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Synthesis, characterization and sensor properties of a new sulfonyl hydrazone derivative molecule: potentiometric determination of Pb(II) ions

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Abstract

In this study, a new sulfonyl hydrazone derivative molecule was synthesized, and its characterization was performed using several spectroscopic methods (^{1}H–, ^{13}C NMR, FT–IR and Q-TOF). New potentiometric sensors were developed using this molecule, and subsequently, their potentiometric performance properties were investigated. Based on the data obtained, we found that the prepared sensors are selective to Pb^{2+} ions. These novel lead(II)–selective sensors had a low detection limit of 2.89×10^{-6} M, and a Nernstian response (27.7 ± 1.3 mV/decade) over a wide concentration range of 1.0×10^{-5}–1.0×10^{-1} M. They were also highly reproducible, selective and able to work in a wide pH range (3.0–9.0) without being affected by the changes in pH. We showed that these potentiometric sensors can detect Pb^{2+} ions with very high recoveries when applied to real samples. In conclusion, we here report the synthesis and characterization of a new molecule and its potentiometric sensor properties.

Keywords Heavy metal · Sensor · Potentiometry · Ion–selective electrode · Lead(II)

Introduction

Heavy metals are naturally occurring elements with high atomic weights and densities more than five times greater than that of water (Tchounwou et al. 2012). Multiple applications and usage of these elements in various areas including the industry, agriculture, medicine, and technology have resulted in their wide distribution in the environment, ultimately raising concerns over their potential influences on animal/human and environmental health (Alengebawy et al. 2021; Bradl 2002). Due to their high degree of toxicity,

certain elements including arsenic, cadmium, chromium, lead and mercury rank among the priority metals which are of high significance in terms of public health. These metallic elements are considered systemic toxicants which were reported to induce multiple organ damage, even at lower concentrations of exposure (Tchounwou et al. 2012). Therefore, the regular and frequent determination of the presence of these elements is highly critical.

One of these heavy metals, lead (Pb), is a bluish-gray element widely used in several industries such as in the manufacturing of products including automobile batteries, pipes, fishing sinkers, ammunition, dyes and paints, ceramic glazes, toys, and certain cosmetics or traditional remedies (Naranjo et al. 2020; Mohsin 2022). This heavy metal can be easily molded and is also resistant to corrosion. Besides, it does not degrade to other molecules, resulting in its accumulation in the body and the environment over time. Over the past century, lead has highly contaminated the environment as a result of increased human activities involving it. It is now apparent that both acute and chronic exposure to lead at any concentration is detrimental to animal/human health, such as with adverse effects on neurodevelopment and cognition (damage to the brain and nervous system, slowed growth and development, learning and behavior problems, hearing and

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speech problems) (Naranjo et al. 2020; Özbek et al. 2022a). Lead can accumulate in dust, soil, and water sediment, particularly close to urban areas and mining and industrial sites, where it can persist for a long time. Lead from pipes and solder can also be released into drinking water service lines when the water passing through is acidic, thus contaminating drinking water (Levin et al. 2021). Many previous studies indicated an adverse effect of lead exposure even when the blood lead concentrations are low (Raymond and Brown 2015; Bellinger 2012; Miranda et al. 2007). Thus, highly selective and sensitive monitoring of lead ions in diverse samples and settings is required to minimize the health risks associated with lead.

Multiple methods for lead determination exist, including spectrophotometry, high performance liquid chromatography, X-ray fluorescence, electrochemical methods, atomic absorption spectroscopy and inductively coupled plasma mass spectrometry (Cao et al. 2008; Szymczycha-Madeja et al. 2016; Liang et al. 2018; Jankiewicz et al. 2001). In terms of electrochemical techniques, there is a growing interest in recent years on potentiometric techniques, where ion-selective electrodes (ISEs) are used for measurements (Lyu et al. 2020; Wardak 2011). These devices are advantageous due to their high versatility, low production costs and low power/energy consumption, easy and fast measurement capabilities, quite high robustness, as well as the possibility of miniaturization and high selectivity based on a variety of ionophores. Furthermore, improved values of certain parameters such as potential stability and reversibility and a lower limit of detection can be obtained with these sensors, compared to their alternatives (Isildak et al. 2023; Cheong et al. 2021; Michalska 2012; Özbek 2023; Özbek and Isildak 2022a; Cetin et al. 2023; Subasi et al. 2022; Topcu et al. 2019). Here, it should also be highlighted that low costs associated with these sensors make them more broadly applicable, for instance in resource-limited settings.

The molecular structure of ionophores present in the composition of ion-selective electrodes, which interact directly with the analyte, is of high importance in terms of the design and performance of potentiometric sensors. Ionophores containing various functional groups in their structure are important components of the potentiometric sensors due to their interaction with ions. The use of non-commercial ionophores is an important factor that makes novel sensors very cost-effective (Özbek et al. 2022b, 2023). In other words, synthesis of ionophores instead of obtaining them from industrial producers might decrease the costs associated with the manufacturing of sensors. In the present study, a new sulfonyl hydrazone derivative molecule (Fig. 1) was synthesized, and the characterization of its ionophore properties was then performed using some spectroscopic methods (^{1}H–, ^{13}C NMR, FT–IR and Q-TOF) in the context of potentiometric determination of Pb(II) ions.
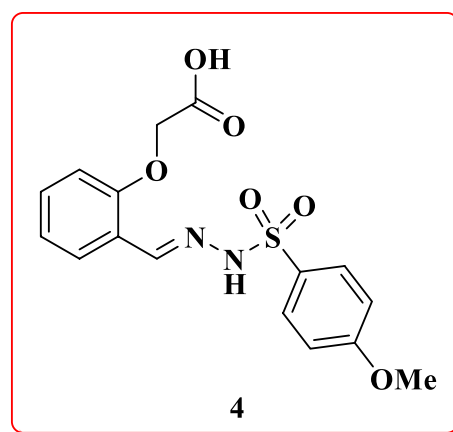
Fig. 1 The chemical structure of the newly synthesized sulfonyl hydrazone derivative molecule

Experimental

Chemicals and reagents

All chemicals (salicylaldehyde, ethylchloro acetate, potassium carbonate, sodium hydroxide, hydrazinium hydroxide, hydrochloric acid and acetic acid) and solvents (acetonitrile, ethanol and tetrahydrofuran) used in the ionophore (**4**) synthesis were purchased from Sigma-Aldrich and Merck. Graphite, epoxy (Macroplast Su 2227) and hardener (Desmodur RFE), utilized for the preparation of conductive solid contact were supplied from Sigma-Aldrich, Henkel (Istanbul, Turkey) and Bayer AG (Darmstadt, Germany), respectively. High molecular weight poly (vinyl chloride) (PVC), plasticizers [dibutyl phthalate (DBP), bis (2–ethylhexyl) adipate (DEHA), *o*–nitrophenyloctylether (*o*–NPOE) and bis(2–ethylhexyl)sebacate (BEHS)], anion excluder potassium tetrakis (*p*–chlorophenyl) borate (KT*p*ClPB) which are used to prepare polymer membrane sensors were obtained from Sigma-Aldrich. Metal nitrate salts used in the selectivity studies were obtained from Fluka, Merck and Sigma-Aldrich. All solutions were prepared freshly using ultrapure water (Human ultrapure water system; Zeneer Power I 18.2 MΩ cm^{-1}).

