



# AN ELECTROCHEMICAL SENSOR FOR PARACETAMOL AND METRONIDAZOLE DETECTION BASED ON POLY (SCHIFF BASES) FILM MODIFIED ELECTRODE

Sajida J. Kadhim<sup>[a]</sup>, Mohammed Q. Mohammed<sup>[b]\*</sup>, Jasim M. S. Alshawi<sup>[c]</sup>

**Article History:** Received: 28.07.2022

Revised: 26.08.2022

Accepted: 16.09.2022

**Abstract:** Monomers contain pyrrole and thiophene moieties and conjugated Schiff bases were synthesized. The study herein describes the electrochemical detection of some drugs, specifically paracetamol and metronidazole. Modification of electrodes with functional groups such as Schiff bases leads to improve sensitivity of the electrode to analytes. In this study, a glassy carbon electrode has, for the first time, been modified with poly(schiff bases) in acetonitrile containing tetrabutylammonium perchlorate (TBAP) to detect paracetamol and metronidazole. The structures of prepared compounds were characterized by Fourier transform infrared spectroscopy, Proton and Carbon-13 Nuclear Magnetic Resonance and Electron Ionization Mass Spectroscopy. The electrochemical synthesis and redox state response in monomer-free electrolytes synthesized films have examined by using cyclic voltammetry. A voltammetric sensor based on a polymeric schiff bases film coated GC electrode was developed. The proposed electrode was appropriate for detection of paracetamol and metronidazole in pharmaceutical formulations.

**Keywords:** Schiff base, electroactive polymer, modified electrode, electrochemical sensors and cyclic voltammetry

[a]. Department of Chemistry, College of education for pure sciences, University of Basrah, Basrah, Iraq.

[b]. Department of Chemistry, College of education for pure sciences, University of Basrah, Basrah, Iraq.

[c]. Department of Chemistry, College of education for pure sciences, University of Basrah, Basrah, Iraq.

**DOI: 10.31838/ecb/2022.11.07.003**

## INTRODUCTION

Electrochemical sensors are of pivotal importance in various areas including monitoring of different species in the industrial processes; atmosphere, bio-medical analysis, and food monitor (Kareem et al., 2019). Generally, electrochemical techniques are more appropriate, economic and reliable compared to other techniques. When electrochemical methods used, modified electrodes are applied for passing current to electrolyte solutions and the resulting responses, caused by the electrochemical reactions occurring between analyte and electrode surface, are recorded. The modified electrode surfaces containing polymers which have functional groups presently an intensive field of scientific research (Emriye, 2016). Potential applications of these modified conducting films include electro sensor, catalysts, and energy storage. Recent research of electrochemical features of metal complex polymer films was led to a good understanding of the key parameters that control their electro-responses. The best successful ways for creating thin polymeric metal complex films is electropolymerization (Yassin., 2020).

Generally, electroactive polymers have unique properties, biocompatibility, optical and electrical physical merits. Due to these properties, make these polymer films to be potential candidate for applications in electrochemical sensors (Kumar et

al., 2015). One of these polymers is Schiff bases polymers are generally conjugated polymers which can be produced by using condensation reactions. These conjugated systems can be improved the electrical conductivity considerably for Schiff bases polymers (Alshawi et al., 2022, Almashal et al., 2020).

The various monomers which can be used to synthesis Schiff base polymers with different functional can be designed to be suitable candidate for different requirements (El-Sonbati et al., 2016). Several studies were demonstrated that these polymers can be deposited on electrode surface to form thin films which improved the stability of electrode (Bartyzel, 2017). Therefore, these type of compounds were attracted widespread attention and have applied to create electrochemical sensors. For example, electroactive film was prepared from p-benzaldehyde-thionine aminealdehyde and used for electrochemical sensing of glucose. Further, conducting film was prepared with 1,10-phenanthroline groups which was used to develop pH and glucose electrochemical sensor.

Azo methene compounds have wide range of potential applications in the multi-areas such as of sensor, (Kareem et al., 2019) and water splitting, catalysis, lighting (Kumar et al., 2015) and energy generation In diverse cases, the metal-containing materials required to be processed to form thin films on electrode surfaces. Among other deposition methods, electropolymerization is considered the best approach to formation of metal - polymeric systems. Electropolymerization process has many features such as controlling of thickness of film, fast film formation, overcoming of solubility problems (Alshawi et al., 2022). Several complexes of metal ions have used for creating redox-systems metal polymers. Over previous studies, imine polymers have found that have a number of unique implicit properties such as sensing activity for different analytes, electrocatalytic activity in organic and inorganic reactions, electrochromism, which have enabled them to be promising candidates (Mohammed et al., 2022).

The goal of the current study is to modify the chemical structure of electrode surfaces with schiff base to be used for selective detection of drugs in solution and to improve the sensitivity and of modified polymer electrodes to be more efficient with regard to medicines and biological molecules determination and with improved stability, repeatability, and conductivity of the electrodes. The aims of this project were: firstly; to electropolymerise and modify a Schiff base polymers electrode in non-aqueous medium; secondly; to monitor the response of the prepared modified polymer electrode using cyclic voltammetry; thirdly; to study the effect of scan rate; and finally to investigate the interaction of the polymer electrode with biological molecules, in particular Paracetamol and Metronidazole.

