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Speciation of Sb(III) and Sb(V) in meglumine antimoniate pharmaceutical formulations by PSA using carbon nanotube electrode

Vivian Silva Santos[a], Wilney de Jesus Rodrigues Santos[b], Lauro Tatsuo Kubota[b], César Ricardo Teixeira Tarley[a,*]

[a] Departamento de Ciências Exatas, Universidade Federal de Alfenas, Unifal-MG, Alfenas 37130-000, MG, Brazil
[b] Departamento de Química Analítica, Instituto de Química, Universidade Estadual de Campinas, Unicamp, Campinas 13083-970, SP, Brazil

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ABSTRACT

A new and simple electroanalytical method for speciation of Sb(III) and Sb(V) in pharmaceutical formulation by potentiometric stripping analysis (PSA) using a multiwall carbon nanotube paste electrode was developed. All instrumental and chemical parameters influencing the performance of the method were carefully assessed and optimized. Trivalent antimony was determined in acid medium (pH 3.6) under the optimized condition (deposition potential of −0.7 V, deposition time of 180 s, ionic strength of 0.3 M and oxidant mercury concentration of 10 mg l^{-1}). Total antimony was determined after quantitative reduction of Sb(V) with L-cysteine (1.5%, w/v) and its concentration was calculated from difference between the total antimony and Sb(III). The developed method provided two distinct linear calibration one ranging from 10 up to 50 $\mu g\,l^{-1}$ and other from 100 up to 800 $\mu g\,l^{-1}$ with respective correlation coefficient of 0.9978 and 0.9993, presenting a detection limit of 6.2 $\mu g\,l^{-1}$. Repeatability for the six independent samples expressed in terms of relative standard deviation was found to be 3.01 and 1.39% for 40.0 and 300.0 $\mu g\,l^{-1}$ antimony concentration, respectively. Results on the effect of foreign substances [Al(III), Mg(II), Fe(III), Cd(II), Zn(II) and meglumine] on analytical signal of antimony showed no interference even using high content of foreign ions in the analyte:interferent ratio up to 1:100. The proposed method was successfully applied for the speciation of Sb(III) and Sb(V) in pharmaceutical formulation and the accuracy was assessed from addition and recovery tests as well as comparing with graphite furnace atomic absorption spectrometry (GF AAS) technique used as reference analytical method.

1. Introduction

The antimony is a metalloid and among its various applications, the large use for Leishmaniasis therapy can be highlighted. Leishmaniasis is an inflammatory disease, which occurs in tropical regions. It affects 12 million people worldwide, and 1.5–2 million new cases of Leishmaniasis are estimated to occur annually [1]. World Health Organization recommends as first-choice medicines based on pentavalente antimonies, mainly the meglumine antimoniate [2]. The oxidized form of antimonies is unstable and molecular modifications may occur in these medicines. In addition, the most dangerous of these modifications are the reduction to Sb(III), which constitutes a highly toxic chemical species having toxicity 10 times higher than Sb(V) [3]. A survey of the literature demonstrates the presence of considerable amount of Sb(III) in different medicine samples used in the treatment of Leishmaniasis [4]. For this reason, studies based on Sb(III) and Sb(V) monitoring in these samples are very important.

There are several methods for speciation of Sb(III) and Sb(V) in pharmaceutical formulations such as: capillary electrophoresis-inductively coupled plasma mass spectrometry (CE-ICP-MS) [5], high performance liquid chromatography hydride generation-atomic fluorescence spectrometry (HPLC-HG-AFS) [6], high performance liquid chromatography-hydride generation-atomic absorption spectrometry (HPLC-HG-AAS) [7,8]. Despite their appropriate analytical performance for speciation of antimony, these methods require skills from analysts and are much expensive for routine laboratories owing to high cost of acquisition and maintenance of equipment, justifying the search for better methods.

Electrochemical stripping analyses have always been recognized as a powerful tool for measuring metals [9]. These techniques offer several advantages such as: simple instrumentation and operation, low cost, high sensitivity and excellent selectivity, which allow in some cases, to differentiate the oxidation state of many metals and metalloids [10]. Stripping techniques, including anodic stripping voltammetry (ASV) and cathodic stripping voltammetry (CSV) have been mostly used for metal determination. The potentiometric

* Corresponding author. Tel.: +55 35 3299 1483; fax: +55 35 3299 1262.
E-mail address: ctarleyquim@yahoo.com.br (C.R.T. Tarley).

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stripping analysis (PSA) has also been used. This technique has been shown to present advantages in sensitivity and selectivity over the voltammetric techniques [11–13]. Conceptually, the most important difference between potentiometric and voltammetric stripping methods is that the time is the physical parameter measured in stripping potentiometry that can be measured with higher accuracy, precision and resolution than currents used in voltammetric methods [11].

