CM2120 Fundamentals of Chemical Engineering 2
Department of Chemical Engineering
Michigan Technological University

Homework 2
Due 4 February 2009

1. **Pump problem (20 points)**
At the end of this handout is a pump characteristic curve. Answer the following questions.

a) This pump needs to deliver a 50 ft head and a flow rate of 240 gal/min. Determine the pump speed in rpm, the pump power in hp, and the efficiency.
b) This pump is being run at 3 hp and at a flow rate of 150 gal/min. Determine the pump speed in rpm, the pump head in ft, and the efficiency.
c) Suppose that for the pump sized in part b, the pump speed is changed to 2000 rpm. Use the affinity laws to determine the pump flow rate in gpm, the pump head in ft, and the power in hp.

2. **Flash Separation (20 points)**
Wankat Problem D2 (in Chapter 2)

3. **Compressor for a Fuel Cell (10 points)**
Solve the compressor problem described on the following pages.

CACHE Modules on Energy in the Curriculum

Fuel Cells

Module 11 (First Draft): Compressor Sizing and Fuel Cell Parasitic Losses

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Course: Fluid Mechanics

Text Reference: Geankoplis (4th ed.), Section 3.3;
McCabe, Smith, and Harriott (4th ed.), Section 8.2

Concept Illustrated: Gas compression; parasitic losses in fuel cells

Problem Motivation: Fuel cells are a promising alternative energy conversion technology. One type of fuel cell, the Solid Oxide Fuel Cell (SOFC) uses hydrogen as a fuel. The fuel reacts with oxygen to produce electricity. Fundamental to the design of an SOFC is an understanding of the power needed to compress the inlet air and the impact of operating the compressor on the fuel cell power output.

The SOFC reactions are:
Anode: $H_2 + O^{-2} \rightarrow H_2O + 2\,e^-$
Cathode: $1/2O_2 + 2\,e^- \rightarrow O^{-2}$
Overall: $H_2 + 1/2O_2 \rightarrow H_2O$

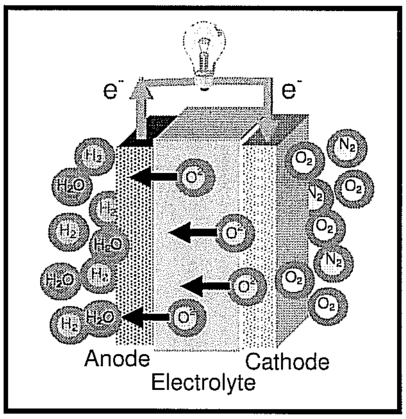

Figure 1: Reactions within SOFC

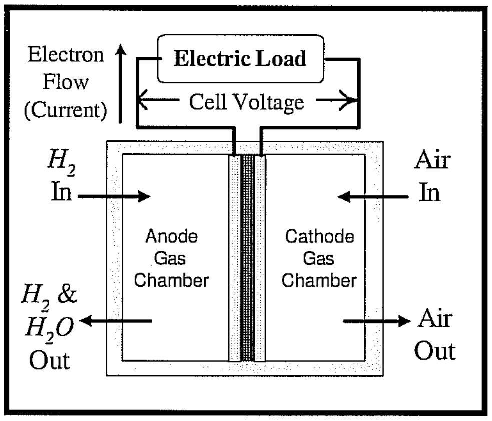

Figure 2: Flow Diagram for SOFC

For each mole of hydrogen consumed, two moles of electrons are passed through the electric load. To convert electron flow (moles of electrons/s) to electrical current (coulombs/s or amps), one would use Faraday's constant: $F = 96{,}485\ \text{coulombs / mole of}$ electrons. The primary objective of a fuel cell is to deliver energy to the electric load. To calculate the energy delivery rate (also know as power) one would multiply the current times the cell voltage: $Power = Current \cdot Voltage$. (Recall the unit conversions: $coulomb \cdot volt = Joule$ and $Joule / s = Watt$).

