

Electrochemical Behavior of 1-Methyl-2-oxo-4,5-dichloroquinolone in Aprotic Media at Glassy Carbon Electrode

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Abstract: Many quinolones and substituted quinolones are well known for their biological activity. The redox characteristics of such biological substances may provide valuable information about the redox behavior in living systems. The present scenario involves electrochemical reduction of 1-methyl-2-oxo-4,5-dichloroquinolone in aprotic solvent dimethylsulphoxide, carried out in basic medium which is irreversible and involves transfer of two electrons. A linear behavior of peak current *versus* square root of scan rate indicates that the electrochemical reduction processes are diffusion controlled.

Keywords: Quinolone, Cyclic voltammetry, Glassy carbon electrode, Diffusion-controlled, Irreversible

Introduction

Quinolones are very important compounds because of their pharmacological properties. Members of this family have wide applications in medicinal chemistry, being used as anti-malarial, anti-inflammatory, anti-asthmatic, anti-bacterial, anti-hypertensive and tyrosine kinase inhibiting agents¹⁻³. The structural core of quinolone has been generally synthesized by various conventional named reactions⁴⁻⁷. The quinolone ring systems are important structural units in naturally occurring alkaloids and synthetic analogues with interesting biological activities. Therefore, the development of new and efficient synthetic route for the preparation of their analogues is of importance in both synthetic organic chemistry and medicinal chemistry.

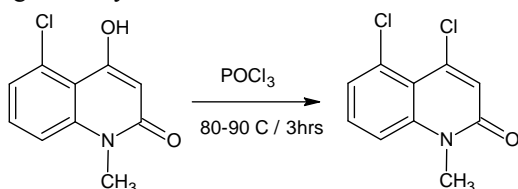
Electrochemical synthesis is much more economical eco-friendly, avoid massive chemical effluents. Such type of reactions is easy to control automatically as well as their reaction conditions are generally mild and effects of potential, pH, buffer and solvent can be studied⁸⁻¹¹. Electrochemical technique is a novel alternative method in organic synthesis, where one can synthesize the desired compound by oxidation or reduction of the substrate¹²⁻¹³.

The electrochemical reduction is one of the greener approaches because it is pollution free as electrons may be regarded as one of the reagents and it reduces the use of at least one hazardous chemical reagent¹⁴⁻¹⁵. As cyclic voltammetry is the most effective and versatile

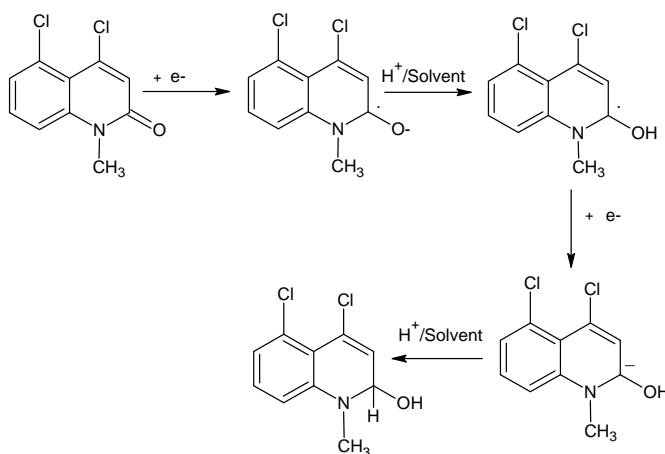
technique in the diagnosis of complex electrode mechanisms, in the present study this technique is employed to examine the electrochemical reduction of carbonyl group in BR buffer solution.

Experimental

All the reagents used were of analytical grade. 1-methyl-2-oxo-4,5-dichloroquinolone (Compound 1, Figure 1) was prepared from 1-methyl-2-oxo-4-hydroxy-5-chloroquinolone as shown in Scheme 1. Stock solution of compound 1 was prepared at a concentration of $1 \times 10^{-3} \text{ mol L}^{-1}$ in DMSO. More diluted solutions were prepared from this solution in DMSO just prior to analysis. Britton-Robinson (BR) universal buffer of pH 12 were prepared and used and as a supporting electrolyte.



