Journal of New Developments in Chemistry
Open Access - Peer-Reviewed - ISSN 2377-2549

Portico Archived | Crossref DOI | CC BY 4.0 Licensed

Research Article

# An Optical Chemical Sensor for Determination of Nickel in Water and Hydrogen Peroxide Samples

**Saeed Babaee [1*], Shahram Ghanbari Pakdehi [1], Akram Sadat Nabavi [1]**

[1] Faculty of Chemistry and Chemical Engineering, Malek Ashtar University of Technology, Lavizan Avenue, Tehran, P.O. Box 16765/3454, Iran

*** Correspondence:** Saeed Babaee , Faculty of Chemistry and Chemical Engineering, Malek Ashtar University of Technology, Tel.: +98 2122970168, Fax: +98 2122962257

**Published citation:** Saeed Babaee, Shahram Ghanbari Pakdehi, Akram Sadat Nabavi (2016) **An Optical Chemical Sensor for Determination of Nickel in Water and Hydrogen Peroxide Samples**. *Journal of New Developments in Chemistry* - 1(2):61-72. https://doi.org/10.14302/issn.2377-2549.jndc-16-1212

**Article DOI:** 10.14302/issn.2377-2549.jndc-16-1212

## Abstract

Application of nickel in different industries has been developed and so contamination of natural water is a great concern due to its potentially toxic effects on living beings. Therefore, fast monitoring of $Ni^{2+}$ in aqueous samples is important. In this work, we fabricated a sensitive optical sensor for determination of nickel in mineral water samples and hydrogen peroxide solutions. The optode was prepared by incorporation of 1-(2-pyridylazo)-2-naphthol and sodium tetraphenylborate in a plasticized poly (vinyl chloride) membrane containing dioctyladipate as a plasticizer. The influence of several parameters such as pH, base matrix, solvent mediator and ligand concentration was optimized. Comparison of the obtained results with previously reported sensors revealed that the proposed method, in addition to fast and simplicity, provided good linear range (1.70–85.20 µmol $L^{-1}$) and low detection limit (0.17 µmol $L^{-1}$). The precision (relative standard deviation) was better than 1.55% for 7 replicate determinations of 17.10 µmol $L^{-1}$ of Ni in various membranes.

**Keywords:**
Optical sensor; Nickel determination; Poly (vinyl chloride) membrane; Hydrogen peroxide

| Article Information | |
|---|---|
| **Academic Editor** | Dr. Praveen Kumar Sharma, Phagwara |
| Received Date | 8 July 2016 |
| Accepted Date | 28 September 2016 |
| Published Date | 3 October 2016 |
| Online | 3 October 2016 |

## Article Information (continued)


| | |
|---|---|
| Publication | Volume 1; Issue 2; Pages 61–72 |
| Copyright | © 2016 Saeed Babaee, et al |
| License | This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.<br>https://creativecommons.org/licenses/by/4.0/ |


### Introduction

Nowadays, the pollution of natural water by heavy metals is a great concern due to their potentially toxic effects on living beings; therefore the detection and monitoring of toxic metals in water samples is necessary and very important [1].

Due to wide applications of nickel in different industries [2], [3], [4], [5], [6], its contamination of natural water leads to serious environmental hazards. Nickel and some of its compounds can cause an allergic reaction, asthma, lung cancer and leukemia in the human body [7], [8], [9], [10]. The amount of nickel should not be more than 1.70 µmol $L^{-1}$ in drinking water resources [11].

Hydrogen peroxide is used as a disinfectant, oxidizer and so forth in usual applications [12]. High concentration of hydrogen peroxide can be used either as a monopropellant or as an oxidizer for military applications [13]. If cationic impurities exist in commercial grade of hydrogen peroxide solutions, its purification to military grade (over 85%) can cause to explosion. So nickel concentration in commercial $H_2O_2$ solutions must be lower than 0.68 µmol $L^{-1}$ [14]. Because of oxidation medium or presence of oxygen bubbles in $H_2O_2$ solutions, it is difficult to directly determine any ions before initial pretreatments. Therefore, it is important to develop a safe, selective and sensitive technique for the rapid measurement of $Ni^{2+}$ in different media.

Determination of nickel is performed by several techniques such as x-ray absorption spectroscopy [15], flame and electro thermal atomic absorption spectrometry [16], [17], [18], [19], [20], atomic emission spectrometry [21], spectrophotometry [22], [23] and fluorescence spectroscopy [24]. Among the methods, spectrophotometric methods offer many appealing characteristics including: simple instrumentation, rapid response times and easy operation. These properties are desirable to the future design and development of portable analytical devices for nickel analysis.

Recently, an interest has been increased on the development of optical sensors compared to electrochemical sensors [25]. These sensors have better analytical characteristics [26] and they do not require internal and external reference devices, their time preconditioning are short and are not subjected to electrical noise [27]. The choice of the optode matrix is governed by the parameters such as permeability for analyte, cost, good mechanical properties and immobilization suitability for chromophore along with uptaking [28], [29], [30].

The most widely used polymers in optical sensors are poly (vinyl chloride) groups. They have many desirable features and compare well with sol–gel matrices for most applications [31]. Several optodes have been reported in trace analysis of different analytes such as metal ions, anions and organic compounds [32], [33], [34], [35], [36], [37].

1-(2-pyridylazo)-2-naphthol (PAN) is a red solid which is readily soluble in common organic solvents such as methanol, ethanol etc. It forms coloured complexes with a large number of metal ions [38].

In this research, we introduced a selective, sensitive and rapid method based on PVC sensor for spectrophotometric determination of nickel by using PAN in water and hydrogen peroxide samples. To the best of our knowledge, although analysis of $Ni^{2+}$ was reported by this method previously, there is no information for monitoring of this cation in $H_2O_2$ media.