## EXPERIMENTAL SECTION

### Materials and Instruments

p-phenylenediammine, Thiophene-2-carboxaldehyde, Pyrrole-2-carboxaldehyde, Glacial acetic acid, Ethanol, chloroform, Acetonitrile and Tetrabutylammonium perchlorate (TBAP) were purchased from Sigma-Aldrich, Merck and Scharlau. All chemicals were of a high degree of purity (~97-99 %). FT-IR spectra were recorded on (FT-IR-84005-SHIMADZU) using KBr pellets in the range of (400–4000  $\text{cm}^{-1}$ ),  $^1\text{H}$  and  $^{13}\text{C}$ -NMR spectra of the ligand were recorded on (Bruker- 400Hz) spectrometer in  $\text{DMSO-d}_6$  by using tetramethylsilane (TMS) as an internal standard. (UV–VIS) spectra were recorded in DMF using (T80+UV/VIS Spectrometer PG Instruments Ltd) in the range (200-800 nm) at room temperature. (EI-MS) of ligands were recorded on (quadrupole analyzer spectrometer 5975

Agilent). The Schiff bases were polymerized by using cyclic voltammetry method (DY2311 Potentiostat).

### Methods

#### Synthesis of the Schiff base ligand, N, N'-(1,4-phenylene) bis(1-(1H-pyrrol-2-yl) methanimine) (L1)

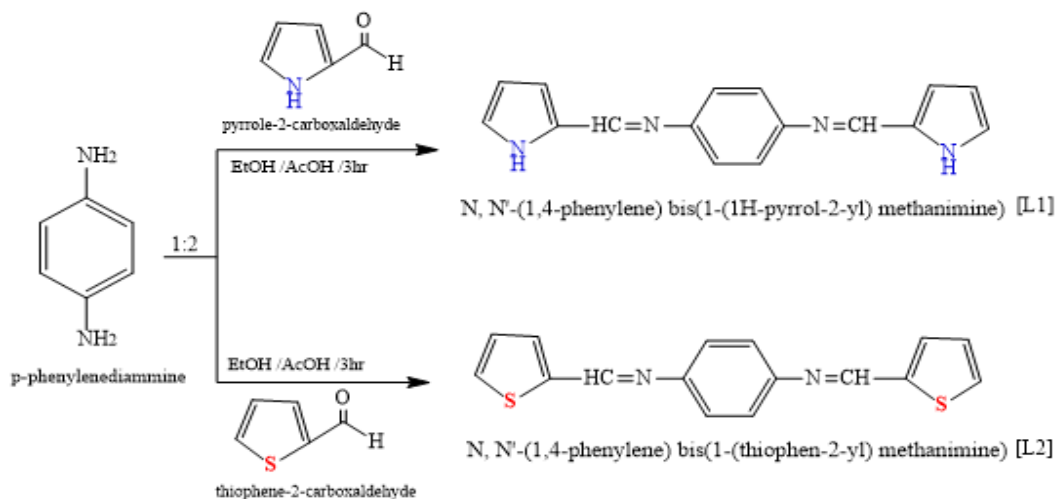
The ligand (L1) was prepared by using condensation reaction where (0.02mol, 1.902g) pyrrole-2-carboxaldehyde was dissolved in (10 ml) of absolute ethanol, then 3 drops of glacial acetic acid were added to solution. Next step, (0.01mol, 1.081g) of p-phenylenediammine was dissolved in (10 ml) of hot ethanol and then added as drop wise to first solution over 30 minute. The resulting mixture was left under reflux for 3 hours with stirring. Finally, The yield was recrystallized in chloroform, filtered off, and dried under vacuum (Mohammed et al., 2022). Scheme 1 shows the preparation reaction of ligand. Some physical properties were showed in Table 1.

#### Synthesis of the Schiff base ligand, N, N'-(1,4-phenylene) bis(1-(thiophen-2-yl) methanimine) (L2)

The ligand (L2) was prepared in two-necked flask from (0.02mol, 2.243g) thiophene-2-carboxaldehyde was dissolved in (10 ml) of absolute ethanol with 3 drops of glacial acetic acid. Next (0.01mol, 1.08g) of p-phenylenediammine was dissolved in (10 ml) of hot ethanol and then was added drop wise over 30 minute. The resulting mixture was left under reflux for 3 hours with stirring. Finally, the solution was cooled and precipitate was obtained and recrystallized by chloroform (Mohammed et al., 2022). Fig. 1 shows the preparation reaction of ligand 2. Some physical properties were showed in Tables 1.

**Table 1:** Some physical properties of prepared Schiff base and complexes

symbol	Molecular formula	Molecular weight	Melting point	Yield (%)
L1	$\text{C}_{16}\text{H}_{14}\text{N}_4$	262	212-214	74
L2	$\text{C}_{16}\text{H}_{12}\text{N}_2\text{S}_2$	296	172-174	80



**Figure. 1** depicts chemical structure of Imine compounds

### Electropolymerization of ligands

The electrochemical polymerisation of Schiff bases was performed by cyclic voltammetry method (CV) in a cell with

three electrodes using (DY2311 potentiostat). Glassy carbon electrode and platinum were applied as working and auxiliary electrodes, respectively, with an Ag/AgCl reference electrode

made from an Ag wire placed in saturated KCl solution. The Glassy carbon-working electrode polished using 0.3 $\mu$ m alumina paste. The electropolymerisation process was achieved using a 0.2 M solution of each monomer (ligands) separately in acetonitrile solution containing supporting electrolyte (0.1M) from (TBAP) (Tetrabutylammonium perchlorate). The electrode was scanned over a potential range from - 0.5 to 1.6 V at various scan rates 100 mV s<sup>-1</sup> for 15 cycles, with all experiments carried out at 25  $\pm$  2  $^{\circ}$ C. (Alshawi et al., 2022, Mohammed et al., 2022).

