Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.6, No.23, 2016
www.iiste.org

Cyclic Voltammetric Study of Paracetamol at Nickel Hexacyanoferrate Modified Carbon Paste Electrode

Tamiru Gashaw Gete* Marye Mulugeta Kassaw
College of Natural and Computational Sciences, Department of Chemistry,
Wolaita Sodo University, Ethiopia

Abstract

Electrochemical response characteristics of modified carbon paste electrode towards detection of paracetamol was investigated by cyclic voltammetric technique in 0.1 M acetate buffer solution containing 0.1 M KCl as supporting electrolyte. In the present work, carbon paste (CPE) was prepared by grinding the mixture of dry graphite powder and paraffin oil of ratio 75:25 respectively. Nickel Hexacyanoferrate modified carbon paste electrode was developed by immobilizing different ratios of Nickel Hexacyanoferrate. The best ratio was 20% (w/w) NiHCF; 55% graphite and 25% (w/w) paraffin oil respectively. The peak currents in voltammogram of paracetamol were increased at Nickel Hexacyanoferrate modified carbon paste electrode when compared to unmodified carbon paste electrode in 0.1 M acetate buffer solution containing 0.1 M KCl of pH 7.5 at scan rate of 100 mV/s. The electrode process of paracetamol was examined and then some of the experimental parameters which affect the electrochemical response of paracetamol, such as pH, scan rate and ratio of modified carbon paste electrode have been studied. The effect of scan rate showed that the electrode process was both diffusion and surface controlled.

Keywords: Paracetamol, Nickel Hexacyanoferrate, cyclic voltammetry, Modified Carbon Paste Electrode

1. Introduction

In 1893, the white, odorless crystalline compound with a bitter taste that became known as paracetamol was discovered. Initially, paracetamol was found in the urine of patients who had taken phenacetin and in 1889 it was demonstrated that paracetamol was a urinary metabolite of acetanilide. These discoveries, however, failed to attract much attention and were largely ignored at the time. The painkilling properties of paracetamol were discovered by accident when a similar molecule (acetanilide) was added to a patient's prescription about 100 years ago. But since acetanilide is toxic in moderate doses, chemists modified its structure to try and find a compound that was less harmful but which still retained the analgesic properties. One of these compounds is N-acetyl-Para-aminophenol, which is also known as acetaminophen in the US and paracetamol (from ***Para*-acet**yl-**am**ino-phen**ol**) in the UK. [1] Its structure is

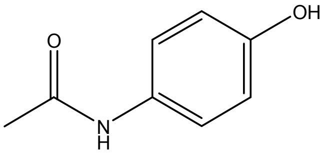

Fig.1a. Structure of paracetamol (N-**acet**yl-p-**amino phen**ol)

The electrochemical oxidation mechanism of paracetamol proceeds by a two-electron, two-proton process, and the result is *N*-acetyl-*p*-quinoneimine and the final product is *p*-benzoquinone.[2]

