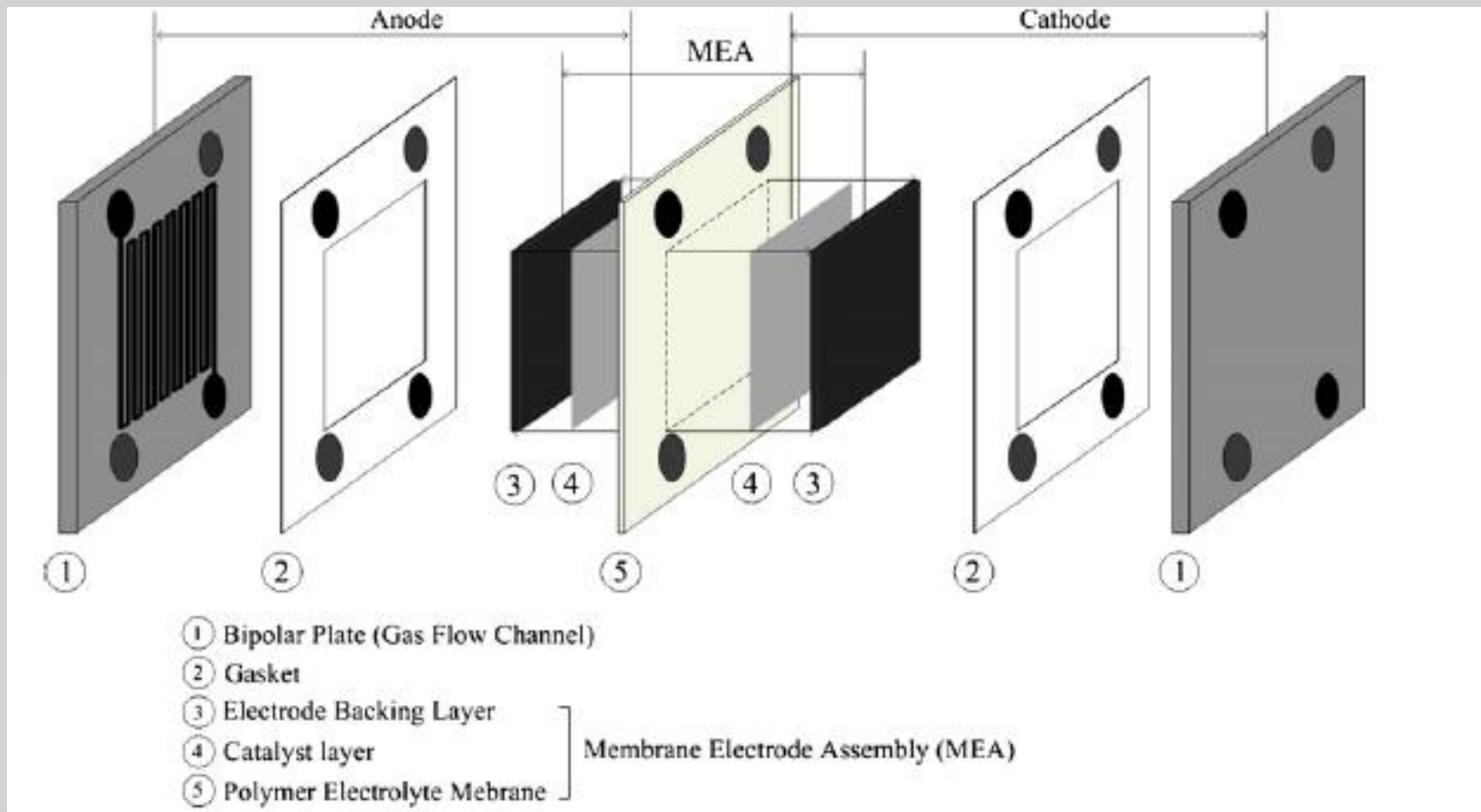


Design of Polymer Electrolyte Fuel Cell

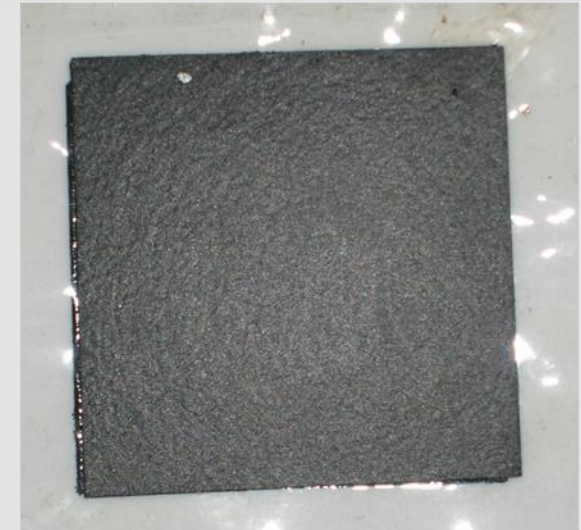
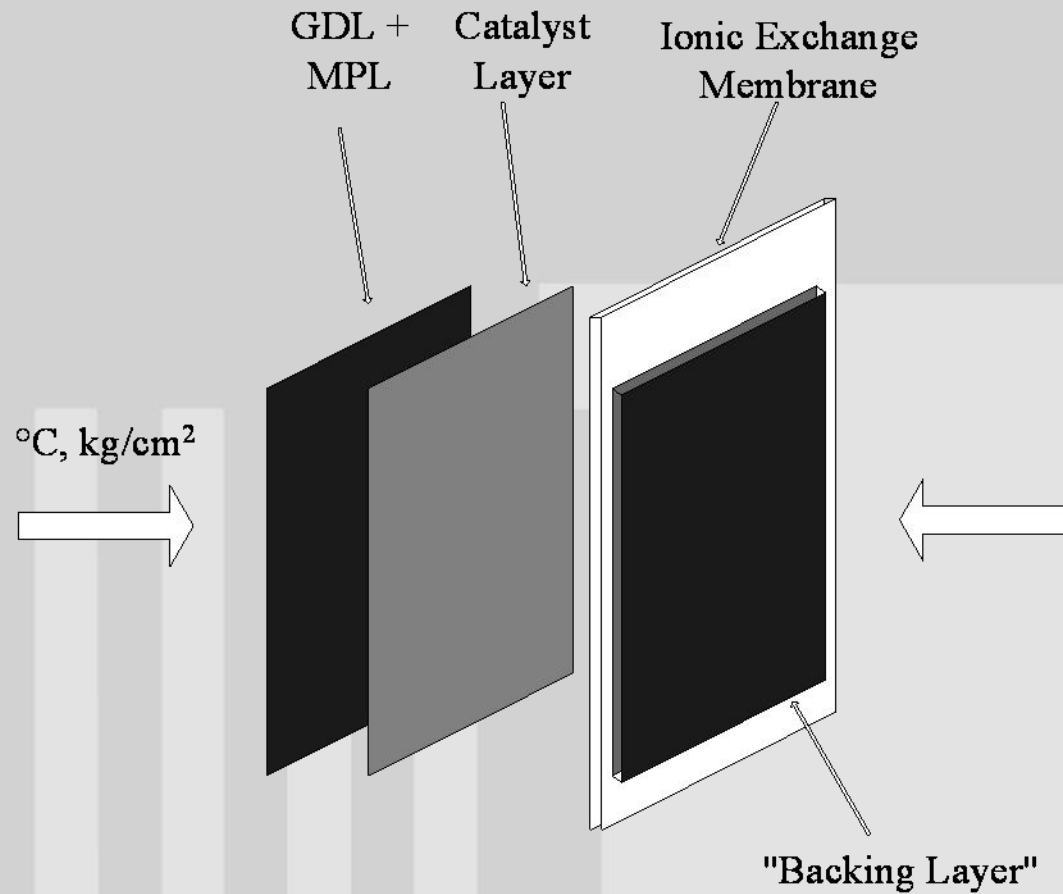
Timisoara, 05.11.2013

Duteanu Narcis

Basic principle for fuel cell operation



MEA – Membrane Electrode Assembly



Anode (hydrogen oxidation reaction):



Cathode (oxygen reduction reaction):

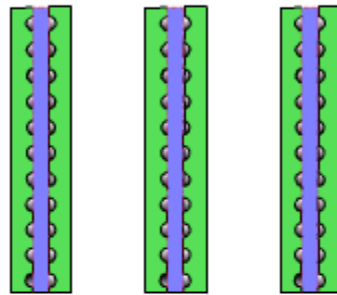


Global cell reaction:



