ اکسایش الکتروشیمیایی؛ ولتامتری؛ نانوکامپوزیت La_2O_3/Co_3O_4.

Abstract

In the present study, the cysteamine electrochemical features were explored by La_2O_3/Co_3O_4 nanocomposite-modified screen printed electrode ($La_2O_3/Co_3O_4/SPE$) using voltammetry, chronoamperometry, and differential pulse voltammetry (DPV) techniques. The synthesized La_2O_3/Co_3O_4 nanocomposite qualities were considered by SEM, FT-IR, and XRD analyses. Exploiting the modified SPE electrode with La_2O_3/Co_3O_4 nanocomposite, the cysteamine electrooxidation kinetics was significantly enhanced by reducing the anodic over-potential. The constructed $La_2O_3/Co_3O_4/SPE$ revealed voltammetric reactions of high sensitivity for cysteamine, resulting in a highly appropriate means of trace levels cysteamine measurement. The electrooxidation peak currents for cysteamine were found to change linearly in relation to its concentrations (1.0–700.0 μM) in detection limit of 0.3 μM. $La_2O_3/Co_3O_4/SPE$ was utilized for the cysteamine quantification in real specimens.

Keywords
Cysteamine; Screen Printed Electrode; Electrooxidation; Voltammetry; La_2O_3/Co_3O_4 nanocomposite.

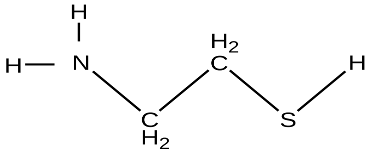
1. INTRODUCTION

Cysteamine (2-mercaptoethylamine, Scheme 1) as an aminothiol drug is exploited for the cystinosis cure [1-4]. The absence of cystine carrier in the

---

*Corresponding Author: szmohammadi@yahoo.com

lysosomal membrane causes the accumulation of cystine in the lysosomes, consequently crystallizing in essential organs, namely the spleen, intestines, liver, kidney, and cornea [3-6]. As cysteamine therapy has become accessible for patients with nephropathic cystinosis (MIM219800) in the early 1980s, life quality for these patients has seriously improved [7, 8]. Due to position of cysteamine in the clinical requests and its contribution in the treatment of cystinosis, this drug quantification is extremely vital within biological specimen.



Scheme 1. Chemical structures of cysteamine.

Numerous approaches have been considered to quantify cysteamine in pharmaceutical samples containing electrophoresis, gas chromatography with flame photometric detection, ion exchange chromatography, and electrochemical techniques [9-14]. Because of complications in chromatographic performances, namely the selection of a mobile phase or a proper column using liquid chromatographic techniques, costly instruments, lengthy response time, difficult process, and low detection ability, electrochemical approaches for analyte measurement was executed in this investigation [15].

Some of the benefits of the electrochemical techniques are as follows: (i) an instantaneous or integrated rate can be achieved; (ii) the measurements can be made very fast; (iii) the outcomes are obtainable as an electrical signal that can be simply transmitted, amplified, digitized, or displayed; and (iv) the determinations can be carried out, in most cases, with very little surface disturbance [16-19]. Because of the extra excellence of electrochemical approaches, electrochemical sensors are highly recommended for numerous electroactive and non-electroactive composites recently [20-22]. According to prior reports, the direct electrochemical oxidation of analyte on unmodified electrodes entails a high over-potential as well as a low electrical signal [23]. Consequently, researchers have exploited modified electrodes to analyze trace levels of analyte in pharmaceutical and clinical samples [24]. Nano-based materials, such as metal oxide-based nanoparticles, have been recommended to modify the electrodes for developing the sensitivity of sensors [25-26]. Furthermore, they have an extensive range of technological uses e.g. catalysis, microelectronics, and chemical/ biological sensors [27-29]. Nanoparticles, exploited in nanomaterial-modified electrodes, have several unique benefits, including high mass transport rate, low solution resistance effect, poor detection limits and enhanced signal-to-noise ratio in comparison with typical electrodes [30]. In this event, La_2O_3/Co_3O_4 nanocomposite was used for cysteamine sensor transducer surface that accelerates the electron transfer, develops the operative electroactive surface area and improves the detection limit of cysteamine.

