Chemical Engineering Science 64 (2009) 5073–5083

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Comparison of dual fluidized bed steam gasification of biomass with and without selective transport of CO_2

C. Pfeifer*, B. Puchner, H. Hofbauer

Institute of Chemical Engineering, Vienna University of Technology, Getreidemarkt 9/166, A-1060 Vienna, Austria

A R T I C L E   I N F O

Article history:
Received 10 September 2008
Received in revised form 16 May 2009
Accepted 13 August 2009
Available online 19 August 2009

Keywords:
Absorption
Energy
Biomass
Gasification
Synthesis gas
Hydrogen

A B S T R A C T

A comparison of dual fluidized bed gasification of biomass with and without selective transport of CO_2 from the gasification to the combustion reactor is presented. The dual fluidized bed technology provides the necessary heat for steam gasification by circulating hot bed material that is heated in a separate fluidized bed reactor by combustion of residual biomass char. The hydrogen content in producer gas of gasifiers based on this concept is about 40 vol% (dry basis). Addition of carbonates to the bed material and adequate adjustment of operation temperatures in the reactors allow selective transport of CO_2 (absorption enhanced reforming—AER concept). Thus, hydrogen contents of up to 75 vol% (dry basis) can be achieved. Experimental data from a 120 $kW_{Fuel\ input}$ pilot plant as well as thermodynamic data are used to determine the mass- and energy-balances. Carbon, hydrogen, oxygen, and energy balances for both concepts are presented and discussed.

1. Introduction

In times of discussions of global warming attention is drawn to renewable energy and its potential. Solid biomass is a renewable energy source that has the potential to be used as a main substitute for fossil fuels. Steam gasification of solid biomass yields high quality producer gases that can be used for efficient combined heat and power production (CHP) and for chemical synthesis processes.

At the Vienna University of Technology a dual fluidized bed steam gasification technology has been developed to provide the heat for the gasification reactor by circulating hot bed material. This system is a further development of the so called FICFB technology (fast internally circulating fluidized bed described in detail by Hofbauer et al., 1997, 2002; Loeffler et al., 2003; Kaiser et al., 2003). The technology is demonstrated at the 8 MW (fuel power) combined heat and power plant in Guessing, Austria which is in operation since 2002 (Hofbauer et al., 2003).

A new approach in improving the dual fluidized bed process is the absorption enhanced reforming (AER) concept. By using a bed material that not only acts as a heat carrier but also influences the gasification process and especially the product gas composition a hydrogen rich gas can be produced. Within this work the main aspects of the two concepts are presented by comparing experimental results of both of them. Furthermore, the main differences are pointed out with the help of mass and energy balances generated using experimental results but also data achieved by a simulation model based on the process simulation tool $IPSE_{pro}^{®}$.

2. Process description

2.1. Conventional steam gasification of biomass

Fig. 1 shows the principle of the dual fluidized bed steam gasification processes. The biomass enters a fluidized bed gasification zone where drying, thermal devolatilization, and partially heterogeneous char gasification take place at bed temperatures of about 850 °C (Franco et al., 2003; Higman and van der Burgt, 2003). Residual biomass char leaves the gasification zone together with the bed material towards the combustion zone which is operated at about 920 °C. The combustion zone is used for heating up the bed material which afterwards flows back to the gasifier. Air is used as fluidization agent in the combustion zone.

The temperature difference between the combustion and the gasification zone is determined by the energy needed for gasification as well as the bed material circulation rate. Further parameters with energetic significance are the amount of residual char that leaves the gasifier with the bed material and the gasification temperature. The system is inherently auto-stabilizing since a decrease of the gasification temperature leads to higher amounts of residual char which results in more fuel for the combustion reactor. This, in turn, transports more energy into the gasification zone and thereby stabilizes the temperature. In practical operation, the gasification

* Corresponding author. Tel.: +43 1 58801 15951; fax: +43 1 58801 15999.
E-mail address: cpfeifer@mail.zserv.tuwien.ac.at (C. Pfeifer).

0009-2509/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2009.08.014

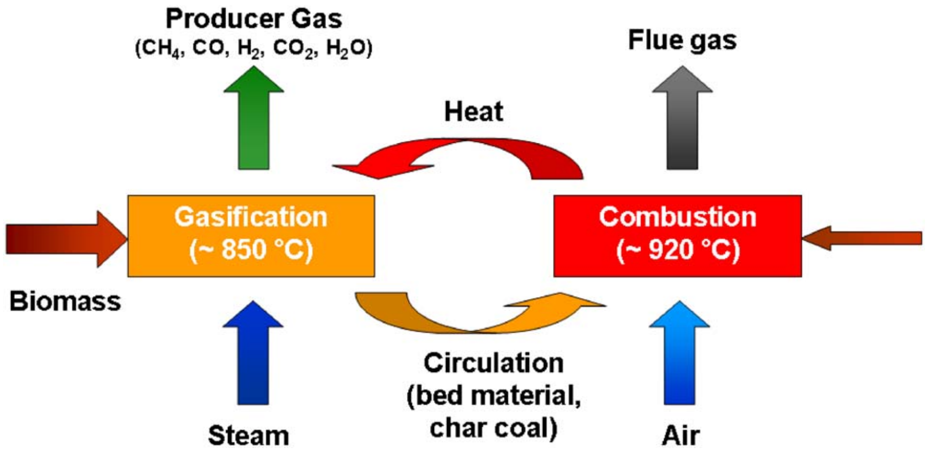

Fig. 1. Steam gasification with selective transport of CO_2.

