Electroanalytical Performance of $(SiPy^+Cl^-/CuTsPc)_5$ LbL Film for Detecting Promethazine Hydrochloride

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Abstract
A $(SiPy^+Cl^-/CuTsPc)_5$ layer-by-layer film was employed for the electroanalytical determination of promethazine hydrochloride in BR buffer pH 5.0 with peaks at 0.48 and 0.79 V. After optimisation of the square-wave parameters ($f = 100\ s^{-1}$, $a = 40$ mV and $\Delta E_s = 2$ mV), the peak at 0.79 V was used for quantification and a detection limit of 8.71×10^{-9} mol L^{-1} and a quantification limit of 9.31×10^{-8} were calculated. The applicability of this procedure was tested on commercial formulations of promethazine hydrochloride by observing the stability, specificity, recovery and precision of the procedure in complex samples, without any preliminary treatment.

Keywords: LbL films, Phthalocyanines, Sensors, Square-wave voltammetry, Promethazine hydrochloride

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1 Introduction

With the increasing number of harmful drugs discharged into the environment, it is necessary to develop analytical techniques that are rapid and sensitive in the determination of these drugs. In this sense, an option that has been widely used in recent decades involves the formation of nanostructured thin films of different materials and their potential application as analytical sensors [1–4]. The use of modified electrodes with thin films can offer substantial benefits to electroanalysis [5]. These films should be very sensitive when compared to traditional analytical methods, e.g. high-performance liquid chromatography (HPLC).

Considering nanofabrication, the electrostatic layer-by-layer (LbL) assembly technique, developed in the 1990s by Decher et al. [6] stands out because it presents the major advantage of experimental simplicity, affords molecular-level control in the fabrication of ultrathin films by the precise control of polymer assembly, and provides an ideal tool for tailoring the properties of films on the nanometre scale by electrostatic deposition of polycation and polyanion charged on a solid substrate, e.g. negatively [6,7]. Thus, a substrate is immersed in a cationic solution to form a layer of polycation. It is then immersed in the anionic solution and the polyanion is adsorbed on a previously deposited layer of polycation [6,7]. After each deposited layer, the substrate is immersed for a specified time, usually several minutes, in the solution and washed in an aqueous solution containing polyelectrolytes with the pH equal to the solution pH to remove molecules that were not adsorbed. At the end of the process the substrate is dried in air or N_2 jet [4,8,9], obtaining the first bilayer. Repeating this process, the desired number of bilayers is achieved. Therefore, LbL assembly provides a versatile method for ultrathin film preparation for sensor applications.

The simplicity and versatility of the LbL technique combined with electrochemical techniques have attracted the interest of several researchers in the determination of dopamine [9,10] and ascorbic acid [11]. However, in the literature there are no reports related to the use of these films in electroanalytical determination of pharmaceuticals.

Promethazine hydrochloride (PMZ, hydrochloride *N*, *N*-dimethyl-1-phenothiazine-10-yl-propan-2-amine) belongs to the group of phenothiazines, a pharmaceutical compound that is widely used because of its antihistamine activity, and its sedative, antipsychotic and analgesic properties [12,13]. PMZ also has the ability to prolong sleep

induced by barbiturates, and its use is therapeutically useful in clinical anaesthesia [14]. However, it can cause adverse effects in humans, such as changes in the endocrine system and cardiac abnormalities. Based on this, it is important to develop methodologies with high sensitivity and selectivity for their determination in complex samples.

There are several electrode surfaces used as working electrodes in the quantification of PMZ, such as glassy carbon [12,15,16], graphite powder [13], gold [17] and highly boron-doped diamond electrodes [18]. However, no study has been reported on the application of modified electrodes with LbL films for PMZ determination. In this sense, the LbL film was formed by using chloride of 3-*n*-propylpyridinium silsesquioxane ($SiPy^+Cl^-$) and tetrasulphonated phthalocyanine copper (II) (CuTsPc), with the formed film containing five bilayers, designed $(SiPy^+Cl^-/CuTsPc)_5$, as described by de Jesus et al. [9]. This modified surface was used to develop an electroanalytical procedure for PMZ determination in commercial formulations using square-wave voltammetry (SWV).

