Preliminary tests with a birch wood pellets up-draft air gasifier

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Abstract

In Sweden and Cuba a variety of biomass have been investigated for energy conversion through thermochemical processes into solid, liquids and gaseous products. Biomass gasification in fixed bed seem to be attractive option for the conversion of agricultural and forest residues into gases suitable for use as alternative fuel in gas engines in rural areas, heat or electricity production.

This paper discusses the performance characteristics of a up-draft gasifier with Birch wood pellets. The bench scale gasifier was designed and built in the Royal Institute of Technology, Sweden.

A series of parameters, such as the gas and liquids yields, temperatures and ash yield were measured as a function of the time.

Keywords: Pellets; Birch wood; Up draft air gasification.

1. Introduction

The use of agricultural and forest residues like bagasse from the sugar and alcohol industry or wood residues from sawmills, traditionally used to fuel boilers to satisfy the heat and electricity demand of the processing plants with low conversion efficiencies, are now being increasingly considered for use in more efficient conversion systems, creating the opportunity for power supplies.

Biomass gasification is the conversion of an organically derived, carbonaceous feedstock by partial oxidation into a gaseous product, synthesis gas or “syngas,” consisting primarily of hydrogen (H\textsubscript{2}) and carbon monoxide (CO), with lesser amounts of carbon dioxide (CO\textsubscript{2}), water (H\textsubscript{2}O), methane (CH\textsubscript{4}), higher hydrocarbons (C\textsubscript{2}+), and nitrogen (N\textsubscript{2}). The reactions are carried out at elevated temperatures, 600-1000°C, and atmospheric or elevated pressures. The oxidant used can be air, pure oxygen, steam or a mixture of these gases.

Air-based gasifiers typically produce a product gas containing a relatively high concentration of nitrogen with a low heating value between 4 and 6 MJ/m\textsuperscript{3}. Oxygen and steam-based gasifiers produce a product gas containing a relatively high concentration of hydrogen and CO with a heating value between 10 and 20 MJ/m\textsuperscript{3}.
2. Gasification Reactions

The chemistry of biomass gasification is complex. Biomass gasification proceeds primarily via a two-step process, pyrolysis followed by gasification (see Figure 1).

Pyrolysis is the decomposition of the biomass feedstock by heat. This step, also known as devolatilization, is endothermic and produces 75 to 90% volatile materials in the form of gaseous and liquid hydrocarbons. The remaining nonvolatile material, containing a high carbon content, is referred to as char.

![Figure 1: gasification steps](image)

The volatile hydrocarbons and char are subsequently converted to syngas in the second step, gasification. A few of the major reactions involved in this step are listed below:

As the biomass particle is heated, it initially pyrolyses to form charcoal plus gases and vapour (Shafizadeh, 1982).

**Biomass → Charcoal + Volatile + Gases**

After pyrolysis is completed, the charcoal can react with oxygen and steam or the products of pyrolysis according to

**Charcoal + Gases → reduced gases**

In addition, the vapours formed initially from the solid may undergo cracking to form secondary products, either gases or other condensable species.

a) Heterogeneous (gas-solid) reactions (McKendry, 2002). Plus and minus signs indicate the release and supply of heat energy during the process, respectively.
Oxidation of carbon:

\[ C + \frac{1}{2} O_2 \leftrightarrow CO \quad \Delta H = +268 MJ/Kg mole \] (1)

\[ C + O_2 \leftrightarrow CO_2 \quad \Delta H = +406 MJ/Kg mole \] (2)

Boudouard reaction:

\[ C + CO_2 \leftrightarrow 2CO \quad \Delta H = -173 MJ/Kg mole \] (3)

Water gas reaction:

\[ C + H_2 O \leftrightarrow CO + H_2 \quad \Delta H = -118 MJ/Kg mole \] (4)

Methane formation:

\[ C + 2H_2 \leftrightarrow CH_4 \quad \Delta H = +75 MJ/Kg mole \] (5)

b) Homogeneous (gas phase) reactions.

\[ CO + H_2 O \leftrightarrow CO_2 + H_2 \quad \Delta H = +42 MJ/Kg mole \] (6)

\[ CH_4 + H_2 O \leftrightarrow CO + 3H_2 \quad \Delta H = +88 MJ/Kg mole \] (7)

In updraft gasifiers, the air intake is at the bottom and the gas leaves at the top. Fuel is fed from the top of the gasifier and undergoes various processes as it moves to the bottom against the air and gas flow.

The major advantages of an updraft gasifier are its simplicity, ability to gasified vary wet fuels, high charcoal conversion and internal heat exchange, leading to low gas exit temperature and high gasification efficiency. A disadvantage is the large amount of tar produced. This is of minor importance if the gas is used for direct heat applications, in which case the tar is simply burnt. If the gas is used for electricity-producing gas engines, however intensive gas clean is required (McKendry, 2002).

3. Process description

The first step in the gasification process is the ignition of the bed; initially 0.2 Kg of charcoal is burned over the distributor and after this a weighed amount of biomass is feed through the feeder (1). Different air factors (defined as ratio of actual ratio of actual air flow rate to stoichiometric air flow rate) can be achieved adjusting the air flow rate. (Di Blasi, 1999).

