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# Influence of the biomass gasification processes on the final composition of syngas

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## Abstract

Interest in the technology of gasification has shown a number of ups and downs since its first appearance. It appears that interest in gasification research correlates closely with the relative cost and availability of liquid and gaseous fossil fuels. Gasification is a versatile thermo-chemical conversion process which produces a gas mixture of $H_2$, CO and $CH_4$ the proportions being determined by the use of air, oxygen or steam as oxidizer, with a concomitant range of heat values, low (4–6 MJ/Nm$^3$), medium (12–18 MJ/Nm$^3$) and high (40 MJ/Nm$^3$). A variety of biomass gasifiers have been developed. Differentiation is based on the means of supporting the biomass in the reactor vessel, the direction of flow of both the biomass and oxidant, and the way heat is supplied to the reactor. Gases formed by gasification are contaminated by some constituents such as particles, alkali metals, nitrogen components, tars, sulfurs and chlorides. The level of contamination varies, depending on the gasification process and the feedstock. Gas cleaning must be applied to prevent erosion, corrosion and environmental problems in downstream equipment. In this work, a global perspective about the producer gas final composition dependence, the so-called syngas, from the biomass, oxidizer, reactor type, temperature and pressure is given based on a literature benchmarking. This study shows that there are some discrepancies in the values given by various authors. This highlights the strong dependence of the syngas final composition from the biomass conditions, type of gasifier and pressure and temperature of the process. Thus, in order to make precise studies on the use of syngas it will be necessary to consider that its composition will be rather constant. The development of mathematical models for numerical simulation fully validated experimentally are strongly desirable and may be a very useful tool to determine the final composition of syngas by changes in initial conditions without laborious and expensive experimental tests.

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*Keywords*: gasification; gasifier; syngas; biomass

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## 1. Introduction

Interest in the technology of gasification has shown a number of ups and downs since its first appearance. It appears that interest in gasification research correlates closely with the relative cost and availability of liquid and gaseous fossil fuels. These are the cases of the Second World War, the double fuel crises of 1973 and 1979, and the recent oil crises of 2008 [1]. Gasifiers are of two main types, fixed bed and fluidized bed, with variations within each type and specific characteristics which determine the need for and extent of feedstock preparation/pre-treatment. Some

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gasifiers are undergoing design evolutions that will enable them to use a wider range of fuels; nevertheless, fuel properties are very important in determining satisfactory operating conditions.

The gasification of biomass allows the production of a synthesis gas or "syngas", consisting primarily of $H_2$, CO, $CH_4$, $CO_2$ and $N_2$ [2]. The specific composition depends upon the fuel source and processing technique. These substantial variations in composition and heating value are among the largest barriers toward their usage [3].

In this work, a global perspective about the syngas final composition dependence from the biomass, oxidizer, reactor type, temperature and pressure is given based on a literature benchmarking.

## 2. Biomass gasification

Gasification is the thermo-chemical conversion of a carbonaceous fuel at high temperatures, involving partial oxidation of the fuel elements [4]. The result of the gasification is a fuel gas - the so-called syngas - consisting mainly of carbon monoxide (CO), hydrogen ($H_2$), carbon dioxide ($CO_2$), water vapor ($H_2O$), methane ($CH_4$), nitrogen ($N_2$), some hydrocarbons in very low quantity and contaminants, such as carbon particles, tar and ash.

Gasification takes place in a reactor, the so-called gasifier, in the presence of an oxidizing agent that may be pure oxygen, steam, air or combinations of these. Inside the gasifier, regardless of their nature, occur simultaneously in several cases for which there is still no consensus within the scientific community. Three or four steps are usually referred to. In the context of thermal sciences, the reactions of gasification are only those that occur between the gas and solid fuel devolatilized excluding the oxygen [5]. However, in general terms gasification is the partial or total transformation of a solid fuel into gas. Thus also the devolatilization and oxidation are an integral part of gasification.

