Biosensors and Bioelectronics 35 (2012) 297–301

Contents lists available at SciVerse ScienceDirect

Biosensors and Bioelectronics

journal homepage: www.elsevier.com/locate/bios

Amperometric sulfide detection using *Coprinus cinereus* peroxidase immobilized on screen printed electrode in an enzyme inhibition based biosensor

Iman Shahidi Pour Savizi, Hamid-Reza Kariminia*, Mohammad Ghadiri, Reza Roosta-Azad

Department of Chemical and Petroleum Engineering, Sharif University of Technology, P.O. Box 11155-9465, Azadi Ave., Tehran, Iran

ARTICLE INFO

Article history:
Received 5 January 2012
Received in revised form 29 February 2012
Accepted 2 March 2012
Available online 10 March 2012

Keywords:
Sulfide detection
Screen printed electrode
Enzyme inhibition biosensor
Coprinus cinereus peroxidase

ABSTRACT

In the present work, an amperometric inhibition biosensor for the determination of sulfide has been fabricated by immobilizing *Coprinus cinereus* peroxidase (CIP) on the surface of screen printed electrode (SPE). Chitosan/acrylamide was applied for immobilization of peroxidase on the working electrode. The amperometric measurement was performed at an applied potential of −150 mV versus Ag/AgCl with a scan rate of 100 mV in the presence of hydroquinone as electron mediator and 0.1 M phosphate buffer solution of pH 6.5. The variables influencing the performance of sensor including the amount of substrate, mediator concentration and electrolyte pH were optimized. The determination of sulfide can be achieved in a linear range of 1.09–16.3 μM with a detection limit of 0.3 μM. Developed sensor showed quicker response to sulfide compared to the previous developed sulfide biosensors. Common anions and cations in environmental water did not interfere with sulfide detection by the developed biosensor. Cyanide interference on the enzyme inhibition caused 43.25% error in the calibration assay which is less than the amounts reported by previous studies. Because of high sensitivity and the low-cost of SPE, this inhibition biosensor can be successfully used for analysis of environmental water samples.

1. Introduction

The determination of sulfide contamination in water is important due to its serious threat to the environment and human life (Puacz et al., 1995). The content of sulfide in water is usually expressed as the sum of hydrogen sulfide (H_2S), bisulfide (HS^-) and sulfide (S^{2-}) ions. The hydrogen sulfide, which is soluble in water, can be produced by natural sources like swamps or from industry processes such as coking coal. This gas is in equilibrium with bisulfide and sulfide in aqueous solution (Brouwer, 1995). Because of sulfide high toxicity, a reliable analytical technique is needed for recognition of this compound at low levels. Accordingly, many methods have been developed for monitoring of sulfide, such as chromatographic (Howard and Yeh, 1998), spectrophotometric (Guenther et al., 2001; Koh et al., 1990), polarographic (Canterford, 1975), amperometric (Lawrence et al., 2003; Yang et al., 2004; Zhong et al., 2011), potentiometric (Hassan et al., 2002) and voltammetric (Baldo et al., 2002; Kia et al., 2011). Some of these methods are time-consuming due to the sample pretreatment. Some methods cannot monitor trace amount of sulfide. Consequently, development of new methods for effective and simple determination of sulfide is of great importance.