The screen-printing (thick film) method, used to fabricate sensors and biosensors, has been greatly developed. Screen-printed electrodes (SPEs) are essentially facile to organize, quick and adaptable, which seem to be the most cost-efficient innovation [31]. Their low-cost property makes conceivable application as replaceable electrodes. The SPE with a counter electrode, a serigraphied pseudo-reference Ag/AgCl electrode, and a working electrode within the same device may be arranged via various modifiers that contain metal oxides, metals, nanoparticles, nanocarbons, phthalocyanines, conducting polymers, or prussian blue, as well as several others [32-34].

In this case, cysteamine quantification was done by the voltammetric technique utilizing La_2O_3/Co_3O_4/SPE. In succession, for the purpose of demonstrating the catalytic competency of the La_2O_3/Co_3O_4/SPE sensor in the electrooxidation of cysteamine within real samples, the procedure was applied to voltammetrically determine cysteamine within urine samples.

2. EXPERIMENTAL

2.1. Reagents and apparatus

Cysteamine was prepared from Merck (Darmstadt, Germany). The solution was preserved in the dark condition at 4 ^oC inside a refrigerator. Additional dilute solutions were set via serial dilutions by water. All other chemicals exploited in this case had analytical grade and bought from Merck. Double-distilled water was applied entirely. Phosphate buffer solutions (PBS) (sodium dihydrogen phosphate and disodium monohydrogen phosphate plus sodium hydroxide, 0.1 M) were prepared with different pH values.

Scanning Electron Microscopy (SEM, KYKY, EM 3200) was used to explore the surface morphology of the composites. The SPE (DropSens, DRP-110, Spain) included three basic sections of graphite working, a silver pseudo-reference and a graphite counter electrodes. Voltammetric measurements were performed on a potentiostat/galvanostat (PGSTAT. 302N, Autolab, Eco-Chemie, The Netherlands) using

GPES version 4.9 software. A pH meter (Metrohm 710) containing a glass electrode was used to measure pH values.

2.2. Preparation of La_2O_3/Co_3O_4 nanocomposite

The chemicals with analytical grade, including cobalt acetate ($Co(CH_3COO)_2.2H_2O$), thiourea ($(NH_2)_2CS$) and ammonia (25% NH_3), were used to prepare the nano-powders, and deionized water was utilized to dissolve all the precursors. The ammonia was considered as a complexing agent within the preparation of the nano-powders. Moreover, 0.46 mol of cobalt acetate was dissolved in 80 ml of deionized water, 0.18 mol of thiourea in 80 ml of deionized water and 19.76 ml of ammonia in 80 ml of deionized water to prepare the Co_3O_4 nanostructures. The constant ratio of 1:1:1 was considered for the solutions of cobalt acetate, thiourea and ammonia. After pouring the cobalt acetate solution in a beaker of the reaction bath, the thiourea solution was added and stirred for seconds, followed by adding ammonia gently while stirring for 5 min. Then, the reaction temperature was elevated by 80 °C, and resulting precipitation was left overnight and finally filtered and washed with ethanol. The drying process of the resulting powders was carried out for several days at the room conditions.

The preparation of La_2O_3/Co_3O_4 nanocomposites was performed by placing La_2O_3 nanoparticles onto the surface of the Co_3O_4 hexagonal nanosheets. Thus, 0.2 mol of lanthanium nitrate in 50 ml of deionized water was mixed with 0.1 g Co_3O_4 hexagonal nanosheets. The certain value of 1.5 M NaOH was poured as dropwise in the solution to adjust the pH=10. The obtained precipitation was heated up to a reaction temperature of 80 °C and was stirred for one hour. After completion of the reaction, the product was cooled to the ambient temperature and centrifuged at 3000 rpm for 15 min, followed by washing with water several times and vacuum drying at 60 °C overnight. The resulting black precipitate was La_2O_3/Co_3O_4 nanocomposite.

2.3. Real samples

Instantly upon being collected, urine samples were preserved inside a refrigerator, followed by the centrifugation of 10 ml of the sample at 3000 rpm for 15 min. The supernatant was diluted by PBS (pH=7.0) ten times. Without any further pretreatment, the solution was placed in a voltammetric cell for analysis. The standard addition method was applied for the cysteamine measurement within real samples.

Five capsules of cysteamine (labeled 50.0 mg per each capsule) were homogenized completely, and then 100 mg was dissolved with ultrasonication in 20 ml of water, filtered, transferred into a 100-ml volumetric flask, and diluted to the mark by 0.1 M PBS (pH=7.0). Finally, certain volume of the produced solutions was poured in electrochemical cell for the analysis of cysteamine. The sample was mixed with different amounts of cysteamine and analyzed with the aid of standard addition method to avoid any matrix effect.