temperature can be influenced by addition of fuel (e.g. recycled producer gas, saw dust, etc.) into the combustion reactor. The pressure in both zones, gasification and combustion, is close to atmospheric conditions. The process results in two separate gas streams, a high quality producer gas and a conventional flue gas, at high temperatures. The producer gas is generally characterized by a relatively low content of condensable higher hydrocarbons (2–10 g/m^3 of so called tars, heavier than toluene), low N_2 (< 1 vol%db), and a high H_2 content of 35–40 vol%db (dry basis). For practical use, olivine, a natural mineral, has proven to be a suitable bed material with enough resistance to attrition and moderate tar cracking activity (Rauch et al., 2004).

2.2. *Steam gasification coupled with CO_2 capture*

Curran and co-workers proposed already in the 1960's the use of calcium oxide as a CO_2 acceptor inside a fluidized bed gasifier (Curran and Gorin, 1964; Curran et al., 1967). The chemical reaction of CO_2 with CaO is described in detail by Bhatia and Perlmutter (1983) as well as by Stanmore and Gilot (2005). Recently, two types of application for the selective capture of CO_2 using calcium based sorbents become interesting: the removal of CO_2 from combustion exhaust gases in combination with carbon capture and sequestration technologies and the sorption enhanced reforming technologies in order to obtain a hydrogen rich producer gas via gasification (Proell and Hofbauer, 2008a,b). The first group of technologies has been investigated recently by several research groups (Abanades et al., 2003, 2004; Gupta and Fan, 2002; Shimizu et al., 1999; Sun et al., 2005; Manovic et al., 2008; Wei et al., 2008). The behavior of dolomite resp limestone during repeated cycles of calcinations and carbonations has been intensively studied of various research groups (e.g. Fennell et al., 2007; Gallucci et al., 2008; Li et al., 2005).

The proposed gasification process uses in-situ CO_2 capture and the principle of the process is shown in Fig. 2. Details about the identification of suitable sorbents can be found in Bandi et al. (2005) and Marquard-Moellenstedt et al. (2008). The absorption enhanced reforming (AER) process is more efficient than conventional gasification with downstream gas cleaning due to (i) in-situ integration of the reaction heat of CO_2 absorption and water–gas shift reaction heat (both exothermic) into the gasification zone and (ii) the internal reforming of primary and secondary tars, which avoids the formation of higher tars. Thus, the chemical energy of tars remains in the product gas. The product gas after dust removal can directly be used in a gas engine for electricity generation without further tar separation. Due to the low operation temperature (up to 700 °C) and due to

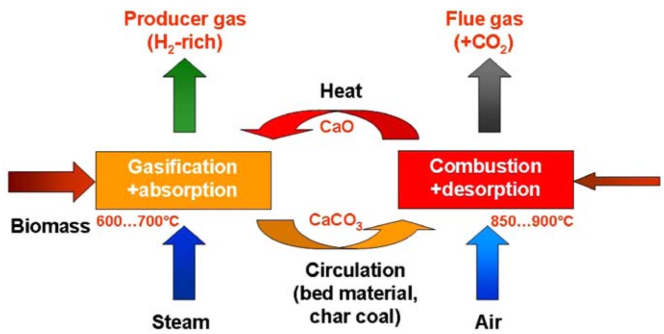

Fig. 2. Steam gasification without selective transport of CO_2.

CaO-containing bed materials, the proposed process allows the use of problematic feedstocks such as biomass with high mineral and high moisture content, e.g. straw, sewage sludge, etc., leading to an increased market potential for biomass gasification processes. Details about the process and the theoretical background can be found in Pfeifer et al. (2007) and Proell and Hofbauer (2008a,b).

3. Experimental

3.1. *Apparatus and procedure*

Fig. 3 shows a schematic drawing of a dual fluidized bed steam gasification process. This process was used for the investigations. The biomass enters a bubbling fluidized bed gasifier where drying, thermal devolatilization, and partially heterogeneous char gasification take place at bed temperatures of about 850–900 °C. Residual biomass char leaves the gasifier together with the bed material through an inclined, steam fluidized chute towards the combustion zone. The combustion zone is designed as highly expanded fluidized bed (riser) and air is used as fluidization agent. After particle separation from the flue gas in a cyclone, the hot bed material flows back to the gasifier via a loop seal. Both connections, the loop seal and the chute are fluidized with steam, which effectively prevents gas leakage between gasification and combustion zone and also allows high solid throughput.

The process development unit used in this work represents the third generation of 100 kW (fuel power) dual fluidized bed gasifiers at the Vienna University of Technology and started operation in January 2003. A simplified flowsheet of the experimental equipment is given in Fig. 4. In the following a brief description of the process