2 Experimental

2.1 Chemicals, Solutions and Sample Preparation

All reagents used in this study were of analytical grade and water purified by the Milli-Q system from Millipore. CuTsPc was purchased from Aldrich Co. and used without further purification and chloride silsesquioxane polymer 3-*n* propylpiridinium, designated $SiPy^+Cl^-$, was prepared by a method described elsewhere [19]. The aqueous solutions of phthalocyanine and $SiPy^+Cl^-$ were used in a concentration of 2.0 mg mL^{-1} and pH 8. Promethazine hydrochloride (USP grade) stock solution of 1.0×10^{-4} mol L^{-1} was prepared by dissolving the appropriate amount in ultrapure water, stored away from sunlight, and kept in a refrigerator to prevent degradation. Britton–Robinson (BR) supporting buffer was prepared as described in a previous paper [20] and the pH was adjusted to the desired value by adding appropriate amounts of 2.0 mol L^{-1} NaOH stock solution.

2.2 Apparatus

The electrochemical experiments were conducted in a three-electrode single-compartment glass cell. A Pt wire was used as counter electrode and an Ag/AgCl/saturated KCl electrode was used as reference. The $(SiPy^+Cl^-/CuTsPc)_5$ LbL film was used as working electrode (1 cm^2 geometric area). The working electrode was obtained using the LbL assembly technique. The sequential deposition of multilayers was carried out by immersing the FTO substrates alternately into the $SiPy^+Cl^-$ and CuTsPc solutions for five minutes. After deposition of each layer, the substrate/film system was rinsed with water and dried in air, as described in the literature [9]. The voltammetric measurements were carried out using an Autolab PGSTAT 30, Metrohm-Eco Chemie potentiostat/galvanostat, controlled by a personal computer, using GPES version 4.9 software (General Purpose Electrochemical System, Metrohm-Eco Chemie). The pH was measured using a Micronal B474 pH-meter (model B474). Cyclic voltammmetry (CV) was employed for preliminary studies on the electrochemical behaviour of PMZ. SWV was used for the development of the electroanalytical method and PMZ determination in real samples.

2.3 Working Procedure

To confirm the effectiveness of the $(SiPy^+Cl^-/CuTsPc)_5$ LbL films as an electrochemical sensor for PMZ, studies were performed using CV with the fluorine-doped tin oxide (designed as FTO substrate from Flexitec, $R_s = 10$–$20\ \Omega$ m), in absence and presence of PMZ [9].

Aiming to verify the electrochemical behaviour of PMZ on the working electrode, preliminary studies were conducted by CV in the potential range from 0.0 V to 1.0 V at 50 mV s^{-1} using 0.04 mol L^{-1} BR buffer as supporting electrolyte. The determination of PMZ was made by using SWV. The experimental and voltammetric parameters were optimised to obtain maxima peak current and selectivity. The voltammetric behaviour of PMZ on the $(SiPy^+Cl^-/CuTsPc)_5$ LbL films was investigated at pH values between 3.0 and 8.0 (adjusted with 2.0 mol L^{-1} NaOH) using SWV. The parameters of the SWV, potential pulse frequency (f), amplitude of the pulse (a) and height of the potential step (ΔE_s), which exercise strong influence on the redox process, are optimised based on a systematic study. After this stage, analytical curves were constructed by adding aliquots 40 μL from a stock solution of PMZ 1×10^{-4} mol L^{-1}. The standard deviation of the mean current measured in the oxidation potential of PMZ (at 0.79 V) for ten blank voltammograms in pure electrolytes (S_b) and the slope of the straight line of the analytical curves (s) was employed to calculate the detection limit (DL) and the quantification limit (QL), using $DL = 3S_b/s$ and $QL = 10S_b/s$ according to the guidelines recommended by IUPAC [21,22]. However, the S_b value used was determined by the standard deviation of the y-intercept in the analytical curves.