2.4. Preparation of modified electrode

As revealed in the following, the bare SPE was coated with La_2O_3/Co_3O_4 nanocomposite. The preparation of stock solution of La_2O_3/Co_3O_4 nanocomposite was performed in 1 ml of the aqueous solution by dispersing 1 mg of La_2O_3/Co_3O_4 nanocomposite with ultrasonication for an hour, whilst 2 µl of aliquots of the $La_2O_3/Co_3O_4/H_2O$ suspension was poured in the carbon working electrodes and left for the solvent to evaporate under 25°C temperature.

3. RESULT AND DISCUSSION

3.1. Morphology and structure of La_2O_3/Co_3O_4 nanocomposite

The FT-IR spectra of La_2O_3/Co_3O_4 nanocomposite sample within frequencies between 400 cm^{-1} and 4000 cm^{-1} are shown in Fig. 1. According to the FT-IR spectrum of La_2O_3/Co_3O_4 nanocomposite, strong vibrational bands were appeared in the lower frequency regions of 449 and 520 cm^{-1}, related to the vibration of metal–O. The absorption at ~3417 cm^{-1} was related to the symmetric vibration of the -OH groups in the absorbed molecules of H_2O [35].

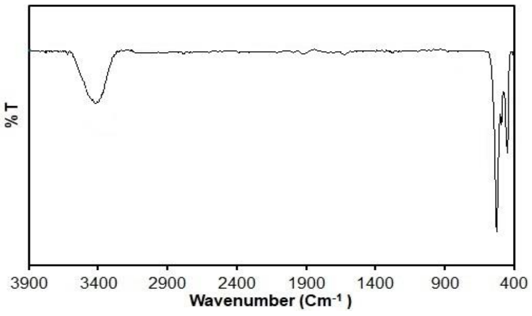


Fig. 1. FT-IR image of La_2O_3/Co_3O_4 nanocomposite.

The X-ray diffraction (XRD) pattern of La_2O_3/Co_3O_4 nanocomposite shown in Fig. 2 means the match of all main diffraction peaks with the standard peak of this sample. For La_2O_3/Co_3O_4 nanocomposite, the diffraction peaks at 31.7°, 36.1°, 44.5°, 59.9° and 64.9° (JCPDS 74-2120) can be indexed to (220), (311), (400), (511) and (400) planes of Co_3O_4, the diffraction peaks at 15.1°, 28.5°, 29.1°, 39.8°, 49.1° and 55.2° (JCPDS 41-4019) can be indexed to (100), (002), (101), (102), (211) and (201) plane of La_2O_3, respectively [36,37].

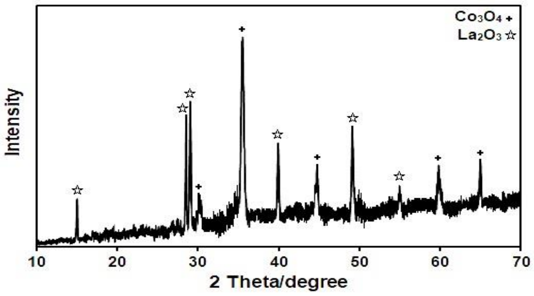


Fig. 2. XRD pattern of La_2O_3/Co_3O_4 nanocomposite.

The SEM was used to evaluate the product morphology. Fig. 3 shows that Co_3O_4 nanosheets and La_2O_3 nanoparticles construct a La_2O_3/Co_3O_4 nanocomposite.

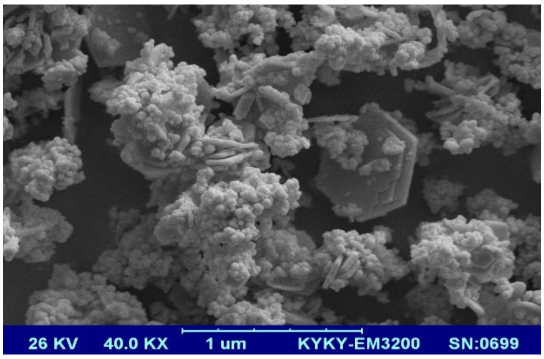


Fig. 3. SEM image of La_2O_3/Co_3O_4 nanocomposite.

