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Nanostructured Modified Electrode for Electrocatalytic Determination of Epinephrine in the Presence of Acetaminophen

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Abstract

In this paper, a nanostructured modified electrode was fabricated by incorporating of 2,2′-[1,9-nonanediylbis(nitriloethylidyne)]-bis-hydroquinone (NNH) as a newly synthesized modifier and TiO_2 nanoparticles to the carbon paste (MTCPE) and then was used for the electroanalysis of epinephrine (EP). The electrochemical studies were carried out by using cyclic voltammetry, chronoamperometry and differential pulse voltammetry (DPV) techniques. It has been found that the oxidation of EP at the surface of this electrode occurs at a potential about 235 mV less positive than that of an unmodified carbon paste electrode. A dynamic range of 1.0–2000.0 μM, with a detection limit of 0.37 μM for EP, was obtained using DPV. Also, this modified electrode exhibits well separated oxidation peaks for EP and acetaminophen (AC) using DPV.

1. Introduction

Chemically modified electrodes can be used as successful chemical sensors due to the electrode surfaces can be customized to achieve the needed selectivity or sensitivity [1]. Chemical modifiers incorporated in the carbon paste electrodes give smart properties such as ease of modification, renewable surface and low cost [2, 3].

Recent researches have focused on the growth of nanomaterials applied in analytical chemistry for its special physicochemical properties [4]. Many kinds of nanomaterials, including nanoparticles, have been widely used in electrochemical sensors and biosensors. These nanomaterials play different roles

in different electrochemical sensing systems based on their unique properties [5-7].

Epinephrine (EP, 1-(3,4-dihydroxyphenyl)-2-methyloaminoethanol), a hormone secreted by the medulla of adrenal glands, is an important catecholamine neurotransmitter in the mammalian central nerves system. The changes in its concentration may result in many diseases [8, 9]. Therefore, the quantitative determination of EP is important in different human fluids. The analytical methods employed for the determination of EP are based on chromatographic techniques using different detection systems [10, 11]. These methods often require several previous sample preparation steps to obtain a final extract completely compatible with chromatographic determination which makes the procedure more complicated and more expensive. Electrochemical methods have a number of advantages as: low cost, high sensitivity, easy operation and on-site monitoring [12]. Therefore the electrochemical analysis of EP has developed in recent years [13].

Acetaminophen (AC, N-acetyl-p-aminophenol), is an antipyretic and minor analgesic drug which practically has no anti-inflammatory action. It is an effective and safe analgesic agent used worldwide for the relief of mild to moderate pain associated with headaches, backaches, arthritis, and postoperative pains [14]. Unfortunately, owing to its easy accessibility, the use of AC in suicide attempts and overdoses has been increased. It is known that overdoses will cause serious or fatal liver and kidney damage [15]. So a quantitative determination of AC concentration is useful for nerve physiology, pharmacological research and life science. Current methods for the analysis of acetaminophen include titrimetry [16], spectrophotometry [17], chromatography [18], and electrochemical approaches [19]. However, the development of a simple, specific, sensitive, and inexpensive method for determination of EP and AC is yet highly desirable.

In continuation of our previous studies on the preparation of modified electrodes [20, 21], and on the simultaneous determination of EP and AC [22, 23], we described in the present work, initially the use of NNH as a new mediator and TiO_2 nanoparticles as an effective material for preparation of MTCPE and then the electrocatalysis of EP in the presence of AC.

2. Experimental

2.1 Materials and apparatus

All solutions were freshly prepared with doubly distilled water. Buffer solutions were prepared from ortho-phosphoric acid and its salts in pH range of 2.0 – 12.0 in concentration of 0.1 M. EP, AC and other reagents were analytical grade (Merck, Darmstadt). TiO_2 nanoparticles and (NNH) were synthesized in laboratory.

