

# Electrochemical properties of N'-ferrocenylmethyl-N'-phenylbenzohydrazide in aqueous and organic mediums

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## ABSTRACT

We carried out a detailed study of the kinetics of oxidation of N'-ferrocenylmethyl-N'-phenylbenzohydrazide (FcX) to ferrocenium ion (FcX<sup>+</sup>) in aqueous and organic mediums. This study using cyclic (CV) and rotating disk electrode (RDE) voltammetry showed that the FcX/FcX<sup>+</sup> redox couple is reversible. The N'-ferrocenylmethyl-N'-phenylbenzohydrazide and ferrocenium ion diffusion coefficients (D) were calculated from these results. In addition, the electron transfer rate constant and the exchange current density for the oxidation of ferrocene were determined. A comparison of the kinetic data obtained from the two electrochemical techniques appears to show that the data from the RDE experiments are more reliable because they are collected under strict mass transport control.

**Keywords:** Cyclic voltammetry; diffusion coefficient; ferrocene derivative; half-wave potential; Randles-Sevcik equation

## 1. INTRODUCTION

Many studies and analysis by electrochemical methods were effected on the oxido-reducing properties of ferrocene. In general, the cathodic behavior ferrocene usual in organic media such as dichloromethane, acetonitrile and DMF can be described by a reversible reduction in an electron, leading to ion Ferrocenium [1-2]. In the present work the oxidation of ferrocene, Fe(C<sub>5</sub>H<sub>5</sub>)<sub>2</sub> to the ferrocenium cation, Fe(C<sub>5</sub>H<sub>5</sub>)<sub>2</sub><sup>+</sup>, was examined in the solvents dichloromethane solution containing tetrabutylammonium tetrafluoroborate, and aqueous solution containing sulfuric acid using the technique of cyclic voltammetry [3-4]. The results indicate that redox reactions of ferrocene/ ferricenium couple were a reversible process of diffusion-controlled single electron transfer in both studied solutions. One of the ferrocene derivative compound N'-Ferrocenylmethyl-N'-henylbenzohydrazide are very important electron transfer systems for molecular electronics owing to its characteristic redox behaviors [5,6], and they could also be expected to play a key role of an electron chemical probe of the electron-transferprocess in biological molecules [7,8]. It is well known that N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide easily undergoes one electron oxidation to form ferrocenium cation in a reversible manner [9,10] Figure 1. Thus, we investigated the electrochemical N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide behaviors in aqueous media.