In this work it is considered that gasification occurs in a set of four steps: drying, pyrolysis, oxidation and reduction with the following description [6]:

- Drying – biomass fuels consist of moisture ranging from 5 to 35%. At temperatures above 373 K, the water is removed and converted into steam. In the drying process, fuels do not experience any kind of decomposition.
- Pyrolysis – is the thermal decomposition of biomass in the absence of oxygen whereby the volatile components of a solid carbonaceous feedstock are vaporized in primary reactions by heating, leaving a residue consisting of char and ash. The ratio of products is influenced by the chemical composition of biomass fuels and the operating conditions.
- Oxidation – introduced air in the oxidation zone contains, besides oxygen and water vapors, inert gases such nitrogen and argon. These inert gases are considered nonreactive with fuel constituents. The oxidation takes place at temperatures of 975 to 1275 K. Heterogeneous reaction takes place between oxygen in the air and solid carbonized fuel, producing carbon monoxide. Plus and minus signs indicate the release and supply of heat energy during the process, respectively:

  $C + O_2 = CO_2 + 393.8$ MJ / kmol

  Hydrogen in the fuel reacts with oxygen in the air blast, producing steam.

  $H_2 + 1/2\ O_2 = H_2O + 242$ MJ / kmol.
- Reduction – in the reduction zone, a number of high temperature chemical reactions occur in the absence of oxygen. Assuming a gasification process using biomass as feedstock, the first step of the process is the thermochemical decomposition of the lignocelluloses components with production of char and volatiles. The main gasification reactions that occur in the reduction process are mentioned below [6,7,8]:

  Boudouard reaction - balance between the reaction of carbon and its phases gaseous CO and $CO_2$. It is the reaction of Boudouard the limiting step of the reduction process.

  $CO_2 + C = 2CO - 172.6$ MJ / kmol

  steam reaction

  $C + H_2O = CO + H_2 - 131.4$ MJ / kmol

  water-shift reaction

  $CO2 + H_2 = CO + H_2O + 41.2$ MJ / kmol

  methanation

  $C + 2H_2 = CH_4 + 75$ MJ / kmol

Main reactions show that heat is required during the reduction process. Thus, the temperature of the gas goes down during this stage. If complete gasification occurs, all the carbon is burned or reduced to carbon monoxide, and some other mineral matter that is vaporized. The remains are ash and some char (unburned carbon). Other reactions occur during the gasification process, such as: $C + CO_2 = 2CO$ and $CH_4 + H_2O = CO + 3H_2$.

Gasification process can be classified according to various criteria. The most important are:

Gasification process:

- Atmospheric;
- Pressurized.

Gasifier type:

- Fixed;
- Fluidized.

Oxidizing agent:

- Air;
- Oxygen;
- Steam;
- Other gases containing oxygen, such as $CO_2$ [9].

Gasifier heating:

- Direct ;
- Indirect.

Heating value [10] :

- Low: 4 -6 MJ/Nm$^3$ (using air or air / steam);
- Medium: 12 -18 MJ/Nm$^3$ (using oxygen and steam);
- High: 40 MJ/Nm$^3$, using hydrogen and hydrogenation.

### 2.1 Gasifier types

A variety of biomass gasifier types have been developed. They can be grouped into four major classifications: fixed-bed updraft, fixed-bed downdraft, bubbling fluidized-bed and circulating fluidized bed. Differentiation is based on the means of supporting the biomass in the reactor vessel, the direction of flow of both the biomass and oxidant, and the way heat is supplied to the reactor [11]. Table 1 lists the most commonly used configurations.

Table 1 – Gasifier classification [12, 13]

| Gasifier | Flow direction | | Support | Heat source |
|---|---|---|---|---|
| | Fuel | Oxidant | | |
| Fixed bed -Updraft | Descending | Ascending | Grate | Coal partial combustion |
| Fixed bed- Downdraft | Descending | Descending | Grate | Volatile partial combustion |
| Fluidized bed - Bubbling | Ascending | Ascending | None | Coal and volatile partial combustion |
| Fluidized bed- Circulating | Ascending | Ascending | None | Coal and volatile partial combustion |

#### 2.1.1 Fixed bed gasifiers

Typically, the fixed bed gasifiers have a grate that serves to support the solid fuel and to maintain the area's reaction stationary. They are relatively easy to deploy and operate, and more suitable for applications from small or medium power (under 1 MW). However, there is some difficulty in maintaining uniform temperatures and ensure appropriate mixtures in the area of reaction. As a result, income is variable and the final composition of the gas fuel obtained. The two main types of fixed bed gasifiers are: counter-current (updraft) and co-current (downdraft).