A potentiostat/galvanostat (SAMA 500, electroanalyzer system, I.R. Iran) was used for carrying out the electrochemical experiments. A three electrode cell was used at 25 ± 1°C. A saturated calomel electrode, platinum wire, and MTCPE were used as reference, auxiliary and working electrodes, respectively. A Metrohm model 691 pH/mV meter was also used for pH measurements.

2.2. Synthesis of TiO_2 nanoparticles

Colloidal suspension of TiO_2 nanoparticles was synthesized by mixing titaniumtetraisopropoxide (Merck), H_2O_2 (Merck), and H_2O, with volume proportions of 12:90:200, respectively. The resulting

solution was refluxed for 10 h to promote the crystallinity (surface area = 84 m^2 g^{-1}).

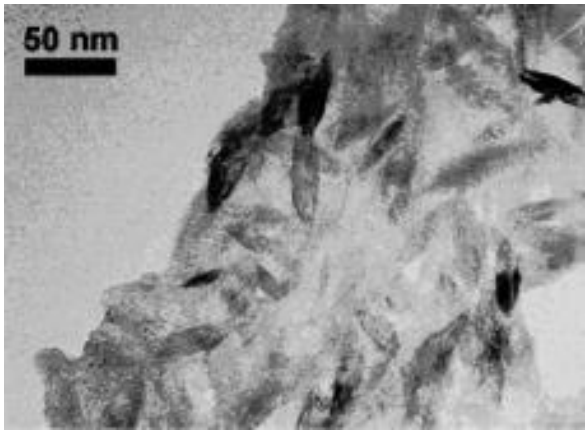

Fig. 1.TEM image of TiO_2 nanoparticles.

Fig. 1 shows typical TEM images of nanoparticles. The particles are elongated with average long and short axis sizes of 54 and 15 nm. The crystalline phase has been verified as pure anatase using X-ray diffraction. Anatase is the photocatalytically most active crystalline phase of TiO_2.

2.3. Preparation of the electrode

MTCPE were prepared by mixing 0.01 g of NNH and hand mixing with 95 times its weight of graphite powder and 4 times its weight of TiO_2 nanoparticles using a mortar and pestle. Paraffin was added to the above mixture and mixed for 20 min until a uniformly wetted paste was obtained. This paste was then packed into the end of a glass tube (ca. 3.6 mm i.d. and 10 cm long). A copper wire inserted into the modified carbon paste provided an electrical contact. The NNH-modified CPE (MCPE), TiO_2 nanoparticles CPE (TCPE) and unmodified carbon paste (CPE) were prepared in the same way but without adding TiO_2 nanoparticles, NNH and both of them respectively.

3. Results and discussion

Study on the electrochemical properties of NNH in aqueous media was investigated by cyclic voltammetry. This compound is insoluble in aqueous media; therefore, we prepared MTCPE by incorporating NNH together TiO_2 nanoparticles into CPE and studied its electrochemical properties in a buffered aqueous solution (pH 7.0) using cyclic voltammetry. Cyclic voltammograms of MTCPE exhibited an anodic peak and corresponding cathodic peak *(*E_{pa} = 0.210 V, E_{pc} = 0.140 V, $E_{1/2}$ = 0.175 V versus SCE and ΔE_p = 0.07 V). The peak separation potential, $\Delta E_p = (E_{pa} - E_{pc})$, was greater than the 59/n mV expected for a reversible system. This result suggests that redox couple in MTCPE shows quasi-reversible behavior in an aqueous medium.

The effect of the potential scan rate on electrochemical properties of the MTCPE was studied in an aqueous solution with cyclic voltammetry (Fig. 1a). Plots of the anodic peak currents (I_p) were linearly dependent on ν at scan rates from 10 to 1800 mV s^{-1}. A linear correlation was obtained between peak currents and the scan rate indicates that the nature of redox process was controlled in a surface-confined manner (Fig. 1b).

The charge transfer coefficient, α, of a surface-confined redox couple can be evaluated from cyclic voltammetric experiments and by using the variation of anodic peak potentials with logarithm of scan rate, according to the procedure of Laviron [24].

