

# Oxygen reduction on teflon-bonded carbon electrode<sup>①</sup>

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**Abstract:** Oxygen reduction on Teflon-bonded carbon gas diffusion electrode without catalyst in 6 mol/L KOH solution was investigated with ac impedance spectroscopy and other electrochemical techniques. The kinetic parameters were measured with an exchange current density of  $J^0 = 3.44 \times 10^{-9}$  and a Tafel slope of 46 mV/dec in low overpotential range ( $-0.05 \sim -0.14$  V vs SCE), which are comparable with those reported on carbon supported platinum electrode. The reaction mechanism of OR and the active effect of carbon black were examined.

**Key words:** oxygen reduction; gas diffusion electrode; ac impedance; chronopotentiometry

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## 1 INTRODUCTION

Oxygen reduction (OR) in concentrated KOH solution is an important process involved in alkaline fuel cells and metal-air batteries. Some fundamental studies of the kinetics and mechanisms of OR in concentrated alkaline electrolytes though relatively limited. In alkaline electrolytes, OR proceeds by two pathways as follows: 1) 4 electrons ( $4e^-$ ) pathway leading directly to  $OH^-$ ; 2) 2 electrons pathway with hydrogen peroxide as intermediate or final products, depending on electrode surface state such as the oxygen adsorption, oxide coverage and impurities<sup>[1-7]</sup>.

For gas consuming reaction as oxygen reduction, Teflon-bonded carbon electrodes were introduced to provide larger reaction area and favorable condition for gas diffusion processes thereby to obtain an acceptable power density. For the systems at low or moderate temperatures, the electrodes with platinum as catalyst are used in acid or alkaline media and cheaper catalysts are always searched. On other side, the carbon black materials in electrode have not only large specific surface but also electrocatalytic effect on OR reaction, which is not yet much understood. So that it is of great practical significance to study the OR mechanism and kinetics on these types of electrodes.

The limited number of the reported works on the OR at porous carbon electrode was done on electrodes with platinum as catalyst, and the reported results are very variables. Holze and Vielstich<sup>[8]</sup> studied the oxygen reduction in neutral and alkaline cells with ac impedance method. They obtained a value of 2.85 mA/cm<sup>2</sup> for the exchange current density of OR on

platinum carbon electrode in 3 mol/L NaCl solution. They found that in the gas electrode covered with a porous Teflon backing layer on the gas side, oxygen reduction occurs in a small reaction zone located near the electrolyte side and the utilization of the catalyst is poor. Striebel et al<sup>[9]</sup> investigated the OR on Teflon-carbon electrode in 2 - 11 mol/L KOH electrolyte using voltamperometric and galvanostatic techniques. The kinetic parameters were obtained with a Tafel slope of 44 mV/dec and an exchange current density of  $7.5 \times 10^{-9}$  A/cm<sup>2</sup> for OR on carbon supported Pt electrode in 6.9 mol/L KOH electrolyte.

The present work is done to study the mechanism and kinetics of oxygen reduction on Teflon-bonded carbon electrode without other catalyst by using ac impedance method combined with voltamperometric, chronopotentiometric measurements. The kinetic parameters such as exchange current density and Tafel slope are obtained and compared with those obtained on carbon supported platinum electrodes.

## 2 EXPERIMENTAL

### 2.1 Electrodes

The Teflon-bonded carbon electrode presents a sandwich structure with a nickel net as current collector between the active layer and the gas diffusion layer. The composition of active layer was: carbon black 5 mg/cm<sup>2</sup> and Teflon 2.5 mg/cm<sup>2</sup>; the gas diffusion layer was a Teflon film. The carbon black (acetylene UV of Knapsack) had a specific surface of 50 m<sup>2</sup>/g and a density of 0.07. The particles were in spheric form with diameter of 35 - 45 nm.

In fabrication of the electrode, the powders of

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carbon black were mixed mechanically then the Teflon powder was added and mixed once. The mixed powders were rolled to a fine sheet with a thickness of about 0.2 mm. The sheets obtained were then pressed at  $10^6$  kg/cm<sup>2</sup> to a nickel net at room temperature then sintered at 300 °C for 30 min.