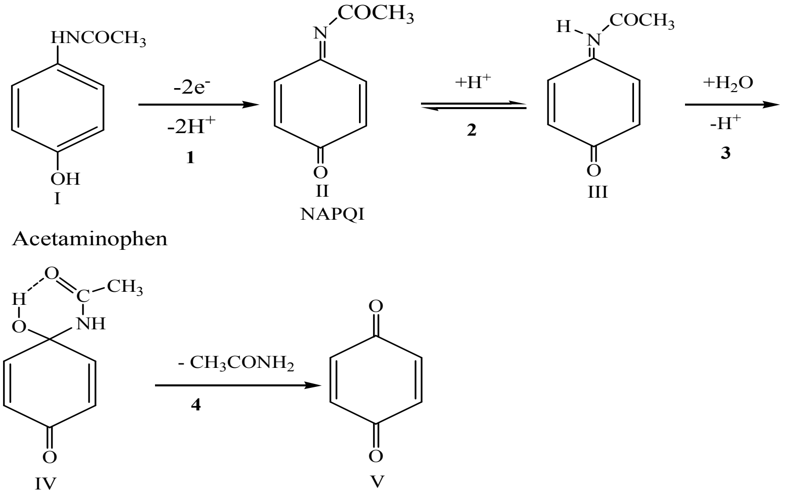

Fig.1b. Oxidation mechanism of paracetamol

Paracetamol is oxidized in a quick pH dependent step involving the loss of two electrons and two protons to give N-acetyl-*p*-quinoneimine (NAPQI) as shown in step 1 of the above mechanism. At a pH greater than or equal to pH 6.0 NAPQI (II) exists in its stable, unprotonated form. Under more acidic conditions (ex. pH 2.2), NAPQI is readily protonated to give species III, which is a less stable, but electrochemically active species. Species III then rapidly yields a hydrated species (IV), which is electrochemically inactive in the examined potentials. Finally, under increasingly more acidic conditions the hydrated species (IV) converts to benzoquinone (V). Only under extremely acidic conditions will the reduction of benzoquinone observed with cyclic voltammetry.[3]

The performance of the voltammetric techniques is strongly affected by the aspects of the working electrode material such as chemical and physical properties of electrode surfaces, applied potential, and adsorption and coatings applied to the electrode surface to enhance detection.[4] Good electrical conductivity of the electrodes is an important factor. Carbon-based electrodes usually have a wider potential range than the other solid electrodes because of their broad potential window, low background current; rich surface chemistry, chemical inertness, low cost and suitability for various sensing and detection applications. However, electron transfer rates observed at carbon surfaces are often slower than those observed on noble metal electrodes.[5-7]

Carbon-based electrodes are generally inexpensive and they are available in a variety of forms. Among the carbon based electrodes, Heterogeneous electrodes (electrochemical sensors composed not only of one uniform substance, but also consist of an electrically conductive material embedded in a matrix) are of particular importance. Because of the simple preparation and easy renewal of the surface, carbon has been used extensively as a working electrode for a variety of electrochemical applications. It has also been shown that carbon tends to be more compatible with biological tissues than other commonly used electrode materials. The ease and speed of preparation and of obtaining a new reproducible surface, the low residual current, porous surface and low cost are some advantages of CPEs over all other carbon electrodes. Therefore, the CPE can provide a suitable electrode substrate for preparation of modified electrodes.[5, 7-9]

The chemical modifications can impart higher sensitivity, selectivity, reproducibility and stability to electrochemical devices. Electroanalytical applications of the chemically modified electrodes are mostly based on achieving a certain degree of selectivity, which can then be coupled with the high sensitivity achievable from instrumental analysis. This selectivity can be obtained by either an analyte specific preconcentration effect or by selecting the properties of the layer so as to catalyze a specific reaction. [4, 10 -12]

In the present work the modification was done by adding Nickel (II) Hexacyanoferrate (III) for electrochemical investigation of paracetamol by using cyclic voltammetry. NiHCF modified electrode on carbon paste electrode surface (CPE/NiHCF) to improve the electrochemical behavior of the prepared modified electrode. This layer can be formed.[13]

$$[Fe(CN)_6]^{-4} + Ni^{+2} + 2K^+ \rightleftharpoons K_2Ni^{+2}[Fe(CN)_6] \rightleftharpoons KNi^{+2}[Fe^{+3}(CN)_6] + K^+ + e^-$$

Nickel hexacyanoferrate is an inorganic coordination compound with an open, zeolite-like structure which is characterized by well-defined, reversible and reproducible responses in supporting electrolytes containing not only potassium but also other alkali metal cations such as lithium, sodium. In comparison to other metal hexacyanoferrates, NiHCF can be viewed as an active cation-exchange matrix since both oxidized and reduced NiHCF structures permit unimpeded transport of electrolyte cations of different sizes while providing charge balance during the system's redox reaction.[14]

2. EXPERIMENTAL PART

2.1. Reagents and Chemicals

Graphite powder (BDH, England), paraffin oil (Nice), pure paracetamol (Addis pharmaceutical factory, Ethiopia), glacial acetic acid (Finken), sodium acetate trihydrate (Lobachemi Pvt.Ltd., India), and NaOH (Scharlau, Spain), HCl, Potassium chloride (Nice chemicals Pvt.Ltd.) Nickel chloride (Nice), potassium hexacyanoferrate III (KiraLight, India).