Problem Information

The power output from an adiabatic compressor is given by combining equations 3.3-15 and 3.3-17 in Geankoplis (4th edition):

$$\text{brake kW} = \frac{\gamma}{\gamma - 1}\frac{RT_1}{M}\frac{m}{1000\eta}\left[\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

Where:

γ is the heat capacity ratio (1.4 for air)
R is the gas constant (8.314 J/mol – K)
M is the gas molecular weight (kg/mol)
T_1 is the temperature of the gas entering the compressor (K)
p_1 is the compressor inlet pressure
p_2 is the compressor exit pressure
m is the mass flow rate in kg/s
η is the compressor efficiency

The temperature of the gas exiting the compressor can be found from the power from the energy balance:

$$P_B = mC_p\Delta T$$

Noting that the air heat capacity is 1 kJ/kg-K.

Problem Statement: A SOFC that produces 400 kW of electricity is operated with an inlet flow of 1000 g/s of air at 298 K at 1 atm pressure. This feed is to be compressed (at 80% efficiency) to 2 atm pressure within the fuel cell. Determine:

a) The compressor power
b) The temperature of the air exiting the compressor
c) The percent of the total fuel cell power needed to power the compressor

TABLE 8.1
Affinity laws for pumps

Characteristic	Constant D	Constant n
Capacity	$q \propto n$	$q \propto D$
Head	$\Delta H \propto n^2$	$\Delta H \propto D^2$
Power	$P \propto n^3$	$P \propto D^3$

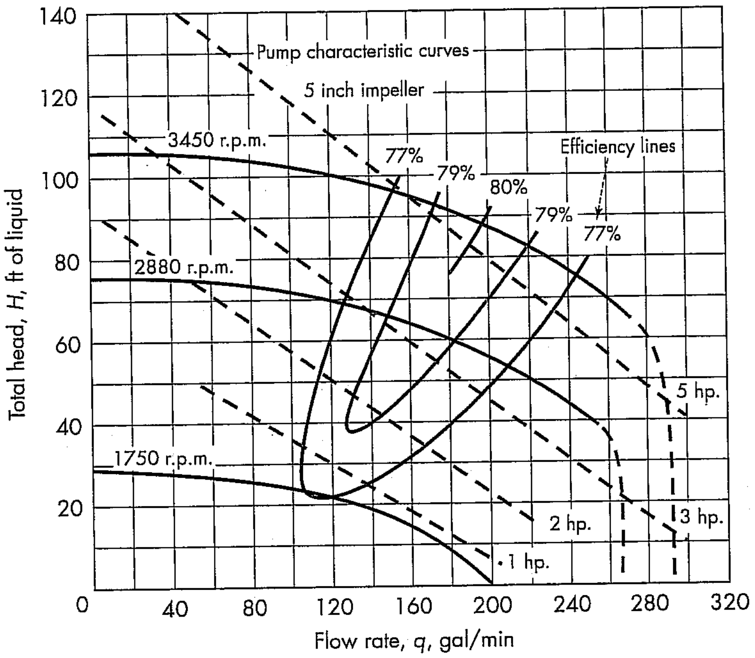

FIGURE 8.12
Characteristic curves of a centrifugal pump operating at various speeds. (*By permission from Perry's Chemical Engineers' Handbook, 7th ed., p. 10-25. Copyright © 1997, McGraw-Hill.*)

relationships are called the *affinity laws;* they are given in Table 8.1, in which D is the diameter of the pump impeller and n is the impeller speed.

Affinity laws are useful when an existing pump must be modified to give a higher or lower head or a different capacity. Changing the impeller size or speed is often less expensive than buying a new pump.

Multistage centrifugal pumps

The maximum head that it is practicable to generate in a single impeller is limited by the peripheral speed reasonably attainable. A so-called high-energy centrifugal pump can develop a head of more than 650 ft (200 m) in a single stage; but generally when a head greater than about 100 ft (30 m) is needed, two or more

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