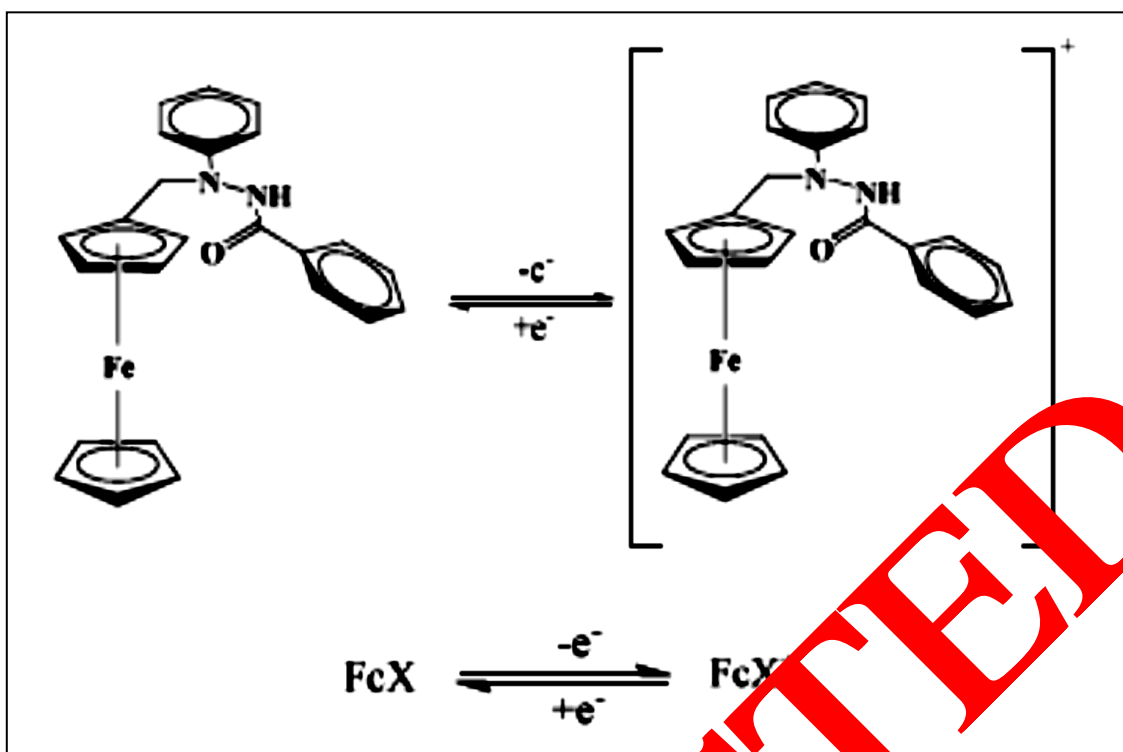


Fig. 1. Reversible mono electronic oxidation of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide

## 2. MATERIALS AND METHODS

### 2. 1. Instrumentation and software

Cyclic voltammetric measurements were performed using PGZ301 potentiostat (radiometer analytical SAS) and a voltammetric cell with a volumetric capacity of 25ml containing a glassy carbon electrode (GCE) working electrode (radiometer analytical SAS), a Pt wire counter electrode and an Hg/HgCl<sub>2</sub> reference electrode (3.0M KCl). Solutions were deoxygenated with high purity nitrogen for 3 min prior to each experiment. Data acquisitions were accomplished with a Pentium IV (CPU 3.0 GHz and RAM 1 Gb) microcomputer using VoltaMaster software version 5.08 (radiometer analytical SAS). Graphs plot and calculus were carried out using OriginLab software version 2.0 (Integral Software, France).

### 2. 2. Chemicals

Electrochemical characterization was carried out on a potentiostat type voltalab 40 of radiometer, with a three-stand electrode cell. Cyclic voltammetric experiments were performed in deoxygenated CH<sub>2</sub>Cl<sub>2</sub> and aqueous ethanol solutions of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide with respectively 10<sup>-1</sup> M of Bu<sub>4</sub>NBF<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub> as supporting electrolyte and N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide concentration of 10<sup>-3</sup> M. The three electrodes used were glassy carbon disk as the working electrode, saturated calomel electrode as a reference electrode, and Pt wire as an auxiliary electrode. The working electrode was polished with 0.05 μm alumina slurry for 1–2 minutes, and then rinsed with double-distilled and deionized water. This cleaning process is done before each cyclic voltammetry experiment.

### 3. RESULTS AND DISCUSSION

#### 3. 1. Electrochemical measurement on a fixed electrode

The synthesized compound in previous work [5]. Cyclic voltammograms of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide at glassy carbon electrode were performed at concentration of  $10^{-3}$  M of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide in deoxygenated dichloromethane and in aqueous ethanol solutions with respectively  $10^{-1}$  M of  $\text{Bu}_4\text{NBF}_4$  and  $\text{H}_2\text{SO}_4$  as supporting electrolyte, each solution was scanned at scan rate equal to 0.05, 0.10, 0.30 and  $0.50 \text{ V}\cdot\text{s}^{-1}$ .