## Experimental

### *Chemicals*

All the chemicals were of analytical grade. 1-(2-pyridylazo)-2-naphthol (PAN), Low molecular weight poly vinyl chloride (LPVC, mol wt ~ 48000 g $mol^{-1}$), dioctyladipate (DOA) and sodium tetraphenylborate (NaTPB) were used without purification. Nickel solutions were prepared from a 17.04 mmol $L^{-1}$ standard solution. A buffer of pH 6.0 was prepared from sodium hydroxide (0.046 M) and potassium hydrogenphthalate (0.05 M) solutions [39].

### *Apparatus*

Absorption measurements were carried out on a Hitachi-U 3310 model Lambada-25 double beam UV-Vis spectrophotometer. The pH of the solutions was measured by a Metrohm model 691 pH/Ion Meter using a combined glass electrode.

### *Membrane Preparation*

The membrane consisted of appropriate amounts of active components. 30.0 mg of PVC, 75.0 mg of DOA, 8.0 mg of PAN and 5.0 mg of NaTPB were transferred in a glass vial and dissolved into 1 ml THF. The solution was immediately shaken vigorously to achieve complete homogeneity. A glass plate ($1\times9\times50$ $mm^3$) was cleaned with pure THF and then placed in the spin-on device. Ninety micro liters of the above solution was injected to the glass plate. After 30 s spinning, at rotation frequency of 600 rpm, the membrane was located in ambient air and allowed to dry in air for few minutes.

### *Procedure*

The sensing membrane (optode) was placed in a beaker filled with 20 ml of the test solutions containing EDTA ($1.0\times10^{-2}$ mol $L^{-1}$) and different concentrations of $Ni^{2+}$ (1.70 - 85.20 µmol $L^{-1}$) at pH 6.0. After 10 min the optode was mounted into the spectrophotometer directly and its net absorbance was recorded at 570 nm against a blank membrane.

Water samples (Mineral and river) were collected in 1 L amber glass bottles from Haraz (Anahita, Polur) and Jajrud (Lavasan) rivers in Iran. After sample pretreatments [34], 3 ml of each sample was spiked with appropriate amount of Ni (II) and was subjected to the above procedure.

Hydrogen peroxide (10-20%) samples were prepared freshly from commercial hydrogen peroxide (30%) solution after filtration. Then, each of the samples after Ni (II) spiking was subjected to the membrane methodology.

## Results and Discussion

### *Preliminary Investigations*

1-(2-pyridylazo)-2-naphthol )PAN) was recommended as a spectrophotometric reagent by Cheng and Bray where it gives reddish-colored chelates with metal ions as an example of Ni (II) [40]. Because PAN is organic, it is efficiently immobilized in the hydrophobic part of the membrane without prior lyophilization [41]. It was observed that by optimized fabricating a sensor from incorporation of PAN in a plasticized PVC membrane containing DOA, the determination of nickel could be practicable spectrophotometrically.

When nickel ions diffused into the membrane, they formed a complex with PAN so the membrane colors changed from yellow to red. The absorption spectra of the PAN optodes in different concentrations of Ni ($\lambda_{max}$=570 nm) are shown in Figure 1.

### *Membrane Composition*

The response characteristics and working concentration range of each optical sensor depend significantly on the different ingredients such as base matrix, solvent mediator, ionophore and additive used in the membrane structure. Therefore the sensor matrix should be selected, firstly. In comparison of different polymers, low molecular weight PVC was observed as the best selection for the membrane

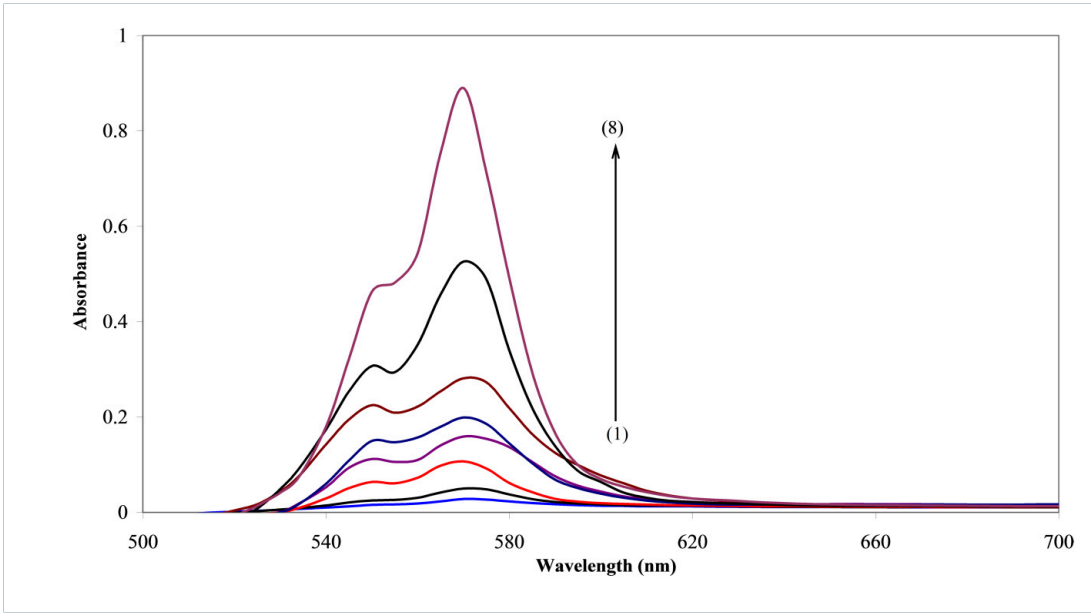


**Figure 1.** Absorption spectra of the proposed optode at various concentrations of $Ni^{2+}$: (1) 1.70, (2) 3.41, (3) 8.52, (4) 13.64, (5) 17.04, (6) 25.56, (7) 51.12, (8) 85.20 µmol $L^{-1}$;
Conditions: pH=6.0; T=25°C; response time=10 min; membrane layer containing 25.42% PVC, 63.56% DOA, 6.78% PAN and 4.24% NaTPB.

base. This choice was due to several parameters such as appropriate transmittance, suitable immobilization of PAN without any leakage, good mechanical stability and reliable permeability to $Ni^{2+}$ ions.

