

Synthesis and Characterization of 1-phenyl-3-methyl-4-benzoylpyrazolone-5 (HPMBP) and its application as Ionophore in Neodymium (III) Selective Membrane Electrodes

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Abstract

It has been successfully synthesized and characterized of 1-phenyl-3-methyl-4-benzoyl-5-pyrazolone (HPMBP) to be used as ionophore in neodymium(III) selective membrane electrode. This electrode has been used as indicator electrode for determination of Nd(III) potentiometrically. The performance of the electrode has been investigated in 10^{-6} to 10^{-2} M of Nd^{3+} standard solution at pH 4 and ionic strength adjusted by 10^{-2} M of KCl. Sensitivity and limit detection of the electrode is 39.91 ± 1.33 mV/decade and 1.02×10^{-4} M of Nd^{3+} respectively. The response time of the electrode is 22 second and its life time is 3 week. The electrode has been tested for determination of Nd^{3+} concentration in real sample solution of Bangka monasit sand prepared by Centre Research of Mineral and Coal Mine-Bandung. The result has a good agreement with the Nd^{3+} concentration determined by ICP-OES.

Keywords: ion selective electrode, HPMBP, neodymium.

1. Introduction

1-phenyl-3-methyl-4-benzoyl-5-pyrazolone (HPMBP), can be synthesized by reacting 1-phenyl-3-methyl-5-pyrazolone (PMP) with benzoyl chloride in dioxane as solvent. This condensation reaction may take place with calcium hydroxide, $Ca(OH)_2$ as catalyst[1]. HPMBP is often used as a ligand, either in solvent extraction or column chromatography to extract and separate lanthanide and actinide metal ions, and some bivalence metal ions such as Ba^{2+} , Cu^{2+} , Pb^{2+} , Co^{2+} and Mg^{2+} from water[2]. The extraction of Ba^{2+} and Eu^{2+} can be extracted in acidic solution with HPMBP as ligand in chloroform, benzene, and octanol as organic phase[3]. Several experiments which have been performed by liquid-liquid extraction with HPMBP either as single-ligand and as synergistic system with other ligands such as tri-n-octylphosphine oxide (TOPO), tributylphosphat (TBP), the n-oyltrifluoroacetone (HTTA), crown ether (CE), Aliquat-336 (QC) and with n-octylphenyl(N,N-diisobutylcarbamoyl-methyl) phosphine oxide (CMPO)[4]. Table 1 show some investigation of utilization of HPMBP as a single ligand, and as a synergistic system with other ligands for metal extraction purpose. Base on the performance of HPMBP as ligand in the extraction of rare earth element, it is also possible that these compounds are used as ionophore in ion selective membrane electrodes (ISE). The expectation in this investigation is that the membrane electrode will have good selectivity and sensitivity, low detection limits, short response times, and long time of usage. This investigation has been started by synthesizing and characterizing the HPMBP, and studied its potentiometric performance as ionophore for determination of Nd(III).

Table 1 Utilization of HPMBP as a single ligand, and as a synergistic system with other ligands for metal extraction

Ion	extractants	solvent	reference
Eu ³⁺ and Sc ³⁺	HPMPBP with TOPO		5 – 10
Pr ³⁺ , Gd ³⁺ and Yb ³⁺	Synergistic HPMPBP-1-(2-pyridylazo-2-naphthol), HPMPBP- tri-n-octylamine, HPMPBP-TOPO	Synergic of C ₆ H ₆ , CHCl ₃ , CCl ₄	5 – 10
La ³⁺ , Eu ³⁺ and Am ³⁺ ,	Synergistic HPMBP- CMPO, HPMBP-TBP-TOPO, and HPMBP-bis(2ethylhexyl) sulphoxide (B2EMSO), HPMBP-CMPO, HPMBP - B2EMSO		5 – 10
Pr ³⁺ , Gd ³⁺ and Yb ³⁺	HPMBP-tridodecyl-ammonium(TDAHA), HPMBP-dioctyl-ammonium (DOAHA), and trioctylammonium (TOAHA), HPMBP-Aliquat 336, HPMBP with primary ammonium salts, and HPMBP-Aliquat336-Ion ammonium salts		11-13
Lu ³⁺ , Th ⁴⁺ , Mo ⁶⁺ , alkali metals and alkaline earth	HPMBP		14-17
Ce ³⁺ , La ³⁺ and Pr ³⁺	HPMBP vs HPMBP-TIBPS		18-19
Ce ³⁺ adsorption	HPMBP incapsulated in alginate		

The Nd³⁺-ISE prepared is an indicator electrode with internal filling solution type, using a Teflon tube as body of the electrode, and 0.45µm pore size of polytetrafluoroethylene (PTFE) membrane as sensing material. The membrane was prepared by impregnation procedure in ionophore solution. Therefore, potential's response of the electrode is strongly influenced by the ionic strength and pH of the solution, it is necessary to examine the influence of these two factors.