## 2.2 Electrochemical cell

A two-chamber cell was used for the electrochemical measurements. The gas diffusion electrode was mounted in a Teflon holder. The geometric surface area of the electrode was 1 cm<sup>2</sup>. Oxygen was introduced into the gas chamber and diffused through the electrode. The electrolyte was 25% KOH (mass fraction) solution prepared with the Merck extra pure grade potassium hydroxide pellets and distilled water. The reference electrode was an Hg/HgO electrode connected to the cell via a Luggin capillary. Potential values in this paper are related to the Hg/HgO electrode. The counter electrode was a platinum plate of 10 cm<sup>2</sup>. The electrochemical measurements were performed at room temperature.

## 2.3 Electrochemical measurements

Polarization and chronopotentiometric measurements were carried out with a Model 263 EG&G Princeton potentiostat/galvanostat controlled with the M270 computer program. The polarization curves were determined in oxygen atmosphere at a scan rate of 1 mV/s, without correction for  $iR$  drop. Chronopotentiometric measurements were performed at 3  $\mu$ A. Impedance spectroscopy technique was also applied in our investigation. The electronic instruments consisted of an EG&G Model 5210 lock-in amplifier and the potentiostat/galvanostat. The ac frequency was from 100 kHz to 1 mHz. The ac impedance data were collected with a M398 electrochemical program. The experimental results were analyzed with the EQUIVCRT program of Boukamp<sup>[10]</sup>.

## 3 RESULTS

### 3.1 Cyclic voltammetry (CV)

As the voltammogram recorded on gas diffusion electrode are generally less characteristic than those recorded on smooth electrode due to the adsorption of gaseous reactants in the porous structure. The voltammetry was performed after a chronopotentiometric measurement at 15  $\mu$ A for 15 min (Fig. 1).

The CV with scan rate of 100 mV/s started at 0.6 V toward negative direction until -0.5 V and then returned to 0.6 V. On the curve toward negative direction, we see a peak at about +0.32 V and two peaks in the potential range of reduction: at -0.2 V and at -0.45 V. On the return part, we see an anodic peak at -0.2 V following a pre-wave less visible at a potential slightly less positive. This

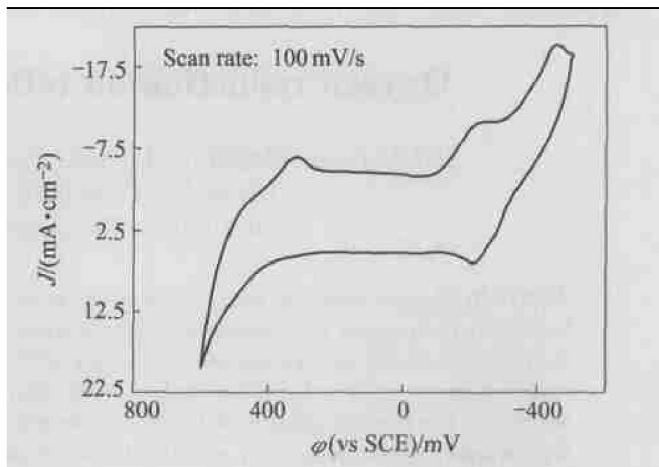


Fig. 1 Voltammogram recorded on carbon electrode in 6 mol/L KOH at 20 °C

peak is followed by a plateau. From 0.3 V, the current increases rapidly and we do not find the waves.

We noticed on the CV curves two reduction zones in the regions of +0.5 to -0.1 V and -0.1 to -0.5 V. In the 0.5 to -0.1 V region, the cathodic peak at +0.3 V is attributed to the reduction of oxygen to OH<sup>-</sup> with the oxygen specimen generated by the anodic prepolarisation and chemically adsorbed in carbon sites. In the range of -0.1 to -0.5 V, the cathodic peaks are due to the reduction of atmospheric oxygen. The two cathodic peaks at -0.2 V and -0.45 V indicate that OR proceeds via two different reactions according to potential. At low overpotential (potential less negative than -0.2 V), the reaction produces HO<sub>2</sub><sup>-</sup>. As carbon is not effective enough for its decomposition, the formed HO<sub>2</sub><sup>-</sup> ions accumulate on electrode and are then reduced at stronger overpotential. On return, the anodic peak followed by the plateau at -0.2 V is due to the re-oxidation of HO<sub>2</sub><sup>-</sup> to O<sub>2</sub>. From +0.4 V, the anodic current increases due to the oxygen release from OH<sup>-</sup>.