The nature of plasticizer is important and must be physically adaptable with polymer. In order to have a homogenous organic phase, several plasticizers such as dibutylphthalate (DBP), tributylphosphate (TBP), dioctylphthalate (DOP), ortho-nitrophenyloctyl ether (O-NPOE) and DOA were tested as potential plasticizers. From the graphs in Figure 2 (a and b), it was concluded that the membranes containing DBP, TBP, DOP and O-NPOE did not produce suitable signals because of either improper physical properties with LPVC or leakage of PAN from the membrane. We found that DOA was the best selection with respect to good physical properties, the highest sensitivity and the lowest leakage.

As shown in Table 1 (membrane no. 1-5), the sensors with a weight ratio of DOA to LPVC as 2.5 provided best absorbance. Thus, 30 mg of PVC and 75 mg of DOA were selected as the optimum values. A decrease of the $Ni^{2+}$ uptaking efficiency, at values lower than 75 mg, is explained by improper solidity of the optode that led to low diffusion of analyte cations into the membrane. At quantities more than 75 mg, flexibility of the optode increased, leading to ionophore leakage into the test solution.

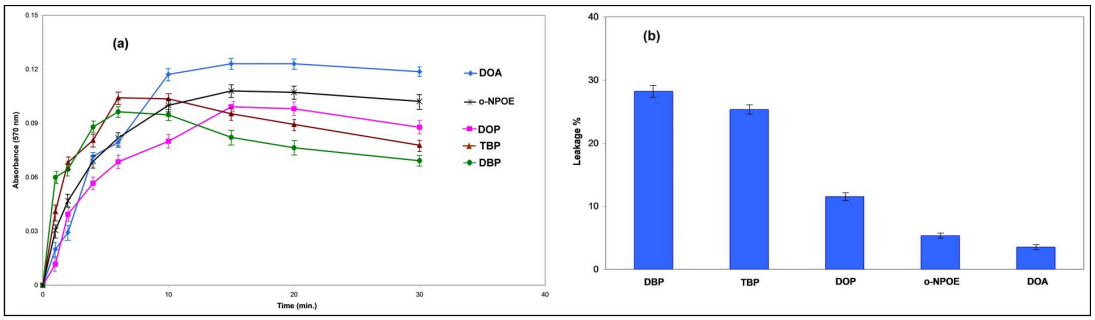


**Figure 2.** Effect of plasticizer nature on the response of the membrane after 10 min (a) and on the membrane leakage% after 30 min (b).
Conditions: 34.08 µmol $L^{-1}$ $Ni^{2+}$; T=25°C; membrane layer containing 30.0 mg of PVC, 75.0 mg of each plasticizer, 8.0 mg PAN.

**Table 1.** Effects of membrane composition on the absorbance of the proposed optode

| Membrane | LPVC (mg) | DOA (mg) | PAN (mg) | NaTPB (mg) | Response time (min) | Absorbance (570 nm)[a] |
|---|---|---|---|---|---|---|
| 1 | 30 | 65 | 8 | 5 | 10 | 0.197 ± 0.021 |
| 2 | 30 | 70 | 8 | 5 | 10 | 0.285 ± 0.012 |
| 3 | 30 | 75 | 8 | 5 | 10 | 0.357 ± 0.005 |
| 4 | 30 | 80 | 8 | 5 | 10 | 0.315 ± 0.009 |
| 5 | 30 | 85 | 8 | 5 | 10 | 0.177 ± 0.018 |
| 6 | 30 | 75 | 4 | 5 | 10 | 0.214 ± 0.017 |
| 7 | 30 | 75 | 6 | 5 | 10 | 0.303 ± 0.011 |
| 8 | 30 | 75 | 8 | 5 | 10 | 0.357 ± 0.005 |
| 9 | 30 | 75 | 10 | 5 | 10 | 0.348 ± 0.008 |
| 10 | 30 | 75 | 12 | 5 | 10 | 0.325 ± 0.010 |
| 11 | 30 | 75 | 8 | 3 | 10 | 0.231 ± 0.024 |
| 12 | 30 | 75 | 8 | 4 | 10 | 0.314 ± 0.011 |
| 13 | 30 | 75 | 8 | 5 | 10 | 0.358 ± 0.006 |
| 14 | 30 | 75 | 8 | 6 | 10 | 0.326 ± 0.017 |
| 15 | 30 | 75 | 8 | 7 | 10 | 0.280 ± 0.032 |
| 16 | 30 | 75 | 8 | 5 | 2 | 0.132 ± 0.023 |
| 17 | 30 | 75 | 8 | 5 | 6 | 0.300 ± 0.011 |
| 18 | 30 | 75 | 8 | 5 | 10 | 0.358 ± 0.004 |
| 19 | 30 | 75 | 8 | 5 | 12 | 0.359 ± 0.006 |
| 20 | 30 | 75 | 8 | 5 | 14 | 0.358 ± 0.005 |

[a] Mean absorbance ± SD (n=3) of each parameter is recorded from three solutions of 34.08 µmol $L^{-1}$ $Ni^{+2}$ (pH 6.0).

Effect of different amounts of PAN on the membrane response is observed in Table 1. As seen in membrane no. 6-10, the absorbance increased by increasing amounts of PAN up to 8 mg and decreased at higher amounts that were resulted from membrane leakages. Therefore, 8 mg PAN was selected as optimum value.

Due to the complete mass transfer of $Ni^{2+}$ ions into the membrane and decreasing of response time, the presence of an anionic additive such as NaTPB facilitates the ion-exchange equilibrium [42]. The effect of NaTPB was investigated in the range 3.0-7.0 mg (membrane no. 11-15 of Table 1). It is shown that the highest absorbance is recorded by using 5.0 mg of NaTPB.