The recovery experiments were performed in order to attest the methodology's efficiency by standard addition method. To this end, the supporting electrolyte was spiked with 7.94×10^{-7} mol L^{-1} of PMZ and voltammetric signal recorded. After that, four additions of equal amounts of PMZ were added to the final concentration of 2.34 μmol L^{-1}. The recovery efficiencies (% Rec) were calculated considering the ratio between the value of the concentration obtained by extrapolating the analytical curves of the corresponding spiked samples and the concentration previously added [23]. The precision and accuracy of methodology were tested with different standard solutions of PMZ and the relative standard deviations (% RSD) were calculated, considering the standard deviation of the mean current values obtained and the mean

peak current values. All measurements were performed in triplicate.

After each experiment, the solution was stirred for one minute to remove any adsorbed species on the electrode surface in order to guarantee the reproducibility of the experiments. All electrochemical measurements were evaluated under ambient conditions.

2.4 Analysis of Commercial Formulations

After calculating the *DL* and *QL* for the determination of PMZ in the supporting electrolyte, the accuracy, reproducibility, and precision of the procedure, and the interference from excipients used in the commercial PMZ formulations, were studied in order to evaluate the applicability of the proposed methodology.

The first commercial formulation was *Fenergan* tablets (25 mg/tablet), each containing 25 mg of PMZ. The contents of 10 tablets were weighed to obtain the average mass of each tablet and then powdered. After this, a portion of the powder was carefully weighed, a mass sufficient to produce a final concentration of 1.0×10^{-4} mol L^{-1} of PMZ, and then transferred to 10 mL volumetric flask and diluted to volume with pure water. The mixture was sonicated for 10 minutes. The commercial formulation was an Aventis Pharma (Brazil) product. The second commercial formulation was injectable *Fenergan*, each 2 mL ampoule containing 50 mg of PMZ. The solution was prepared by taking an appropriate amount from the ampoule, placing it in a 10 mL volumetric flask and completing the volume with pure water to a final PMZ concentration of 1.0×10^{-4} mol L^{-1}. This formulation also came from Aventis Pharma (Brazil). The third commercial formulation was *Lisador* drops produced by Farmasa (Brazil), a pharmaceutical compound containing 5 mg of PMZ, 500 mg of dipyrone, 10 mg of adiphenine hydrochloride and an undetermined concentration of propylene glycol in each 1.5 mL ampoule. This compound was utilised to evaluate the influence of the other pharmaceutical compounds on the proposed procedure. A sample of this formulation was prepared in a manner similar to that of the injectable *Fenergan*. All samples were used immediately after their preparation to prevent decomposition by light or heat.

Aliquots of this solution were transferred to a voltammetric cell containing 0.04 mol L^{-1} BR buffer in order to obtain 7.94×10^{-7} mol L^{-1} as final concentration. The square-wave voltammograms were then recorded in an open circuit condition.

3 Results and Discussion

3.1 Electrochemical Behaviour

To confirm the possibility of applying the modified electrode by LbL technique as an electrochemical sensor for PMZ, this was investigated by using cyclic voltammetry. A comparative study was carried out with the $(SiPy^+Cl^-/CuTsPc)_5$ film, the LbL film modified with polyelectrolyte monolayer, the CuTsPc film and the FTO substrate. For this study a fixed concentration of 2.91×10^{-4} mol L^{-1} PMZ in 0.04 mol L^{-1} BR buffer at pH 5.0 and 50 mV s^{-1} was used, as shown in Figure 1.