In PSA, the most widely used working electrodes are static mercury drop or mercury film deposited onto glassy carbon electrode, which are efficient for metal accumulation during the deposition step [14]. However, these electrodes require meticulous experimental precautions regarding the stability and recovery of mercury drop after each experiment, as well as careful manipulation of mercury solutions for film deposition. Hence, much effort has been made for the development of new electrode alternatives, but until now it has been limited to the use of bismuth film and composites based on epoxy-graphite [15,16] and no satisfactory analytical performance has been observed in terms of sensitivity. Taking into account that in PSA a deposition step is carried out, the electrode must comprise excellent specific surface area. In this context, carbon nanotubes (CNTs) present excellent attractive features such as high surface area, high adsorption capacity for metal ions, chemical inertness, metallic properties, low cost and a more positive potential window than mercury electrodes [17,18]. Although CNTs have generated a great deal of interest, their application in electroanalytical analysis has been mostly used for biosensor construction and for the development of electrochemical sensors for gases [19,20]. To the best of our knowledge, the application of these materials in electroanalytical methods based on stripping analysis is still limited and has been restricted to DL-α-tocopherol determination by anodic stripping voltammetry (ASV) [21] and mercury, cadmium and lead ions determination by ASV using multiwall carbon nanotubes film coated glassy carbon electrode [22,23].

Thus, according to the above comments, this work offers a reliable, low cost and sensitive method based on PSA for determination/speciation of Sb(III) and Sb(V) in pharmaceutical samples used in treatment of Leishmaniasis. In addition, the method reports the great potentialities of the use of carbon nanotube paste as working electrode in potentiometric stripping analysis for the first time.

2. Experimental

2.1. Instrumentation

All electrochemical experiments were performed using a potentiostat/galvanostat Autolab® PGSTAT-12 (Eco Chimie B.V.; The Netherlands). Experiments were performed in a conventional single-compartment three-electrode cell. A carbon nanotube paste electrode was employed as the working electrode. A platinum wire was employed as the auxiliary electrode. All potentials were recorded in relation to an Ag/AgCl (KCl, 3 M) reference electrode.

In order to check the accuracy of the method, addition and recovery tests in pharmaceutical samples were carried out. Moreover, Graphite Furnace Atomic Absorption Spectrometer (GF AAS) (Zeiss AA55, Germany) equipped with deuterium lamp for background correction and a hollow cathode lamp as radiation source for antimony was used for the same purpose. The hollow cathode lamp was operated at 5 mA and the wavelength was set at 217.6 nm. All other operation conditions of GF AAS were employed according to manufacturer instructions. A glassy carbon electrode (Metrohm, 2.0 mm in diameter) employed as a comparative electrode was carefully polished with 0.5 μm alumina slurry on a flat surface, rinsed thoroughly with deionized water, and then sonicated immediately before using in deionized water for 2 min.

2.2. Reagents and solutions

All chemicals were of analytical grade reagent. Metal ion solutions employed in the interference studies were prepared daily by appropriate dilution of 1000 mg l^{-1} stock solutions from Merck (Darmstadt, Germany). Stock standard antimony(III) solution was prepared by dissolving appropriate amounts of potassium antimony tartrate (Merck). Mercury stock solution was prepared from their nitrate salt (Merck) without further purification. Acetate buffer solution was prepared without further purification from acetic acid and its sodium salt, purchased from Merck. Aqueous solutions were prepared with deionized water ($\rho > 18.2$ MΩ cm, Millipore Milli-Q system). The multi-walled carbon nanotubes (MWCNTs) used for electrode preparation were supplied by CNTs Co., Ltd. (Yeonsu-Gu, Incheon, Korea) with >95% purity, diameters between 10 and 40 nm and lengths of 5–20 μm and the mineral oil used was obtained from Aldrich (Milwaukee, USA). Graphite powder (purity 99.9%) was supplied by Aldrich.

2.3. Preparation of carbon nanotube paste electrode

The carbon nanotube paste electrodes used in the present work were prepared by mixing multi-walled carbon nanotubes, graphite and mineral oil at different ratios. The paste was carefully hand-mixed in a mortar and then packed into a cavity (3 mm diameter; 1 mm depth) at the end of a glass tube. The electrical contact was provided by a copper wire connected to the paste in the inner hole of the tube. The surface of the resulting paste electrodes was smoothed and rinsed carefully with Milli-Q water prior to each measurement. Prior to the electrochemical measurements, the carbon nanotube electrode was submitted to electrochemical activation, carried out by cyclic voltammetry, cycling the potential between −1.0 and 1.0 V (18 cycles) in a 0.3 M acetate buffer solution, pH 3.6 [24].

2.4. Analytical procedure

The potentiometric stripping analysis procedure was performed using an electrochemical cell with 15 ml capacity containing the carbon nanotube paste electrode, Ag/AgCl (KCl, 3 M) reference electrode and the platinum auxiliary electrode. An aliquot of a stock solution of antimony was added into the electrochemical cell containing 0.3 M acetate buffer solution (pH 3.6) and Hg(II) ions at 10 mg l^{-1}. A constant potential of −0.7 V (vs. Ag/AgCl) was applied for 180 s at stirred solution. After a 20 s rest the chemical stripping step was performed from −0.7 to −0.15 V at unstirred solution. Stripping potentiograms were recorded as dt/dE (s/V) vs. E (V). All experiments were carried out without removal oxygen.