### *Effects of pH*

The influence of media pH on the sensor response was studied in the range 4-8. As it is shown in Figure 3 optode absorbance increased at pH 6.0 and then decreased. At pH<6, protonation of the ligand prevents its reaction with $Ni^{2+}$ ions and at pH>6.0, the response decrease could be due to the hydrolysis of $Ni^{2+}$ ions that is caused to incomplete diffusion of $Ni^{2+}$ cations into the membrane. Therefore, a buffer with

DOI: 10.14302/issn.2377-2549.jndc-16-1212

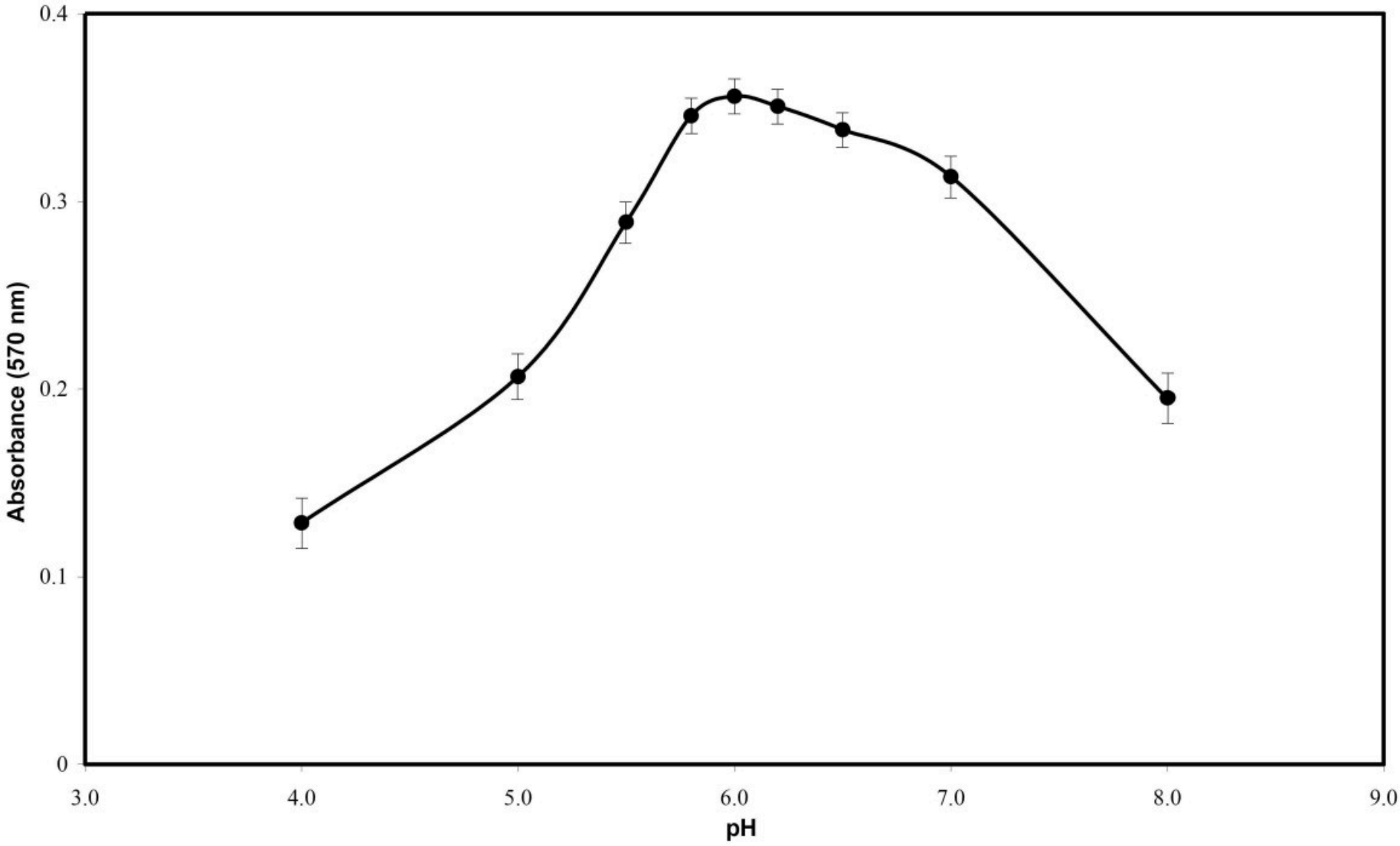


**Figure 3.** Effects of pH on the absorbance of the proposed optode; conditions: 34.08 µmol $L^{-1}$ $Ni^{2+}$; T=25°C; response time=10 min; membrane layer containing 25.42% PVC, 63.56% DOA, 6.78% PAN and 4.24% NaTPB.