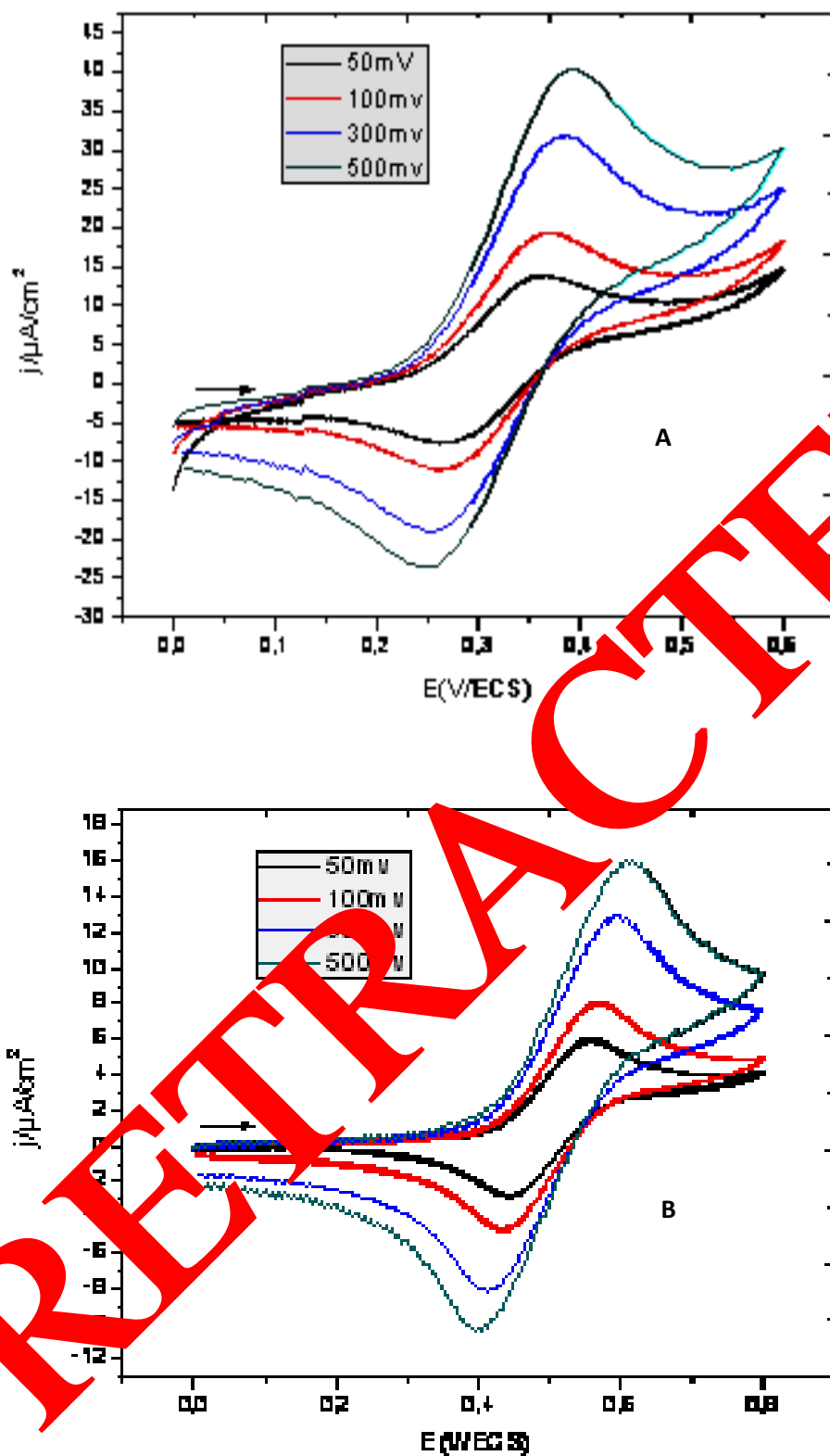
The resultant CV curves and the electrochemical parameters are shown respectively in Figure 2 and Table 1.