## RESULTS AND DISCUSSION

### Fourier transforms infrared spectroscopy

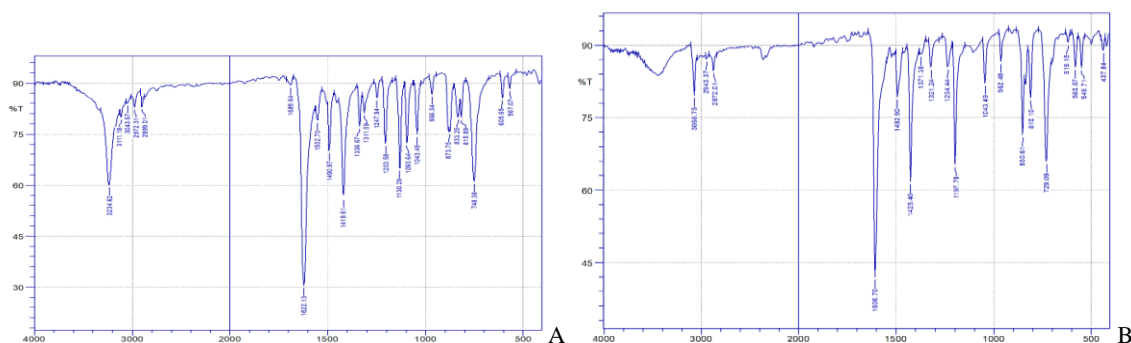


Figure. 2 shows the FT- IR spectrum for A) L1 and B) L2

### <sup>1</sup>H NMR spectroscopy

The <sup>1</sup>H-NMR spectrum of Ligand (L<sub>1</sub>) was recorded in DMSO-d<sub>6</sub> using tetramethylsilane (TMS) as an internal standard, shows a signal at  $\delta$  (8.36) ppm assigned to (s, 2H of CH= N group). Signal at  $\delta$  (11.77) ppm assigned to (s, 2H of N-H group). In addition, signal at  $\delta$  (7.23) ppm assigned to (s, 4H from phenylene group). (Three Signals) within range  $\delta$  (6.21-

FTIR spectroscopy was applied to identify polymeric films that were prepared from Schiff bases. Sharp and a strong intensity bands appear at (1622-1606) cm<sup>-1</sup> for azomethine bond (C=N) stretching frequency, which indicates formation of Schiff bases. The aromatic C-H bands were observed within 3065- 3110cm<sup>-1</sup> region for both ligands. The presence of aromatic structure has identified by their characteristic ring vibrations at 1550–1450, 1120–1070 and 920–750 cm<sup>-1</sup> regions. The absence of bands characteristic of primary amine (NH) and carbonyl groups (C=O) confirms the formation of the suggested Schiff base compounds. Furthermore, bands at 3234 cm<sup>-1</sup> and 850 cm<sup>-1</sup> is attributed to (N-H) and (C-S) respectively. Figure. 2 (A and B) show IR spectra of Schiff bases L<sub>1</sub>, L<sub>2</sub> respectively (Warad et al., 2020)

7.04) ppm assigned to (m,6H of pyrrole groups). Furthermore, <sup>1</sup>H-NMR spectrum of Ligand (L<sub>2</sub>), shows a Signal at  $\delta$  (8.85) ppm assigned to (s, 2H of CH= N group), a Signal at  $\delta$  (7.34) ppm assigned to (s, 4H from phenylene group), (Three Signals) within range  $\delta$  (7.23 -7.84) ppm assigned to (m,6H of thiophene groups). Figure. 3 shows <sup>1</sup>H-NMR spectrum of Ligands (A for L<sub>1</sub> and B for L<sub>2</sub>) (Singh et al., 2010).

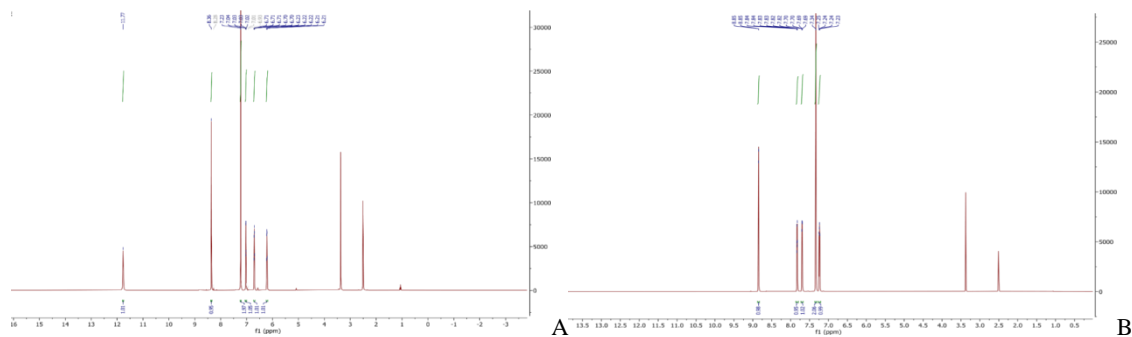


Figure. 3 depicts the H1NMR spectrum for A) L1 B) L2

### <sup>13</sup>C NMR spectroscopy

The <sup>13</sup>C NMR spectrum of the Schiff base ligands was represented in Figure. 4 was recorded in DMSO-d<sub>6</sub>. The Figure. 4 A shows the spectrum for Schiff base (L<sub>1</sub>).The peak at  $\delta$  (150.07) ppm may be assigned due to azomethine carbon (C=N). The peak at  $\delta$  (149.63) ppm attributed to (C6).The peak at  $\delta$  (122.08) due to carbon of (phenylene group). In addition, four peaks at (110.19, 116.78, 124.24 and 131.19) ppm

attributed to carbon (Pyrrole groups). Figure. 4 B shows (<sup>13</sup>C NMR) for Schiff base (L<sub>2</sub>), where a peak of azomethine carbon (C=N) was appeared at  $\delta$  (153.75) ppm. The peak at  $\delta$  (149.13) ppm attributed to (C6). The peak at  $\delta$  (122.60) ppm attributed to carbon of (phenylene group). Further, four signals within range (128.77-143.07) ppm attributed to carbon (thiophene groups) (Chaudhary, 2013).