### 3.2 Polarization curve

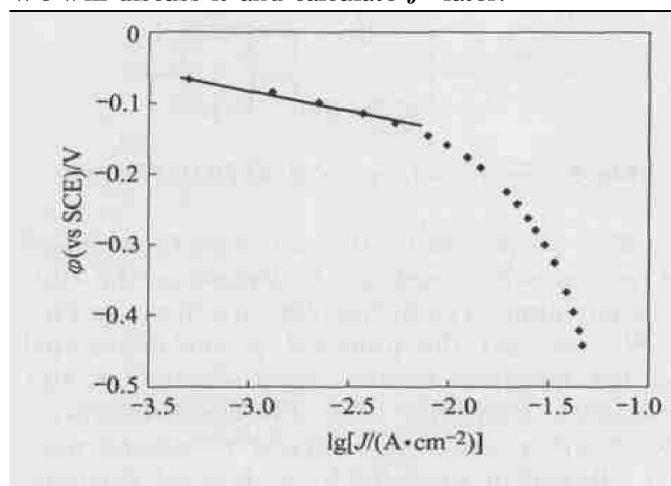
The polarization measurement was carried out by linear voltammetry at 1 mV/s. The  $\varphi$  vs  $\lg J_c$  curve is shown in Fig. 2, which gives the Tafel relationship in the low overpotential range (-0.05 ~ -0.14 V vs SCE) as

$$\varphi = -0.230 - 0.046 \lg J_c$$

There is limited information in literature about OR on carbon or graphite electrodes especially on gas diffusion electrodes and the reported results are variable. Tarasevich et al observed two Tafel slopes on

pyrolytic graphite electrode in alkaline electrolyte, at low overpotential, the slope was  $-0.03$  V/dec. But Yeager et al. obtained only one slope of  $120$  mV/dec.

Striebel et al.<sup>[9]</sup> investigated the OR on Teflon-carbon electrode in  $2-11$  mol/L KOH electrolyte using the voltamperometric and galvanostatic techniques. The reported Tafel slope at low overpotential and exchange current density are  $-44$  mV/dec and  $7.5 \times 10^{-9}$  A/cm<sup>2</sup>, respectively. At high overpotential, the Tafel slope doubled. In calculating the exchange current density, they got the real active electrode surface from the hydrogen desorption charge. The obtained Tafel relation allows us to calculate the exchange current density  $J^0$  for OR. This calculation is relative to the equilibrium potential of the reaction. We will discuss it and calculate  $J^0$  later.



**Fig. 2** Polarization curve for OR on carbon electrode in 6 mol/L KOH at 20 °C

### 3.3 Chronopotentiometry

The chronopotentiometric technique was applied here to measure the double-layer capacity of electrode and the charge transfer resistance  $R_{ct}$  of OR near rest potential. At rest potential, the charge transfer resistance  $R_{ct}$  of OR has its maximal value. Combined with the relatively large double-layer capacity  $C_{dl}$  of the gas electrode, the relaxation time constant would have a great value. If we use impedance method, as the relaxation frequency of the charge transfer process is given by  $\omega = 1/(C_{dl}R_{ct})$ , we will have to apply very low frequencies and the measurement duration will become too long.

The technique consists of applying a small current on electrode from rest potential and recording the evolution of electrode's potential. For a relaxation procedure at low current with the effect of concentration being negligible, the potential evolves following the relation as

$$\varphi - \varphi_{eq} = JR_{\Omega} + JR_{ct}[1 - \exp(-t/\tau)]$$

If  $R_{\Omega} \ll R_{ct}$ , we get

$$\eta = \varphi - \varphi_{eq} = JR_{ct}[1 - \exp(-t/\tau)]$$

For  $t \rightarrow \infty$ ,  $\eta_{\infty} = iR_{ct}$ , the charge transfer resistance  $R_{ct}$  is thus obtained and we have the relationship as