**Table 1:** Electrochemical parameters obtained from voltammograms of Figure 2.

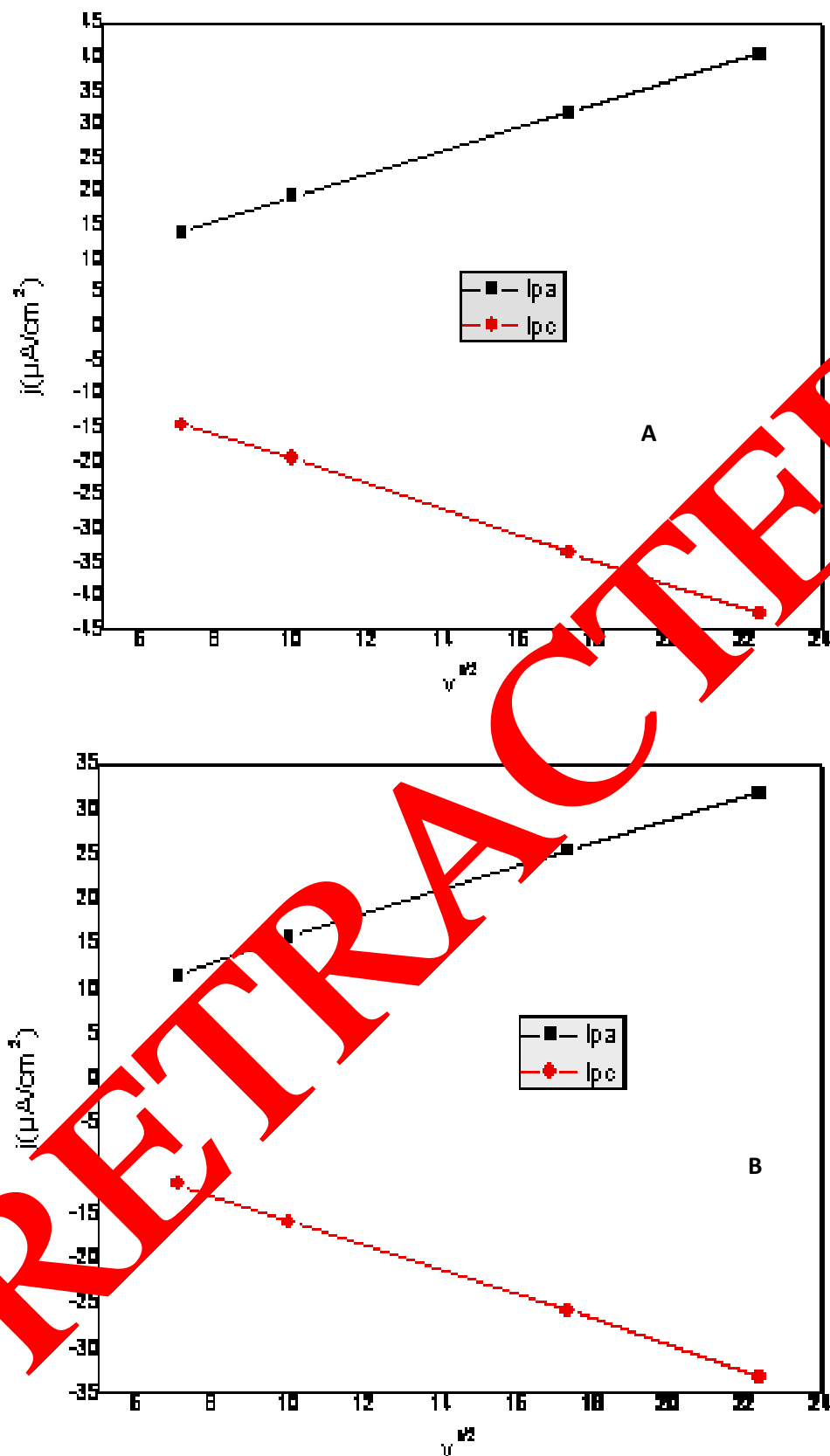
| Mediums  | $\nu$<br>mV/s | $i_{pa}$<br>$\mu\text{A}/\text{cm}^2$ | $i_{pc}$<br>$\mu\text{A}/\text{cm}^2$ | $E_{pa}$<br>mV | $E_{pc}$<br>mV | $E_{pa} - E_{pc}$<br>mV | $E_{1/2}$<br>mV | $\left \frac{i_a}{i_c}\right $ |
|--|---------------|---------------------------------------|---------------------------------------|----------------|----------------|-------------------------|-----------------|--------------------------------|
| <b><math>\text{Bu}_4\text{NBF}_4</math><br/>(0.5g)<br/>+<br/><math>\text{CH}_2\text{Cl}_2</math></b> | 50            | 11.51                                 | -11.665                               | 582.5          | 447            | 135                     | 513.25          | 0.98                           |
|  | 100           | 15.76                                 | -15.90                                | 594            | 431            | 163                     | 512.5           | 0.99                           |
|  | 300           | 25.36                                 | -25.76                                | 600            | 405            | 225                     | 517.5           | 0.98                           |
|  | 500           | 31.68                                 | -31.1                                 | 600            | 385            | 275                     | 522.5           | 0.95                           |
| <b><math>\text{H}_2\text{SO}_4</math><br/>(0.1M)<br/>+<br/>Ethanol<br/>(1/1) (v/v)</b>               | 50            | 15.23                                 | -14.49                                | 367.5          | 264.5          | 103                     | 316             | 0.96                           |
|  | 100           | 15.7                                  | -19.54                                | 372            | 258            | 114                     | 315             | 0.99                           |
|  | 300           | 18.81                                 | -33.58                                | 381            | 258            | 123                     | 319.5           | 0.94                           |
|  | 500           | 40.4                                  | -42.52                                | 395            | 250            | 145                     | 322.5           | 0.95                           |