2.5. Sample treatment

Three lots of 5 ml ampoules containing approximately 85 mg ml^{-1} of Sb(V) as meglumine antimoniate in aqueous solution were purchased from suppliers and used in this study. Prior to analyses, an aliquot of samples was diluted in 0.5 M hydrochloric acid so that Sb(V) and Sb (III) bound to meglumine could be released in the solution. This procedure is of paramount importance to the success of the analysis. Since the present method does not detect Sb(V), the determination of pentavalent species was carried out after its reduction to Sb(III) using 1.5% (w/v) L-cysteine solution. When the procedure was performed in the presence of L-cysteine, the total antimony was determined. Thus, Sb(V) was calculated by subtraction of total antimony from Sb(III) after reduction of Sb(V) to Sb(III) by L-cysteine. Therefore, to each aliquot of meglumine antimoniate, previously acidified with 0.5 M hydrochloric acid, L-cysteine was added. As it is well known, the effective reduction of Sb(V) to Sb(III) depends on the kinetic of the

reaction. So, after L-cysteine was added in the solution, it was kept at rest for 20 min before analysis by stripping potentiometry. After this step was over, the samples were buffered with 0.3 M acetate buffer solution at pH 3.6 and analyzed by the proposed method.

3. Results and discussion

3.1. Composition of carbon nanotube paste electrode

The literature has demonstrated the useful incorporation of CNTs in composite matrices using different binders, such as Teflon [25], bromoform [26] and mineral oil [27]. Indeed, the composite of CNTs with mineral oil presents several advantages in the electrode building, such as simplicity, low cost and feasibility for several electroanalytical techniques. However, the content of mineral oil is an important aspect to consider when preparing carbon nanotube paste electrodes. Therefore, the first study carried out was to establish the best composition of carbon nanotube paste. The assays were performed in a medium containing 0.3 M acetate buffer solution (pH 3.6) in the presence of 12 mg l^{-1} Hg(II). The concentration of the antimony solution was 500 μg l^{-1}. This solution was submitted to the application of a constant potential of −0.5 V for 180 s. The equilibrium time was 10 s and the chemical stripping step was carried out from −0.5 to −0.15 V. The potentiograms obtained are shown in Fig. 1. In spite of the facility to handle the paste containing 77.0% (w/w) oil, it proved to be the worst composition regarding the analytical signal. This result was expected due to the reduced conductivity of the paste. When pastes containing only 20.0% (w/w) oil were used, a high analytical signal was observed, but the background was somewhat high. Moreover, this composition was difficult to handle. In order to prevent this drawback, graphite powder was also introduced in the paste composition. The composition MWCNTs:mineral oil:graphite (70:20:10, w/w) showed a reduced background as well as a high analytical signal, similar to that observed in the paste containing 20.0% (w/w) oil. Another advantage that can be pointed out is related to the surface of the electrode, which was smoother than those of the other electrodes tested.

3.2. Influence of deposition potential and deposition time

The profile of the analytical signal as function of the influence of the deposition potential is shown in Fig. 2. The potential range varied from −0.4 up to −1.0 V and, as expected, the best results were

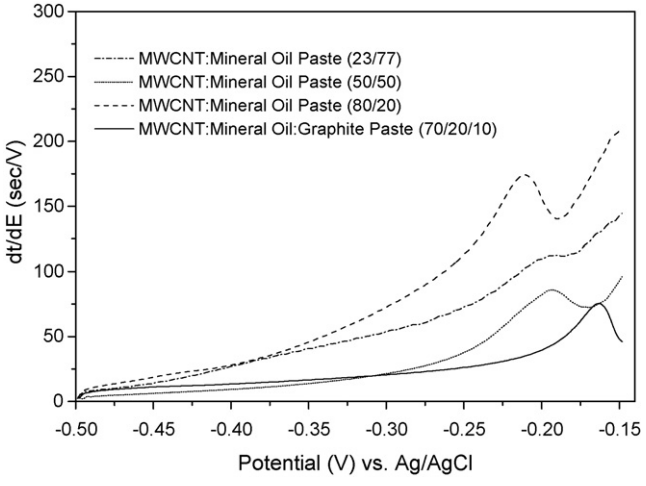

Fig. 1. Effect of paste composition on the analytical signal for antimony. The experiment was performed in a medium containing 0.3 M acetate buffer (pH 3.6) in the presence of 12 mg l^{-1} Hg(II) ions. The concentration of the antimony solution was 500 μg l^{-1}.

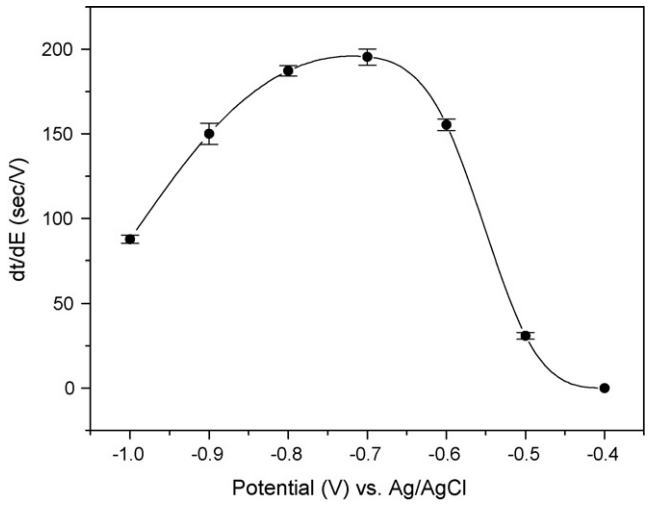

Fig. 2. Influence of deposition potential on the analytical signal for antimony. The experiment was performed in a medium containing 0.3 M acetate buffer (pH 3.6) in the presence of 12 mg l^{-1} Hg(II) ions. The concentration of the antimony solution was 200 μg l^{-1}.