Apparatus

The characterization studies of the synthesized sulfonyl hydrazone derivative molecule were performed using NMR (Bruker Avance DPX–400 instrument), Q-TOF (Agilent 6530 Accurate–Mass), FTIR (ATR, Jasco FTIR–4700 spectrometer) and melting points analysis (Electrothermal 9100). Surface images of prepared polymer membrane

sensors were taken with a scanning electron microscope (SEM) (Quanta FEG 450–FEI). Potentiometric measurements were carried out using a multi-channel potentiometer (Medisen Medical Ltd. Sti., Turkey). The potentiometric measurement system has a laboratory-made software program. Silver/silver chloride (Ag/AgCl) electrode was used as reference electrode (Thermo Scientific Orion 900100).

Method

Synthesis of 2-(2-formylphenoxy)acetic acid (2)

The corresponding aldehyde **2** was obtained according to the method previously reported (Reddy et al. 2014). Salicylaldehyde **1** (10 mmol) was placed in a 50 mL round-bottom flask, to which dry acetonitrile (20 mL) was added and dissolved. Ethylchloro acetate (12 mmol) and potassium carbonate (15 mmol) were added to the reaction flask, and the mixture was then refluxed for 3 h. Later, the mixture was cooled to room temperature and filtered off. The solvent was removed under reduced pressure. The crude product was dissolved in water (50 mL), and sodium hydroxide (20 mmol) was added and stirred at room temperature for 2 h. The mixture was then acidified with dilute hydrochloric acid, and the precipitate formed was filtered out. The desired product **2** was recrystallized from ethanol (Fig. 2).

Off–white solid, yield 83%, mp: 131–133 °C, **^{1}H NMR** (500 MHz, DMSO) δ 13.21 (s, 1H), 10.45 (s, 1H), 7.72 (d, $J = 9.3$ Hz, 1H), 7.63 (t, $J = 8.7$ Hz, 1H), 7.15 (d, $J = 8.5$ Hz, 1H), 7.10 (t, $J = 7.5$ Hz, 1H), 4.90 (s, 2H). **^{13}C NMR** (125 MHz, DMSO) δ 189.7, 170.3, 160.7, 136.7, 128.0, 125.0, 121.8, 114.3, 65.6.

### Synthesis of 4-methoxybenzenesulfonohydrazide (3)

The 4-methoxybenzenesulfonohydrazide **3** was synthesized according to the method previously reported (Oguz et al. 2020). 4-methoxybenzene-1-sulfonyl chloride (5 mmol, 1.03 g) was placed in a 50 mL round bottom flask, dissolved in 10 mL of THF and stirred in an ice bath. Hydrazinium hydroxide (12.5 mmol, 0.64 g, 98%) was then added to the reaction flask, and the reaction was stirred for 1 h. After completion, the solvent was removed from the evaporator under reduced pressure. The crude mixture was washed with water to remove the hydrazinium chloride salts, and dried in a vacuum desiccator without purification for the next step.

Synthesis of (*E*)-2-(2-((2-((4-methoxyphenyl)sulfonyl)hydrazineylidene)methyl)phenoxy) acetic acid (4)

2-(2-formylphenoxy)acetic acid (2 mmol, 360.3 mg) was placed in a 50 mL round-bottomed flask equipped with a magnetic stirrer bar and a reflux condenser, dissolved in absolute ethanol (10 mL), and later 4-methoxybenzenesulfonohydrazide (2 mmol, 404.4 mg) was added to this solution. Then, 4–5 drops of acetic acid were added with a Pasteur pipette, and the mixture was refluxed for 2 h. The mixture was cooled down to room temperature, and the solid formed was filtered. The desired product **4** was recrystallized from ethanol (Fig. 2) (Demir et al. 2023).

White solid, 86% yield, mp: 145–147 °C, **FTIR** (cm^{-1}): ν_{max} 3473, 3173, 2842, 1732, 1597, 1491, 1355, 1300, 1184, 846, 752; **^{1}H NMR** (400 MHz, DMSO) δ 11.36 (s, 1H), 8.29 (s, 1H), 7.81 (AA′ part of AA′BB′ system, 2H), 7.63 (dd, $J = 7.7$, 1.6 Hz; 1H), 7.33 (ddd, $J = 8.4$, 7.2,
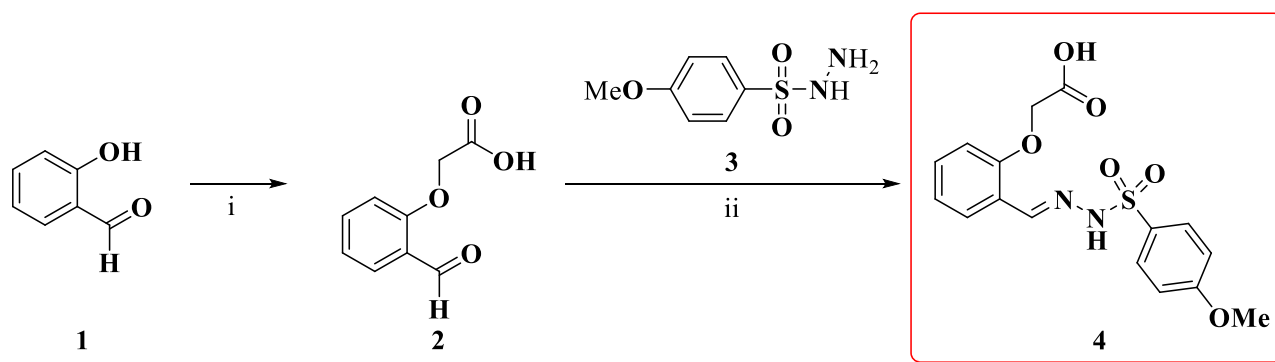
Reaction conditions: (i) ethyl chloroacetate (1.2 eq.), K$_2$CO$_3$, CH$_3$CN, reflux, 3h, NaOH (2.0 eq.), water, rt, 2h (ii) **3** (1.0 eq.), acetic acid (4-5 drops), ethanol, reflux, 2h.