As can be seen, all films and the FTO substrate showed electroactivity for the oxidation of PMZ, with well-defined oxidation and reduction processes. It was noticed that, for the FTO substrate, oxidation processes occurred at more negative potentials (0.38 and 0.73 V) when compared to the LbL film $(SiPy^+Cl^-/CuTsPc)_5$. However, with the $(SiPy^+Cl^-/CuTsPc)_5$ film, higher current values were obtained than for the other electrodes studied ($(SiPy^+Cl^-)_5$, $(CuTsPc)_5$ and FTO). Furthermore, the LbL film was highly stable on the electrode surface, unlike the films containing only the polyelectrolytes, which leached into the solution after successive voltammetric scans. The stability of the $(SiPy^+Cl^-/CuTsPc)_5$ film in the supporting electrolyte (0.04 mol L^{-1} BR buffer at pH 5.0) was studied for a period of 24 hours, measuring the change in absorbance band at 616 nm of the film. The $(SiPy^+Cl^-/CuTsPc)_5$ LbL film was highly stable, with an average decrease of less than 1% in absorbance. The stability of the $(SiPy^+Cl^-/CuTsPc)_5$ film is due to the self-assembly technique, which provides thin films with high molecular ordering and stability due to electrostatic interactions occurring between components of the film [24], according to the scheme showed in Figure 2 proved by XPS measurements [9].

Voltammetric studies for the $(SiPy^+Cl^-/CuTsPc)_5$ film, with a scan potential of 0.0 to 1.1 V, revealed two anodic process at 0.48 V (peak 1) and 0.79 V (peak 2), and a cathodic process around 0.40 V during the reverse scan. With the completion of successive scans, it can be observed that the current intensity related to the second peak decreased, whereas the anodic process at 0.48 V showed an increase of current. These results indicate that PMZ is oxidised in two stages, with the formation of an

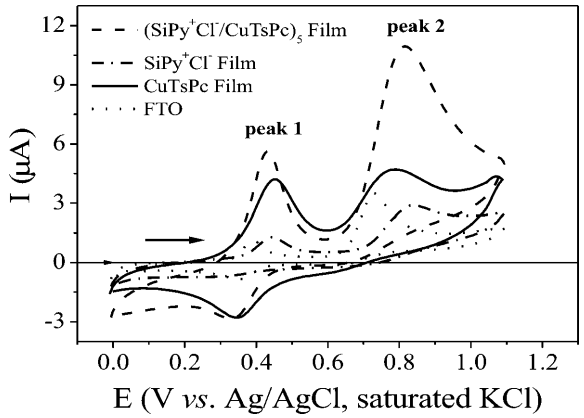

Fig. 1. Cyclic voltammograms for 2.91×10^{-4} mol L^{-1} of PMZ in BR buffer, pH 5.0 at $(SiPy^+Cl^-/CuTsPc)_5$ LbL film, $(SiPy^+Cl^-)_5$ film, $(CuTsPc)_5$ film and FTO substrate. With scan potential ranging from 0.0 to 1.1 V vs. Ag/AgCl/saturated Cl^-, at 50 mV s^{-1}.

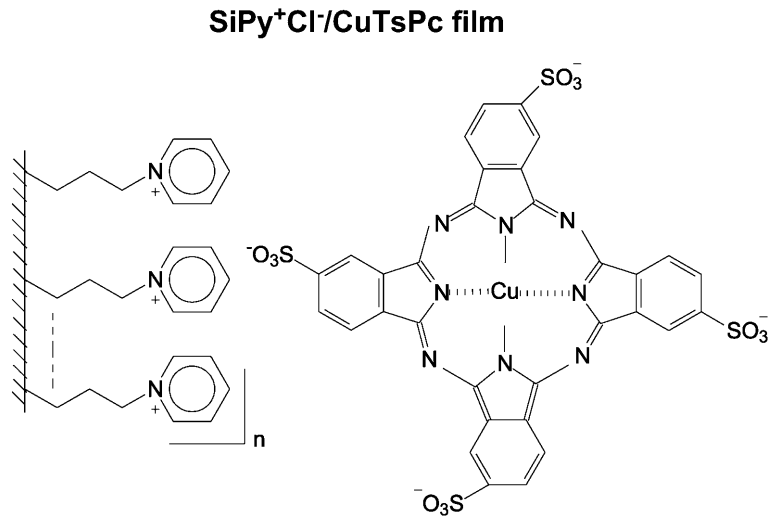

Fig. 2. Representation of polyelectrolyte interactions in the $(SiPy^{+}Cl^{-}/CuTsPc)_5$ LbL film.

adsorptive product at 0.79 V, which, in turn, is oxidised more easily, due to the lower potential value, generating a new oxidation process at 0.48 V. The literature reports that the oxidation process of the PMZ and other compounds of the phenothiazine family occur with the removal of an electron of the nitrogen atom, thus forming a relatively stable cation radical, which then is oxidised to sulphoxide promethazine [18].

