

# Direct Electrochemical Analysis of 3-Methyl-4-Nitrophenol in Water Using Carbon Fiber Microelectrode Modified with Nickel Tetrasulfonated Phthalocyanine Complex

Yibor Fabrice Roland Bako<sup>1,2,3\*</sup>, Boukaré Kaboré<sup>1,4</sup>, Amidou Tall<sup>1,4</sup>, Wendepoui Félix Sawadogo<sup>3</sup>, Issa Tapsoba<sup>1</sup>

<sup>1</sup>Laboratoire de Chimie Analytique, Environnementale et Bio-Organique (LCAEBiO), Université Joseph KI-ZERBO, Ouagadougou, Burkina Faso

<sup>2</sup>Laboratoire Interdisciplinaire de Recherche en Sciences Appliquées (LIRSA), Ecole Normale Supérieure, Koudougou, Burkina Faso

<sup>3</sup>Laboratoire de Chimie Analytique, de Physique Spatiale et Energétique (L@CAPSE), Université Norbert ZONGO, Koudougou, Burkina Faso

<sup>4</sup>Laboratoire de Sciences et Technologies (LaST), Université Thomas SANKARA, Ouagadougou, Burkina Faso  
Email: \*fabrice.bako@gmail.com

**How to cite this paper:** Bako, Y.F.R., Kaboré, B., Tall, A., Sawadogo, W.F. and Tapsoba, I. (2026) Direct Electrochemical Analysis of 3-Methyl-4-Nitrophenol in Water Using Carbon Fiber Microelectrode Modified with Nickel Tetrasulfonated Phthalocyanine Complex. *Materials Sciences and Applications*, 17, 1-14.  
<https://doi.org/10.4236/msa.2026.171001>

**Received:** November 30, 2025

**Accepted:** January 13, 2026

**Published:** January 16, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

This study reports a tetrasulfonated nickel phthalocyanine complex (p-NiTSPc) modified carbon fiber microelectrode (CFME) for the detection of 3-methyl-4-nitrophenol (MNP) at low potentials. The voltammogram of MNP showed a cathodic peak at  $-0.86$  V vs Ag/AgCl corresponding to the reduction of the nitro group. An electrocatalytic activity towards the MNP redox process was observed in the presence of p-NiTSPc. The effects of support electrolyte pH, frequency, scan increment, and pulse amplitude on square wave voltammetry (SWV) peak current were studied and optimized to improve the sensor's electrochemical response. With these optimized parameters, the calibration curve showed that the peak current increased linearly with MNP concentration, with a limit of detection (LoD) of  $0.025$   $\mu\text{g/L}$ . Therefore, we report, for the first time, an electrochemical LoD of MNP below  $0.1$   $\mu\text{g/L}$ , the current regulatory limit for drinkable water.

## Keywords

3-Methyl-4-Nitrophenol, Carbon Fiber Ultramicroelectrode, Nickel Tetrasulfonated Phthalocyanine, Direct Electrochemical Analysis, Square Wave Voltammetry

## 1. Introduction

Organophosphorus (OP) compounds are widely used pesticides that help control insects and improve crop yields. In Burkina Faso, fenitrothion (FT), an organophosphate insecticide, plays a critical role in cotton cultivation and during locust invasions [1]-[3]. Globally, the challenge lies in detecting the degradation products of such pesticides, especially the stable and persistent 3-methyl-4-nitrophenol (MNP) [4], which forms from FT and poses significant environmental risks due to its toxicity and endocrine-disrupting effects [2] [5]. Therefore, there is a global need for innovative analytical methods to effectively monitor these pollutants. While traditional analytical methods exist for detecting organophosphates, electroanalytical techniques stand out on a global scale because of their simplicity, high sensitivity, and selectivity [6] [7].

Several studies have advanced the development of electrochemical sensors for OP pesticides and their metabolites, highlighting specific capabilities and limitations. For instance, the work by Ensafi *et al.* [8] on using a polysilicon-modified glassy carbon electrode for fenitrothion detection in water and fruit samples demonstrates an approach focused on sample diversity. Similarly, Kumaravel *et al.* [9] introduced a nanosilver/dodecane-modified glassy carbon electrode targeting fenitrothion in potato samples, addressing the challenge of matrix complexity. Han *et al.* [10] advanced the field with a nitrogen-sulfur co-doped holey graphene (NS-HG) sensor to tackle sensitivity issues in various environments.

However, few studies focus on the electrochemical detection of MNP, fenitrothion's stable metabolite, indicating a significant gap in the existing sensor capabilities. Recognizing this gap, we previously developed an electrochemical sensor based on a tetrasulfonated nickel phthalocyanine complex-modified carbon fiber microelectrode (CFME/p-NiTSPc) for detecting MNP through the direct oxidation of the phenol group [1]. Another approach reported by us involved the indirect detection of MNP by monitoring the oxidation peak of the hydroxylamine group, formed upon the reduction of the nitro group [2]. Despite these advancements, the limits of detection remained high. This led us to consider a research question: Does targeting the nitro-group reduction yield lower detection limits than oxidation-based approaches in MNP detection?

This work, therefore, focuses on the direct detection of 3-methyl-4-nitrophenol by monitoring the reduction peak of the nitro group using square-wave voltammetry with CFME/p-NiTSPc, addressing the sensitivity required for environmental monitoring.