Fig. 2 Synthesis route for ionophore (**4**)

1.6 Hz; 1H), 7.13 (BB′ part of AA′BB′ system, 2H), 6.96 (m, 2H), 4.72 (s, 2H), 3.81 (s, 3H); ^{13}**C NMR** (100 MHz, DMSO) δ 170.0, 162.6, 156.1, 142.4, 131.3, 130.7, 129.4, 125.3, 122.1, 121.1, 114.4, 112.7, 65.1, 55.6. HRMS m/z: $[M + H] +$ $C_{16}H_{16}N_2O_6S$ calculated: 365.0803; found: 365.0797.

Preparation of Pb(II)-selective sensors

In this study, sensors selective to lead(II) ions were prepared by following the procedures given below:

First, conductive solid contact electrodes were prepared by dissolving the graphite (50.0 mg), epoxy (35.0 mg) and hardener (15.0 mg) in THF (approximately 3 mL). Copper wires were dipped several times into the mixture and left to dry for 24 h at dark.

In the second step, polymer membrane sensors were prepared. For this purpose, ionophore, plasticizers, KT*p*ClPB and PVC were dissolved in approximately 3 mL of THF in the ratios given in Table 1, and mixed until it becomes homogeneous (Özbek and Ölcenoglu 2023; Özbek and Isildak 2022b). The previously prepared conductive solid contact electrodes were coated with these mixtures and left to dry. Potential measurements were taken with these prepared sensors.

Potential measurements

All potential measurements were carried out at 25 ± 1.0 °C temperature by using the following cell assembly:

- Ag/AgCl; KCl (3 M) ‖ Pb^{2+} sample solution │ Pb^{2+}-selective membrane │ solid contact │ Cu wire

# Results and discussion

Ionophore characterization

The desired aldehyde **2** was obtained in 83% yield by a substitution reaction of salicyl aldehyde with ethyl chloroacetate in the presence of base followed by hydrolysis (Tokalı et al. 2023). The target compound was synthesized with 86% yield from the condensation reaction of the aldehyde **2** with compound **3**, which was produced following the treatment of 4–methoxybenzenesulfonyl chloride and hydrazine.

When the IR spectrum of the molecule was examined in detail, a broad peak at wavenumber 3473 cm^{-1} was observed to be the O–H stretching vibration between hydrogen-bonded acetic acid moieties of the molecule (Fig. 3). It is compatible with the vibrational bands of molecules containing acetic acid moieties (Reddy et al. 2014). The N–H stretching vibration of the N–H bond was also observed at 3173 cm^{-1}. The

Table 1 The prepared sensors and their potentiometric performance properties

Electrode No	Membrane composition (w/w)								Potentiometric performance			
	Ionophore	PVC	Plasticizer				KT*p*ClPB		Linear concentration range (M)	Limit of detection (M)	Slope (mV/decade)	R^2
			DEHA	BEHS	DBP	o–NPOE						
1	3.0	32.0	64.0				1.0		1.0×10^{-2}–1.0×10^{-5}	5.97×10^{-6}	22.7 ($\pm$2.9)	0.9759
2	3.0	32.0		64.0			1.0		1.0×10^{-1}–1.0×10^{-5}	3.46×10^{-6}	25.5 ($\pm$3.6)	0.9859
3	4.0	32.0	63.0				1.0		1.0×10^{-2}–1.0×10^{-5}	6.37×10^{-6}	23.0 ($\pm$3.7)	0.9515
4	**4.0**	**32.0**			**63.0**		**1.0**		$\mathbf{1.0\times10^{-1}}$–$\mathbf{1.0\times10^{-5}}$	$\mathbf{2.89\times10^{-6}}$	**27.7 ($\pm$1.3)**	**0.9981**
5	4.0	32.0		63.0			1.0		1.0×10^{-1}–1.0×10^{-5}	7.99×10^{-6}	33.3 ($\pm$2.5)	0.9825
6	4.0	32.0				63.0	1.0		1.0×10^{-1}–1.0×10^{-4}	8.38×10^{-5}	11.6 ($\pm$2.1)	0.9245

Fig. 3 IR spectra of the synthesized ionophore **(4)**
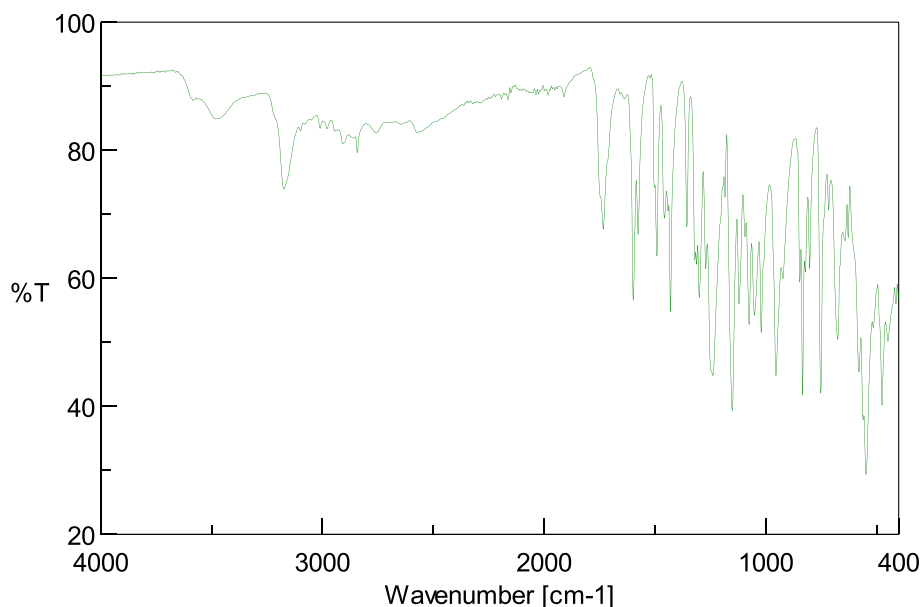
aliphatic C–H stretching band was seen at 2842 cm^{-1}. The relatively sharp and strong absorption band at wavenumber 1732 cm^{-1} was due to the C=O stretching vibration of its acetic acid fragment. The C=N stretch band indicating the presence of azomethine, which is the most characteristic fragment of the molecule, was detected at 1597 cm^{-1}. The SO$_2$ fragment had two prominent peaks in the IR spectrum, whose vibration bands were observed as asymmetric stretching band at 1355 cm^{-1} and symmetric stretching band at 1184 cm^{-1}. Peak at wavenumber 1300 cm^{-1} corresponds to the C–O stretching vibration of the C–O bond (Fig. 3) (Mecozzi et al. 2012; Beekes et al. 2007).

When we examined the ^{1}H–NMR spectrum of compound **4**, the proton of its carboxylic acid moiety appeared as a broad singlet at 11.36 ppm (Fig. 4). The CH=N part, which we define as the characteristic proton of the molecule, resonated as a singlet at 8.29 ppm. Identical protons of the 1,4-disubstituted aromatic benzene ring of the molecule gave the AA′BB′ system at 7.81 and 7.13 ppm (Fig. 4). The protons of the 1,2-disubstituted aromatic ring of the molecule gave peaks in the range of 7.63–6.96 ppm. Methylene (OCH$_2$COO) and methoxy (OCH$_3$) protons resonated as a singlet at 4.72 and 3.81 ppm, respectively (Demirci et al. 2023).

