A Highly Sensitive Electrochemical Glucose Sensor By Nickel-Epoxy Electrode With Non-Enzymatic Sensor

[1*]Riyanto

[1]Department of Chemistry, Faculty of Mathematics and Natural Sciences,
Islamic University of Indonesia, Yogyakarta
*Email: riyanto@uii.ac.id

ABSTRAK

Pembuatan sensor baru untuk analisis glukosa berbasis non enzim glukosa oksidase telah berhasil dilakukan. Elektroda nikel-epoksi dipreparasi dengan cara memotong nikel yang berbentuk plat dengan panjang 1 cm dan lebar 1 mm, kemudian dihubungan dengan kawat perak dan perekat *silver conductive paint*. Bagian yang tidak diinginkan ditutup dengan epoksi. Hasil penelitian menunjukkan bahwa elektroda nikel epoksi dalam larutan glukosa dan elektrolit 0,1 M NaOH menghasilkan R^2 = 0,9984. Nilai LOD, LOQ dan % perolehan kembali masing-masing sebesar 4,4 μM, 1,48 μM dan 98,19%. Elektroda nikel-epoksi menunjukkan kemampuan elektrooksidasi yang baik dalam mengoksidasi glukosa dalam larutan alkali. Elektroda nikel epoksi berdasarkan parameter elektrokimia menunjukkan hasil yang sensitive, range linieritas yang lebar, limit deteksi yang baik, selektifitas tinggi dan stabil. Elektroda nikel-epoksi sangat sesuai sebagai elektroda untuk membuat sensor glukosa non enzim dengan keuntungan biaya rendah, pembuatan mudah dan hasil uji yang memuaskan.

Kata Kunci: glukosa, sensor, nikel, epoksi, non enzim

ABSTRACT

The preparation of new sensor for glucose was based on the fact that glucose can be determined by non-enzymatic glucose oxidase. The Ni metals (99.98% purity, 0.5 mm thick, Aldrich Chemical Company) was used to prepare Ni-Epoxy electrode. The Ni-epoxy electrodes were prepared in square cut of 1 cm and 1 mm by length and wide respectively. The Ni metal electrodes were connected to silver wire with silver conducting paint prior covered with epoxy gum. The prepared of nickel-epoxy modified electrode showed outstanding electro catalytic activity toward the oxidation of glucose in alkaline solution. The result from this research are correlation of determination using Nickel-Epoxy electrode for electroanalysis of glucose in NaOH was R^2 = 0.9984. LOQ, LOD and recovery of the Nickel-Epoxy electrode towards glucose were found to be 4.4 μM, 1.48 μM and 98.19%, respectively. The Nickel-Epoxy wire based electrochemical glucose sensor demonstrates good sensitivity, wide linear range, outstanding detection limit, attractive selectivity, good reproducibility, high stability as well as prominent feasibility use of non-enzymatic sensor for monitoring glucose in human urine owing to its advantages of low cost, simple preparation and excellent properties for glucose detection.

Keywords: *glucose, sensor, nickel-epoxy, non-enzymatic*

Introduction

The detection of glucose is an important issue, because of the clinical significance of measuring human urine glucose (Wang, 2008). Thus, diabetics need a tight monitoring of their human urines glucose levels. Because the diabetes mellitus becomes a more

serious health problem in recent years, glucose has been recognized as one of the most commonly tested analytes. Enzymatic glucose sensor, based on an enzyme electrode immobilized with glucose oxidase (GOx), has been proposed to measure the urine glucose level for several decades (Shervedani *et al.,* 2004 and Yang *et al.,* 2002).

Development of the glucose sensors has attracted extensive attentions due to their applications in biological systems, food analysis, clinical detections and environmental monitoring (Newman and Turner, 2005) where the merits as high sensitivity, fast response, good stability and low cost have been considered.

Enzymatic sensors from several disadvantages such as poor stability, high cost of enzymes, critical operational conditions and complicated immobilization procedure (Shervedani and Mehrjadi, 2007). Furthermore, instability of the enzyme molecules, originated from various environmental factors such as temperature, pH, humidity, or their inherent properties can influence the sensitivity, selectivity and reproducibility of these electrode (Chung *et al.,* 2006 and Turner and Wilson, 1992).

In terms of non-enzymatic glucose sensors, electrochemical biosensors normally are more reliable, highly sensitive, low cost, and easier to operate compared to other detection schemes such as colorimetry, fluorescent, electrochemical, and optical methods. In particular, graphene/metal oxides (e.g., nickel or cobalt oxides) nanocomposites, which show excellent electrocatalytic activities during glucose detection, have drawn considerable research and development attentions (Veeramani *et al.,* 2015).