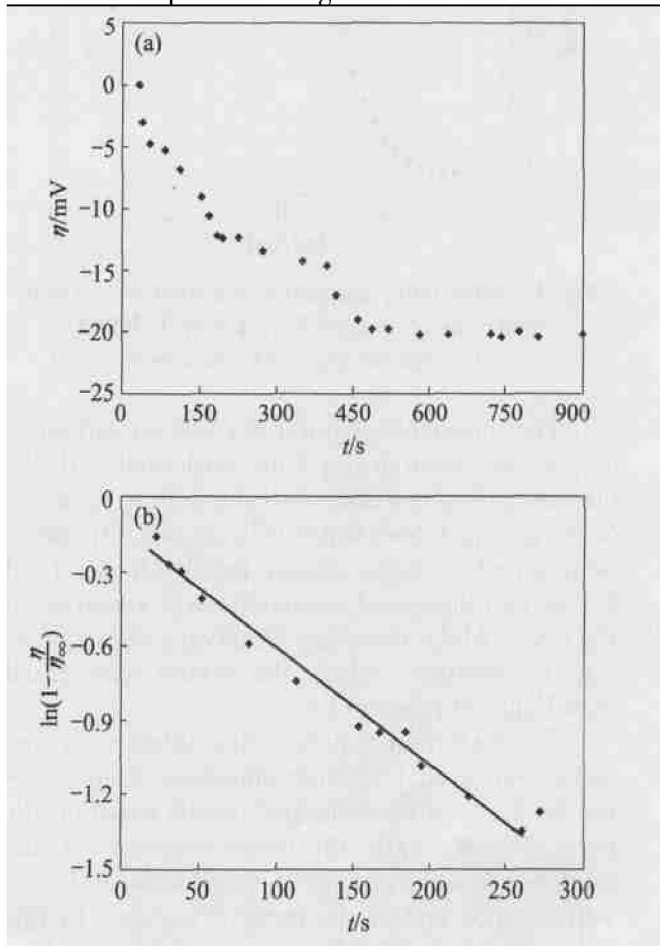
$$\ln(1 - \frac{\eta}{\eta_{\infty}}) = -\frac{t}{\tau}$$

By tracing the  $\ln(1 - \frac{\eta}{\eta_{\infty}})$  plot, we obtain the relaxation time constant and hence the double-layer capacity  $C_{dl}$ .

In our measurement, the imposed current was  $3 \mu\text{A}$ . The chronopotentiogram recorded on carbon electrode is shown in Fig. 3(a). We see that with the small cathodic current imposed, the overpotential increases with time and arrives to  $-20$  mV after  $450$  s then becomes stable, from which we obtain the value of  $R_{ct}$  as  $6.7 \times 10^3 \Omega/\text{cm}^2$ . The  $\ln(1 - \frac{\eta}{\eta_{\infty}})$  vs  $t$  plot is shown in Fig. 3(b) from which we get  $C_{dl} = 25.3 \text{ mF}/\text{cm}^2$ .

### 3.4 Impedance spectroscopy

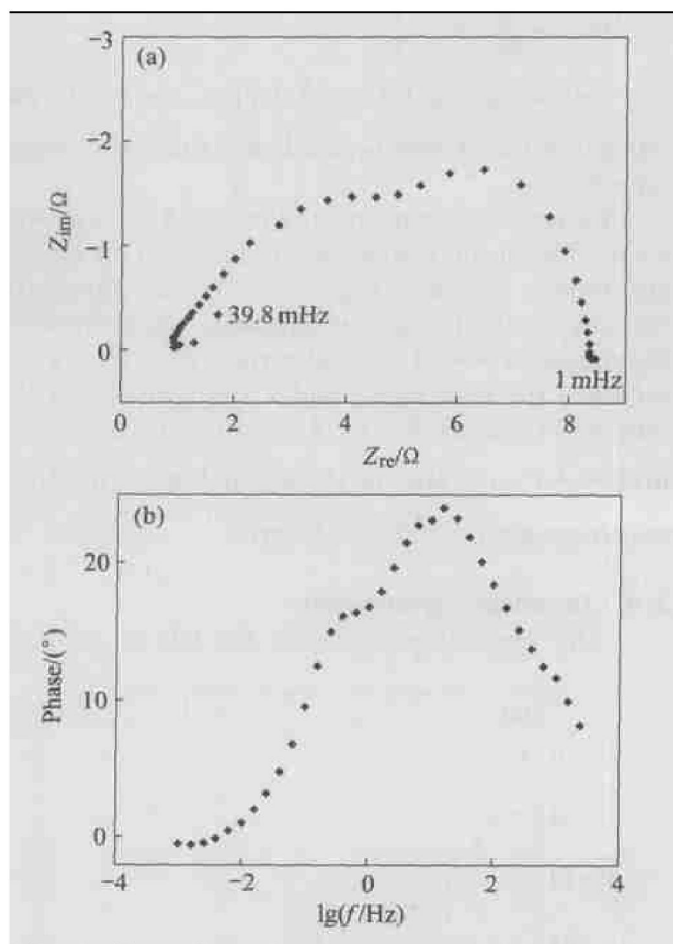
The impedance diagrams for OR at  $-0.2$  V



