10.491 Integrated Chemical Engineering (ICE-II)

Homework Problem Set Number 1

Assigned 27 February 2004
Due Date 6 March 2006 (No later than 12:00 noon)

Introduction to Problem Set

The purpose of this problem set is to get you started on your design project and develop some basic building blocks that may be useful in your project. In many cases you will have to make assumptions in order to solve the problems – please make sure that you document them very carefully. You can either do the modeling calculations by hand or preferably use Aspen. Many of the needed building blocks have been built in the Aspen workshops. For this problem set you may work together with your project team but I expect you to turn in your own solution – the critical point is to make sure that you understand the solution.

Problem Number 1.1 – Order of Magnitude Estimation

A recent book on energy trends made a claim that sometime in 2006 the world consumption of oil would exceed 1000 barrels/second! Conduct a literature search and determine if this estimate is true. Please document your sources. (A barrel is a standard unit of volume in the oil industry and is equivalent to 42 US gallons or approximately 159 liters.)

Problem Number 1.2 – Energy Required to Generate Electricity and to Separate CO_2 from a Gas Stream

A 500 MW power plant uses a bituminous coal, with an effective molecular formula of $CH_{0.8}S_{0.008}$, to generate steam in a boiler that is in turn released into a turbine to generate electricity. If you assume that the combustion can be represented by the overall stoichiometry and that the residence time is long enough to enable complete combustion.

a) Compare the coal composition C/H ratio against the one used in the Aspen workshop, what do you conclude?

b) If there is 15% excess air, write down the overall stoichiometry for the combustion occurring inside the boiler. Assume that the sulfur reacts to sulfur trioxide (SO_3)

c) Estimate the heat release per kg of coal (calculate both the LHV and HHV) and compare your results for coal against those we discussed in class for methane. What do you conclude?

d) Using the composition of the exhaust gas from the boiler estimate the energy required to separate CO_2 from the output stream. You will have to assume appropriate exit conditions. Repeat the calculation for the case where the oxidant is pure oxygen.

e) Make a plot of the amount of coal needed to generate 500 MW of power as a function of the boiler thermal efficiency with and without CO_2 capture. What do you conclude?

Problem Number 1.3 – A First Order Model of a Power Plant

A very simplified schematic of a power plant is shown in the figure below. Using the modules that you developed in the Aspen workshops (boiler, turbine, CO_2 removal, etc.) construct a working Aspen model of the power plant.

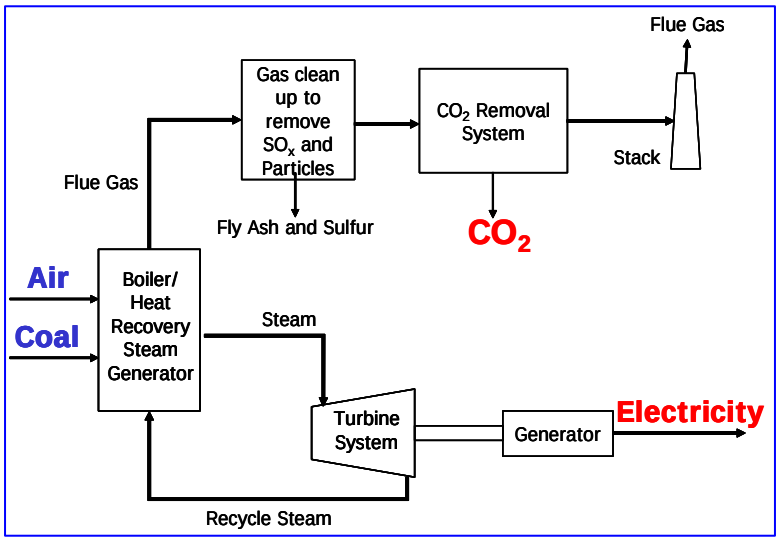

Figure 1.3a Schematic representation of a coal fired power plant.

The goal of developing the Aspen model is to use it as a basis for some very preliminary design calculations. In particular:

a. Using the coal composition employed in the Aspen work shop on modeling develop a simple Aspen flowsheet for a system whose power output is 500 MW. Use a boiler thermal efficiency of 40% as a design basis. (In the initial design do not worry about the treatment of the recycled steam)

b. Estimate the energy requirements for CO_2 capture.

c. Estimate the adiabatic flame temperature for a coal/O_2 feed.

d. If the maximum temperature inside the boiler under oxygen firing conditions is to be kept below 1200 K how much of the exhaust gas would have to be recycled to cool the boiler.

Note to students: The problem statement is purposely vague, you will have to make assumptions about the level of detail, and how to treat the individual unit operations. In addition I want you to keep to the time allocated for study/home work in this class. The goal is to do the best that you can do in the time available, not to work yourself into exhaustion as there are a lot of other project related activities to be completed.