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Synergetic Utilization of Renewable and Fossil Fuels: Dual Fluidized Bed Steam Co-gasification of Coal and Wood

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Abstract

Gasification of biomass and coal is an attractive technology for combined heat and power production, as well as for synthesis processes such as the production of liquid and gaseous biofuels. The allothermal steam blown gasification process yields a high calorific product gas, practically free of nitrogen. Originally designed for wood chips, the system can also handle a large number of alternative fuels. To demonstrate the influence on the system performance of fuels that have a different origin, wood pellets, as the designated feedstock, and hard coal as an example fossil fuel were fed into the DFB gasifier with a fuel blend ratio of 20 % coal in terms of energy. A fuel power of 78 kW and a steam to fuel ratio of 1.0 kg/kg_{db} were achieved. The system was operated at gasification temperatures between 830 and 870 °C. This paper points out the influence of the temperature on the system.

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Keywords: Co-gasification; coal; biomass; renewable energy;

1. Introduction

During the last decade there has been a large amount of research done on the field of gasification of woody biomass. One big issue in the gasification of biomass is that the feedstock is often only available locally at a certain period of the year in large amounts. Co-gasification of biomass, as the designated feedstock, with a cheap fossil fuel could help to overcome this problem as fuel flexibility is the key feature for an economic breakthrough. It also offers the opportunity to build larger plants with higher feedstock flexibility as the combination with coal overcomes the drawback of the relatively low specific energy content of biomass-derived fuels. Conventionally, autothermal gasification processes always require an oxidizing gasification agent, like air. This results in the drawback of a syngas with a low

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heating value as it is diluted with nitrogen. Especially for further synthesis processes (Fischer-Tropsch Synthesis, synthetic natural gas, methanol synthesis) this dilution is a big drawback. Dual fluidized bed gasification solves this problem as the gasification zone and combustion zone, which provide the energy for gasification, are separated and pure steam is used as a gasification agent. This gasification technology [1] has been developed at the Vienna University of Technology and is successfully demonstrated in Güssing and Oberwart, Austria, on the 8 and 10 MW scale, respectively, since 2001 and 2008 [2, 3]. Further plants in Villach, Austria [1], Gothenburg, Sweden [1] and Senden, Germany are currently under construction and will gain a fuel power of 15 MW (Villach) and 32 MW (Gothenburg). During a previous experimental campaign, the combined heat and power (CHP) gasification plant in Güssing was operated with coal ratios of up to 22 % in terms of energy. These tests were successful as they showed that the dual fluidized bed design could also handle coal as a fuel [4]. The addition of 20 % of coal (in terms of energy) can be beneficial for the process and its performance as by the lower activity of the coal, the residence time of the coal/coke mixture in the system is longer and therefore accumulates to a higher level than when only using biomass as a fuel. In this paper there will be a focus on the possibility of process optimization by changed gasification temperatures. A series of tests with gasification temperatures between 830 and 870 °C will be discussed with a focus on gas quality and process efficiency.

2. Experimental

2.1. Experimental setup

For the experiments on the pilot scale, at Vienna University of Technology, a dual fluidized bed gasification reactor is in operation. The basic principle of the dual fluidized bed gasification process is shown in Fig. 1 and a schematic drawing of the pilot rig is shown in Fig. 2. This system separates gasification and combustion as two fluidized bed reactors connected together by loop seals are used. The fuel, usually biomass, enters the gasification reactor, a bubbling fluidized bed fluidized with steam, where

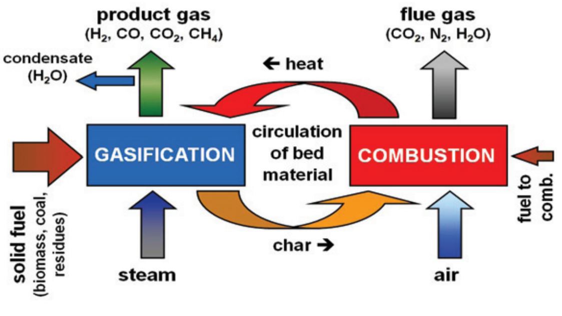

Fig. 1. Principles behind the dual fluidized bed gasifier

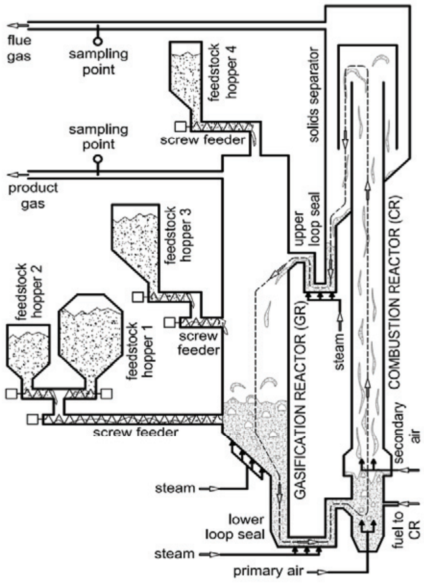

Fig. 2. Schematic drawing of the gasifier

drying, pyrolysis and heterogeneous char gasification take place at bed temperatures of up to 900 °C. The remaining residual char leaves the gasification reactor at the bottom together with the bed material, which circulates between the two reactors, through the lower loop seal to the combustion reactor. This reactor is implemented as a fast fluidized bed that is fluidized with air to maintain combustion of the residual char and additional fuel, if required. The producer gas for biomass gasification is generally characterized by a relatively low content of condensable higher hydrocarbons (2-10 g/Nm³ of so called tars, heavier than toluene), low N_2 (< 1 vol%$_{db}$), and a high H_2 content of 35-40 vol%$_{db}$. A more detailed description of the dual fluidized bed gasifier used at VUT can be found in [1].