The oldest and simplest type of gasifier is the counter current or updraft gasifier (Fig.1). In the updraft gasifier the downward-moving biomass is first dried by the upflowing hot product gas. After drying, the solid fuel is pyrolysed, giving char which continues to move down to be gasified, and pyrolysis vapours which are carried upward by the upflowing hot product gas. The tars in the vapour either condense on the cool descending fuel or are carried out of the reactor with the product gas, contributing to its high tar content. The extent of this tar 'bypassing' is believed to be up to 20% of the pyrolysis products. The condensed tars are recycled back to the reaction zones, where they are further cracked to gas and char. In the bottom gasification zone the solid char from pyrolysis and tar cracking is partially oxidized by the incoming air or oxygen. Steam may also be added to provide a higher level of hydrogen in the gas.

The product gas from an updraft gasifier thus contains a significant proportion of tars and hydrocarbons which contribute to its high heating value. The fuel gas requires substantial cleanup if further processing is to be performed.

The advantages of updraft gasifier are [14]:

- simple and low cost process;
- able to handle biomass with high moisture and high inorganic content (for example, municipal solid wastes);
- Proven technology.

The main disadvantage of updraft gasifier is the tar content (10 to 20% of tar by weight), requiring intensive cleanup.

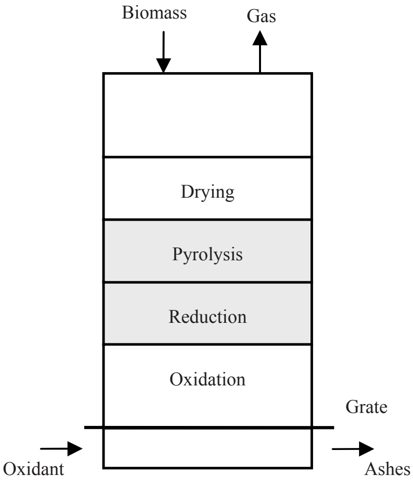

Fig.1. Updraft gasifier

A solution to the problem of tar entrainment in the gas stream has been found by designing co-current or downdraught gasifiers, in which primary gasification air is introduced at or above the oxidation zone in the gasifier (Fig.2). The producer gas is removed at the bottom of the apparatus, so that fuel and gas move in the same direction. On their way down the acid and tarry distillation products from the fuel must pass through a glowing bed of charcoal and therefore are converted into permanent gases hydrogen, carbon dioxide, carbon monoxide and methane.

Depending on the temperature of the hot zone and the residence time of the tarry vapours, a more or less complete breakdown of the tars is achieved. The main advantage of downdraught gasifiers lies in the possibility of producing a tar-free gas suitable for engine applications. In practice, however, a tar-free gas is seldom if ever achieved over the whole operating range of the equipment: tar-free operating turn-down ratios of a factor 3 are considered standard; a factor 5-6 is considered excellent.

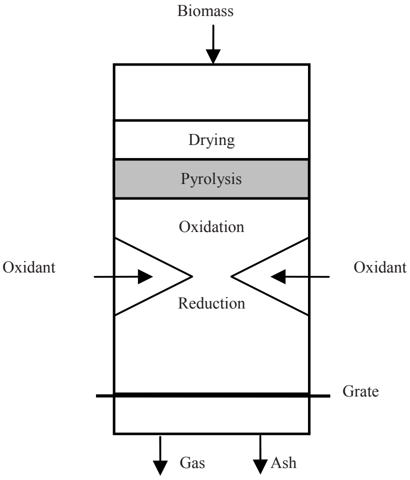

Fig. 2. Downdraft gasifier

Because of the lower level of organic components in the condensate, downdraft gasifiers suffer less from environmental objections than updraft gasifiers. A major drawback of downdraft equipment lies in its inability to operate on a number of unprocessed fuels. In particular, fluffy, low density materials give rise to flow problems and excessive pressure drop, and the solid fuel must be pelletized or briquetted before use. Downdraft gasifiers also suffer from the problems associated with high ash content fuels (slagging) to a larger extent than updraft gasifiers. Minor drawbacks of the downdraft system, as compared to updraft, are somewhat lower efficiency resulting from the lack of internal heat exchange as well as the lower heating value of the gas. Besides this, the necessity to maintain uniform high temperatures over a given cross-sectional area makes impractical the use of downdraft gasifiers in a power range above about 350 kW (shaft power).