## 2. Materials and Methods

### 2.1. Reagents and Solutions

3-methyl-4-nitrophenol (MNP), sodium phosphate monobasic ( $\text{NaH}_2\text{PO}_4$ ), sodium phosphate dibasic ( $\text{Na}_2\text{HPO}_4$ ), nickel tetrasulfonated phthalocyanine (NiTSPc), potassium ferrocyanide ( $\text{K}_4\text{Fe}(\text{CN})_6$ ), potassium chloride (KCl), sodium hydrox-

ide (NaOH), sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), and absolute ethanol were procured from Sigma-Aldrich and utilized without additional purification. A phosphate buffer solution was prepared by combining the requisite quantities of NaH<sub>2</sub>PO<sub>4</sub> and Na<sub>2</sub>HPO<sub>4</sub>, serving as the supporting electrolyte. A solution for the electrochemical cleaning of naked carbon fiber ultramicroelectrode (CFME) was formulated by equi-volume mixing 0.5 M H<sub>2</sub>SO<sub>4</sub> and absolute ethanol. A 2 mM solution of NiTSPc was prepared by dissolving 98 mg of the chemical in 50 mL of 0.1 M NaOH. All aqueous solutions were prepared with pure water. MNP solutions were deaerated by passing nitrogen gas through them prior to electrochemical analysis of MNP.

## 2.2. Apparatus

All voltametric measurements were conducted using a potentiostat DY 2300 (Digi-IVY Instruments, USA), which was controlled by DY 2300 EN software on a computer. A carbon fiber microelectrode (CFME) with a diameter of 12 μm and a length of 5 mm, as well as a modified carbon fiber microelectrode coated with NiTSPc film (CFME/p-NiTSPc), were employed as working electrodes. An Ag/AgCl electrode served as the reference electrode, while a platinum electrode with a diameter of 250 μm was used as the counter electrode. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) analyses of the CFME and CFME/p-NiTSPc were performed using a JEOL JSM-6301F (SCIAM, Angers University). SEM images were obtained using secondary electrons at an accelerating voltage of 3 - 5 keV, with magnifications between 3000 and 5000. EDX spectra were gathered using a 20 keV beam.

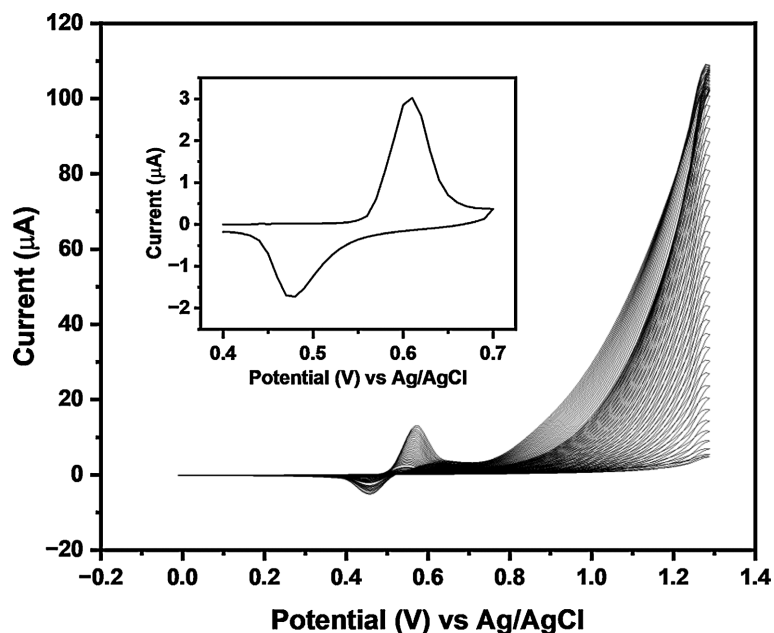
## 2.3. Analytical Procedure

Cyclic voltammetry was employed to modify CFME and to explore the electrochemical behaviors exhibited by MNP on both the unmodified CFME and the CFME/p-NiTSPc. Furthermore, square wave voltammetry served as a powerful tool for the quantitative analysis of aqueous samples, focusing specifically on tracking the direct reduction peak of MNP.

## 2.4. Electrochemical Modification of CFME

Before employing a CFME, it is essential to clean it to remove contaminants from the carbon fiber. The cleaning process is conducted electrochemically using a 1:1 mixture of H<sub>2</sub>SO<sub>4</sub> and absolute ethanol. Cleaning is achieved by cyclic voltammetry at 50 mV/s over 10 cycles, ranging from -1.5 V to 1.5 V [1]. Subsequently, the purified CFME is modified by p-NiTSPc, following the established protocol described in previous studies [11]. **Figure 1** illustrates the voltammograms acquired during the electrodeposition of p-NiTSPc on CFME, alongside the electrochemical revelation depicted in the insert for the modified CFME/p-NiTSPc. The thickness of the p-NiTSPc film was assessed based on the final cyclic voltammogram obtained from the electrodeposition of p-NiTSPc. Under the specified experi-

mental conditions, the p-NiTSPc film electrodeposited exhibits a recovery of approximately  $1.28 \times 10^{-8}$  mol/cm<sup>2</sup>, as determined by integrating the oxidation peak, which corresponds to a film thickness of 128 nm, in accordance with a previous report [12].



**Figure 1.** 75 successive cyclic voltammograms of CFME in a 0.1 M NaOH aqueous solution containing 2 mM of NiTSPc at the potential scan rate of 100 mV/s. Inset shows 1 cyclic voltammogram of CFME/p-NiTSPc in a 0.1 M NaOH aqueous solution at the potential scan rate of 100 mV/s.