The E_{pa} values are proportional to the logarithm of the potential scan rate, for scan rates higher than 300 mV s^{-1} (Fig. 1c). The slope of the linear segment is equal to $2.303RT/(1 - \alpha)nF$for the anodic peak. The evaluated value for the anodic transfer coefficients (αa) is 0.36.

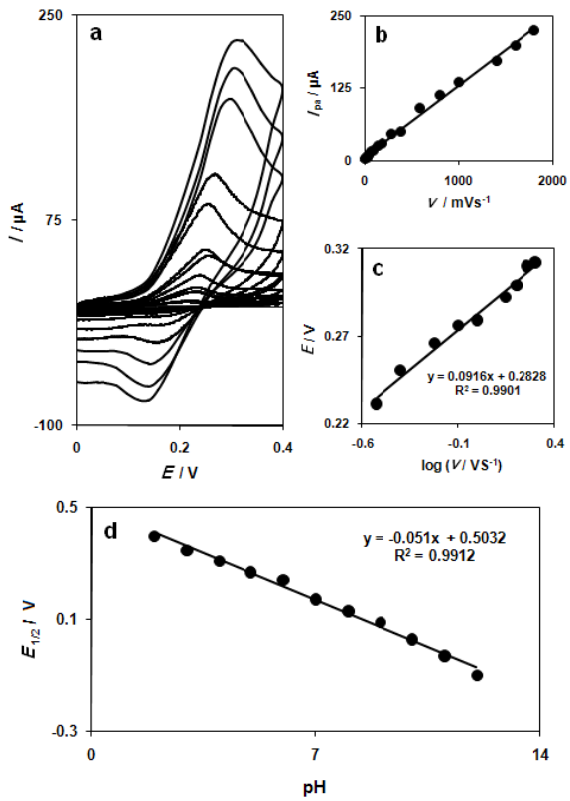

Fig. 2. (a) Cyclic voltammograms of MTCPE in 0.1 M phosphate buffer (pH 7.0) at various scan rates: from 10 to 1800 mV s^{-1}, (b) Variations of I_{pa} versus scan rate, (c) Variation of E_{pa} versus the logarithm of scan rate for scan rates higher than 300 mVs^{-1}, (d) Variations of $E_{1/2}$ versus pH.

The cyclic voltammetry of the MTCPE was studied at different pHs to investigate the pH-dependence of NNH molecule. Anodic and cathodic peak potentials of the MTCPE were shifted to less positive values with increases in pH. A potential-pH diagram was constructed by plotting the calculated $E_{1/2}$ values as a function of pH (Fig. 1d). This diagram is composed of a straight line with slope of 0.051 V/pH. Such behavior suggests that it confirm the Nernst equation for a two electron and two proton transfer reaction [25].

The cyclic voltammetric responses of the electrochemical oxidation of 1.0 mM EP at the modified carbon paste electrode (MCPE) (curve a), MTCPE (curve b), TiO_2 nanoparticles carbon paste electrode (curve d) and unmodified CPE (curve c) shown in Fig. 2. As shown, the anodic peak potential for EP oxidation at the MCPE (curve a) and MTCPE (curve b) was about 210 mV, while at the TCPE (curve d) and at the unmodified CPE (curve c), the peak potential was about 390 mV and 445 mV, respectively. From these results, it was concluded that the best electrocatalytic effect for EP oxidation was observed at the MTCPE (curve b). The peak potential of EP oxidation at the MTCPE (curve b) shifted by about 180 and 235 mV toward negative values when compared with that at the TCPE (curve d) and unmodified carbon paste electrode (curve c), respectively.

Similarly, when comparing the oxidation of EP at the MCPE (curve a) and MTCPE (curve b), a dramatic enhancement of the anodic peak current at the MTCPE relative to that obtained at the MCPE was observed. In other words, the data clearly show that the combination of TiO_2 nanoparticles and mediator NNH definitely improve the characteristics of EP oxidation.