The anodic and the cathodic peak heights as function of the square root of the scanning rate for glassy carbon electrode in different medium are shown in Figure 3. The obtained linear relationship indicates clear diffusion character.

As it can be seen from figures 3, the ratio of the anodic and cathodic current peak heights is close to one for both solutions; this indicates the reversible character of the oxidation of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide in both studied medium.



**Fig. 2 (A, B).** cyclic voltammetry of 1 mM N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide in (B) 100 mM  $\text{Bu}_4\text{NBF}_4$  in  $\text{CH}_2\text{Cl}_2$  and (A) in ethanol/aq.  $\text{H}_2\text{SO}_4$  at 2 mm diameter glassy carbon working electrode, Pt counter electrode, and CSE reference electrode at (0.05, 0.10, 0.30, 0.50  $\text{V}\cdot\text{s}^{-1}$ ).



**Fig. 3.** The anodic and the cathodic peak heights as function of the square root of the scanning rate in  $CH_2Cl_2$  (B) and in ethanol/ $H_2SO_4$  (A) at 2 mm diameter glassy carbon working electrode

### 3. 2. Electrochemical measurement on rotating disk electrode

Rotating disk electrode is a hydrodynamic electrode technique which utilizes convection as the mode of mass transport as opposed to CV which is governed by diffusion. Convection is more efficient and is not diffusion limited with the result that the analytical data is more reproducible and precise.

Thus a comparison of the kinetic parameters obtained from CV and RDE experiments is informative to elucidate the role of mass transport on electrode reaction kinetics. Figure 4 A shows RDE voltammograms for N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide at a series of rotation rates.