3.2. Electrochemical behaviour of fabricated sensor

The pH of aqueous solution is effective on the cysteamine's electrochemical behaviour. Therefore, the solution pH was optimized to approach high accurate efficacy for electrooxidation of cysteamine. Accordingly, the electrochemical activity of cysteamine was examined in 0.1 M PBS with different values of pH from 2.0 to 9.0 at the exterior of La_2O_3/Co_3O_4/SPE via voltammetry. Evidently, neither acidic nor basic medium was appropriate for the electro-oxidation of cysteamine at the exterior of La_2O_3/Co_3O_4/SPE and best results obtained at neutral conditions. Accordingly, the optimal pH value was selected to be 7.0 for the cysteamine electro-oxidation at the exterior of La_2O_3/Co_3O_4/SPE.

The CV reactions for electro-oxidation of 100.0 µM of cysteamine at the La_2O_3/Co_3O_4/SPE (a) and unmodified SPE (b) are shown in Fig. 4. The peak potential on the surface of modified electrode was observed at 680 mV corresponding to the cysteamine oxidation, about 120 mV more negative than the bare SPE. Moreover, anodic peak current for the cysteamine oxidation at La_2O_3/Co_3O_4/SPE was much higher in comparison with the unmodified SPE, indicating to effectiveness of SPE modification with La_2O_3/Co_3O_4 nanocomposite in the cysteamine oxidation process. Moreover, the impact of potential scan rates concerning the cysteamine oxidation current was assessed, as seen in Fig. 5. Based on the outcome, increasing the potential scan rate cause an increment in the peak current. The linear relationship between anodic peak current (I_p) and the square root of the potential scan rate ($\nu^{1/2}$) during the oxidation of cysteamine demonstrated that the oxidation procedure is subject to diffusion control [38]. The electrocatalytic mechanism of cysteamine was shown in Scheme 2.

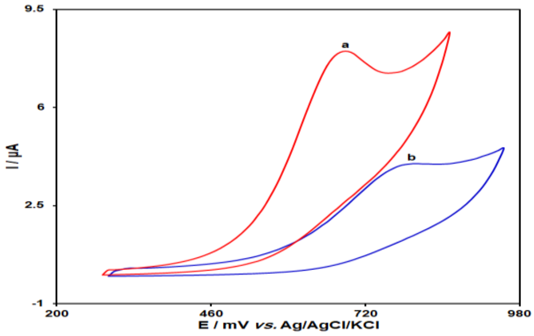


Fig. 4. CVs of La_2O_3/Co_3O_4/SPE (a)and unmodified SPE (b) in 0.1 M PBS (pH 7.0) consisting of 100.0 µM cysteamine. In every case the scan rate was 50 mV s^{-1}.

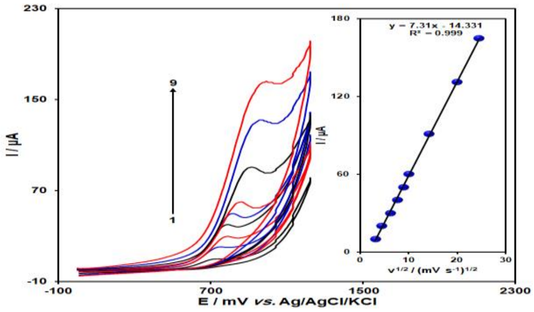
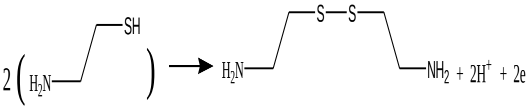


Fig. 5.CVs of La_2O_3/Co_3O_4/SPE in 0.1 M PBS (pH 7.0) consisting of 700.0 µM cysteamine at different scan rates; 10, 20, 40, 60, 80, 100, 200, 400 and 600 mV s^{-1}, respectively. Inset: Variation of anodic peak current *vs.* $\nu^{1/2}$.



Scheme 2. Electrocatalytic oxidation of cysteamine at the La_2O_3/Co_3O_4/SPE electrode.

3.3. The working curve and detection limit

The higher pulse techniques sensitivity for the CV occurs because of higher influential scan rates and the current design. The cysteamine in the solution can be determined using the cysteamine electro-oxidation peak currents at the exterior of La_2O_3/Co_3O_4/SPE. Due to further sensitivity and enhanced function of DPV in the analytical implementations, the DPV experiments were carried out using La_2O_3/Co_3O_4/SPE in 0.1 M PBS consisting of different cysteamine levels (Fig. 6).

