Exam Energy from Biomass

4S610

Thursday, May 10, 2007

This exam consists of **3** 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 all the questions on different pieces of paper.

Success!

1 General

Points: all questions 3 points (total = 45)

1. Give 3 good reasons for using biomass as an energy source
2. Give 3 disadvantages of using biomass as an energy source
3. What is 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
4. What is meant by the expression "CO_2 neutral"?
5. Which 3 chemical elements are the major constituents of biomass?
6. How is the analysis denoted for determination of the elemental composition of biomass?
7. Which main molecules is biomass made of?
8. What is a typical composition of biogas, i.e. gasified biomass?
9. Can biogas be burned with any burner? Why?
10. What conservation equations are relevant to describe thermal biomass conversion?
11. With what type of reactors can biomass be converted?
12. Which kind of models are available for thermal conversion of biomass particles?
13. What dimensionless number is a measure for the heat transfer at the gas side of a particle compared to the heat transfer inside a particle?
14. What physical combustion quantities are important for the combustion of biogas?
15. Name a primary measure to reduce emissions.

2 Gasification

Points: all questions 6 points (total = 30)

An efficient way of biomass conversion is gasification. Here, we consider gasification of wood in a perfectly stirred reactor. The composition of the wood can be denoted as $CH_{1.4}O_{0.6}$. This wood is fed into a reactor with volume $V = 4$ m^3 at a rate of $m^{\mathrm{fu}} = 2$ kg/h. Primary air with 23 wt% oxygen is added to this same reactor at a rate of m^{air}. The oxygen in the air stream reacts with the biomass to form carbon monoxide CO and hydrogen H_2,

$$CH_{1.4}O_{0.6} + \nu_1 O_2 \longrightarrow \nu_2 CO + \nu_3 H_2,$$

with ν_i the stoichiometric coefficients. The rate of this reaction ω_1 [kmol/m^{3}s] is given by

$$\omega_1 = A_1 Y_{O_2} \exp(-T_{a1}/T),$$

with Y_{O_2} the mass fraction of oxygen, $A_1 = 10^7$ kmol/m^{3}s and $T_{a1} = 2.5\times10^4$ K. The reactor can be considered to be a perfectly stirred reactor in steady state. The temperature T of the mixture in the reactor is $T = 10^3$ K.

a. Suppose there is just enough air fed into the reactor to get complete conversion of the wood into CO and H_2. Compute the air rate m^{air}[kg/h].

b. Give the conservation equations for total mass, and O_2 mass fraction. Clearly indicate what the meaning is of variables you introduce and express them in terms of variables introduced above. (Advise: check the dimensions of the different terms.)

c. Determine Y_{O_2} in the reactor by solving the equations. Note that $Y_{O_2} > 0$ although just enough air is supplied for complete conversion.

The mixture leaves the reactor through a pipe with radius $R = 0.1$ m. The temperature in the pipe is $T = 900$ K and the flow through the pipe can be assumed to be a plug flow. In the pipe the remaining oxygen reacts with CO following the reaction

$$CO + \frac{1}{2}O_2 \longrightarrow CO_2$$

The reaction rate ω_2 [kmol/m^{3}s] is given by

$$\omega_2 = A_2 Y_{O_2} \exp(-T_{a2}/T),$$

with $A_2 = 10^5$ kmol/m^{3}s and $T_{a2} = 1.5 \times 10^4$ K.

d. Give the conservation equation for mass and O_2 mass fraction.

e. Compute Y_{O_2} at an axial distance of $x = 1$ m from the inlet of the pipe.

Element	Mass (kg/kmol)
C	12
H	1
O	16

Table 1: Molar mass of different elements (right).

3 Torrefaction of wood

Points: a=5, b=5, c=5, d=5, e=5, f=10, g=5 (total = 40)

a. Thermal processing of solid biofuels (e.g. wood) may be distinguished into 3 categories: pyrolysis, gasification and combustion. Explain briefly the fundamental differences, with focus on the air equivalence ratio.

b. Torrefaction and fast pyrolysis both belong to the first category. Torrefaction is a process in which wood is roasted at temperatures in the range of 250-300°C, in which mainly hemicellulose (the least thermally stable component) reacts. Please give a description of a fast pyrolysis process; in which aspects does it differ from torrefaction?

c. Suppose that woody biomass consists of 50 wt% cellulose, 25 wt% hemicellulose and 25 wt% lignin. Calculate the average composition of wood! Required information: cellulose = $(C_6(H_2O)_5)_n$, hemicellulose = $(C_5(H_2O)_4)_n$, lignin = $(C_{40}H_{44}O_6)_n$

d. Calculate gross heat of combustion (HHV) and net heat of combustion (LHV) of wood. Empirical correlation for HHV [kJ/g]:

$$HHV = 34.91Y_C + 117.83Y_H + 10.05Y_S - 1.51Y_N - 10.34Y_O - 2.11Y_{Ash}$$

Enthalpy of evaporation of water: $\Delta H_{vap,H_2O} = 2.442$ kJ/g

e. Wood is reacted in a torrefaction process, and after completion of the process 86.4% of the wood is recovered with an (increased) HHV of 24.6 kJ/g. Assuming that the weight loss is only H2O (g) (this assumption is not completely realistic), calculate the reaction enthalpy.
Is the reaction endo- or exothermic?

f. Set up an overall enthalpy balance for the torrefaction process, using the following process conditions:
Incoming wood @ 25°C
Products (torrefied wood and steam) @ 300°C
The heat capacity Cp is temperature-dependent, but may be approximated by the following average values: $Cp_{TORREFIEDWOOD} = 1.03$ kJ/kg K, $Cp_{H_2O} = 2$ kJ/kg K.
Is the process endo- or exothermic?
What would be the effect of ash or moisture present in the wood feedstock?

g. As the fibrous structure of wood is destroyed in the torrefaction process, torrefied wood is much more brittle and can be easily pulverized.
For which type of gasifier would that be beneficial: fixed bed, fluidized bed or entrained flow, and why?
What are the advantages of this type of gasifier?
(hint: think about 'operating conditions' and its effect on tar production, unreacted carbon and reactor capacity)