In addition, in the cases assigned to the oxidation of promethazine, it is also possible to observe the presence of an anodic process around 0.18 V in the tenth cycle of the scan, which can possibly be attributed to the oxidation of copper present in the polyanion CuTsPc. This observed oxidation potential is close to that reported by Portela and co-workers [25] as being characteristic of the oxidation process of copper.

Figure 3 illustrates cyclic voltammograms obtained for PMZ oxidation on $(SiPy^{+}Cl^{-}/CuTsPc)_5$ film in BR buffer, pH 5.0, at 50 mV s^{-1}, indicating the first and tenth cycles of potential scans.

Preliminary experiments using SWV were performed to determine the electroanalytical responses of PMZ on $(SiPy^{+}Cl^{-}/CuTsPc)_5$ film and to evaluate the presence of forward and backward current components that can be applied to determine the reversibility of the occurring electrochemical redox process. These experiments showed the presence of one well-defined voltammetric peak towards the positive sweep direction in approximately 0.79 V vs. Ag/AgCl/sat. KCl (Figure 4).

From the analysis of the current components, shown in Figure 4, it can be observed that the intensity of direct current is greater than the reverse current, and also that there is a small shift of the reduction potential to less positive values. This indicates that the oxidation of PMZ on the $(SiPy^{+}Cl^{-}/CuTsPc)_5$ film has a characteristic quasi-reversible process, with a strong indication that adsorption of reactants or products occurs on the electrode surface. The resulting current was used for quantification of the pharmaceutical, since it is the sum of the modules of the forward and reverse currents, and therefore has the highest intensity.

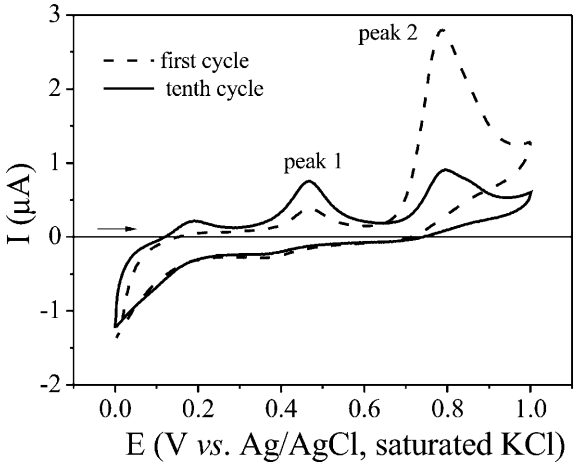

Fig. 3. Cyclic voltammograms for 2.91×10^{-5} mol L^{-1} of PMZ at $(SiPy^{+}Cl^{-}/CuTsPc)_5$ LbL film in BR buffer, pH 4.0, with a scan potential ranging from 0.0 to 1.1 V vs. Ag/AgCl/ saturated Cl^{-}, at 50 mV s^{-1}.

3.2 Influence of pH

SWV was used to study the pH effect on peak current of 2.91×10^{-5} mol L^{-1} PMZ solutions. The influence of pH on the oxidation peak of PMZ was investigated in the pH range of 3–8 in BR buffer. It was observed that the voltammetric response is markedly dependent on pH. In this interval, the dependence between current peak and pH is non-linear, with a maximum located in pH 7.0. However, for pH values above 7.0, a strong adsorption of the molecule on the electrode surface was observed, which compromises the reproducibility of the experiment. From this perspective, pH 5.0 was established to be optimal in order

