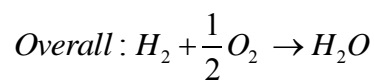
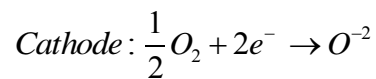
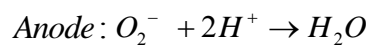
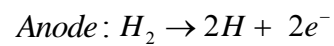


Appendix A

Fuel Cell operating principle

A.1: Chemical reaction on the electrodes:

The reaction below shows the chemical reactions for hydrogen as fuel:



A.2: fuel cell thermodynamics

$$\Delta G = \Delta G_{\text{products}} - \Delta G_{\text{reactants}}$$

Where:

ΔG : is the Gibbs free energy

$$\Delta G_0 : E_0 * n_e F$$

Where:

ΔG_0 : is the Gibbs free energy at start

E_0 : cell voltage at start

n_e : number of electrons

F: faraday's constant (F=1)

$$E_{CELL} = \frac{\Delta G_O}{neF} + \frac{RT}{neF} \ln \left[\frac{P_{H_2} P_{O_2}^2}{P_{H_2O}^2} \right]$$

Where:

R: gas constant.

T: temperature.

P_{H2}: partial pressure for hydrogen.

P_{O2}: partial pressure for oxygen.

P_{H2O}: partial pressure for water.

A.3: Voltage loss

$$V_{cell} = E_{cell} - \eta_{act} - \eta_{ohmic} - \eta_{con}$$

Where:

η_{act} : Activation polarization loss.

η_{ohmic} : Ohmic loss.

η_{con} : concentration/diffusion loss.

A.3.1: Activation loss (η_{act})

$$\eta_{act} = \frac{RT}{\beta neF} \ln \frac{i}{i_o}$$

Where:

β : Butler-Volmer Constant.

i : Current density.

i_o : Exchange current density at an electrode/electrolyte interface.

$$i = 2 * i_{o,k} \sinh \left(\frac{neF\eta_{act,k}}{RT} \right) \rightarrow \eta_{act,k} = \frac{2RT}{neF} \sinh^{-1} \left(\frac{i}{2i_{o,k}} \right)$$

Where:

k: Cp/Cv

A.3.2: Ohmic loss (η_{ohmic})

$$\eta_{Ohmic} = i * R_{ohm}$$

Where:

i: Current density.

R_{ohm}: ohmic resistance.

$$R_{ohm} = R_a + R_e + R_c + R_i$$

Where:

R_a: Anode resistance.

R_e: Electrolyte resistance.

R_c: Cathode resistance.

R_i: Interconnector resistance.

A.3.3: Concentration/diffusion loss (η_{con})

$$\eta_{con} = m e^{(ifc)}$$

Where:

m: mass.

ifc: current per unit area for fuel cell.