Scheme 1



Scheme 2. Proposed Mechanism of Electrochemical Reduction

Apparatus

The voltammetric measurements were carried out on an electrochemical analyzer (CH instruments, USA, Model CHI 1230) equipped with a 10 mL single compartment three electrode glass cell. Glassy carbon electrode was used as the working electrode, a platinum wire as counter electrode and Ag/ AgCl electrode as reference electrode. All solutions used in the voltammetric system were deaerated with nitrogen for at least 15 min before executing the voltammetric experiments. All experiments were carried out at room temperature of $25 \pm 1 \text{ }^\circ\text{C}$. The GCE was polished using 0.3 micron aluminum oxide before each experiment.

Results and Discussion

The electrochemical behavior of 1-methyl-2-oxo-4,5-dichloroquinolone (Figure 1) at a GCE was studied by cyclic voltammetry in BR buffer of pH 12.0. The cyclic voltammogram obtained

for 1×10^{-6} mol L⁻¹ solution (Figure 2) shows one distinct and well defined cathodic peak at -0.3V. No peak was observed on the reverse scan, indicating the irreversibility of electrode processes. The proposed mechanism involves single step electrochemical reduction which shows one cathodic peak in which carbonyl group is reduced directly to hydroxyl group by one two-electron charge transfer step (Scheme 2).

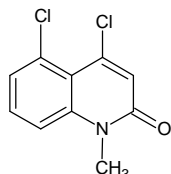


Figure 1. 1-Methyl-2-oxo-4,5-dichloroquinolone (Compound 1)

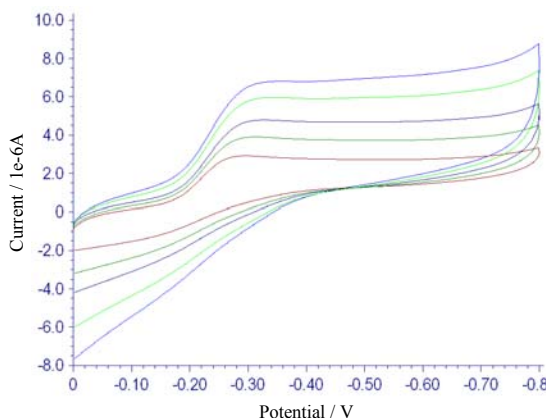


Figure 2. Cyclic voltammogram of 1×10^{-6} mol L⁻¹ compound 1 in Britton-Robinson buffer at different scan rates: (a) 25 mV⁻¹ (b) 50 mV⁻¹ (c) 75 mV⁻¹ (d) 100 mV⁻¹ (e) 125 mV⁻¹

Scan rate dependence

The study of effect of scan rate was made in order to postulate the mechanism and the feasibility of electrochemical reactions involved at GCE. It was observed in all cases, that the peak potential (E_{pc}) value shifts towards more negative side as the sweep rate (ν) increases. The electrochemical data obtained are summarized in Table 1. It is well evident from the results that the cathodic peak current (i_{pc}) increases with increasing sweep rate. The cathodic shift of peak potential with sweep rate, absence of anodic wave on reverse scan and fairly constant value of $i_{pc} / \nu^{1/2}$ at higher scan rates confirm the reduction process to be diffusion controlled irreversible one.

