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Review

Biomass gasification technology: The state of the art overview

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ABSTRACT

In the last decades the interest in the biomass gasification process has increased due to the growing attention to the use of sustainable energy. Biomass is a renewable energy source and represents a valid alternative to fossil fuels. Gasification is the thermochemical conversion of an organic material into a valuable gaseous product, called syngas, and a solid product, called char. The biomass gasification represents an efficient process for the production of power and heat and the production of hydrogen and second-generation biofuels. This paper deals with the state of the art biomass gasification technologies, evaluating advantages and disadvantages, the potential use of the syngas and the application of the biomass gasification. Syngas cleaning though fundamental to evaluate any gasification technology is not included in this paper since; in the authors' opinion, a dedicated review is necessary.

1. The biomass gasification process

The biomass gasification process consists in the conversion of a solid/liquid organic compound in a gas/vapor phase and a solid phase. The gas phase, usually called "syngas", has a high heating power and can be used for power generation or biofuel production. The solid phase, called "char", includes the organic unconverted fraction and the inert material present in the treated biomass. This conversion represents a partial oxidation of the carbon in the feeding material and is generally carried out in the presence of a gasifying carrier, such as air, oxygen, steam or carbon dioxide. Biomass gasification is considered as a way to increase the use of biomass for energy production allowing widespread biomass utilization. The development of biomass gasification processes is pushed up by the growing awareness of the possible effects of fossil fuels on the climate and by the continuous increase in oil prices.

The syngas produced is a gas mixture of carbon monoxide (CO), hydrogen (H_2), methane (CH_4) and carbon dioxide (CO_2) as well as light hydrocarbons, such as ethane and propane, and heavier hydrocarbons, such as tars, that condense at temperatures between 250 and 300 °C. Undesirable gases, such as sulphidric (H_2S) and chloridric acid (HCl), or inert gases, such as nitrogen (N_2), can also be present in the syngas. Their presence depends on the biomass treated and on the operational conditions of the gasification process. The lowest heating value (LHV) of the syngas ranges from 4 to 13 MJ/Nm^3, depending on the feedstock, the gasification technology and the operational conditions [1–3].

The char produced is a mixture of unconverted organic fraction, largely carbon, and ash. The amount of unconverted organic fraction mainly depends on the gasification technology and the operational conditions. On the other hand, the amount of ash depends on the biomass treated. The LHV of the char ranges from 25 to 30 MJ/kg [4], depending on the amount of unconverted organic fraction.

The principal reactions of the gasification are endothermic and the necessary energy for their occurrence is, generally, granted by the oxidation of part of the biomass, through an allo-thermal or an auto-thermal phase. In the auto-thermal process, the gasifier is internally heated through partial combustion, while in the allo-thermal process the energy required for the gasification is supplied externally [5,6]. Considering the auto-thermal system, gasification can be seen as a sequence of several stages. A simplified schematic representation of the gasification is reported in Fig. 1. The main steps of the gasification process are:

(1) Oxidation (exothermic stage).
(2) Drying (endothermic stage).
(3) Pyrolysis (endothermic stage).
(4) Reduction (endothermic stage).

An additional step, consisting in tar decomposition, can be also included in order to account for the formation of light hydrocarbons due to the decomposition of large tar molecules.