The standard method for REE's analysis in general are AAS, ICP/ICP-MS, and ICP-OES. Meanwhile, the conventional method of REE's analysis is gravimetric[20-21]. However, such methods require sample manipulation, time consuming, substantial cost and expensive equipment. The ion selective electrode (ISE) is one of the simple potentiometric methods used for analyzing Nd³⁺, Pr³⁺ and Dy³⁺. Ion selective electrode for determination of La³⁺, Nd³⁺, Pr³⁺, Dy³⁺, and Ce³⁺ have been designed using trithiane as ionophore. In the last of 2 decades, potentiometric analysis by ISE is still well developed because this method is cheap, simple to operate, sensitive, selective, and environmentally friendly(22-24).

2. Experiments

Chemicals

All chemicals used were pro-analysis grade such as 1-phenyl-3-methylpyrazolone-5 (PMP) (Fluka), Ca(OH)₂, (Sigma Aldrich), HCl (Merck), benzoyl chloride (Merck), 1,4-dioxane (Merck), Nd₂O₃ (Sigma Aldrich), NaOH (Merck), HNO₃ (Merck), Ag wire, and Teflon tube.

Instrument

The equipment involved in this investigation were, hotplate (Thermolyte), three-neck flask, thermocouple (Mirak), Büchner funnel, melting point apparatus, Fourier transform infrared spectrophotometer (Shimadzu/Prestige), nuclear magnetic resonance spectrophotometer (¹HNMR) and (¹³CNMR), mass spectrophotometer (MS) and potentiometer/ion meter (Metrohm, type 692).

3. Procedure

3.1. Synthesis and characterization of HPMBP

The synthesis was carried out by dissolving 57.4mmol of 1-phenyl-3-methylpyrazolon-5 (PMP) in 50mL of 1,4-dioxane which placed in a three-neck flask. The mixture was heated to 50°C for 20 minutes, and then added 8 grams of Ca(OH)₂, 10mL of benzoyl chloride dropwise and 50mL of 1,4-dioxane. The mixture temperature was raised slowly until it reached 110-120°C and then was allowed for 3 hours while stirring with a magnetic stirrer. After 3 hours the mixture was allowed to cooldown to room temperature, and added with 100mL of 2M HCl, and was shaken for 10 minutes to obtain a yellowish brown precipitate. The precipitate was filtered with a Buchner funnel and then washed with water until neutral. Other organic impurities are removed with ethanol treatment. The obtained HPMBP crystal was a bright yellow powder. Characterization was performed by determination of its melting point, infrared absorption spectrum (FTIR), proton and carbon nuclear magnetic resonance spectrum (¹HNMR, and ¹³CNMR), and molecular mass spectrum (Masspec).

3.2. Preparation of HPMBP-Nd membrane system

The sensing membrane was prepared by immersing PTFE membrane in a 1.5 - 2.0% w/v HPMBP solutions in chloroform for 24 hours. After that the membrane was dried at room temperature, than attached to tubular type electrode body made of Teflon with 10 cm length, 1.5 cm diameter and 0.5 cm hole. The electrode body which has been equipped by membrane and Ag/AgCl internal reference electrode then was filled with internal solution consist of KCl and Nd³⁺ with certain ratio. Finally HPMBP-Nd electrode was ready to investigate.

3.3 Determination of HPMBP-Nd membrane potential

First, measurement of potential of the electrode was carried out to optimize pH of the analyte which are performed by adjusting the pH of the solution using HCl and NaOH. Base on the solubility product constant, *K_{sp}*, value of the Nd(OH)₃, the pH optimization was varied not more then pH 7. The Nd(III) selective membrane electrode potential was evaluated based on the Nernst equation[25].

$$E_{Nd^{3+}} = K + \frac{2,303RT}{zF} \log[Nd^{3+}] \quad (1)$$

Where, K = constant

R = 8,314 j,mole⁻¹.K⁻¹

F = Faraday constant (96,485 coulomb.mole⁻¹)

T = temperature (K)

z = ionic charge

At room temperature, the Nernst equation can be simplified into:

$$E_{Nd^{3+}} = K + \frac{0,05916}{3} \log[Nd^{3+}] \quad (2)$$

The electrode potential of a series of Nd³⁺ standard solutions with concentrations of 10⁻⁶ to 10⁻²M can be mentioned to be Nernstian if the slope of the linear curve or its sensitivity satisfies the following equation:

$$S = \frac{0,05916}{3} = 19.72 \text{ mV/decade} \quad (3)$$

3.3. Influence of the pH and the Ionic Strength Adjuster (ISA)

A series of standard solutions of 10⁻⁶ to 10⁻²M Nd³⁺ were prepared using the KCl as ISA with its concentrations varied 10⁻⁴M, 5 x 10⁻⁴M, 10⁻³M, 5x10⁻³M, 10⁻²M, 5x10⁻²M and 10⁻¹M, and its pH varied for each sequence concentrations of 1, 2, 3, 4, 5, 6 and 7.