Experimental

Solutions

All solutions were prepared by dissolving their analytical grade reagent (Merck) in deionised distilled water. D-Glucose NaOH, and buffer phosphate was used as the supporting electrolyte. Buffer phosphate solution was prepared using 0.1 M KH_2PO_4 (Merck) and 0.1 M NaOH (Merck).

Preparation of Nickel-Epoxy Electrode

Cyclic Voltammetric (CV) analysis was performed with PGSTAT 100 N 100 V/250 mA (Metrohm Autolab). The three electrode system consisted of a nickel-epoxy electrode as working electrode, platinum wire as auxiliary electrode and an Ag/AgCl (saturated KCl) or SCE electrode as the reference electrode against which all potentials were measured. Electrochemical measurements were carried out at room temperature with a scan rate of 30 mVs^{-1}.

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Calibration and validation method

Calibration curves were obtained by plotting anodic peak height (current) versus acetaminophen concentration. Validation parameters including linearity, limit of detection (LOD), limit of quantification (LOQ), precision and accuracy were assessed. Cyclic voltammograms (CVs) of acetaminophen solutions were recorded in a wide range of concentrations (1.0, 3.0, 5.0, 7.0, and 9.0 mM) in 0.1 M NaOH solution at room temperature.

Result and Discussion

Electrocatalytic oxidation of glucose at the Nickel-Epoxy electrode

The electrocatalytic activity of Nickel-Epoxy electrode toward oxidation of glucose is investigated in 0.1 M NaOH solution by using cyclic voltammetry. As shown in Fig. 1, in the absence of glucose (curve a), a well-defined redox wave with sharp peaks is observed. Upon the addition of 1.0 mM glucose into the NaOH test solution, the anodic peak current is increased significantly and its potential is shifted to more positive direction, while the cathodic peak current is decreased slightly without significant shift in its potential (curves b). This behavior indicates an irreversible electrochemical process related to the oxidation of glucose. The electrocatalytic oxidation mechanism of glucose at the nickel electrode surface may be simply described by the following reactions (Peng *et al.,* 2012):

$Ni(OH)_2 + OH^- NiO \rightarrow (OH) + H_2O + e^-$

$NiO(OH)$+ glucose $\rightarrow$ $Ni(OH)_2$ + gluconolactone

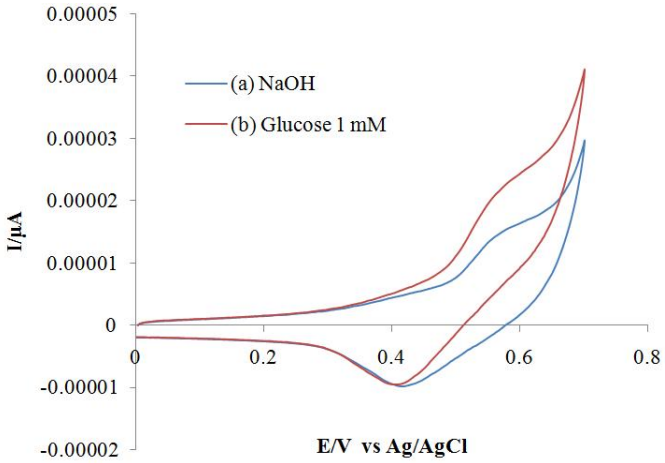

Figure 1. Cyclic voltammogram of (a) 0.1 M NaOH (without glucose), (b) 0.1 M NaOH + glucose 1 mM glucose at scan rate 30 mVs^{-1}

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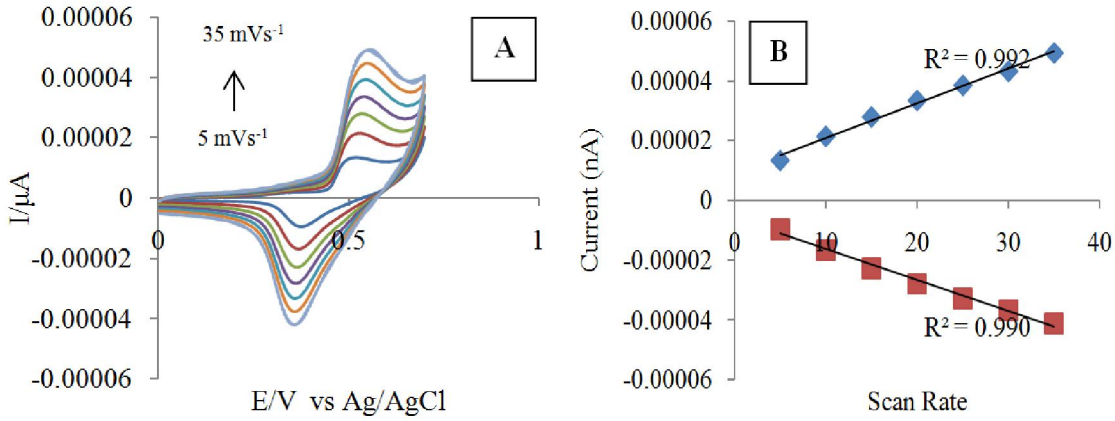