The ^{13}C signals of compound **4** were characterized by the DEPT technique (Fig. 5). Accordingly, the CO$_2$H fragment gave a peak at 170 ppm. The ipso carbons adjacent to OCH$_2$ and OCH$_3$ resonated at 162.6 and 156.2 ppm, respectively, while the characteristic CH=N carbon signal was observed at 142.4 ppm. Other eight non-identical aromatic carbons also gave signals at the 131.3–112.7 ppm region. The methylene carbon (OCH$_2$) resonated at 65.1 ppm, while the methoxy carbon (OCH$_3$) resonated at 55.6 ppm (Demirci

et al. 2023). Hence, the structure of the carboxylic group attached to sulfonylhydrazone **4** was elucidated by NMR spectroscopic analysis. According to HRMS spectrum analysis, the molecular ion peak [M + 1] was found to be compatible with its calculated molecular weight (Fig. 6).

Membrane composition

In this study, six different sensors with different compositions were prepared. Different PVC and KTpClPB ratios were used to determine the ideal ionophore ratio. Considering the potentiometric performance characteristics of the prepared sensors given in Table 1, the ideal ionophore ratio was determined as 4.0%. We observed that the sensor prepared with DBP exhibits the lowest detection limit (2.89 × 10^{-6} M) and Nernstian response (27.7 ± 1.3 mV/decade), among the sensors prepared at the same ratios and using four different plasticizers. Based on data shown in Table 1, the ideal sensor composition was determined to have 4.0% synthesized ionophore, 63.0% DBP, 32.0% PVC and 1.0% KTpClPB. Sensors prepared with these composition ratios were used in all the subsequent steps of the study.

Surface analysis

The surface image of the membrane structure was obtained by SEM imaging. Scanning electron micrograph of the sensor with optimum components is given in Fig. 7 which shows that the prepared sensor has a tight and porous structure. The resulting surface image is as expected for ion selective electrodes.
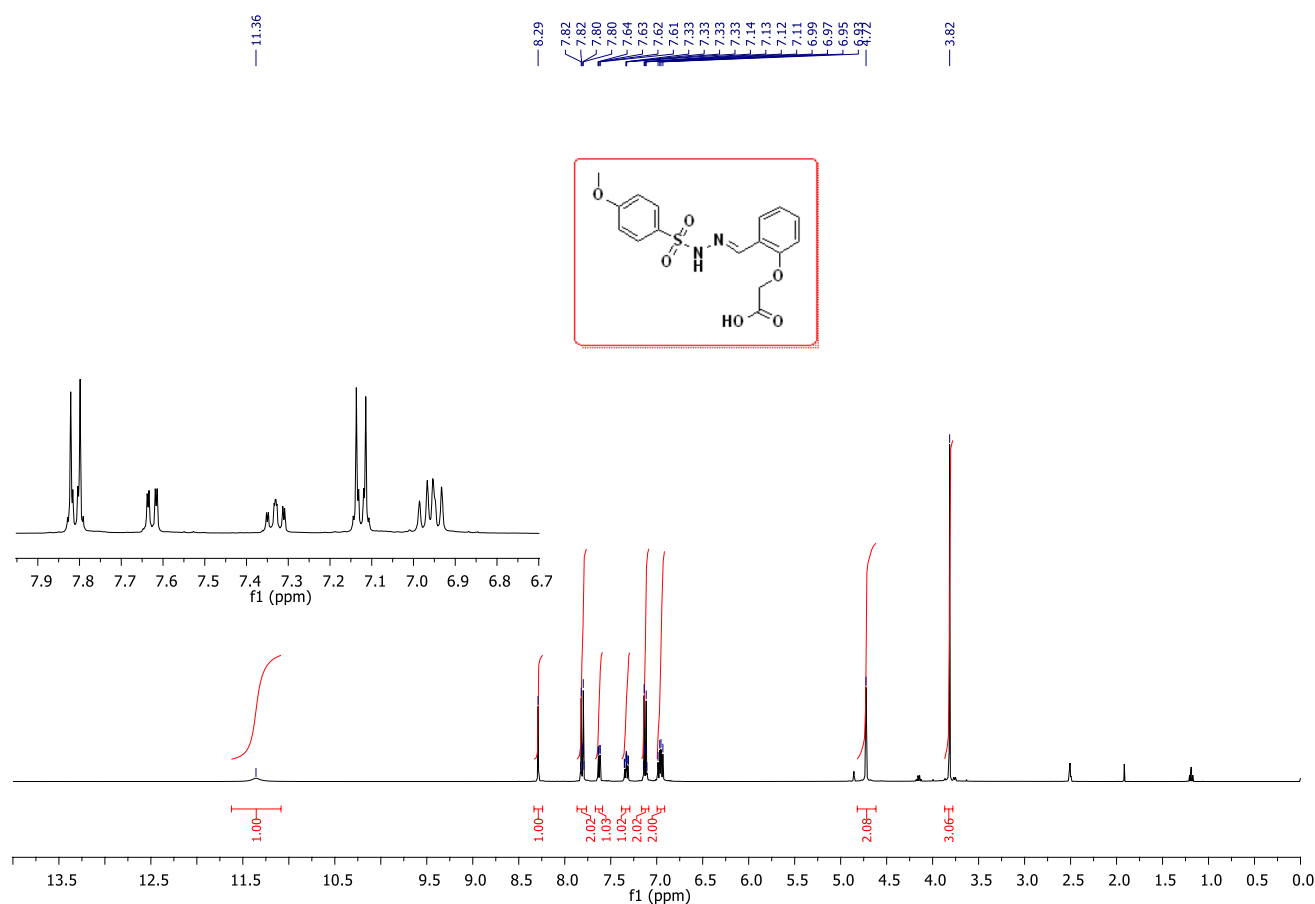
Fig. 4 ¹H NMR spectra of the synthesized ionophore **(4)**

Ionophore effect

Ionophores are molecules that interact directly with the analyte ion. In this study, a new sulfonyl hydrazone derivative molecule was synthesized, and its ionophore properties were subsequently investigated. In order to show the effect of the newly synthesized molecule on the sensor behavior, the response of the electrode without ionophore to Pb(II) ions was firstly investigated. As shown in Fig. 8, solid contact electrodes with no ionophore in their structure (32.0% PVC, 1.0% KTpClPB and 63.0% DBP) did not respond to Pb(II) ions, whereas sensors with an ionophore exhibited an ideal potentiometric response to Pb(II) ions. As a result, we can state that the newly synthesized sulfonyl hydrazone derivative molecule interacts directly with Pb(II) ions and exhibits ideal ionophore properties.