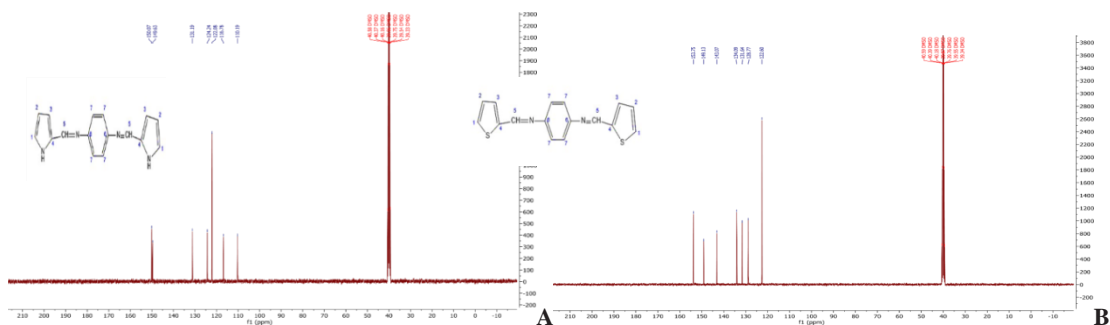


Figure. 4 shows  $^{13}\text{C}$ -NMR spectrum of Ligand A) L1 and B) L2

#### Mass spectroscopy

Figure. 5 shows the EI-MS spectrum of the Schiff base ligand (L1) where gives molecular ion peak  $[\text{M}^+]$  at (262.1)  $m/z$  which corresponds with the molecular weight of the compound (L1) which has the molecular formula  $(\text{C}_{16}\text{H}_{14}\text{N}_4)^+$ . The peak at (194.2)  $m/z$  due to the ion  $(\text{C}_{12}\text{H}_9\text{N}_3)^+$  and the peak at (130.2)

$m/z$  attributed to ion  $(\text{C}_8\text{H}_6\text{N}_2)^+$ . Further, Figure. 6 shows (EI-MS) spectrum of ligand (L2) where gives molecular ion peak  $[\text{M}^+]$  at (296.3)  $m/z$ , which corresponds with the molecular weight of the compound (L2)  $(\text{C}_{16}\text{H}_{12}\text{N}_2\text{S}_2)^+$ . The peak (211.2)  $m/z$  attributed to the ion  $(\text{C}_{12}\text{H}_8\text{N}_2\text{S})^+$  and a peak at (186.2)  $m/z$  due to the ion  $(\text{C}_{11}\text{H}_9\text{NS})^+$  (Vairalakshmi et al., 2018).

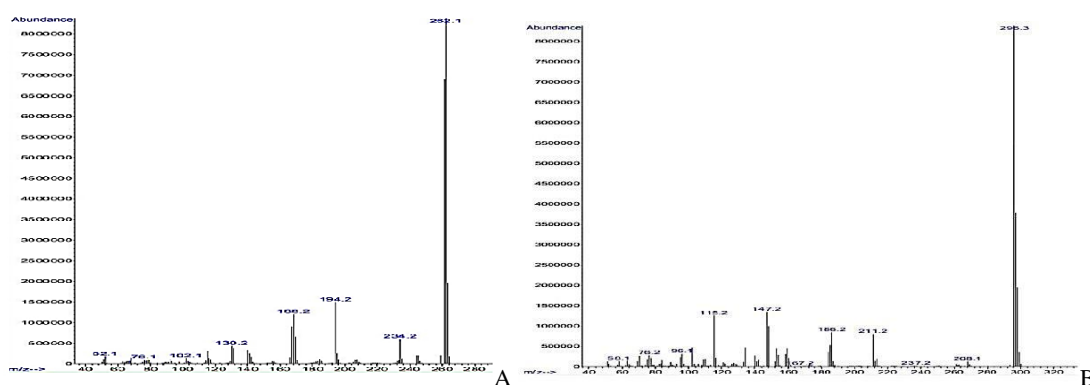


Figure. 5 depicts the mass spectrum for A) L1 B) L2

#### UV-Vis Spectroscopy:

Electronic absorption spectra of the Schiff bases was recorded in DMF solvent in concentration  $(1 \times 10^{-3} - 1 \times 10^{-4})$  M of ligands solutions. The electronic spectra of these compounds are given in Figure. 5 (A for L1 and B for L2). The uv-vis spectra show a strong absorption bands at the range (261-296 nm) and the range (357-381 nm) which are attributed to  $(\pi \rightarrow \pi^*)$  and  $(n \rightarrow \pi^*)$  transitions respectively (Ozcelikay et al., 2020).

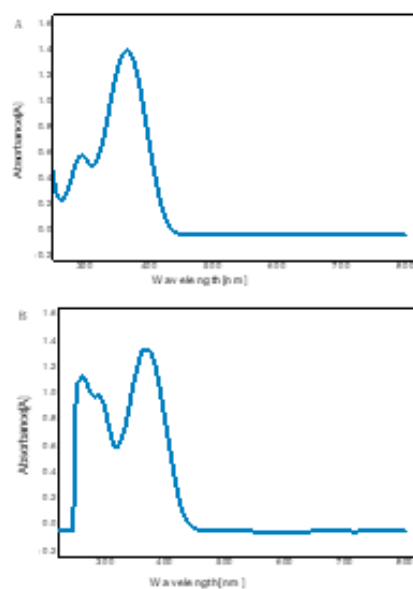
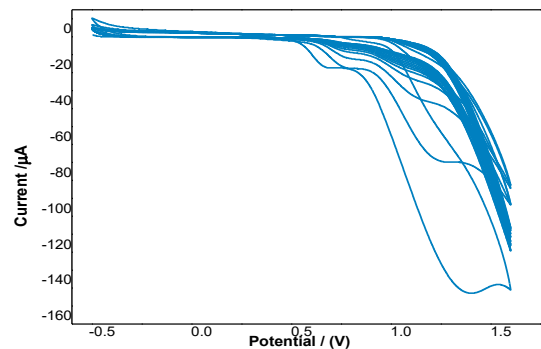