3.4 Range of Concentration and Limit of Detection

The range of concentration and limit of ESI-Nd detection with HPMBP as ionophore was carried out by measuring the electrode potential in a solutions of Nd³⁺ with concentration range of 10⁻⁶M to 10⁻²M. From the linear curve of electrode potential versus the Nd³⁺ concentration, one can determine the slope (sensitivity), intercept (electrode constant) and linearity (*R*²) of the curve.

3.5 Response Time and Life Time

The response time of the HPMBP-Nd electrode is determined by measuring the potential of the electrode from initially it immersed in solution studied until the time taken a stable potential.

Life time of the electrode are determined since the first time of application of the electrode for measurement until the time which the electrode no longer provides a slope that qualifies Nernstian.

3.6 Determination of Potentiometric Selectivity Coefficient (K_{ij}^{pot})

The potentiometric selectivity coefficient (K_{ij}^{pot}) of the HPMBP-Nd membrane electrode was determined by separate match potential methods (SMPM). In principle, one made a measurement of electrode potential in solution contain only Nd^{3+} (E_i) and in solution contain only interfering ions (E_j). The concentration of respective ion was 10^{-6} M to 10^{-2} M. The K_{ij}^{pot} was calculated from the concentration of measuring and interference ion at same electrode potential. If it suppose that response of the electrode has same sensitivity (slope), the calculation of potentiometric selectivity coefficient of the HPMBP-Nd electrode was performed by following equation:

$$a_{Nd} = K_{Nd/j}^{pot} \cdot a_j \quad (4)$$

But, if each response potential has different sensitivity (slope), the $K_{Nd/j}^{pot}$ can be determined by following some of the following equations:

$$E_{Nd} = K_{Nd} + \frac{2,3 RT}{z_{Nd} F} \log a_{Nd} = K_{Nd} + S_{Nd} \log a_{Nd} \quad (5)$$

and the solvent-containing solution alone used the equation:

$$E_j = K_j + \frac{2,3 RT}{z_j F} \log K_{Nd/j}^{pot} a_j^{z_{Nd}/z_j} = K_j + S_j \log K_{Nd/j}^{pot} a_j^{z_{Nd}/z_j} \quad (6)$$

if $E_{Nd} = E_j$,

$$K_{Nd} + S_{Nd} \log a_{Nd} = K_j + S_j \log K_{i/j}^{pot} a_j^{z_{Nd}/z_j} \quad (7)$$

$$S_j \log K_{i/j}^{pot} a_j^{z_{Nd}/z_j} = (K_i - K_j) + S_{Nd} \log a_{Nd} \quad (8)$$

and simplified to be,

$$K_{Nd/j}^{pot} a_j^{z_i/z_j} = 10^{\frac{(K_{Nd} - K_j) + S_{Nd} \log a_{Nd}}{S_j}} \quad (9)$$

or

$$K_{Nd/j}^{pot} = \frac{10^{\frac{(K_{Nd} - K_j) + S_{Nd} \log a_{Nd}}{S_j}}}{a_j^{z_{Nd}/z_j}} \quad (10)$$

$K_{Nd/j}^{pot}$ = potentiometric selectivity coefficient

K_{Nd} = intercept of Nernst equation for Nd^{3+} .

K_j = intercept of interference

S_{Nd} = sensitivity of Nd^{3+} .

S_j = sensitivity of interference

a_{Nd} = activity of Nd^{3+}

a_j = activity of interference

z_{Nd} = ionic charge of Nd^{3+}

z_j = ionic charge of interference

The interference which have been studied were, Ce^{3+} , La^{3+} , and Th^{4+} in the same concentration.

3.7 Use of HPMBP-Nd Electrode in real samples (Monazite)

Finally, the HPMBP-Nd electrode fabricated has been used to analyze the concentration of Nd^{3+} in the solution resulted from the treatment of monazite sand from Bangka. The result then to be compared with the concentration of Nd^{3+} in the same sample resulted by standard method.

4. Results and discussion

4.1 Synthesis and characterization of HMPBP

The HMPBP synthetic was a yellow powder and the yield was 9.0037 g. The powder is easily soluble in chloroform resulting, a yellow solution. Figure 1 show the stoichiometric synthesis reaction of HPMBP from PMP and benzoyl chloride as reactants in presence of $Ca(OH)_2$ as catalyst and chloroform as solvent.