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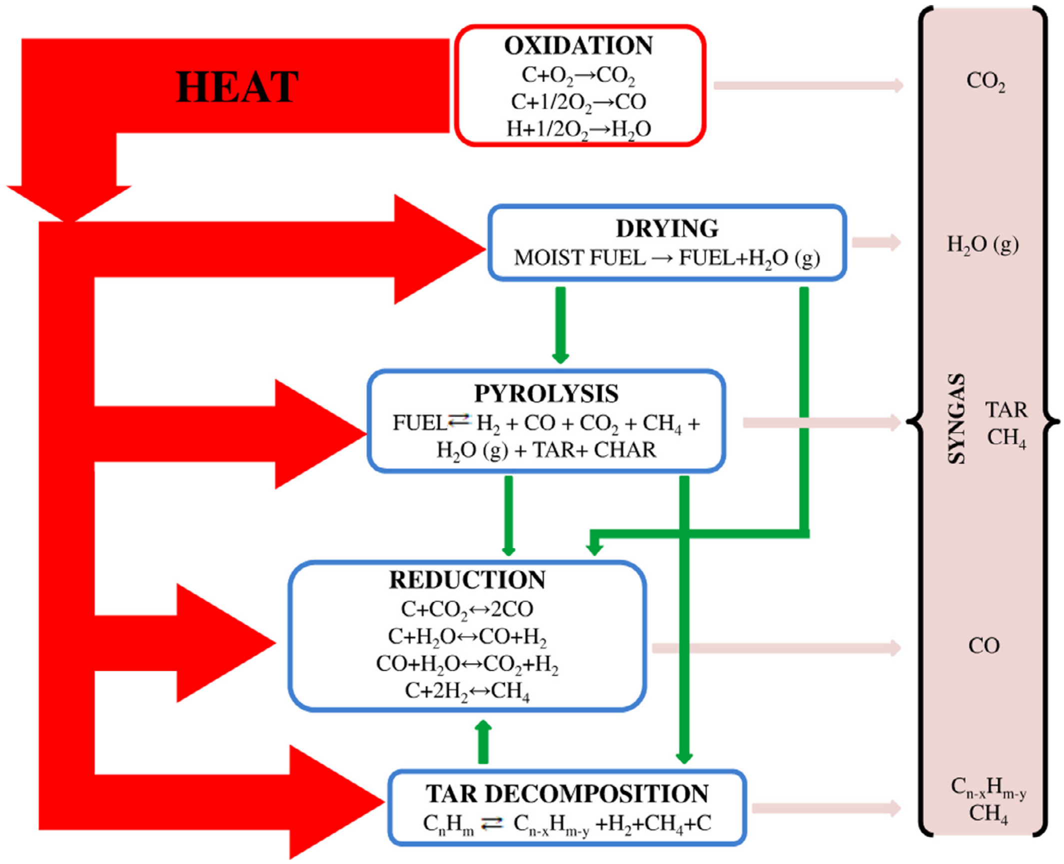

Fig. 1. Main stages of the gasification process.

1.1. Oxidation

The oxidation of part of the biomass is necessary to obtain the thermal energy required for the endothermic processes, to maintain the operative temperature at the required value. The oxidation is carried out in conditions of lack of oxygen with respect to the stoichiometric ratio in order to oxidize only part of the fuel. Despite the partial oxidation involving all carbonaceous species (tars included), it is possible to simplify the system considering that only char and the hydrogen contained in the syngas participate in the partial oxidation reactions. The main reactions that take place during the oxidation phase are the following:

$$C + O_2 \rightarrow CO_2 \quad \Delta H = -394\,\text{kJ/mol} \quad \text{Char combustion} \tag{1}$$

$$C + 1/2O_2 \rightarrow CO \quad \Delta H = -111\,\text{kJ/mol} \quad \text{Partial oxidation} \tag{2}$$

$$H_2 + 1/2O_2 \rightarrow H_2O \quad \Delta H = -242\,\text{kJ/mol} \quad \text{Hydrogen combustion} \tag{3}$$

The main product of this step is the thermal energy necessary for the whole process, while the combustion product is a gas mixture of CO, CO_2 and water. In this mixture nitrogen can be present if the biomass oxidation is performed with air, otherwise nitrogen is practically absent if only oxygen is used.

1.2. Drying

Drying consists in the evaporation of the moisture contained in the feedstock. The amount of heat required in this stage is proportional to the feedstock moisture content. Generally, the heat required derives from the other stages of the process. Drying can be considered complete when a biomass temperature of 150 °C is achieved, as discussed by Hamelinck and co-workers [187].

1.3. Pyrolysis

This phase consists in the thermochemical decomposition of the matrix carbonaceous materials; in particular, the cracking of chemical bonds takes place with the formation of molecules with a lower molecular weight. By pyrolysis it is possible to obtain different fractions: a solid, a liquid/condensed and a gaseous fraction [7–10].

The solid fraction, which can range from 5–10 wt% for fluidized bed gasifiers to 20–25 wt% for fixed bed gasifiers [7–10], has a high carbon content and is characterized by a high heating value. This fraction includes the inert materials contained in the biomass in the form of ashes and a high carbon content fraction, called “char”.

The liquid fraction, usually called "tars", varies according to the gasifier type, such as lower than 1 wt% for downdraft gasifiers, 1–5 wt% for bubbling bed gasifiers, 10–20 wt% for updraft gasifiers and is constituted by complex organic substances, condensable at relatively low temperatures [10,47,188,189].

The gaseous fraction is typically 70–90 wt% of the fed material [10,188] and is a mixture of gases that are incondensable at ambient temperature. The gaseous fraction is called "pyrolysis gas" and consists mainly of hydrogen, carbon monoxide, carbon dioxide and light hydrocarbons such as methane and other C_2, C_3 hydrocarbons; minor constituents are acid or inert gases.

The pyrolysis reactions take place with a temperature in the range 250–700 °C. They are endothermic and, as in the drying step, the heat required comes from the oxidation stage of the process.