EXAM ENERGY FROM BIOMASS (4S610)

Thursday, January 30, 2014

The exam consists of 4 questions. Read the questions carefully. Be brief and concise. You may answer in English or Dutch. No books are allowed, only a calculator.

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!

Separate the answers to **questions 1 and 2** from the answers to **questions 3 and 4** by using different pieces of paper. Hand them in separately.

Success!

QUESTION 1

General questions:

a. What is the environmental advantage of using biomass as an energy source?

b. Name the typical conversion processes in thermal biomass conversion and explain what happens chemically and energetically.

c. What are the main organic compounds of biomass? Give an indication of their weight fraction in woody biomass.

d. What is a proximate analysis and how is it carried out?

e. Name at least one primary and one secondary reduction measure for reducing harmful emissions in biomass reactors.

f. What is torrefaction, why and when can it be advantageous?

QUESTION 2

Biomass particles can be gasified in an entrained flow reactor.

a. Can you name 3 typical modes of single particle gasification?

b. Can you name the dimensionless numbers that indicate the conversion mode and how these numbers are build up from what physical quantities?

c. What law does apply, when the conversion takes place at the outer surface of the particle?

d. What dimensionless number determines the speed of the process, when the conversion takes place at the outer surface of the particle?

e. Can you name a few turbulent modes of particles conversion and draw a picture of these modes?

f. What parameter determines the mode of particle conversion in turbulent flows?

QUESTION 3 (PLEASE START ON A NEW PIECE OF PAPER!)

In the lab an ultimate analysis has been performed of a woody biomass sample. The initial mass of the dry sample was 10 gram. The measured amounts of CO_2 and H_2O are 19 and 5.5 gram, respectively. No nitrogen was found. The molar masses of element C, H, O and N are 12, 1, 16 and 14 g/mol, respectively.

a. Write down the reaction equation for the complete oxidation of a CH_xO_y biomass fuel.
b. Determine x and y in CH_xO_y for this biomass.

Use x = **1.40** and y = **0.60** in the remainder of this question.

c. Compute the higher heating value (HHV) of this fuel using the empirical relation below.

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

d. The actual measured HHV of this fuel is **20 MJ/kg**. Compute the lower heating value of this fuel assuming that the heat of evaporation of 1 gram of water is 2.442 kJ.

This woody biomass is combusted in a power plant with air (23 wt% O_2). The thermal efficiency of this plant, based on the HHV, is η = 45%.

e. How much biomass (kg/s) needs to be burnt to realize a power of 10 MW?
f. How much air (kg/s) needs to be supplied for an air equivalence ratio of 2?

QUESTION 4

Woody biomass can be gasified in an updraft fixed-bed gasifier.

a. Make a schematic drawing of an updraft gasifier. Indicate the streams entering and leaving the reactor. Also indicate the different conversion zones in this reactor.

The product gas leaving the gasifier ("wood gas") is burnt with air in a combustor. Assume that this wood gas consists of 20% CO, 10% H_2 and 70% N_2 by volume, and that its heating value is 6 MJ/kg. The wood gas is burnt at stoichiometric conditions: The equivalence ratio is 1. The mass fraction of O_2 in air is 23%.

b. How much air (kg) is fed to the reactor per kg of wood gas?
c. What is the total (air + wood gas) mass flow m (kg/s) for a thermal power of 10 MW?
d. Compute the mass fraction Y_{CO} in this mixture of air and wood gas.

In the following you may assume that the total mass flow m = **3 kg/s**. The combustion reactor has a volume V of 0.025 m^3 and can be assumed to be a perfectly stirred reactor. The temperature T and density ρ of the gas mixture may be assumed constant: T = 2000 K and ρ = 0.5 kg/m^3. The rate of the oxidation of CO is given by

$$\omega_{CO} = -\rho A Y_{CO} \exp(-T_a / T)$$

with $A = 10^4\ s^{-1}$ and T_a = 4000 K.

e. What is the residence time τ [s] of the gas in the reactor?
f. Compute the CO mass fraction in the outlet of the reactor.