Figure 1. Stoichiometric reaction of HPMBP synthesis

Based on the stoichiometric of reaction, theoretically the product resulted as much as 16.0000 gram. Experimentally, the results obtained was 9.0070g or 56.27% of its rendement. The melting point of the solid obtained in the form of enol, was 92 - 94⁰C. The characterization by infrared spectroscopy show a vibration weak band on $\bar{\nu}=3053.32\text{cm}^{-1}$ originally from C-H aromatic stretching. The strong and sharp band of $\bar{\nu}=1598.99\text{cm}^{-1}$ came from the C = C aromatic vibration and $\bar{\nu}=1560.41\text{cm}^{-1}$ was the vibration of C = O. The C-N vibration band of the pyrazolone ring appear at the wave number $\bar{\nu}=1496.76\text{cm}^{-1}$ and reappears at $\bar{\nu}=1192.01\text{cm}^{-1}$. The C-H vibration band of the methyl group (-CH₃) appears at wave number $\bar{\nu}=1444.88\text{cm}^{-1}$ and the vibration band O-H occurs at $\bar{\nu}=1362.10\text{cm}^{-1}$ and $\bar{\nu}=1145.72\text{cm}^{-1}$, whereas the peak of the pyrazolone skeleton appears at $\bar{\nu}=947.05\text{cm}^{-1}$. Determination of molecular mass of the compound by mass spectrophotometer is 278.1 z/e (C₁₇H₁₄N₂O₂).

The ¹H NMR spectrum showed a singlet with chemical shift $\delta_{\text{H}} = 2.11\text{ppm}$ of the -CH= group, proton at C₄ of benzene give triplet signal and indicate 1 proton at $\delta_{\text{H}} = 7.30 - 7.33\text{ppm}$. The triplet signal show indicate the 2 protons on C₃ and C₅ atoms of the benzene ring at $\delta_{\text{H}} = 7.47 - 7.50\text{ppm}$. The pyrazolone framework appear at $\delta_{\text{H}} = 7.51 - 7.54\text{ppm}$. Triple signal with 1 protons of C₄ from the pyrazolone detected at position $\delta_{\text{H}} = 7.58 - 7.61\text{ppm}$. Doublet signal with 2 protons on C₂ and C₆ of the benzene ring appear at $\delta_{\text{H}} = 7.65 - 7.66\text{ppm}$ and from the pyrazolone at $\delta_{\text{H}} = 7.89 - 7.90\text{ppm}$. The ¹³C NMR analysis the C carbonyl signals at C₄ and C₅ at $\delta_{\text{C}} = 191.96\text{ppm}$ and 147.94ppm. C₁ signal from methyl at $\delta_{\text{C}} = 15.84\text{ppm}$. The C₂ and C₃ signals of the pyrane ring are at $\delta_{\text{C}} = 161.50\text{ppm}$ and 103.60ppm. C₁ - C₆ atomic signals from benzene ring at $\delta_{\text{C}} = 127.75 - 128.41\text{ppm}$ and C₁ - C₆ from the pyrazolone framework at $\delta_{\text{C}} = 129.12\text{ppm} - 137.60\text{ppm}$.

4.2 Influence of pH

The investigation was performed by measuring a series of 10⁻³ M of Nd³⁺ solutions with a with its pH varied between 1 to 7, that was adjusted using HCl and NaOH. The PTFE membrane as supporting sensing material was performed to determine the pH of analyt solution provide a Nernstian potential response of the electrode. The optimal pH conditions used for the next potential electrode measurements in the varied concentration of Nd³⁺ solution, obtained meet Nernst requirements. The results of the influence of pH on the potential response of the electrode which have Nernstian value was obtained at pH 4, and 6. But the pH used for the next analysis parameter was pH 4, because Nd³⁺ are very easy to settle at pH more then 6 that can disturb the measurement. Figure 2a and 2b show influence of pH on the response of potential of two HMPBP-Nd membrane electrodes prepared by the same procedure.

Figure 2a. Influence of pH on response potential offirst HPMBP-Nd electrode (code-1).

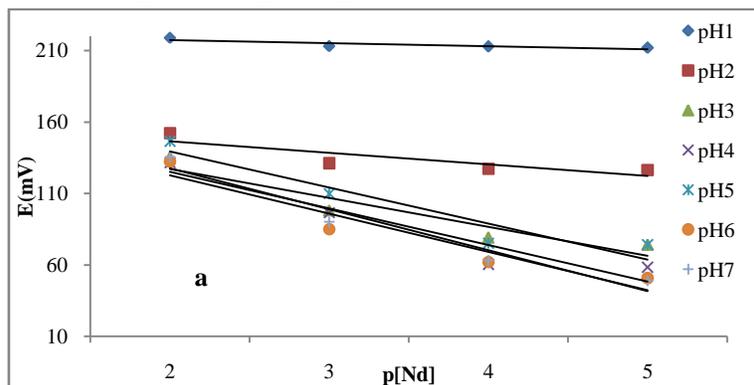
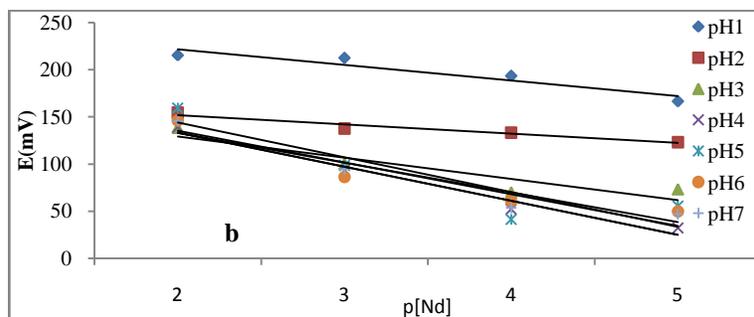


Figure 2b. Influence of pH on response potential of second HPMBP-Nd electrode (code-2).

