Paramaeters that Affect Biomass Gasification

Subjects: Energy & Fuels

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Gasification is a thermochemical process commonly used for bioenergy production, and it is particularly attractive mainly due to its high efficiency. However, its performance is influenced by parameters such as type of feedstock, size of biomass particle, feed rate, type of reactor, temperature, pressure, equivalence ratio, steam to biomass ratio, gasification agent, catalyst, and residence time.

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1. Types of Feedstock

The biomass's physical, chemical, and morphological properties can affect the gasification process and the composition and quality of the gas produced. For instance, samples with a high moisture content can make ignition more challenging and reduce the heating value of the gas since a higher energy input will be required to gasify the samples. Higher ash content can also influence the efficiency of the gasification process since it can fuse and produce slags which can interfere with the flow of the biomass [1].

2. Biomass Size

The biomass size can affect the amount of energy required in the gasification process and influence the heat transfer process. Specifically, larger biomass particles can reduce heat transfer and produce a higher biochar yield. It has been observed that reducing the particle size can improve the conversion process and increase the amount of hydrogen produced. In addition, utilizing smaller particles can enhance the syngas quality and reduce tar production. However, particle size should not be reduced further than needed since it is an energy-intensive process that can decrease the profitability of the gasification process [2].

3. Biomass Feeding Rate

The biomass feeding rate is affected by factors such as the reactor design and biomass characteristics. For instance, an excessively high feeding rate can reduce the conversion efficiency or even stop the reaction process since it can cause plugging [3]. Therefore, even though increasing the feeding rate can increase the syngas yield, it is important to determine the optimum value of the rate for the proper functioning of the reactor and to avoid incomplete gasification, lower quality of the syngas and deterioration in the reactor performance [4]. The feeding type can also impact the gasification performance. For instance, a continuous feeding rate leads to a steady operation due to the constant biomass supply, unlike batch feeding, which can result in lower performance and an uneven operation [3]. The feeding rate of the biomass is related to the gasifier power output, lower heating value of the biomass, and gasifier efficiency as per Equation (1) [5]:

$$\text{Biomass feeding rate} = \frac{\text{Required power output}}{\text{Lower heating value} \times \text{Gasifier efficiency}} \qquad (1)$$

4. Type of Reactor

The type of reactor can significantly impact the quality of the gas produced and the operational conditions of the process. For instance, fluidized bed gasifiers, especially circulating fluidized bed reactors, require a higher air speed than fixed bed gasifiers [6]. This air has enough speed to entrain the particles as it passes through them, lifting them over the bottom of the combustion chamber. With an increase in air velocity, the reaction between the solid and gaseous phases speeds up [7]. In addition, the amount of resulting tar also varies with the reactor type. Fixed bed gasifiers produce gas with high tar content because heat and mass transfer between the gasifying agent and the biomass are low and non-uniform. Different types of fixed-bed reactors also have different amounts of tar. In an updraft fixed bed reactor, the pyrolysis zone is above the combustion zone; as a result, the tar does not enter the combustion zone, increasing the tar level, whereas, in downdraft fixed reactors, the tar passes through this zone. Thus the tar content is less [8]. In the case of fluidized bed reactors, the amount of unconverted tar is lower than that of the circulating fluidized bed because of the reactor's short residence period of tar molecules. Moreover, the gasifier's design affects the amount of particle loading in the product gas. Natural minerals found in biomass feedstock are transformed into ash in the form of very small particles during gasification and dust particles are generated from unconverted carbon materials. In comparison to fixed bed gasifiers, fluidized bed gasifiers often produce gas with a greater particle loading, which can block internal combustion engines by accumulating in the nozzle, cause abrasions on the blades of turbines, as well as result in exceeding the environmental regulation's emission limit since they persist in the gas [6].

5. Temperature

The temperature of the gasification can affect the quality of the gas produced, the amount of tar formed, the costs of the process, and the operational conditions of the reactor to a great extent [9]. As the temperature of gasification rises, more gas is formed, which causes the yields of tar and char to fall. The higher gas yield is due to the larger amount of gases released during the initial devolatilization stage and the secondary reactions that the char and tars undergo [10]. The composition of the produced gas is also influenced by temperature. Typically, higher temperatures increase hydrogen and carbon monoxide concentrations [11]. Furthermore, a temperature increase can improve the samples' heating value and carbon conversion efficiency [12]. However, operating the gasifier at higher temperatures will require more energy, increasing the operating cost.

6. Pressure

Generally, higher gasification pressures can be beneficial in reducing equipment size and conserving energy for compression [13][14]. The compression energy will be conserved since the producer gas can be transported over great distances without using additional energy by immediately combusting it in a gas turbine. Additionally, a pressure increase can increase the yield of valuable products and boost the calorific value of the produced gas [15]. Higher working pressures may be advantageous by accelerating some reactions, and since downstream operations typically demand pressurized gas streams, greater pressures can improve both energy and exergy efficiencies. However, higher pressures can result in some operational difficulties brought on by the project's complications, the building of, and the use of pressurized gasifiers [16].

7. Air Equivalence Ratio (ER)

The ratio of actual air supplied to the stoichiometric air required for the process is referred to as air equivalence ratio (ER) [2]. This is a significant parameter in the gasification process since higher ER leads to a decrease in hydrogen and carbon monoxide yields and to an increase in carbon dioxide, which will further influence the heating value of the samples. However, high ER can also enhance the tar cracking because more oxygen is available for volatile species to react with and the reaction temperature is greater [17].

8. Steam/Biomass Ratio

An increase in the steam-to-biomass ratio can lead to a decrease in the conversion yield, therefore, the steam-to-carbon ratio (SCR) is considered a critical parameter in steam biomass gasification. The SCR is calculated by dividing the steam mass flow rate by the carbon feed rate, as shown in Equation (2). The steam flow rate to biomass ratio (S/B) is used similar to the steam to carbon ratio [18].

$$\text{Steam to Carbon Ratio (CSR)} = \frac{\text{Steam mass flow rate} \left(\frac{\text{kg}}{\text{s}}\right)}{\text{Carbon feed rate} \left(\frac{\text{kg}}{\text{s}}\right)} \tag{2}$$

9. Gasification Agent

The gasification agent chosen, or the combination of agents used, can highly affect the composition and heating value of the produced gas. Using oxygen or steam as agents produces gases with a higher heating value than air gasification.

Additionally, product gas from air gasification contains high nitrogen content, whereas oxygen and steam result in high carbon monoxide and hydrogen concentrations in the gas [19].

10. Catalyst

The presence of a catalyst can improve biomass gasification because it facilitates heat and mass transfer between the particles. In air gasification, a catalyst can increase the hydrogen and carbon monoxide in the syngas, increasing the higher heating value due to the cracking of tar into gaseous products. On the other hand, in steam gasification, catalysts increase the production of hydrogen-rich gas. However, methane content can decrease slightly [20].

11. Residence Time

There are different definitions in the literature for residence time based on the purpose. For example, in fluidized beds, the residence time can be referred to as the time needed for the biomass to move from one reference point on the bed to another, or the amount of time needed for the full conversion of all biomass. The fuel conversion time can be prolonged if the fuel does not receive enough heat and gasification agent inside the bed. In gasifiers, a larger residence time implies lower velocity of the gas and larger bed height. In addition to the bed height and gas velocity, other factors can influence the residence time such as the particle size which increases the duration when it increases [21].

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