Downdraft gasification is simple, reliable and proven for certain fuels, such as relatively dry (up to 30 wt% moisture) blocks or lumps with a low ash content (< 1 wt%) and containing a low proportion of fine and coarse particles (not smaller than 1 cm and not larger than 30 cm in the longest dimension). Owing to the low content of tars in the gas, this configuration is generally favoured for small-scale electricity generation with an internal combustion engine. The physical limitations of the diameter and particle size relation mean that there is a practical upper limit to the capacity of this configuration of about 500 kg/h or 500 $kW_e$.

The advantages of this gasifier are [14]:

- About 99,9% of tar formed is consumed, requiring minimal or no tar cleanup;
- Minerals remain with the char /ash, reducing the need for a cyclone;
- Proven technology, simple and low cost process.

The disadvantages are:

- Requires feed drying to a low moisture content (<20%);
- The fuel gas produced leaves the gasifier at high temperatures, requiring cooling before use;
- 4 to 7% of carbon is not converted.

### *2.1.2 Fluidized bed gasifiers*

Fluidized bed (FB) gasification has been used extensively for coal gasification for many years, its advantage over fixed bed gasifiers being the uniform temperature distribution achieved in the gasification zone. The uniformity of temperature is achieved using a bed of fine grained material into which air is introduced, fluidizing the bed material and ensuring intimate mixing of the hot bed material, the hot combustion gas and the biomass feed. Two main types of FB gasifier are in use:

- Circulating fluidized bed,
- Bubbling fluidized bed.

A third type of FB is currently being developed, termed a fast, internally circulating gasifier, which combines the design features of the other two types [10]. The reactor is still at the pilot-stage of development and thus is not treated in these notes.

Bubbling FB gasifiers consist of a vessel with a grate at the bottom through which air is introduced (Fig.3). Above the grate is the moving bed of fine-grained material into which the prepared biomass feed is introduced. Regulation of the bed temperature to 700–900º C is maintained by controlling the air/biomass ratio. The biomass is pyrolysed in the hot bed to form a char with gaseous compounds, the high molecular weight compounds being cracked by contact with the hot bed material, giving a product gas with a low tar content, typically <1–3 $g/Nm^3$.

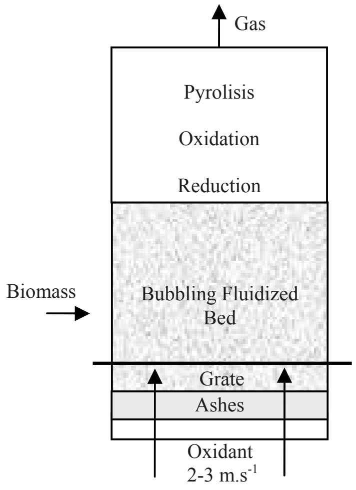

Fig. 3. Bubbling fluidized bed gasifier.

The advantages of bubbling fluidized bed gasification are [13]:

- Yields a uniform syngas;
- Nearly uniform temperature distribution throughout the reactor;
- Able to accept a wide range of fuel particles sizes;
- Provides high rates of heat transfer between the inert material, fuel and gas;
- High conversion possible with low tar and unconverted carbon.

The disadvantages are the large bubble size may result in gas bypass through the bed.

Circulating FB gasifiers are able to cope with high capacity throughputs and are used in the paper industry for the gasification of bark and other forestry residues.

The bed material is circulated between the reaction vessel and a cyclone separator, where the ash is removed and the bed material and char returned to the reaction vessel (Fig.4). Gasifiers can be operated at elevated pressures, the advantage being for those end-use applications where the gas is required to be compressed afterwards, as in a gas turbine.

The advantages of such gasifier are [13]:

- Suitable for rapid reactions;
- High heat transport rates possible due to high heat capacity of bed material;
- High conversion rates possible with low tar and unconverted carbon.

The disadvantages are [13]:

- Temperature gradients occur in direction of the solid flow;
- Size of fuel particles determine minimum transport velocity; high velocities may result in equipment erosion;
- Heat transfer less efficient than bubbling fluidized bed.