Meanwhile, Table 2a and 2b show the influence of pH on regression's equation resulted by two HPMBP-Nd membrane electrodes prepared by the same procedure.

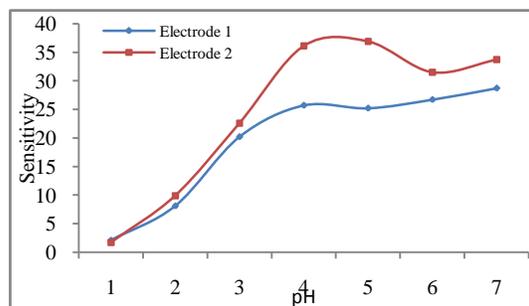
Table 2a. Influence of pH on potential response of first HPMBP-Nd electrode

pH	Equation of regression	R ²
1	$E = 219.5 + 2.1 \log [\text{Nd}^{3+}]$	0.7547
2	$E = 154.5 + 8.1 \log [\text{Nd}^{3+}]$	0.7434
3	$E = 147.3 + 20.2 \log [\text{Nd}^{3+}]$	0.8886
4	$E = 150.8 + 25.7 \log [\text{Nd}^{3+}]$	0.9073
5	$E = 164.4 + 25.2 \log [\text{Nd}^{3+}]$	0.8985
6	$E = 149.3 + 26.7 \log [\text{Nd}^{3+}]$	0.9167
7	$E = 156.2 + 28.7 \log [\text{Nd}^{3+}]$	0.9434

Table 2b. Influence of pH on potential response of second HPMBP-Nd electrode

pH	Equation of regression	R ²
1	$E = 238.4 + 1.7 \log [\text{Nd}^{3+}]$	0.9013
2	$E = 161.8 + 9.9 \log [\text{Nd}^{3+}]$	0.9470
3	$E = 151.8 + 22.6 \log [\text{Nd}^{3+}]$	0.8476
4	$E = 169.4 + 36.1 \log [\text{Nd}^{3+}]$	0.9727
5	$E = 180.9 + 36.9 \log [\text{Nd}^{3+}]$	0.8066
6	$E = 164.5 + 31.5 \log [\text{Nd}^{3+}]$	0.8883
7	$E = 169.2 + 33.7 \log [\text{Nd}^{3+}]$	0.9156

At pH 1 to pH 4 the sensitivity and constant of both electrodes increase significantly, and practically constant at pH 4 to pH 7. Based on the above table, the influence of pH on the potential response of the electrode which have Nernstian value was obtained at pH 4, and 6. But the pH, used for the next parameter investigation was pH 4. At pH 6, Nd^{3+} is very easy to settle and consequently the measurement at pH 6 and more will disturb by hydroxide of the Nd(III). The limit of the concentration can be predicted based on the K_{sp} of the hydroxide of Nd(III). In general the value of REE's K_{sp} lie between 1.0×10^{-22} to 9.4×10^{-27} , means that REE's ions will precipitate at pH 6. More clearly the influence of pH on the sensitivity of the two HPMBP-Nd electrodes prepared by same procedure can be seen in Figure 3 below.

Figure 3. The influence of pH on sensitivity of two HPMBP-Nd electrodes prepared by same procedure

At pH 1 to pH 4, the sensitivity of both electrode increase significantly and practically constant at pH 5. The Nd^{3+} concentration could be predicted from the solubility of hydroxide of Nd(III). This prediction can be proved that, although the precipitate appear, both electrodes show the potential response to Nd^{3+} concentration, and this is the limitation of performance of HPMBP-Nd electrode.

4.3 Influence of ISA concentration

Beside influence of pH on the performance of the membrane electrodes, it will be important to investigate the influence of the stability and ionic strength of the solution. The ionic strength and ions stability determined by the ionic strength adjuster (ISA) which serves to maintain ionic strength in solution at various concentrations. According to the Debye-Huckel equation, ionic strength is defined as $I = 1/2 \sum C_i z_i^2$ and $a_i = \gamma_i C_i$, where γ_i is the activity coefficient obtained from the equation $-\log \gamma_i = 0.5 z_i^2 \sqrt{I}$. In this study, ISA of the solution was maintained by KCl with a concentration of 10^{-4}M to 10^{-1}M . The ISA should not react with the analyte and should not affect the measurement (non interfering). The measurement of the electrode potential response of ion selective electrode is then carried out at pH 4 with a concentration variation of ISA solution from 10^{-4}M to 10^{-1}M . The curve of HPMBP-Nd electrode potential measurement can be seen in Figure 4. Performance of the electrode is showed by regression equation's parameters.