### 3. Results and Discussions

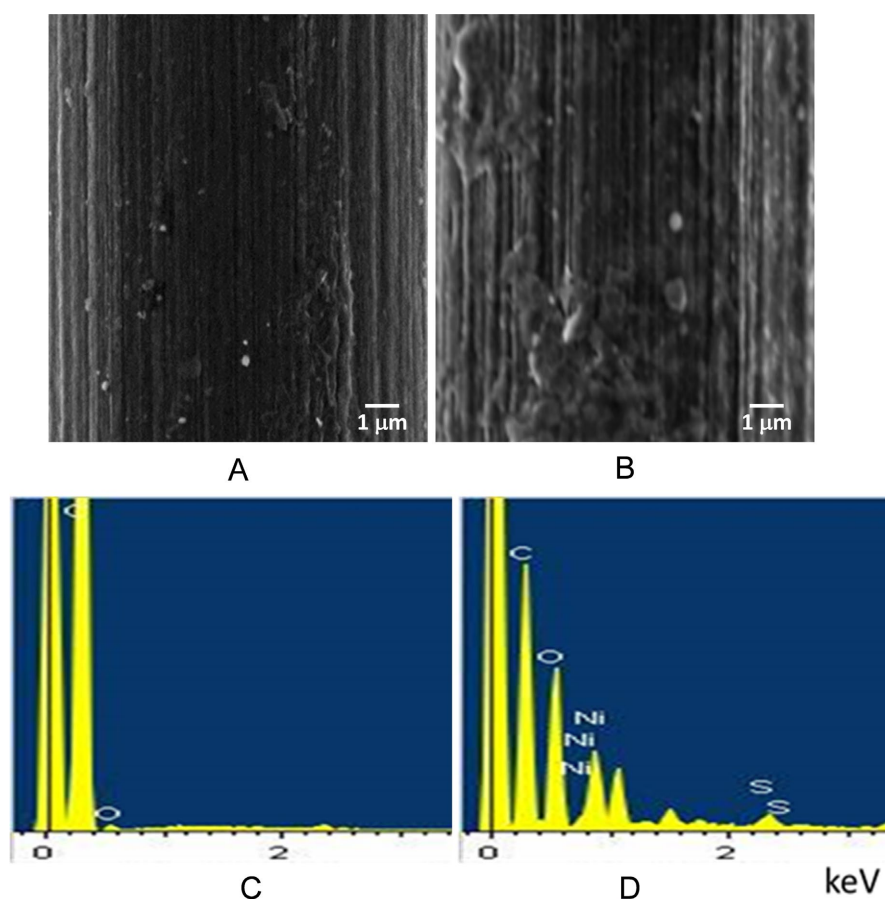
#### 3.1. SEM and EDX Characterization of Working Electrodes

**Figure 2(A)** and **Figure 2(B)** present SEM images of unmodified and modified carbon fiber microelectrodes, respectively. A distinct difference is observed between the unmodified and modified carbon fibers. **Figure 2(A)** displays a fiber with evenly distributed streaks, whereas **Figure 2(B)** depicts a fiber coated with nickel phthalocyanine film. Additionally, energy-dispersive X-ray (EDX) analyses were performed on both unmodified and modified CFMEs, with the results shown in **Figure 2(C)** and **Figure 2(D)**.

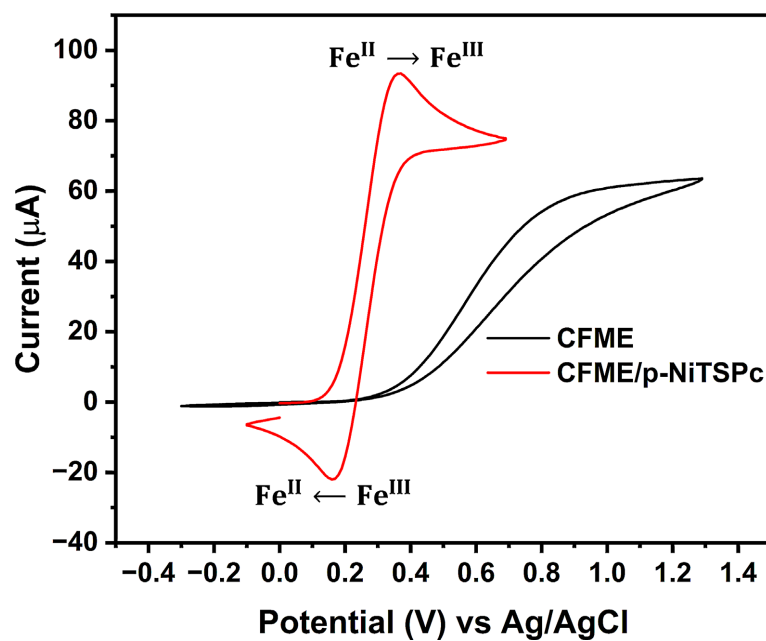
Both the two EDX images show carbon and oxygen. Carbon comes from the carbon fiber, and oxygen on the carbon fiber is likely from electrochemical cleaning. For the modified electrode, nickel and sulfur also appear. These elements likely originate from the tetrasulfonated nickel phthalocyanine film, consistent with the SEM image of the modified electrode.

