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Fabrication and Characterization of a PVC Membrane Ni (II)-Selective Sensor Using 3-Hydroxy-4-[(2-Hydroxyphenyl) amino] cyclobut-3-ene-1,2-dione as a Neutral Carrier

Narendra Kumar
Department of Chemistry, Maharaj Singh College, Saharanpur, Uttar Pradesh, India

Corresponding Author: * Narendra Kumar

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Abstract

A poly (vinyl chloride) (PVC)-based ion-selective membrane electrode was successfully fabricated for the selective detection of nickel (II) ions by employing 3-hydroxy-4-(2-hydroxyphenylamino) cyclobut-3-ene-1,2-dione (L) as the ionophore. The membrane formulation included sodium tetraphenylborate (NaTPB) as a lipophilic anionic additive to enhance ion-exchange characteristics and tris-(2-ethylhexyl) phosphate (TEHP) as the plasticizer. Among the different membrane formulations investigated, the composition containing L: NaTPB: TEHP: PVC in a weight ratio of 10:1:100:200 exhibited the best analytical performance. The optimized membrane electrode produced a linear potentiometric response toward Ni^{2+} over the concentration range of 2.1×10^{-8} to 1.0×10^{-1} M, with a detection limit of 1.3×10^{-9} M. It showed a near-Nernstian sensitivity of 29.1 mV per decade change in nickel ion activity. Reliable and stable potential measurements were obtained within the pH range of 2.0–10.0, while the electrode reached equilibrium within approximately 8 s, indicating a rapid response. The sensor also maintained satisfactory performance in mixed solvent systems containing up to 30% (v/v) non-aqueous media and retained its sensing characteristics for nearly four months without significant deterioration. In addition, the membrane demonstrated excellent selectivity for Ni^{2+} over a wide range of interfering mono-, di-, and trivalent metal ions. The practical utility of the developed electrode was further demonstrated by its successful application as an indicator electrode during potentiometric titration of nickel (II) with EDTA and for the quantitative determination of nickel ions in real samples.

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1. INTRODUCTION

Nickel is extensively utilized as a catalyst in numerous industrial processes, resulting in its frequent occurrence in industrial wastewater. In addition, trace concentrations of nickel are naturally present in a variety of food products, such as chocolate, soybeans, nuts, oatmeal, cottonseed, cornmeal, hydrogenated vegetable oils, milk, and other dairy products. Under normal conditions, the concentration of dissolved nickel in unpolluted freshwater generally ranges from 0.001 to 0.005 mg L^{-1} [1]. However, concentrations exceeding this range may pose significant risks to human health. Excessive exposure to nickel has been associated with adverse effects including dermatitis, skin allergies, asthma, eczema, pulmonary inflammation, lung and nasal cancers, gastrointestinal disorders, haematological abnormalities, renal dysfunction, and damage to both the respiratory and central nervous systems. Consequently, the development of reliable, selective, and sensitive sensors for the determination of Ni^{2+} ions has become increasingly important for monitoring industrial effluents, environmental waters, food products, and biological samples.

Several techniques, including atomic absorption spectrometry (AAS), flame atomic absorption spectrometry with electrothermal atomization (AAS-ETA) [2–5], inductively coupled plasma-atomic emission spectroscopy (ICP-AES), and flame photometry [6], can be used to measure nickel levels. However, these methods usually need sample preparation and a backup system, making them less suitable for routine testing of a large number of environmental samples. Because of this, there is a strong need to develop a selective, portable, and affordable tool for detecting nickel. Potentiometric detection using ion-selective electrodes is a straightforward method. It offers several benefits, such as fast results, easy setup and operation, simple equipment, quick response time, no risk of contamination, non-destructive analysis, and it's not affected by colour or cloudiness. It also has a broad range of measurement and good enough selectivity.

Literature survey shows that several Ni (II) selective electrodes using different ionophores have been developed [7-27]. However, many of these electrodes suffer from issues like high detection limit, limited working concentration range, narrow pH range, or slow response time. So, these electrodes couldn't be used widely for measuring Ni^{2+} ions. Because of that, there's still a need to create an electrode that's more selective and sensitive. That's why new materials are constantly being tested for this purpose. Continuing this work, A novel Schiff base, 3-hydroxy-4-(2-hydroxyphenylamino) cyclobut-3-ene-1,2-dione [L], was recently synthesized. This ligand was employed in the fabrication of a poly (vinyl chloride) (PVC) membrane electrode exhibiting selectivity toward Ni^{2+} ions, and it was further applied for the quantification of Ni^{2+} in real sample matrices. The findings of this investigation are presented in this study.