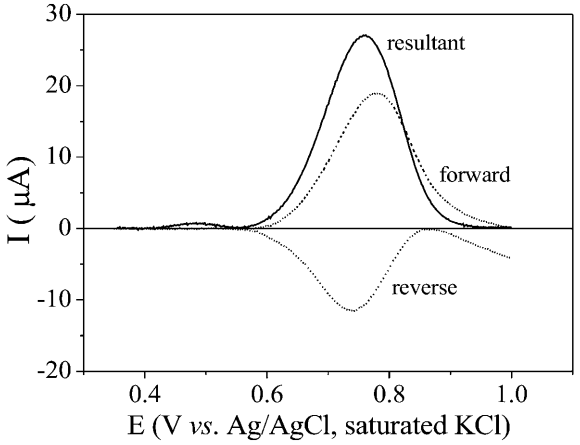

Fig. 4. Square-wave voltammograms for PMZ oxidation, with forward, reverse and resultant components of current, for 2.91×10^{-5} mol L^{-1} of pH in 0.04 mol L^{-1} BR, pH 5.0, on $(SiPy^{+}Cl^{-}/CuTsPc)_5$ with $f = 100\ s^{-1}$, $a = 40$ mV and $\triangle E_s = 2$ mV.

to achieve the best response of the voltammetric profile for analytical purposes.

3.3 Voltammetric Optimization

In order to obtain a calibration curve for the PMZ determination in pharmaceutical formulations, different optimisation procedures were used.

The f value, in SWV experiments, is an important parameter that determines the signal intensity and thus the sensitivity of the analytical methodology. Peak currents usually show an increase as a function of the increase in the employed frequencies, regardless of the reversibility of the redox process, but the correlation between peak currents and frequency is not strictly linear [26]. Frequencies were applied from 10 to 300 s^{-1} and it was observed that there is a linear relationship for current values up to until 100 s^{-1}. Therefore, this frequency was chosen, as optimal for the analytical determination of PMZ on $(SiPy^{+}Cl^{-}/CuTsPc)_5$ film.

When the amplitude was varied in the range 5–80 mV, the peak currents increased with increasing amplitude, as expected from SWV theory [27,28]. However, the peak width also increased at the same time, in particular when the amplitude was greater than 40 mV. Therefore, 40 mV was chosen.

The last parameter investigated was the $\triangle E_s$, which was varied from 1 mV to 7 mV. The obtained voltammograms suggested that an increase in the scan increment is responsible for better sensitivity in the analysis. However, with an increase of this parameter, the peaks became larger and this fact implies loss of selectivity. The resultant peak currents showed that values above 2 mV have no significant effects on the results. As such, 2 mV was chosen for the analytical applications.

3.4 Analytical Curves

After the optimisation of pH and SWV parameters, analytical curves were obtained in the range from 3.98×10^{-7} to 3.85×10^{-6} mol L^{-1} by the standard addition method, as described in Section 2. The curves showed a linear increase of peak current with increasing concentration of PMZ. Figure 5 shows the square-wave voltammograms, and the insert shows the analytical curve.

From the analytical curves, DL and QL were calculated as recommended by IUPAC and described in Section 2. Table 1 shows the region of linearity, curve equation, correlation coefficient (R), standard deviation of the arithmetic mean of ten blank solutions (S_b), slope of the analytical curve (s), DL, QL, repeatability (% RSD) and reproducibility (% RSD). All data were obtained in triplicate and the results presented refer to mean values. These values were compared to results obtained using the UV-vis spectrophotometric method [18], as recommended in British Pharmacopoeia [29].

The calculated detection limit was much lower than those obtained for the electrochemical determination on the other LbL films containing phthalocyanine. Zucolotto and co-workers [10] showed that DL is equal to 10×10^{-5} mol L^{-1} for the film from polyaniline and iron phthalocyanine tetrasulphonated (PANI/FeTsPc) in the presence of dopamine with a concentration range from 0.25 to 8 mM [30]. The calculated DL and QL values by the proposed procedure were lower than those observed in the quantification of promethazine hydrochloride onto electrodes, such as glassy carbon electrodes [12], graphite powder electrodes modified by ionic liquid [31] and boron-doped diamond electrodes [18], but close to the values found for the glassy carbon electrode modified with deoxyribonucleic acid [32] and DNA-modified carbon paste electrode [33], as can be seen in Table 2.