obtained at the more negative deposition potential. In this study the concentration of antimony solution was fixed at 200 μg l^{-1}. As observed, when a deposition potential more negative than −0.8 V was employed, a significant decrease in the antimony peak was observed, probably due to competitive reduction of mercury ions onto the electrode surface, since it is very well known that mercury ions suffer electrolysis at *ca.* −0.9 V onto carbon electrode such as glassy carbon electrode [28]. Thus, −0.7 V was chosen as the best applied potential as well as to avoid possible interferences from analysis of real samples. A study for evaluating the influence of the deposition time on the sensitivity of the antimony peak was performed from 5 up to 180 s. The response for the analyte peak increased with increasing deposition time, reaching a saturation condition at 180 s (Fig. 3). Thus, 180 s for deposition time was adopted in this work. It is important to stress out that this value is considerably lower than those results observed from other previously published potentiometric stripping methods [15,29].

Under optimized condition (electrodeposition potential at −0.7 V), mercury ions do not suffer electrolysis onto MWCNT surface [28]. Thus, a mercury film onto MWCNT surface is not formed. Hence, during the electrodeposition the electrochemical process

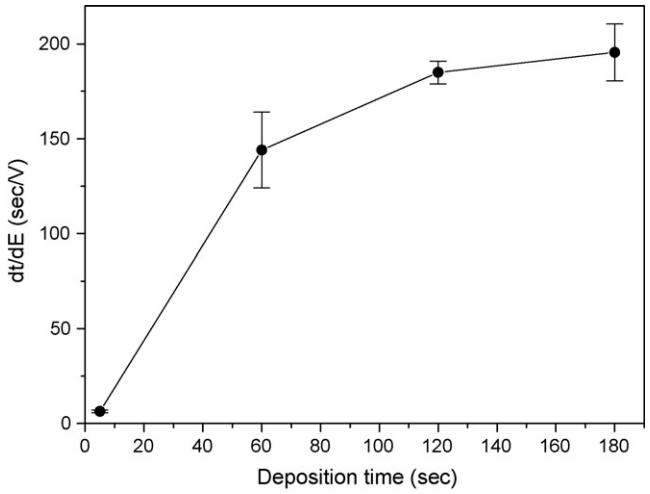

Fig. 3. Influence of deposition time on the analytical signal for antimony.

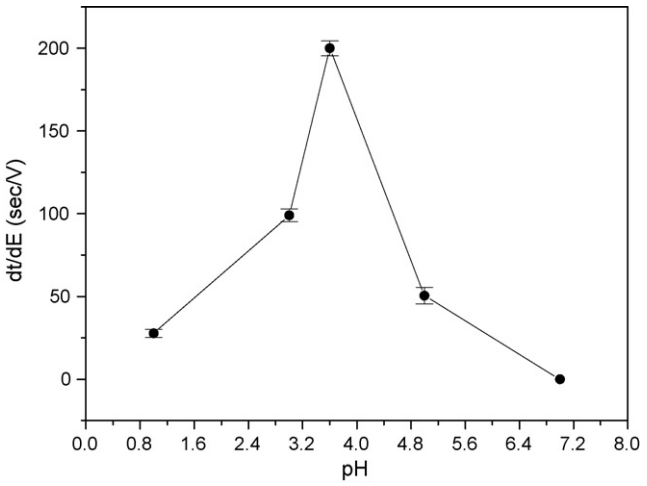

Fig. 4. Influence of pH medium on the analytical signal for antimony.

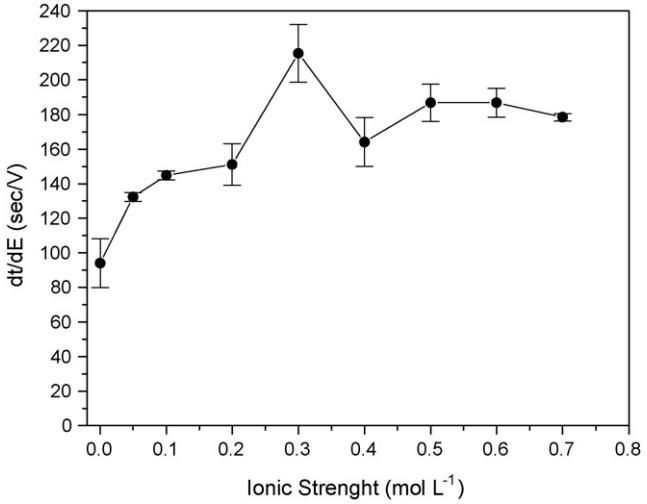

Fig. 5. Influence of ionic strength on the analytical signal for antimony. The experiment was in the presence of 12 mg l^{-1} Hg(II) ions. The concentration of the antimony solution was 200 μg l^{-1} and the deposition potential was −0.7 V.

