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Fabrication and Applications of Potentiometric Sensors Based on *p-tert*-butylthiacalix[4]arene Comprising Two Triazole Rings Ionophore for Silver Ion Detection

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This work describes the fabrication and applications of potentiometric silver-selective sensors, based on the use of a newly synthesized *p-tert*-butylthiacalix[4]arene comprising two triazole rings, as a novel neutral ionophore in plasticized poly(vinyl chloride) (PVC) membranes. The effect of lipophilic anionic additives on the voltammetric responses of the sensors was investigated in details. The constructed sensors exhibited a Nernstian behavior with 53 ± 0.9 mV per decade change in Ag^+ activity over the range from $7.0\text{x}10^{-6}$ to $8.0\text{x}10^{-3}$, with a repetitive detection limit of 0.421 μg mL^{-1}. Moreover, the effect of lipophilic salts, plasticizers and various interfering ions were probed. Importantly, validation of the method is achieved in terms of good performance characteristics, including good selectivity for Ag^+ over alkali, alkaline earth and transition metal ions (e.g. Na^+, K^+, Pb^{2+}, Mg^{2+}, Co^{2+} Ni^{2+}, and Cu^{2+}) together with long life span. Other important characteristics such as low detection limit, acceptable accuracy and precision, long term stability, reproducibility were also demonstrated. On the application side, the sensors were utilized for facile potentiometric measurements of iodide ions (I^-) over the concentration range of 0.749 to 856 μg mL^{-1} and also employed for probing sequential titration of some importantly relevant anions (e.g. Cl^-, Br^-, I^- , SCN^- and N^{-3}). Significantly, sequential binding of these anions with Ag^+ cations produces sharp stepwise titration curves with consecutive end point breaks at the equivalent points.

Keywords: Thiacalix[4]arenes; silver-ion selective electrode ; Potentiometry.

1. INTRODUCTION

The determination of silver in environmental, industrial and waste samples is of considerable interest in analytical chemistry [1]. To date, the most commonly used techniques for silver ion determination are atomic and flame absorption spectrophotometry [2]. These techniques, however, have their known limitations and drawbacks [2]. Potentiometric detection of silver ions, based on ion-selective electrode (ISE), on the other hand, is relatively much simpler and offers several advantages such as rapid and easy procedures, low cost instrumentations, fast and highly selective responses [3-9].

Calixarenes, have gained remarkable interest in recent years owing to their fascinating ionic and molecular-binding properties [10, 11]. Thus, calixarene derivatives comprising pendant ester, amide, ketone, or ether groups such as calix(mono- and bis-crowns) have been incorporated, as neutral carriers, into ion-selective electrodes for selective sensing of K^+ and Cs^+ ions [12-17]. Furthermore, facile detection of soft metals such as Ag^+, Pb^{2+} and Hg^+ over alkali and alkaline earth metals via introduction of soft donor atoms such as sulfur and nitrogen into calixarene skelton have been accomplished.

Importantly, thiacalix[4]arenes have also been shown to possess interesting functions, which entitled them to be used for many important applications in supramolecular chemistry [24-30]. Thus, chemically-synthesized thiacalix[4]arene ionophores containing cyclic or linear O, S, N ligating and *p*-coordinate groups on the lower rim have shown enhanced binding ability of Ag^+ ions [31]. Moreover, the presence of thiacalixarene at the surface layer of the sensor has been shown to improve the selectivity and reversibility responses for transition metal ions [32, 33].

In spite of the large number of publications in the utilization of thiacalixarene derivatives-ISEs for detection of alkali and alkaline earth metals, only few investigations have been reported for silver ion [34]. In this contribution, we describe the synthesis and application of p-*tert*-butylthiacalix[4]arene derivative having two triazole rings at lower rim (Figure 1), as a novel ionophore, for silver ion-selective PVC membrane electrodes. Significantly, the constructed silver ISEs have been employed for estimation of trace quantities (μg level) of Ag^+ ions in pharmaceutical samples. Additionally, the same electrode composites have also been utilized for probing the titrations of Cl^-, I^-, Br^-, SCN^- and N^{3-} with silver nitrate titrant.

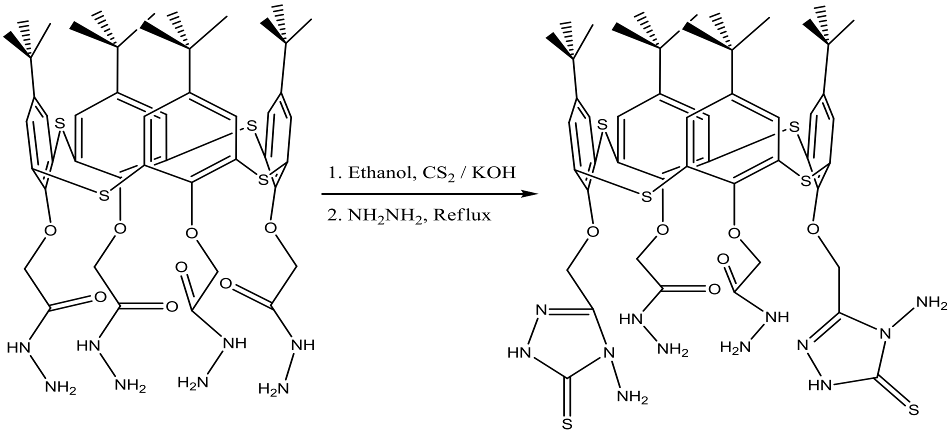

Figure 1. Synthesis of new *p*-*tert*-butylthiacalix[4]arene derivative containing two triazole rings at the lower rim.