The effect of scan rate on the electrocatalytic oxidation of EP at the MTCPE was investigated by cyclic voltammetry. The CVs of EP oxidation at the MTCPE for different scan rates show in Fig. 3a. The plot of peak height (I_p) versus the square root of scan rate ($v^{1/2}$), in the range of 5–75 mV s^{-1}, was constructed (Fig. 3b).

This plot was found to be linear, suggesting that, at sufficient overpotential, the process was diffusion rather than surface controlled. A plot of the sweep rate normalized current ($I_p/v^{1/2}$) versus sweep rate (Fig. 3c) exhibits the characteristic shape typical of an EC′ process [25].

Fig. 3d, shows a Tafel plot that was drawn from data of the rising part of the current–voltage curve recorded at a scan rate of 20 mV s^{-1}. This part of

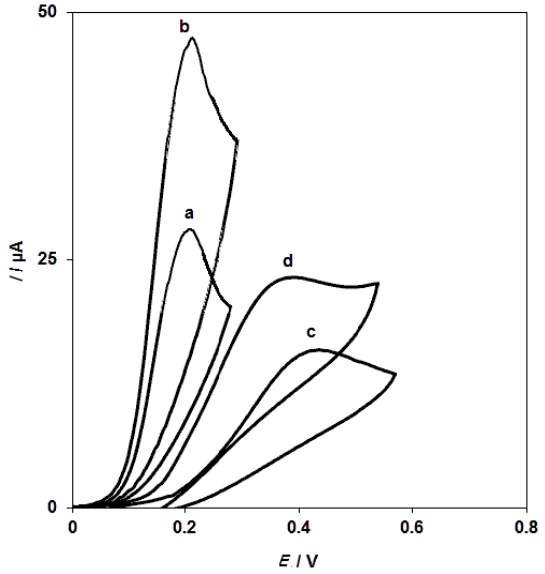

Fig. 3. Cyclic voltammograms of (a) MCPE, (b) MTCPE,(c) unmodified CPE and (d) TCPE in 1.0 mM EP solution (pH 7.0); scan rate is 20 mV s^{-1}.

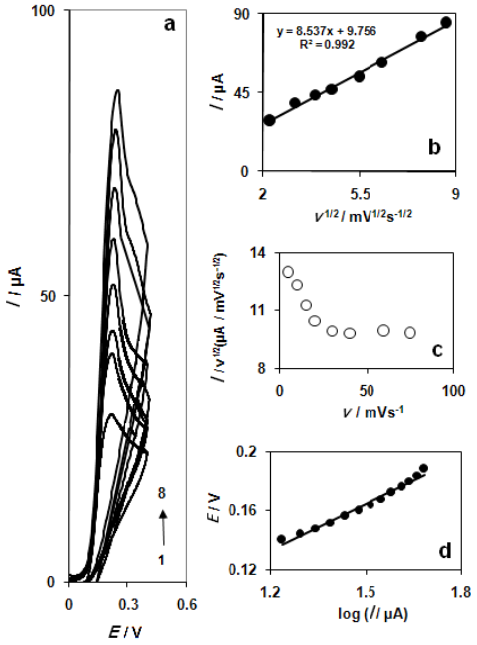

Fig. 4. (a) Cyclic voltammograms of MTCPE in 0.1 M phosphate buffer (pH 7.0) containing 1.0 mM EP at different scan rates; the numbers 1 to 8 correspond to 5, 10, 15, 20, 30, 40, 60 and 75 mV s^{-1}, (b) Variation of the electrocatalytic currents vs. the square root of scan rate, (c) Variation of the scan rate normalized current (I_p/v) with scan rate, (d) Tafel plot derived from the rising part of the voltammogram recorded at the scan rate of 20 mV s^{-1}.

voltammogram is affected by electron transfer kinetics between EP and surface confined NNH, assuming the deprotonation of substrate as a sufficiently fast step. In this condition, the number of electron involved in the rate determining step can be estimated from the slope of Tafel plot. A slope 0.105 V $decade^{-1}$ is obtained indicating a one electron transfer to be rate limiting assuming a transfer coefficient of $\alpha = 0.44$.