that takes place in the electrode is:

$$MWCNT(s) + e^- + Sb^{3+} \rightarrow MWCNT(Sb^o).$$

The retention of Sb^{3+} onto MWCNT surface takes place by both, electrostatic attraction and electrochemical deposition. When the time of electrodeposition had elapsed, the electric circuit is interrupted and the chemical oxidant (Hg^{2+}) present in the solution will establish the reoxidation (stripping process):

$$MWCNT(Sb^o) + Hg^{2+} \rightarrow MWCNT(s) + Sb^{3+} + Hg_2{}^{2+}.$$

3.3. Influence of pH and ionic strength

Potentiometric stripping analysis, similar to other electrochemical techniques, requires the use of supporting electrolytes. In antimony determination, acidic electrolytes are commonly used to avoid the hydrolysis of the element. Thus, in the present study, a hydrochloric acid solution at pH 1.0 as supporting electrolyte was firstly studied for antimony determination; however no antimony peak was observed. The strong dependence of the antimony deposition onto the carbon nanotube paste surface on sample pH confirms that the deposition mechanism does not only occur by electrodeposition, but also occurs by electrostatic attraction with the functional groups at the MWCNTs surface, which contain carboxylic and hydroxyl groups that probably have pK_a values ranging from 3 to 5 [30]. Thus, it is reasonable that measurements at low pH values lead to absence of analytical signal. This consideration was confirmed by studying a pH range from 1 to 7, in which the best antimony peak was observed at pH 3.6 in acetate buffer solution (Fig. 4). After choosing the sample pH, the influence of ionic strength was investigated. Fig. 5 shows the behavior of the analytical signal over a range varying from 0.05 to 0.7 M. From the results, the analytical signal increased as the ionic strength increased until 0.3 M. At ionic strength lower than 0.3 M, the analytical signal seriously decreases since during the deposition step the ions' amount is not sufficient to conduct the electric current. On the other hand, it seems that using high ionic strength naturally makes the formation of electrical double layer of antimony ions with MWCNTs surface difficult, and as a consequence, the deposition efficiency. Another possible explanation is related to the antimony ions' diffusion towards the solution bulk, in which it is seriously diminished during the stripping step. Therefore, a 0.3 M acetate buffer concentration was established as the best value in this study.

3.4. Influence of mercury concentration

As it is well known, the stripping step in potentiometric stripping analysis can be performed by using chemical oxidation or by constant current. In this work, when a constant current (25 μA) was used, the analytical signal of antimony was very small. On the other hand, when mercury ions were used as chemical oxidant, the signal was significantly increased. This result makes it possible to emphasize that mercury ions play a more important role in the stripping analysis than constant current. Therefore, the effect of mercury concentration on the analytical signal was investigated from 2 up to 16 mg l^{-1}. As observed in Fig. 6, the best mercury concentration was 10 mg l^{-1}, being this value chosen throughout the study. At low mercury concentrations the mercury ions are not sufficient to chemically strip off antimony ions. Concentrations of mercury ions higher than 10 mg l^{-1} provide a decrease of analytical signal, probably due to competition between antimony and mercury ions on the carbon nanotubes surface.

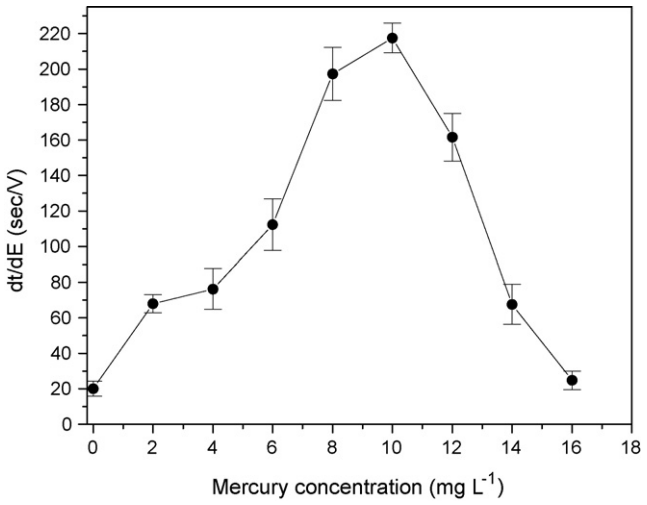

Fig. 6. Influence of mercury concentration on the analytical signal for antimony. The experiment was performed in a medium containing 0.3 M acetate buffer (pH 3.6). The concentration of antimony solution was 200 μg l^{-1} and the deposition potential was −0.7 V.