Figure 4. The HPMBP-Nd electrode potential curve at various ISA KCl concentrations.

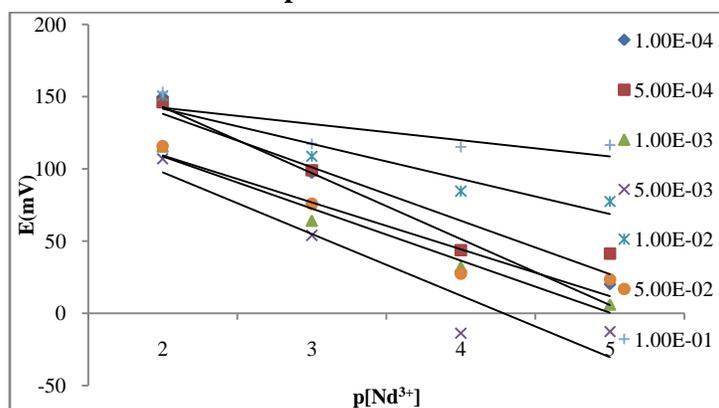


Table 3. Regression equation of HPMBP-Nd electrode response at various concentrations of ISA KCl

KCl (M)	Regression equation	R ²
1×10^{-4}	$E = 188.55 \text{ mV} + 45.7 \text{ mV/decade } \log [\text{Nd}^{3+}]$	0.9331
5×10^{-4}	$E = 175.10 \text{ mV} + 37.0 \text{ mV/decade } \log [\text{Nd}^{3+}]$	0.9088
1×10^{-3}	$E = 144.65 \text{ mV} + 36.1 \text{ mV/decade } \log [\text{Nd}^{3+}]$	0.9746
5×10^{-3}	$E = 140.25 \text{ mV} + 42.7 \text{ mV/decade } \log [\text{Nd}^{3+}]$	0.8943
1×10^{-2}	$E = 166.15 \text{ mV} + 24.4 \text{ mV/decade } \log [\text{Nd}^{3+}]$	0.9078
5×10^{-2}	$E = 141.85 \text{ mV} + 32.5 \text{ mV/decade } \log [\text{Nd}^{3+}]$	0.9197
1×10^{-1}	$E = 153.60 \text{ mV} + 11.2 \text{ mV/decade } \log [\text{Nd}^{3+}]$	0.6160

From Fig. 4. and Table 3 .its can be seen that a good ISA concentration is 10^{-2}M , as it gives a sensitivity of 24.4mV/decade. The sensitivity of the electrode obtained is upper Nernstian, but practically close to the Nernstian factor (19.71mV/decade). For the next, the ISA concentrations used is 10^{-2}M of KCl. This decision to be taken based on the calculations of ionic strengths, that with ISA concentrations smaller than 10^{-2}M did not provide significantly changes in ionic activity of Nd^{3+} .

4.4 Influence of internal solution

The composition of the internal solution should be adjusted to allow a complex equilibrium of ionophores on the inside of the membrane. The influence of internal solution compositions on the sensitivity and constant of HPMBP-Nd electrodes can be seen in Table 4. Performance of the electrode is showed by regression equation's parameters, R², S and K.

Table 4. Influence of internal solution composition on the HPMBP-Nd electrode performance

Internal solution	Composition					
	1	2	3	4	5	6
KCl [M]	2.5×10^{-4}	3.3×10^{-4}	5×10^{-4}	6×10^{-4}	6.7×10^{-4}	7.5×10^{-4}
Nd ³⁺ [M]	7.5×10^{-4}	6.7×10^{-4}	5×10^{-4}	4×10^{-4}	3.3×10^{-4}	2.5×10^{-4}
R ²	0.7868	0.8061	0.8037	0.7271	0.8302	0.8291
S	19.8	30.5	27.1	21.0	24.7	28.8
K	134.4	24.0	126.9	129.8	134.7	159.4

Based on Table 4. the respective concentration ratios between Cl⁻ and Nd³⁺ in internal solutions that provide a Nernstian sensitivity value are 2.5×10^{-4} M and 7.5×10^{-4} M or a volume ratio of 1: 3 in concentrations of 10^{-3} M.

4.5 Response time

The response time of the electrode is calculated as the HPMBP-Nd electrode begins to be dipped in the solution until a stable potential value is obtained on the analyte with a concentration range of 10^{-7} M to 10^{-2} M. The HPMBP-Nd electrodes are used measuring consecutively from small concentrations to large concentrations (10^{-7} , 10^{-6} , 10^{-5} , 10^{-4} , 10^{-3} and 10^{-2} M). Results of HPMBP-Nd electrode response time determination can be seen in Table 4.