Potentiometric response and calibration curve

The behavior of the new lead(II)-selective potentiometric sensor toward Pb(II) ions is given in Fig. 9 which shows that the sensor exhibited a stable and ideal potentiometric behavior in the concentration range of 1.0×10^{-6}–1.0×10^{-1} M. The calibration curve of the sensor is given in Fig. 10 which demonstrates that the developed sensor exhibited a linear response in the concentration range of 1.0×10^{-5}–1.0×10^{-1} M. Also, the detection limit of the sensor was calculated using data given in Fig. 10. The potential value corresponding to the intersection of the horizontal and vertical axes on the calibration curve was written in the linear equation. Thus, ultimately, the limit of detection was calculated as 2.89×10^{-6} M. The response time of the developed lead(II)-selective potentiometric sensor was determined by recording the time it took to equilibrate when immersed from one solution to another at each tenfold concentration change (Buck and Lindner 1994). Thus, the response time of the sensor was determined as 5s. Additionally, the lifetime of the sensor was determined by monitoring its potential behavior for 6 weeks, and we observed that there was no significant change in the slope (mV/decade) value for 4 weeks.
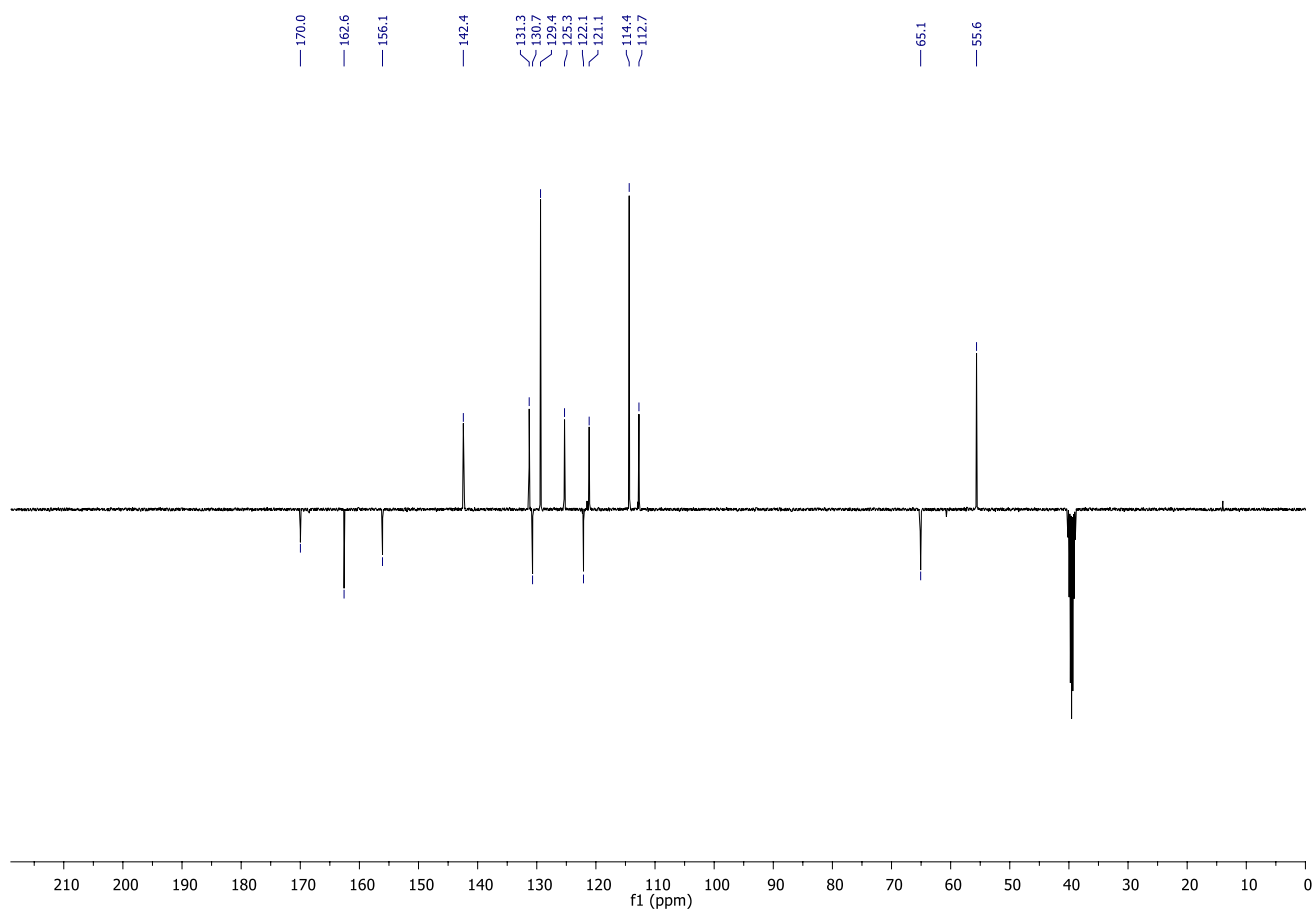
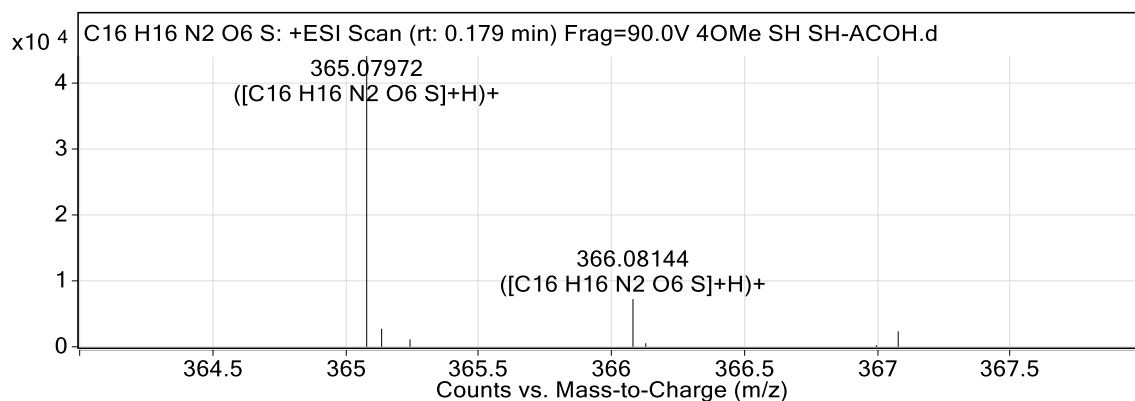**Fig. 5** ^{13}C NMR spectra of the synthesized ionophore **(4)**