OPEN ACCESS

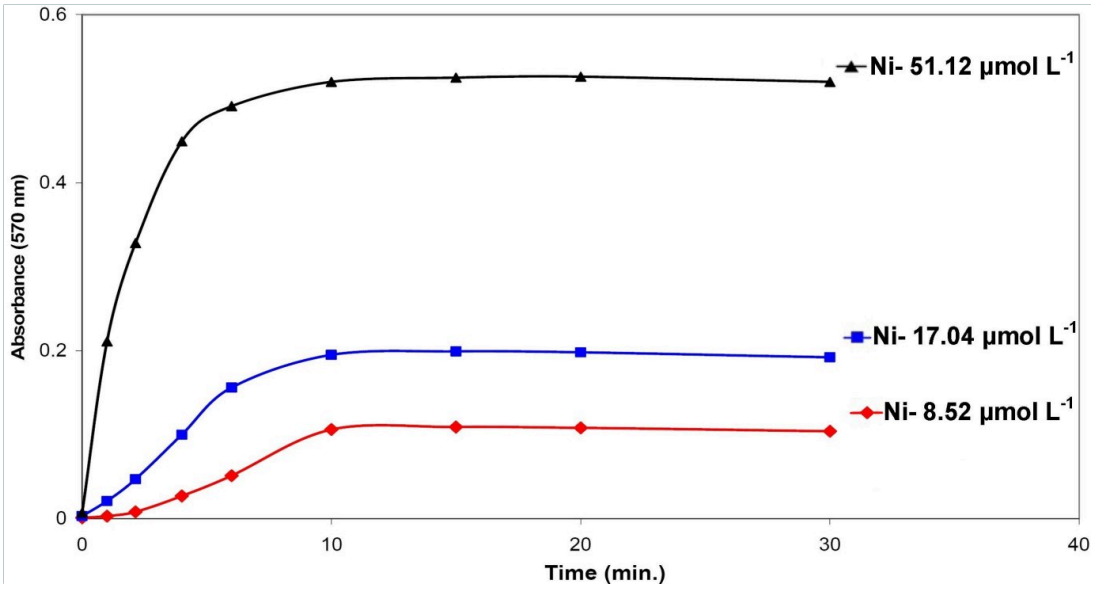


**Figure 4.** Response time of the optode membranes for different concentrations of nickel, Conditions: pH=6.0; T=25°C; membrane layer containing 25.42% PVC, 63.56% DOA, 6.78% PAN and 4.24% NaTPB

pH 6.0 was chosen in all experiments. In comparison, the optimum pH for Ni-PAN complex in aqueous solution has been reported as 6.5 [43].

### *Response Time of Optode*

Response time of optodes is defined as the diffusion time of the metal ions from solution into the membrane (slowest step in complexation process) [44]. The effect of this parameter on the optode response was studied (Table 1 membrane no. 16-20). As seen, at least a time interval of 10 min is required for quantitative uptake at room temperature. It was observed that the optode response remained constant for more than 2 hours.

### *Membrane Properties*

The properties of the optode membrane were measured by recording absorbance changes at 570 nm from individual solutions of 8.52, 17.04 and 51.12 µmol $L^{-1}$ of Ni. As it is seen in Figure 4 all of the three cases, the optodes reached to 98% absorbances after 10 minutes.

The stability of membranes was tested for 2 hours and during this period a mean difference of absorbances for the mentioned solutions was ±0.007. Also the membrane responses were stable for one month in air.

The salting-out phenomenon on the optode response was investigated by adding different amounts of sodium nitrate. The results indicated that this parameter had no effect on the membrane response, up to 0.04 mol $L^{-1}$ of $NaNO_3$ and above this concentration it was reduced slightly. This is due to a decrease in the activity of $Ni^{2+}$ ions at higher concentration of electrolyte which reduces the interaction of nickel (II) cation with PAN in the membrane.

The sensor regeneration was studied by using different compounds such as hydrochloric acid, nitric acid, sulfuric acid, sodium fluoride and oxalic acid in different concentrations. It was found that all of the reagents could not regenerate the optode membrane thoroughly and thus the membrane could be used as a probe (single test).

### *Analytical Characteristics*

Table 2 summarizes the analytical characteristics of the optimized membrane. In this manner the dynamic linear range was within 1.70–85.20 µmol $L^{-1}$ of nickel and detection limit was 0.17 µmol $L^{-1}$.

**Table 2.** Analytical characteristics of the proposed sensor.

| Regression equation (n=12) | A = 0.1721C + 0.018, r = 0.9991 |
|---|---|
| Linear range (µmol $L^{-1}$) | 1.70-85.20 |
| Limit of detection (µmol $L^{-1}$)[a] | 0.17 |
| Reproducibility (RSD%)[b] | 1.55 |

[a] For seven replicate determinations of the sensor in the absence of nickel (n=7).
[b] For seven replicate determinations of Ni: 17.10 µmol $L^{-1}$

**Table 3.** Comparison of optical sensor papers for Ni (II) determination

| Membrane type | Ionophore | pH | LDR[a] (M) | LOD[b] (M) | Ref. |
|---|---|---|---|---|---|
| Nafion | 1-(2-pyridylazo)-2- naphthol | 6.5 | $2\times10^{-5}$-$12\times10^{-5}$ | $1.7\times10^{-5}$ | 43 |
| ″ | 2-(5-bromo-2-pyridylazo)-5-(diethylamino) phenol | 6.5 | 5. $1\times10^{-6}$-$3.4\times10^{-2}$ | $8.5\times10^{-6}$ | 45 |
| PVC | 2-amino-1-cyclopentene-1-dithiocarboxylic acid | 4-6.5 | $5.0\times10^{-6}$ -$1.0\times10^{-3}$ | $5.2\times10^{-7}$ | 46 |
| ″ | 1,2-di(*o-salicylaldiminophenylthio)ethane* | 6 | $1.0\times10^{-5}$-$5.0\times10^{-3}$ | $8.5\times10^{-6}$ | 47 |
| Triacetyl cellulose-optical | triazene-1-oxide derivative | 5.7 | $1.18\times10^{-9}$-$7.34\times10^{-5}$ | $1.0\times10^{-9}$ | 48 |
| PVC | 1-(2-pyridylazo)-2- naphthol | 6 | $1.70\times10^{-6}$-$8.52\times10^{-5}$ | $1.70\times10^{-7}$ | This work |

[a] Linear Dynamic Range; [b] Limit of Detection

Also the relative standard deviation (RSD %) for 7 replicate determinations of 17.10 µmol $L^{-1}$ of $Ni^{+2}$ in various membranes was 1.55% and so the method is reproducible during the experiments.

Table 3 presents a comparison between the proposed optode and the other sensors for determination of nickel previously [43], [45], [46], [47], [48]. It is obvious that the obtained results of this work are comparable with these existing sensors. In some cases, it provides better linearity range and detection limit.

### *Study of Interferences*

The selectivity of this sensor for determination of 8.52 µmol $L^{-1}$ of $Ni^{+2}$ was summarized in Table 4. The tolerance limit was defined as the concentration of added ion causing less than ±5 ٪relative error.