2. EXPERIMENTAL

2.1. Reagents and Materials

All chemicals used in the study were of analytical reagent grade. Squaric acid was procured from Otto Chemie Pvt. Ltd., Mumbai, India. 2-Aminophenol, high molecular weight poly (vinyl chloride) (PVC), and different metal salts were obtained from CDH Fine Chemicals Pvt. Ltd., New Delhi, India. Solvent mediators and plasticizers, including sodium tetraphenylborate (NaTPB), chloronaphthalene (CN), and diphenoxyethane (DPE), were supplied by Merck, Germany. Additional plasticizers such as di(2-ethylhexyl) adipate (DEHA), dioctyl sebacate (DOS), dibutyl sebacate (DBS), and tris(2-ethylhexyl) phosphate (TEP) were sourced from Reidel, India. Metal nitrate solutions were prepared using doubly distilled water and standardized by suitable chemical procedures. Working solutions of different concentrations were obtained through appropriate dilution of a 0.1 M stock solution.

2.2. Synthesis of Ionophore.

The Ligand 3-hydroxy-4-(2-hydroxyphenyl amino cyclobut-3-ene-1,2-dione [**L**] was synthesized according to the previously reported procedures [28] as shown in Figure 1.

The ligand was synthesized by dissolving 2.28 g of squaric acid in 30 mL of diethyl ether, followed by heating at 50 °C on a magnetic hot plate with continuous stirring at 300 rpm. After approximately 30 minutes, the solution developed a pale pink coloration and became clear and homogeneous. Subsequently, 2.18 g of 2-aminophenol, previously dissolved in 15 mL of diethyl ether, was gradually introduced into the stirred squaric acid solution after one hour, and stirring was then discontinued. After completion of the reaction, the mixture was cooled to room temperature for approximately 20 minutes. The resulting product was separated by filtration and thoroughly rinsed several times with diethyl ether to remove any remaining unreacted materials. The filtrate was then collected in a beaker, covered with perforated aluminium foil, and kept undisturbed for three days to facilitate slow evaporation of the solvent. The obtained solid was subsequently dried in a desiccator over calcium chloride for an additional three days, producing a light brown precipitate.

2.3. Preparation of Membranes

Predetermined amounts of the ionophore (L), high-molecular-weight poly (vinyl chloride) (PVC), selected plasticizers or solvent mediators (DPE, DEHA, DOS, TEP, DBS, or CN), and sodium tetraphenylborate (NaTPB) as an anionic additive were dissolved in nearly 25 mL of tetrahydrofuran (THF). The mixture was stirred thoroughly until a clear and uniform solution was obtained, ensuring complete removal of entrapped air bubbles. The resulting casting solution was poured into polyacrylate rings placed on a clean, level glass surface and left undisturbed to permit slow evaporation of the solvent at room temperature. Once the membranes had completely dried, they were carefully peeled from the glass plate, cut into the desired size, and firmly attached to one end of a Pyrex glass tube using Araldite adhesive. The different membrane formulations investigated, together with their potentiometric performance characteristics, are presented in Table 2.

2.4. Equilibration of Membranes and Potential Measurements

Prior to analytical measurements, the prepared membrane was activated by soaking it in a 0.1 M nickel nitrate [$Ni(NO_3)_2$] solution for 3–4 days to ensure proper equilibration. Following conditioning, the electrode response was evaluated by measuring the potential of nickel nitrate solutions over a concentration range from 1.0×10^{-1} to 1.0×10^{-9} M. The calibration solutions were obtained by serial dilution of a freshly prepared 0.1 M Ni $(NO_3)_2$ stock solution, providing a series of standards with progressively lower nickel ion concentrations. Membranes of varying compositions were fabricated and evaluated, and those demonstrating consistent and reliable performance were chosen for further investigation. All potential measurements were carried out at 25 °C using a saturated calomel electrode as the reference system, arranged in the following configuration:

$Hg/Hg_2Cl_2|KCl$ (satd.) | 0.1M Ni $(NO_3)_2$ ||PVC membrane ||test solution $|Hg/Hg_2Cl_2|KCl$ (satd.)

Activity coefficients were calculated according to the Debye–Huckel procedure, using the following equation [29]:

$$log\ \gamma\ =\ -0.511z^2\left[\frac{\sqrt{\mu}}{1+1.5\sqrt{\mu}}\ -\ 0.2\mu\right]$$

where μ is the ionic strength and z the valency.