Distilled water and acetate buffer were used for the preparation of all solutions. The supporting electrolyte used for all experiments was a mixture of 0.1 mol L^{-1} CH_3COOH and 0.1 mol L^{-1} CH_3COOH buffer solution containing 0.1mol L^{-1} potassium chloride. Supporting electrolyte of acetate buffer solution containing 0.1 mol L^{-1} potassium chloride in the pH range 3-10 were prepared in distilled water and the pH of the solutions were adjusted by adding drops of concentrated HCl and NaOH. 15 mM Stock solution of paracetamol was prepared daily by dissolving in 100 ml of acetate buffer. The required concentration of paracetamol solutions were prepared by diluting the stock solution of paracetamol with acetate buffer. Graphite powder and paraffin oil of high purity were used in the preparation of a carbon paste.

2.2. Apparatus

All cyclic voltammetric measurements and processing of data were carried out in glass voltammetric cell, using BAS 50W CV voltammetric analyzer, which was connected to Dell Pentium personal computer containing three electrode system, Nickel (II) hexacyanoferrate (III) modified carbon paste electrode as a working electrode, silver-silver chloride as a reference electrode and platinum wire as auxiliary electrode. The pH of the buffer solution was measured with a 353 ATC digital pH meter with combination glass electrode. 1ml Syringe (Plastipak, Spain) and Whatman filter paper (Whatman, England) were used for the preparation of the working electrode in the experiment.

2.3. Preparation of Nickel (II) Hexacyanoferrate (III)

Nickel (II) Hexacyanoferrate (III) compound was prepared by mixing 0.25 mol L^{-1} potassium hexacyanoferrate (III) solution and a 0.5 mol L^{-1} Nickel chloride solution with the atomic ratio of Ni/Fe = 2. The precipitate obtained was filtered in whatman filter paper, washed with distilled water several times and dried at 25 ^{O}C for 72 hrs.

2.4. Preparation of working Electrodes

Bare carbon paste (w/w) was prepared by mixing graphite powder with Paraffin oil. The composition of the paste was 75 % (w/w) graphite powder and 25 % (w/w) paraffin oil. The mixture was homogenized with mortar and pestle for 30 minutes. The homogenized paste was packed in to the tip of a plastic syringe equipped with copper wire serving as an external electric contact. A copper wire was inserted from the backside of the syringe to provide electrical contact. Then the surface of the electrode was smoothed against a filter paper.

Modified carbon paste electrode was prepared by carefully mixing the dispersed graphite powder with NiHCF at varying ratio and subsequently added to 0.250 g of paraffin oil (25% w/w). The mixture was homogenized with mortar and pestle for 30 minutes. The modified carbon paste was packed into an electrode body, consisting of plastic syringe equipped with copper wire serving as an electric contact. Appropriate packing was achieved by pressing the electrode surface against a whatman filter paper.