Importantly, in order to show the level of sensitivity and selectivity of the proposed sensor, we provide a direct comparison of the selectivity and working ability of the constructed silver electrode with the reported ones (Table 1). Virtually, as can be seen, very good enhancement in the responses and detection limits were achieved via the proposed silver sensors.

Table 1. General potentiometric characteristics of some silver sensors based on different calixarene ionophores

Type of caliaxarine	**Slope, mV/ decade**	**Linear range, mol/L^{-1}**	**pH range**	**DetectionLimit, mol/L^{-1}**	**Interference**	**Ref.**
1,3-dithioether calix[4]arene	56.0	1.0 $x10^{-5}$ –1.0 $x10^{-2}$	3.0 –7.0	1.0 $x10^{-5}$	Na^+ (-5.5), K^+ (-5.25), Mg^{2+} (-4.9), Ca^{2+} (-4.7), Cu^{2+} (-4.50), Zn^{2+}(-4.3), Ni (-4), Cd^{2+} (-3.7), NH_4^+(-3.5), Pb^{2+} (-3.2), Hg^{2+} (-2.8).	[15]
5,11,17,23-tetra-*tert*-butyl-25,26,27,28-tetrakis (hydroxyl-carbonylmethoxy)-2,8,14,20-tetra-thiacalix[4]arene (glassy carbon)	63±3	7.0×10^{-7} - 1.0×10^{-2}	2.0-3.0	1.0 $x10^{-7}$	Na^+ (2.64), K^+ (2.82), Pb^{2+} (4.46), Cd^{2+} (2.87), Hg^{2+} (-0.25). Cu^{2+} (3.47)**,** Fe^{3+}(-1.71)	[10]
nitrogen containing calixarene derivatives	53.2	$1x10^{-5.}$ - $1x10^{-1..}$	3-7	$1x10^{-5}$	Na^+ (-4.3), K^+ (-4.3), NH_4^+(-4.2), Ca^{2+}(-4.5), Mg^{2+} (-4.5) , Cu^{2+} (-4.6), Zn^{2+}(-4.5), Ni^{2+} (-4.4), Cd^{2+} (-4.5), Pb^{2+} (-3.5),Hg^{2+}(-1.8)	[33]
calixarene derivative containing nitrogen atom	57	5.0×10^{-6} - 1.0×10^{-2}	8.0-10.0	1.0x10-^{5}	Ca^{2+}(-4.8), Mg^{2+} (-4.6), Zn^{2+}(-4.5), Cu^{2+} (-4.6), Cd^{2+} (-4.5), Na^+ (-4.4), K^+ (-4.3), NH_4^+(-4.0), Ni^{2+} (-3.9), Pb^{2+} (-3.8), Hg^{2+}(1.5)	[2]
PPy doped with p-sulfonic calix[4]arene	57.2	1.0 $x10^{-5}$– 1.0 x 10^{-1}		1.0 $x10^{-5}$	Li (-2) , Na^+ (-2.2), K^+ (-2.2), Mg^{2+} (-2.9) . Ca^{2+}(-3), NH_4^+(-3), Mn $^{2+}$(-3), Co^{2+} (-3.5), Ni^{2+} (-3.6), Cu^{2+} (-3.4), Zn^{2+}(-4), Pb^{2+}(-2.7)Cd^{2+} (-4), Hg^{2+}(-1)	[19]
5,11,17,23-tetra-*tert*-butyl-25,27-dihydroxy -calix[4]arene-thiacrown-4	53.8±1.6	$1x10^{-6}$-1.0 $x10^{-1}$	2.0–6.0	8.0 x 10^{-7}	Sr^2 (-3.8), Co^2(-3.08), Zn^2 (-3.60), Cd^2 (-3.72), Ni^2 (-3.71), Cu^2 (-3.73), Mg^2 (-3.87), Pb^2 (-2.98), K^+(-3.95), Na^+(-3.69), Li^+(-3.89), NH4$^+$ (-3.85), Hg^{2+}(-0.28)	[20]
5,11,17,23-tetra-*tert*-butyl-25,27-bis-(diethylcarbamoylmethoxy)-26,28-bis-(diphenylphosphinoylmethoxy)calix[4]arene (*Calix*),	58.4	$1.0x10^{-6}$- $1.0x10^{-2}$	4-6.7	$6.3x10^{-7}$	Li (-3.67), Na (-3.30), K (-3.36), NH4(-2.80), Ca^{+2}(-0.15), Sr^2(-2.69),Ba^{2+} (-2.84),Mn^{2+} (-1.64) Cd^{2+} (-1.51), Co^{2+} (-2.72),Ni^{2+}(-2.64),Cu^{2+} (-2.14),Zn^{2+} (-1.21), Pb^{2+} (-0.45),Fe^{3+} (-1.94), La^{3+} (-0.54) Sm^{3+}(-0.39), Th^{4+} (-0.27)	[21]
p-*tert*-butylthia-calixarene **2**	53±0.2	7×10^{-6}-8.0 $\times10^{-3}$	3-5	3.9x10-6	Ni^{2+} (-3.25), Co^{2+}(-3.23), Mn^{2+} (-3.022) , Pb2+(-2.65), Cu^{2+}(-2.50), Hg^{2+} (-1.9), K^+ (-1.55), Na^+ (-1.25)	This work