Figure. 6 UV-Vis spectrum of Ligand A) L1 and B) L2

#### Electropolymerisation of N, N'-(1,4-phenylene) bis(1-(1H-pyrrol-2-yl)methanimine)(L1) monomer

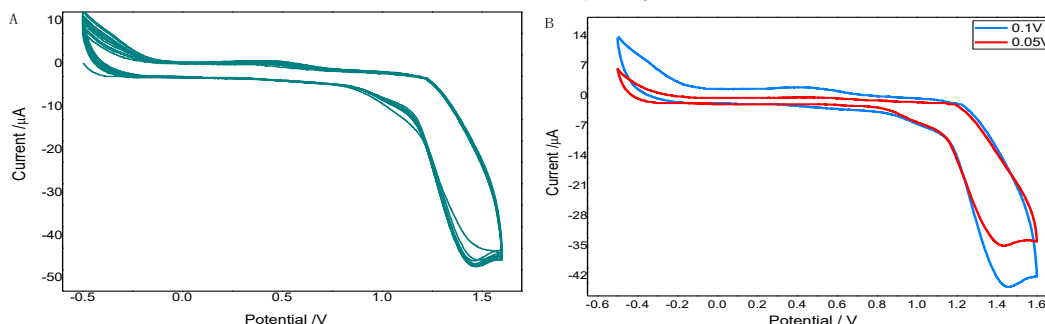
Electrochemical oxidation of active components like pyrrole and thiophene allow the film formation on the electrode surface. The electropolymerization of derivatives with imine group's structure leads to electrodeposition of polymers. Electropolymerization experiments were first achieved with Schiff base monomers (0.1M) by cyclic voltammetry method. These studies have conducted in acetonitrile solution containing supporting electrolyte (0.1M) from (TBAP) (Tetrabutyl ammonium perchlorate) with repeated scans between (-0.5- 1.6) V versus Ag/AgCl at scan rate 100 mV s<sup>-1</sup> for 15 cycles. The electropolymerization of L<sub>1</sub> was shown in Figure. 7. The first scan for L<sub>1</sub> displays an oxidation peak at (0.6) V corresponding to the irreversible monomer oxidation. This first scan has the highest intensity in the oxidation step while successive scans exhibited a continued decrease of current response. Overall, results have revealed that limited current response indicating the difficulty of polymer growth on electrode surface. Another probable explanation to polymerization results may be found in monomers structure. Therefore, these findings likely lead to poor electroactive polymers corresponding to multi- conjugated aromatic units (Alshawi et al., 2022, (Ozcelikay et al., 2020).



**Figure.7** Cyclic voltammogram of polymerization of ligand (L<sub>1</sub>) in CH<sub>3</sub>CN/TBAP solution with potential range (-0.5- 1.6 V) at 100 mV s<sup>-1</sup>.

#### Electrical study of L<sub>1</sub> polymer films

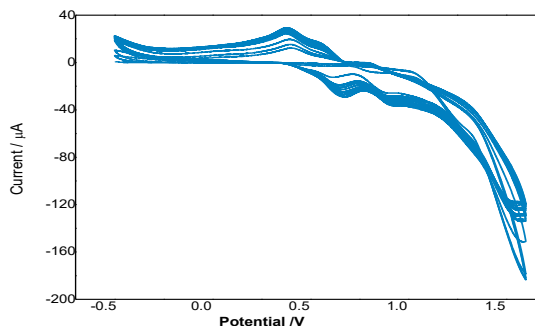
In order to study the electrochemical properties and electrostability of the polymer films, the polymer film L<sub>1</sub> was examined using cyclic voltammetry in a background electrolyte (monomer-free) of acetonitrile containing TBAP (0.1 M), as depicted in Figure. 8 A. In this study, the effect of scan rate on current response has examined in monomer-free, as shown in Figure. 8 B. From this curve, we can observe that current peak was proportional to the scan rate; this supports the assumption of good electroactivity and stability of the polymer film (Kaya et al., 2019)..



**Figure. 8 A)** shows cyclic voltammograms of the response of the polymer film prepared with scan rates 100 mV s<sup>-1</sup> of ligand L<sub>1</sub> in background electrolyte solution, 10 cycles. B) Shows cyclic voltammograms of the response of the polymer film (L<sub>1</sub>) in CH<sub>3</sub>CN/TBAP solution with potential range (-0.5- 1.6) at various scan rates 50 and 100 mV s<sup>-1</sup> (scan No.10).