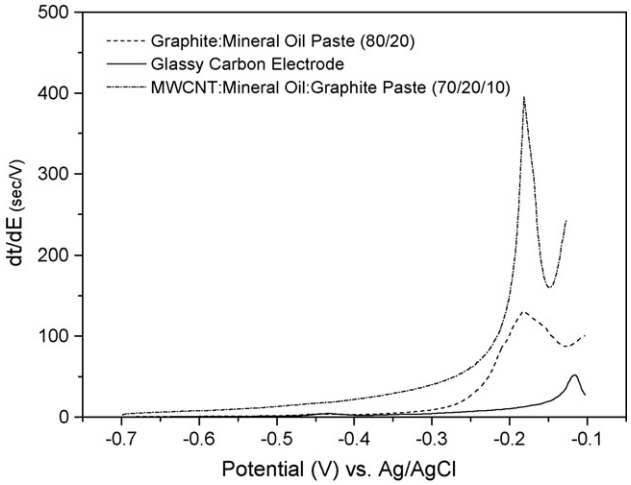

Fig. 7. Stripping potentiograms of antimony performed with MWCNT electrode, graphite paste electrode and glassy carbon electrodes. The experiment was performed in a medium containing 0.3 M acetate buffer (pH 3.6). The concentration of antimony solution was 200 $\mu g\,l^{-1}$ in the presence of 10 $mg\,l^{-1}$ Hg(II) ions and the deposition potential was −0.7 V.

3.5. Comparative study of MWCNT electrode with graphite paste and glassy carbon electrodes

In order to emphasize the beneficial of MWCNT as a nanostructured material in PSA measurements, experiments under optimized conditions, using different electrodes, *i.e.* glassy carbon electrode and graphite paste, were conducted (Fig. 7). As shown, the use of MWCNT electrode in comparison to graphite paste and glassy carbon electrodes promotes a high analytical signal as well as a narrower peak, thus emphasizing the great advantages of MWCNT in detriment of other carbon electrodes.

3.6. Influence of L-cysteine concentration

Several substances have been used as reducing agent of Sb(V), such as hydrazine sulfate, L-cysteine, sulfur dioxide and a combination of sodium thiosulfate and potassium iodide [29,31]. In this study, the Sb(V) was reduced to Sb(III) with L-cysteine since previous studies have demonstrated that L-cysteine can successfully promote this reduction in acid medium [32]. Accordingly, Sb(V) quantification was carried out by reduction of Sb(V) to Sb(III) followed by total species determination. The influence of L-cysteine concentration on reduction of Sb(V) to Sb(III) was investigated by employing real samples of pharmaceutical formulation of meglumine antimoniate. For this task, the sample was appropriately diluted according to Section 2.5, considering a final concentration of 300 $\mu g\,l^{-1}$ Sb(V). It is important to remember that under the appropriate dilution, the amount of Sb(III) was not naturally detected by the method. The rate of reduction reaction of Sb(V) to Sb(III) was assessed by comparing the analytical signal with those obtained by analysis of a standard solution of Sb(III) at 300 $\mu g\,l^{-1}$. According to Fig. 8, the best results for Sb(V) occur by using 1.5% (w/v) L-cysteine concentration leading to a conversion rate of 100%.

3.7. Interference studies

Potentiometric stripping analysis can be subject to overlapping of the stripping signals due to similar redox potentials of the elements stripped out. Moreover, other interference can be observed by competition between analyte ions and interfering ions for those sites of MWCNTs. Table 1 presents the results obtained from antimony determination in the presence of different concentrations of several foreign species. A given species was considered to interfere if it resulted in more than ±5% variation of the antimony peak. For this study, different amounts of the species were added to a 100 $\mu g\,l^{-1}$ solution of Sb(III). The ratios of antimony/interferents investigated were 1:1, 1:10 and 1:100. As observed from Table 1, the foreign ions Pb(II), Ni(II), Co(II) and Cr(III) decreased the analytical signal of antimony only at high concentration; however, it is important to stress that these ions are not found in real samples, mainly in pharmaceutical samples. Copper ions promote severe interference even using low ratio analyte:interferent 1:1, possibly due to the formation of intermetallic compound (Sb–Cu). Nevertheless, this drawback can be circumvent by using L-cysteine, as employed in this study. Furthermore, the organic compound meglumine was also studied under different ratios analyte:interferent, and no interference was observed.

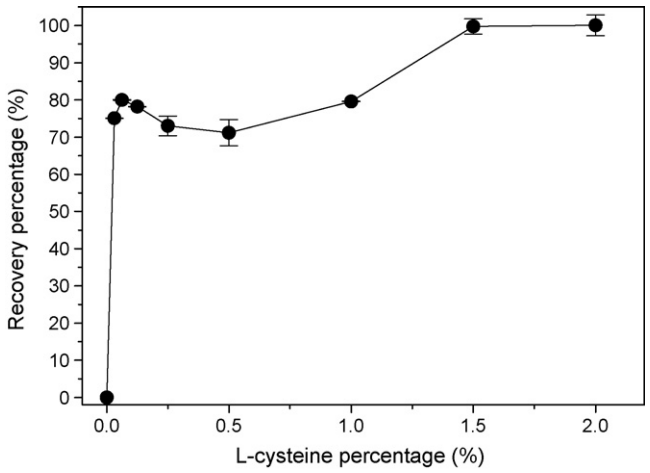

Fig. 8. Influence of L-cysteine concentration on the analytical signal for total antimony.