Due to the prominent advantages of quick response, procedural simplicity and low cost, electrochemical technique has been proposed for sulfide detection (Liu et al., 2008; Periasamy et al., 2011; Shan et al., 2010). During the last decade, biosensors have been played a large role in the environmental monitoring applications. Selectivity and sensitivity are the two main factors that affect the performance of biosensors. This is why, enzyme-based biosensors have been proposed for improving electrodes selectivity because of substrate specificity of enzymatic reactions. Sensitivity of enzymatic biosensors against chemicals can be increased by using inhibition based enzyme detectors (Robinson et al., 1995; Taraban et al., 1997; Yang et al., 2004). Zhao et al. (1996) have shown the capability of using an enzyme inhibitor detector which utilized colloidal gold/immobilized horseradish peroxidase (HRP), in order to detect three different toxic substances including sulfide. However, this immobilized enzyme electrode was more sensitive to thiourea and cyanide than to sulfide. Due to the low detection limit for sulfide, this biosensor was not applicable for water analysis. Yang et al. (2004) have developed a HRP inhibition biosensor based on a cysteamine self-assembled monolayer (SAM) for measuring the sulfides. They demonstrated that sulfides determination can be conducted in the range of 0.5–12.7 μM with a detection limit of 0.3 μM. Although the detection limit was improved compared to the previous works, however, the poor selectivity restricted the application of this biosensor. Liu et al. (2008) presented an inhibition biosensor constructed using layer-by-layer technique based on

* Corresponding author. Tel.: +98 21 66166426; fax: +98 21 66166426.
E-mail address: kariminia@sharif.ir (H.-R. Kariminia).

0956-5663/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.bios.2012.03.004

biospecific affinity of concanavalin A (Con A) and HRP for determination of sulfide. They showed that measurement of sulfide can be achieved in a linear range of 0.1 to 38.5 μM, and the detection limit of developed biosensor was 0.05 μM. Despite, the improvement of sensor selectivity, cyanide and some other cations interfered in the calibration assay.

Screen-printing technology is a method usually applied for the fabrication of electrodes. A screen printed electrode (SPE) is a device constructed from multi layers of printed inks on the surface of different materials such as plastic (Miserere et al., 2006) or alumina ceramic (Ledru et al., 2006), which can be used in disposable biosensors. There are some advantages of using screen printed electrode in the electrochemical sensors including reliability, small size, portability, simplicity and low cost. Tangkuaram et al. (2007) designed and developed a biosensor on screen printed carbon electrode (SPCE) based on HRP for determination of hydrogen peroxide. They reported that the SPCE can measure H_2O_2 in a linear range of 0.01 to 11.3 mM.

In this work, we attempted to use SPE for determination of sulfide, based on its inhibitory effect on the activity of *Coprinus cinereus* peroxidase (CIP). Peroxidase was immobilized on the surface of the electrode by using chitosan and acrylamide, and hydroquinone was utilized in our measurements as an electron mediator. Screen printed electrode was used in this study due to the advantages of low cost, small size, portability and simplicity. To the best of our knowledge, SPE has not been applied for development of sulfide biosensor. In this research, a method was developed to manufacture sulfide biosensor by using cheap and available SPE available commercially. The main goal of this research was developing disposable biosensor which is as good as previously available sulfide biosensors.

2. Materials and methods

2.1. Chemicals

Hydrogen peroxide (30%) and chitosan were purchased from Merck (Germany), and 4-aminoantipyrine (4-AAP) was obtained from Sigma (United States). All other chemicals were of analytical grade available commercially. The 0.1 M buffer solutions were prepared over the pH range of 4–8. For low pH range (4–5.7), the buffer solution was provided using citric acid and $Na_2HPO_4.12H_2O$. For high pH range (5.7–8), the buffer solution was prepared using $NaH_2PO_4{\cdot}2H_2O$ and $Na_2HPO_4{\cdot}12H_2O$. A sulfide stock solution (1 mM) was made daily by dissolving 24 mg of $Na_2S{\cdot}9H_2O$ salt in 100 mL of O_2 free de-ionized water. The sulfide solution was standardized using iodometric method (APHA, 1985), and the working standard solutions were provided by dilution of the stock with the buffer solution.