Table 1. Effect of scan rate on cyclic voltammetric parameters

SR(v) mV/s	i_p , μA	log SR, mV/sec	E_p , V	$E_{p/2}$, V	$\nu^{1/2}$, mV/sec	log i_p , μA	α
25	1.999	1.397	-0.267	-0.1919	5.0	0.300	0.388
50	2.496	1.698	-0.302	-0.1948	7.071	0.397	0.388
75	2.983	1.875	-0.326	-0.1931	8.66	0.474	0.387
100	3.611	2.0	-0.351	-0.1831	10	0.557	0.387
125	4.012	2.096	-0.368	-0.1764	11.18	0.603	0.388

The relationship between the peak current (i_{pc}) and the voltage scan rate (v) was examined using the solution of concentration $1 \times 10^{-6} \text{ molL}^{-1}$ and recording cyclic voltammograms at different scan rates of 25, 50, 75, 100 and 125 mVs^{-1} (Figure 2). The relationship between the cathodic peak current i_p (μA), the diffusion coefficient of the electro active species, D_o ($\text{cm}^2 \text{ s}^{-1}$) and the scan rate, v (mVs^{-1}), is described by the modified Randles-Sevcik equation¹⁶ (Eq. 1)

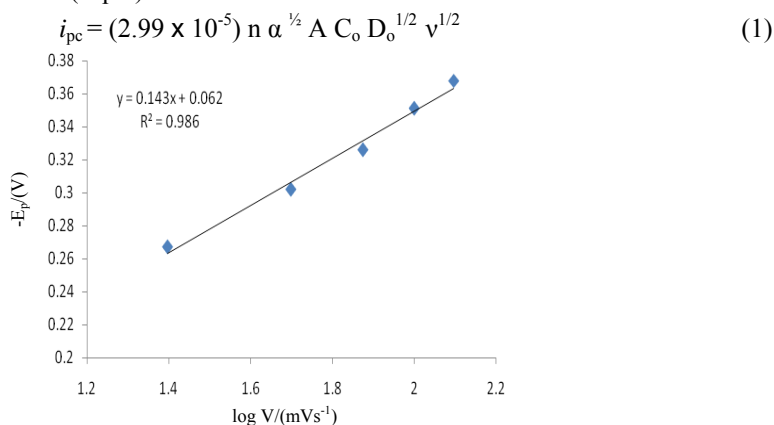


Figure 3. Plot of $-E_p$ vs. $\log v$ for the cyclic voltammogram of $1 \times 10^{-6} \text{ molL}^{-1}$ compound 1 in Britton-Robinson buffer of pH 12.0

Where 'n' is the number of electrons exchanged in reduction, α is the transfer coefficient, A is the apparent surface area of the electrode (cm^2) and C_o is the concentration of the electro active species (mol dm^{-3}). The transfer coefficient for an irreversible process can be calculated from following equation¹⁷ (Eq. 2)

$$[E_{pc} - E_{pc/2}] = 47.7 / \alpha \quad (2)$$

Where $E_{pc/2}$ is the potential at which the current equals one half of the peak current. The height of the peak decreased with respective scans, its potential being not shifted. The relationship between the peak potential (E_{pc}) and the scan rate (v) is expressed as (Eq.3),

$$E_{pc} = (2.303RT \alpha n F) \log (RT / \alpha n F) - (2.303RT \alpha n F) \log v \quad (3)$$

In the present work, the plot of $-E_{pc}$ vs. $\log v$ was linear having a correlation coefficient of 0.995 (Figure 3) in pH 12.0 and can be expressed as (Eq. 4),

$$(E_{pc}) = 0.143 \log v + 0.062(\text{V}), \quad (4)$$

According to the Randles - Sevcik equation in a linear diffusion controlled process (i_{pc} versus $v^{1/2}$), for the adsorptive process ($\log i_{pc}$ versus $v^{1/2}$) and (i_{pc} versus v). The peak currents of Compound I were plotted against the scan rate. The peak current (i_{pc}) increases linearly with the increasing scan rate. A linear relationship was observed between the reduction peak current versus the square root of the scan rate (Figure 4, 5 & 6) with the significant correlation coefficient of 0.98 indicating thereby that the electrode process is diffusion-controlled between the scan rate of 25 and 125 mVs^{-1} which is expressed by the equation,

$$i_{pc} (\mu\text{A}) = 0.330 v^{1/2} (\text{mVs}^{-1}) - 0.245 ; r^2 = 0.984 \quad (5)$$