Figure 2. Cyclic Voltammogram of (A). Ni electrode in 0.1 mol L^{-1} NaOH potensial scan rates from 5 – 35 mVs^{-1} (B). Calibration curve of 0.1 M NaOH with various scan rates

The cyclic voltammograms obtained on the Nickel-Epoxy electrode in 0.1 M NaOH solution at different scan rates are presented in Fig. 2A. Both anodic and cathodic peak currents increase as a function of scan rate. Since no electroactive species exists in the solution phase for this potential window, the observed currents are related to the confined redox reaction of Ni(III)/Ni(II). Implying that the reaction is under diffusion control of OH− from solution phase (Nie et al. 2011).

$NiO(OH) + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$

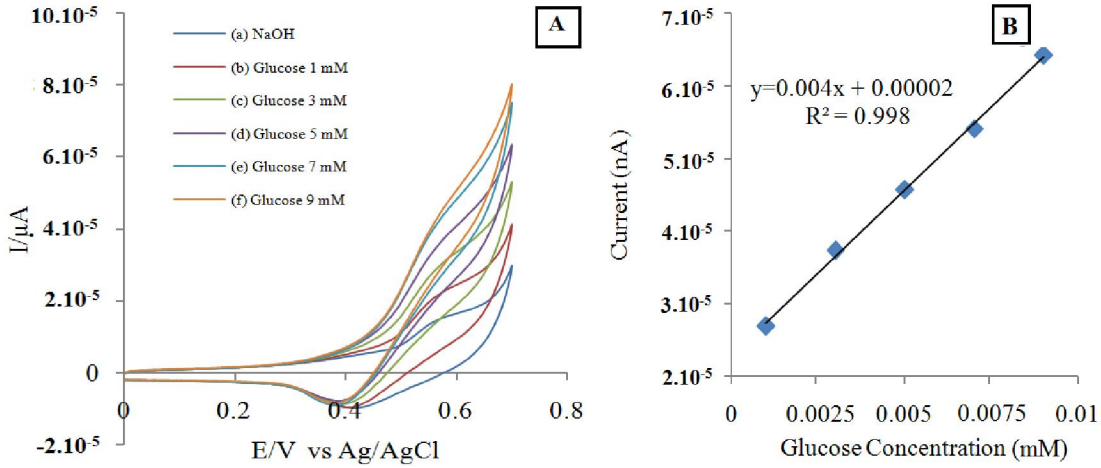

Figure 3. (A). Cyclic voltammogram and (B). Calibration curve of various concentration of glucose at Ni-Epoxy electrode in 0.1 M NaOH solution ([Glucose]: (a) 0, (b) 1.0, (c) 3.0, (d) 5.0, (e) 7.0, (f) 9.0 mM), at a scan rate 30 mVs^{-1}

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Fig. 3A shows CV curves of the Nickel-epoxy electrode measured in 0.1 M NaOH solution containing various concentrations of glucose, i.e., 0, 1.0, 3.0, 5.0, 7.0 and 9.0 mM, at a scan rate of 30 mV/s. It can be seen that there are one anodic peak and one cathodic peaks in the background CV curve measured before glucose addition; this CV characterization is consistent with that of the last cycle CV curve shown in Fig. 3A. The anodic peak corresponds to the oxidation from β-$Ni(OH)_2$ to β-NiOOH, and the cathodic peaks correspond to the reduction from β-NiOOH to β-$Ni(OH)_2$, the reduction from γ-NiOOH to β-$Ni(OH)_2$, and the reduction from γ-NiOOH to α-$Ni(OH)_2$. After the addition of glucose, a remarkable increase in the anodic peak current density can be observed in the corresponding CV curve, with reference to the anodic peak current density of the background CV curve obtained before glucose addition.

The dramatic increase in indicates that the $Ni(OH)_2$ Nickel-epoxy electrode shows an excellent electrocatalytic ability toward glucose this high catalytic activity may be attributed to both the excellent catalytic property of Nickel-epoxy. The apparent and linear increase at the applied potential of about 0.63 V (vs. Ag/AgCl/KCl sat'd) indicates that the Nickel-epoxy electrode can be used for the glucose sensor with high sensitivity and excellent linearity.