2.2. Microorganism and culture media

The fungus *C. cinereus* (NBRC 30628) was obtained from National Biological Resource Center (Japan) and used for peroxidase production. This strain was stored on potato dextrose agar (PDA) slants at 4 °C. The production of peroxidase was performed in the liquid medium (pH 4) containing of 30 g/L glucose, 10 g/L peptone, 5 g/L yeast extract. A piece of agar (1 cm diameter disk) was cut out from the growing fungal on PDA plate and inoculated into 100 mL of liquid medium in 500 mL Erlenmeyer flask. The fungi were incubated in a rotary shaker (150 rpm) for about 23 days at 30 °C. The final clear solution after filtration and concentration with centrifugal concentrator (Vivaspin® 20, Germany) had an approximate activity of 450 U/mL. Other peroxidases including lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase were assayed and none of them were found in the crude enzyme solution. LiP activity was determined as described by Tien et al. (1988). MnP was assayed as described by Wariishi et al. (1992) and laccase was measured as described by Wolfenden and Wilson (1982).

2.3. Peroxidase assay

A solution containing of 65 mM phosphate buffer (pH 7.0), 3.1 mM hydrogen peroxide, 0.63 mM 4-AAP, 0.97 g/L Triton X-100 and 10 mM phenol in a total volume of 3.1 mL was incubated in a fixed temperature bath for 10 min. The reaction was initiated by adding 0.1 mL of enzyme solution. The peroxidase activity was monitored at 500 nm with a scan time of 1 min. One unit of peroxidase activity (U) defined as the amount of enzyme required to oxidize 1 μmL of hydrogen peroxide per 1 min (Sakurai et al., 2001).

2.4. Apparatus

Electrochemical experiments including amperometric and cyclic voltammetry were conducted with an AUTOLAB-PGSTAT302N (Eco Chemie BV, Netherlands). SPE was purchased from Pine Research Instrumentation (NC, USA). The pattern of this low cost SPE includes a carbon working electrode with 5 mm × 4 mm surface area, a large carbon counter electrode and a silver/silver chloride reference electrode. Similar technology, which has been applied in most blood glucose sensors, was used for the fabrication of this electrode. This SPE behaved like a conventional three-electrode system. All experiments were performed at ambient temperature unless otherwise stated.

2.5. Enzyme electrode preparation

Chitosan solution was prepared by adding 1.0 g chitosan to 60 mL distilled water under stirring condition. pH of the solution was kept near 3.0 by adding concentrated HCl until the dissolution of whole chitosan. The solution was filtered to remove undissolved materials and then the pH was adjusted to 5.0 by using 1.0 M NaOH solution. The filtrate was diluted with distilled water to 100 mL, achieving a 1% chitosan solution (Tangkuaram et al., 2007).

Enzyme and chitosan solutions were mixed together, and then acrylamide (monomer) was added to the solution and stirred until complete dissolution. Polymerization reaction was initiated by adding $K_2S_2O_8$ to the mixture and then 10 μL of this solution, containing 0.6 mg acrylamide, 0.03 mg chitosan and 3 U peroxidase was pipetted onto the surface of the SPE. The electrode was incubated for 48 h at 4 °C in order to complete the polymerization reaction. The enzyme electrode was washed three times with phosphate buffer (pH 6.5), then rinsed with distilled water and dried in air. For each test, a newly prepared sensor was fabricated and examined.

2.6. Enzyme inhibition measurement

All electrochemical experiments were performed in an electrochemical cell containing 3 mL of 0.1 M phosphate buffer solution. A 0.5 M KCl solution was added to increase the stability of buffer solution against the Ag/AgCl reference electrode. Cyclic voltammetric experiments and amperometric measurements were conducted under unstirred and stirred condition, respectively.

For recording the initial baseline current, the SPE was immersed into a stirred phosphate buffer solution (pH 6.5) containing 1 mM hydroquinone. A 1 mM H_2O_2 (substrate) solution was added to record the steady state current (I_0). The sulfide (inhibitor) was added to the solution, and then a quasi-steady state current (I_1) was achieved for each sulfide concentration. This current was proportional to the ultimate concentration of inhibitor in the above

