BIOMASS AND BIOENERGY 64 (2014) 190–198

Available online at www.sciencedirect.com

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Evaluation of biomass gasification in a ternary diagram

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ARTICLE INFO

Article history:
Received 25 September 2012
Received in revised form
13 March 2014
Accepted 25 March 2014
Available online 21 April 2014

Keywords:
Wood gasification
Ternary diagram
Thermodynamic modeling
Cold gas efficiency
Gasifying agent

ABSTRACT

The present paper addresses the development of an alternative approach to illustrate biomass gasification in a ternary diagram which is constructed using data from thermodynamic equilibrium modeling of air-blown atmospheric wood gasification. It allows the location of operation domains of slagging entrained-flow, fluidized-bed/dry-ash entrained-flow and fixed/moving-bed gasification systems depending on technical limitations mainly due to ash melting behavior. Performance parameters, e.g. cold gas efficiency or specific syngas production, and process parameters such as temperature and carbon conversion are displayed in the diagram depending on the three independent mass flows representing (1) the gasifying agent, (2) the dry biomass and (3) the moisture content of the biomass. The graphical approach indicates the existence of maxima for cold gas efficiency (84.9%), syngas yield (1.35 m^3 ($H_2 + CO$ STP)/kg (waf)) and conversion of carbon to CO (81.1%) under dry air-blown conditions. The fluidized-bed/dry-ash entrained-flow processes have the potential to reach these global maxima since they can operate in the identified temperature range from 700 to 950 °C. Although using air as a gasifying agent, the same temperature range posses a potential of H_2/CO ratios up to 2.0 at specific syngas productions of 1.15 m^3 ($H_2 + CO$ STP)/kg (waf). Fixed/moving-bed and fluidized-bed systems can approach a dry product gas LHV from 3.0 to 5.5 MJ/m^3 (dry STP). The ternary diagram was also used to study the increase of gasifying agent oxygen fraction from 21 to 99 vol.%. While the dry gas LHV can be increased significantly, the maxima of cold gas efficiency (+6.5%) and syngas yield (+7.4%) are elevated only slightly.

1. Introduction

In order to fulfill CO_2 reduction commitments and to prevent a shortage of depletable fossil energy carriers, interest in biomass gasification increases especially for the production of alternative fuels of the second generation. The EU for instance enforces the use of biomass derived transportation fuels by setting a share of 10% of biofuels for 2020 [1–3]. Consequently, the focus of research is directed towards biomass gasification

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http://dx.doi.org/10.1016/j.biombioe.2014.03.054
0961-9534/

processes. The comprehensive assessment of such processes is difficult due to many independent variables such as feedstock composition and reactivity, temperature, pressure, moisture and other varying boundary conditions. A well-known approach to systemize the C–H–O reactions originated from Grout [4] in form of a ternary diagram which was later used by Ghosh [5] for classification of carbonaceous feedstock. Stephens [6], Battaerd and Evans [7] identified the potential of displaying mixing lines for the reaction of coal or hydrocarbons with oxygen or steam. More recently, the C–H–O diagram became a suitable measure to show the soot or char formation boundaries at varying temperatures and pressures [8–11] or in the presence of sensitive substances where a carbon-free operation is required [12,13]. Nagel et al. [14,15] already indicated some operating ranges for gasifiers and comment on possible cold gas efficiencies in the several regions. Ptasinski et al. [16] identified the boundary of carbon formation as line of complete gasification and therefore as a desirable range for plant operation. Vassilev et al. [17] recently constructed an O–(C + H)–(N + S + Cl) ternary diagram on dry and ash free wt.%-basis to compare mean ultimate fuel compositions. Soon, the disengagement from the molar fractions became an attractive idea which was followed again to systemize compositions [18,19].

The present work introduces a further step in which the three main mass flows into a biomass gasifier (dry biomass, moisture, air) are normalized to 100 wt.% plotted as corners of a ternary diagram similar to earlier work [20]. A distinct atomic C–H–O definition for each stream is not longer necessary. Hence, biomass may contain all impurities (e.g. N, Cl, S, and mineral matter) and air can keep its atmospheric composition. It allows the assessment of process and performance parameters and provides a comprehensive overview. Consequently, the diagram is easy to use because the mass flows into a technical gasifier from practice can be applied directly.

2. Theoretical and technological background

2.1. Constructing the ternary diagram

The data which is shown in the ternary diagram is provided by means of equilibrium modeling applying minimization of Gibbs free enthalpy, e.g. in the software Aspen Plus [21]. But also data from kinetic models or experimental data can be plotted in the same way. Fig. 1 provides a principal overview on the ternary diagram setup. In this study, air was chosen as a gasifying agent at the beginning. Because biomass can vary in water content over a wide range, it is reasonable to split the wet fuel stream in moisture and dry biomass. Hence, the mass flows of air, moisture, and dry biomass are treated independently and are normalized as mass fractions in wt.%.

In order to investigate the relevant area of gasification, the upper part of the diagram is enlarged where air is between 50 and 100 wt.%. As shown by Fig. 1, reasonable combinations of output parameters are identified for this enlarged area leading to five types of ternary diagrams.

1. Temperature and carbon conversion are combined offering a general overview and an easy location of gasifier operating ranges.
2. Cold gas efficiency on lower heating value (LHV) basis and dry methane gas yield are fitted together because the high LHV of methane contributes significantly to the cold gas efficiency but limits gas quality in terms of synthesis applications or CO_2 separation processes.

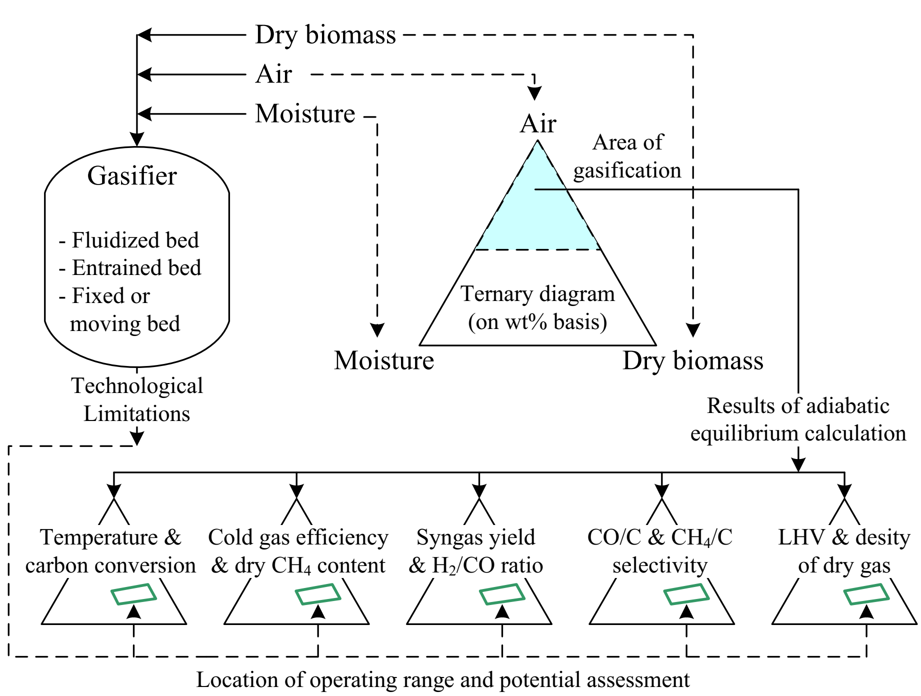

Fig. 1 – Schematic overview of the ternary gasification diagram setup.