The possible interaction of Ni^{2+} with the ionophore is shown in Figure 2. The coordination environment around the Ni^{2+} center is octahedral. Two ionophore **L** molecules coordinate to the metal ion, with the phenolic oxygen atoms binding in their deprotonated form. In addition, two nitrogen donor atoms from the ionophores occupy two coordination sites, while the remaining two positions are occupied by solvent molecules.

3. RESULTS AND DISCUSSION

3.1. Determination of stability constants

The stability constants of the ion–ionophore complexes were evaluated using a potentiometric technique employing the sandwich membrane method [30]. In this method, a composite membrane is prepared by combining two layers, where only one layer includes the ionophore. The resulting membrane electrode is immersed in an aqueous ionic solution with identical concentrations on both sides, and the corresponding cell potential is recorded. In addition, the potential of a membrane lacking the ionophore is measured under similar conditions. The membrane potential (E_M) is then obtained as the difference between the potential of the sandwich membrane and that of the ionophore-free membrane. Finally, the formation constant is calculated using the appropriate equation.

$$\beta_{IL_n} = \left(L_T - \frac{nR_T}{Z_I}\right)^{-n} \exp\left(\frac{E_M Z_I F}{RT}\right) \qquad (2)$$

Here, L_T represents the overall concentration of the ionophore within the membrane phase, while R_T denotes the amount of lipophilic ionic site additives present. The term *n* corresponds to the stoichiometric ratio of the ion–ionophore complex, and E_M indicates the membrane potential. The symbols R, T, and F retain their standard thermodynamic meanings, and Z_I refers to the charge of ion I. This expression provides a practical way to evaluate the formation constants of ion–ionophore complexes in the membrane phase by using transient potential measurements obtained from two-layer sandwich membranes, assuming that ion pairing effects are negligible. Determining these formation constants is important for refining ionophore design and adjusting the composition of ion-selective electrode (ISE) membranes to achieve improved performance for specific target ions. The values of stability constants for a number of complexes calculated by the above method are listed in Table 1.0. The values of formation constants (Table 1.0), for ion-ionophore complexes, obtained by the sandwich membrane method indicate that the value of the formation constant is highest for the complex of Ni^{2+} with ligands [L]. It can be concluded from these results that the ligand forms a stable complex with Ni (II) and complexes of comparatively poor stability with other metal ions. Because of its high affinity towards Ni^{2+} ion, I thought it desirable to explore the ligand as a potential ionophore in the preparation of a Ni^{2+} ion-selective electrode.

3.2. Selection of membranes

Multiple membranes were prepared by incorporating the ligand 3-hydroxy-4-(2-hydroxyphenyl) amino cyclobut-3-ene-1,2-dione [L] into a PVC-based matrix. Among the different formulations evaluated, the membrane with a composition ratio of 10:1:200 (L: NaTPB: PVC) exhibited superior performance. The effect of various solvent mediators was also investigated. Out of the membranes containing TEHP, DPE, DOS, TEP, CN, and DBS, the formulation with a ratio of 10:1:100:200 (L: NaTPB: TEHP: PVC) provided the broadest working concentration range and overall best results. An equilibration period of approximately 3–4 days was found to be optimal when the membrane was conditioned in a 0.1 M Ni (II) solution. Detailed information regarding the compositions and response behaviour of the most effective membranes is summarized in Table 2.

3.3. Working concentration range and slope

The performance of all membrane sensors was evaluated by studying their response to Ni^{2+} activity (Figure 3) over a concentration range of 1.0×10^{-9} to 1.0×10^{-1} M. Membrane 1, prepared without any solvent mediator, exhibited a relatively narrow working range of 9.1×10^{-6} to 1.0×10^{-1} M and produced a super-Nernstian slope of 36.8 mV per decade. The developed membrane electrode exhibited a rapid response, requiring approximately 25 s to attain a stable potential in relatively concentrated nickel solutions, whereas the response time increased to nearly 45 s when the nickel concentration decreased below 1.0×10^{-6} M. Because plasticizers play an important role in enhancing the physicochemical properties of PVC membranes, different solvent mediators were evaluated to investigate their effect on electrode performance. The incorporation of suitable plasticizers considerably extended the linear working range of the sensor and improved its potentiometric behaviour. Among the tested membranes, those containing TEHP and DPE (membranes 2 and 3) displayed