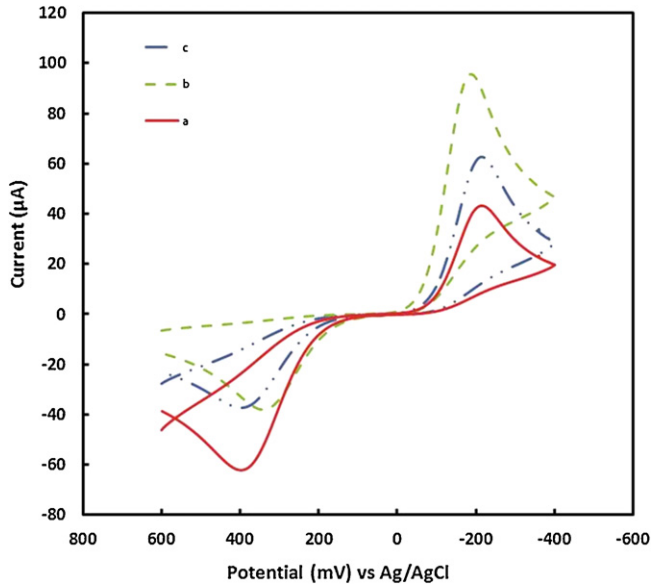

Fig. 1. Cyclic voltammograms of the sensor with a scan rate of 100 mV/s at three different stages: (a) CIP/chitosan/SPE in 0.1 M phosphate buffer (pH 6.5) solution including 1.0 mM hydroquinone in the absence of H_2O_2; (b) the same as (a) with 1.0 mM H_2O_2 added; (c) the same as (b) with 10 μM sulfide added.

solution. The inhibition percentage (I, %) was calculated using the following equation (Nwosu et al., 1992):

$$I(\%) = \frac{I_0 - I_1}{I_0} \times 100$$

3. Results and discussion

An inhibition biosensor for determination of sulfide by using SPE has been developed in this study. Electrochemical properties of this electrode are investigated in Section 3.1. Experimental variables which can affect the determination of sulfide are optimized in Section 3.2. Biosensor calibration for sulfide determination is described in Section 3.3. Selectivity and life time of the sensor are checked in Sections 3.4 and 3.5, respectively.

3.1. Electrochemical characterization of CIP/chitosan/SPE

Cyclic voltammetery was carried out between −0.4 and 0.6 V vs. Ag/AgCl with a scan rate of 100 mV/s for electrochemical characterization of developed electrode. Fig. 1 demonstrates the cyclic voltammograms (CV) of CIP/chitosan/SPE in 0.1 M phosphate buffer solution including 1.0 mM hydroquinone in the absence (Fig. 1a) or presence (Fig. 1b) of 1.0 mM H_2O_2. Fig. 1c shows the CV recordings after addition of 10 μM sulfide solution under similar condition. The CV peaks observed in Fig. 1a are related to oxidation of hydroquinone-to-benzoquinone and reduction of benzoquinone-to-hydroquinone. Fig. 1b shows that addition of H_2O_2 into the solution of phosphate buffer and hydroquinone increased the cathodic peak current due to the reduction of H_2O_2. This reduction current is proportional to the activity of CIP and concentration of H_2O_2, and the height of the peak increased by adding more H_2O_2 or enzyme (data not shown). The catalytic effect of HRP in the presence of hydroquinone has been well explained before (Taraban et al., 1997; Yang et al., 2004). According to the HRP mechanism and the CV data obtained (Fig. 1), the possible mechanism which is consistent with experiments can be presented as follows:

$$\text{CIP}(Fe^{3+}) + H_2O_2 \rightarrow \text{Intermediate(I)} + H_2O \quad (1)$$

$$\text{Intermediate(I)} + QH \rightarrow \text{Intermediate(II)} + BQ \quad (2)$$

$$\text{Intermediate(II)} + QH \rightarrow \text{CIP}(Fe^{3+}) + BQ + H_2O \quad (3)$$

$$BQ + 2e^- \rightarrow QH \quad (4)$$

where, HQ is hydroquinone and BQ represents benzoquinone. This mechanism can explain CV signals observed in Fig. 1a and b. Injection of sulfide, decreased the height of the reduction peak in Fig. 1c. The decreased current response is related to the inhibitory effect of sulfide on the CIP activity and proportional to its concentration. Therefore, by using this feature of sulfide (inhibitor), we were able to develop an inhibition biosensor.