The results revealed a linear dependency on the surface of La_2O_3/Co_3O_4/SPE between the electrocatalytic peak currents of cysteamine oxidation and its concentrations (Fig. 6) from 1.0 to 700.0 μM, whose correlation coefficient was 0.9984. Also, the detection limit (3σ) was 0.3 μM. These values can be compared those in other studies [39-43] for cysteamine electro-oxidation on the chemically modified electrode surface (Table 1).

Table 1. Comparison of the efficiency of electrochemical methods used in detection of cysteamine.

Electrode	Modifier	LOD (μM)	LDR (μM)	Ref.
Carbon Paste Electrode	Magnesium oxide nanoparticles and N-(4-hydroxyphenyl)-3-5-dinitrobenzamide	0.009	0.03-600.0	39
Multi wall carbon nanotube paste electrode	----	0.09	0.25-400	40
Carbon nanotube paste electrode	p-Aminophenol	0.15	0.5-300	41
Carbon Paste Electrode	NiO/CNT and (9,10-dihydro-9,10-ethanoanthracene-11,12-dicarboximido)-4-ethybenzene-1, 2-diol	0.007	0.01-250	42
Carbon nanotube paste electrode	Vinyl ferrocene	0.05	0.09-500	43
Screen Printed Electrode	La_2O_3/Co_3O_4 nanocomposite	0.3	1-700	This work

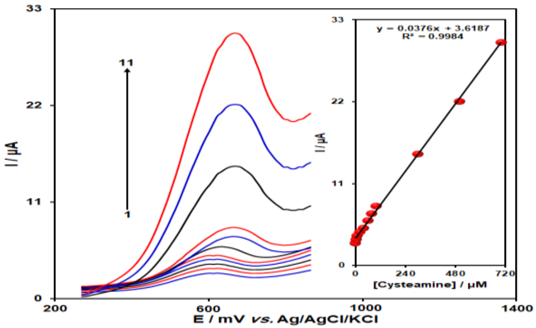


Fig. 6. DPVs of La_2O_3/Co_3O_4/SPE in 0.1 M PBS (pH 7.0) consisting of various concentrations of cysteamine 1.0, 5.0, 10.0, 20.0, 40.0, 60.0, 80.0, 100.0, 300.0, 500.0 and 700.0 μM. Inset:Plot of I *vs.* cysteamine concentrations.

3.4. Analysis of real samples

The systematic practicality of the suggested approach was evaluated through the quantification of cysteamine within systematic capsule and urine specimen using the standard addition approach. The outcomes for the cysteamine determination within systematic capsule urine samples are presented in Table 2. The test outcomes showed acceptable recoveries for cysteamine. The method reproducibility was investigated via the mean relative standard deviation (RSD).

The systematic amount in capsule was 50.4 mg/ capsule. The results showed no significant difference in the findings from the La_2O_3/Co_3O_4/SPE and the nominal value on the capsule label (50.0 mg/ capsule). The t-test results found no significant difference at the 95% confidence level.

Table 2. The application of La_2O_3/Co_3O_4/SPE for determination of cysteamine in capsule and urine samples (n=5). All concentrations are in μM.

Sample	Spiked, μM	Found, μM	Recovery, %	RSD, %
cysteamine capsule	0.0	30.2	---	2.4
	5.0	35.4	104.0	3.0
	10.0	39.9	97.0	2.7
	15.0	44.8	97.3	2.5
	20.0	50.6	102.0	2.8
Urine	0.0	----	-	-
	5.0	4.9	98.0	2.3
	10.0	10.2	102.0	3.1
	15.0	15.2	101.3	2.9
	20.0	19.9	99.5	2.2

3.5. The repeatability and stability of La_2O_3/Co_3O_4/SPE

Long lasting durability of the La_2O_3/Co_3O_4/SPE was evaluated within three weeks. Following the modification of electrode without application within three weeks stored at atmosphere for three weeks, the tests were performed repeatedly. The cyclic voltammograms revealed no change at the peak potential of cysteamine oxidation, with the exception of a decrement below 2.4 % when comparing with the first response.