The chronoamperometry was employed for the investigation of electrode processes at chemically modified electrodes. For an electroactive material with a diffusion coefficient of D, the current for the electrochemical reaction (at a mass transport limited rate) is described by the Cottrell equation [25]. Under diffusion control, a plot of Iversus $t^{-1/2}$ will be linear, and from the slope the value of D can be obtained.

Double-step potential chronoamperometry for different concentrations of EP at MTCPE were carried out by adjusting the working electrode potential at 250 mV (first step) and 0 mV (second step), the results shown in Fig. 4. Inset (a) of Fig. 4 shows the I-$t^{-1/2}$ plots with the best fits for different concentration of EP. The slopes of the resulting straight lineswere plotted versusthe EPconcentration (Fig. 4b). Thevalue of the D was found to be 5.78×10^{-6} cm^2 s^{-1}.

Chronoamperometry can also be employed to evaluate the catalytic rate constant, k, for the reaction between EP and the MTCPE according to the method of Galus [26]:

$$I_C/I_L = \pi^{1/2}\gamma^{1/2} = \pi^{1/2}(kC_bt)^{1/2}$$

Where I_C is the catalytic current of EP at the MTCPE, I_L the limited current in the absence of EP, $\gamma = kC_b t$, t is the time elapsed andC_b is the bulk concentration of EP. The above equation can be used to calculate the rate constant of the catalytic process k. Based on the slope of the I_C/I_L versus $t^{1/2}$plot; k can be obtained for a given EP concentration.

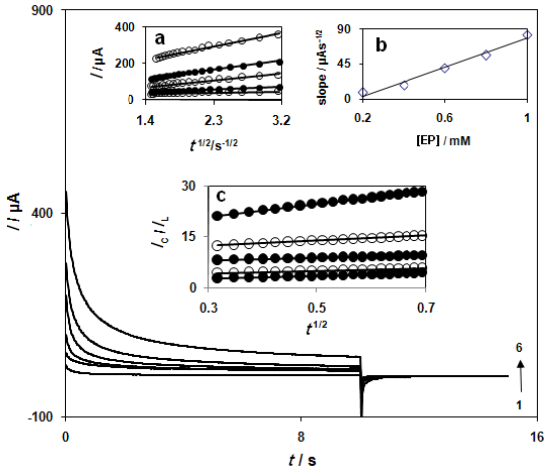

Fig. 5. Chronoamperograms obtained at MTCPE in 0.1 M phosphate buffer solution (pH 7.0) for different concentration of EP. The numbers 1–6 correspond to 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 mM of EP. Insets: (a) plots of I vs. $t^{-1/2}$ obtained from chronoamperograms 2–6, (b) plot of the slope of the straight lines against the EP concentration and (c) dependence of I_{cat}/I_l on $t^{1/2}$ derived from the data of chronoamperograms.

Such plots obtained from the chronoamperograms in Fig. 4 are shown in Fig. 4c. From the values of the slopes an average value of k was found to be k= 3.6×10^4 M^{-1} s^{-1}.The value of k explains as well as the sharp feature of the catalytic peak observed for catalytic oxidation of EP at the surface of MTCPE.

Differential pulse voltammetry was used to determine the concentration of EP. Voltammograms clearly show that the plot of peak current versus EP concentration is constituted of two linear segments with different slopes (slope: 0.371 µA μM^{-1} for first linear segment and 0.044 µA μM^{-1} for second linear segment), corresponding to two different ranges of substrate concentration, 1.0 to 30.0 µM for first linear segment and 30.0 to 2000.0 µM for second linear segment (Fig. 5 insets (a) and (b)). The decrease of sensitivity (slope) in the second linear range is likely to be due to kinetic limitation. The detection limit (3σ) for EP in the lower range region was found to be 0.37 µM.