superior analytical characteristics, producing near-Nernstian slopes over broader concentration ranges. Membrane 2 responded linearly from 2.1×10^{-8} to 1.0×10^{-1} M with a sensitivity of 29.0 mV decade^{-1}, while membrane 3 exhibited a working interval of 1.8×10^{-5} to 1.0×10^{-1} M and a slope of 31.8 ± 1.0 mV decade^{-1}. Likewise, membranes plasticized with DOS and CN (membranes 4 and 6) also demonstrated satisfactory analytical performance, providing linear response ranges of 1.2×10^{-6}–1.0×10^{-1} M and 5.7×10^{-6}–1.0×10^{-1} M, respectively, with corresponding slopes of 32.0 and 32.3 mV decade^{-1}. Conversely, membranes prepared using TEP and DBS as plasticizers failed to produce any substantial improvement in either the linear detection range or the electrode slope. The experimental results presented in Table 2 identify the membrane containing TEHP as the most efficient formulation. Its optimized composition consisted of L: NaTPB: TEHP: PVC = 10:1:100:200, which delivered the best sensing performance. Additional optimization was performed by adjusting the ionophore content, and the composition designated as membrane 3 in Table 3 (equivalent to membrane 2 in Table 2) was found to be the optimum formulation. Further increases in the ionophore concentration did not produce any measurable enhancement in the analytical response of the electrode. The precision of the proposed sensor was assessed by recording 20 consecutive potential measurements at the same membrane surface, resulting in a standard deviation of only 0.3 mV. Furthermore, the calculated slope values showed standard deviations between 0.8 and 1.0 mV decade^{-1}, confirming the excellent repeatability, stability, and reproducibility of the fabricated nickel-selective membrane sensor.

3.4. Response and lifetime

It is well known that the dynamic response time of a sensor is one of the most important factors in its evaluation. In this study, the practical response time was recorded by fast stepwise changing of the Ni^{2+} concentration from 1.0×10^{-7} to 1.0×10^{-2} M. The actual potential versus time (Figure 4) shows that the dynamic response time of the sensor made from Ni (II) takes about 8 seconds on average to reach a voltage that is within less than one millivolt of its final stable value. The voltage it produces stayed steady for roughly 5 minutes. The sensor was used for 4 months without any noticeable change, but after that time, the slope of its response started to decrease slightly. Reproducibility of the sensor was examined by using six similar constructed sensors under the optimum conditions. The result showed good reproducibility (± 0.6 mV) for the sensor.

3.5. pH and non-aqueous effect

Hydrogen ions are inherently present in aqueous solutions and may interfere with the electrochemical behaviour of ion-selective electrodes. Consequently, identifying the pH range over which the sensor provides reliable and interference-free measurements is essential. The effect of pH on the performance of the developed Ni (II)-selective electrode was investigated using 1.0×10^{-3} M and 1.0×10^{-4} M nickel ion solutions within the pH range of 2.0–11.0. The solution pH was carefully modified by the gradual addition of 1.0 M HNO_3 or NH_4OH. As presented in Figure 5, the electrode exhibited a stable and nearly constant potential response between pH 2.0 and 10.0, demonstrating that this interval represents the optimum operating pH range. At pH values above 10.0, the observed variation in potential is primarily associated with the hydrolysis of Ni (II) ions, whereas at lower pH values, excessive hydrogen ion concentration competes with nickel ions, leading to interference in the electrode response.

The applicability of the sensor in partially non-aqueous media was examined using binary solvent systems comprising methanol–water, ethanol–water, and acetone–water mixtures. Such an evaluation is important because environmental and industrial samples, particularly wastewater, frequently contain varying amounts of organic solvents. The fabricated electrode maintained stable potentiometric behavior in solutions containing up to 30% (v/v) of the organic solvent, as presented in Table 4. Beyond this concentration, significant deviations in electrode potential were observed, which may be attributed to the gradual leaching of the ionophore from the membrane into the sample solution.

3.6. Potentiometric selectivity

Selectivity is one of the most important features of a sensor. The potentiometric selectivity of the developed Ni (II) sensor was tested using the fixed interference method (FIM) [31,32], with the formula, $K_{A,B}^{Pot} = \frac{a_A}{(a_B)^{Z_A/Z_B}}$. The selectivity coefficients were measured at a concentration of 1.0×10^{-2} M for foreign ions. The values of these coefficients are listed in Table 5. These values show that the developed Ni (II) sensor is more sensitive to Ni (II) ions compared to several other cations.

