SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

Renewable Energy: Solar Fuels Solution

This exercise deals with assessment of solar fuels generation. In the first part, the production of hydrogen by photoelectrochemical water-splitting is investigated. In the second part, you use solar thermochemical route for the production of synthesis gas used in a fuel cell.

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1. (a) The solar cell with the larger band gap will be on top.

   (b) E_g=2.16 eV implies $\lambda_1 = 0.574$ μm; $E_g = 1.1$ eV implies $\lambda_2 = 1.127$ μm;
   $F_{0-\lambda_1 T} = 0.346$, fraction of top cell;
   $F_{0-\lambda_2 T} = 0.779$, fraction bottom cell: $F_{\lambda_1 T-\lambda_2 T} = F_{0-\lambda_2 T} - F_{0-\lambda_1 T} = 0.433$

   (c) Short cicuit current density (i.e i @ V=0) is i_{sc}= 115 A/m^2
   Open circuit voltage (i.e V @ i=0) is $V_{oc} = 2.59$ V (using V = $\ln(\frac{i_0}{i_1}+1)\frac{nk_BT}{q}$)
   Fill factor (FF) = $P_{max}/(i_{sc}V_{oc})$
   P_{max} can be calculated using the plot below or numerically using $\frac{d(i \cdot V)}{dV} = 0$;
   $P_{max} = 284.76$ W/m^2 and hence FF = 0.954

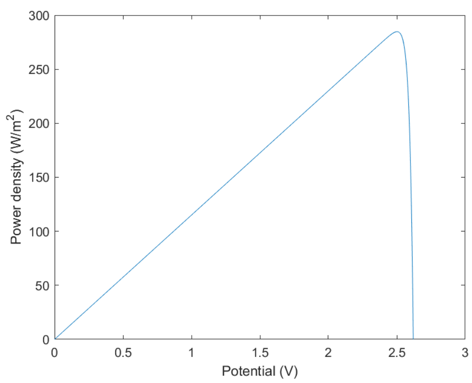

Figure 1: Plot of the power density Vs potential of the solar cell

   (d) The first term is the equilibrium potential, second term is ohmic losses due to resistances in the solution, the third and fourth terms are the kinetic overpotential due to reaction, one for the anode and one for the cathode.
   $\triangle V_{ohmic} = i\rho l_p = 1.6$ V (@ i=200 A/m^2)
   $\triangle V_{anode} = a_1 log(\frac{i}{i_{0a}}) = 256$ mV (@ i=200 A/m^2)
   $\triangle V_{cathode} = a_2 log(\frac{i}{i_{0c}}) = 159$ mV (@ i=200 A/m^2)

   (e) Operating point: $i_{op} = 112.1$ A/m^2; $V_{op} = 2.525$ V; implies $P_{op} = 283.1$ W/m^2 which is smaller than P_{max}
   We need to reduce the overpotentials: i.e. by using better conducting solution, using catalysts that can support faster reaction kinetics, etc.

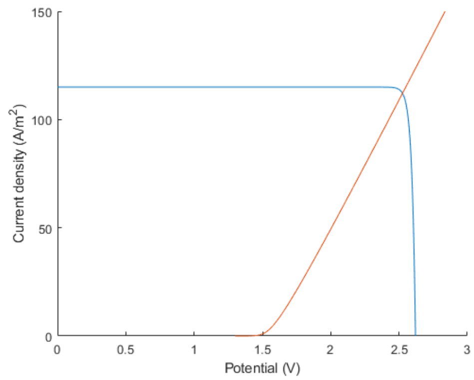

Figure 2: Operating curves of PEC cell

(f) Efficiency: $\eta = \frac{i_{op}V_0}{Q_{in}}$ = 112.1 · 1.23 / (1000) = 0.14 = 14%

(g) m = $\frac{\eta Q_{in}}{HHV_{H_2}}t = \frac{(0.14 \cdot 1000)}{141 \cdot 10^6} 1900 \cdot 3600 = 6.7$ kg/m^2.

2. (a) $\gamma_i = \frac{\nu_i/M_i}{\sum_n \nu_n/M_n}$, with γ molar fraction, ν weight fraction, and M molar mass of species i; implies
$x_1 = \frac{0.49/0.012}{0.49/0.012+0.06/0.001+0.45/0.016}$ =0.317,
$y_1 = \frac{0.06/0.001}{0.49/0.012+0.06/0.001+0.45/0.016} = 0.465$,
$z_1 = \frac{0.45/0.016}{0.49/0.012+0.06/0.001+0.45/0.016} = 0.218$,
y = y_1/x_1 = 1.469;
z = z_1/x_1 = 0.689;
Total number of H_2 moles: (y/2 + 2-z) = 2.046;
Total number of CO moles: 1

(b) $\eta_{absorption}$ = 1 - $\frac{\sigma T^4}{IC}$ = 1 - $\frac{5.67 \cdot 10^{-8} \cdot 1200^4}{1800 \cdot 1000}$ = 0.935.

(c) $\eta_{absorption} = \frac{\dot{Q}_{Reactor,net}}{\dot{Q}_{solar}}$; hence
$\dot{Q}_{solar} = \frac{\dot{Q}_{Reactor,net}}{\eta_{absorption}}$ = 210/0.935 = 224.7 kW

(d) $\dot{n}_{H_2,fuelcell}$ = (y/2 + 2 - z)$\dot{n}_{CH_yO_z}\eta_{PSA}$ = (1.469/2 + 2 - 0.689)(1 · 0.94) = 1.92 mol/s
$\dot{W}_{out} = \dot{n}_{H_2,fuelcell} \cdot HV_{H_2} \cdot \eta_{fuelcell}$ = 1.92 · 285 · 0.62 = 339.8 kW

(e) EGF = $\frac{\dot{W}_{out}}{\dot{W}_{Rankine}}$;
$\dot{W}_{Rankine} = \eta_{Rankine} \cdot \dot{n}_{CH_yO_z} \cdot HV_{CH_yO_z}$ = 0.40 · 1 · 570 = 228 kW; hence
EGF = 339.8/228 = 1.49

(f) $\dot{m}_{CO_2} = \dot{n}_{C_xH_yO_z} \cdot M_{CO_2}$ = 1 · 0.044 = 0.044 kg/s;
$Em_{solar} = \frac{\dot{m}_{CO_2}}{\dot{W}_{out}} = \frac{0.044 \cdot 3600}{339.8}$ = 0.47 kgCO$_2$/kWh$_e$

$$Em_{Rankine} = \frac{\dot{m}_{CO_2}}{\dot{W}_{Rankine}} = \frac{0.044 \cdot 3600}{228} = 0.69 \text{ kgCO}_2/\text{kWh}_e$$