Fig. 6 Q-TOF spectra of the synthesized ionophore **(4)**

Repeatability

The repeatability of the newly developed lead(II)-selective sensor was determined at three different lead concentrations. The repeatability of the sensor is given in Fig. 11 which shows that the sensor exhibited a stable behavior at these three lead concentrations. The repeatability data of the sensor are presented in Table 2. According to Table 2, the standard deviation values were calculated as ± 0.93, ± 0.36 and ± 0.98, respectively. The data in Fig. 11 and Table 2 clearly show that the sensor exhibits a highly stable, reproducible and Nernstian behavior.
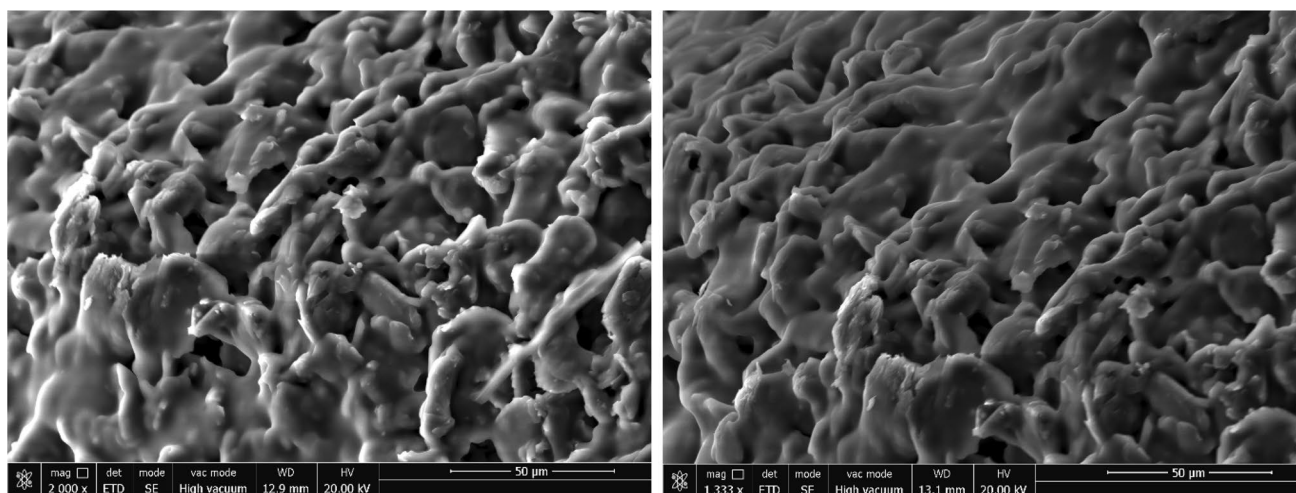
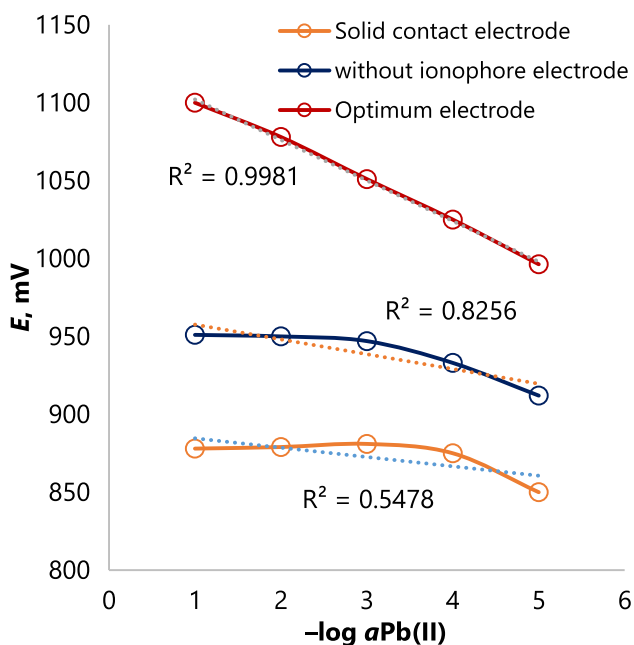**Fig. 7** Surface image of prepared PVC membrane sensors

Fig. 8 Effect of ionophore on sensor behavior

pH working range

The pH working range of the sensor was investigated in the pH range of 2.0–12.0. Test solutions were prepared using nitric acid for pH 2.0–7.0 and sodium hydroxide for pH 8.0–12.0. Pb(II) (1.0×10^{-2} M) was added to the prepared pH solutions, and later measurements were performed. The pH working range of the sensor is given in Fig. 12 which indicates that the sensor can work in the pH range of 3.0–9.0 without being affected by the changes in pH. The high potential at pH = 2 is due to the hydronium

ion concentration, while the low potentials at pH > 9.0 are due to Pb(OH)$_2$.

Selectivity

Ion-selective electrodes can respond to more than one ion in a solution, but exhibit selectivity toward only one ion present. This is explained as the selectivity of the ion-selective electrodes. In this study, the selectivity of the newly developed lead(II)–selective sensor was investigated using a total of twelve different ions with different charges. The selectivity coefficients ($K_{A,B}^{pot}$) were calculated according to the separate solution method (SSM) recommended by IUPAC (Umezawa et al. 2000), using the equation given below to calculate the potential values of the ions at 10^{-2} M concentrations.

$$logK_{A,B}^{pot} = \frac{(E_B - E_A)Z_AF}{RTln10} + \left(1 - \frac{Z_A}{Z_B}\right)loga_A$$

where $K_{A,B}^{pot}$ = selectivity coefficient, a_A = activity of lead ion, a_B = activity of interfering ion, z_A = charge of lead ion, z_B = charge of interfering ion; R, T, and F have the usual meanings.

The calculated selectivity coefficients are given in Table 3 which points that the new lead(II)–selective potentiometric sensor is at least 10 times more selective to lead(II) ions than to other ions.

Analytical applications

Following the successful completion of its characterization studies as reported above, analytical applications of the new lead(II)–selective sensor were carried out using real