#### Electropolymerisation of N, N'-(1,4-phenylene)bis(1-(thiophen-2-yl) methanimine) (L<sub>2</sub>) monomer

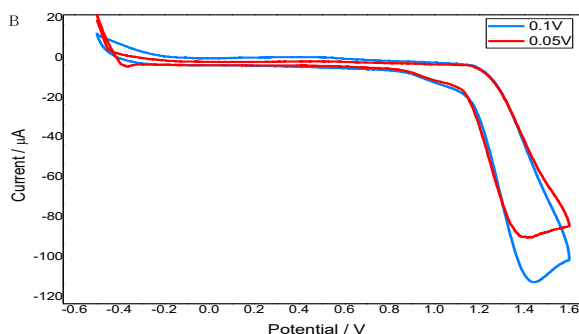
Electropolymerization experiments were first accomplished with L<sub>2</sub> monomer (0.1M) using cyclic voltammetry in acetonitrile solution containing (0.1M) of (TBAP) with repeated scans between (-0.5- 1.6) at at scan rate 100 mV s<sup>-1</sup> for 15 cycles. The electropolymerization of L<sub>2</sub> was shown in Figure. 9. The first scan for L<sub>2</sub> exhibited two oxidation peaks at 0.2 and 0.6V and two reduction peaks at 0.6 and 0.9 V. Successive scans have exhibited a continued decrease of current response. Generally, results have revealed that limited current response indicating the difficulty of polymer growth on electrode surface. Another probable explanation to polymerization results may be found in monomers structure. Therefore, these findings likely lead to poor electroactive polymers corresponding to multi- conjugated aromatic units (Kaya et al., 2019).



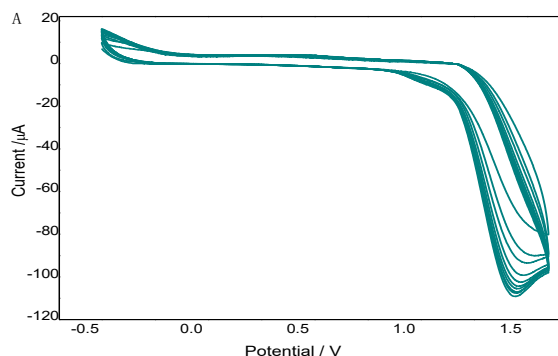
**Figure. 9** Cyclic voltammograms for polymerization of ligand (L<sub>2</sub>) in CH<sub>3</sub>CN/TBAP solution with potential range (-0.5- 1.6 V) at 100 mV s<sup>-1</sup>.

### Electrical study of L2 polymer films

In order to study the electrochemical properties and electro-stability of the polymer films, the polymer film L<sub>2</sub> was examined using cyclic voltammetry in a background electrolyte (monomer-free) of acetonitrile containing TBAP (0.1 M), as



depicted in Figure. 10 A. In this study, the effect of scan rate on current response has examined in monomer-free, as shown in Figure. 10 B. From this curve, we can observe that current peak was proportional to the scan rate; this supports the assumption of good electroactivity and stability of the polymer film.

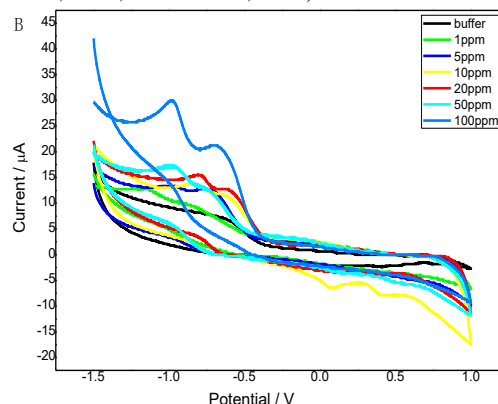
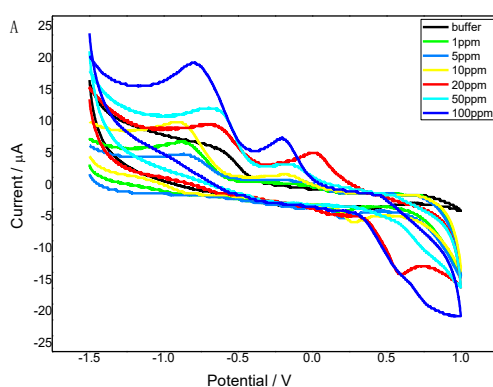


**Figure. 10 A) shows cyclic voltammograms of the response of the polymer film prepared with scan rates 100 mV s<sup>-1</sup> of ligand L<sub>2</sub> in background electrolyte solution, 10 cycles. B) Shows cyclic voltammograms of the response of the polymer film (L<sub>2</sub>) in CH<sub>3</sub>CN/TBAP solution with potential range (-0.5- 1.6) at various scan rates 50 and 100 mV s<sup>-1</sup> (scan No.10).**

### Detection of drugs by polymer electrode L<sub>1</sub>

The voltammetric responses as a function of scan rate were applied to detection drugs (Paracetamol) and (Metronidazole) and electroactivity with different concentrations 1 to 100 ppm at (PH=7) in Phosphate buffer. These films gave interesting results for detection of these drugs to 1 ppm. The aim of the work described in this paper is the development of electrochemical sensors from modified polymer electrodes with two (L<sub>1</sub> and L<sub>2</sub>), and to study the prospect of their use as sensing systems for certain drugs. The prepared modified electrode L<sub>1</sub> was immersed in 10 ml of 1 ppm solutions of both drugs in 0.1 M Phosphate buffer solution without stirring. The modified

electrodes, including drugs, were rinsed with pure water. Next, cyclic voltammetry experiments were achieved directly using a buffer solution with voltage ranging between -1.5 to 1V vs. Ag/AgCl at 100 mV s<sup>-1</sup> scan rates. Figure. 11 A and B shows the cyclic voltammograms of the L<sub>1</sub> electrode obtained with Paracetamol and Metronidazole with different concentrations (1- 100 ppm) using 100 mV s<sup>-1</sup> respectively. From this Figure. we can note the appearance of new redox current peaks at (-1.0,-0.25 and 0.4V) for Paracetamol and current peaks at (-1.0,-0.35, 0.15 and 0.42V) which can indicate to the ability of the modified electrode to sensing drugs in solution (Chaurasia et al., 2019, Uzma et al., 2018).