2. MATERIALS AND METHODS

All chemicals and reagents were of analytical grade and used without further purification. High molecular weight poly(vinyl chloride) (PVC) [average Mw ¼ 85 000], dioctyl phthalate (DOP), and sodium tetraphenylborate (NaTPB) were purchased from Fluka (Switzerland). Dibutyl sebacate (DBS), ethylhexyl sebacate (EHP) were obtained from BDH Chemical Ltd. (England). Melting points (°C, uncorrected) were determined using an open glass capillaries via a Barnstead 9001 electrothermal melting point apparatus. Infrared (IR) spectra of the prepared compound were undertaken with a Perkin Elmer Spectrum 1000 FT-IR Spectrometer. ^{1}H- and ^{13}C-NMR spectra of compounds were measured in deutrated chloroform ($CDCl_3$) at room temperature using JEOL ECP-400 MHz spectrometers. A 0.1 mol.L^{-1} $AgNO_3$ stock solution was prepared and different sample concentrations were prepared on a daily basis by dilution of this stock solution. The ionic strength of the solution was adjusted by using 10^{-3} M $NaNO_3$ solution.

*2.1. Synthesis of p-tert-butylthiacalix[4]arene **2***

A mixture of *p-tert*-butylthiacalix[4]arene tetrahydrazides **1** (1g, 0.99 mmol), KOH (0.24 g ,4.2 mmol) and CS_2 (0.3 mL g, 4.2 mmol) were dissolved in 50 mL ethanol and stirred for 24 h on cold. Then 1 ml of hydrazine hydrate was introduced to the reaction mixture and heated under reflux for 24 h until the disappearance of the green color of the reaction mixture. The reaction mixture was then concentrated by evaporation to a 10 mL volume and diluted with 20 mL distilled water, followed by acidification with acetic acid. The precipitated white solid was separated by filtration and then recrystallized from ethanol (yield more than 90 %). White solid, M.P: 295 0C; IR (KBr): ν = 3321, 3213 cm^{-1} (NH, NH_2) , 2967 (CH) cm^{-1} , 1682 cm^{-1} (C=O); ^1H NMR ($CDCl_3$, 400 MHz) δ= 0.93 (18H, s, Bu^t), 1.14(18H, s, Bu^t), 4.1(4H, br, NH_2), 4.40 (4H, d, CH_2), 4.70 (4H, s, NH_2), 4.78 (4H, d, CH_2), 7.21(4H, d, Ar-H), 7.45 (2H, s, NH), 7.48(4H, d, Ar-H), 9.3(2H, s, NH).; ^{13}C NMR, (100 MHz, $CDCl_3$) δ=30.93, 31.32, 34.12, 34.28, 74.04, 120.45, 121.39, 129.78, 134.26, 134.71, 135.49, 135.84, 143.20, 149.50, 156.29, 168.65.

2.2. Apparatus

All potentiometric determinations were carried out using a Cole Parmer pH/mV meter (model 59003-05) at 25 ± 0.1^{0}C. The working electrode is an Ag^+ ion-PVC membrane sensors is placed in conjunction with a Sentek Ag/AgCl double junction reference electrode (model R2/2MM) in an outer compartment containing 4 M KNO_3. A glass pH electrode (Schott blue line 25) was also employed for all pH measurements. Electromotive Force (EMF) measurements was performed by using a cell of the type: Ag/$AgCl_{(s)}$, 4.0 M KCl/1.0 mol.L^{-1} KNO_3/sample solution/ISE membrane/internal reference filling solution, $AgCl_{(s)}$/Ag.

2.3 Sensors Construction and Electromotive Force (EMF) Measurements

Detailed procedure for the preparation of the polymeric membrane was as follows. The ionophore (m/m 1%), plasticizer (m/m 66%), PVC (m/m 33%) and dissolved in THF. The resulting PVC-THF syrup was poured into a glass moulid and THF was evaporated at room temperature overnight. A flexible, transparent membrane of thickness 0.2-0.4 mm was achieved. A 6 mm diameter disks were pasted onto the PVC tip clipped to the end of the electrode body comprising an Ag/AgCl wire placed in an internal solution of 0.01 M silver nitrate. Pre-conditioning of the PVC membrane electrodes were conducted by soaking in a 0.01 M silver nitrate for at least 12 h prior to use. The behavior of the electrodes was checked by measuring the EMF of an aqueous solutions of some specific cations over the concentration range from 10^{-6} to 10^{-2} mol.L^{-1}. The dynamic response curves were constructed by adding standard solutions of cations to a stirred pH 5 buffer solution (0.01 M acetate). The selectivity coefficients ($Log\ K_{Ag+\ +\ B}$) were estimated by the fixed solution method (FIM) using cations having nitrate as counteranion. Detection limits were calculated at the intersection of two linear lines, including the one extrapolated from a high concentration range along with the other parallel to the one used in the plot of the potential change versus the Ag^+ concentration.