3. RESULT AND DISCUSSION

3.1. Electrochemical Response of Paracetamol at Nickel (II) Hexacyanoferrate (III) Modified Carbon Paste Electrode.

The cyclic voltammograms of 5mM paracetamol at unmodified carbon paste electrode and Nickel Hexacyanoferrate modified carbon paste electrode as the working electrode in 0.1 M acetate buffer solution containing 0.1 M potassium chloride at pH 7.5 and scan rate 100 mV/s shown in Fig.3a below

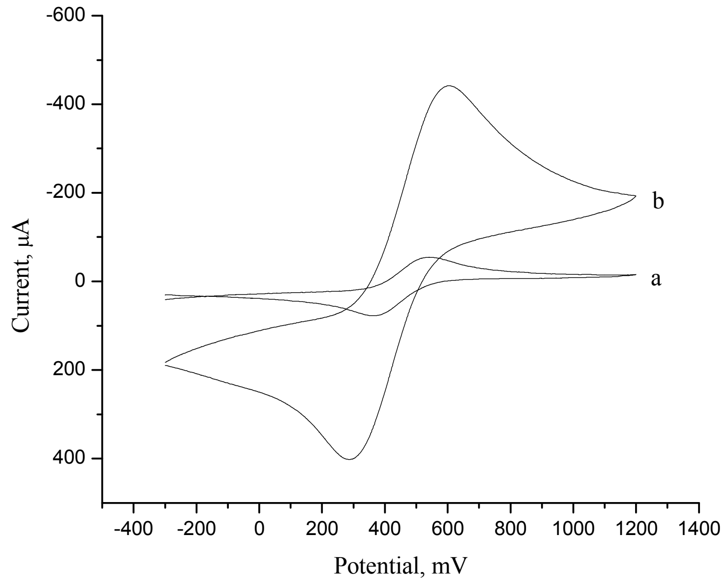

Fig.3a. Cyclic voltammograms of 5mM paracetamol obtained at BCPE (curve a) and NiHCF Modified carbon paste electrode (curve b) in 0.1 M acetate buffer solution containing 0.1 M KCl at pH 7.5 with scan rate 100mV/s.

In comparison to unmodified carbon paste electrode, electrochemical response of paracetamol at Nickel Hexacyanoferrate modified carbon paste electrode after modification with 20% of Nickel Hexacyanoferrate the electrode shows improvement in enhancement of both cathodic and anodic peak current, 2.41×10^{-4} A and -2.815×10^{-4} A respectively (curve b). The oxidation peak potential occurs at 597.6 mV and reduction peak potential at 300.2 mV (Vs.Ag/AgCl). The peak to peak separation (ΔE_p) was found to be 297 mV and the ratio of redox peak current (Ipa/Ipc) was 1.17, which were the characteristics of irreversible electrode process.

The cyclic voltammograms of 5mM paracetamol in 0.1 M acetate buffer solution containing 0.1 M potassium chloride of pH 7.5 showed five times increase in the oxidation peak current enhancement of modified carbon paste electrode with Nickel Hexacyanoferrate as compared to bare carbon paste electrode shown in Fig.3a above. These results essentially support with the fact of the voltammetric response of the modified electrode is based on the phenolic group oxidation of acetaminophen with hexacyanoferrate (III) complex, strong promoting effect, high stability and high electrocatalytic activity of Nickel Hexacyanoferrate in the carbon paste electrode for the redox reaction of acetaminophen.[2]

3.2. Effect of Electrode Composition on Peak Current

One of the most effective parameters in modified electrodes performances is the compositions. The amount of the modification agents in the carbon paste usually varies between 10 to 30 % (w/w), depending on the characteristics and the capability of the modification agent of forming enough active sites in modified carbon paste.[4]