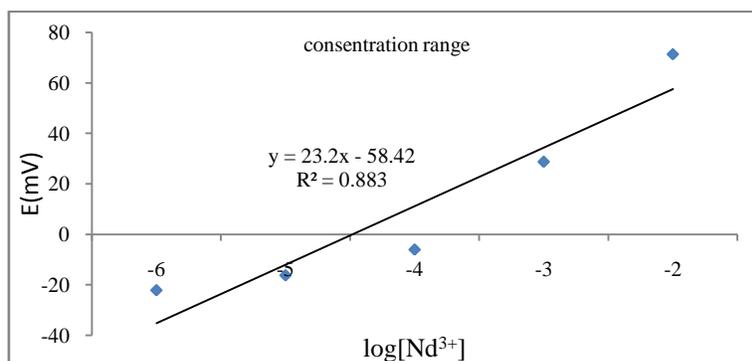
Table 5. Response Time of HPMBP-Nd electrode

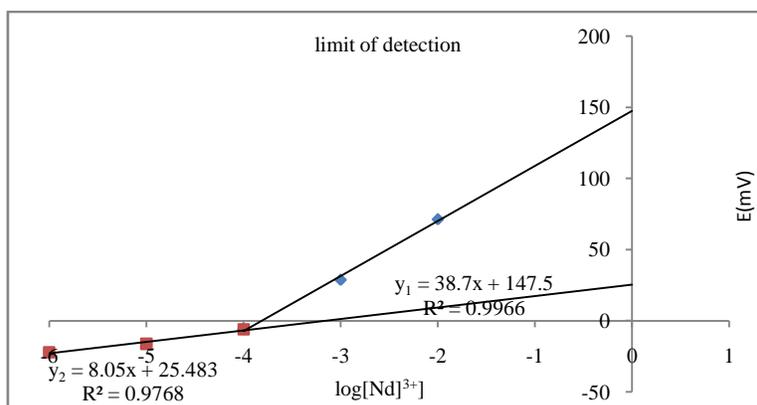
p[Nd ³⁺]	2	3	4	5	6	7	R	S	K
E(mV)	67.8	37.1	8.4	-10.3	-17.2	-23.3	0.9565	18.2	93.2
t(s)	18	18	34	16	25	21	Average 22 s		

From Table 5. the response time of the HPMBP-Nd electrode at various concentrations of the solution averaged 22 seconds, while the determination of response time with a fixed concentration of 10^{-3} M and repeated measurements obtained faster response time ie less of 20 seconds.

4.6 Concentration range and detection limit

The concentration range of the HPMBP-Nd electrode is performed using multiple electrodes. The concentration range is known from curves that still follow Nernst's law while the detection limit is determined from the intersection of two straight lines of Nernstian and non-Nernstian[28]. The measurement range values and the detection limit of the electrodes can be seen in Figure 5.

Figure 5. Concentration range and detection limit of HPMBP-Nd electrode



Determination of HPMBP-Nd electrode detection limit is done by joining the two equations of curves in Figure 7. as follows. with

$$y_1 = 38.7x + 147.5$$

$$y_2 = 8.1x + 25.4$$

if $y_1 = y_2$ will be obtained;

$$38.7x + 147.5 = 8.1x + 25.5$$

or

$$38.7x - 8.1x = 25.5 - 147.5$$

than,

$$30.6x = -122$$

so

$$x = -122/30.6 = -3.99$$

$$\log [x] = 10^{-3.99} [x] = 1.02 \times 10^{-4}M$$

Then the limits of HPMBP-Nd electrode detection to the concentration of $Nd^{3+} = 1.02 \times 10^{-4}M$ solution.

4.7 Test of realibility

After the optimum condition of HPMBP-Nd potential measurement is obtained then determined the toughness of the electrode. By using several electrodes, the calculation of each parameter as in Table 8. follows.

Table 8. Potential for determination of toughness of HPMBP-Nd electrode

p[Nd]	Electrode								Aver age	SD
	1	2	3	4	5	6	7	8		
5	-71.9	-66.9	-68.8	-66	-67.3	-67.3	-52.1	-75.4	-67.0	6.33
4	-73	-65.9	-64.5	-56.8	-66.3	-72.6	-63	-66.3	-66.1	4.86
3	-14.1	-5.8	-6.2	-11.6	-11.3	-13.3	-12.1	-14.1	-11.1	3.09
2	47.3	53.1	53.2	46.3	45.1	47.4	50.8	38.8	47.8	4.43
R	0.9400	0.9468	0.9535	0.9601	0.9459	0.9291	0.9018	0.9654	0.9428	0.0188
S	41.65	42.01	42.43	38.21	39.22	40.34	35.96	39.48	39.91	2.03
K	117.85	125.66	126.93	111.71	112.32	114.74	106.76	108.93	115.61	6.93