**Fig. 3** Chronopotentiograms for OR on carbon electrode in 6 mol/L KOH at 20 °C,  $I = 3 \mu\text{A}$

(a)  $-\eta$  vs  $t$ ; (b)  $-\ln(1 - \frac{\eta}{\eta_{\infty}})$  vs  $t$

are shown in Fig. 4. On the Nyquist plot we see two capacitive loops in the applied frequency range (from 10 kHz to 10 mHz). In lower frequencies (from 6.5 to 1.0 mHz), an inductive part appears. The Bode plot shows more evidently the two arcs and the turn point of phase at frequency of 1 Hz.



**Fig. 4** Impedance diagrams recorded on carbon electrode at  $-0.2$  kV in 6 mol/L KOH  
(a) —Nyquist plot; (b) —Bode plot

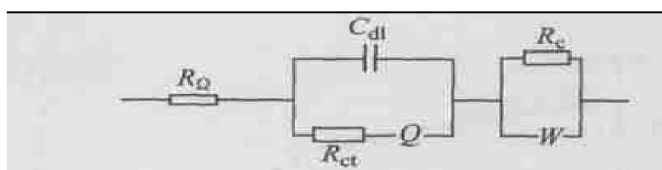
The impedance features for OR on carbon electrode as shown in Fig. 4 are associated with the OR mechanism and also with the porous structure of the gas electrode, which is thus quite difficult to be interpreted. Some similar profile characterized by the two depressed semicircles was reported on  $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$  electrode for oxygen reduction at high temperature, where the results were fitted with Equevrt program<sup>[11]</sup>.

The formation of porous film obtained by corrosion was treated for their impedance characteristics by the “transmission line” model based on the pores of finite length, this model considers that the reaction proceeds in pore at the interface of pore wall/ solution and at the exterior surface. In this case, the faradic impedance can be represented by two parallel RC circuits ( $R_w C_w$ ) ( $R_b C_b$ ), where the sign “w” is for the interior interface and “b” for the exterior surface. Depending on the charge transfer resistance, on the

film thickness and electrode surface state, the Nyquist plot gives at certain instances a supplementary capacitive boucle<sup>[12]</sup>.

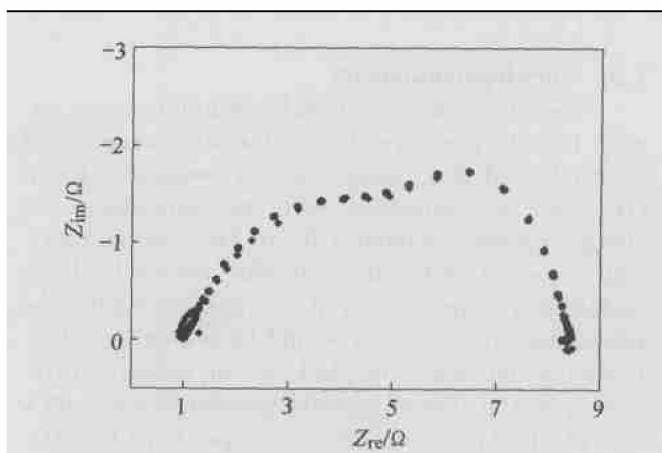
We proposed several equivalent circuits to fit the impedance data for OR at DE-C. At first, we tried the circuit  $R(C[RO])(C[RW])$  according to the porous film model, where the introduced element  $O$  represents the Nernst impedance for the effect of thin porous film and  $W$  for the Warburg impedance,  $R$  for ohmic resistance and charge transfer resistance of electrode reaction. This circuit fitted the two arcs in plot but did not fit in general the experimental data. Another circuit  $R(C[RO][RW])$  fitted in general the plot characteristics but did not fit well the two boucles.