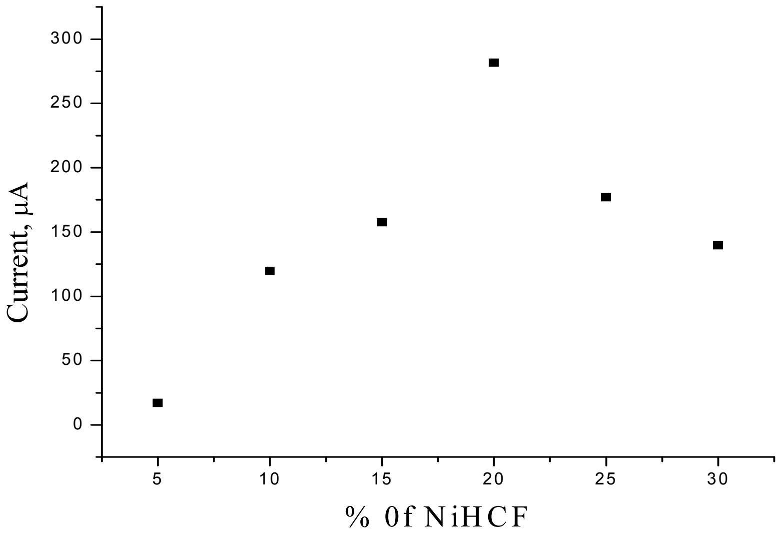

Fig.3b. Effect of modifier amount on anodic peak current in 5mM paracetamol. 0.1 M acetate buffer solution containing 0.1 M potassium chloride of pH 7.5 at scan rate 100 mV/s.

Fig.3b shows the effect of the electrode composition on their voltammetric profiles in acetate buffer solution at pH 7.5. It was prepared of different ratio (%) by adding different amounts of Nickel Hexacyanoferrate.

As the quantity of Nickel Hexacyanoferrate increases from 5 % (w/w) to 30 % (w/w) NiHCF, the anodic peak current was increased up to 20 % (w/w) for 5mM paracetamol in 0.1 M acetate buffer solution containing 0.1 M KCl at pH 7.5, and further decrease by increasing the quantity of modifier up to 30 % (w/w) of Nickel Hexacyanoferrate. CPE content greater than 20 % (w/w) of NiHCF resist voltammetric profiles. This may be due to a decreasing of the graphite content in the paste. A decrease in oxidation sites in the paste leading to unsuitable electrode for electrochemical oxidation of paracetamol and consequent reduction of the actual electrode area. Therefore the role of modifier is to enhance the peak current for the oxidation and reduction of paracetamol. The optimum carbon paste composition was found for an electrode composition of 20 % (w/w) NiHCF, 55 % (w/w) graphite and 25 % (w/w) paraffin oil.

3.3. Effect of pH

The electrochemical behavior of the carbon paste electrode modified with NiHCF was studied over a large pH range between 3.3 and 10.4 in solution containing 5 mM of paracetamol in 0.1 M acetate buffer solution containing 0.1 M KCl as supporting electrolyte at scan rate 100 mV/s to optimize the electrochemical response of modified carbon paste electrode for the oxidation and reduction of paracetamol in Fig.3c below

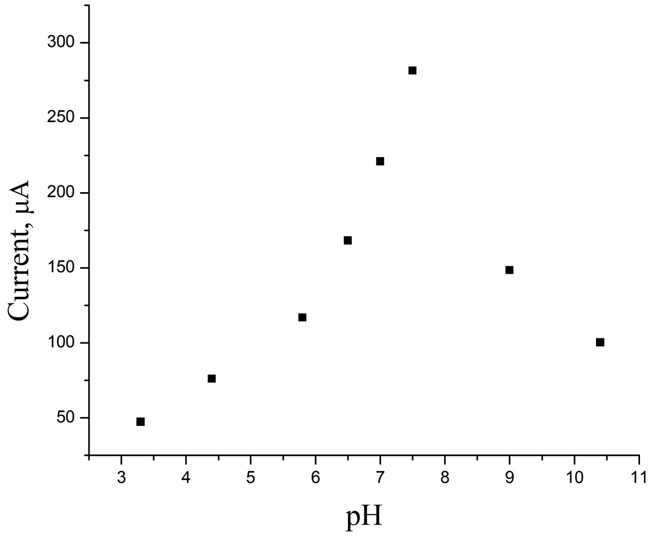

Fig.3c. Effect of variation of pH on the anodic peak current of 5mM paracetamol in 0.1 M acetate buffer solution containing 0.1 M potassium chloride at NiHCF modified carbon paste electrode. Scan rate: 100 mV/s.