The vapours, gases and fines solid particles pass through a novel cyclonic condenser (11) where the particles and part of the tar are separated from the gas steam.
and are collected in the tar collector (10). The gas is further purged through a closed water tank (9) and a packed-bed filter (13). Finally, the exit gas flow rate is again measured by a rotameter (12).

In this gasification system, it is possible to examine the effect of different operating parameters on the product yields, gas composition, axial temperature profiles, the presence of fines, etc. The operating parameters included: air factor, feedstock differing in type and particle size and gasification gas.

![Schematic diagram of the updraft Gasifier](image)

**Figure 2. Schematic diagram of the updraft Gasifier:** (1) feeder, (2) updraft Gasifier, (3) thermocouples, (4) viewer, (5) distributor, (6) inlet air, (7) cone (8), ash valve, (9) closed acetone flasks (gas scrubbing), (10) tar and char collector, (11) cyclonic condenser, (12) rotameter, (13) packed-bed filter.

### 4. Experimental

In the fixed-bed up draft gasification of biomass the different physical and chemical processes are stratified along the reactor height in the order of combustion, gasification, devolatilization and drying (from the bottom), a first set of experiments has been carried out for fixed-bed gasification of birch wood, through a bench-scale reactor.
The main purpose of this activity is the determination of product yields, gas composition and temperatures profiles.

4.1 Measurement of temperature

Three temperature probes of chromel alunem thermocouple were inserted in the thermocouples case for recording the temperature profile at combustion zone, reduction zone and gas outlet. The evolution of the temperatures during the gasification has been represented in the graphics.

4.2. Measurement of air and gas flow rates

The inlet air flow (m$^3$/h) (gasificant agent) is injected under the grid and is measured by a rotameter. At the end of the cleaning zone there is another rotameter, which measures the volume (m$^3$/h) of gas that comes out from the process.

4.3. Analysis of gas and tars

Gas analysis was carried out immediately after the collection of samples to avoid diffusion of hydrogen from the walls of polyethylene bags. Gas chromatography analysis was used to measure CO, CH$_4$, CO$_2$, C$_2$H$_y$ and H$_2$ yields. Nitrogen was estimated from the volumetric difference of the gases evaluated and gas sample.

The liquids (water + tars) were collected in the cyclone, a glass condenser and after this the gas pass though 3 acetone wash flasks to wash away the remain tarry matter. The acetone extract was filtered to collect the filtrate in round bottom glass flasks. The acetone extract collected in the round bottom glass flasks was evaporated under room temperature at 25–30$^\circ$C for several hours. All the quantity of tar trapped was then determined by weight.

5. Results

Experiments were carried out with birch wood pellets using the same operating conditions. The warm-up time of the gasifier is about 7–10 min, during which the gases emitted are flared out to evade smoky and lower caloric value gas. The appearance of a steady and colourless flame, within 5–7 min of warm-up time, when the gas is burnt at the Lare gives an approximate indication that the gas is ready for use. The air flow chosen for carrying out gasification experiments has an equivalence ratio, the ratio of mass of air consumed to gasify 1 kg of fuel and air required in kg for complete combustion of kg of fuel, approximately in the range of 0.25–0.5.
5.1. Gas product yields and temperature profiles

The gas product yields and temperatures profile of gasification of birch wood pellets were shown in Figures 3, 4 and 5 respectively for three different volumes of air and two kilos of biomass. The figures shown that the maximum yields of gas obtained after the beginning of measurements were between 5 and 10 minutes when 2 m$^3$/h of air was used, 10 and 20 minutes with 1,5 m$^3$/h and 15 and 25 minutes with 1,1 m$^3$/h. After those times the concentrations of the gases goes down due to the biomass extenuation in the bed.

Figure 3. Gas yields and temperatures profile. Air = 2 m$^3$/h

Figure 4. Gas yields and temperatures profile. Air = 1.5 m$^3$/h
The figures shown that the highest yields of all gases were obtained using 2 m$^3$/h of air. The main part of the gas are carbon dioxide, carbon monoxide and hydrogen. Methane and hydrocarbons (saturated and insaturated C$_2^+$) were obtained in less amount.

5.2. Liquids yields

The main part of the tarry matter was collected in the ciclon and the condenser, a little part was trapped in the acetone flasks when the gas pass though them, this part was in all experiments insignificant compared with the first two.
Figure 6 shown the volume of liquids obtained in function of the air volume used in the experiments. The higher amount is obtained when 2 m$^3$/h of air is used, this can be attributed to the retention time of the vapors inside the gasifier, when high volume of air is used this retention time is short and the volume of liquid obtain is high.

6. Conclusions

Up-draft batch gasification of birch wood pellets at bench scale has been carried out and some fundamental data have been obtained on process dynamics and gasification characteristics (temperature profiles, product yields, and gas composition).

For the optimal conditions achieved by the bench scale plant developed in this study and with pretreatment on biomass maintained at a minimum (essentially predrying and elimination of fines from residues) the best molar composition of the producer gas was obtained using 2 m$^3$/h of air and consists of 13-15% CO, 19-21% CO$_2$, 6-8% H$_2$, 3-4% CH$_4$, and minor fractions of C$_2$+ species (apart from nitrogen).

The volume of the tarry matter is high and can be reduced increasing the residence time of the vapors inside the gasifier, this can be achieve by installing a valve between the reactor gas outlet and the cyclone and form part of future studies.

References