From Table 4, presence of alkaline metals and anions such as sulfate, chloride and others did not have adverse effects on nickel uptake. As seen, bivalent and some trivalent cations can interfere at different ratios. For elimination of these interferences, EDTA was selected as a masking agent. The effect of EDTA interfering was investigated firstly. The result was that $EDTA^{2-}$ did not affect (causing less than 4% negative deviation) Ni measurement up to $1.0\times10^{-2}$ mol $L^{-1}$. Thus, the presence of EDTA in the test solution can effectively mask 0.2 mmol of any interfering cations. Hence, the proposed membrane is a selective sensor for nickel monitoring in water and $H_2O_2$ samples.

### *Method Application*

The results of applicability of the membrane methodology are presented in Table 5. As shown, the mean recoveries for the addition of different concentrations of nickel to the water samples and $H_2O_2$ solutions were in the range of 98-104% and 98-105% respectively. Therefore, the proposed sensor can be successfully applied for the determination of nickel in the mentioned samples.

**Table 4.** Tolerance limits of diverse ions on the $Ni^{+2}$ (8.52 µmol $L^{-1}$) determination[a]

| Foreign ions | Tolerance Ratio ([M]:[$Ni^{+2}$]) |
|---|---|
| Cations | |
| $Na^{+}$, $K^{+}$, $Li^{+}$ and $NH_4^{+}$ | 2000:1 |
| $Ca^{2+}$, $Mg^{2+}$, $Ba^{2+}$, $Sr^{2+}$, $Cr^{3+}$, $UO_2^{2+}$ and $ZrO_2^{2+}$ | 100:1 |
| $Mn^{2+}$, $Fe^{2+}$, $Fe^{3+}$, $Al^{3+}$, $Zn^{2+}$, $Ga^{3+}$ and $Cu^{2+}$ | 50:1 |
| $Co^{2+}$, $Cd^{2+}$ and $Pb^{2+}$ | 10:1 |
| Anions | |
| $SO_4^{2-}$, $CO_3^{2-}$, $NO_3^{-}$, $NO_2^{-}$, $BO_3^{-}$ and $HCO_3^{-}$ | 2000:1 |
| $I^{-}$, $HPO_4^{2-}$ and $PO_4^{3-}$ | 1000:1 |
| $CN^{-}$, $Cl^{-}$ and $F^{-}$ | 20:1 |

[a] ≤ 5.0% Deviation in the absence of masking agent.

**Table 5.** Determination of $Ni^{2+}$ in different spiked samples

| Samples[a] | $Ni^{2+}$ (µmol $L^{-1}$) | | |
|---|---|---|---|
| | Added | Found[b] | Recovery (%) |
| Mineral | - | n.d.[c] | - |
| | 1.7 | 1.77 ± 0.34 | 104 |
| | 13.63 | 13.46 ± 0.17 | 99 |
| River | - | n.d.[c] | - |
| | 6.82 | 6.64 ± 0.34 | 98 |
| | 17.04 | 17.38 ± 0.17 | 102 |
| $H_2O_2$ (10%) | - | 1.87 ± 0.51 | - |
| | 5.11 | 7.16 ± 0.34 | 103 |
| | 11.93 | 13.63 ± 0.17 | 99 |
| $H_2O_2$ (20%) | - | 2.90 ± 0.51 | - |
| | 3.41 | 6.47 ± 0.34 | 105 |
| | 13.63 | 16.19 ± 0.34 | 98 |

[a] Sample sources as described in the text.
[b] Mean value of three replicate determinations ± Standard deviation.
[c] Not detected.

## Conclusion

The proposed optode is a precise, low cost and sensitive device for determination of nickel, based on PVC membrane. Also the proposed method, in addition to being fast and simple, provides a wide dynamic range, reliable reproducibility and a good limit of detection. EDTA was used as a masking agent and the method could be made selective in this way. A comparison of the proposed optode with the previously reported sensors indicates that the proposed method in some cases provides wider linear range and lower detection limit. Finally, the fabricated sensor can be successfully applied to nickel monitoring in water and hydrogen peroxide samples. To the best of our knowledge no manufactured optode has been reported in the literature for the determination of Ni in $H_2O_2$ solutions.

## Competing Interests

The authors have declared that no competing interests exist.

## References


1. Steinberg IM, Lobnik A, Wolfbeis OS. Characterisation of an optical sensor membrane based on the metal ion indicator Pyrocatechol Violet. *Sens. Actuators*. 2003;90:230–235. https://doi.org/10.1016/s0925-4005(03)00033-9
2. Repo E, Warchol JK, Kurniawan TA, Sillanpaa M E T. Adsorption of Co(II) and Ni(II) by EDTA- and/or DTPA-modified chitosan: Kinetic and equilibrium modeling. *Chem. Eng. J*. 2010;161:73–82. https://doi.org/10.1016/j.cej.2010.04.030
3. Fu F, Chen R, Xiong Y. Comparative investigation of N, N-bis(dithiocarboxy) piperazine and diethyldithiocarbamate as precipitants for Ni(II) in simulated wastewater. *J. Hazard. Mater*. 2007;142:437–442. https://doi.org/10.1016/j.jhazmat.2006.08.036
4. Demirbas E, Kobya M, Oncel S, Sencan S. Removal of Ni (II) from aqueous solution by adsorption onto hazelnut shell activated carbon: equilibrium studies. *Bioresour. Technol*. 2002;84:291–293. https://doi.org/10.1016/s0960-8524(02)00052-4
5. Kadirvelu K, Senthilkumar P, Thamaraiselvi K, Subburam V. Removal of Ni (II) from aqueous solution by adsorption onto hazelnut shell activated carbon: equilibrium studies. *Bioresour. Technol*. 2002;81:87–90.
6. Cempel M, Nikel G. Nickel: A Review of Its Sources and Environmental Toxicology. *Pol. J. Environ. Stud*. 2006;15:375–382.
7. Costa M, Davidson TL, Chen H, Ke Q, Zhang P, Yan Y, et al. Nickel carcinogenesis: epigenetics and hypoxia signaling. *Mutat. Res*. 2005;592:79–88. https://doi.org/10.1016/j.mrfmmm.2005.06.008
8. Amais RS, Ribeiro JS, Segatelli MG, Yoshida I V P, Luccas PO, et al. Assessment of nanocomposite alumina supported on multi-wall carbon nanotubes as sorbent for on-line nickel preconcentration in water samples . *Sep. Purif. Technol*. 2007;58:122–128. https://doi.org/10.1016/j.seppur.2007.07.024
9. Dadfarnia S, Shabani A M H, Shirani Bidabadi M, Jafari A A. A novel ionic liquid/microvolume back extraction procedure combined with flame atomic absorption spectrometry for determination of trace nickel in samples of nutritional interest. *J. Hazard. Mater*. 2010;173:534–538. https://doi.org/10.1016/j.jhazmat.2009.08.118
10. Ahmadpour A, Tahmasbi M, Rohani Bastami T, Amel Besharati J. Rapid removal of cobalt ion from aqueous solutions by almond green hull. *J. Hazard. Mater*. 2009;166:925–930. https://doi.org/10.1016/j.jhazmat.2008.11.103
11. *United State Department of health and human services, Public Health Service Agency for Toxic Substances and Disease Registry, Agency for toxic substances and disease registry (ATSDR)*. http://www.atsdr.cdc.gov/toxfaq.html
12. Othmer K. *Encyclopedia of Chemical Technology*. NY: J. Wiley and Sons, Inc.; 1980.
13. Love JE, Stillwell WH. *The Hydrogen-peroxide rocket reaction-control system for the X-1B research airplane*. Washington; 1959.
14. MIL-PRF-16005F. *Performance specification-Propellant-Hydrogen peroxide, Defense Standardization Program office (DLSC-LM)*. Virginia; 2003.