The electrochemical oxidation of paracetamol at NiHCF modified carbon paste electrode is pH dependent. The results are illustrated in Fig.3c, from which it can be seen that the peak currents increases with increasing pH up to 7.5 and then decreased for higher pH values. The better sensitivity and shape of the voltammogram was observed at pH 7.5 suggested it as optimal pH value. At a pH near to 7 N-acetyl-p-Quinone imine exists in its stable and unprotonated form. The decrease in the anodic peak current above pH 7.5 was observed in Fig.3c above. Most hexacyanoferrate can maintain stable electrochemical response only in neutral or weakly acidic solution, except tin hexacyanoferrate, which maintain stable electrochemical response in basic solution, while in alkaline solution the hydrolysis of iron and other transition metal ions can cause deterioration of the frame work of metal hexacyanoferrate complex and are gradually dissolved.[15]

3.4. Effect of Variation of Scan Rate on the Peak Currents of Paracetamol

The effect of varying scan rates on the cyclic voltammograms of 5mM paracetamol solution using NiHCF modified carbon paste electrode as working electrode in 0.1 M acetate buffer solution containing 0.1 M potassium chloride of pH 7.5 supporting electrolyte was studied over 50- 400 mV/s in Fig. 3d below

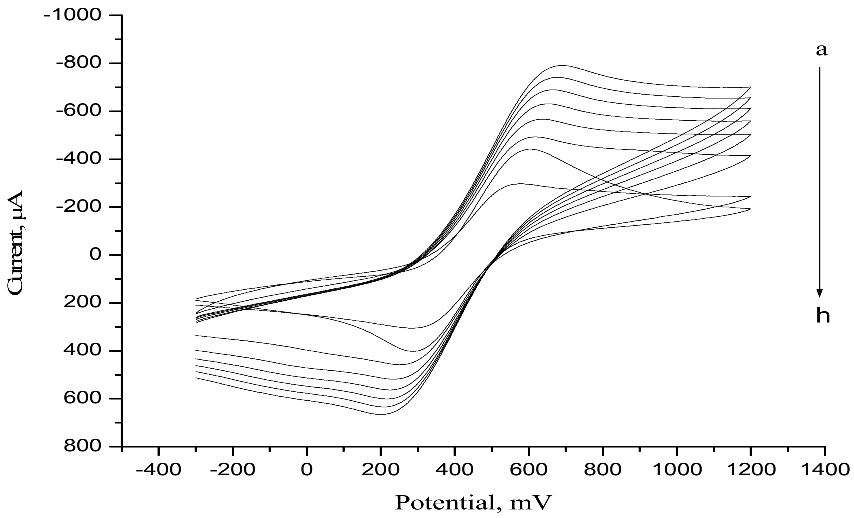

Fig.3d. Cyclic voltammograms of different scan rate in the presence of 5x10^{-3} M paracetamol at NiHCF modified carbon paste electrode in 0.1 M acetate buffer solution containing 0.1 M potassium chloride, scan rate 50 – 400 mV/s.

It was found that with the increase of the scan rate, the oxidation current increased gradually and the oxidation peak potential shifted towards more positive potential. This is also the characteristics of irreversible electrode process. Each curve has almost the same form from 150 mV/s to 400 mV/s but it is clearly seen that the peak current increases with increasing scan rate as shown in Fig.3d above. This can be rationalized by diffusion layer and the time taken to record the scan. It is obvious that the cyclic voltammogram will take more time to record as the scan rate is decreased.

