Exercise 11: Biomass, Options for technical use

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A detailed solution is provided at 6th of December, please see: http://www.psi.ch/ene/ret1

Question 1: General questions

a) Oil is formed out of which raw material under pressure over a period of millions of years?

b) Which biological base materials can be used as feedstock for biomass?

c) Explain the meaning of the air-fuel equivalence ratio λ in words and give the range of λ for a pyrolysis, gasification and a combustion process.

d) What is the main difference between autothermal and allothermal gasification?

e) How can the production of biogas from an anaerobic digestion process be optimized?

Question 2: Production of steam with waste wood chips from a sawmill

Your engineering company receives an order to develop a combustion process of waste wood chips from a sawmill to produce steam for electricity generation in a steam turbine. To run the process in an optimal way, surplus heat is used in a pre-drying process step to reduce the water content of the wood chips before entering the combustion chamber. Dry wood chips can be regarded as $C_6H_{10.4}O_5$. The process diagram is shown in figure 1. As a good approximation, formula (1) can be used to calculate the combustion process.

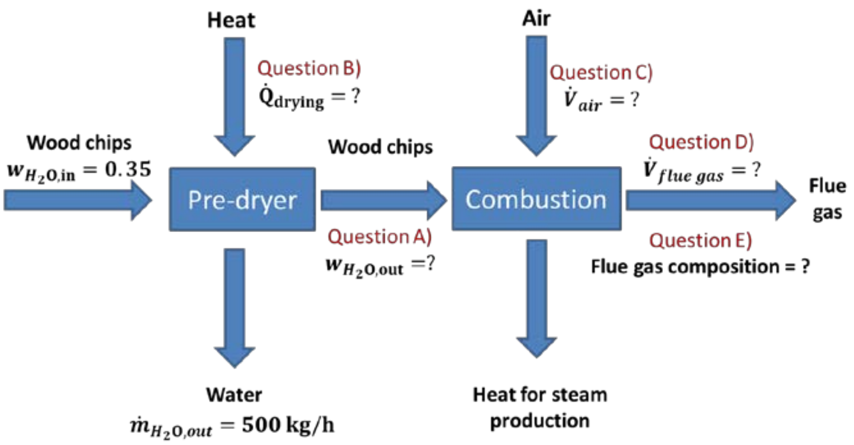

Figure 1: Process scheme of biomass power plant

$$C_nH_aO_b + (n + a/4 - b/2)\ O_2 \rightarrow n\ CO_2 + a/2\ H_2O \qquad (1)$$

A. The pre-dryer is fed with 2000 kg/h of wood chips with a water content w_{H_2O} of 0.35. Calculate the water content after the pre-dryer if 500 kg/h of water are evaporated.

B. Which amount of heat is required to evaporate the water? Please calculate with an evaporation enthalpy for H_2O of 40.8 MJ/kmol.

C. Calculate the required volume flow of air for a stoichiometric combustion of the wood chips. The composition of the combustion air is y_{N_2} = 0.79 and y_{O_2} = 0.21. The molar volume of air at standard conditions is 22.4 m^3/kmol

D. Calculate the flue gas composition after the combustion chamber.

$$w_{H_2O} = \frac{\text{mass of water [kg]}}{\text{mass of wet biomass [kg]}} = \frac{\text{mass of water [kg]}}{\text{mass of dry biomass [kg] + mass of water [kg]}}$$

$$\dot{m}_{Biomass,wet} = 1500\ \frac{kg}{h}$$

$$\widetilde{M}_{C_6H_{10.4}O_5} = 162.4\ \frac{kg}{kmol}$$

$$\widetilde{M}_{H_2O} = 18\ \frac{kg}{kmol}$$

$$\widetilde{M}_{O_2} = 32\ \frac{kg}{kmol}$$

$$\widetilde{V}_{m,air} = 22.4\ \frac{m^3}{kmol}$$

Question 3: Cold gas efficiency of a gasification process

Dry biomass is gasified in a fluidized bed gasifier. The efficiency of the gasification process has to be judged for a given product gas composition by means of the cold gas efficiency. 2000 Nm^3/h of air and 200 kg/h of steam are used as gasification agents. The product gas composition is given in *Table 2*. Air is as a mixture of 79 Vol.-% N_2 and 21 Vol.-% O_2. All gases can be regarded as ideal. Calculate at norm temperature T_N and norm pressure p_N.

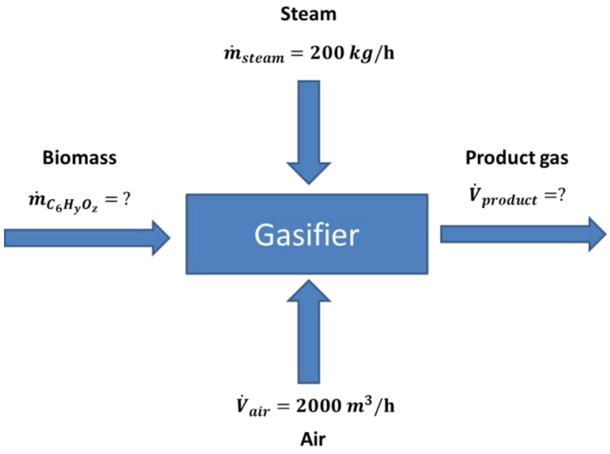

Table 2: Product gas composition after the gasifier

	H_2	CO_2	CO	CH_4	N_2
Vol.-%	27	22	11	7	33

A. Calculate the volume flow of the product gas.

B. Determine the molecular formula of the used biomass ($C_6H_yO_z$) and calculate the mass flow of biomass entering the column under the assumption that the conversion grade of biomass is 100%.

C. The cold-gas efficiency η_{CG} of the gasifier is 75 %. Calculate the lower heating value of the biomass entering the gasifier.

$$\eta_{CG} = \frac{LHV_{product} \cdot \dot{V}_{product}}{LHV_{fuel} \cdot \dot{m}_{fuel}}$$

$T_N = 273.15\ K$

$$p_N = 101325\ Pa$$

$$\widetilde{M}_C = 12\ g/mol$$

$$\widetilde{M}_O = 16\ g/mol$$

$$\widetilde{M}_H = 1\ g/mol$$

$$LHV_{Biomass} = 19\ {}^{MJ}/_{kg}$$

$$LHV_{H_2} = 10.78\ {}^{MJ}/_{Nm^3}$$

$$LHV_{CH_4} = 35.88\ {}^{MJ}/_{Nm^3}$$

$$LHV_{CO} = 12.63\ {}^{MJ}/_{Nm^3}$$

$$R = 8.314\ {}^{J}/_{mol \cdot K}$$