How Fuel Cells Work

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Isotherm – isobar condition

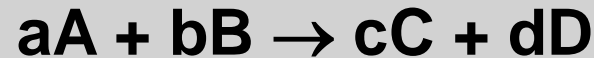
$$W_{el} = \Delta G = -nFU$$

n – number of exchanged electrons,

F – Faraday number,

U – fuel cell electromotive force,

ΔG – Gibbs free energy variation



$$\Delta G = c\mu_c + d\mu_d - a\mu_a - b\mu_b \quad \longrightarrow \quad \Delta G = \Delta G^0 + RT \ln \frac{a_C^c a_D^d}{a_A^a a_B^b}$$

$$E = E^0 + \frac{RT}{zF} \ln \frac{a_A^a a_B^b}{a_C^c a_D^d}$$

Particular case of PEMFC:



$$U = U^0 + \frac{RT}{2F} \frac{P_{H_2} P_{O_2}^{1/2}}{P_{H_2O}}$$

$$\text{Fuel cell efficiency} = \frac{\text{Electrical power output}}{\text{Total available energy}}$$

Considering an ideal process the heat added to the system is:

$$\Delta Q = T\Delta S = \Delta H - \Delta G$$



the total energy lost from fuel is: $-(\Delta G + \Delta Q)$



$$\eta_{ideal} = \frac{-\Delta G}{-\Delta G - \Delta Q} = \frac{\Delta G}{\Delta H}$$