As the one objective of this study, the utilization of the MTCPE for the simultaneous determination of EP and AC was demonstrated by simultaneously changing their concentrations. The DPV results show that the simultaneous determination of EP and AC, with two well-distinguished anodic peaks at potentials of 145 and 390 mV, corresponding to the oxidation of EP and AC, respectively, was possible at the MTCPE (Fig. 5). Rather the bare electrode could not separate the voltammetric signals of EP and AC.

The calibration plots of EP and AC shown in insets of Fig. 5. The sensitivities of the MTCPE towards EP in the absence and presence of AC are virtually the same, indicative that the oxidation processes of EP and AC at the MTCPE are independent. Therefore, simultaneous or independent measurements of the two analytes are possible without any interference. The linear range of calibration curve and the detection limit (3σ) for AC are 100.0-1200.0 µM and 5.0 µM respectively.

The proposed MTCPE was found to work well under laboratory conditions. The electrode was also successfully applied to the direct determination of EP content of ampoule samples. The EP was determined by the multi-point standard addition method in order to prevent of any matrix effect. The results and recovery percent for the analysis of ampoule samples with the DPV method are in the range of 98.4-100.1%.

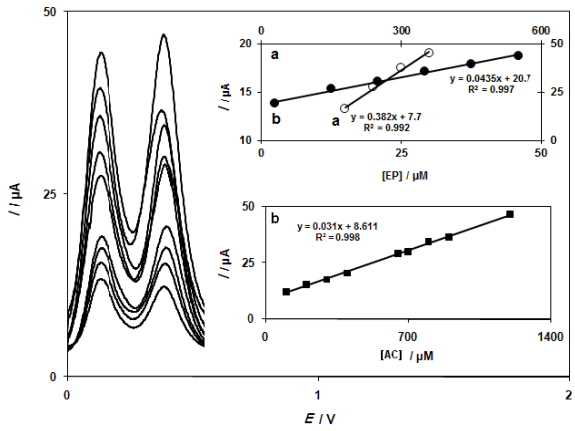

Fig. 6. Differential pulse voltammograms of MTCPE in 0.1 M phosphate buffer solution (pH 7.0) containing different concentrations of EP and AC, (from inner to outer) mixed solutions of 15.0 + 100.0, 20.0 + 200.0, 25.0 + 300.0, 30.0+ 400.0, 150.0 + 650.0, 250 + 700.0, 350.0 + 800.0, 450.0 + 900.0 and 550.0 + 1200.0, respectively, in which the first value is concentration of EP and the second value is concentration of AC in µM. Insets: (a) curve a and b are plots of the peak currents as a function of EP concentrations for tow linear region, (b) plots of the peak currents as a function of AC concentrations.

Also, for investigation of applicable of MTCPE for simultaneous determination of EP and AC in real sample, this electrode applied in mixture solutions. The recovery percent for EP and AC in synthetic solutions using MTCPE by standard addition method are in the range of 97.8-102.1% and 97.1-102.5%, respectively.

4. Conclusion

This work describes the construction of a nanostructured chemically modified carbon paste electrode by the incorporation of NNH and TiO_2 nanoparticles as a modifying species. Electrochemical studies show that the oxidation of EP is catalyzed at pH 7.0, whereas, the peak potential of EP is shifted by 235 mV to a less positive potential at the surface of MTCPE. The detected potential differences of 245 mV between EP and AC, was large enough to determine this tow compound individually and simultaneously. Therefore, the electrocatalytic oxidation of EP and the separation of EP and AC peaks at the surface of this modified electrode can be employed as a new method for the voltammetric determination of EP and AC in real samples.

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References

[1] M. Mazloum-Ardakani, M.A. Sheikh-Mohseni, A. Benvidi, Electroanalysis, 23 (2011) 2822–2831.

[2] M. Mazloum-Ardakani, H. Beitollahi, M.A. Sheikh-Mohseni, H. Naeimi, N. Taghavinia, Appl. Catal. A. Gen. 378 (2010) 195–201.