3.2. Optimization of experimental variables

Effect of three experimental variables including the amount of substrate, mediator concentration and electrolyte pH are investigated in Sections 3.2.1, 3.2.2 and 3.2.3. To select the optimal applied potential, the response of the biosensor at different potentials was measured. With the decreasing potential from −60 the biosensor response increased significantly. Small changes were observed from −150 mV to −220 mV (data not shown). The potential of −150 mV vs. Ag/AgCl was selected for all amperometric experiments, in which interferences at high negative potential can be avoided. This applied potential is similar with the Yang result obtained for HRP (Yang et al., 2004).

3.2.1. Influence of substrate (H_2O_2) amount

Effect of substrate (H_2O_2) amount on the inhibition of sulfide was examined. The H_2O_2 concentrations of 0.2, 0.4, 0.6, 0.8 and 1 mM were used for determination of its effect on enzyme electrode response. At low concentration of substrate (<0.6), the current response from biosensor was so small that the measuring of sulfide was not possible in that range. At very high amount of H_2O_2, all active sites of CIP enzyme will be blocked by the substrate and there will be no free site for sulfide (inhibitor) to inhibit the activity of the enzyme. Hence, the concentration of 0.6 mM was chosen for further measurements.

3.2.2. Concentration of mediator

The influence of hydroquinone concentration on the current response of enzymatic sensor was investigated. The amperometric response of the electrode for different amount of mediator in phosphate buffer solution containing 0.6 mM H_2O_2 at the potential of −150 mV was obtained (data shown in Supplementary figure). The current increased rapidly by adding a little amount of mediator to the solution, and suddenly the current reached to a stable value of 0.119 μA at 1.25 mM hydroquinone. This behavior has been also observed for HRP inhibitor biosensor (Yang et al., 2004) and some other mediator-based sensors (Oungpipat et al., 1995). At high concentration of mediator, large background current caused trouble for our measurements. However, low concentration of hydroquinone would limit the rate of enzyme-mediator kinetics. Thus, in this research 1.25 mM of hydroquinone was selected for further experiments.

Supplementary material related to this article found, in the online version, at doi:10.1016/j.bios.2012.03.004.

3.2.3. Effect of electrolyte pH

The effect of pH on the performance of enzyme electrode over the range of 5–8 for the buffer solution containing sulfide at a fixed concentration of 6 μM, 0.6 mM H_2O_2 and 1.25 mM hydroquinone was examined. According to the following equations, sulfides (H_2S, HS^- and S^{2-}) are in equilibrium with each other:

$$H_2S \leftrightarrow HS^- + H^+ \quad (5)$$

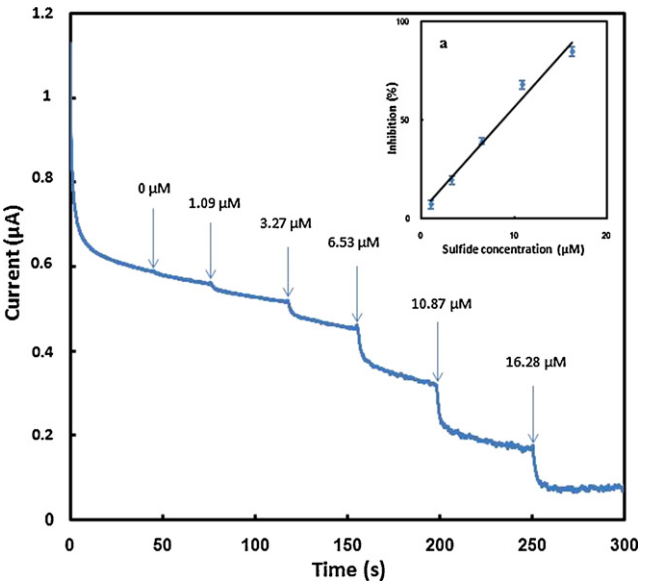

Fig. 2. Amperometric responses of CIP biosensor for different concentrations of sulfide at −150 mV vs. Ag/AgCl in 0.1 M phosphate buffer (pH 6.5) solution containing 0.6 mM H_2O_2 and 1.25 mM of hydroquinone. Inset (a): calibration curve for sulfide determination with CIP inhibition sensor.