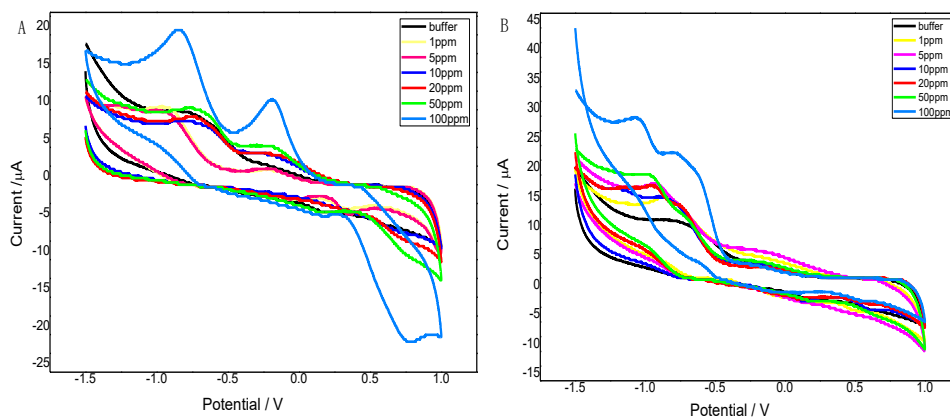


**Figure. 11 shows the cyclic voltammograms of the L<sub>1</sub> electrode for A) Paracetamol and B) Metronidazole with different concentrations (1- 100 ppm) using 100 mV s<sup>-1</sup>.**

### Detection of drugs by polymer electrode L<sub>2</sub>

The prepared modified electrode L<sub>2</sub> was applied as sensor to detection paracetamol and metronidazole in same conditions previous experiments which used with L<sub>1</sub> electrode. Figure. 12 A and B shows the cyclic voltammograms of the L<sub>2</sub> electrode obtained with Paracetamol and Metronidazole with different (Akila et al., 2013, (Boddula & Srinivasan, 2014).

concentrations (1- 100 ppm) using 100 mV s<sup>-1</sup> respectively. From this Figure. we can note the appearance of new redox current peaks at (-1.1,-0.3 and 0.25V) for Paracetamol and current peaks at (-1.0,-0.4 and 0.75V) which can indicate to the ability of the modified electrode to sensing drugs in solution



**Figure. 12** shows the cyclic voltammograms of the L2 electrode for A) Paracetamol and B) Metronidazole with different concentrations (1- 100 ppm) using 100 mV s<sup>-1</sup>.

## CONCLUSIONS

The aim of this project was to modify functionalized electrodes to application them as electrochemical sensor for drugs in solution. Preparation of modified electrode films and electrochemical performance was investigated by using electrochemical methods. All compounds which were prepared were characterized using spectroscopic (FTIR) techniques Proton and Carbon-13 Nuclear Magnetic Resonance and Electron Ionization Mass Spectroscopy. Further, all modified electrodes were characterized using cyclic voltammetry. The results indicated the successful synthesis of polymer films via CV and then films were examined by using various scan rates (50 and 100 mV s<sup>-1</sup>) to study electrochemical stability. L<sub>1</sub> and L<sub>2</sub> were electrodeposited on a GC electrode using electrochemical methods (CV) and then applied for detection of paracetamol and metronidazole in solution. Both modified electrodes exhibited good sensitivity during electro-detection of trace amounts of certain drugs.

## ACKNOWLEDGEMENTS

The authors thank the University of Basrah, College of Education for Pure Science, Chemistry department for providing the required materials and instruments for this work.

**Conflicts of interest:** "There are no conflicts to declare". The authors declare no competing financial interest.

## COMPLIANCE WITH ETHICAL STANDARDS STATEMENTS

### I. Ethical approval:

The manuscript is written in original and all the data, results pertaining to this manuscript are original according to the research performed. The authors followed academic integrity and have not copied any content/results from another source.

### II. Funding details (In case of Funding):

The authors of this manuscript did not receive any funding to perform the present research

### III. Conflict of interest

The authors of the study do not have any conflict of interest

## IV. Informed Consent:

The authors of the manuscript agrees to publish this research in the journal if it's considerable by the editors of the journal. The authors provide full consent for reviewing and publishing this manuscript.

**V.** All the authors of this study contributed equally in terms of performing the research as well as in preparing the manuscript. All the authors of the study followed the guidelines of the corresponding author. Any query/suggestion related to the manuscript can be reached to the corresponding author

## REFERENCES

- i. Akila, E., Usharani, M., & Rajavel, R. (2013). A REVIEW-GENERAL APPLICATIONS OF SCHIFF BASE TRANSITION METAL COMPLEXES DERIVED FROM 2-AMINOPHENOL. *International Journal of Advance Scientific and Technical Research*, 5(3), 457-469. Available online on <http://www.rspublication.com/ijst/index.html>
- ii. Almashal, F. A., Mohammed, M. Q., Ali Hassan, Q. M., Emshary, C. A., Sultan, H. A., & Dhumad, A. M. (2020). Spectroscopic and thermal nonlinearity study of a Schiff base compound. *Optical Materials*, 100, 109703. <https://doi.org/10.1016/j.optmat.2020.109703>
- iii. Alshawi, J. M. S., Mohammed, M. Q., Alesary, H. F., Ismail, H. K., & Barton, S. (2022). Voltammetric Determination of Hg<sup>2+</sup>, Zn<sup>2+</sup>, and Pb<sup>2+</sup> Ions Using a PEDOT/NTA-Modified Electrode. *ACS Omega*. <https://doi.org/10.1021/acsomega.2c02682>
- iv. Bartyzel, A. (2017). Synthesis, thermal study and some properties of N<sub>2</sub>O<sub>4</sub>-donor Schiff base and its Mn (III), Co (II), Ni (II), Cu (II) and Zn (II) complexes. *Journal of Thermal Analysis and Calorimetry*, 127(3), 2133-2147. <https://doi.org/10.1007/s10973-016-5804-0>
- v. Boddula, R., & Srinivasan, P. (2014). Benzoyl peroxide oxidation route to the synthesis of solvent soluble polycarbazole. *International Scholarly Research Notices*, 2014. <http://dx.doi.org/10.1155/2014/987236>