2.4. Direct potentiometric determination of silver

Silver nitrate solution in pharmaceutical samples were determined using synthesized *p-tert*-butylthiacalix[4]arene derivative as novel neutral ionophore membrane sensor. Silver nitrate solution 0.5% was diluted 1 to 3 times with de-ionized water, respectively. For determination of silver ion, the silver sensor and an Orion Ag/AgCl single junction reference electrode were placed in a 10 mL beaker containing 10 mL of 1.0 x 10^{-2} mol.L^{-1} acetate buffer of pH 5. A portion (200 µL) of the dilute silver nitrate drug was progressively added and the potential response of each sample was measured after stabilization. A calibration curve was obtained by plotting the potential change against the logarithm of the Ag^+ concentration. This plot was employed for subsequent determination of unknown Ag^+ test solutions.

2.5. Potentiometric titration of anions

A specific series of potentiometric precipitation titrations were performed in which the sensor was used as an indicator electrode to locate the end point. Test solutions containing a single anions (e.g. Cl^-, I^-, Br^-, SCN^- and N^{3-}) or binary mixture of (Cl^- and I^-, Cl^- and Br^-, Cl^- and SCN^-, I^- and SCN^-) or ternary mixture of (Cl^-, SCN^- and I^-) were titrated with 1.0 × 10^{-2} M Ag^+. Equivalence points at each inflection break were calculated and the concentration of each ion was determined (1 mol Ag^+ = 1 mol Cl^- = 1 mol SCN^- = I^- = 1 mol Br^- = 1 mol N^{3-}).

3. RESULTS AND DISCUSSION

3.1 Membrane composition and response characteristics

Heteroditopic receptors have been synthesized by placing amide functions at the lower rim of the thiacalix[4]arene as efficient extractors for both cations and anions owing to their high stability and hydrophobicity [35]. Facile extraction of picrate complexes in the organic phase was achieved via the reaction of Ag^+ with thiacalixarene containing pyridine fragments in the substituents at lower rim [32].

p-tert-butylthiacalixarene **2** (Figure. 1) were prepared from *p-tert*-butylthiacalixarene tetrahydrazide **1** [36,37] and its structure has been confirmed by IR, ^1H and ^{13}C NMR spectroscopies (see experimental part) . Ionophore properties of **2** were examined in terms of being novel neutral carriers for Ag^+ ions in PVC matrix. The composition of the membranes was 63.6 wt% plasticizer, 34.5 wt% PVC, and 1.8 wt% ionophore. For each ionophore, four membrane sensors were constructed and evaluated over a period of six months, in accord with the IUPAC recommendations [38].

In preliminary experiments, the new thiacalixarene derivative **2** combined with various plasticizers was investigated. Three plasticizer of different polarity including dioctyl phethalate (DOP), dibutyl sebecate (DBS), ethyl hexthyl phathalte (EHP), were utilized to prepare all Ag^+-PVC membrane ISEs. The results showed that the nature of the plasticizer affects the state of ligands, the dielectric constant of the membrane phase, and the mobility of the ionophore molecules [39, 40]. The potentials of the membranes-containing the ionophores were investigated as a function of $[Ag^+]$. The generated data are depicted in Table 2. Silver-PVC matrix membrane sensors comprising *p-tert*-butylthiacalixarene derivative (**2**) ionophore gave rise to a sub-Nernstian slope of 40.5±2.3, 28.4±0.3 and 32.3±0.3 mV decade^{-1} with lower detection limit of 0.539, 1.078 and 0.605 μg mL^{-1} for membrane sensors plasticized in DBS ($\mathcal{E}$= 4.1), EHP ($\mathcal{E}$= 8) and DOP ($\mathcal{E}$= 8), respectively.

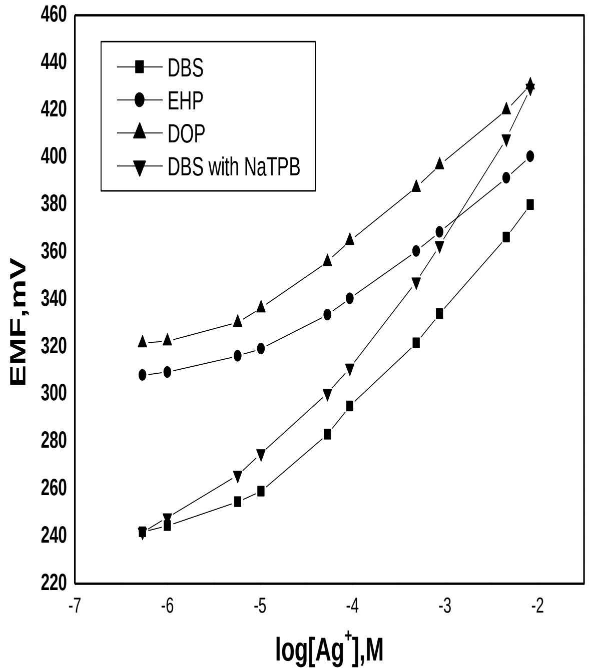

Figure 2. Effect of plasticizer and NaTPB additives on the potentiometric response of Ag membrane based sensor.

