PROBLEM 1.58

KNOWN: Electrolytic membrane dimensions, bipolar plate thicknesses, desired operating temperature and surroundings as well as air temperatures.

FIND: (a) Electrical power produced by stack that is 200 mm in length for bipolar plate thicknesses 1 mm < t_{bp} < 10 mm, (b) Surface temperature of stack for various bipolar plate thicknesses, (c) Identify strategies to promote uniform temperature, identify effect of various air and surroundings temperatures, identify membrane most likely to fail.

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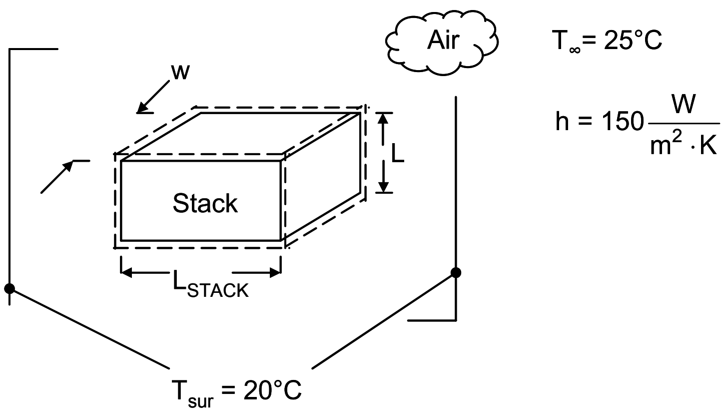
SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Large surroundings, (3) Surface emissivity and absorptivity are the same, (4) Negligible energy entering or leaving the control volume due to gas or liquid flows, (5) Negligible energy loss or gain from or to the stack by conduction.

ANALYSIS: The length of the fuel cell is related to the number of membranes and the thickness of the membranes and bipolar plates as follows.

$$L_{stack} = N \times t_m + (N + 1) \times t_{bp} = N \times (t_m + t_{bp}) + t_{bp}$$

For $t_{bp} = 1$ mm, 200×10^{-3} m $= N \times (0.43\times10^{-3}$ m $+ 1.0\times10^{-3}$ m$) + 1.0\times10^{-3}$ m
or $N = 139$

For $t_{bp} = 10$ mm, 200×10^{-3} m $= N \times (0.43\times10^{-3}$ m $+ 10\times10^{-3}$ m$) + 10\times10^{-3}$ m
or $N = 18$

(a) For $t_{bp} = 1$ mm, the electrical power produced by the stack is

$$P = E_{STACK} \times I = N \times E_c \times I = 139 \times 0.6 \text{ V} \times 60 \text{ A} = 5000 \text{ W} = 5 \text{ kW}$$ <

and the thermal energy produced by the stack is

$$\dot{E}_g = N \times \dot{E}_{c,g} = 139 \times 45 \text{ W} = 6{,}255 \text{ W} = 6.26 \text{ kW}$$ <

Continued…

PROBLEM 1.58 (Cont.)

Proceeding as before for t_{bp} = 10 mm, we find P = 648 W = 0.65 kW; $\dot{E}_g$ = 810 W = 0.81 kW $<$

(b) An energy balance on the control volume yields

$$\dot{E}_g - \dot{E}_{out} = 0 \quad \text{or} \quad \dot{E}_g - A(q''_{conv} + q''_{rad}) = 0 \tag{1}$$

Substituting Eqs. 1.3a and 1.7 into Eq. (1) yields

$$\dot{E}_g - A[h(T_s - T_\infty) + \varepsilon\sigma(T_s^4 - T_{sur}^4)] = 0$$

where A = 4 × L × w + 2 × H × w

$$= 4 \times 200\times10^{-3}\text{ m} \times 100\times10^{-3}\text{m} + 2 \times 100\times10^{-3}\text{ m} \times 100\times10^{-3}\text{ m} = 0.1\text{ m}^2$$

For t_{bp} = 1 mm and $\dot{E}_g$ = 6255 W,

$$6255\text{ W} - 0.1\text{ m}^2 \times [150\ \frac{\text{W}}{\text{m}^2\cdot\text{K}} \times (T_s - 298)\text{ K} + 0.88 \times 5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4} \times (T_s^4 - T_{sur}^4)\text{ K}^4] = 0$$

The preceding equation may be solved to yield

$$T_s = 656\text{ K} = 383°\text{C}$$

Therefore, for t_{bp} = 1 mm the surface temperature exceeds the maximum allowable operating temperature and the stack must be cooled. $<$

For t_{bp} = 10 mm and $\dot{E}_g$ = 810 W, T_s = 344 K = 71°C and the stack may need to be heated to operate at T = 80°C. $<$

(c) To decrease the stack temperature, the emissivity of the surface may be increased, the bipolar plates may be made larger than 100 mm × 100 mm to act as *cooling fins*, internal channels might be machined in the bipolar plates to carry a pumped coolant, and the convection coefficient may be increased by using forced convection from a fan. The stack temperature can be increased by insulating the external surfaces of the stack.

Uniform internal temperatures may be promoted by using materials of high thermal conductivity. The operating temperature of the stack will shift upward as either the surroundings or ambient temperature increases. The membrane that experiences the highest temperature will be most likely to fail. Unfortunately, the highest temperatures are likely to exist near the center of the stack, making stack repair difficult and expensive. $<$

COMMENTS: (1) There is a tradeoff between the power produced by the stack, and the operating temperature of the stack. (2) Manufacture of the bipolar plates becomes difficult, and cooling channels are difficult to incorporate into the design, as the bipolar plates become thinner. (3) If one membrane fails, the entire stack fails since the membranes are connected in series electrically.