The best fitting results were obtained using the circuit  $R(C[RO])(RW)$ , as shown in Fig. 5.



**Fig. 5** Sketch of circuit  $R(C[RO])(RW)$

$R_c$  is introduced for the resistance for a chemical reaction whose rate would depend on the electrode potential. The fitting plots are shown in Fig. 6. We see that the proposed circuit interpreted well the impedance feature, especially the two arcs separated at frequency 1 Hz. The circuit interprets OR on carbon electrode as an electrochemical reaction followed or preceded by a chemical reaction. The whole reaction is affected by the diffusion procedure.



**Fig. 6** Nyquist plot fitted with equivalent circuit for OR at  $-0.2$  V on carbon electrode, cooperated with experimental

The parameters obtained are reproduced in the Table 1.  $R_\Omega$  is the ohmic resistance between current collector and reference electrode. The value is not too large, showing the quite good conductivity of the car-

bon black.

**Table 1** Impedance parameters for OR  
at  $-0.2$  V vs Hg/HgO

$R_{ct}/(\Omega \cdot \text{cm}^2)$	$C_{dl}/(\text{mF} \cdot \text{cm}^{-2})$	$R_{ct}/(\Omega \cdot \text{cm}^{-2})$	$\sigma_0/(\Omega \cdot \text{cm}^{-1/2})$	$\mathcal{D}^{-1/2}/\text{s}^{1/2}$	$R_{ct}/(\Omega \cdot \text{cm}^{-2})$	$\sigma_0/(\Omega \cdot \text{cm}^{-1/2})$
0.98	16.9	0.80	19.7	1.26	4.23	17.5

At  $-0.2$  V, the electrode reaction is composed of a charge transfer process in serial with a chemical reaction. The charge transfer resistance  $R_{ct}$  is much smaller than the resistance of the chemical reaction  $R_c$ , indicating that the charge transfer is a rapid step and the chemical reaction is relatively slow. We notice also that the total resistance ( $R_{ct} + R_c$ ) is much smaller at  $-0.2$  V than that near rest potential ( $R_{ct} = 6.7 \times 10^3 \Omega/\text{cm}^2$ ).

The value of the double-layer capacity  $C_{dl}$  obtained is in consistence with that obtained at rest potential by chronopotentiometric technique ( $25.3 \text{ mF}/\text{cm}^2$ ), which gives us an indication of the real surface of our gas diffusion electrode. In Ref. [13], the values of the double layer capacity on smooth carbon and graphite electrodes are quite variable, from  $3.7 \mu\text{F}/\text{cm}^2$  to  $20 \mu\text{F}/\text{cm}^2$ . If we suppose an average value of  $10 \mu\text{F}/\text{cm}^2$  for used carbon black, the real electrode surface will be about  $2000 \text{ cm}^2$ , which means a surface factor  $S = 2000$ . In gas diffusion electrode, the parameter  $C_{dl}$  is a good indication of active area involved in electrochemical reaction. It depends on the wettability of electrode that is in turn affected by the electrode's composition and fabrication conditions<sup>[14]</sup>.

The Nernst parameters  $\sigma_0$  and  $\mathcal{D}^{-1/2}$  allow us to estimate the mass transport properties  $O_2$  ( $D$  and  $C$ ) in our carbon electrode. From the obtained values of  $\sigma_0$  and the relation  $\sigma_0 = \frac{RT}{\sqrt{2n^2F^2AD^{1/2}C}}$ , we get a value for the product  $AD^{1/2}$  ( $A$  is the electrode surface), between  $2.39 \times 10^{-9}$  and  $5.60 \times 10^{-9} \text{ mol} \cdot \text{s}^{-1/2} \cdot \text{cm}^{-2}$ . From the value of  $\mathcal{D}^{-1/2}$ , we can estimate the value for  $\delta$ , between 34 and 36  $\mu\text{mol/L}$ .

The impedances related to the diffusion processes are significantly greater than those associated with charge transfer and chemical reaction, which may be due to the diffusion of oxygen and reaction products in the wetted porous structure. It constitutes another key problem besides the intrinsic catalytic properties of the active materials associated to the performance of OR on gas diffusion electrode.