Replicate responses (n ¼ 10) for an internal quality control sample (IQS) (16.9 mg mL^{-1}, 1.57 x 10^{-4} mol.L^{-1} of certified reference of Ag^+) produced an average result of 16.5± 0.6 μg mL^{-1}. In addition, the student's (t) value at 95% confidence level was estimated via Eq (1):

$$T_{exp} = (\mu - x) \times n^{1/2/s} \qquad (1)$$

Where μ is the concentration of the initial internal quality control sample, x is the average concentration noted, n is the number of analyzed replicates, and s is the standard deviation of measurements. Significantly, we noted that there is no statistical difference between the practically obtained (T_{exp} = 1.53) and the theoretical (t_{tab} = 1.833) values. Thus, the null hypothesis is achieved and therefore the accuracy of the method is virtually acceptable.

On the other hand, the potentiometric response of the membrane was greatly improved in the presence of lipophilic anionic additive, NaTPB. It is well known that lipophilic salts can not only reduce the membrane resistance, therefore improves the selectivity, but also they enhance the sensitivity of the membrane electrode [41-43]. Thus, addition of 5 mg of NaTPB relative to the ionophore to the membranes showed great enhancement of the potentiometric responses. Virtually, these membrane electrodes gave rise to a slope of 53.5±0.2 mV per decade with a detection limits of 0.42 µg/ml, as given in Table 2.

Table 2. Response characteristics of Ag+ membrane based sensors in 0.01 mol.L^{-1} acetate buffer of pH 4.

Parameter	DBS	DBS +NaTPB	EHP	DOP
Slope, mV/decade	40.5±2.3	53±0.2	28.4±0.3	32.3±0.3
coefficient, r (n=3)	0.996	0.999	0.996	0.999
Detection limit, µg mL-1	5.0 × 10-6	3.9x10-6	1 × 10-5	5.62 × 10-6
Linear range, mol L-1	1×10-5- 8.0 × 10-3	7×10-6-8.0 ×10-3	4.46×10-5-8.0 ×10-3	1.2×10-5- 8.0 × 10-3
Response time, s	10 - 20	10 - 20	10 - 20	10 - 20
Working range, pH	3 – 5	3 – 5	3 – 5	3 – 5
Standard deviation (%)	2.6	3.2	1.5	3.2
Accuracy (%)	99.3	99.1	98.7	98.3
Precision (%), Cvw(%)	0.9	0.7	1.1	0.8
Between-day variability, Cvb (%)	1.1	0.9	0.9	0.95

3.2. Method Validation

The fundamentally important parameters for the validation of an analytical method are based on sensitivity, selectivity, accuracy, precision, reproducibility, as well as the stability. Additionally, measurements of every analyte sample in a given matrix should be ratified. Moreover, typical procedures for validation of an analytical methodology would include determination of the following items: (1) the selectivity and stability of analyte in spiked samples, (2) linearity and detection limit of the sample, and (3) the accuracy, precision, recovery, as well as robustness of the method. In the present work, we have used six batches (6 replicates each) of silver cation (Ag^+) for assessment of the linearity, detection limit, selectivity, accuracy, precision, along with robustness of the methodology.

3.2.1. Linearity and Detection Limit of the Method

The linear range of the calibration plot is 7×10^{-6}- 8.0×10^{-3} mol.L^{-1} (0.754 mg.L^{-1}– 862.4 mg.L^{-1}) on DBS/NaTPB membrane based sensors. Least square analysis of the data gives Eq 2.

$$E(\text{mV}) = (-53.5 \pm 0.2) \log [\text{Ag}^+] + (240.5 \pm 0.7) \qquad (2)$$

The lower detection limit (LOD) was estimated on the basis of IUPAC guidelines and found to be 3.9×10^{-6} mol.L^{-1} (0.420 mg.L^{-1}) [44]. Additionally, the lower limit quantitation (LLQ) was about to ~ 0.155 µg.mL^{-1}. We also found that there is no noticeable difference between the measured and expected concentrations.

3.2.2. Accuracy, Precision and Robustness of the Methodology

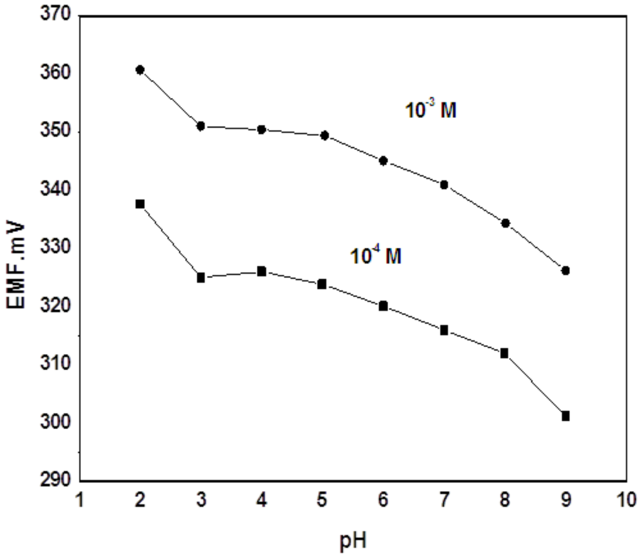

Figure 3. Effect of pH on Ag membrane based sensor plasticized in DBS.