#### 3.2. Electrochemical Characterization of CFME and CFME/p-NiTSPc by Cyclic Voltammetry

**Figure 3** displays the voltammograms of iron obtained using both a naked electrode



**Figure 2.** SEM images of (A) CFME and (B) CFME/p-NiTSPc. EDX spectra of (C) CFME and (D) CFME/p-NiTSPc.



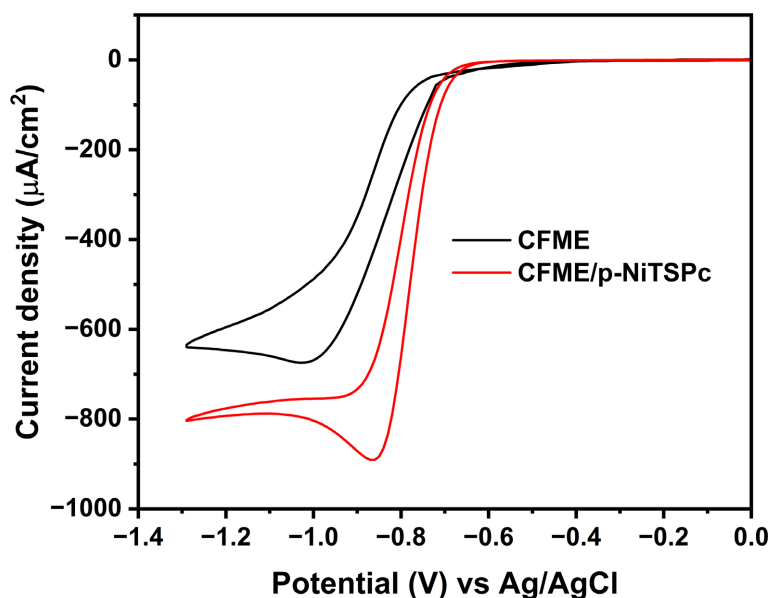
**Figure 3.** Cyclic voltammogram of 5 mM  $[\text{Fe}(\text{CN})_6]^{4-}$  in PBS pH 7 on unmodified CFME (black) and CFME/p-NiTSPc (red) at the scan rate  $v = 100$  mV/s.

and a modified electrode.

This figure indicates a substantial difference between the voltammograms of  $[\text{Fe}(\text{CN})_6]^{4-}$  recorded with the unmodified and modified electrodes. The voltammogram obtained with the CFME exhibits a poorly defined peak during the forward scan, corresponding to the oxidation of  $\text{Fe}^{\text{II}}$  to  $\text{Fe}^{\text{III}}$ , and no peak during the reverse scan, suggesting that  $[\text{Fe}(\text{CN})_6]^{4-}$  exhibits slow electron-transfer kinetics on this electrode. In contrast, modification of the electrode with tetrasulfonated nickel phthalocyanine results in  $[\text{Fe}(\text{CN})_6]^{4-}$  exhibiting rapid electron-transfer behavior. The appearance of an oxidation peak at 0.37 V ( $I_{p_a} = 93 \mu\text{A}$ ) and a reduction peak at 0.16 V ( $I_{p_c} = 91 \mu\text{A}$ ) can be attributed to the oxidation of  $\text{Fe}^{\text{II}}$  to  $\text{Fe}^{\text{III}}$  and the reduction of previously generated  $\text{Fe}^{\text{III}}$  to  $\text{Fe}^{\text{II}}$ , respectively. Furthermore, the peak intensity ratio, which is close to 1, meets the criteria for a fast electron-transfer system [13].

### 3.3. Comparison of Voltammetric Behavior of 3-Methyl-4-Nitrophenol at Naked and Modified Carbon Fiber Microelectrodes

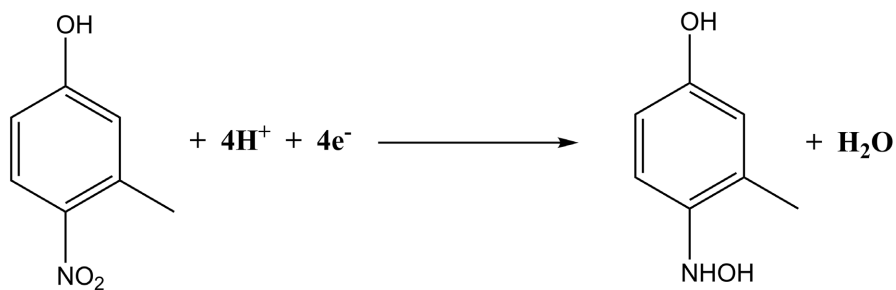
**Figure 4** shows the cyclic voltammograms of MNP at 40 mg/L in a pH 7 phosphate buffer, using both an unmodified CFME and a CFME/p-NiTSPc.



**Figure 4.** Cyclic voltammograms of 40 mg/L MNP in PBS at pH 7 recorded at unmodified CFME (black) and CFME/p-NiTSPc (red) with a scan rate of 100 mV/s.

For the CFME, the irreversible peak appears around 1 V, with a peak intensity of  $659 \mu\text{A}/\text{cm}^2$ . In contrast, for the CFME/p-NiTSPc, the peak occurs at approximately 0.86 V, with a peak intensity of  $890 \mu\text{A}/\text{cm}^2$ . Previous reports suggest that this peak results from the direct reduction of the nitro group to a hydroxylamine group after a transfer of 4 electrons, as shown in **Scheme 1** [14].

The observed changes in potential and reduction peak intensity are attributed

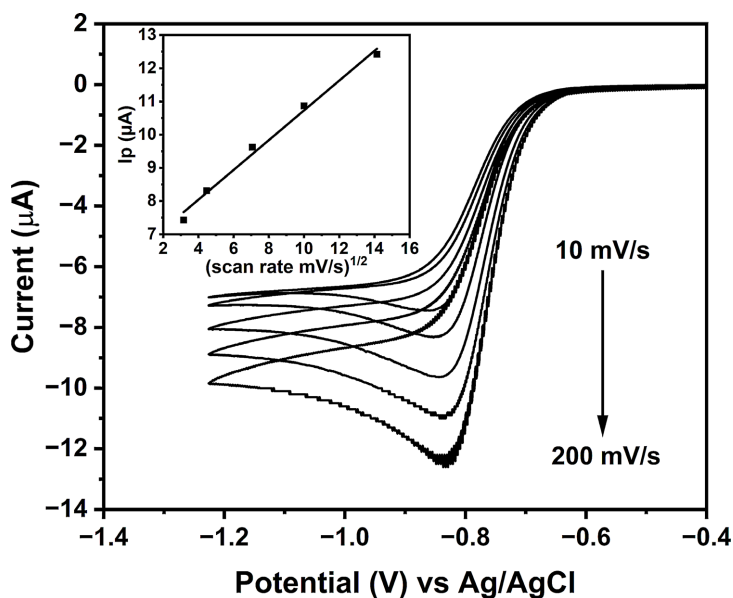


**Scheme 1.** Equation of the electrochemical reduction of 3-methyl-4-nitrophenol.

to the presence of the p-NiTSPc film. These results further demonstrate the effectiveness of electrode modification. Additionally, the increased intensity of the reduction peak, together with the decreased reduction potential, indicates that the p-NiTSPc film exhibits an electrocatalytic effect on the direct reduction of MNP [15]. Therefore, the CFME displays boosted sensitivity in the presence of the p-NiTSPc film.