Therefore, the size of the diffusion layer above the Nickel Hexacyanoferrate electrode surface is different depending up on the voltage scan rate used. In a slow voltage scan rate the diffusion layer will grow much further from the electrode in comparison to a fast scan rate. From these results, a scan rate of 100 mV/s was chosen for the further studies.[16]

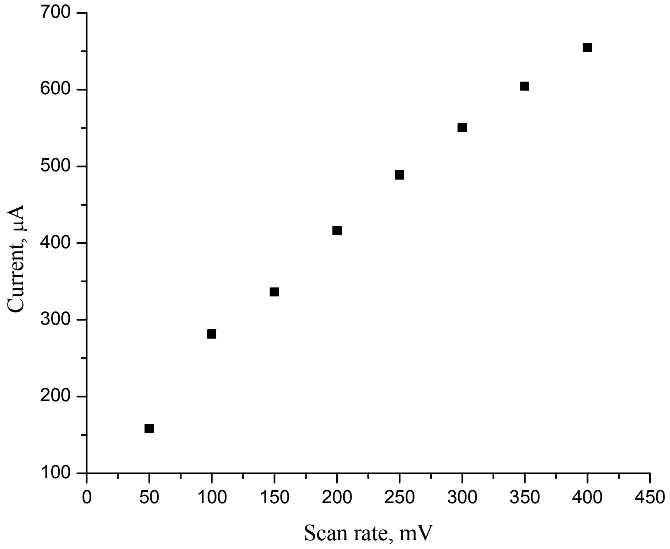

Fig.3e. Effect of variation of scan rate on the anodic peak current of 5x10^{-3} M paracetamol in 0.1 M acetate buffer solution containing 0.1 M potassium chloride at pH 7.5, scan rate: 50 mV/s – 400 mV/s.

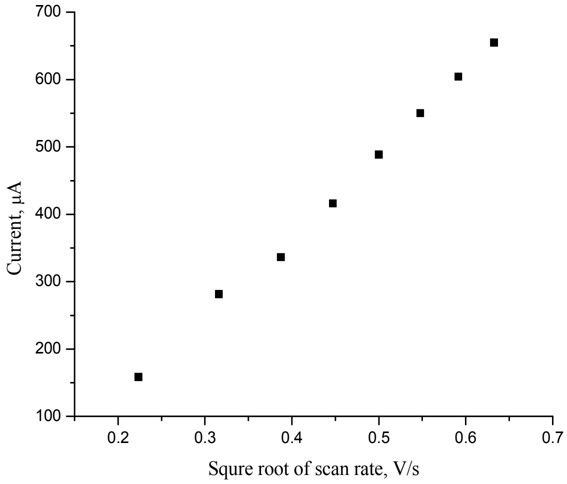

Fig.3f. The dependence of peak current of 5mM paracetamol on square root of scan rate at Nickel Hexacyanoferrate modified carbon paste electrode in 0.1 M acetate buffer solution containing 0.1 M potassium chloride at pH 7.5.

The graph of anodic peak current (i_{pa}) versus scan rate (V) and square root of scan rate ($V^{1/2}$) were plotted. The graph obtained were nearly straight lines shown in Fig.3e and Fig.3f above. In the range from 50 mV/s to 400 mV/s the anodic peak currents were proportional to the scan rate (V) and also the square root of scan rate ($V^{1/2}$) with correlation coefficient, r^2, 0.986 and 0.996 for i_{pa} Vs V and i_{pa} Vs $V^{1/2}$ respectively. The dependence of anodic peak current on the scan rate and square root of scan rate indicated that, the electrode transfer reaction was both adsorption controlled and diffusion controlled.

4. Conclusion

In the present study, the carbon paste electrode modified with NiHCF showed good electrocatalytic response for the oxidation of acetaminophen. The anodic peak current of paracetamol at NiHCF modified carbon paste electrode appeared with enhancement of five times compared to unmodified carbon paste electrode. The effect of composition of modified electrode, pH and scan rate was observed on voltammetric response. The optimum conditions for the oxidation of paracetamol were as follows: composition of the electrode 20 % (w/w) NiHCF; acetate buffer containing 0.1 M potassium chloride; pH 7.5 and scan rate of 100 mV/s. The cyclic voltammogram using modified NiHCF electrode shows irreversible nature for paracetamol with the enhancement in current signal. The variation of scan rate study shows that the system undergoes both diffusion and surface controlled electrode process.