The accuracy (trueness) and precision (relative standard deviation, RSD) of the batch together with flow injection procedures were estimated on the basis of Eqs 3 and 4 [45, 46], respectively:

$$\text{Accuracy \%} = (x / \mu) \times 100 \qquad (3)$$

$$\text{Precision \%} = (SD / x) \times 100 \qquad (4)$$

Where: x, µ and SD are the average of the measured concentration, reference-value and standard deviation, respectively as shown in Table 2. The method robustness was estimated by examining the effect of pH and measuring time on the accuracy of the results. The influence of the pH on the potentiometric behavior of silver based membrane sensors was examined using 10^{-4} and10^{-3} mol.L^{-1} silver solutions over the pH range 2–10. From pH-potential profiles, apparently there is no change in potential response within the pH range 3–5 as shown in Fig.3. At higher pH values (> 5), the sensor response decreases, probably as a result of silver hydroxide formation. However, at pH < 3, the response towards silver increases due to the protonation of the electrode PVC membrane.

The response time was evaluated after successive immersions of proposed electrodes in a series of solutions (with 10-fold concentration difference) [47–48]. The resulting E–t responses for the sensors were obtained upon increasing the Ag$^+$ concentration from 1.0×10^{-6} to 1.0×10^{-3} mol.L^{-1}. Our results indicated that the potentiometric response time of the utilized electrode is approximately 20 s for the Ag-ISE.

Importantly, the lifetime of the electrode was checked by periodically recalibrating the electrode in standard $AgNO_3$ solution to the probe the silver response of the electrode. Repeated calibrations of the DBS/NaTPB electrode (seven times over a one month period) showed no change in the performance of the electrode. In all instances, there was a rapid response (10-20 S) and good linearity with constant slope 53±2 mV/ decade.

3.2.3. Selectivity

The potentiometric selectivity coefficient of an electrode is a crucial characteristic and is identified as the relative response of the primary ion compared to other ions exit in the solution. This of course depends upon the types of the ionophore/plasticizer used in the sensor preparation. Therefore, the responses of the constructed sensors were checked in combination with other interfering cations. The potentiometric selectivity coefficients ($K^{pot}_{Ag,B}$) were measured via fixed solution approach [44]. In this approach, solutions of 10^{-2} mol.L^{-1} were used for alkaline earth metals as well as transition metals. The obtained potential values are plotted versus the activity of the primary ion Ag^+. Potentiometric selectivity coefficients were estimated graphically using equation (5): [44]

$$\log K^{pot}_{Ag+,B} = aAg+/(a_B)^{2/ZB} \qquad (5)$$

Where a_{Ag+} and a_B are the activities and Z_B is the charge of the interfering ions.

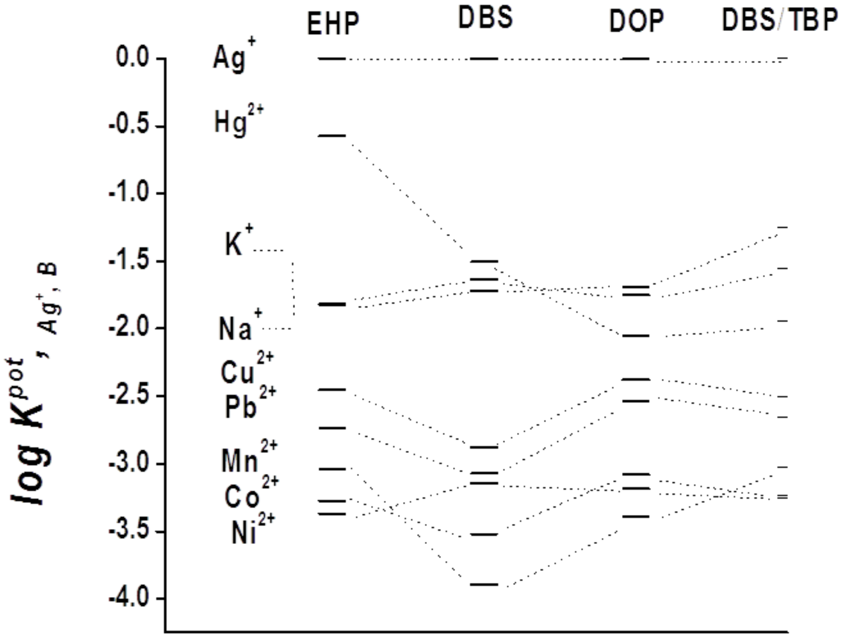

Figure 4. The effect of anionic additives and plasticizer on the selectivity of silver membrane sensors

The influence of the plasticizer and lipophilic anionic sites on the selectivity of the membrane electrodes is also determined in view of the data depicted in Fig. 4. For electrodes with less polar plasticizer membranes (DBS), a better selectivity toward silver ions over interfering cations is attained compared to membranes with more polar plasticizers (DOP & EHP). The selectivity order for these plasticizers was: $Ag^{+} > Hg^{2+} > K^{+} > Na^{+} > Cu^{2+} > Pb^{2+} > Ni^{2+}\ Co^{2+} > Mn^{2+}$; $Ag^{+} > Na^{+} > K^{+} > Hg^{2+} > Cu^{2+} > Pb^{2+} > Co^{2+} > Ni^{2+} > Mn^{2+}$; $Ag^{+} > Hg^{2+} > Na^{+} \sim K^{+} > Cu^{2+} > Pb^{2+} > Mn^{2+} > Ni^{2+} > Co^{2+}$.