In Table 8. HPMBP-Nd electrode toughness value can be calculated. If the average value of R^2 is 0.9428 and the average sensitivity is 39.91mV/decade and the mean value of the intercept is 115.61mV. The R^2 toughness test of the following measurements;

$$\overline{R^2} = 0.9428 \quad \text{and} \quad SD = 0.019 \text{ then,}$$

$$\Delta R = \frac{SD \times t_{90}}{\sqrt{n}} = \frac{0.019 \times 1.86}{\sqrt{8}} = \frac{0.03534}{2.8284} = 0.01$$

So the toughness of the correlation coefficient is:

$$\mu R^2 = \overline{R} \pm \Delta R = 0.9428 \pm 001$$

then performed calculation of toughness test of sensitivity of electrode with data:

$\bar{S} = 39.91$ mV/decade and $SD = 2.03$ than,

$$\Delta S = \frac{SD \times t_{90}}{\sqrt{n}} = \frac{2.03 \times 1.86}{\sqrt{8}} = \frac{3.7758}{2.8284} = 1.33$$

Thus, the sensitivity limit of HPMBP-Nd electrode is obtained;

$$\mu S = \bar{S} \pm \Delta S = 39.91 \pm 1.33 \text{ mV/decade}$$

Then also performed toughness test intercept electrode with data as follows;

$\bar{K} = 115.61$ and $SD = 6.93$ than,

$$\Delta K = \frac{SD \times t_{90}}{\sqrt{n}} = \frac{6.93 \times 1.86}{\sqrt{8}} = \frac{12.8898}{2.8284} = 4.56$$

So as to obtain the limit of toughness of the intercept of HPMBP-Nd electrode is;

$$\mu K = \bar{K} \pm \Delta K = 115.61 \pm 4.56 \text{ mV}$$

4.8 Selectivity coefficient $K_{Nd/j}^{pot}$

Selectivity is the ability of the electrode to distinguish the major ions and the interfering ions present in a solution. The selectivity of the HPMBP-Nd electrode was determined by calculating the potential influence of the interfering metal ions La^{3+} , Ce^{3+} and Th^{4+} against the Nd^{3+} potential ions. La^{3+} and Ce^{3+} ions are used to determine their effect on main Nd^{3+} ions that are similar in nature to being in the same group (lanthanides). While Th^{4+} ions besides having different oxidation numbers are also in other classes. The results of electrode selectivity analysis of the three disturbing ions can be seen in Table 9.

Table 9. Selectivity of HPMBP-Nd electrode

p [Nd]	$K_{Nd/j}^{pot}$		
	La^{3+}	Ce^{3+}	Th^{4+}
5	1.05	1.00	0.101
4	1.00	1.00	0.102
3	1.00	1.00	0.178
2	1.00	1.00	0.316
1	1.00	1.00	0.309

Based on the theory if the value of $K_{Nd/j}^{pot} = 1$ then the electrode is not selective to the disturbing ion, whereas if the value $K_{Nd/j}^{pot} < 1$ then the electrode is selective to the intruder ion [29]. The results of the calculations in the Table above are known, HPMBP-Nd electrodes are not selective against similar REE's ions such as La^{3+} and Ce^{3+} but are selective against Th^{4+} ions.

The use of HPMBP-Nd electrodes for the analysis of the real samples was performed on the monazite solution which was removed from Th^{4+} ions which results were compared with the monazite concentrations obtained from the measurements using ICP. Based on the analysis results obtained Nd^{3+} 3378.56ppm or $2.34 \times 10^{-2}M$. By dilution of the sample 10 times the potential value of sample obtained compared to potential value of the standard curve as in Table 10.

Table 10. Determination of standard and sample potentials

p[Nd^{3+}]	2	3	4	5	Sample
E(mV)	102.9	92.1	80.8	73.9	92.2

With the potential comparison of standard solutions and samples in Table 10. above we obtain Nd^{3+} concentrations with HPMBP-Nd electrode $1.02 \times 10^{-2}M$ or close to $2.32 \times 10^{-2}M$. thus the HPMBP-Nd electrode can be used as one of the methods used for the analysis of Nd^{3+} ions in the sample.

5. Conclusions

HPMBP compounds can be synthesized and used as ionophores in analysis especially neodymium selective electrodes using tubular Teflon electrodes and PTFE polymer as membranes. The HPMBP-Nd electrode gave a good response to the Nd^{3+} standard solution under pH 4 and ISA KCl $10^{-2}M$ concentration and the internal solution composition of 3: 1 base volume of KCl and Nd^{3+} $10^{-3}M$ solutions.

Measuring range of electrode obtained 10^{-6} to 10^{-2} M with detection limit of 1.02×10^{-4} M with sensitivity 39.91 ± 1.33 mV/decade with 22 second response time and 3 weeks usage period. The use of electrodes in the analysis of monazite solution samples obtained Nd^{3+} concentration of 1.02×10^{-2} M and selective against Th^{4+} ions but less selective against Ce^{3+} and La^{3+} ions.

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