References

1. Bradley N 1996 BMJ should use paracetamol instead of acetaminophen in its index. *BMJ.* **313 (7058)** 689.
2. Marcos FST, Luiz HM, Orlando F, Fernando CM and Ronaldo SN 2009 Determination of Analgesics (Dipyrone and Acetaminophen) in Pharmaceutical Preparations by Cyclic Voltammetry at a Copper (II) Hexacyanoferrate (III) Modified Carbon Paste Electrode. *Current Analytical Chemistry.* **5(4)** 305.
3. Miner DJ, Rice JR, Riggin R.M and Kissinger PT 1981 Voltammetry of acetaminophen and its metabolites. *Anal. Chem.* **53** 2258-2263.
4. Bengi U and Sibel AO 2007 Solid Electrodes in Electroanalytical Chemistry: Present Applications and Prospects for High Throughput Screening of Drug Compounds. *Combinatorial Chemistry & High Throughput Screening.* **10(7)**
5. Wang J 2006 Electroanalytical Chemistry, 3rd ed.; Wiley-VCH Pub: New Jersey
6. Wang J, Jianmin L, Samo BH, Percio AM and Farias BO 2000 Bismuth-Coated Carbon Electrodes for Anodic Stripping Voltammetry. *Anal. Chem.* **72 (14)** 3218–3222.
7. Uslu B and Ozkan SA 2007 Electroanalytical application of carbon based electrodes to the pharmaceuticals. *Anal. Lett.* **40** 817-853.
8. Kalcher K, Svancara I, Metelka R, Vytras K and Walcarius A 2006 Heterogeneous carbon electrochemical sensors. *Encyclopedia of sensors.* **10**
9. Svancara I, Vytras K, Barek J and Zima J 2001 Carbon paste electrodes in modern electroanalysis. *Anal. Chem*. **31** 311
10. Honeychurch K.C and Hart JP 2003 Screen-printed electrochemical sensors for monitoring metal pollutants. *Trends in Analytical Chemistry*. **22** 456
11. John PH and Stephen AW 1994 Screen-printed Voltammetric and Amperometric electrochemical sensors for decentralized testing. *Electroanalysis*. **6** 617
12. Ivan S, Petr K, Martin B and Karel V 2005 Groove electrodes a new alternative of using carbon pastes in electroanalysis. *Electrochem. Comm.* **7** 657
13. Hathoot AA, Elmaghrabi S and Abdelazzem M 2011 Electrochemical and electrocatalytic properties of hybrid films composed of conducting polymer and metal hexacyanoferrate. *Int. J. Electrochem. Sci*. **6** 637 – 649
14. Richard PJ and Sriman, NS 2009 Catalytic Oxidation of Dopamine at a Nickel Hexacyanoferrate Surface Modified Graphite Wax Composite Electrode Coated with Nafion. *Electroanalysis*. **21(13)** 1481 – 1489.
15. Sabzi RE, Hasanzadeh A, Ghasemlu K and Heravi, P 2007 Preparation and characterization of carbon paste electrode modified with tin and hexacyanoferrate ions. *J. Serb. Chem. Soc.* **72 (10)** 993-1002.
16. Bard A J and Faulkner L R 2000 Electrochemical Methods: Fundamentals and Applications, 2nd ed.; John wiley & sons, inc.: New York

Acknowledgements

The authors gratefully acknowledge P.A.Subramanian (PhD) for his unreserved valuable guidance, consistence encouragement and constructive comment throughout my project work, Mekelle University Department of chemistry, Ethiopian Ministry of Education (MOE) and Addis Pharmaceutical Manufacturing Share Company, for sample and financial support.