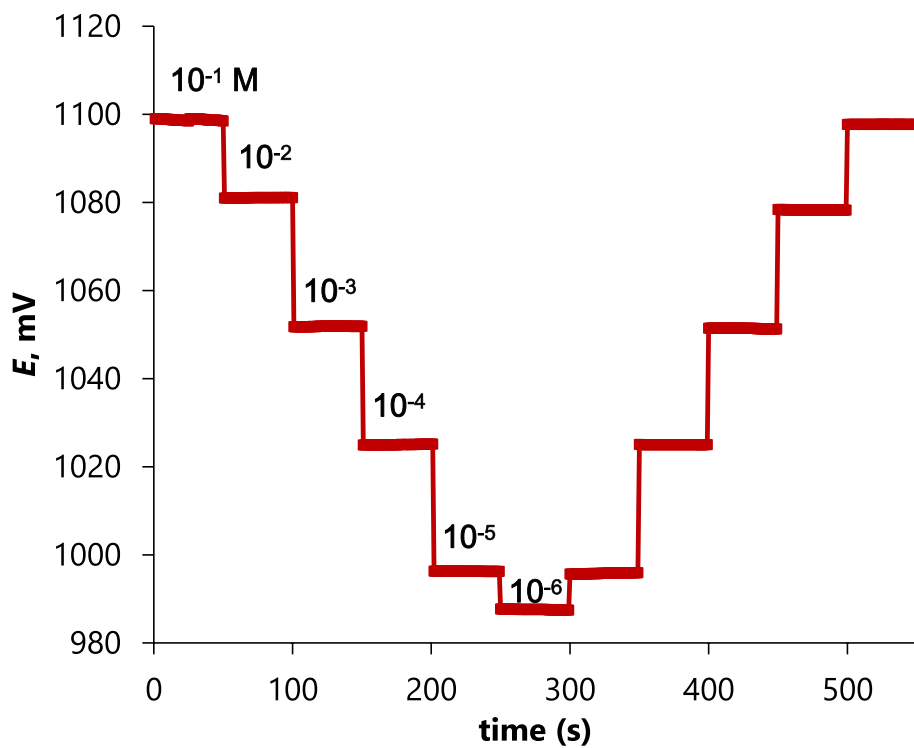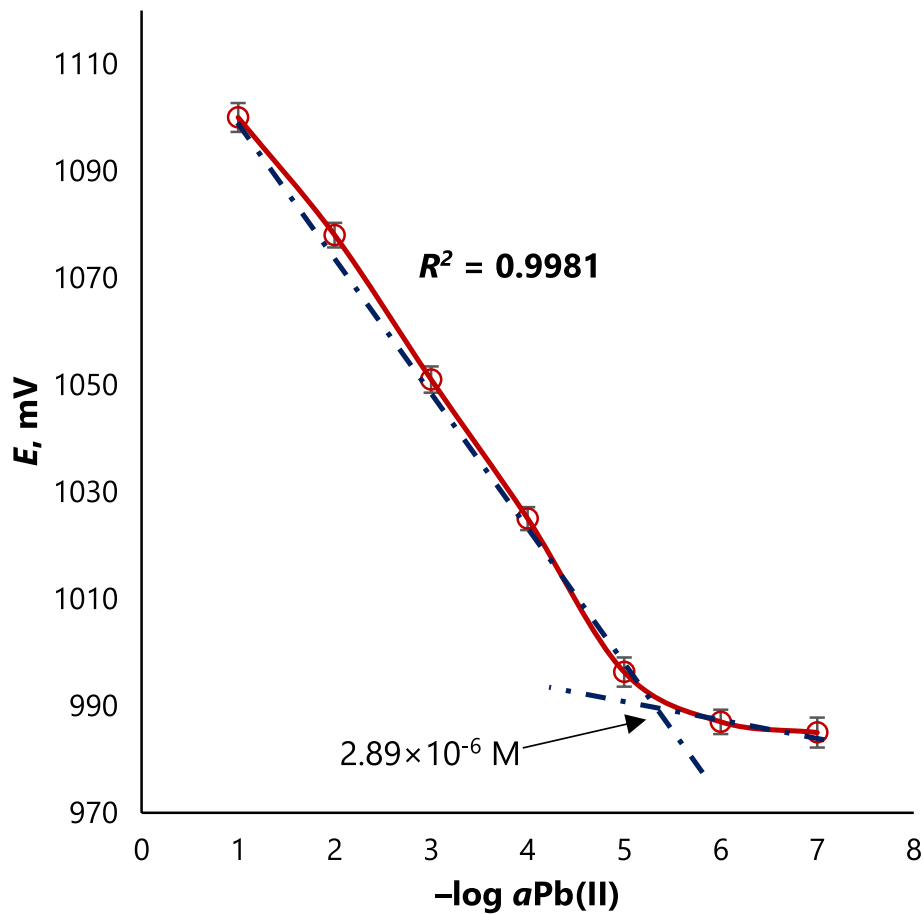**Fig. 9** Potentiometric response of the novel lead(II)–selective sensor

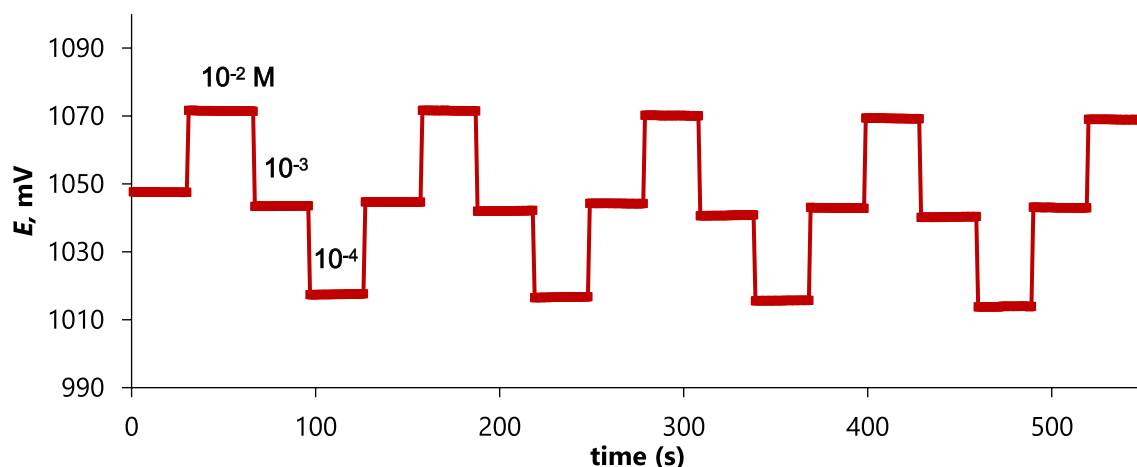**Fig. 10** The calibration curve of the novel lead(II)–selective sensor

Fig. 11 Repeatability of the novel lead(II)–selective sensor

Table 2 The repeatability data of the novel lead(II)–selective sensor

Pb^{2+} solution (M)	Potential (mV)				
	I	II	III	IV	Average ($\pm$SD)^a
1.0×10^{-2}	1071.6	1071.7	1070.2	1069.5	1070.8 ($\pm$0.93)
1.0×10^{-3}	1043.5	1044.1	1043.6	1043.1	1043.6 ($\pm$0.36)
1.0×10^{-4}	1017.3	1016.6	1015.7	1014.7	1016.1 ($\pm$0.98)

^{a}Potential values are given for four separate experimental measurements (I-IV)

samples. Pb(II) ions were added to different water samples in the amounts indicated in Table 4. Then, their concentrations were determined with the developed sensor. Calculations were performed using the linear equation on the calibration curve. According to Table 4, we can state that the developed

sensor can detect lead ions in different water samples with high recoveries.