The adsorption process was also identified by a plot of $\log i_p$ versus $\log v$ (Figure 7) giving a straight line which can be expressed by the equation;

$$\log i_{pc} (\mu\text{A}) = 0.436 \log v (\text{mVs}^{-1}) + 0.325 ; r^2 = 0.979 \quad (6)$$

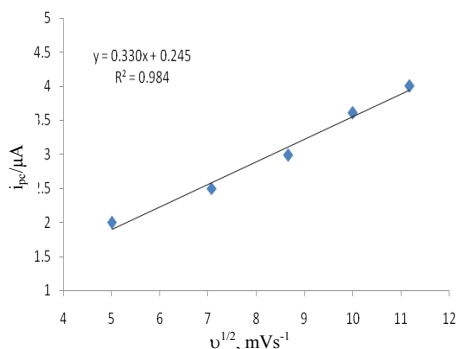


Figure 4. Plot of i_p vs. $v^{1/2}$ for the cyclic voltammogram of 1×10^{-6} molL⁻¹ compound 1 in Britton-Robinson buffer of pH 12.0

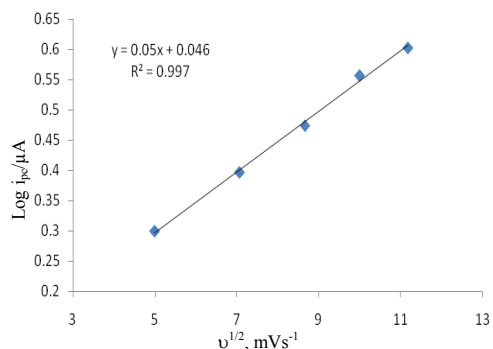


Figure 5. Plot of $\log i_p$ vs. $v^{1/2}$ for the cyclic voltammogram of 1×10^{-6} molL⁻¹ compound 1 in Britton-Robinson buffer of pH 12.0.

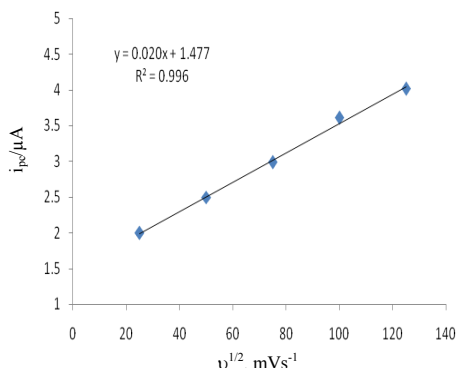


Figure 6. Plot of i_p vs. v for the cyclic voltammogram of 1×10^{-6} molL⁻¹ compound 1 in Britton-Robinson buffer of pH 12.0

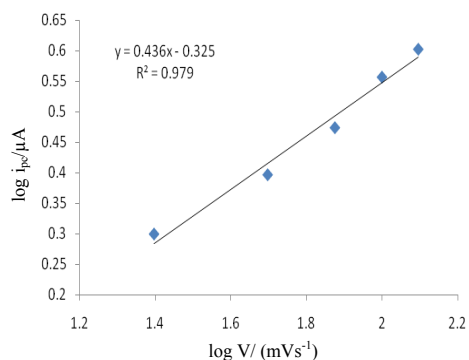


Figure 7. Plot of $\log i_p$ vs. $\log v$ for the cyclic voltammogram of 1×10^{-6} molL⁻¹ compound 1 in Britton-Robinson buffer of pH 12.0.

The value of α as calculated from the slope of the plot between E_{pc} vs. $\log v$ is 0.388. In most of the irreversible cases α lies in the range of 0.30 to 0.70. On the basis of above studies it is observed that the electrochemical reduction of Compound I at pH 12.0 occurs in irreversible way and almost constant α values clearly indicates that the reaction is diffusion controlled.