4. ANALYTICAL APPLICATIONS

4.1. Potentiometric titration

The sensor's practical utility was assessed by employing it as an indicator electrode in the potentiometric titration of Ni^{2+} ions with EDTA. For this purpose, 10 mL of a 1.0×10^{-3} M nickel (II) solution was titrated against a 1.0×10^{-2} M EDTA solution under controlled conditions at pH 5.0. The resulting titration profile (Figure 6) displayed the characteristic S-shaped curve expected for such measurements, with a sharp and distinct inflection at the equivalence point, indicating the stoichiometric complexation of Ni^{2+} by EDTA. The clear endpoint obtained demonstrates that the fabricated sensor can serve as a reliable indicator electrode for the accurate potentiometric determination of nickel (II) ions.

4.2. Determination of the Ni (II) in Wastewater Samples

The developed electrode was successfully employed for the quantification of nickel ions in wastewater collected from industrial electroplating facilities. As presented in Table 6, the nickel concentrations measured with the proposed sensor closely matched those determined by atomic absorption spectrometry (AAS). The strong agreement between the two analytical methods demonstrates the reliability and accuracy of the fabricated electrode, confirming its potential for the determination of Ni^{2+} in environmental and industrial wastewater samples.

4.3. Comparison with other Ni^{2+} Electrodes

Table 7 presents a comparative evaluation of the analytical performance of the proposed Ni (II)-selective electrode with previously reported nickel ion sensors. Although many earlier electrodes exhibit satisfactory calibration slopes and acceptable working concentration ranges, they often suffer from drawbacks such as limited linear response intervals, higher limits of detection, slower response times, or reduced operational durability. In contrast, the developed sensor demonstrates a near-Nernstian slope, a broad linear working range, rapid potential stabilization, low detection limit in the sub-micromolar region, and excellent long-term stability. These combined characteristics indicate an overall improvement in sensing performance. It should be noted that direct comparison among different electrodes should be interpreted carefully, since variations in membrane composition, fabrication procedures, experimental conditions, and calibration methodologies can influence the reported analytical parameters. Despite these differences, the overall comparison confirms that the proposed electrode offers an effective combination of high sensitivity, excellent selectivity, and sustained stability, making it a promising platform for accurate and reliable determination of Ni (II) ions in real sample analysis.

5. CNCLUSION

Among the various membrane formulations investigated, the PVC-based electrode containing 10 mg of ligand (L), 1 mg of NaTPB, 100 mg of TEHP, and 200 mg of PVC displayed the highest analytical performance. The optimized membrane provided excellent reproducibility and remained operationally stable for approximately four months without significant deterioration. It enabled accurate quantification of Ni^{2+} ions across a wide concentration interval ranging from 2.1×10^{-8} to 1.0×10^{-1} M. Furthermore, the electrode exhibited dependable performance over a pH range of 2–10 and achieved a rapid equilibrium response within nearly 8 seconds.

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FIGURES:

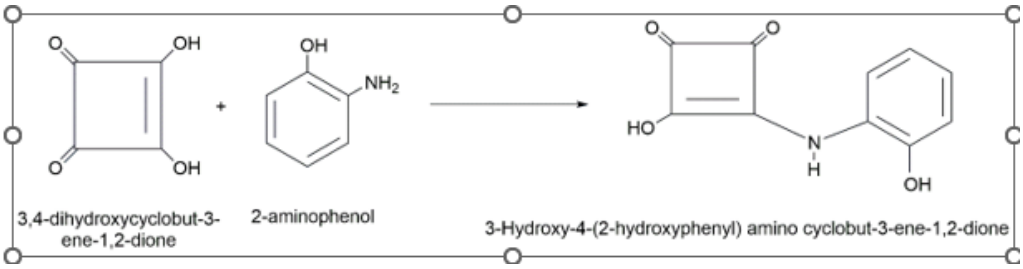

Figure 1: Synthetic Scheme of 3-hydroxy-4-(2-hydroxyphenylamino) cyclobut-3-ene-1,2-dione (L).

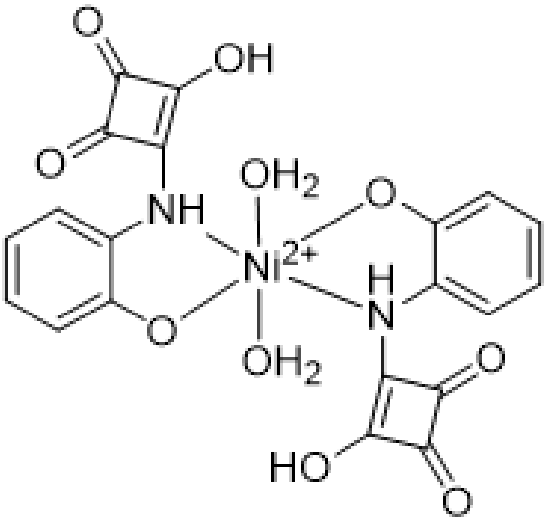

Figure 2. Proposed structure of Ni^{2+} complex with the ionophore **L**.