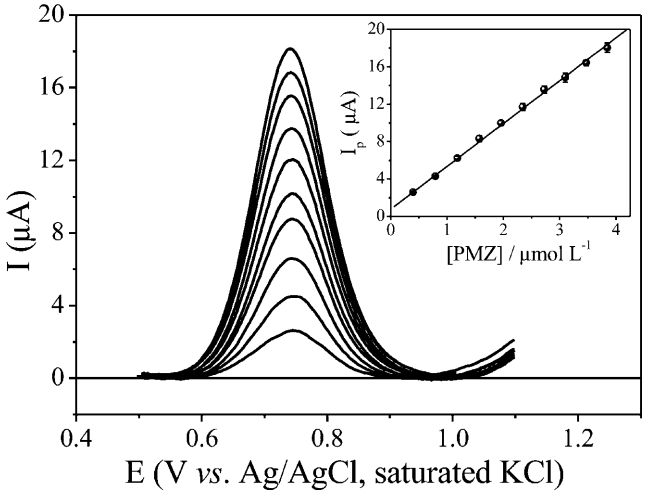

Fig. 5. Square-wave voltammograms for PMZ in 0.04 mol L^{-1} BR pH 5.0 at $(SiPy^{+}Cl^{-}/CuTsPc)_5$ film, with, $f = 100\ s^{-1}$, $a = 40$ m V, $\triangle E_s = 2$ mV, and concentrations of 3.98×10^{-7} and 3.85×10^{-6} mol L^{-1} of PMZ. The insert shows the average current obtained from five analytical curves for voltammetric peak.

Table 1. Analytical parameters obtained for linear regression curves of PMZ to work on $(SiPy^+Cl^-/CuTsPc)_5$ film in pure electrolyte (BR buffer 0.04 mol L^{-1}) for SWV.

Parameter	SWV
LR	3.98×10^{-7} mol L^{-1} and 3.85×10^{-6} mol L^{-1}
Curve equation	$I_{peak}=(9.33\pm0.294)\times10^{-6}+(4.52\pm0.065)$ [PMZ]
R	0.9994
SE_a	2.936×10^{-7} (A)
SE_b	5.27×10^{-8} (A/mol L^{-1})
S_b	4.15×10^{-9} (A/mol L^{-1})
DL (mol L^{-1})	8.71×10^{-9} (2.79 μg L^{-1})
QL (mol L^{-1})	9.31×10^{-8} (9.31 μg L^{-1})
RSD (repeatability)	2.12% ($n=12$)
RSD (reproducibility)	2.90% ($n=7$)

Table 2. *DL* and *QL* obtained in the determination of PMZ in pure electrolyte using the different working electrodes.

Ref.	Method	Electrode	*DL* (μg L^{-1})	*QL* (μg L^{-1})
[12]	DPSV	GCE	34.00	–
[13]	Voltammetry	Graphite-$BIMPF_6$	1604.40	–
[19]	Spectroeletroanalysis	Au-CDtrodes	9626.40	35296.80
[20]	SW-AdSV	HDDB	14.77	49.19
[33]	DPV	DNA/GCE(ox)	0.096	–
[34]	PSA	DNA-modified carbon paste	1.60	–

Table 3. Results obtained from recovery curves of PMZ in pure electrolyte and in commercial formulations by SWV on LbL film $(SiPy^+\ Cl^-/CuTsPc)_5$ with $f=100\ s^{-1}$, $a=40$ mV, $\triangle E_s=2$ mV. $[PMZ]_{added}=7.94\times10^{-7}$ mol L^{-1}.