### 3.4. Effect of Scan Rate on the Reduction of MNP

The effect of scan rate on the reduction peak of MNP was examined. Specifically, 20 mg/L MNP in 0.1 M PBS (pH 7) was analyzed by cyclic voltammetry using CFME/p-NiTSPc at scan rates of 10 - 200 mV/s. The resulting cyclic voltammograms are presented in **Figure 5**.



**Figure 5.** Cyclic voltammograms of 20 mg/L MNP in PBS at pH 7 on CFME/p-NiTSPc with different scan rates: 10, 20, 50, 100 and 200 mV/s. Inset: curve of the linear dependence of  $I_p$  versus  $\nu^{1/2}$ .

The figure shows that the reduction peak intensity increases with increasing scan rate, and that a linear relationship between cathodic current and the square root of the scan rate is observed over the range of 10 - 200 mV/s. The linear equa-

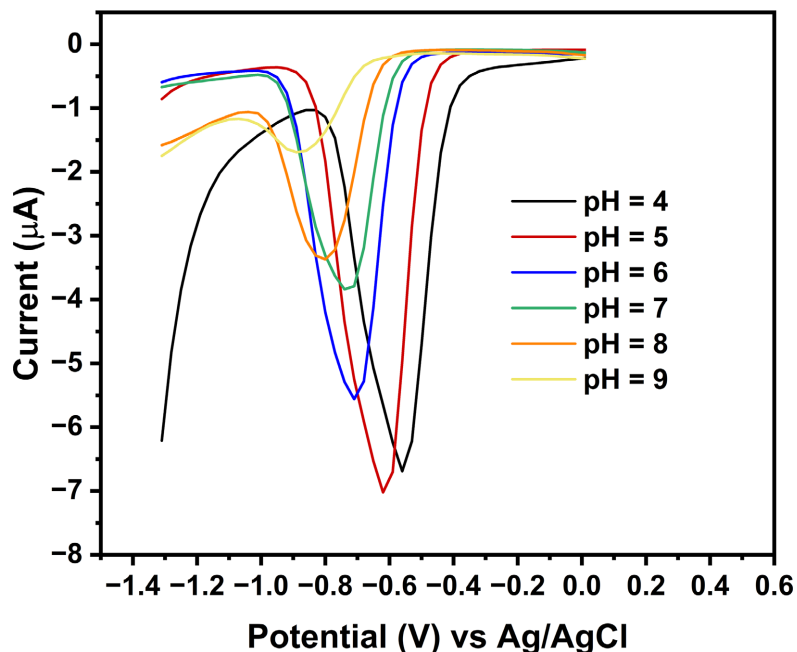
tion is:

$$I_p = 0.4483v^{1/2} + 6.2475,$$

with  $R^2 = 0.991$ . These results indicate that a diffusion-controlled process governs the reduction of MNP on CFME/p-NiTSPc [16].

### 3.5. Optimization of Support Electrolyte pH

**Figure 6** presents the voltammograms of MNP measured at various pH values in PBS.

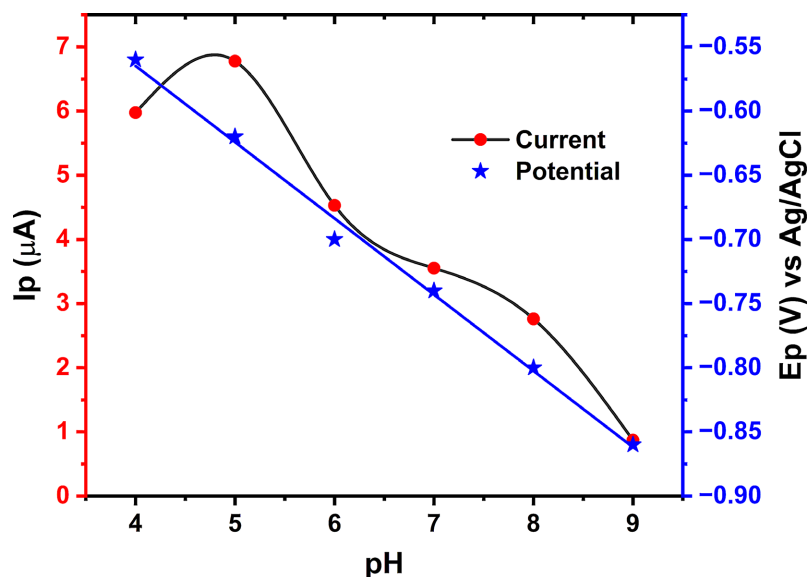


**Figure 6.** SWV of MNP at 10 mg/L in a phosphate buffer at different pH at a CFME/p-NiTSPc. SWV Parameters: frequency = 50 Hz; pulse amplitude = 100 mV; step potential = 30 mV.

It can be seen from **Figure 6** that the reduction peak potential shifts negatively with increasing pH, which indicates that the proton participates in the electrochemical redox processes. This observation is crucial as it sets the basis for the linear relationship that follows. Indeed, **Figure 7** shows a linear relationship between  $E_p$  vs pH with the linear regression equation:  $E_p$  (V) =  $-0.0594\text{pH} - 0.327$  ( $R^2 = 0.9947$ ). This linearity confirms the involvement of protons in the process.