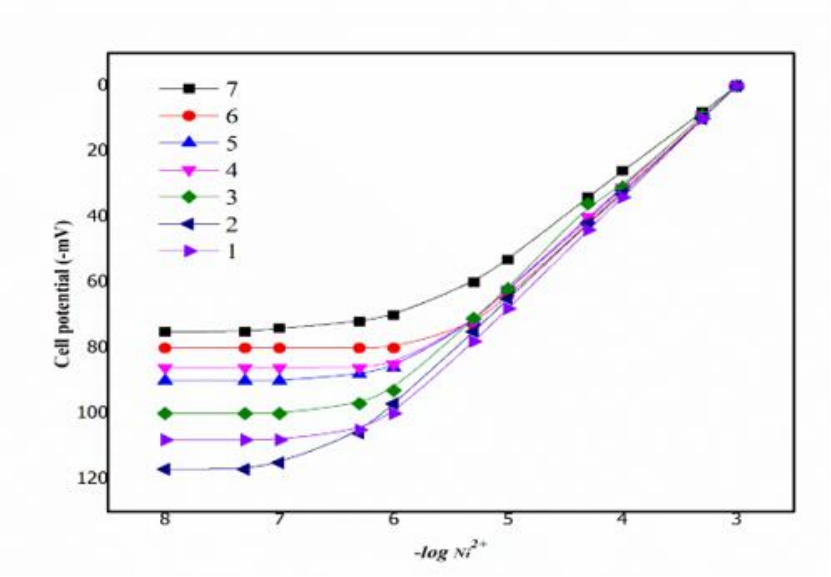

Figure 3: Variation of cell potential with Ni^{2+} concentration for electrode nos. 1–7

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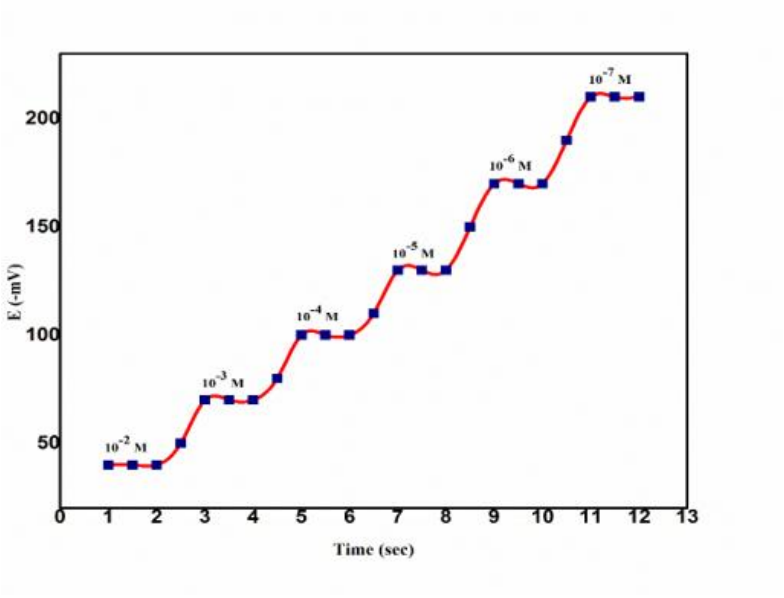

Figure 4: Dynamic response time of the Nickle electrode for step changes in the Ni^{2+} concentration