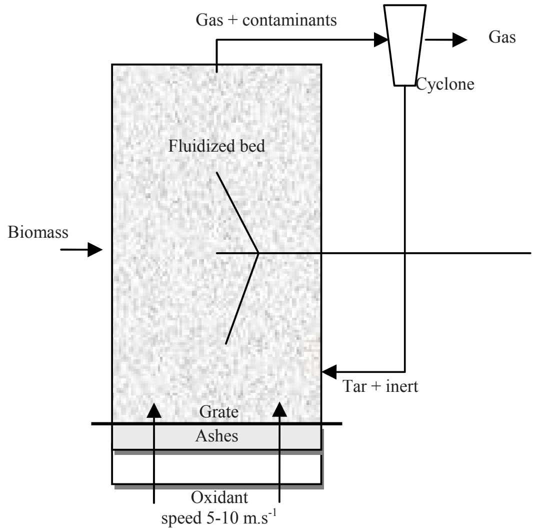

Fig. 4. Circulating fluidized bed gasifier

Apart from the described gasifiers, there are several other models that have been developed to improve the quality of the produced gas, such as: twin fluidized bed and entrained bed [2]. The first one aims to increase the heat value of the produced gas by promoting the production of $H_2$. The second operates at high temperatures from 1200 to 1500°C in order to eliminate tar and condensable gases in the produced gas. In fact, it has conversion efficiencies close to 100%. However, some problems arise in the materials selection to withstand the high temperatures and liquefaction of ash. Readers interested in deepening this topic may consult the cited reference.

## 3. Syngas characterization

The quality of the producer gas depends upon several factors including type of fuel, gasifier type and operational conditions (temperature, pressure and oxidizing agent). Next each one is described.

### *3.1 Influence of biomass type*

In large samples there is a relatively constant atomic ratio of $C_{10}H_{14}O_6$ for all biomass kinds [15]. A direct link between the chemical composition of biomass and gas obtained by gasification exists. Table 2 shows experimental values of the chemical composition of syngas for different types of biomass in a downdraft gasifier. As shown in Table 2 the influence of biomass type is not considerable. The highest heat value of the syngas obtained with pine and almond shell, being the lowest heat value obtained with husks. The wood types in Table 2 (pine and eucalyptus) are largely the most available biomass resource in Portugal[18] and therefore some special attention should be given to them. The main combustible components of wood are cellulose, hemicelluloses, and lignin, which are compounds of carbon, hydrogen, and oxygen. Other minor combustible components in wood are fats, resins, and waxes. The major non-combustible component of wood is water, which makes up to 50% of freshly cut wood. Though the ash content is low (<1%), because of high oxygen content, the heat value is low (16-20 MJ/kg).

Table 2 – Characteristics of syngas by biomass type.

| Residues | Gas produced (mol/kg) | | | | | | | HHV (MJ/m$^3$) |
|---|---|---|---|---|---|---|---|---|
| | $H_2$ | CO | $CO_2$ | $CH_4$ | $C_2H_2$ | $C_2H_4$ | $C_2H_6$ | |
| Rice husk [9] | 0.00236 | 0.00651 | 0.00717 | 0.00209 | $6.2\times10^{-5}$ | $7.6\times10^{-4}$ | $1.1\times10^{-4}$ | 11.11 |
| Nut shell [9] | 0.00485 | 0.00788 | 0.00477 | 0.00293 | $4.9\times10^{-5}$ | $6.1\times10^{-4}$ | $2.1\times10^{-4}$ | 14.55 |
| Pine [9] | 0.00529 | 0.00722 | 0.00505 | 0.00272 | $1.2\times10^{-4}$ | $8.1\times10^{-4}$ | $1.7\times10^{-5}$ | 14.68 |
| Eucalyptus [9] | 0.00275 | 0.00712 | 0.00380 | 0.00316 | $2.6\times10^{-5}$ | $5.5\times10^{-4}$ | $1.5\times10^{-4}$ | 13.41 |
| Vine Pruning[16] | 0.0104 | 0.02378 | - | 0.00641 | 0.00199 | $8.8\times10^{-4}$ | 0.00121 | 11.41 |
| Cherry Stone [17] | 0.00639 | 0.00668 | - | 0.00371 | 0.00103 | 0.00217 | 0.00173 | - |

Most wood species have ash contents below two percent and are therefore suitable fuels for fixed bed gasifiers. As wood contains high volatile matter, an updraft gasifier system produces gas containing tar, which needs to be cleaned out before use in engines. Gas cleaning is a difficult and labour-intensive process. Hence wood is not suitable in updraft gasifier coupled with internal combustion engines. However, the gas containing tar from an updraft gasifier can be used for direct burning. Downdraft systems can be designed to deliver a virtually tar-free product gas in a certain capacity range when fuelled by wood blocks or wood chips of low moisture content. After passing through a relatively simple cleanup train the gas can be used in internal combustion engines.