## 4 DISCUSSION

### 4.1 OR equilibrium potential

We consider at first the equilibrium potential for

the reaction  $O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$ ,

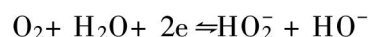
the process of four electrons produces directly  $OH^-$ .

In 6 mol/L KOH solution, the average activity coefficient of KOH  $\gamma_{\pm} = 3^{[15,16]}$ , and we hence have  $a(OH^-) = 18$ . Supposing  $a(H_2O) = 1$ , and  $p(O_2) = 1.01 \times 10^5 \text{ Pa}$ , we get the equilibrium potential:

$$\varphi_{eq} = 0.327 \text{ V (vs NHE) or } 0.222 \text{ V (vs SCE)}$$

On the cyclic voltammogram, we observed the potential at  $i = 0$  for OR on our carbon electrode being  $0.45 \text{ V (vs SCE)}$ . This value is more positive than the thermodynamic potential for the couple  $O_2/OH^-$ , associated with a four electrons process. It may be attributed to the good electroactivity of oxygen generated during the anodic prepolarisation during the scan. The oxygen was adsorbed in atomic form in carbon black and then reduced directly to  $OH^-$ .

In polarization measurement by linear voltammetry, the rest potential of  $+0.05 \text{ V (vs SCE)}$  was observed. This value is evidently far more negative than the calculated value for the couple  $O_2/OH^-$ . The two-electron pathway is considered for OR in our carbon electrode. With the oxygen from atmosphere, the OR reaction would proceed via the irreversible process:

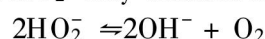


The standard potential for this system is  $-0.065 \text{ V (vs NHE)}$  corresponding to  $-0.170 \text{ V (vs SCE)}$ . From Nernst formula, the potential for this equilibrium can be written as (vs SCE)

$$\begin{aligned} \varphi_{O_2/HO_2^-} = & \delta_0 - 0.03 \lg a(HO_2^-) - \\ & 0.03 \lg a(OH^-) + 0.03 \lg p(O_2) + \\ & 0.03 \lg a(H_2O) \end{aligned}$$

$$\varphi_{O_2/HO_2^-} = -0.207 - 0.03 \lg a(OH_2^-)$$

Supposing the content of KOH is 6 mol/L,  $p(O_2) = 1.01 \times 10^5 \text{ Pa}$ ,  $a(H_2O) = 1$ , it is known that  $HO_2^-$  may dismute according to the reaction as

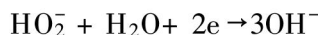


This is a reaction completely to the right (according to as Charlot<sup>[17]</sup>, the  $HO_2^-$  concentration at equilibrium would reach to  $10^{-18} \text{ mol/L}$ ), but this is a slow process and  $HO_2^-$  exists in metastable form in high concentration solution.

Theoretically in the presence of catalyst sufficiently effective, the peroxide may be decreased to equilibrium concentration ( $10^{-15} \text{ mol/L}$  in 10 mol/L KOH solution) and we can get an electrode potential close to a thermodynamic value for of  $O_2/OH^-$  system. But it is not true because the process is controlled by the slow diffusion of  $HO_2^-$  which should transport across the electrolyte to get to the surface of catalyst.

$HO_2^-$  may also dismute by the reaction as





with  $\varphi_0 = 0.867 \text{ V}$  (vs NHE) or  $\varphi_0 = 0.762 \text{ V}$  (vs SCE). This reaction is less probable near rest potential but would contribute to the second step of oxygen reduction at more negative potential. In our case, we can interpret the measured rest potential as a mixed potential between the system  $\text{O}_2/\text{HO}_2^-$  and  $\text{O}_2/\text{OH}^-$ .

