Experimental study of a down-draught fixed bed gasifier

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Abstract: Air gasification experiments were carried out in a downdraft gasifier with two combustion chambers. Briquettes made from different agriculture residues were used in the present study. The effects of varying excess air ratio and gasification temperature on syngas composition and heating value were investigated. The excess air ratio for the gasifier is found to be in range 0.17-0.33. The gasification temperature depends on the amount of air fed to the gasifier and therefore by the excess air ratio. An increase in the air flow rate resulted in a decrease in the concentrations of H2 and CO and a higher CO2 production. It has been found that the LHV of the syngas is high for low excess air ratios due to the high H2 and CO contents.

Key-Words: agricultural residue, briquettes, air excess ratio, gasifier, syngas

1 Introduction

A promising way to use biomass for production of heat, electricity, and other biofuels is through biomass gasification. It is a thermo-chemical process of gaseous fuel production by partial oxidation of biomass at high temperature around 800-900°C in the presence of a gasifying agent such as air, steam or oxygen. In this process, the chemical energy of the solid fuel is converted into the chemical and thermal energy of the product gas [1]. The product gas from the biomass gasification is a mixture of carbon dioxide, carbon monoxide, hydrogen, methane, water and nitrogen if air is used as a gasifying agent.

Thermochemical gasification is a well-known technology which can be classified depending on the reactor type (bubbling or circulating fluidized beds, moving - updraft or downdraft - beds, etc.), its pressure (atmospheric or pressurized), gasifying agent (air, steam, steam + oxygen, air + steam, O2-enriched air) [2].

In a down-draught fixed bed gasifier, the biomass is fed in from the top, the gasifying agent is introduced at the sides above the grate and the producer gas is withdrawn under the grate (Figure 1).

The thermo-chemical processes that occur inside a downdraft gasifier are very complex involving pyrolysis, partial oxidation and successive gasification at elevated temperatures. The processes are largely dependent on the parent biomass composition, moisture content, reactivity of biomass, local stoichiometry and the gasifier design.

A suitable model of the downdraft gasifier can predict the optimum performance parameters for its operation [4].

The present paper presents and discusses the results of the experimental study of a downdraft biomass gasifier. Briquettes made from different agriculture residues were used as fuel.
Agricultural residues have acquired considerable importance as biofuels for domestic cooking, industrial process heating, electrical power generation, and are used directly as well as in briquetted form for a variety of energy end uses [5]. The composition and heating value of the syngas are found to be similar to those reported by other researchers [6], [7].

2 The gasifier and experimental procedure

Air gasification experiments were carried out in a downdraft gasifier (Figure 2) with two combustion chambers separated by a refractory plate. This plate has three slots provided with holes for secondary air supply. In a downdraft gasifier the combustion process occurs in two phases: (1) volatile matter combustion and (2) char combustion. While the flue gases are moved down they transfer their heat to water channels and then flow from the bottom to the chimney using an upstream blower (air fan).

Briquettes made from different agriculture residues were used in the present study: (a) pure reed, (b) pure sawdust, (c) mixture of sawdust with ground wheat straw. Acacia wood briquettes were also tested. The briquettes have a diameter of 7 cm and different lengths. Table 1 shows the basic characteristics of biomass used. The gasifying medium in all analyses is the combustion air at 25°C consisting of 21 mol% oxygen and 79 mol% nitrogen. During biomass gasification in a fixed bed gasifier the processes which take place are drying, pyrolysis, combustion, and gasification.

Table 1: Fuel properties

<table>
<thead>
<tr>
<th>Fuel sample</th>
<th>Ultimate analysis (% of dry fuel with ash)</th>
<th>Proximate analysis (% of wet fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>Acacia wood briquettes</td>
<td>52.43</td>
<td>35.73</td>
</tr>
<tr>
<td>Reed briquettes</td>
<td>52.04</td>
<td>33.55</td>
</tr>
<tr>
<td>Sawdust briquettes</td>
<td>53.3</td>
<td>35.75</td>
</tr>
<tr>
<td>Sawdust 50% corn stalk 50% briquettes</td>
<td>49.41</td>
<td>40.73</td>
</tr>
<tr>
<td>Sawdust 50% wheat straw 50% briquettes</td>
<td>50.63</td>
<td>38.08</td>
</tr>
</tbody>
</table>

Figure 2: Scheme of the down-draught gasifier
The principle chemical reactions during the process of gasification are [8]:

1. Combustion reactions

\[ C + \frac{1}{2}O_2 = CO \quad -111 \text{ MJ/kmol} \]  
(1)

\[ CO + \frac{1}{2}O_2 = CO_2 \quad -283 \text{ MJ/kmol} \]  
(2)

\[ H + \frac{1}{2}O_2 = H_2O \quad -242 \text{ MJ/kmol} \]  
(3)

2. The Boudouard reaction

\[ C + CO_2 \rightleftharpoons 2CO \quad +172 \text{ MJ/kmol} \]  
(4)

3. The water gas reaction

\[ C + H_2O \rightleftharpoons CO + H_2 \quad +131 \text{ MJ/kmol} \]  
(5)

4. The methanation reaction

\[ C + 2H_2 \rightleftharpoons CH_4 \quad -75 \text{ MJ/kmol} \]  
(6)

5. CO shift reaction

\[ CO + H_2O \rightleftharpoons CO_2 + H_2 \quad -41 \text{ MJ/kmol} \]  
(7)

6. Steam methane reforming reaction

\[ CH_4 + H_2O \rightleftharpoons CO_2 + 3H_2 \quad +206 \text{ MJ/kmol} \]  
(8)

The arrows indicate that the reactions are in equilibrium and can proceed in either direction, depending on the temperature, pressure and concentration of the reacting species. It follows that the product gas from gasification consists of a mixture of carbon monoxide, carbon dioxide, methane, hydrogen and water vapour [9]. CO is produced by combustion (eq 1), Boudouard reaction and water gas reaction. Methane is mainly produced by methanation reaction and \( H_2 \) is mainly generated by water gas reaction. In all these reactions, the value of the reaction enthalpy refers to the temperature of 298.15 K.