3.8. Analytical features and application of the method in pharmaceutical samples

Under optimal experimental conditions, the validation data including, analytical curve building, limits of detection and quantification, precision in terms of repeatability and accuracy, were determined. Peak height was linearly dependent on antimony concentration, and, as observed in Fig. 9, there are two distinct analytical curves ranging from 10 up to 50 $\mu g\,l^{-1}$ and 100 up to 800 $\mu g\,l^{-1}$ with good linear correlation coefficients, 0.9978 and 0.9993, respectively. As one can see, in the first analytical curve, where low antimony concentration is employed, a low angular

Table 1
Influence of coexisting ions and molecular compound in antimony(III) analysis.

Interferents	Ratio of antimony/interferent		
	1:1	1:10	1:100
	Recovery (%)		
Al(III)	96.5	102.5	102.8
Mg(II)	98.5	98.5	99.1
Fe(III)	105.6	99.6	102.2
Cd(II)	97.0	97.4	102.9
Pb(II)	99.5	84.5	ND
Zn(II)	101.3	103	98.8
Ni(II)	105.2	95.2	71.04
Co(II)	78.9	13.5	ND
Cr(III)	90.7	33.6	ND
Meglumine	97.5	99.8	99.5

ND = Not detected (absence of analytical signal).

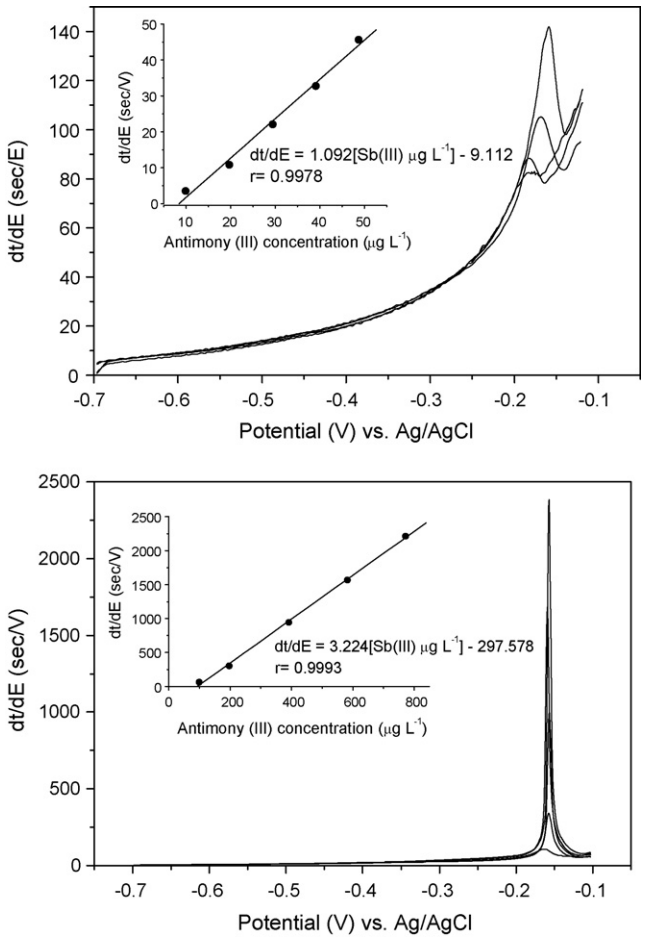

Fig. 9. Analytical curve for Sb(III) determination. Linearity covering the range of concentration of 10–50 $\mu g\,l^{-1}$ and the range of 100–800 $\mu g\,l^{-1}$.

coefficient was observed, which suggests a competition between ions Sb(III) and Hg(II) in solution towards carbon nanotube paste electrode surface. Such behavior was not observed for analytical curve built from 100 up to 800 $\mu g\,l^{-1}$. Both analytical curves show good analytical application, since the common concentration of

Table 2
Recovery percentage for antimony(III) in meglumine antimoniate.

Samples	[Sb(III)] added ($mg\,ml^{-1}$)	[Sb(III)] found ($mg\,ml^{-1}$)	Recovery (%)
Ampoule 1	–	0.264 ± 0.004	–
	0.100	0.339 ± 0.006	93.1
Ampoule 2	–	0.281 ± 0.003	–
	0.100	0.393 ± 0.002	103.1
Ampoule 3	–	0.241 ± 0.003	–
	0.100	0.339 ± 0.005	99.4

The results are expressed as mean ± SD based on three replicate ($n = 3$) determinations. Confidence interval, 95%.

Table 3
Determination of Sb(III), Sb(V) and Sb (total) in meglumine antimoniate samples using the proposed method.

Sample	Sb(III) ($mg\,ml^{-1}$)	Sb(V) ($mg\,ml^{-1}$)	Sb (total) ($mg\,ml^{-1}$)
Ampoule 1	0.264 ± 0.004	92.4 ± 1.9	92.7 ± 2.0
Ampoule 2	0.281 ± 0.003	88.2 ± 1.85	88.5 ± 1.8
Ampoule 3	0.241 ± 0.003	89.1 ± 2.2	89.4 ± 2.2

The results are expressed as mean ± SD based on three replicate ($n = 3$) determinations. Confidence interval, 95%.