The CVs were documented to evaluate antifouling characteristics of the adjusted electrode for cysteamine oxidation and related oxidation derivatives. The record of voltammograms was performed in the presence of cysteamine following the cycling of potential 12 times with a scanning rate of 50 mV s-1. According to the findings, there was no change in peak potentials and a decrement below 2.3 % in currents, as well as the use of modified La2O3/Co3O4/SPE elevated sensitivity and declined fouling effect of the analyte and related oxidation derivatives.

4. CONCLUSION

In this case, SPE modified with La_2O_3/Co_3O_4 nanocomposite was employed for the cysteamine determination. The electrochemical examinations presented influential electrocatalytic activity regarding the adjusted electrode in reducing the anodic overpotential for the cysteamine oxidation. A new voltammetric approach for the cysteamine detection is rapid, reproducible, sensitive, and can be exploited to analyze real samples.

Acknowledgements

The current study was conducted thanks to the support of Payame Noor University.

REFRENCESE

[1] J. Ogony, S. Mare, W. Wu, N. Ercal, High performance liquid chromatography analysis of 2-mercaptoethylamine (cysteamine) in biological samples by derivatization with *N*-(1-pyrenyl) maleimide (NPM) using fluorescence detection, *J. Chromatogr. B* 843 (2006) 57-62.

[2] K. Ngamdee, S. Kulchat, T. Tuntulani, W. Ngeontae, Fluorescence sensor based on d-penicillamine capped cadmium sulfide quantum dots for the detection of cysteamine, *J. Lumin.* 187 (2017) 260-268.

[3] H. Kataoka, Y. Imamura, H. Tanaka, M. Makita, Determination of cysteamine and cystamine by gas chromatography with flame photometric detection, *J. Pharm. Biomed. Anal.* 11 (1993) 963–969.

[4] T. Ahlenstiel-Grunow, N.K. Kanzelmeyer, K. Froede, M. Kreuzer, J. Drube, C. Lerch, L. Pape, Switching from immediate- to extended-release cysteamine in nephropathic cystinosis patients: a retrospective real-life single-center study, *Pediatr. Nephrol.* 32 (2017) 91–97.

[5] L.A. Smolin, J.A. Schneider, Measurement of total plasma cysteamine using high-performance liquid chromatography with electrochemical detection, *Anal. Biochem.* 168 (1988) 374–379.

[6] M. Stachowicz, B. Lehmann, A. Tibi, P. Prognon, V. Daurat, D. Pradeau, Determination of total cysteamine in human serum by a high-performance liquid chromatography with fluorescence detection, *J. Pharm. Biomed. Anal.* 17 (1998) 767–773.

[7] F. Chekin, R. Boukherroub, S. Szunerits, MoS_2/reduced graphene oxide nanocomposite for sensitive sensing of cysteamine in presence of uric acid in human plasma, *Mater. Sci. Eng. C* 73 (2017) 627–632.

[8] D. Singh Swami, P. Kumar, R.K. Malik, M. Saini, D. Kumar , M.H. Jan, Cysteamine supplementation revealed detrimental effect on cryosurvival of buffalo sperm based on computer-assisted semen analysis and oxidative parameters, *Anim. Reprod. Sci.* 177 (2016) 56–64.

[9] A.J. Jonas, J.A. Schneider, A simple, rapid assay for cysteamine and other thiols. Analytical Biochemistry, *Anal. Biochem.* 114 (1981) 429–432.

[10] H. Kataoka, H. Tanaka, M. Makita, Determination of total cysteamine in urine and plasma samples by gas chromatography with flame photometric detection, *J. Chromatogr. B* 657 (1994) 9-13.

[11] M. Hsiung, Y.Y. Yeo, K. Itiaba, J.C. Crawhall, Cysteamine, penicillamine, glutathione, and their derivatives analyzed by automated ion exchange column chromatography, *Biochem. Med.* 19 (1978) 305–317.

[12] A. Özcan, D. Topçuoğulları, Voltammetric determination of 17-β-estradiol by cysteamine self-assembled gold nanoparticle modified fumed silica decorated graphene nanoribbon nanocomposite, *Sens. Actuators B* 250 (2017) 85–90.

[13] T.F. Yuan, S.T. Wang, Y. Li, Quantification of menadione from plasma and urine by a novel cysteamine-derivatization based UPLC–MS/MS method, *J. Chromatogr. B* 1063 (2017) 107-111.

[14] A. Wong, A.M. Santos, O. Fatibello-Filho, Simultaneous determination of dopamine and cysteamine by flow injection with multiple pulse amperometric detection using a boron-doped diamond electrode, *Diam. Relat. Mater.* 85 (2018) 68–73.