$$HS^- \leftrightarrow S^{2-} + H^+ \quad (6)$$

Therefore, variation of pH can change the fraction equilibrium of sulfide. Enzyme activity can also be affected by changing the solution pH. The maximum inhibition of sulfides on CIP was observed at pH 6.5 (data shown in Supplementary figure). This observation is similar to Zhao et al. (1996) and Yang et al. (2004) results obtained for HRP. Hence, we should adjust the pH of the sample solution to this point to get the best performance from our sensor.

3.3. Sulfide calibration of CIP biosensor

Amperometric responses of CIP biosensor over the concentration range of 1.09–16.3 μM are shown in Fig. 2. This amperometric measurement was conducted under the optimized experimental condition. The electrode provided a linear response to the elevation of sulfide concentration over a specified range (Fig. 2a) and the linear regression parameters related to this curve are presented in Table 1. The response time to sulfide was about 43 s on average. This response time is shorter than the amount of 65 s, reported by Liu et al. (2008). The detection limit of the sensor was 0.3 μM which is higher than Con A/HRP bilayer sensor (Liu et al., 2008), and is the same as SAM-modified biosensor (Yang et al., 2004).The observed detection limit was less than the result of Liu et al. However, as mentioned before, our main goal was to produce a cheap and reliable biosensor based on SPE which is as good as previous sulfide biosensors. The linear range and detection limit of the developed biosensor were good enough for environmental samples analysis. This CIP based biosensor had the advantage of quicker response time against sulfide, compared to the biosensor developed by Liu et al.

Table 1
Characteristics of the inhibition biosensor for sulfide detection.

Working electrode	SPE
Reference electrode	Ag/AgCl
Enzyme	*Coprinus cinereus* peroxidase
Applied voltage	−150 mV
Working pH range	5–8
Substrate	H_2O_2 (0.6 mM)
Calibration slope	5.28
Calibration intercept	3.50
Calibration R^2	0.98
Repeatability R.S.D.	3.2%
Reproducibility R.S.D.	4.7%
Detection range	1.09–16.3 μM
Detection limit	0.3 μM

Table 2
Effect of different ions on determination of sulfide using CIP inhibition sensor.

Interference ions	Ions added (μM)	Sulfide found (μM)	Error (%)
Standard solution	–	4.00	–
Na^+	400	4.02	0.5
K^+	400	4.12	3.0
NH_4^+	400	3.94	−1.5
Fe^{2+}	400	3.85	−3.75
Fe^{3+}	40	3.54	−11.5
Ni^{2+}	200	3.89	−2.75
Mg^{2+}	400	3.92	−2.0
Co^{2+}	200	3.86	−3.5
Cd^{2+}	40	3.47	−13.25
Zn^{2+}	200	3.75	−6.25
F^-	400	3.91	−2.25
Cl^-	400	4.01	0.25
Br^-	400	4.07	1.75
I^-	40	4.13	3.25
CN^-	8	5.73	43.25
CO_3^{2-}	400	4.04	1.0
SO_4^{2-}	400	4.09	2.25