### *3.2 Influence of reactor type*

Dry wood was experimental used by several workers in different types of gasifiers being the results shown in Table 3. Some values are just indicative due to unknown gasification conditions.

Table 3 – Characteristics of the produced gas for atmospheric gasifiers [19, 29, 21, 22]

| Property | Downdraft | Updraft | BFB | CFB |
|---|---|---|---|---|
| Tar (mg/Nm$^3$) | 10-6000 | 10000-150000 | Not defined | 2000 – 30000 |
| Particules (mg/Nm$^3$) | 100-8000 | 100-3000 | Not defined | 8000-100000 |
| LHV (MJ/Nm$^3$) | 4.0 – 5.6 | 3.7 – 5.1 | 3.7 – 8.4 | 3.6 – 5.9 |
| $H_2$ (vol%) | 15-21 | 10-14 | 5 – 16.3 | 15-22 |
| CO (vol%) | 10-22 | 15-20 | 9.9 – 22.4 | 13-15 |
| $CO_2$ (vol%) | 11-13 | 8-10 | 9 – 19.4 | 13-15 |
| $CH_4$ (vol%) | 1-5 | 2-3 | 2.2 – 6.2 | 2-4 |
| $C_nH_m$ (vol%) | 0.5 -2 | Not defined | 0.2 – 3.3 | 0.1-1.2 |
| $N_2$ (vol%) | Remaining | Remaining | 41.6 – 61.6 | Remaining |

In Table 4 typical syngas compositions are given relatively to different types of reactors using air as oxidant.

Table 4 – Typical syngas compositions by reactor type [2].

| Gasifier | Gas composition (vol. %, dry) | | | | | HHV (MJ/m$^3$) |
|---|---|---|---|---|---|---|
| | $H_2$ | CO | $CO_2$ | $CH_4$ | $N_2$ | |
| Bubbling fluidized bed | 9 | 14 | 20 | 7 | 50 | 5.4 |
| Updraft | 11 | 24 | 9 | 3 | 53 | 5.5 |
| Downdraft | 17 | 21 | 13 | 1 | 48 | 5.7 |

Comparing both Tables 3-4 is possible to see some discrepancies especially related to CO content. This situation emphasizes the influence of the gasification conditions in the final composition of the produced gas.

### *3.3 Influence of operational conditions*

#### *3.3.1 Temperature*

Several authors [23-26] have reported the increase of gas yield and the decrease in gas heating value with temperature, even when different feedstocks and gasifiers are used. It is expected that the rise of temperature leads to an increase in the rate of the several reactions that take place during gasification process, which, globally, produce hydrogen and carbon monoxide and eliminates hydrocarbons. At higher gasification temperatures lower solids and tar emissions are observed, which means that the produced gas may require a lower cost on gas cleaning processes.

### *3.3.2 Pressure*

Gasifiers can be operated at elevated pressures, the advantage being for those end use applications where the gas is required to be compressed afterwards, as in a gas turbine. Pressurized gasifiers have the following significant features:

- Feeding is more complex and very costly, and has a high inert gas requirement for purging.
- Capital costs of pressure equipment are much higher than for atmospheric equipment, although equipment sizes are much smaller.
- Pressurized gasification systems can cost up to four times as much as atmospheric systems at power outputs up to 20 MWe. This disadvantage is countered by the higher efficiency, and this effect becomes significant at 30-50 MWe, above which pressure systems are believed likely to be more economic than atmospheric systems.
- Gas is supplied to the turbine at adequate pressure, removing the need for gas compression and also permitting relatively high tar contents in the gas; such tar needs to be completely burned in the turbine combustor.
- Hot gas cleanup with mechanical filters (such as sintered metal or ceramic candles) is usually used, which reduces thermal and pressure energy losses and in principle in simpler and of lower cost than are scrubbing systems.
- Overall system efficiency is higher owing to retention of sensible heat and chemical energy of tars in the product gas and the avoidance of a fuel gas compression stage ahead of the turbine. The only significant energy losses are to the environment and in provision of inert gas to the pressure feeders, and these can be as low as 5-8%, giving energy conversion efficiency for the gasifier itself of 92-95%. A corresponding atmospheric gasifier with water scrubbing and product gas compression would have an analogous efficiency as low as 80-85%, depending on capacity and design.