According to the Nernst equation, the obtained slope (0.0593 V/pH) is close to the theoretical value (0.0591 V/pH), indicating that equal numbers of proton and electron transfers were involved in the electrochemical reduction of MNP. Furthermore, it reinforces the earlier observation, establishing a consistent line of evidence for the hypothesized mechanism. In addition, the representation of peak intensity as a function of pH (**Figure 7**) shows that the reduction peak current increased with increasing pH from 4.0 to 5.0. The peak current reached its maximum at pH 5.0 and then sharply decreased at higher pH values. This phenomenon

can be explained by the reduction mechanism, which involves proton transfer, as previously described in **Scheme 1** and demonstrated in this section. At  $\text{pH} > 7$ , the reduction of the nitro group ( $-\text{NO}_2$ ) of MNP to the hydroxylamine group ( $-\text{NHOH}$ ) is retarded due to the decrease in  $\text{H}^+$  concentration, which participates in the reduction mechanism [17]. Additionally, as  $\text{pH}$  increases, the proportion of the anionic form of MNP ( $\text{pK}_a$  value of 7.4) increases, while the amount of the neutral form decreases. This shift results in a reduced intensity of the MNP reduction peak. Therefore,  $\text{pH} 5.0$  was selected as the optimal value for the detection of MNP.



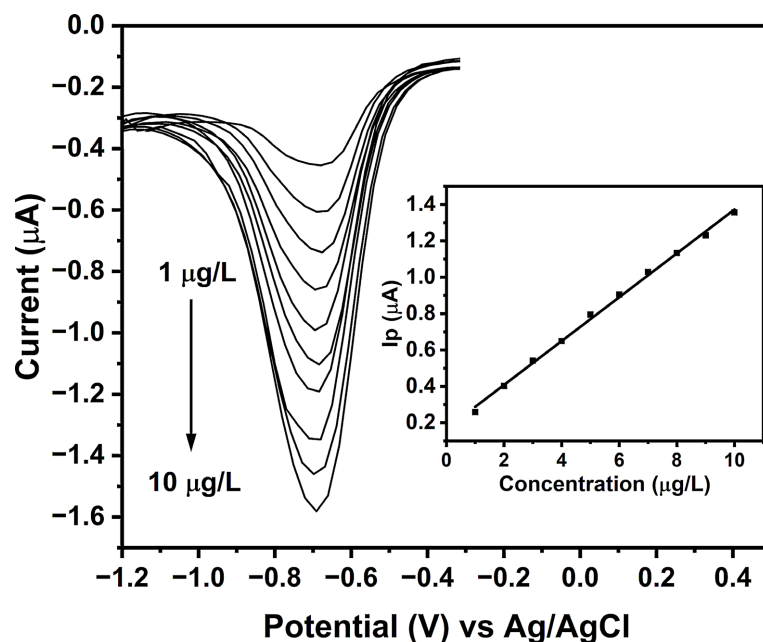
**Figure 7.** Plot of  $I_p$  vs  $\text{pH}$  value and plot of  $E_p$  vs  $\text{pH}$  value.

### 3.6. Quantitative Analysis of MNP

Following the optimization of the  $\text{pH}$  for MNP analysis, the square-wave voltammetry (SWV) parameters were also optimized (data not shown). The optimal parameters identified include a frequency of 50 Hz, a pulse amplitude of 100 mV, and a step potential of 30 mV. These values were subsequently applied in the quantitative analysis of MNP. **Figure 8** presents the square-wave voltammograms corresponding to various concentrations of the MNP standard on CFME/p-NiTSPc.

**Figure 8** demonstrates that, for concentrations between  $1 \mu\text{g/L}$  and  $10 \mu\text{g/L}$ , the intensity of the reduction peak increases proportionally with concentration. The inset of **Figure 8** further illustrates that this relationship is linear. The linear regression equation is  $I_p = 0.1206C + 0.1586$ , with  $R^2 = 0.9986$ . Based on this equation and a signal-to-noise ratio of 3:1, the detection limit (LoD) was calculated to be  $0.025 \mu\text{g/L}$ . **Table 1** compares the electrochemical reaction types, linear ranges, and detection limits of some reported electrochemical sensors with CFME/p-NiTSPc for MNP detection.

To gauge the significance of this detection limit, it is informative to compare it



**Figure 8.** SWV of MNP at different concentrations (1, 2, 3, 4, 5, 6, 7, 8, 9, and 10  $\mu\text{g/L}$ ) in phosphate buffer (pH = 5) at a CFME/p-NiTSPc. Inset: plot of  $I_p$  vs concentration of MNP. SWV parameters: frequency = 50 Hz; pulse amplitude = 100 mV; potential increment = 30 mV.

**Table 1.** Performance comparison of various electrochemical sensors for MNP detection. All detections were made using SWV.

Sensor	Type of electrochemical reaction	Linear range ( $\mu\text{g/L}$ )	Detection limit ( $\mu\text{g/L}$ )	Reference
CFME	Direct oxidation	100 - 1000	3	[1]
CFME/p-NiTSPc	Direct oxidation	10 - 100	0.75	[1]
CFME/p-NiTSPc	Indirect oxidation	10 - 100	1.1	[19]
UME <sup>a</sup> /MIP <sup>b</sup>	Direct reduction	1000 - 17,000	690	[20]
CFME/p-NiTSPc	Direct reduction	1 - 10	0.025	This work

<sup>a</sup>UME: ultramicroelectrode. <sup>b</sup>MIP: molecular imprinted polymer.

with the regulatory standards set by international bodies. The World Health Organization (WHO) and the European Union (EU) have established maximum allowable concentrations for pesticide residues or their metabolites in drinking water at 0.1  $\mu\text{g/L}$  [18]. To our knowledge, our reported LoD represents the lowest electrochemical detection limit for MNP to date.