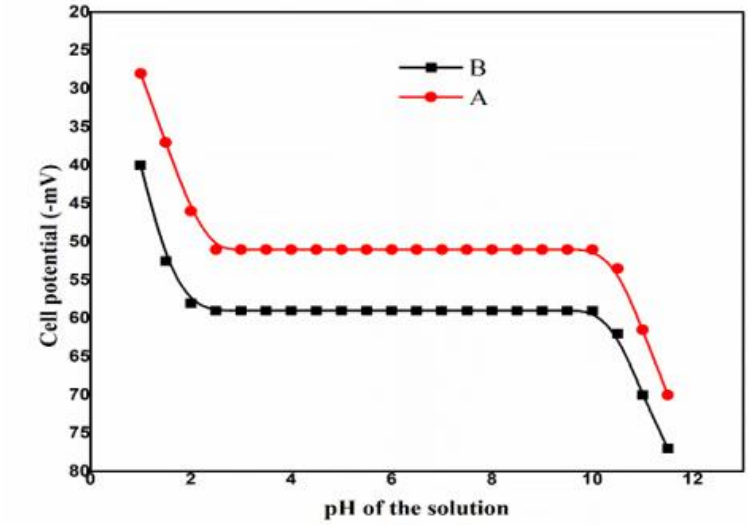

Figure 5: Effect of pH on cell potential: **[Ni] = 1.0 × 10^{-3} M (A) and 1.0 × 10^{-4} M (B).**

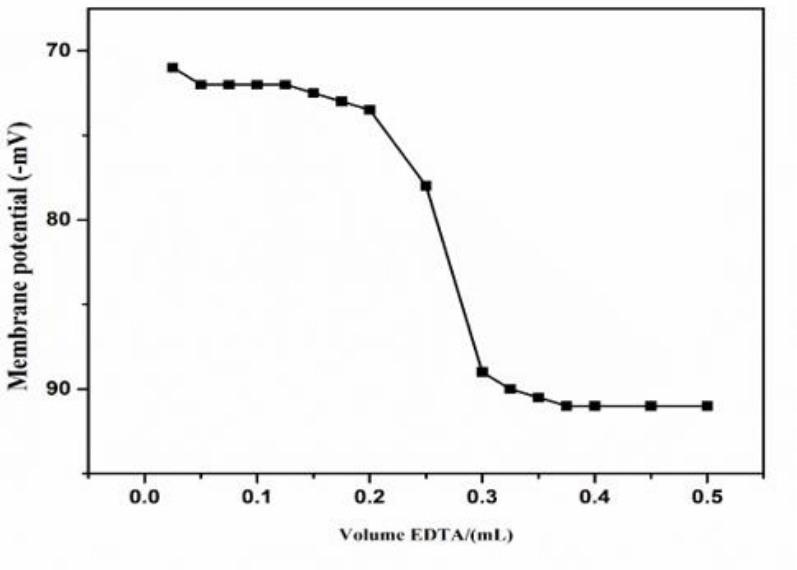

Figure 6: Titration plot of 10 mL of 1.0 × 10^{-3} M Ni^{2+} with 1.0 × 10^{-2} M EDTA solution

TABLES:

Table 1. Stability constants of various metal ions with [L]

Cations	Stability Constant ($log\beta_{Ln}$) $n = 2$
Ni^{2+}	7.94
Cu^{2+}	4.32
Co^{2+}	3.32
Zn^{2+}	3.29
Pb^{2+}	3.22
Cd^{2+}	3.40
Mg^{2+}	2.79
Hg^{2+}	2.68
Fe^{2+}	2.71
Mn^{2+}	2.77
Ca^{2+}	2.82
Ag^{+}	0.98
Fe^{3+}	0.96

Table 2: Compositions and response characteristics of PVC-based membranes having 3-hydroxy-4-(2 hydroxyphenyl amino) cyclobut-3-ene-1,2-dione as electroactive material

Membrane No.	L	NaTPB	TEHP	DPE	DOS	CN	TEP	DBS	PVC	Working concentration range (M)	Slope (mV/decade)	Detection limit (M)	Response time (s)
1	10	1	–	–	–	–	–	–	200	9.1×10^{-6} – 1.0×10^{-1}	35.4	1.0×10^{-6}	25
2	10	1	100	–	–	–	–	–	200	2.1×10^{-8} – 1.0×10^{-1}	29.1	1.3×10^{-9}	8
3	10	1	–	150	–	–	–	–	200	1.8×10^{-6} – 1.0×10^{-1}	31.8	3.0×10^{-6}	23
4	10	1	–	–	100	–	–	–	200	1.2×10^{-6} – 1.0×10^{-1}	32.0	3.9×10^{-6}	15
5	10	1	–	–	–	150	–	–	200	2.8×10^{-6} – 1.0×10^{-1}	33.0	3.2×10^{-6}	16
6	10	1	–	–	–	–	150	–	200	5.7×10^{-6} – 1.0×10^{-1}	32.3	2.4×10^{-6}	17
7	10	1	–	–	–	–	–	200	200	7.8×10^{-6} – 1.0×10^{-1}	31.1	2.0×10^{-6}	21

Table 3: Response characteristics of PVC-based membranes having different amounts of 3-hydroxy-4-(2 hydroxyphenyl amino) cyclobut-3-ene-1,2-dione