Atmospheric gasifiers have the following significant features:

- For gas turbine applications the product gas is required to be sufficiently clean for compression before the turbine. Suggested specifications are given later. For engine applications the gas quality requirements are less onerous and pressure is not required.
- Atmospheric systems have a potentially much lower capital cost at smaller capacities of below 30 MWe as discussed above.

Gas compositions and heating values are not significantly different for either system [2].

### *3.4 Influence of the oxidizer*

It is well-known that the heating value and the $H_2$ content of syngas are higher when gasification is made with steam than it is made with air [24].

Table 5 shows experimental results of wood gasification using different types of oxidizers. It is verified that the use of steam or $O_2$ as oxidizer agent increases remarkably the production of $H_2$ and CO reflecting a significant increase of the syngas heating value. In the case of the fixed bed reactors, an increase of methane yields is also verified using $O_2$ and steam as oxidizer.

Table 5 – Influence of the oxidizer in the final composition of syngas

| Oxidizing agent | Composition (% vol, dry base) | | | | | HHV (MJ/m$^3$) | Reference |
|---|---|---|---|---|---|---|---|
| | $H_2$ | CO | $CO_2$ | $CH_4$ | $N_2$ | | |
| Air (downdraft) | 17 | 21 | 13 | 1 | 48 | 5.7 | [2] |
| Air (updraft) | 11 | 24 | 9 | 3 | 53 | 5.5 | [2] |
| $O_2$ (downdraft) | 32 | 48 | 15 | 2 | 3 | 10.4 | [2] |
| Air (BFB) | 9 | 14 | 20 | 7 | 50 | 5.4 | [2] |
| Air (CFB) | 14.1 | 18.7 | 14.7 | 3.5 | 47.7 | n.d. | [19] |
| Air (BFB) | 9.5 | 18 | 13.5 | 4.5 | 45 | n.d. | [27] |
| Steam (CFB) | 34.2 | 27.2 | 22.7 | 11.1 | 4.8 | n.d. | [28] |
| Steam (BFB) | 52 | 23 | 18 | 7 | n.d. | n.d. | [23] |

Table 6 shows a comparison performed by Javier et al. [24] based on results from Herguido et al. [23], Javier et al. [22] and Narváez et al. [27] in order to determine the effect of gasifying agent on other results like tar content in the produced gas. Three basic ratios were used for comparison of results using different gasifying agents in a bubbling fluidized bed gasifier running with small chips of pine:

- Equivalence ratio ($\phi$) for air;
- Gasifying ratio (GR) [($H_2O$+$O_2$)/Biomass (kg/h)/(kg dry-ash free/h)], for steam-$O_2$ mixtures;
- Steam to biomass ratio (SB) [$H_2O$/Biomass (kg/h)/(kg dry-ash free/h).

Table 6 – Effect of gasifying agent on syngas composition.

| Parameter | Air ($\phi$=0.3) | Steam/$O_2$ GR = 0.9 | Steam SB=0.90 |
|---|---|---|---|
| $H_2$ (vol.% dry basis) | 8-10 | 25-30 | 53-54 |
| CO (vol.% dry basis) | 16-18 | 43-47 | 21-22 |
| LHV (MJ/$m^3$, dry basis) | 4.5-6.5 | 12.5-13.0 | 12.7-13.3 |
| Ygas ($m^3$, dry basis/kg daf) | 1.7-2.0 | 1.0-1.1 | 1.3-1.4 |
| $Y_{tar}$ (g/kg daf) | 6-30 | 8-40 | 70 |
| Tar (g/$m^3$) | 2-20 | 4-30 | 30-80 |

The ratios in the table 6 indicate that gasification with air produces a higher syngas yield. Tar yields are quite different between the gasifying agents being the lowest values obtained with air.

## 4. Conclusion

The influence of various process parameters in the final composition of the syngas was evaluated based on bibliographical data. It is evaluated the influence of the biomass kind, reactor type, oxidizer and reactor operational conditions on the final composition of syngas.

Conclusion can be drawn that there is a significant discrepancy in the final composition of the syngas, even considering the same type of biomass and type of gasifier. This highlights the strong dependence of the final composition of syngas from biomass condition, type of gasifier and pressure and temperature conditions. Thus, in order to make precise studies on the use of syngas it will be necessary to consider that its composition will be very difficult to maintain constant. The development of mathematical models for numerical simulation fully validated experimentally may be a very useful tool to determine the final composition of syngas by changes in initial conditions without laborious and expensive experimental tests.

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