Importantly, the presence of lipophilic anionic sites is found to reduce the resistivity of the membrane, and therefore minimizes the interference from other anions even at high sample concentration. The order of membrane selectivity for sensor plasticized in DBS in addition to 1 wt% NaTPB was: $Ag^{+} > K^{+} > Na^{+} > Hg^{2+} > Cu^{2+} > Pb^{2+} > Mn^{2+} > Co^{2+} > Ni^{2+}$

3.3. Analytical performance

3.3.1 Determination silver in silver nitrate solution (0.5%) in pharmaceutical samples

Table 3. Determination of silver ions in Silver nitrate solution (0.5%) samples using DBS/NaTPB based membrane sensor.

Matrix	Diluted samples	Recovery found *(%) Potentiometric sensor	Flame Atomic Absorption Spectrometry
Silver Nitrate Solution 0.5%	1:5	96.2±0.9	97.2±0.1
	1:8	97.8±0.6	98.7±0.3
	1:10	99.1±0.5	99.2±0.2

*Average of 5 determinations

Aqueous silver nitrate ($AgNO_3$) (0.5%) is effective as a topical bacteriostatic agent in massively burned patients and its use against a wide variety of organisms has been demonstrated [49]. The results obtained for determining silver in silver nitrate solution (0.5%) samples were in good agreements with those obtained using Flame Atomic Absorption (FAA) technique [50] (Table 3).

3.3.2 Potentiometric titration of metal ions

The optimized DBS/NaTPB electrode was found to behave very under laboratory conditions. Significantly, it was successfully implemented as an indicator electrode for potentiometric titration of some anions (e.g. Cl^{-}, I^{-}, Br^{-}, SCN^{-} and N^{3-}) as well as singly, binary or ternary mixtures using a standard $AgNO_3$ solution. The obtained titration curves showed sharp inflection breaks (~ 200 mV) at 1:1 for Ag^{+}/Cl^{-} , Ag^{+}/I^{-} , Ag^{+}/Br^{-} and Ag^{+}/SCN^{-} respectively and sharp inflection breaks (~ 310 mV) at 1:1 Ag^{+}/N^{3-}. In the case of titrations of binary mixture including ($Cl^{-} + I^{-}$), ($Cl^{-} + Br^{-}$), ($Cl^{-} + SCN^{-}$) and ($I^{-} + SCN^{-}$) two successive sharp inflection steps at the equivalence points of both anions were observed. Importantly, three successive inflection points were achieved for ternary mixture comprising $Cl^{-} + I^{-} + SCN^{-}$. Typical potentiometric titration curves are shown in Figures (5, 6 and.7).

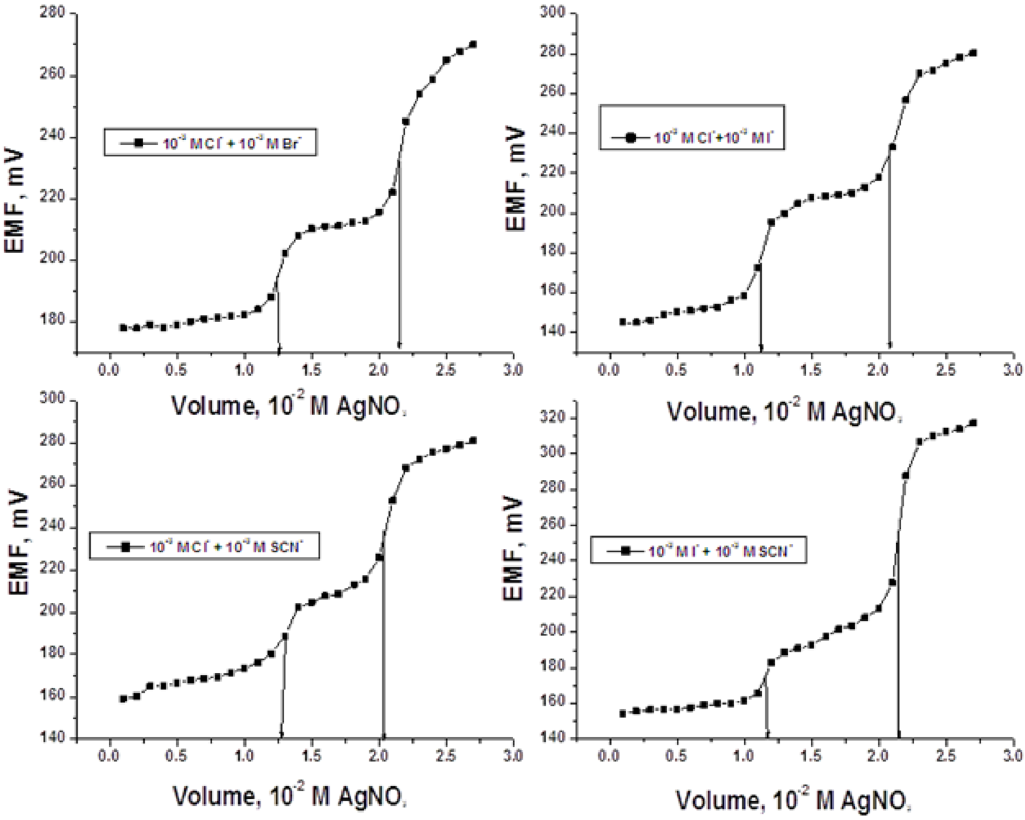

Figure 5. Potentiometric titration plot of binary mixture (Cl^- + I^-), (Cl^- + Br^-), (Cl^- + SCN^-) and (I^- + SCN^-) with 1.0 × 10^{-2} mol.L^{-1} Ag^+ using silver membrane sensor

