Fuel Processing Technology 141 (2016) 138–147

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Research article

Analysis of optimization potential in commercial biomass gasification plants using process simulation

V. Wilk [a],*, H. Hofbauer [b]

[a] Bioenergy2020 + GmbH, Wienerstraße 49, 7540 Güssing, Austria
[b] Institute of Chemical Engineering, Vienna University of Technology, Getreidemarkt 9/166, 1060 Vienna, Austria

ARTICLE INFO

Article history:
Received 28 February 2015
Received in revised form 25 July 2015
Accepted 31 July 2015
Available online 8 August 2015

Keywords:
IPSEpro
Dual fluidized bed
Steam gasification
Parameter variation

ABSTRACT

The performance of the dual fluidized bed gasification plant Oberwart was evaluated by means of an extensive measurement campaign and calculation of mass and energy balances using IPSEpro. Process simulation was also applied to identify future optimization potentials. Different aspects are discussed such as the reduction of gasification temperature and the reduction of steam for gasification and air for combustion. Gasification pilot plant experience is integrated in the simulation models to increase significance of the simulation results. The mass and energy balances confirm that the performance of the CHP plant Oberwart is highly satisfactory and currently achieves an electrical efficiency of 29%. The variations of plant parameters provide deeper insight in the process itself and show interdependencies of different process units. With lower gasification temperatures and reduction in combustion air, the electrical efficiency can be increased to 31%.

Symbols

Symbol		Unit
A	Area	m^2
All	Overall	
Ash		
Bed	Bed material	
C	Carbon	
C	Concentration	Vol.-%
comb	Combustion reactor	
el	Electrical	
Fuel		
gasif	Gasification reactor	
Init	Initial state	
λ	Excess air ratio	kg/kg or m^3/m^3
$\dot{m}$	Mass flow	kg/s
meas	Measured	
η	Efficiency	
P	Power	kW
pc	Post combustion chamber	
Φ	Steam-to-fuel ratio	kg/kg
Ψ	Throughput	kg/(hm^2)
χ	Steam conversion	kg/kg
$\dot{Q}$	Heat flow	kW
steam	Steam for fluidization	
stoich	Stoichiometric	
T	Temperature	°C
tar	Tar	
th	Thermal	
w	Mass fraction	kg/kg
waf	Water and ash free	
WHSV	Weight hourly space velocity	1/h
x	Load	g/Nm^3

1. Introduction

Solid biomass is going to play an increasing role in the energy supply of the future, as it is an important renewable source of energy and the only source of renewable carbon. The efficient use of biomass is currently receiving increasing attention. Gasification – as an innovative and viable technology for the thermal conversion of biomass – has been the focus of considerable research for a number of decades. For gasification processes, fluidized bed reactors are applied by preference. The good mixing conditions of fuel particles, bed material, and gas phase and an excellent heat transfer promote the conversion of the feedstock. Detailed reviews of different types of gasification reactors and their applications are available in [1–6]. Conventional air gasification yields a

---

Abbreviations: CHP, combined heat and power; DFB, dual fluidized bed; GCMS, gas chromatograph with mass spectrometer; LCV, lower calorific value; Nm^3, volume at standard conditions of 101325 Pa and 273.15 K; ORC, organic Rankine cycle; RME, rape seed methyl ester (biodiesel); vol.-%, volume percent (Nm^3/Nm^3 × 100%); waf, water and ash free; wt.-%, weight percent (kg/kg × 100%).

* Corresponding author at: AIT Austrian Institute of Technology, Giefinggasse 2, 1210 Vienna, Austria.

E-mail addresses: veronika.wilk@ait.ac.at (V. Wilk), hermann.hofbauer@tuwien.ac.at (H. Hofbauer).

http://dx.doi.org/10.1016/j.fuproc.2015.07.035
0378-3820/

product gas which is highly diluted with nitrogen and as a consequence has a lower calorific value (LCV) of 4–6 MJ/m^3. In contrast, steam gasification allows the generation of a nitrogen free product gas without the use of pure oxygen as a gasification agent. The LCV is in the range of 12–14 MJ/m^3. Due to absence of nitrogen, product gas from steam gasification is suitable for chemical synthesis processes. Comprehensive reviews on fluidized bed gasification with steam are provided by several authors, [7–9].

At the Vienna University of Technology, the dual fluidized bed (DFB) gasification technology was developed in the 1990s in order to establish an efficient conversion technology to produce electricity, heat, and fuels from solid biomass. The DFB gasification process has been successfully demonstrated in Güssing (Austria), where a DFB steam gasifier has been in operation at the scale of an 8 MWth demonstration plant since late 2001. The second DFB steam gasification went into operation in 2008 in Oberwart (Austria) and represents an important step of development in DFB gasification. Today this technology is commercially available and several industrial plants ranging from 8 to 33 MW are in operation in Europe by now.