[15] M. Saraji, M. Khalili Boroujeni, A.A.H. Bidgoli, Comparison of dispersive liquid–liquid microextraction and hollow fiber liquid–liquid–liquid microextraction for the determination of fentanyl, alfentanil, and sufentanil in water and biological fluids by high-performance liquid chromatography, *Anal. Bioanal. Chem.* 400 (2011) 2149-2153.

[16] S. Tajik, M.A. Taher, First Report for Electrochemical Determination of Levodopa and Cabergoline: Application for Determination of Levodopa and Cabergoline in Human Serum, Urine and Pharmaceutical Formulations, *Electroanalysis* 26 (2014) 796-806.

[17] G. Buica, L. Lazar, E. Saint-Aman, V. Tecuceanu, C. Dumitriu, I. Anton, A. Stoian, E. Ungureanu, Ultrasensitive modified electrode based on poly(1*H*-pyrrole-1-hexanoic acid) for Pb(II) detection, *Sens. Actuators B* 246 (2017) 434-443.

[18] S.Z. Mohammadi, H. Beitollahi, M. Hassanzadeh, Voltammetric determination of tryptophan using a carbon paste electrode modified with magnesium core shell nanocomposite and ionic liquids, *Anal. Bioanal. Chem.* 5 (2018) 55-65.

[19] M. Mazloum-Ardakani, H. Beitollahi, B. Ganjipour, H. Naeimi, Novel Carbon Nanotube Paste Electrode for Simultaneous Determination of Norepinephrine, Uric Acid and D-Penicillamine, *Inter. J. Electrochem. Sci.* 5 (2010) 531–546.

[20] H. Parham, N. Rahbar, Square wave voltammetric determination of methyl parathion using ZrO_2-nanoparticles modified carbon paste electrode, *J. Hazard. Mater.* 177 (2010) 1077-1084.

[21] H. Karimi-Maleh, M. Moazampour, H. Ahmar H. Beitollahi, A.A. Ensafi, A sensitive nanocomposite-based electrochemical sensor for voltammetric simultaneous determination of isoproterenol, acetaminophen and tryptophan, *Measurement* 51 (2014) 91-99.

[22] S.Z. Mohammadi, H. Beitollahi, H. Fadaeian, Voltammetric Determination of Isoproterenol using a Graphene Oxide Nano Sheets Paste Electrode, *J. Anal. Chem.* 73 (2018) 705-712.

[23] E. Molaakbari, A. Mostafavi, H. Beitollahi, Simultaneous electrochemical determination of dopamine, melatonin, methionine and caffeine, *Sens. Actuat. B* 208 (2015) 195-203.

[24] R. Suresh, R. Prabu, A. Vijayaraj, K. Giribabu, A. Stephen, V. Narayanan, Fabrication of α-Fe_2O_3 Nanoparticles for the Electrochemical Detection of Uric Acid, *Synth. React. Inorg. Met. Org. Chem.* 42 (2012) 303-307.

[25] S.Z. Mohammadi, H. Beitollahi, N. Mohammad Rahimi, Voltammetric Determination of Epinephrine and Uric Acid Using Modified Graphene Oxide Nano Sheets Paste Electrode, *J. Anal. Chem.* 74 (2019) 345–354.

[26] H. Beitollahi, F. Garkani-Nejad, Graphene Oxide/ZnO Nano Composite for Sensitive and Selective Electrochemical Sensing of Levodopa and Tyrosine Using Modified Graphite Screen Printed Electrode, *Electroanalysis* 28 (2016) 2237-2244.

[27] S.Z. Mohammadi, A. Seyedi, Preconcentration of cadmium and copper ions on magnetic core–shell nanoparticles for determination by flame atomic absorption, Toxicol. Environ. Chem. 98 (2016) 705-713.

[28] S.Z. Mohammadi, H. Beitollahi, M. Mousavi, Determination of Hydroxylamine Using a Carbon Paste Electrode Modified with Graphene Oxide Nano Sheets, *Rus. J. Electrochem.* 53 (2017) 374-379.

[29] H. Beitollahi, H. Karimi-Maleh, H. Khabazzadeh, Nanomolar and selective determination of epinephrine in the presence of norepinephrine using carbon paste electrode modified with carbon nanotubes and novel 2-(4-oxo-3-phenyl-3, 4-dihydro-quinazolinyl)-N′-phenyl-hydrazinecarbothioamide, *Anal. Chem.* 80 (2008) 9848-9851.

