EXAM ENERGY FROM BIOMASS (4S610)

Wednesday, June 30, 2010

The exam consists of 4 questions. Read the questions carefully. Be brief and concise. Limit your answer to 4 lines of text at questions 2 and 3.

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 all 4 questions on different pieces of paper.

Success!

QUESTION 1

(25 points)

The composition of a certain dry woody biomass is 45% cellulose ($C_6H_{10}O_5$), 30% hemicellulose ($C_5H_8O_4$), and 25% lignin ($C_{20}H_{22}O_3$). The molar masses of element C, H, and O are 12, 1, and 16 g/mol, respectively.

a. Compute the average composition of this fuel in terms of CH_xO_y.
b. Write down the reaction equation for the complete oxidation of this fuel.
c. Compute the higher heating value of this fuel using

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

d. Compute the lower heating value of this fuel assuming that the heat for evaporation of 1 gram of water is 2.442 kJ.
e. This fuel is used as a feedstock for the boiler furnace of a steam power plant. How much fuel (kg/h) needs to be burnt to realize a thermal power of 10 MW?
f. How much CO_2 (kg/h) is emitted in this case? But why is biomass then considered to be a CO_2-neutral fuel?

QUESTION 2

(25 points)

There are many conversion routes from biomass to a usable form of energy.

a. Give one biochemical process for biomass conversion.
b. What are the three main thermo-chemical conversion processes?
c. Give their typical operating temperatures and air ratio's.
d. What are the main (energy-containing) products of each thermo-chemical conversion process?
e. Are these processes endothermic or exothermic?
f. What is torrefaction? What is the added value of torrefied biomass?

QUESTION 3

(35 points)

a. Describe the different modes of conversion of a single isolated particle. What happens if particles are not isolated anymore?
b. What forces determine the fluidization velocity of isolated particles (i.e. low concentrations)? What happens when the particle concentration rises?
c. What does the Thiele number express? Draw a typical graph of the oxygen content in the particle as function of radius for a small Thiele number.
d. What does the Biot number express? Copy the previous graph and draw an additional line for low Biot number at the same Thiele number.
e. What does the d^2 law describe?
f. In conversion of a carbon particle the reaction $C + O_2 \rightarrow CO_2$ is called unimolecular and it therefore induces no flow. However the number of molecules is halved. How can this assumption be true?
g. Draw an updraft gasifier and indicate the functional zones. Explain the working principle.
h. How can conversion in a grate furnace be modeled with a one-dimensional approach? It is advised to use a schematic drawing to explain this.
i. Which fixed-bed conversion mode can be observed when smoking a cigarette, if one considers the direction of the front propagation and air flow direction?

QUESTION 4

(15 points)

A reactor with volume V [m^3] has to be designed to convert species A to B in a single step at a certain reaction rate r [mol/m^3s]:

$$A \xrightarrow{r} B \quad \text{with} \quad r = k\frac{\rho Y_A}{M_A}\exp(-T_a / T)$$

in which Y [-] is the mass fraction, M_i [kg/mol] the molar mass of species i, and ρ [kg/m^3] the density. Remember that the chemical source term [kg/m^3s] is given by

$$\omega_i = M_i \sum_j (\nu_{ij}'' - \nu_{ij}') r_j$$

a. Write down the mass and species balance for a stationary Perfectly Stirred Reactor model.
b. Apply the mass balance in the species balance.
c. Write the species balance in terms of $\tau = \rho V / \dot{m}$ [s].
d. Write the outflow mass fraction of species A in terms of its inflow mass fraction.

The system is isothermal: the temperature is equal to the activation temperature of the reaction $T = T_a$.

e. We want to have species A at the outflow to be half the mass fraction of the inflow. What should be the value of τ in terms of the rate constant k [1/s] ?
f. For this case, determine the required volume V (in closed form).