	Pure electrolyte	*Fenergan* injectable	*Fenergan* tablet	*Lisador* drops	*Lisador* tablet
Nominal dosage	–	50 mg/mL	25 mg/tablet	5 mg/1.5 mL	25 mg/tablet
$[PMZ]_{found}$ (mol L^{-1})	8.51×10^{-7}	8.90×10^{-7}	8.03×10^{-7}	8.21×10^{-7}	9.18×10^{-7}
Recovery (%)	107.21	112.07	99.51	104.41	115.57
RSD (%)	0.81	1.60	4.68	3.99	3.77
BIAS (%)	7.18	12.09	1.13	3.40	15.62

3.5 Application of the Method

To assess the efficiency of the proposed methodology, recovery tests were performed. Firstly, studies of the apparent recovery in pure electrolyte (0.04 mol L^{-1} BR buffer and pH 5.0) were analysed, followed by commercial pharmaceutical PMZ samples (tablets, drops and injectables). Recovery studies were carried out by the addition of known amounts of PMZ in each sample followed by SWV analysis. Three determinations were carried out for each sample, and the standard deviations were calculated. Analytical curves were constructed for a concentration range from 7.94×10^{-7} to 2.34×10^{-6} mol L^{-1} using a procedure similar to that previously described. Figure 6 shows the square-wave voltammograms, with the analytical curve ($n=3$) as insert.

As shown in Table 3, the recovery values for the four different commercial formulations, ranging from 99.51% to 115.57%, indicate that the matrix effect does not present any significant interference. The calculated values were at the suitable range for analytical purposes, between 70% and 130% (with *RSD* lower than 5%) [34].

The recovery curves obtained from the *Lisador* sample can also be used to evaluate the specificity of the pro-

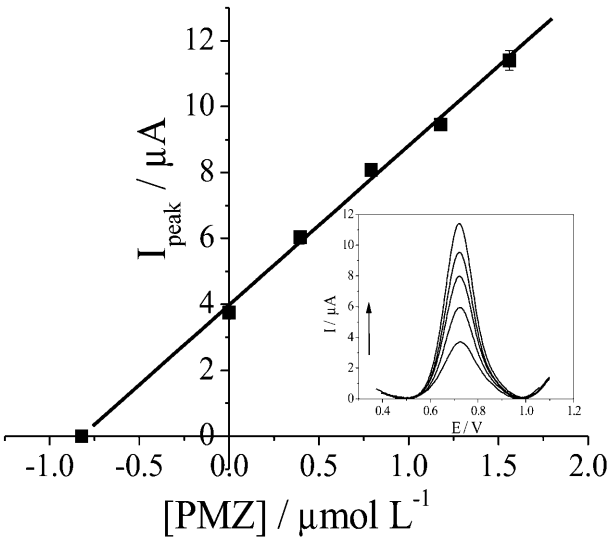

Fig. 6. Relation of I_{peak} vs. concentration for PMZ recovery in *Lisador* sample obtained from the mean values of peak current ($n=3$), with their respective standard deviation bars. The insert shows voltammograms with varying concentrations of 7.94×10^{-7} to 2.34×10^{-6} mol L^{-1}.

posed procedure, since this product contains other pharmaceutical compounds (dipyrone and adiphenine hydrochloride), which may interfere in the analytical response of PMZ on $(SiPy^{+}Cl^{-}/CuTsPc)_5$ film. Despite the presence of other compounds, however, the percentages of recovery in these samples proved to be suitable for analytical purposes, indicating that the procedure can be considered specific for PMZ, with little interference from other compounds.

4 Conclusions

The application of the $(SiPy^{+}Cl^{-}/CuTsPc)_5$ film on the FTO substrate through the LbL technique for determining promethazine hydrochloride showed satisfactory results when compared to the literature, which always presents higher values of detection and quantification limits than those found in this study (2.79 μg L^{-1} and 9.31 μg L^{-1}, respectively). These data indicate that the modified electrode surface by the LbL technique enables high sensitivity, stability and reproducibility to be obtained, allowing its application in samples of commercial formulations, which makes this electrode a promising alternative for PMZ determination.

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