Effect of concentration

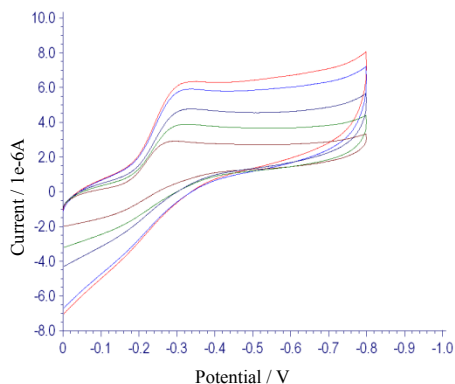
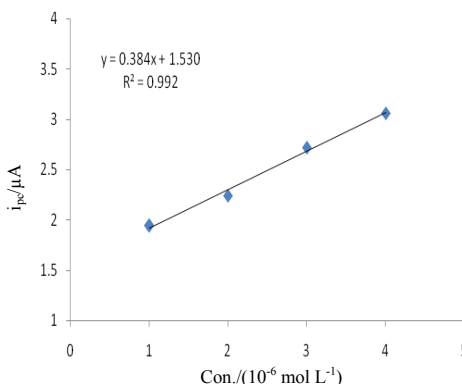
Table 2 summarizes voltammetric data for Compound 1 in the highly basic medium. Concentration likewise affected the magnitude of the peak current. This was seen by obtaining scans of 1×10^{-6} , 2.0×10^{-6} , 3.0×10^{-6} , 4.0×10^{-6} and 5.0×10^{-6} mol L⁻¹ of desired compound 1 using a scan rate of 50 mVs⁻¹ at pH 12.0. The effect of concentration for compound 1 on the appearance of the cyclic voltammograms can be seen in Figure 8.

The Randles-Sevcik equation also indicates that i_{pc} is directly proportional to concentration. A plot of this equation ($i_{pc}/\text{conc.}$) for compound 1 is shown in Figure 9 curve yields a straight line.

$$i_{pc} (\mu\text{A}) = 0.384 (10^{-6} \text{ M}) + 1.530, \quad (r^2 = 0.992) \quad (7)$$

Table 2. Effect of concentration on cyclic voltammetric parameters

Concentration, mol/L	i_{D_2} , μA	$\log i_{D_2}$, μA	E_{D_2} , V	$E_{D_2/2}$, V
1.0×10^{-6}	1.941	0.2880	-0.294	-0.1919
2.0×10^{-6}	2.241	0.3504	-0.325	-0.1905
3.0×10^{-6}	2.720	0.4345	-0.337	-0.1934
4.0×10^{-6}	3.062	0.486	-0.333	-0.1791
5.0×10^{-6}	3.315	0.5204	-0.350	-0.1872

**Figure 8.** Cyclic voltammogram of compound I in Britton-Robinson buffer at scan rate 50 mVs^{-1} in different concentrations: (a) $1 \times 10^{-6} \text{ mol L}^{-1}$ (b) $2.0 \times 10^{-6} \text{ mol L}^{-1}$ (c) $3.0 \times 10^{-6} \text{ mol L}^{-1}$ (d) $4.0 \times 10^{-6} \text{ mol L}^{-1}$ (e) $5.0 \times 10^{-6} \text{ mol L}^{-1}$ **Figure 9.** Plot of i_p vs. conc. for the cyclic voltammogram of compound I in Britton-Robinson buffer at scan rate 50 mVs^{-1} in different concentrations: (a) $1 \times 10^{-6} \text{ mol L}^{-1}$ (b) $2.0 \times 10^{-6} \text{ mol L}^{-1}$ (c) $3.0 \times 10^{-6} \text{ mol L}^{-1}$ (d) $4.0 \times 10^{-6} \text{ mol L}^{-1}$ (e) $5.0 \times 10^{-6} \text{ mol L}^{-1}$.

Conclusion

The investigations have demonstrated that examined 1-methyl-2-oxo-4,5-dichloroquinolone gave a well defined single irreversible peak at glassy carbon electrode in DMSO. The carbonyl group undergoes one step electrochemical reduction to form hydroxyl group via transfer of two electrons and shows one cathodic peak. The electrochemical process is diffusion controlled indicated by the linearity of peak current vs. square root of scan rate.

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