### 3.7. Interference Study

Interference was evaluated in a 0.1 M phosphate buffer solution (PBS) containing 10  $\mu\text{g/L}$  of MNP, with the addition of potential interfering species including  $\text{Cd}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{K}^+$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , and the parent pesticide fenitrothion (FT). The tolerance threshold was defined as the ratio of the interfering species concentration to the

MNP concentration. **Table 2** presents the relative error of the  $I_p$  following the introduction of these interfering species.

**Table 2.** Summary of various interfering substances and their effects on the detection of MNP (10  $\mu\text{g/L}$ ) using CFME/p-NiTSPc.

Interfering substance	Ratio	Relative error (%)
$\text{Cd}^{2+}$	50	0.66
	100	0.89
	150	1.02
$\text{Pb}^{2+}$	50	0.96
	100	1.23
	150	1.67
$\text{K}^+$	50	0.38
	100	0.51
	150	0.73
$\text{NO}_3^-$	50	0.41
	100	0.59
	150	0.79
$\text{SO}_4^{2-}$	50	0.65
	100	0.84
	150	1.03
FT	1	0.30
	2	4.96
	6	6.99

This table indicates that most interfering substances exhibited negligible influence (relative error  $\leq 5\%$ ) even at concentrations up to 150 times greater than that of MNP. In contrast, fenitrothion demonstrated a substantial effect ( $>6\%$ ) at a concentration only slightly exceeding six times that of MNP. This result is attributed to the presence of the same functional group in both fenitrothion and MNP.

### 3.8. Evaluation of the Repeatability, Reproducibility and Stability

The repeatability, reproducibility, and stability of the CFME/p-NiTSPc electrode were evaluated using square wave voltammetry (SWV). Voltammograms of a 10  $\mu\text{g/L}$  MNP solution in 0.1 M phosphate buffer at pH 5 were initially recorded with the same CFME/p-NiTSPc electrode. The relative standard deviation (RSD) for six repeated measurements was 3.1%, demonstrating strong repeatability for MNP quantification. Reproducibility was assessed by preparing six separate CFME/p-NiTSPc electrodes using an identical protocol; the RSD for MNP detection at 10

$\mu\text{g/L}$  was 5.7%, indicating acceptable reproducibility. Sensor stability was determined by recording the signal from a 10  $\mu\text{g/L}$  MNP solution daily on the same electrode, with the modified electrode retaining approximately 97.1% of its initial response after five days. These results demonstrate that the CFME/p-NiTSPc electrode provides reliable analytical performance, including repeatability, reproducibility, and stability, supporting its suitability for MNP quantification in real-world samples.

#### 4. Conclusion

MNP was detected using square wave voltammetry by measuring the direct reductive peak current corresponding to the reduction of the nitro group to the hydroxylamine group at a modified carbon fiber microelectrode with p-NiTSPc. The pH of the analytical solution and the SWV parameters were optimized, yielding the following optimal values: pH 5, frequency 50 Hz, scan increment 30 mV, and pulse amplitude 100 mV. Within the concentration range of 1  $\mu\text{g/L}$  to 10  $\mu\text{g/L}$ , the peak current exhibited a linear relationship. The lowest limit of detection (LoD) calculated for MNP on CFME/p-NiTSPc was 0.025  $\mu\text{g/L}$ . These findings indicate that CFME/p-NiTSPc provides high sensitivity and enables the detection of MNP at low potential in aqueous solutions. Subsequent research will expand the interference study to additional electroactive species, enhance selectivity with particular emphasis on fenitrothion, and apply the sensor to real samples. This application is essential for confirming the sensor's effectiveness under various environmental conditions.

#### Acknowledgements

The authors would like to thank the International Science Programme (ISP) for financial support of this work through the African Network of Electroanalytical Chemists (ANEC).

#### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

#### References

- [1] Bako, Y.F.R., Kabore, B. and Tapsoba, I. (2017) Electrochemical Sensors Based on Modification of Carbon Fiber Microelectrode by Nickel Phthalocyanine Polymer for 3-Methyl-4-Nitrophenol Analysis in Water. *Materials Sciences and Applications*, **8**, 798-810. <https://doi.org/10.4236/msa.2017.811058>
- [2] Bako, Y.F.R., Tapsoba, I., Pontie, M. and Chelaghmia, M.L. (2018) Direct Electrooxidation of 3-Methyl-4-Nitrophenol (MNP) at Carbon Fiber Microelectrode (CFME). *International Journal of Electrochemical Science*, **13**, 8056-8071. <https://doi.org/10.20964/2018.08.35>
- [3] Ondo Zue Abaga, N., Alibert, P., Dousset, S., Savadogo, P.W., Savadogo, M. and Sedogo, M. (2011) Insecticide Residues in Cotton Soils of Burkina Faso and Effects of Insecticides on Fluctuating Asymmetry in Honey Bees (*Apis mellifera* Linnaeus). *Chemosphere*, **83**, 585-592. <https://doi.org/10.1016/j.chemosphere.2010.12.021>

