EXAM ENERGY FROM BIOMASS (4S610)

Wednesday, January 25, 2012

The exam consists of 4 questions. Read the questions carefully. Be brief and concise.

Try to use variables as long as possible in your answer and fill in the numbers at the end. Don't forget the correct units!

Please, separate the answers to questions 1 and 4 from the answers to questions 2 and 3 by using different pieces of paper.

Success!

QUESTION 1

General questions

a. Give 3 good reasons for using biomass as an energy source
b. Give 3 disadvantages of using biomass as an energy source
c. What was agreed upon in the Kyoto protocol?
    a. Mitigation of greenhouse gases
    b. Decrease of CO_2 emissions
    c. Establishing CO_2 equivalents for general greenhouse gases
    d. Limitations on economic growth
d. What is meant by the expression "CO_2 neutral"?
e. How is the analysis denoted for determination of the elemental composition of biomass?
f. Which main molecules is woody biomass made of?
g. What is a typical composition of biogas, i.e. gasified biomass?
h. What conservation equations are relevant to describe thermal biomass conversion?
i. Name four different reactor classes for biomass conversion?
j. What is torrefaction?
k. Name a primary measure to reduce emissions.

QUESTION 2

An electricity company wants to produce "green" electricity by co-firing woody biomass in a pulverized coal power plant. An ultimate analysis of the woody biomass shows that it consists of 6% H and 40% O on a mass basis. The rest is carbon. The molar masses of element C, H, and O are 12, 1, and 16 g/mol, respectively. Coal may be assumed to consist of 100% carbon and its lower heating value is 30 MJ/kg. The desired thermal power of the plant is 500 MW.

a. Determine the composition of this woody fuel in terms of CH_xO_y.

b. Write down the reaction equation for the complete oxidation of this woody biomass.

c. How much CO_2 is emitted per kg of the woody fuel?

d. How much CO_2 is emitted per kg of coal?

e. Compute the higher heating value (HHV) of the woody fuel using the empirical relation below.

$$\text{HHV} = 34.91\ Y_c + 117.83\ Y_H - 1.51\ Y_N - 10.34\ Y_O\ \text{[MJ/kg]}$$

f. Compute the lower heating value (LHV) of this fuel assuming that the heat for evaporation of 1 gram of water is 2.442 kJ.

g. How much CO_2 (kg/h) is emitted when the power plant runs on coal only.

h. A part of the coal is now replaced by biomass. 20% of the total energy output should originate from the biomass. How much wood (kg/h) and coal need to be burnt to realize this?

i. How much CO_2 (kg/h) is emitted in this case? Comment on the difference with the 100% coal case.

QUESTION 3

Consider a biomass integrated gasification combined cycle (BIGCC) system. In this system, a certain biomass with composition $CH_{1.4}O_{0.6}$ is gasified by using pure oxygen.

a. Write down the ideal reaction equation for the gasification of this biomass with oxygen into products CO and H_2.

b. How much O_2 is needed to gasify 1 kg of biomass according to this reaction?

c. In practice, more oxygen is used. Why?

Subsequently, the syngas is burned in the combustion chamber of a gas turbine. Assume that the syngas consists of 60% CO and 40% H_2 by volume, and that its heating value is 20 MJ/kg. The syngas is burnt with a large excess of air: The air ratio equals 2. The mass fraction of O_2 in air is 20%.

d. Compute the mass fractions Y_{CO} and Y_{H2} in the syngas.

e. How much air (kg) is fed to the reactor per kg of syngas?

f. What is the total mass flow (air + syngas) into the reactor for a thermal power of 50 MW?

The reactor is cylindrical with a diameter D of 0.5 m. The reactor can be assumed to be of a plug-flow type. The temperature T and density ρ of the gas can be assumed constant: T = 2000 K and ρ = 0.5 kg/m^3. The rates of the oxidation of CO and H_2 are given by

$$\omega_{CO} = -\rho A_1 Y_{CO} \exp(-T_1 / T)$$
$$\omega_{H2} = -\rho A_2 Y_{H2} \exp(-T_2 / T)$$

with $A_1 = 10^4$ s^{-1}, $A_2 = 10^5$ s^{-1}, T_1 = 4000 K, and T_2 = 3000 K.

g. Write down the equations that describe the evolution of the mass fractions of CO and H_2 as a function of the distance x from the inlet.

h. Solve the equations for $Y_{CO}(x)$ and $Y_{H2}(x)$ and compute at which distance from the inlet 50% of the CO is burned. What percentage of H_2 is unburned at that distance?

QUESTION 4

In large gasification plants or in co-firing, fuel particle size is very important. It determines the conversion time of the particle, and therefore the associated power.

Considering particle conversion we have the following questions:

a. Give the three main mechanisms of particle conversion.

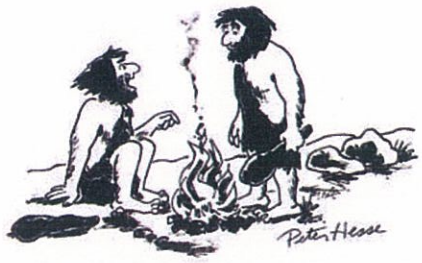
b. What are the roles and/or meaning of the following numbers: Th, Bi?

c. For what cases can the Spalding number be used?

d. Which law is associated with the Spalding number?

e. Describe 4 kinds of group behavior of thermal biomass particle conversion.

f. Draw a diagram of the 4 kinds of group behavior and define the axes clearly!



It´s called fire... a new way to recycle wood!