NPRE 470, Lecture Notes 2-24-11

Class today started with a representative of each row of the class giving an “elevator speech” summary of the position they argued for Homework problem 1: Brave, Clean, World; Hydrogen Genie; Hydrogen in a Bottle; and New War, Old Weapons.

When reviewing the FutureGen critique portion of Homework one, Dr. Miley stressed that FutureGen 1.0 was a synthesis gas from coal project, while FutureGen 2.0 was to combust coal, though with pure oxygen, then sequester the CO2.

Dr. Luo then gave a brief review of homework problem 2.0, stressing that the easiest solution was take the heat of combustion for water (the energy content for the produced hydrogen fuel) and divide it by the heat input into the iodine or iodine bromine process.

Later in the class, Dr. Miley announced that there will be a mid-term exam on Tuesday, March 15, and that Dr. Luo will proctor.

Dr. Miley then returned to reviewing Chapter 2 of O’Hayre et al. First he stressed the Schroeder Chart on p. 32 stressing that ∆H, unlike ∆G, does not include heat released or taken in from the surroundings. He then introduced the text’s equation 2.116 (p. 60) for reversible thermodynamic efficiency:

$$ε\_{thermo}= \frac{Δ\hat{g}}{Δ\hat{h}}$$

We later contrasted this with the “carnot” (heat engine) efficiency:

$$ε\_{carnot}= \frac{T\_{H}-T\_{L}}{T\_{H}}$$

Basically an efficiency based on temperature difference between the inlet and outlet of a heat engine.

Next we discussed the difference between higher heating value (HHV) and lower heating value (LLV). In the case of a hydrogen fuel cell, this refers the energy one could get from condensed water (HHV) versus the heat one could get from water as steam (LLV). For an “honest” efficiency calculation, one uses the (HHV), that is, one considers that extra energy one could get from condensing water vapor to liquid water (text, pp. 60-61). One must be careful when reading papers to know which heating value an author used in making their calculation. Dr. Miley then stressed that ∆G, and hence, fuel cell voltage output, is a function of temperature and that voltage generally goes down with temperature.

Dr Miley then stressed that we have two currents in a fuel cell, an external electron current flowing outside the cell, and an internal ion current flowing in the cell’s electrolyte, and that the two currents must balance. Dr. Miley stressed that ion mobility (speed of ion movement in the electrolyte) is much slower than the electron flow outside the cell, so the ion current is what ultimately limits fuel cell output.

Dr. Miley next covered the text’s figure 2.8 (P. 62) which plots reversible efficiency for both fuel cell and carnot cycle versus temperature. He first noted the “kink” at 100˚C in the fuel cell plot, demarking the change of water from liquid to vapor form. Next he noted the intersection near 650˚C, where the carnot efficiency hypothetically surpasses fuel cell efficiency. He noted that fuel cell efficiency goes down with temperature but that real fuel cells are often more efficient than real heat engines above this intersection temperature.

Next we covered how to calculate this rejected heat, and introduced the imaginary (not experimentally measurable) voltage EH, or enthalpy voltage, calculated from the heat of reaction:

$E^{H}=\frac{\left|Δ\hat{h}\right|}{nF}$

To be contrasted with the open circuit voltage, Eo, calculated from free energy:

$E^{o}=\frac{\left|Δ\hat{g}\right|}{nF}$

EH represents an ideal reversible voltage from enthalpy change, a voltage usually higher than the open circuit voltage. EH – EO represents the minimum heat that a fuel cell will reject. EH – V, V being the actual fuel cell voltage, represents the actual heat a fuel cell will reject. The actual heat loss in joules/second is calculated by multiplying the actual voltage by the current:

$$Heat loss \left(\frac{J}{s}\right)= \left(E^{H}- V\right)i$$

Dr. Miley then stressed that we usually operate fuel cells a constant temperature. We remove heat either by a heat exchanger/coolant system or by using the flow of cooler reactants into the cell and the flow of hotter reactants out.

Dr. Miley then returned to earlier in text (pp. 62-64) and discussed the issue of fuel utilization and the need to match fuel provided to the cell to the fuel cell’s output. To little fuel (fuel input slow), we get starvation; our fuel cell cannot deliver its desired power. Too much fuel, we don’t use all of it, our efficiency drops. We introduced the concept of εfuel, the fuel utilization efficiency, the amount of fuel actually used by the cell to generate electricity divided by the actual fuel provided. We also introduced λ, the fuel stoichiometric factor. λ is the ratio of fuel provided to the cell divided by the fuel required for 100% fuel utilization. We usually set λ in excess of 1. Dr. Miley then turned our attention to Figure 2.9 in the text (p. 64), where we are presented cell voltage versus current density for both constant flow and constant stoichiometry conditions. (The text emphasizes that fuel cells are operated at either constant flow rate or, more often, at constant stoichiometry conditions. In constant flow rate conditions, the cell receives the same amount of fuel regardless of output. At constant stoichiometry conditions, we try to match the fuel to the desired output. Figure 2.9 in the text shows that at under constant stoichiometry, fuel cell efficiency is highest at low current density. For constant flow, efficiency is lowest at low current density, due to fuel being waisted.)

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