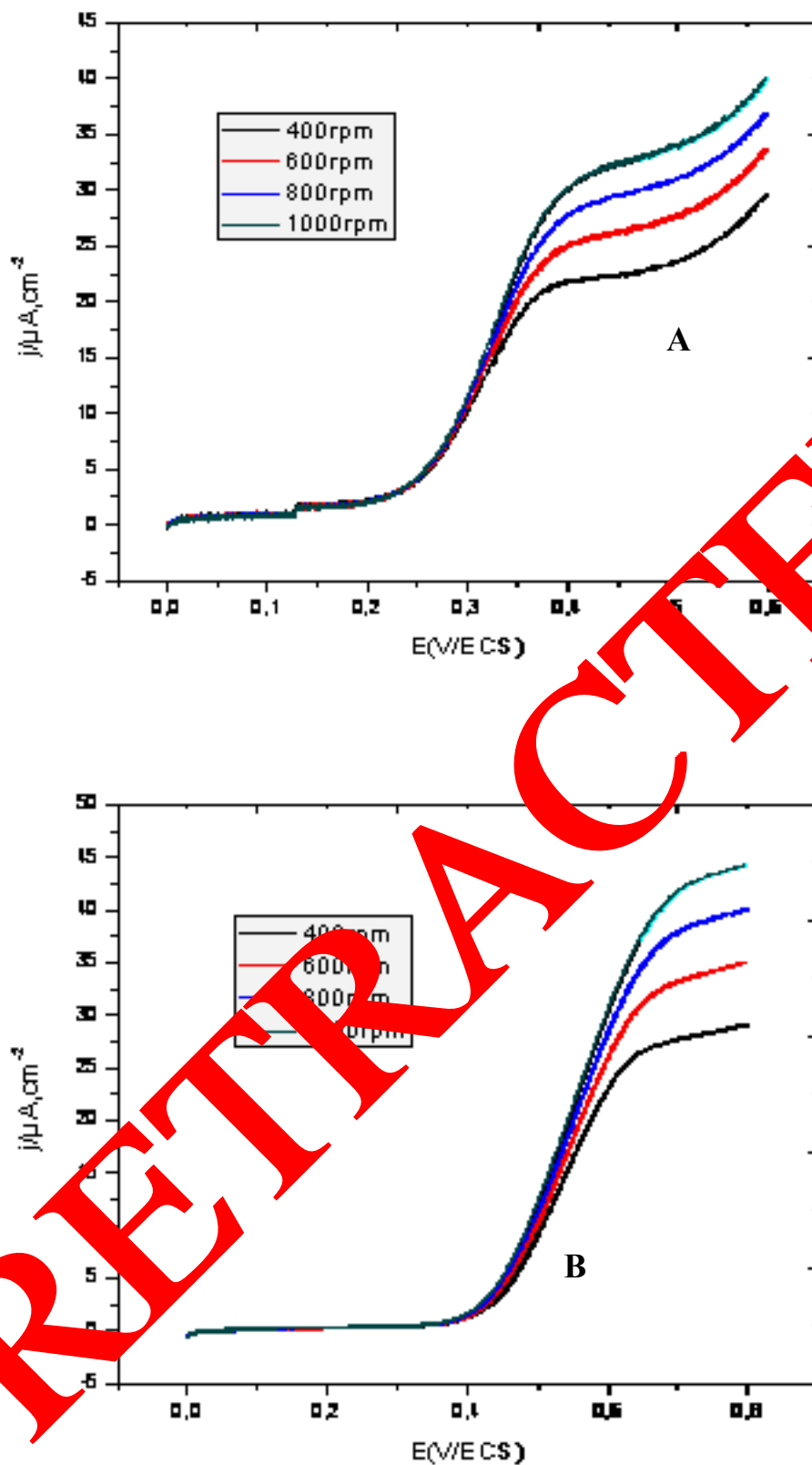
It is evident from the data that the current generated by the RDE method is much larger than that generated under diffusion control.

The much larger current obtained using RDE reflects the efficiency of this method. Also notice that there is significant increase in anodic current while the amount of cathodic current is negligible, essentially making the cyclic voltammogram anodic. This is due to the fast

The diffusion current limit, the current half-wave and half-wave potential are calculated at different rotation speed of the electrode, Table 2.

**Table 2.** Electrochemical parameters calculated from polarograms obtained at glassy carbon electrode of different rotational speed in two media.

| $\omega$<br>tour/min | $i_{lim}$<br>$\mu A/cm^2$ |       | $i_{p/2}$<br>$\mu A/cm^2$ |       | $E_{1/2}$<br>mV |       | $\sqrt{\omega}$ |
|----------------------|---------------------------|-------|---------------------------|-------|-----------------|-------|-----------------|
|                      | org                       | aqu   | org                       | aqu   | org             | aqu   |                 |
| 400                  | 27.58                     | 22.68 | 13.79                     | 11.34 | 532             | 308   | 20              |
| 600                  | 34.4                      | 26.9  | 17.2                      | 13.48 | 543.5           | 314.5 | 24.494          |
| 800                  | 39.1                      | 30.18 | 19.75                     | 15.09 | 549.5           | 319.3 | 28.284          |
| 1000                 | 42.96                     | 32.96 | 21.48                     | 16.48 | 550             | 322.7 | 31.622          |



**Fig. 4(A, B).** Polarogramme of (B) 1 mM N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide and 100 mM Bu<sub>4</sub>NBF<sub>4</sub> in CH<sub>2</sub>Cl<sub>2</sub> and (A) 1 mM of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide in ethanol/H<sub>2</sub>SO<sub>4</sub> at 2 mm diameter glassy carbon working electrode, Pt counter electrode, and CSE reference electrode at 0.50 V·s<sup>-1</sup>. (Rotating rate 400, 600, 800, 1000 rpm).