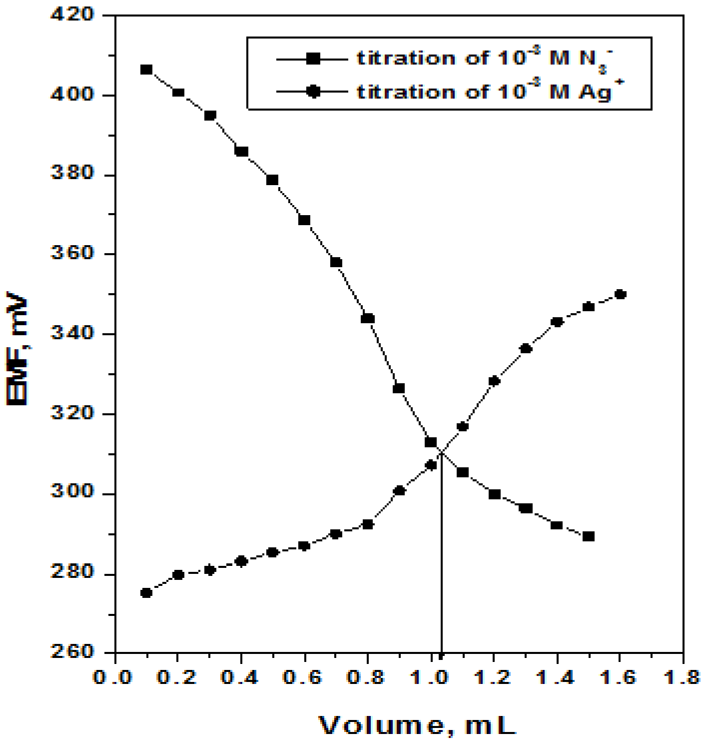

Figure 6. Potentiometric titration plot of N^{3-} with 1.0 × 10^{-2} mol.L^{-1} Ag^+ using silver membrane sensor electrode

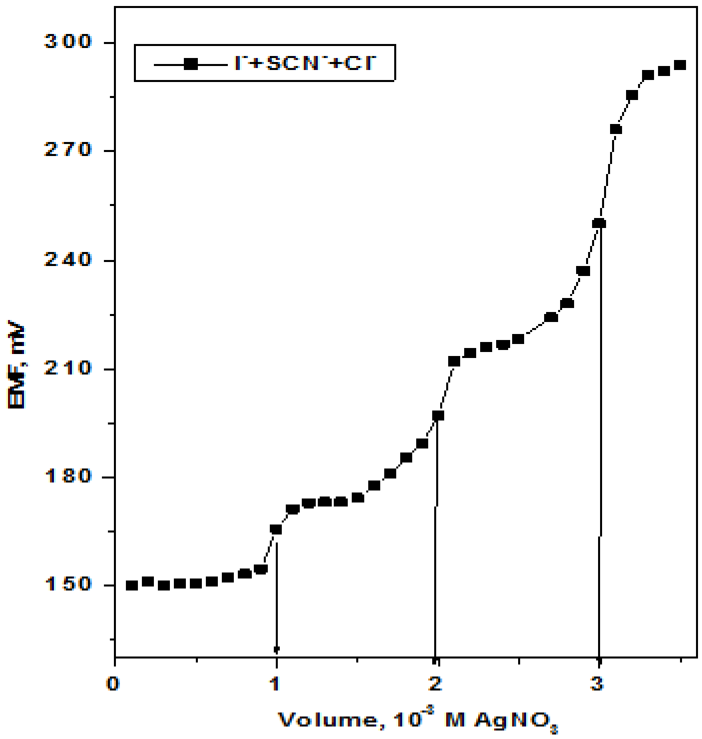

Figure 7. Potentiometric titration plot of ternary mixture (Cl$^-$ + I$^-$ + SCN$^-$) with 1.0 × 10^{-2} mol.L^{-1} Ag$^+$ using silver membrane sensor

4. CONCLUSIONS

Potentiometric silver sensor based on *p-tert*-butylthiacalixarene derivatives ionophore **2** showed stable and selective potential responses towards silver ions over the concentration range from 6.3 x 10^{-6} to 1.0 x 10^{-2} mol.L^{-1} with a detection limit of 2.5x10^{-6} mol.L^{-1} and slope of 53.6 ± 0.3 mV/decade, respectively. Application to silver evaluation in silver nitrate solution (0.5%) in pharmaceutical samples revealed good characteristic responses. Additionally, the silver PVC based membrane sensor was satisfactorily used for potentiometric titration of various anions such as Cl$^-$, Br$^-$, I$^-$, SCN$^-$ and Azid along with binary mixtures such as (Cl$^-$ + I$^-$) and (Cl$^-$ + Br$^-$) and (Cl$^-$ + SCN$^-$) and (I$^-$ + SCN$^-$). In case of ternary mixture of (Cl$^-$ + I$^-$ + SCN$^-$) potentiometric titration with silver nitrate, using the silver sensor to locate the equivalent points, was simply achieved.

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