3.4. Selectivity

Selectivity is an important parameter in determination of components by enzyme inhibition biosensor. Several possible anions and cations were selected from environmental matrix components to investigate whether they have interference on the determination of sulfide. In order to investigate the influence of various anions and cations on the biosensor performance, a standard solution of sulfide with 4.0 μM concentration was used against different ions. As shown in Table 2, among cations examined, Fe^{3+} and Cd^{2+} had a significant interference with the detection of sulfide. This is due to the formation of corresponding sulfides which results in decreased detection values. This interference has been reported by Liu et al. (2008) for HRP based inhibition biosensor. Among all anions, only cyanide (CN^-) interfered with the calibration assay of sulfide. The error caused by CN^- (43.25%) for detection of sulfide by CIP based biosensor was lower than the amount of error (63.7%) reported by Liu et al. (2008). This means that CIP was less sensitive to the interference of cyanide than HRP. Therefore, if by any means cyanide existed in the sample, our result will show less error compared to the previous sulfide biosensors. No doubt that cyanide removal is a must for obtaining reliable assays. Hence, cyanide should be eliminated from the cyanide containing wastewater prior to any measurement. Cyanide removal process consists of two reaction tanks. In the first reaction tank, cyanide is oxidized to cyanate by the addition of chlorine. Caustic is added to keep the pH within the range of 9.5–10. In the second tank, conditions are adjusted to oxidize cyanate to carbon dioxide and nitrogen by introduction of additional chlorine. Again, caustic is added to the second tank to maintain the pH at 8 (Patil and Paknikar, 2000).

3.5. Repeatability, reproducibility and stability

The repeatability of response current of a single biosensor was examined in the presence of 5.0 μM of sulfide. The relative standard deviation (R.S.D.) for eight successive assays was less than 3.2%. The reproducibility of nine different electrodes was also investigated and the R.S.D. was obtained to be 4.7%. The stability and lifetime of the developed biosensor was evaluated by measuring the response

Table 3
Analysis of sulfide content in real wastewater samples.

Wastewater sample	Amount of sulfide (μM) measured by proposed biosensor	Amount of sulfide (μM) measured by standard spectrophotometeric method	Error (%)
From sugar refinery	14.85 (±2.8%)	14.47 (±2.5%)	2.6
From power plant	482.17 (±2.3%)	475.25 (±1.8%)	1.5
From petrochemical industry	1025.39 (±1.8%)	1039.89 (±2.2%)	−1.4

currents with 5.0 μM sulfide over 2 months period. The response of the biosensor was constant for the first 30 days and after 40 days the electrode response was decreased to 93.6%. After 60 days, the developed biosensor retained about 84.3% of its original current response. The decrease in response may be due to the reduction of enzyme activity and denaturation of the peroxidase.

3.6. Application

To investigate the application of proposed biosensor for determination of sulfide concentration in environmental samples, three different wastewater samples, which were collected from a sugar refinery, a power plant and a petrochemical industry, were analyzed by the developed biosensor. The samples were also analyzed by the standard spectrophotometric method (APHA, 1985). The results of water sample analysis are demonstrated in Table 3. The comparison indicates the accuracy of this biosensor and the possibility of enzyme inhibition sensor application for sulfide measurement in real water samples.

4. Conclusions

An enzymatic biosensor for sulfide detection was developed based on the sulfide inhibitory effect on the activity of peroxidase. Fungal peroxidase was isolated from *C. cinereus* broth culture and immobilized on the surface of a SPE by applying chitosan and acrylamide. The experimental conditions for sulfide measurement including the electrolyte pH, substrate and mediator concentration were optimized. The determination of sulfide by enzymatic sensor can be conducted in the range of 1.09–16.3 μM with a detection limit of 0.3 μM. Cyanide interference with the calibration assay was less than the amounts reported by other authors due to the application of *C. cinereus* peroxidase. However, cyanide should be removed from the sample before any measurement. CIP in our work, performed like HRP; however, CIP was less sensitive to the cyanide interference, and also showed quicker response to sulfide compared to HRP (on average, the response time of CIP sensor was 43 s and the response time of HRP sensor developed by Liu et al. was 65 s). The developed inhibition biosensor showed high recovery of sulfide in real wastewater samples, and it was also shown that *C. cinereus* peroxidase is a promising enzyme for development of new sulfide sensors. Due to high sensitivity, good selectivity and the low-cost of SPE, this inhibition biosensor can be applied for analysis of real wastewater samples.