Excess air ratio is defined as the ratio of the actual air to fuel ratio divided by the stoichiometric air to fuel ratio required for complete combustion. The increase of the excess air ratio causes a proportional increase of the \( N_2 \) molar fraction due to the greater amount of air fed to the reactor.

The lower heating value of producer gas is dependent on the percentage quantities of CO, \( H_2 \) and \( CH_4 \) in producer gas and can be calculated from the following equation:

\[
LHV_g = Y_{CO} LHV_{CO} + Y_{H_2} LHV_{H_2} + Y_{CH_4} LHV_{CH_4} \quad (9)
\]

where \( Y \) is the mole fraction of each gas species. The lower heating values of the gas species are: \( LHV_{CO} = 13.1 \text{ MJ/Nm}^3 \), \( LHV_{H_2} =11.2 \text{ MJ/Nm}^3 \), and \( LHV_{CH_4} = 37.1 \text{ MJ/Nm}^3 \) [10].

3 Results and discussion

The effects of varying excess air ratio and temperature on syngas composition and gas heating value were investigated.

The influence of excess air ratio on product gas composition is illustrated in Figure 3. The main components of the producer gases are CO, \( H_2 \), \( N_2 \), \( CO_2 \), \( H_2O \) and \( CH_4 \). The molar fractions of these components were measured before the second air injection.

The increase in the excess air ratio means that the primary feeding air increases. The excess air ratio for the gasifier is found to be in range 0.17-0.33.

The increase of the excess air ratio causes a linearly increase of the \( N_2 \) molar fraction due to the greater amount of air fed to the gasifier. The molar fraction of CO is the most significant contribution to the heating value of the syngas. The molar fraction of the CO decreases with the excess air ratio. Because the Boudouard reaction is endothermic, the temperature rises and \( CO_2 \) reacted with char to produce CO. If the excess air rises, there is insufficient char for the Boudouard reaction (equation 4), which lead to CO decreases and \( CO_2 \) increases. The water-gas reaction (equation 5) is endothermic, and for increasing temperature more char and \( H_2O \) are consumed and production of CO and \( H_2 \) is increased. The methanation reaction (equation 6) being exothermic, increases of gasification temperature decreases the production of \( CH_4 \), which leaves more \( H_2 \) in syngas [11].

The molar fraction of the \( CO_2 \) increases with the increasing of excess air ratio. The increasing of \( CO_2 \) concentration is mainly because of CO shift reaction (equation 7).
The useful energy content in the syngas can be quantified by the syngas heating value. Figure 3 shows the variation of lower heating value against the excess air ratio. The lower heating value was calculated using the equation 9. It is evident that the lower heating value decreases with increasing of excess air ratio. The LHV of the producer gases ranges from 5.7 MJ/Nm$^3$ to 7.8 MJ/Nm$^3$.

Figure 4: The temperature as a function of the excess air ratio
The LHV is high for low excess air ratios due to the high H₂ and CO contents. The gasification temperature plays an important role in biomass gasification. The gasification temperature depends on the amount of air fed to the gasifier and therefore by the excess air ratio.

Figure 4 shows that the temperature decreases with the increase in excess air ratio.

Figure 5: Variation of the molar fractions of H₂ with the excess air ratio

Figure 6: Variation of the molar fractions of CO₂ and CO with the excess air ratio
Figure 5 presents the variation of H₂ molar fraction as a function of the excess air ratio for all agricultural residues briquettes used. As can be seen, the increase of the excess air ratio causes a decrease of the H₂ molar fraction. The highest content of the H₂ in the syngas was obtained by gasification of briquettes made from sawdust 50% + wheat straw 50%. The minimum value of the H₂ molar fraction was obtained by gasification of sawdust briquettes for an excess air ratio λ=0.33. The molar fraction of H₂ has an important contribution in the calculating of syngas heating content. If the gasifier has a better thermal insulation, the gasification temperature increases and higher molar fraction of H₂ is produced without changing the quantity of air.

Figure 6 shows the variation of the molar fractions of CO and CO₂ with excess air ratio. It can be observed that the increase in excess air ratio increases the CO₂ content in the syngas. On the other hand, when the excess air ratio is increased, the molar fraction of CO in the syngas decreases. The highest content of the CO in the syngas was obtained by gasification of briquettes made from sawdust 50% + corn stalk 50%.

4 Conclusion
An experimental investigation of a downdraft biomass gasifier is carried out using agricultural residues briquettes under various operating conditions. The effects of varying excess air ratio and gasification temperature on product gas composition and syngas heating value were investigated.

The syngas composition is strongly influenced by the excess air ratio. An increase in the excess air ratio resulted in a decrease in the concentrations of H₂ and CO, and a higher CO₂ production. The highest content of the H₂ in the syngas was obtained by gasification of briquettes made from sawdust 50% + wheat straw 50%.

The syngas heating value decreases with increasing excess air ratio.

Acknowledgments
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