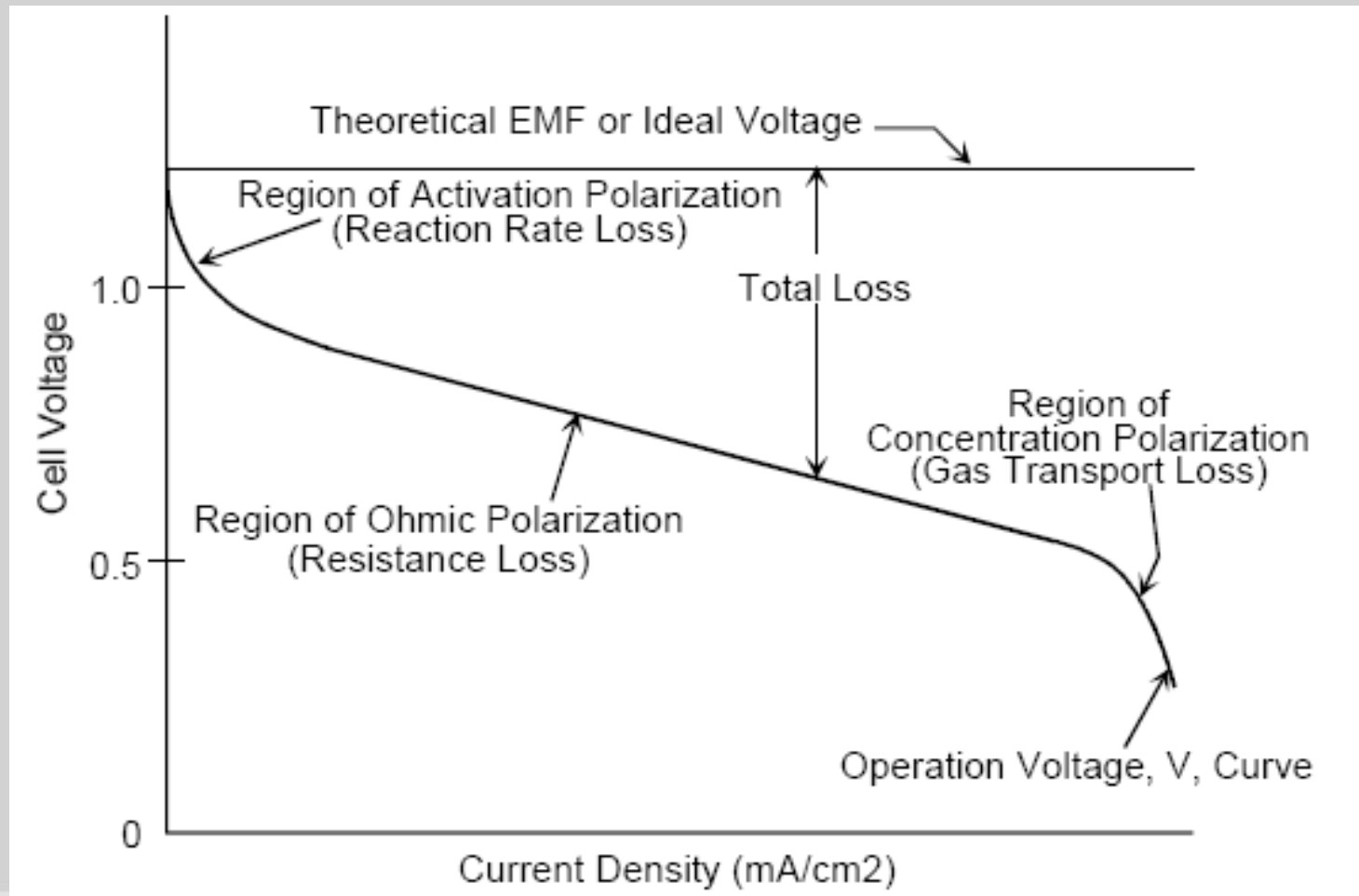
$$\eta_{ideal} = 0.83$$

(when water is produced in liquid form)

$$\rightarrow \eta = \frac{\text{Useful Power}}{\Delta H} = \frac{\text{Useful Power}}{(\Delta G/0.83)} = \frac{\text{volts}_{\text{actual}} * \text{current}}{\text{volts}_{\text{ideal}} * \text{current} / 0.83} = 0.83 \frac{V_{\text{actual}}}{E_{\text{ideal}}}$$

$$\rightarrow \eta = 0.83 \frac{V_{\text{actual}}}{1.229} = 0.675 * V_{\text{cell}}$$

Ideal and real fuel cell voltage versus current



Irreversible losses of fuel cell voltage are due to multiple phenomena, such as:

- **activation overpotential – appear because of the activation energy needed for the electrochemical reactions; are influenced by: **electro-catalyst nature and structure, reactant activities, reaction type.****
- **ohmic overpotential – appears as an effect of system **internal resistance, current collectors, interconnects, contact resistance.****
- **concentration overpotential – mass transport losses are results of finite mass transport rate of reactants and also reaction products; depend on **electrode structure, current density and also reactant activities****

Activation overpotential

➤ for anodic reaction:

$$\eta_{act}^a = \frac{RT}{\alpha z F} \ln \frac{i}{i_0}$$

➤ for cathodic reaction:

$$\eta_{act}^c = \frac{RT}{(1 - \alpha) z F} \ln \frac{i}{i_0}$$

α – the transfer coefficient in anodic sense

i_0 – current exchange density

Ohmic overpotential

$$\eta_{ohmic} = i \times R_{ohmic} = i \times (R_{ionic} + R_{electronic})$$

Concentration overpotential

$$\eta_{dif} = \frac{RT}{zF} \ln \left(1 - \frac{j}{j_{lim}} \right)$$

Total electrode overpotential

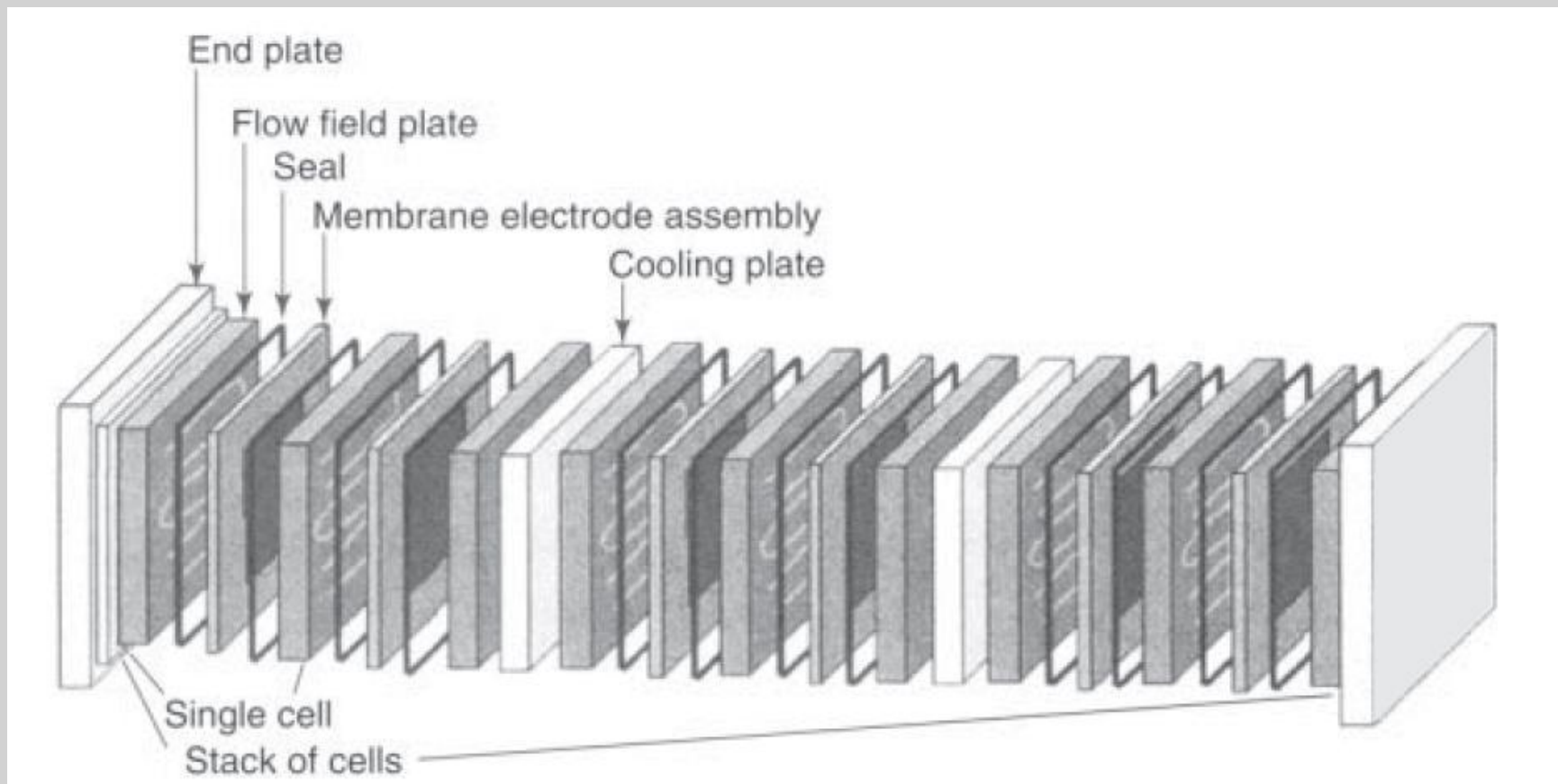
$$\eta_{anode} = \eta_{act}^a + \eta_{dif}^a$$

$$\eta_{cathode} = \eta_{act}^c + \eta_{dif}^c$$

Cell tension

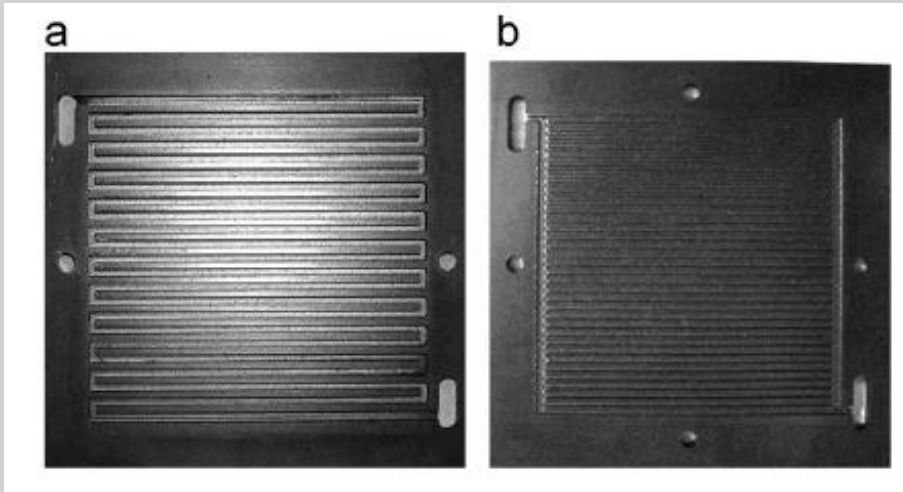
$$U_{cell} = U_{rev} - \sum |\eta| - iR$$