Membrane No.	I	NaTPB	TEHP	PVC	Working concentration range (M)	Slope (mV/decade of activity)	Response time (s)
A	8	1	100	200	9.5×10^{-6} – 1.0×10^{-1}	32.0	42
B	9	1	100	200	2.5×10^{-6} – 1.0×10^{-1}	33.0	32
C	10	1	100	200	2.1×10^{-8} – 1.0×10^{-1}	29.1	8
D	11	1	100	200	2.1×10^{-8} – 1.0×10^{-1}	29.1	8
E	12	1	100	200	2.1×10^{-8} – 1.0×10^{-1}	29.1	8

Table 4: Performance of sensor no. 2 in partially non-aqueous media

Non-aqueous content (%, v/v)	Slope (mV/decade of activity)	Working concentration range (M)
0	29.1	2.1×10^{-8}- 1.0×10^{-1}
Methanol		
10	29.1	2.1×10^{-8}- 1.0×10^{-1}
20	29.1	3.1×10^{-8}- 1.0×10^{-1}
25	29.0	4.1×10^{-8}- 1.0×10^{-1}
30	29.0	3.1×10^{-8}- 1.0×10^{-1}
35	28.1	6.1×10^{-7}- 1.0×10^{-1}
Ethanol		
10	29.1	2.1×10^{-8}- 1.0×10^{-1}
20	29.2	4.1×10^{-8}- 1.0×10^{-1}
25	29.2	5.1×10^{-8}- 1.0×10^{-1}
30	29.1	6.1×10^{-8}- 1.0×10^{-1}
35	27.0	7.1×10^{-7}- 1.0×10^{-1}
Acetone		
10	29.1	6.1×10^{-8}- 1.0×10^{-1}
20	29.1	7.1×10^{-8}- 1.0×10^{-1}
25	29.1	5.1×10^{-8}- 1.0×10^{-1}
30	29.0	2.1×10^{-8}- 1.0×10^{-1}
35	28.1	8.1×10^{-7}- 1.0×10^{-1}

Table 5: Selectivity coefficient values for sensor no. 2 as obtained by modified fixed interference method (interfering ion concentration is 1.0×10^{-2} M)

Interfering Ion (B)	Selectivity Coefficient, (K_ {\text {Ni}^{2+}, B}^{\text {Pot}})
Ag^{+}	2.2×10^{-5}
Pb^{2+}	4.2×10^{-3}
Mg^{2+}	3.3×10^{-4}
Na^{+}	5.6×10^{-5}
Zn^{2+}	3.7×10^{-2}
K^{+}	8.2×10^{-5}
Bi^{3+}	4.6×10^{-3}
Hg^{2+}	3.8×10^{-2}
Co^{2+}	2.2×10^{-2}
Cd^{2+}	8.1×10^{-2}
Al^{3+}	4.5×10^{-3}
Ca^{2+}	4.0×10^{-4}

Cr^{3+}	3.4×10^{-3}
Ni^{2+}	6.2×10^{-3}
Mn^{2+}	5.2×10^{-3}
Ba^{2+}	5.1×10^{-3}

***Average of three replicates is taken.**

Table 7: Comparing of the proposed Ni (II)- electrode characteristics with some of the previously reported Ni (II)-ISEs.

References	Slope (mV decade^{-1})	Response time (s)	pH	Life time (Days)	Linear range (mol L^{-1})	Detection Limits (M)
Proposed Sensor 2.	29.1	8	2.0 -9.0	120	$2.1 \times 10^{-8} – 1.0 \times 10^{-1}$	1.3×10^{-9}
22	29.8	12	2.0 – 7.6	60	7.08×10^{-6}-1.0×10^{-1}	-
26	30.0	10	2.2–5.9	120	3.2×10^{-6} - 5.0×10^{-2}	-
27	29.6	10	2.0–6.5	120	1.0×10^{-6} to 1.0×10^{-1}	1.6×10^{-6}
37	30.0	10	2.0–9.8.	90	1.0×10^{-7} - 1.0×10^{-2}	5.1×10^{-8}
36	29.6	10	5.0 – 9.0	60	5×10^{-6} to 1.0×10^{-1}	5.0×10^{-6}
34	29.5	10	3.0 -8.0	120	4.6×10^{-7}–1.0×10^{-1}	2.7×10^{-7}
33	30.0	10	2.5-9.5	120	1.6×10^{-7} to 1.0×10^{-2}	3.6×10^{-6}

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