15. Xu Y, Axe L, Boonfueng T, Tyson T A, Trivedi P, et al. Ni(II) complexation to amorphous hydrous ferric oxide: An X-ray absorption spectroscopy study. *J. Colloid Interface Sci*. 2007;314:10–17. https://doi.org/10.1016/j.jcis.2007.05.037
16. Baytak S, Turker AR. Determination of lead and nickel in environmental samples by flame atomic absorption spectrometry after column solid-phase extraction on Ambersorb-572 with EDTA. *J. Hazard. Mater*. 2006;129:130–136. https://doi.org/10.1016/j.jhazmat.2005.08.019
17. Ciftci H, Yalcin H, Eren E, Olcucu A, Sekerci M. Enrichment and determination of $Ni^{2+}$ ions in water samples with a diamino-4-(4-nitro-phenylazo)-1H-pyrazole (PDANP) by using FAAS. *Desalination*. 2010;256:48–53. https://doi.org/10.1016/j.desal.2010.02.018
18. Soylak M, Kars A, Narin I. Coprecipitation of $Ni^{2+}$, $Cd^{2+}$ and $Pb^{2+}$ for preconcentration in environmental samples prior to flame atomic absorption spectrometric determinations. *J. Hazard. Mater*. 2008;159:435–439. https://doi.org/10.1016/j.jhazmat.2008.02.034
19. Ghaedi M, Tavallali H, Shokrollahi A, Zahedi M, Montazerozohori M, et al. Flame atomic absorption spectrometric determination of zinc, nickel, iron and lead in different matrixes after solid phase extraction on sodium dodecyl sulfate (SDS)-coated alumina as their bis (2-hydroxy-acetophenone)-1, 3-propanediimine chelate. *J. Hazard. Mater*. 2009;166:1441–1448. https://doi.org/10.1016/j.jhazmat.2008.12.066
20. Campos R C D, Santos H R D, Grinberg P. Determination of copper, iron, lead and nickel in gasoline by electrothermal atomic absorption spectrometry using threecomponent solutions. *Spectrochim. Acta. B*. 2002;57:15–28.
21. Koizumi C, Usuda K, Hayashi S, Dote T, Kono K. Evaluation of Urinary Nickel using Inductively Coupled Plasma Argon Emission Spectrometry. *Bull. Osaka Med. Coll*. 2005;51:1–7.
22. Sarma LS, Kumar JR, Reddy KJ, Thriveni T, Reddy AV. Development of highly sensitive extractive spectrophotometric determination of nickel(II) in medicinal leaves, soil, industrial effluents and standard alloy samples using pyridoxal-4-phenyl-3-thiosemicarbazone. *J. Trace Elem. Med. Biol*. 2008;22:285–295. https://doi.org/10.1016/j.jtemb.2008.06.003
23. Ghaedi M. Selective and sensitized spectrophotometric determination of trace amounts of Ni(II) ion using -benzyl dioxime in surfactant media. *Spectrochim. Acta. A*. 2007;66:295–301. https://doi.org/10.1016/j.saa.2006.02.055
24. Ressalan S, Iyer C S P. Absorption and fluorescence spectroscopy of 3-hydroxy-3-phenyl-1-o-carboxyphenyltriazene and its copper (II), nickel (II) and zinc (II) complexes: a novel fluorescence sensor. *J. Luminescence*. 2005;111:121–129. https://doi.org/10.1016/j.jlumin.2004.02.011
25. Ganjali MR, Hosseini M, Hariri M, Faridbod F, Norouzi P. Novel erbium (III)-selective fluorimetric bulk optode. *Sens. Actuators. B*. 2009;142:90–96. https://doi.org/10.1016/j.snb.2009.08.027
26. Seitz WR. Optical Ion Sensing Fiber Optic. Wolfbeis O.S., Ed. *Chemical Sensors Biosensors II*. Bocaraton: CRC Press; 1991.
27. Absalan G, Asadi M, Kamran S, Torabi S, Sheikhian L. Design of a cyanide ion optode based on immobilization of a new Co (III) Schiff base complex on triacetylcellulose membrane using room temperature ionic liquids as modifiers. *Sens. Actuators. B*. 2010;147:31–36. https://doi.org/10.1016/j.snb.2010.03.013
28. Kalyan Y, Pandey AK, Bhagat PR, Acharya R, Natarajan V, et al. Membrane optode for mercury(II) determination in aqueous samples. *J. Hazard. Mater*. 2009;166:377–382. https://doi.org/10.1016/j.jhazmat.2008.11.027
29. Ganjali MR, Zare Dorabei R, Norouzi P. Design and construction of a novel optical sensor for determination of trace amounts of dysprosium ion. *Sens. Actuators. B*. 2009;143:233–238. https://doi.org/10.1016/j.snb.2009.09.014
30. Kalyan Y, Pandey AK, Naidu G R K, Reddy A V R. Membrane optode for uranium(VI) ions preconcentration and quantification based on a synergistic combination of 4-(2-thiazolylazo)-resorcinol with 8-hydroxyquinaldine. *Spectrochim. Acta. A*. 2009;74:1235–1241. https://doi.org/10.1016/j.saa.2009.09.045
31. Rastegarzadeh S, Pourreza N, Saeedi I. An optical chemical sensor for thorium (IV) determination based on thorin. *J. Hazard. Mater*. 2010;173:110–114. https://doi.org/10.1016/j.jhazmat.2009.08.055
32. Safavi A, Bagheri M. Design and characteristics of a mercury (II) optode based on immobilization of dithizone on a triacetylcellulose membrane. *Sens. Actuators. B*. 2004;99:608–612. https://doi.org/10.1016/j.snb.2004.01.022