From the calibration curve obtained using Nickel-Epoxy electrode, the correlation of determination (R^2) recorded is 0.9984. Linear regression equation (Fig. 3B) is $y = 0.0046x + 2.10^{-5}$. The linear regression equation can be used to determine the concentration of glucose in human urine sample.

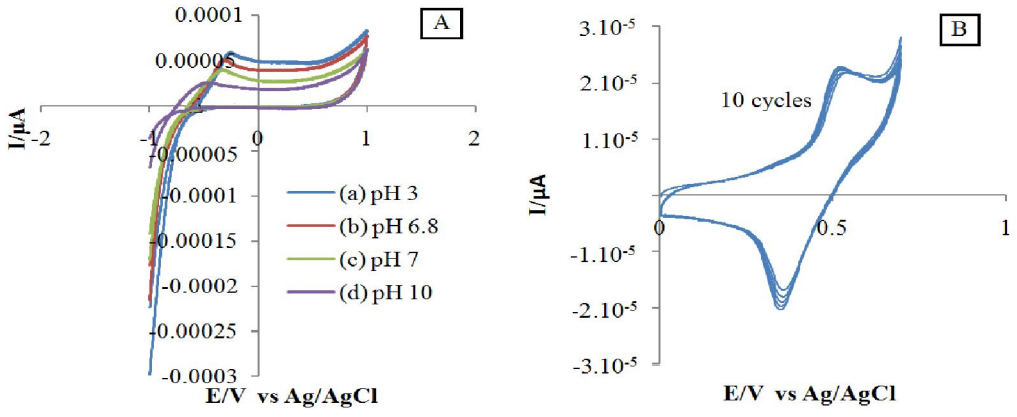

Figure 4. (A). Cyclic voltammogram of 3.0 mM glucose in buffer phosphate solution with vaious pH solutions: (a) 3, (b) 6.8, (c) 7, (d) 10 (B). Cyclic voltammogram of 3 mM glucose in 0.1 M NaOH solution with 10 cycles and scan rate 30 mVs^{-1}

The effect of buffer capacity, we reformulated the results presented in Figure 4A, by presenting the pH variation at a given glucose concentration. The cyclic voltammograms decreases with the increase of phosphate concentration in the buffer solution. With the increase of buffer capacity, more protons will be neutralized by the phosphate present in the buffer and the transducer (the Nickel-Epoxy electrode) will sense a smaller pH variation (Pisoshi *et al.,* 2007).

Table 1. Comparisons of analytical technique for determination of glucose using electrode

Electrode[a]	Technique Analysis	LOD (µM)	Reference
Ni-Co/rGO	Amperometry	3.79	Wang *et al.,* 2013
Ni/indium tin oxide	Amperometry	0.50	Tian *et al.,* 2013
NiO-Ag nanofiber	Amperometry	1.37	Ding *et al.,* 2010
Ni-MWCNT	Amperometry	0.89	Sun *et al.,* 2012
Ni-Epoxy electrode	CV	4.44	This work

[a] ***abbreviations:*** rGO, reduced graphene oxide; MWCNT, multi-walled carbon nanotube; CV, Cyclic voltammetry

Table 2 Determination of glucose in human urine

Sample	Glucose added (mM)	Founded (mM)	Recovery (%)
Human urine	-	2.67	-
Sample 1	3.00	2.76	92.16
Sample 2	5.00	5.09	101.80
Sample 3	7.00	7.04	100.62

Application for real samples

Determination of the glucose in human urine samples is also performed on the Nickel-Epoxy electrode by utilizing the calibration curve method. Briefly, the human urine samples of healthy human are first diluted with the 0.1 M NaOH, and added by glucose standar with spike solution than tested by using the Nickel-Epoxy electrode to monitor its glucose content. The results listed in Table 2 reveal that the Nickel-Epoxy electrode can be used for determination of glucose in human urine samples with favorable accuracy and precision. LOD and LOQ of the electrode towards glucose were found to be 4.4 µM and 1.48 µM, respectively. A comparison of the response characteristics of different modified electrode towards the detection of glucose is tabulated in Table 1.

Conclusion

A novel electrochemical nonenzymatic sensor for sensitive and selective detection of glucose was developed based on the Nickel-Epoxy

electrode. Nickel-Epoxy electrode exhibited excellent electrocatalytic activity toward glucose oxidation, and it could be developed into a highly desirable nonenzymatic glucose sensor, associated with satisfying sensitivity, selectivity and stability. The correlation of determination using Nickel-Epoxy electrode for electroanalysis of glucose was R^2= 0.9984. LOQ, LOD and recovery of the Nickel-Epoxy electrode towards glucose were found to be 4.4 μM and 1.48μM and 98.19%, respectively.

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