[3] M. Mazloum-Ardakani, H. Beitollahi, M.K. Amini, F. Mirkhalf, B.B.F. Mirjalili, Biosens.Bioelectron. 26 (2011) 2102–2106.

[4] C.B. Jacobs, M.J. Peairs, B.J. Venton, Anal. Chim.Acta 662 (2010) 105–127.

[5] M.Mazloum-Ardakani, M.A. Sheikh-Mohseni, H.Beitollahi, A.Benvidi, H. Naeimi, Chin. Chem.Lett. 21 (2010) 1471–1474.

[6] J. Wang, R.P. Deo, P. Poulin, M. Mangey, J. Am. Chem. Soc. 125 (2003) 14706–14707.

[7] M. Mazloum-Ardakani, A. Talebi, H. Naeimi, M.A. Sheikh-Mohseni, Anal. Methods 3 (2011) 2328–2333.

[8] W.A. Banks, Brain Res. 899 (2001) 209–217.

[9] C.G. Amorim, A.N. Araujo, M.C.B.S.M. Montenegro, Talanta 72 (2007) 1255–1260.

[10] I.A. Macdonald, D.M. Lake, J. Neurosci. Methods 13 (1985) 239–248.

[11] C. Sabbioni, M.A. Saracino, R. Mandrioli, S. Pinzauti, S. Furlanetto, G. Gerra, M.A. Raggi, J.Chromatogr. A 1032 (2004) 65–71.

[12] M.Mazloum-Ardakani, H.Beitollahi, M.K.Amini, B.B.F.Mirjalili, F.Mirkhalf, J.Electroanal. Chem. 651 (2011) 243–249.

[13] H. Beitollahi, M. Mazloum-Ardakani, B. Ganjipour, H. Naeimi, Biosens. Bioelectron. 24 (2008) 362–368.

[14] R.M. De-Carvalho, R.S. Freire, S. Rath, L.T. Kubota, J. Pharm. Biomed.Anal. 34 (2004) 871–878.

[15] B.D. Clayton, Y.N. Stock, Basic pharmacology for nurses,2001, St. Louis: Mosby Inc Harcourt Health Sciences Company.

[16] G. Burgot, F. Auffret, J.L. Burgot, Anal.Chim.Acta 343 (1997) 125–128.

[17] N. Erk, Y. Ozkan, E. Banoglu, S.A. Ozkan, Z.Senturk, J. Pharm. Biomed. Anal. 24 (2001) 469–475.

[18] D.J. Speed, S.J. Dickson, E.R. Cairns, N.D. Kim,J. Anal. Toxicol. 25 (2001) 198–202.

[19] M. Mazloum-Ardakani, H. Beitollahi, M.K. Amini, F. Mirkhalaf, M.Abdollahi-Alibeik, Sens. Actuators B Chem. 151 (2010) 243–249.

[20] M. Mazloum-Ardakani, Z. Taleat, H. Beitollahi, H. Naeimi, J. Iran. Chem. Soc. 7 (2010) 251–259.

[21] M. Mazloum-Ardakani, M.A. Sheikh-Mohseni, H. Beitollahi, A. Benvidi, H. Naeimi, Turk. J. Chem.35 (2011) 573–585.

[22] M. Mazloum-Ardakani, H. Beitollahi, M.K. Amini, F. Mirkhalaf, M. Abdollahi-Alibeik, Anal. Methods3 (2011) 673–677.

[23] M. Mazloum-Ardakani, H. Beitollahi, M.A. Sheikh Mohseni, A. Benvidi, H. Naeimi, M. Nejati-Barzoki, N. Taghavinia, Colloids Surf. B76 (2010) 82–87.

[24] E. Laviron, J. Electroanal. Chem.101 (1979) 19–28.

[25] A.J. Bard, L.R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2001, Wiley, New York.

[26] Z. Galus, Fundamentals of Electrochemical Analysis, 1976, Ellis Horwood, New York.