### 3. 3. Calculation of diffusion coefficient

The Levich equation predicts the current observed at a rotating disk electrode and shows that the current is proportional to the square root of rotation speed. The equation is:

$$\delta = 0.645 D_{ox}^{\frac{1}{3}} \gamma^{\frac{1}{2}} \omega^{-\frac{1}{2}}$$

Where  $D_{ox}$ : diffusion coefficient of the oxidant is expressed in  $\text{cm}^2 \cdot \text{s}^{-1}$

$\omega$ : rotational speed of the electrode ( $\text{rad s}^{-1}$ )

$\gamma$ : kinematic viscosity in  $\text{cm}^2 \cdot \text{s}^{-1}$

Kinematic viscosity: is the ratio of the viscosity on the density, we have for dichloromethane [16]:

$$\begin{aligned} \text{viscosity} &= 0.43 \text{ mPa} \cdot \text{s} \quad 25 \text{ }^\circ\text{C} \\ \text{density } d &= 1.328 \end{aligned}$$

$$\gamma = \frac{0.43}{1.328} \times 10^{-3} \frac{\frac{\text{kg}}{\text{m} \cdot \text{s}}}{\frac{\text{kg}}{\text{m}^3}} = 0.323 \times 10^{-3} \frac{\text{m}^3}{\text{m} \cdot \text{s}} = 0.323 \times 10^{-3} \cdot 10^4 \text{ cm}^2 \cdot \text{s}^{-1}$$

$$= 0.0323 \text{ cm}^2 \cdot \text{s}^{-1}$$

$$\gamma = 0.0323 \text{ cm}^2 \cdot \text{s}^{-1}$$

The kinematic viscosity ( $\approx 10^{-6} \text{ m}^2 \cdot \text{s}^{-1}$ , for an aqueous solution at  $25 \text{ }^\circ\text{C}$ )

The relationship between  $i$  and the square root of rotation speed

$$i = P \omega^{\frac{1}{2}} \quad (2)$$

On another hand the limiting current is given by,

$$i = \frac{nFADC}{\delta} \quad (3)$$

Where  $n$ : number of electrons

$F$ : the Faraday ( $9.65 \cdot 10^4 \text{ C/mol}$ )

$A$ : area of the working electrode ( $\text{cm}^2$ ).

$D$ : the coefficient diffusion ( $\text{cm}^2 \cdot \text{s}^{-1}$ )

$C$ : the concentration ( $\text{mol/cm}^3$ ), in our case is equal to  $10^{-3} \text{ mol/l}$

Replacing equations 2 and 3 in 4 gives,

$$D^{\frac{2}{3}} = \frac{P1.61\gamma^{\frac{1}{6}}}{nFAC\sqrt{2\pi}} \quad (4)$$



For a rotating rate of the working electrode equal to 400 t/min., the coefficient diffusion of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide in dichlormethane is.

$$D = 13.2 \times 10^{-6} \text{ cm}^2 \cdot \text{s}^{-1}$$

The coefficient diffusion of ferrocene in aqueous ethanol is calculated as above. Table 2 summarize the obtained values.

**Table 3.** Diffusion coefficients of compound calculated from polarogramme of Figure 5.

| Electrode/medium                     | $p$ | $D \times 10^{-6} \text{ cm}^2/\text{s}$ | $\delta$ (nm) |
|--------------------------------------|-----|--|---------------|
| GC / CH <sub>2</sub> Cl <sub>2</sub> | 1.4 | 13.2                                     | 280           |
| GC / aq.ethanol                      | 1.1 | 2.6                                      |               |

#### 4. CONCLUSION

Voltammetry analysis on a fixed electrode of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide in aqueous and organic solutions indicates that the electrochemical reaction of N'-Ferrocenylmethyl-N'-Phenylbenzohydrazide in both studied solutions is a diffusion controlled process, namely, electrochemical process and, show that the electron withdrawing N'-Phenylbenzohydrazide group introduced to the ferrocene influences the redox potential of the iron centre. This may be due to the non-insulating effect of methylene between the N'-Phenylbenzohydrazide and the cyclopentadienyl ring of ferrocene. In addition  $\Delta E_p$  for the ferrocene in CH<sub>2</sub>Cl<sub>2</sub> is greater than  $\Delta E_p$  in aq. ethanol, this difference can be attributed to the difference in diffusion coefficient between ferrocene in each medium which is a major contributor. However there is a minor contributor which is related to the difference in the rotation resistance of the two electrochemical medium.

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