- [4] Dione, M.M., Djouaka, R., Mbokou, S.F., Ilboudo, G.S., Ouedraogo, A.A., Dinede, G., *et al.* (2023) Detection and Quantification of Pesticide Residues in Tomatoes Sold in Urban Markets of Ouagadougou, Burkina Faso. *Frontiers in Sustainable Food Systems*, **7**, Article 1213085. <https://doi.org/10.3389/fsufs.2023.1213085>
- [5] Seebunrueng, K., Santaladchaiyakit, Y. and Srijaranai, S. (2014) Vortex-Assisted Low-Density Solvent Based Demulsified Dispersive Liquid-Liquid Microextraction and High-Performance Liquid Chromatography for the Determination of Organophosphorus Pesticides in Water Samples. *Chemosphere*, **103**, 51-58. <https://doi.org/10.1016/j.chemosphere.2013.11.024>
- [6] Guo, X., Zhou, H., Fan, T. and Zhang, D. (2015) Electrochemical Detection of P-Nitrophenol on Surface Imprinted Gold with Lamellar-Ridge Architecture. *Sensors and Actuators B: Chemical*, **220**, 33-39. <https://doi.org/10.1016/j.snb.2015.05.042>
- [7] Pérez-Fernández, B., Costa-García, A. and Muñoz, A.d.I.E. (2020) Electrochemical (Bio)sensors for Pesticides Detection Using Screen-Printed Electrodes. *Biosensors*, **10**, Article No. 32. <https://doi.org/10.3390/bios10040032>
- [8] Ensafi, A.A., Rezaloo, F. and Rezaei, B. (2017) Electrochemical Determination of Fenitrothion Organophosphorus Pesticide Using Polyzincon Modified-Glassy Carbon Electrode. *Electroanalysis*, **29**, 2839-2846. <https://doi.org/10.1002/elan.201700406>
- [9] Kumaravel, A. and Muruganathan, M. (2021) Electrochemical Detection of Fenitrothion Usingnanosilver/Dodecane Modified Glassy Carbon Electrode. *Sensors and Actuators B: Chemical*, **331**, Article ID: 129467. <https://doi.org/10.1016/j.snb.2021.129467>
- [10] Han, J., Zhang, Y., Chen, Z., Zhang, A. and Shi, X. (2023) Synergistic Effect of Nitrogen and Sulfur Co-Doped Holey Graphene for Sensitive Fenitrothion Detection Supported by DFT Study. *Microchemical Journal*, **193**, Article ID: 109218. <https://doi.org/10.1016/j.microc.2023.109218>
- [11] Mbokou, S.F., Pontié, M., Razafimandimby, B., Bouchara, J., Njanja, E. and Tonle Kenfack, I. (2016) Evaluation of the Degradation of Acetaminophen by the Filamentous Fungus *Scedosporium dehoogii* Using Carbon-Based Modified Electrodes. *Analytical and Bioanalytical Chemistry*, **408**, 5895-5903. <https://doi.org/10.1007/s00216-016-9704-8>
- [12] Pontie, M., Lecture, H. and Bedioui, F. (1999) Improvement in the Performance of a Nickel Complex-Based Electrochemical Sensor for the Detection of Nitric Oxide in Solution. *Sensors and Actuators B: Chemical*, **56**, 1-5. [https://doi.org/10.1016/s0925-4005\(99\)00027-1](https://doi.org/10.1016/s0925-4005(99)00027-1)
- [13] Bard, A.J., Faulkner, L.R. and White, H.S. (2022) *Electrochemical Methods: Fundamentals and Applications*. 3rd Edition, John Wiley & Sons.
- [14] Rani, A., Banerjee, B. and Haldar, K.K. (2025) AuRh Based Bimetallic Catalyst for Electrochemical Nitroarene Reduction: Reaction Development and Mechanistic Insights. *Discover Catalysis*, **2**, Article No. 13. <https://doi.org/10.1007/s44344-025-00015-6>
- [15] Chang, H.W., Chen, C.L., Chen, Y.H., Chang, Y.M., Liu, F.J. and Tsai, Y.C. (2022) Electrochemical Organophosphorus Pesticide Detection Using Nanostructured Gold-Modified Electrodes. *Sensors*, **22**, Article No. 9938. <https://doi.org/10.3390/s22249938>
- [16] Du, J., Yue, R., Ren, F., Yao, Z., Jiang, F., Yang, P., *et al.* (2013) Simultaneous Determination of Uric Acid and Dopamine Using a Carbon Fiber Electrode Modified by Layer-by-Layer Assembly of Graphene and Gold Nanoparticles. *Gold Bulletin*, **46**, 137-144. <https://doi.org/10.1007/s13404-013-0090-0>
- [17] Simonetti, S.O., Beil, S.B. and Waldvogel, S.R. (2025) Nitro Substrates in Reductive Electrosynthesis: A Review. *ACS Electrochemistry*, **1**, 805-818.

- <https://doi.org/10.1021/acselectrochem.5c00081>
- [18] Disley, J., Gil-Ramirez, G. and Gonzalez-Rodriguez, J. (2025) A Review of Different Removal Techniques for Pesticides Found in European Waters Identified by the European Environmental Agency. *Environmental Science & Policy*, **172**, Article ID: 104194. <https://doi.org/10.1016/j.envsci.2025.104194>
- [19] Bako, Y.F.R., Mbokou, S.F., Kaboré, B., Tapsoba, I. and Pontié, M. (2024) Indirect Electroanalysis of 3-Methyl-4-Nitrophenol in Water Using Carbon Fiber Microelectrode Modified with Nickel Tetrasulfonated Phthalocyanine Complex. *Materials Sciences and Applications*, **15**, 25-35. <https://doi.org/10.4236/msa.2024.152003>
- [20] Bako, Y.F.R., Silga, J.T., Mbokou Foukmeniok, S., Pontié, M. and Tapsoba, I. (2023) Molecular Imprinted Polymer Modified Carbon Ultramicroelectrode for a Selective Detection of 3-Methyl-4-Nitrophenol and Its Bioremediation in a Fungal Microbial Fuel Cell. *Journal of Applied Electrochemistry*, **54**, 1253-1265. <https://doi.org/10.1007/s10800-023-02041-4>