#### 4.2 Exchange current density for OR

As OR is a multistep reaction, the Volmer-Tafel equation can be written as<sup>[18]</sup>

$$\eta_{\text{c}} = \varphi - \varphi_{\text{eq}} = \frac{2.3RT}{\alpha F} \log J^0 - \frac{2.3RT}{\alpha F} \log |J_{\text{c}}|$$

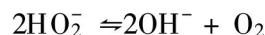
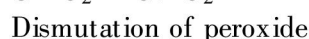
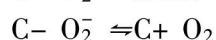
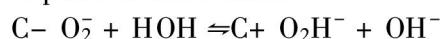
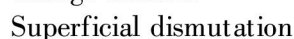
We used this equation to calculate the exchange current density from our experimental results  $\varphi = -0.230 - 0.046 \log J_{\text{c}}$ . Taking the measured rest potential value of  $+0.05 \text{ V}$  (vs SCE) as equilibrium potential, we obtained the apparent exchange current density for OR on carbon electrode as  $J_{\text{app}}^0 = 8.18 \times 10^{-7} \text{ A/cm}^2$ . As the real electrode surface was calculated from measured  $C_{\text{dl}}$  as  $2000 \text{ cm}^2$ , the exchange current density  $J^0$  was calculated as  $4.09 \times 10^{-10} \text{ A/cm}^2$ .

We can also calculate the apparent exchange current density from charge transfer resistance  $R_{\text{ct}}$  obtained in ac impedance measurement with the relation  $J_{\text{app}} = \frac{RT}{\alpha F R_{\text{ct}}}$ . As  $R_{\text{ct}} = 6.7 \times 10^3 \Omega/\text{cm}^2$ , we get  $J_{\text{app}}^0 = 6.87 \times 10^{-6} \text{ A/cm}^2$ . Taking into the surface factor of 2000, the exchange current density  $J^0$  was calculated as  $3.44 \times 10^{-9} \text{ A/cm}^2$ . This result agrees well with that obtained by the polarization method.

The values of kinetic parameters for OR ( $J^0 = 3.44 \times 10^{-9} \text{ A/cm}^2$ ,  $b = 46 \text{ mV/dec}$ ) obtained in our study are the same order-of-magnitude with these reported by Striebel et al even though the used techniques are quite different. It should indicate that our study was performed on carbon electrode without catalyst and the work by Striebel et al was carried out on platinum supported carbon electrode where the real electrode surface was counted on loaded platinum. Further work will be worthy to clarify the effect of the catalysts such as platinum or other cheaper materials.

#### 4.3 Mechanism of OR on carbon electrode

Based on our experimental results, we propose the following mechanism for OR on carbon electrode in the potential range of 0 to  $-0.2 \text{ V}$  (vs SCE)



The  $\text{O}_2$  adsorption is a rapid step, as there are many functional groups hence the active sites for adsorption of  $\text{O}_2$  on carbon surface<sup>[19]</sup>. According to the proposed mechanism, the adsorption of  $\text{O}_2$  would be “end-on” type, assuming a two-electron pathway for oxygen reduction<sup>[20, 21]</sup>.

Following the charge transfer step, the superficial dismutation reaction takes place between two repulsing adsorbed negative radicals. This step would be slow and be affected by the electrode potential. As the dismutation reaction produces  $\text{HO}_2^-$ , it should undergo further step to get to  $\text{OH}^-$  through the dismutation reaction  $2\text{HO}_2^- \rightleftharpoons 2\text{OH}^- + \text{O}_2$ . This reaction and the diffusion of  $\text{HO}_2^-$  would have an important effect on the whole reaction rate.

### 5 CONCLUSIONS

1) The kinetic parameters for OR on Teflon-bonded carbon electrode in  $6 \text{ mol/L KOH}$  solution were measured with an exchange current density of  $J^0 = 3.44 \times 10^{-9} \text{ A/cm}^2$  and a Tafel slope of  $46 \text{ mV/dec}$  in the range of low over potential ( $-0.05 \sim -0.20 \text{ V}$  vs SCE) which are comparable with these obtained on carbon supported platinum electrode.

2) In the process of OR on gas diffusion electrode, carbon material does not act only as catalyst supporter but also provides active sites for oxygen adsorption and charge transfer. OR proceeds via a two-electrons path where a charge transfer step producing  $\text{O}_2^-$  is followed by a superficial dismutation of these radicals to produce as intermediate which will be decomposed into  $\text{OH}^-$ . The materials which can accelerate the dismutation of  $\text{O}_2^-$  or  $\text{HO}_2^-$  will be good catalyst for OR in alkaline media.

3) The chronopotentiometric technique was used to measure the charge transfer resistance of OR and double-layer capacity of electrode near rest potential. Comparing the results with these by ac impedance method, the chronopotentiometric technique appears reliable and practical.

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