References

APHA (American Public Health Association), 1985. Standard Methods for Examination of Water and Wastewater, 15th ed. American Public Health Association, Philadelphia.
Baldo, M.A., Daniele, S., Bragato, C., Mazzocchin, G.A., 2002. Anal. Chim. Acta 464, 217–227.
Brouwer, H., 1995. J. Chem. Educ. 72, 182–183.
Canterford, D.R., 1975. Anal. Chem. 47, 88–92.
Guenther, E.A., Johnson, K.S., Coale, K.H., 2001. Anal. Chem. 73, 3481–3487.
Hassan, S.S.M., Marzouk, S.A.M., Sayour, H.E.M., 2002. Anal. Chim. Acta 466, 47–55.
Howard, A.G., Yeh, C.Y., 1998. Anal. Chem. 70, 4868–4872.
Kia, M., Islamnezhad, A., Shariati, S., Biparva, P., 2011. Korean J. Chem. Eng. 28, 2064–2068.
Koh, T., Miura, Y., Yamamuro, N., Takaki, T., 1990. Analyst 115, 1133–1137.
Lawrence, N.S., Jiang, L., Jones, T.G.J., Compton, R.G., 2003. Anal. Chem. 75, 2499–2503.
Ledru, S., Ruille, N., Boujtita, M., 2006. Biosens. Bioelectron. 21, 1591–1598.
Liu, L.J., Chen, Z.C., Yang, S.N., Jin, X., Lin, X.F., 2008. Sens. Actuator B: Chem. 129, 218–224.
Miserere, S., Ledru, S., Ruille, N., Griveau, S., Boujtita, M., Bedioui, F., 2006. Electrochem. Commun. 8, 238–244.
Nwosu, T.N., Palleschi, G., Mascini, M., 1992. Anal. Lett. 25, 821–835.
Oungpipat, W., Alexander, P.W., Southwellkeely, P., 1995. Anal. Chim. Acta 309, 35–45.
Patil, Y.B., Paknikar, K.M., 2000. Process Biochem. 35, 1139–1151.
Periasamy, A.P., Ting, S.W., Chen, S.M., 2011. Int. J. Electrochem. Sci. 6, 2688–2709.
Puacz, W., Szahun, W., Linke, K., 1995. Analyst 120, 939–941.
Robinson, G., Leech, D., Smyth, M.R., 1995. Electroanalysis 7, 952–957.
Sakurai, A., Toyoda, S., Sakakibara, M., 2001. Biotechnol. Lett. 23, 995–998.
Shan, D., Li, Q.B., Ding, S.N., Xu, J.Q., Cosnier, S., Xue, H.G., 2010. Biosens. Bioelectron. 26, 536–541.
Tangkuaram, T., Ponchio, C., Kangkasomboon, T., Katikawong, P., Veerasai, W., 2007. Biosens. Bioelectron. 22, 2071–2078.
Taraban, M.B., Leshina, T.V., Anderson, M.A., Grissom, C.B., 1997. J. Am. Chem. Soc. 119, 5768–5769.
Tien, M., Kirk, T.K., Willis, A., Wood, S.T.K., 1988. Methods in Enzymology, vol. 161. Academic Press, pp. 238–249.
Wariishi, H., Valli, K., Gold, M.H., 1992. J. Biol. Chem. 267, 23688–23695.
Wolfenden, B.S., Wilson, R.L., 1982. J. Chem. Soc. Perkin Trans. II, 805–812.
Yang, Y.H., Yang, M.H., Wang, H., Jiang, J.H., Shen, G.L., Yu, R.Q., 2004. Sens. Actuator B: Chem. 102, 162–168.
Zhao, J.G., Henkens, R.W., Crumbliss, A.L., 1996. Biotechnol. Prog. 12, 703–708.
Zhong, H., Yuan, R., Chai, Y., Li, W., Zhang, Y., Wang, C., 2011. Bioprocess Biosyst. Eng. 34, 923–930.