Comparison study

In this study, newly synthesized sulfonyl hydrazone derivative molecule was used as an ionophore. The synthesis of ionophores in the laboratory is important for the preparation of sensors with low costs. The newly prepared lead(II)–selective sensor was compared with the other potentiometric sensors previously reported in the literature. When Table 5 is examined, it is clear that the proposed sensor has a wider working range, faster response time and a lower detection limit compared to the some of its counterparts. It also works in a wider pH range than the previous sensors shown in Table 5.

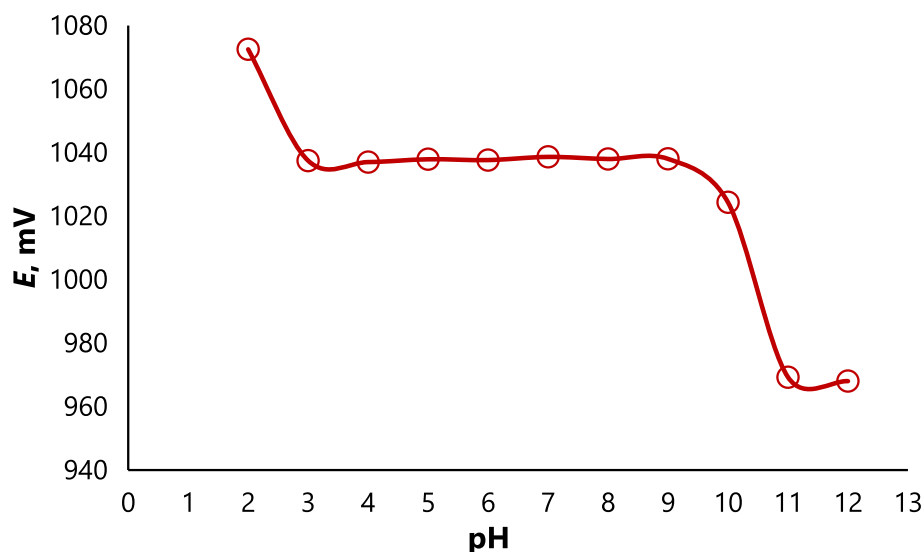**Fig. 12** pH working range of the novel lead(II)–selective sensor

Table 3 The potentiometric selectivity coefficients of the novel lead(II)–selective sensor

Interfering ions	Selectivity coefficient $log\ K_{Pb^{2+},M^{n+}}^{pot}$	Interfering ions	Selectivity coefficient $log\ K_{Pb^{2+},M^{n+}}^{pot}$
Li^+	−1.11	Cr^{3+}	−1.36
Ni^{2+}	−1.18	Co^{2+}	−1.40
Mg^{2+}	−1.25	Sr^{2+}	−1.52
Na^+	−1.28	Cu^{2+}	−1.89
Cd^{2+}	−1.29	Ca^{2+}	−1.93
Al^{3+}	−1.35	Zn^{2+}	−2.03

Table 4 The Pb(II) analysis in different water samples using the novel sensor

Water Samples	Pb^{2+} quantity, (M)		% Recovery
	Added Pb^{2+}	Found (± SD) with sensor*	
Spring water	1.0×10^{-3}	$9.74\ (\pm 0.327) \times 10^{-4}$	97.40
Tap water	1.0×10^{-3}	$9.87\ (\pm 0.095) \times 10^{-4}$	98.70
Bottled water	1.0×10^{-3}	$9.68\ (\pm 0.180) \times 10^{-4}$	96.80
Purification drinking water	1.0×10^{-2}	$9.83\ (\pm 0.276) \times 10^{-3}$	98.30

*Average value ($n = 3$)

Table 5 The comparison of the novel lead(II)–selective sensor with other potentiometric ISEs previously reported in literature

Ionophore	Concentration range (M)	Limit of detection (M)	pH working range	Response time (s)	Slope (mV/ decade)	Lifetime (months)	Reference
acridono-crown ether	1.0×10^{-4} – 1.0×10^{-2}	7.9×10^{-6}	4.0–7.0	5	26.9	3	Golcs et al. (2018)
poly(m-phenylenediamine) microparticles	3.16×10^{-6} – 3.16×10^{-1}	6.31×10^{-6}	3.0–5.0	14	29.8	5	Huang et al. (2011)
PbS nanoparticles	1.0×10^{-5} – 1.0×10^{-2}	Not reported	3.0–7.0	10	Not reported	3	Song et al. (2008)
(E)-2-((1H-pyrrol-2-yl) methylene) hydrazinecarbothioamide	1.0×10^{-5} – 1.0×10^{-1}	3.96×10^{-6}	5.0–9.0	5	29.5 ± 1.6	Not reported	Özbek, (2022)
1,4,8,11-tetrathiacyclotetradecane	1.0×10^{-5} – 1.0×10^{-2}	2.2×10^{-6}	3.0–6.5	15	29.9	3	Elmosallamy et al. (2008)
poly-tetrahydrofurfuryl acrylate	1.0×10^{-5} – 1.0×10^{-1}	3.24 – 3.98×10^{-6}	3.0–8.0	Not reported	26.5–29.8	3	Alva et al. (2019)
bentonite clay	1.0×10^{-5} – 1.0×10^{-1}	9.0×10^{-6}	Not reported	~5	31.0	Not reported	Doğan et al. (2022)
(E)-2-(2-((2-((4-methoxyphenyl)sulfonyl) hydrazineylidene)methyl) phenoxy) acetic acid	1.0×10^{-5} – 1.0×10^{-1}	2.89×10^{-6}	3.0–9.0	5	27.7 ± 1.3	1	This work

Conclusion

In the present study, we synthesized a new sulfonyl hydrazone derivative molecule and characterized it using several spectroscopic methods (^{1}H–, ^{13}C NMR, FT–IR and Q-TOF). We then developed novel potentiometric sensors using this new molecule, and subsequently investigated their potentiometric performance properties. Based on the data obtained in our experiments, we found that the prepared sensors are selective to Pb^{2+} ions and have low detection limit of 2.89×10^{-6} M, and a Nernstian response over a wide concentration range of 1.0×10^{-5}–1.0×10^{-1} M. Moreover, the prepared sensors were reproducible, highly selective and could work in a wide pH range without being affected by the changes in pH. We showed that these potentiometric sensors can detect lead ions with very high recoveries when applied to real samples. Furthermore, since we synthesized the ionophore in our laboratory, sensors developed using this new molecule were comparatively less costly, enabling their uses in resource-limited areas. Considering serious health risks due to lead exposure, wider use of low-cost lead monitoring methods may help lower the risks associated with lead in low income and vulnerable populations where lead exposure is possibly the highest.

Declarations

Competing interests Authors of the present study do not have any conflicts of interest.

Ethical approval The work is not applicable for both human and/or animal studies.

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