33. Khayatzadeh Mahani M, Divsar F, Chaloosi M, Ghanadi Maragheh M, Khanchi AR, et al. Simultaneous determination of thorium and uranyl ions by optode spectra and chemometric techniques. *Sens. Actuators. B*. 2008;133:632–637. https://doi.org/10.1016/j.snb.2008.03.030
34. Beiraghi A, Babaee S, Roshdi M. Spectrophotometric Determination of Trace Amounts of Beryllium Using 1,8-Dihydroxyanthrone as a New Chromogenic Reagent. *J. Hazard. Mater*. 2011;190:962–968.
35. Ensafi A A, Katiraeifar A, Meghdadi S. Highly selective optical-sensing film for lead (II) determination in water samples. *J. Hazard. Mater*. 2009;172:1069–1075. https://doi.org/10.1016/j.jhazmat.2009.07.112
36. Shamsipur M, Sadeghi M, Alizadeh K, Bencini A, Valtancoli B, et al. Novel fluorimetric bulk optode membrane based on 5,8-bis ((5-chloro-8-hydroxy-7-quinolinyl)methyl)-2,11-dithia-5,8-diaza-2,6-pyridinophane for selective detection of lead(II) ions. *Talanta*. 2010;80:2023–2033. https://doi.org/10.1016/j.talanta.2009.11.011
37. Choi M M F, Chung K O P, Wu X. Nicotine derivative optode membrane with nonactin as Ionophore. *Talanta*. 2002;56:1027–1038. https://doi.org/10.1016/s0039-9140(01)00590-2
38. Marczenko Z. *Separation and Spectrophotometric Determination of Elements*. NY: John Wiley and Sons; 1986.
39. Lurie J J. *Handbook of Analytical Chemistry*. English Translation. Moscow: Mir Publishers; 1978.
40. Cheng KL, Bray RH. 1-(2-Pyridylazo)-2-naphthol as possible analytical reagent. *Anal. Chem*. 1955;27:782–785. https://doi.org/10.1021/ac60101a024
41. Coo LD, Belmonte CJ. Nafion-based optical sensor for the determination of selenium in water samples. *Talanta*. 2002;58:1063–1069.
42. Shamsipur M, Poursaberi T, Karami AR, Hosseini M, Momeni A, et al. A novel optical chemical sensor for thallium(III) determination using 4-(5-bromo-2-pyridylazo)-5-(diethylamino)-phenol. *Anal. Chim. Acta*. 2004;501:55–60.
43. Aksuner N, Henden E, Yilmaz I, Cukurovali A. A novel optical chemical sensor for the determination of nickel(II) based on fluorescence quenching of newly synthesized thiazolo-triazol derivative and application to real samples. *Sens. Actuators B*. 2012;269:166–167. https://doi.org/10.1016/j.snb.2012.02.059
44. Fouladgar M, Ensafi A. A novel optical chemical sensor for thallium(III) determination using 4-(5-bromo-2-pyridylazo)-5-(diethylamino)-phenol. *Sens. Actuators B*. 2010;143:590–594. https://doi.org/10.1016/j.snb.2009.09.057
45. Madden JE, Cardwell TJ, Cattrall RW, Deady LW. Nafion-based optode for the detection of metal ions in flow Analysis. *Anal. Chim. Acta*. 1996;319:129–134. https://doi.org/10.1016/0003-2670(95)00495-5
46. Amini MK, Momeni Isfahani T, Khorasani JH, Pourhossein M. Development of an optical chemical sensor based on 2-(5-bromo-2 pyridylazo)-5-(diethylamino) phenol in Nafion for determination of nickel ion. *Talanta*. 2004;63:713–720. https://doi.org/10.1016/j.talanta.2003.12.032
47. Ensafi A, Bakhshi M. New stable optical film sensor based on immobilization of 2-amino-1-cyclopentene-1-dithiocarboxylic acid on acetyl cellulose membrane for Ni(II) determination. *Sens. Actuators B*. 2003;96:435–440. https://doi.org/10.1016/s0925-4005(03)00597-5
48. Rezaei B, Hadadzadeh H, Azimi A. Nickel (II) Selective PVC-Based Membrane Sensor Using a Schiff Base. *Int. J. Spec*. 2011;201:1–7. https://doi.org/10.1155/2011/746372

**Publisher's Note**

All claims, opinions, data, and conclusions expressed in this article are solely those of the author(s) and contributor(s), and do not necessarily represent those of Open Access Pub, the journal, its editors, or reviewers. Open Access Pub does not guarantee or endorse any product, method, instruction, or claim discussed in the article, and disclaims responsibility for any injury to people or property resulting from ideas, methods, instructions, or products referred to in the content.