[30] J.P. Metters, R.O. Kadara, S.E. Banks, New directions in screen printed electroanalytical sensors: an overview of recent developments, *Analyst* 136 (2011) 1067-1076.

[31] S.Z. Mohammadi, H. Beitollahi, N. Nikpour, R. Hosseinzadeh, Electrochemical Sensor for Determination of Ascorbic Acid Using a 2Chlorobenzoyl Ferrocene/Carbon Nanotube Paste Electrode, *Anal. Bioanal. Chem. Res.* 3 (2016) 187-194.

[32] H. Mahmoudi-Moghaddam, H. Beitollahi, S. Tajik, Sh. Jahani, H. Khabazzadeh, R. Alizadeh, Voltammetric determination of droxidopa in the presence of carbidopa using a nanostructured base electrochemical sensor, *Rus. J. Electrochem.* 53 (2017) 452-460.

[33] H. Jo, J. Her, H. Lee, Y. B. Shim, C. Ban, Highly sensitive amperometric detection of cardiac troponin I using sandwich aptamers and screen-printed carbon electrodes, *Talanta* 165 (2017) 442-448.

[34] M.R. Ganjali, F. Garkani- Nejad, H. Beitollahi, Sh. Jahani, M. Rezapour, B. Larijani, Highly Sensitive Voltammetric Sensor for Determination of Ascorbic Acid Using Graphite Screen Printed Electrode Modified with ZnO/Al_2O_3 Nanocomposite, *Int. J. Electrochem. Sci.* 12 (2017) 3231-3240.

[35] F. Khosrow-pour, M. Aghazadeh, B. Sabour, S. Dalvand, Large-scale synthesis of uniform lanthanum oxide nanowires via template-free deposition followed by heat-treatment, *Ceramics Int.* 39 (2013) 9491-9498.

[36] F.L.S. Carvalho, Y.J.O. Asencios, A.M.B. Rego, E.M. Assaf, Hydrogen production by steam reforming of ethanol over $Co_3O_4/La_2O_3/CeO_2$ catalysts synthesized by one-step polymerization method, *Appl. Catal. A* 483 (2014) 52-59.

[37] Y. Xu, Y. Peng, X. Zheng, K.D. Dearn, H. Xu, X. Hu, Synthesis and tribological studies of nanoparticle additives for pyrolysis bio-oil formulated as a diesel fuel, *Energy* 83 (2015) 80-88.

[38] A.J. Bard, L.R. Faulkner, Electrochemical Methods: Fundamentals and Applications, Second ed., Wiley, New York (2001).

[39] V. Arabali, H. Karim-Maleh, Electrochemical determination of cysteamine in the presence of guanine and adenine using a

carbon paste electrode modified with N- (4-hydroxyphenyl)-3,5-dinitrobenzamide and magnesium oxide nanoparticles, *Anal. Method* 8 (2016) 5604-5610.

[40] M. Keyvanfard, S. Sami, H. Karimi-Maleh, K. Alizad, Electrocatalytic determination of cysteamine using multiwall carbon nanotube paste electrode in the presence of 3,4-dihydroxycinnamic acid as a homogeneous mediator, *J. Brazil. Chem. Soc.* 24 (2013) 32-39.

[41] A.A. Ensafi, H. Karimi-Maleh, A voltammetric sensor based on modified multiwall carbon nanotubes for cysteamine determination in the presence of tryptophan using p-aminophenol as a mediator, *Electroanalysis* 22 (2010) 2558–2568.

[42] H. Karimi-Maleh, P. Biparva, M. Hatami, A novel modified carbon paste electrode based on NiO/CNTs nanocomposite and (9,10-dihydro-9,10-ethanoanthracene-11,12-dicarboximido)-4-ethybenzene-1, 2-diol as a mediator for simultaneous determination of cysteamine, nicotinamide adenine dinucleotide and folic acid, *Biosens. Bioelectron.* 48 (2013) 270-275.

[43] M. Keyvanfard, A.A. Ensafi, H. Karimi-Maleh, A new strategy for simultaneous determination of cysteamine in the presence of high concentration of tryptophan using vinylferrocene-modified multiwall carbon nanotubes paste electrode”, *J. Solid State Electrochem.* 16 (2012) 2949–2955.