Sb(III) found in natural water samples is very small (in the order to $\mu g\,l^{-1}$), while antimony determination in meglumine antimoniate can successfully be carried out by using the second analytical curve, without drastic dilution of the sample. Limits of detection (6.2 $\mu g\,l^{-1}$) and quantification (20.0 $\mu g\,l^{-1}$) were calculated according to IUPAC recommendations [33] by using the first analytical curve. The precision of the proposed method was assessed in terms of repeatability. Thus, it was estimated from a series of six measurements of authentic samples of 40.0 and 300.0 $\mu g\,l^{-1}$ Sb(III) solutions. The relative standard deviations (RSD) were found to be 3.01% and 1.39%, respectively. The results suggest that the proposed method has excellent precision for determination of antimony. Regarding the accuracy of the proposed method, it was firstly evaluated after spiking pharmaceutical sample with a known amount of the analyte. Table 2 shows the recovery percentage of Sb(III) ranging from 93.1 up to 103.1%, thus confirming the good accuracy of the method. In addition, the amount of Sb(V) in pharmaceutical samples, determined by subtraction from total Sb is shown in Table 3. The total Sb found by the current method, when using

Table 4
Comparative data about different electroanalytical stripping methods for the antimony determination.

Electrode	Techniques	Sample	Sb(III) and Sb(V) speciation	Deposition time (s)	Linear range ($\mu g\,l^{-1}$)	LOD ($\mu g\,l^{-1}$)	Ref.
Multi-walled carbon nanotube paste	Stripping potentiometry	Pharmaceutical samples	Yes	180	10–800	6.2	This work
Gold nanoparticle-modified carbon screen-printed	Anodic stripping voltammetry	Seawater and pharmaceutical samples	Yes	200	12.04–110	0.11	[34]
Glassy-carbon electrode modified with polyphenols	Stripping voltammetry	Natural water	No	300	10–250	6.0	[35]
Phenylfluorone-modified carbon paste electrode	Anodic stripping voltammetry	Human hair and soil samples	No	600	3.65–12.17	1.08	[36]
Glassy carbon	Stripping potentiometry	Water and orchard leaves	Yes	600	0.3–150	0.3	[32]
Glassy carbon mercury film electrode	Stripping potentiometry	Peach and apple leaves	No	240	0–250	0.9	[37]
Hanging mercury drop electrode	Adsorptive stripping voltammetry	Pharmaceutical preparations and water samples	Yes	407 s for Sb(III) and 500 s for Sb(V)	0.012–0.10	0.012	[38]
Hanging mercury drop electrode	Adsorptive stripping voltammetry	Water samples and phosphoric acid	Yes	300 s for Sb(III) and 600 s for Sb(V)	0–5.0	0.21 for Sb(III) and 0.56 for Sb(V)	[39]

LOD = limit of detection.

Table 5
Comparative data about different analytical methods based on spectrophotometry for the antimony determination.

Method	Sample	Sb(III) and Sb(V) speciation	LOD ($\mu g l^{-1}$)	Linear range ($\mu g l^{-1}$)	Ref.
PSA	Meglumine antimoniate	Yes	6.2	10–800	This work
FA-HG-FTIR[a]-spectrometry	Antileishmanial drugs	Yes	900.0	0–600,000	[40]
FA-HG-GPMAS-(UV)[b]	Homeopathic formulations	No	60.0	0–30,000	[41]
FIA[c]-spectrometry	Antileishmanial drugs	Yes	29.0	50–2500	[42]
Spectrophotometric	Water, soil and dust samples	No	5.0	10–1500	[43]
HPSAM[d]	River and spring water	Yes	–	300–2000	[44]
Spectrophotometric	Waste and tap water, solid waste, soil, plant leaves, serum and urine	No	6.0	16–144	[45]

LOD = limit of detection.
[a] Flow analysis system with hydride generation and Fourier transform infrared.
[b] Flow analysis-hydride generation-gas phase derivative molecular adsorption-(UV).
[c] Flow injection analysis.
[d] H-point standard addition method.

L-cysteine, matched closely with those values derived from comparison method (GF AAS) with 95% confidence level (Student's *t*-test), thereby also attesting the accuracy of the method. Comparative data of analytical characteristics obtained in the present method with those previously reported (stripping potentiometry and voltammetry) (Table 4), show that the analytical approach presents advantages in terms of reduced deposition time and wider linear range. Moreover, according to Table 5, the proposed method provides a lower limit of detection than the majority of those already reported method for antimony determination based on spectrophotometry.

4. Conclusion

In this work the feasibility of potentiometric stripping analysis (PSA) for the speciation of antimony in samples of meglumine antimoniate using carbon nanotube electrode paste electrode was evaluated. Some advantages can be pointed out, such as simplicity and low cost compared to the usual techniques, especially the hydride generation atomic absorption spectrometry (HG-AAS). Additionally, satisfactory analytical features, including good sensitivity, analytical frequency, linear range, precision and accuracy were noted. Such data make the proposed method a viable alternative for antimony determination and quality control of meglumine antimoniate. Furthermore, wide linear range was achieved owing to high surface area of carbon nanotube, which can expand the use of the method for both pharmaceutical and environmental samples.

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