PEMFC stack construction

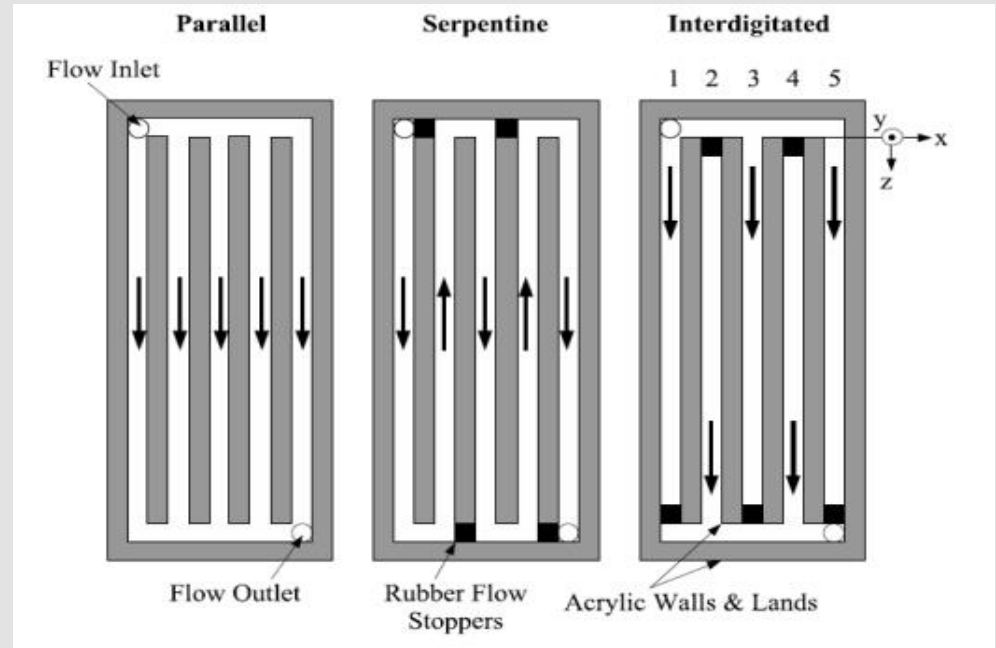


Flow fields:

- fuel transportations
- product removal
- heat transfer
- current collection



(a) Serpentine flow field and (b) parallel flow field





Fuel cell stack design

$$P = 1200 \text{ W}$$

$$U = 24 \text{ V}$$

Individual fuel cell
performance:

$$i = 0.8 \text{ A cm}^{-2}$$

$$U_{\text{cell}} = 0.8 \text{ V}$$

Evaluate:

- a. The maximum number of individual cell necessarily for considered stack.
- b. Active surface area of each individual electrode.
- c. Assuming that the stack must run for three days before the hydrogen tank is recharged, determine the hydrogen fuel tank required if hydrogen is stored as compressed gas at 200 atm, 298 K.
- d. Calculate stack water production in grams per hours.

a. No. of cells = $\frac{24}{0.8} = 30$ individual cells

b. $I = \frac{P \text{ (J s}^{-1}\text{)}}{U \text{ (J C}^{-1}\text{)}} = \frac{1200}{24} = 50 \text{ A}$

Active surface area = $\frac{50}{0.8} = 62.5 \text{ cm}^{-2}$

c.

$$n_{H_2} = \frac{50 \text{ C s}^{-1}}{2 \text{ eq mol}_{H_2}^{-1} \times 96485 \text{ C eq}^{-1}} = 2.59 \times 10^{-4} \text{ mol H}_2 \text{ per second}$$

$$n_{H_2} = 2.59 \times 10^{-4} \text{ mol} \times 3600 \text{ s h}^{-1} \times 24 \text{ h day}^{-1} \times 3 \text{ days} = 67.16$$

mol H₂ required for each single cell for 3 days

From ideal gas law $\longrightarrow V = 8.22$ L of H_2 at 200 atm per cell for 3 days

For entire fuel cell stack $\longrightarrow V_{total} = 246.47$ L of H_2 at 200 atm

d.
$$n_{H_2O} = \frac{I}{zF} = \frac{50 \text{ C s}^{-1}}{2 \text{ eq mol}_{H_2}^{-1} \times 96485 \text{ C eq}^{-1}}$$



$$n_{H_2O} = 25.91 \times 10^{-5} \text{ mols } H_2O \text{ s}^{-1} \text{ per cell}$$

\longrightarrow in one hour each single cell is producing 0.933 mols H_2O , or 16.79 g H_2O

\longrightarrow in one hour entire stack is producing 503.7 g H_2O

Thank you!

UP T