- vi. Chaudhary, N. (2013). In vitro antibacterial studies of some transition metal complexes of Schiff base derived from 2-aminophenol and furan-2-carbaldehyde. Archives of Applied Sciences and Research, 5(6), 227–231. Available online on <http://scholarsresearchlibrary.com/archive.html>
- vii. Chaurasia, M., Tomar, D., & Chandra, S. (2019). Synthesis, spectroscopic characterization and DNA binding studies of Cu (II) complex of Schiff base containing benzothiazole moiety. Journal of Taibah University for Science, 13(1), 1050–1059. <https://doi.org/10.1080/16583655.2019.1681724>
- viii. El-Sonbati, A. Z., Diab, M. A., El-Bindary, A. A., Abou-Dobara, M. I., & Seyam, H. A. (2016). Molecular docking, DNA binding, thermal studies and antimicrobial activities of Schiff base complexes. Journal of Molecular Liquids, 218, 434–456. <https://doi.org/10.1016/j.molliq.2016.02.072>
- ix. Emriye, A. Y. (2016). Synthesis and Characterization of Schiff Base 1-Amino-4-methylpiperazine Derivatives. Celal Bayar University Journal of Science, 12(3), 375–392.
- x. Kareem, I. K., Waddai, F. Y., & Abbas, G. J. (2019). Synthesis, Characterization and biological activity of Some Transition Metal Complexes with New Schiff Base Ligand Type (NNO) Derivative from Benzoin. Journal of Pharmaceutical Sciences and Research, 11(1), 119–124.
- xi. Kaya, İ., Sandal, B. S., & Karaer, H. (2019). Synthesis, characterization and electrochemical properties of poly (phenoxy-imine)s containing peril and tert-butyl units. Journal of King Saud University-Science, 31(1), 75–82. <https://doi.org/10.1016/j.jksus.2017.06.008>
- xii. Kumar, S. P., Suresh, R., Giribabu, K., Manigandan, R., Munusamy, S., Muthamizh, S., Dhanasekaran, T., Padmanaban, A., & Narayanan, V. (2015). Synthesis, characterization of nickel Schiff base complex and its electrocatalytic sensing nature for Hg<sup>2+</sup>. International Journal of Innovative Research in Science Engineering and Technology, 4, 123–130.
- xiii. Mohammed, M. Q., Ismail, H. K., Alesary, H. F., & Barton, S. (2022). Use of a Schiff base-modified conducting polymer electrode for electrochemical assay of Cd (II) and Pb (II) ions by square wave voltammetry. Chemical Papers, 76(2), 715–729. <https://doi.org/10.1007/s11696-021-01882-7>
- xiv. Ozcelikay, G., Karadurmus, L., Kaya, S. I., Bakirhan, N. K., & Ozkan, S. A. (2020). A review: New trends in electrode systems for sensitive drug and biomolecule analysis. Critical Reviews in Analytical Chemistry, 50(3), 212–225. <https://doi.org/10.1080/10408347.2019.1615406>
- xv. Singh, B. K., Prakash, A., Rajour, H. K., Bhojak, N., & Adhikari, D. (2010). Spectroscopic characterization and biological activity of Zn (II), Cd (II), Sn (II) and Pb (II) complexes with Schiff base derived from pyrrole-2-carboxaldehyde and 2-amino phenol. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 76(3–4), 376–383. <https://doi.org/10.1016/j.saa.2010.03.031>
- xvi. Uzma, A. L. I., Tirmizi, S. A., Taj, M. B., & Raheel, A. (2018). PALLADIUM (II) COMPLEXES BASED ON SCHIFF BASE LIGANDS: SYNTHESIS, CHARACTERIZATION, DNA BINDING, ANTI-BACTERIAL AND ANTI  $\alpha$ -GLUCOSIDASE ACTIVITY. Rev. Roum. Chim, 63(11), 1043–1051.
- xvii. Vairalakshmi, M., Princess, R., Rani, B. K., & Raja, S. J. (2018). Synthesis, structural elucidation, catalytic, antibacterial and antioxidant activity of thiophene derived mixed ligand metal complexes. Journal of the Chilean Chemical Society, 63(1), 3844–3849. <http://dx.doi.org/10.4067/s0717-97072018000103844>
- xviii. Warad, I., Ali, O., Al Ali, A., Jaradat, N. A., Hussein, F., Abdallah, L., Al-Zaqri, N., Alsahme, A., & Alharthi, F. A. (2020). Synthesis and spectral Identification of three Schiff bases with a 2-(piperazin-1-yl)-N-(thiophen-2-yl methylene) ethanamine moiety acting as novel pancreatic lipase inhibitors: Thermal, DFT, antioxidant, antibacterial, and molecular docking investigation. Molecules, 25(9), 2253. <https://doi.org/10.3390/molecules25092253>
- xix. Yassin, S. K., Alshawi, J. M. S., & Mohammedsalih, Z. A. (2020). Novel N2O2 Schiff base derived from 1, 2-Hydrazinedicarboximidamide and its complexes with Cu (II), Co (II), Ni (II), Mn (II) and Cr (III): Synthesis and characterization. Oriental Journal Of Chemistry, 05, 940–945.