Process simulation plays an important role for the development of new technologies and allows for assistance in process design, plant operation and optimization. IPSEpro is an equation oriented steady state simulation tool that has been initially developed for thermal power cycle calculations [10]. It has been successfully used already in the phase of basic engineering of the Güssing gasifier, because it can be adapted as well as extended to new processes with user built models [11]. Therefore, this simulation tool has been frequently used for design considerations and technology evaluation for several DFB gasification processes. The potential application of DFB gasification plants in pulp and paper processes for example is described in [12] and for waste wood gasification in [13]. Based on IPSEpro simulations, different process pathways for the production of renewable hydrogen from biomass based on DFB gasification are compared in [14]. Synthesis of natural gas from biomass is evaluated with IPSEpro based on a realized process in [15] and based on a theoretical process that is planned to be realized in [16]. Extensive IPSEpro modeling that also considers gas–solid reactions was used for the design of a chemical looping test facility [17] and for the design of a 10 MW chemical looping plant [18].

Process simulation with IPSEpro is also successfully applied for gasification plants in operation. In this case data from plant operation is then used for balance of plant (BOP). Pröll et al. analyzed the first years of operation of the DFB gasifier in Güssing with IPSEpro. By means of extensive parameter variations in IPSEpro, they evaluated optimization potentials of the gasification process [19]. Parameter variations on the large scale plant are normally restricted as the operator of the plant aims at maintaining a high availability and a high power output. However, process simulation reduces the risk for the operator of the gasification plant and shows the optimization potential.

Similarly, IPSEpro was used at the DFB gasification plant Oberwart, the second DFB gasification plant at industrial scale. The commissioning phase and the first years of operation of the DFB gasification plant in Oberwart were also balanced using IPSEpro [20].

This paper presents a scientific evaluation of the current performance of the DFB gasification plant Oberwart based on IPSEpro simulation. For this purpose, an extensive measurement campaign was carried out in 2013, which included online and discontinuous measurements of biomass, product gas and flue gas quality. These measurements and data retrieved from the process control system were used to calculate mass and energy balances of the entire process. Potentials for future optimization are identified by process parameter variations. Different aspects are discussed in this paper: i) reduction of gasification temperature, ii) reduction of steam for gasification and iii) air for combustion. In order to simulate the influence of these process parameters more precisely, new model units are developed based on extensive experience gained from DFB pilot plant operation at Vienna University of Technology. The simulation shows how the plant configuration reacts to changes in these process parameters, however, the range of variation is sometimes limited due to the existing plant configuration in Oberwart. It provides deeper insight in the process itself and show interdependencies of different process units.

2. Materials and methods

2.1. Dual fluidized bed gasification

The basic principle of DFB gasification is illustrated in Fig. 1. It is a steam gasification process, which is carried out in two reactors: an allothermal gasification reactor fluidized with steam and a combustion reactor fluidized with air that provides heat for gasification. The reactors are connected thermally by circulating bed material. In the gasification reactor, a bubbling fluidized bed is formed, where biomass is devolatilized and partly gasified. The products of devolatilization and gasification react with steam to form the product gas. Ungasified biomass char is transported with the bed material to the combustion reactor, where the char is combusted with air. The combustion reactor is a fast fluidized bed reactor, where the bed material is heated and transported to the top of the reactor. It is separated from the flue gas stream in a cyclone and is returned to the gasification reactor. Some product gas is recycled back to the combustion reactor (fuel to combustion) to fulfill the energy demands of gasification and to obtain the desired temperature in the gasification reactor (e.g., 850 °C). In the DFB gasifier, two separated gas streams are yielded, the product gas and conventional flue gas. Due to steam gasification, the product gas has a moderate calorific value of 12–14 MJ/Nm^3 and is rich in hydrogen (>40%).

2.2. Combined heat and power plant Oberwart (CHP)

The CHP plant in Oberwart, Austria, is in operation since 2008 and is an excellent example for DFB gasification at industrial scale. The plant is designed for a nominal fuel load of 8.5 MW of woody biomass and provides electricity and district heat. It is owned and operated by Energie Burgenland GmbH, a local energy utility. In Fig. 2 the process flow diagram of the CHP plant is illustrated. The plant is operated on wood chips that are fed to a dryer prior to gasification. In the gasification reactor, wood chips are gasified with steam and product gas is formed that is cooled in several heat exchangers. In a bag house filter, entrained particles, char and tar are removed from the product gas stream. In the product gas scrubber tar is removed by RME (biodiesel), an organic scrubbing liquid. As the scrubber is operated at temperatures of about 40 °C, water is condensed from the product gas, which is reused for fluidization. RME saturated with tar is combusted in the combustion reactor. After the product gas blower, the gas is used in two gas engines that produce electricity and district heat.

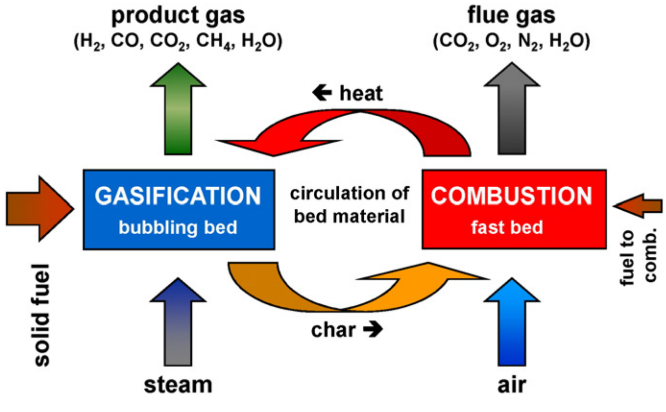

Fig. 1. Basic principle of the DFB gasification technology.