2.2. Analytics

The permanent gases in the syngas, CH_4, H_2, CO, CO_2 and O_2, were measured online by a Rosemount NGA2000 and N_2, C_2H_4, C_2H_6, and C_3H_8 by an online gas chromatograph. Tar, NH_3 and H_2S were sampled isokinetically using washing bottles with toluene, diluted sulfuric acid or aqueous potassium hydroxide solution. In the flue gas of the combustion reactor (riser) CO_2, CO and O_2 were detected online by a Rosemount NGA2000.

2.3. Balance of the Plant

The complexity of the gasification processes is high and requires thermodynamic calculations of high accuracy. That is why the calculation of mass and energy balances has to be done using computer-aided methods. For this purpose, the balance tool IPSEpro was used. Detailed information on IPSEpro, its mode of operation and its utilization for biomass-based energy systems is summarized by Pröll et al. [5].

3. Results

For this test campaign, a fuel power (wood pellets and coal) of about 78 kW was chosen. The fluidizing conditions were kept constant for all three tests, so there was always the same amount of steam and air for fluidization. Wood pellets produced according to the Austrian standard ÖNORM M 7135 are usually used as a standard fuel to represent wood in the gasifier. For the processing of biomass in a power plant, wood chips are mostly the designated fuel, but for the pilot plant, the pieces have to be smaller, and the quality of the fuel has to be held constant for the entire test campaign. Therefore, instead of wood chips, wood pellets were used for the tests, as it was found during previous tests that wood pellets behave like wood chips in the gasifier and the results can be compared [1]. The coal used in these tests was Polish hard coal. Polish coal was chosen as it is widely used in Austria for coal-fired power plants. The proximate and ultimate analyses of these two fuels are listed in Table 1. The bed material used in the reactor was olivine. It was chosen as it shows a catalytic activity for tar reduction and is perceived as a non-toxic, natural catalyst. Three tests at gasification temperatures of 830 °C, 860 °C and 870 °C were carried out at the pilot plant. The key data of the accomplished test runs are summarized in Table 2. Fig. 3 shows the main syngas components and Fig. 4 displays the higher hydrocarbons as well as the lower heating value. Hydrogen increased from 42.5 to 45.7 vol.%$_{db}$ and carbon monoxide increased from 24.8 to 26.3 vol.%$_{db}$ in the syngas, whereas carbon dioxide and methane decreased. Also, the higher hydrocarbons ethylene (C_2H_4) and ethane (C_2H_6) decreased, though the most rigorous decrease was ascribed to ethylene. Only propane (C_3H_8) showed an increase, but only at very small total numbers of 0.02 vol.%$_{db}$. The net effect of these changes of the syngas composition was a slight decrease of the lower heating value of the gas, as the major contribution to the LHV was provided by methane and the higher hydrocarbons and their relatively high heating value. Tar was also sampled during the tests. For a gasification temperature of 830 °C there were about 3.4 g/Nm³ of gravimetrically detectable tars and 9.0 g/Nm³ of GC/MS-detectable tars measured. For 870 °C these values dropped to 2.2 g/Nm³ and 6.4 g/Nm³ for gravimetrically- and GC/MS-detectable tars, respectively.

Table 1. Proximate and ultimate analysis of the fuels

		Polish hard coal		wood pellets	
		dry basis	as used	dry basis	as used
water content	[wt. %]	-	9.86	-	6.11
ash content		7.41	6.68	0.29	0.27
C		76.49	68.95	50.23	47.16
H		3.87	3.49	6.04	5.67
N		1.34	1.21	0.05	0.05
O		10.29	9.26	43.38	40.73
S		0.455	0.410	0.005	0.005
Cl		0.15	0.14	0.003	0.003
volatile matter	[wt. %]	34.66	31.24	86.45	81.17
fixed carbon	[wt.%]	65.34	58.90	13.55	12.72
LHV	[MJ/kg]	29.15	26.03	18.75	17.46

Table 2. Key data of the gasification tests

gasification temperature	[°C]	830 ± 2	860 ± 2	870 ± 2
mean combustion temperature	[°C]	889	939	932
fuel size coal	[mm]	6 ± 2		
fuel size wood pellets (diameter x length)	[mmxmm]	Ø 6 x 30 (max.)		
fluidization mass flow gasifier (steam)	[kg/h]	8.4 ± 0.2		
fluidization flow combustor (primary air)	[Nm³/h]	4.6 ± 0.0		
fluidization flow combustor (secondary air)	[Nm³/h]	50.0 ± 0.2		
fuel mass flow (coal + wood)	[kg/h]	15.4 ± 0.2		
steam/fuel ratio φ_{sf}	[kg/kg_{db}]	1.0		

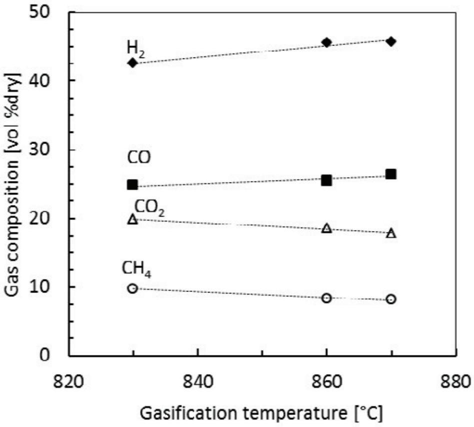

Fig. 3. Main syngas components vs. gasification temperature

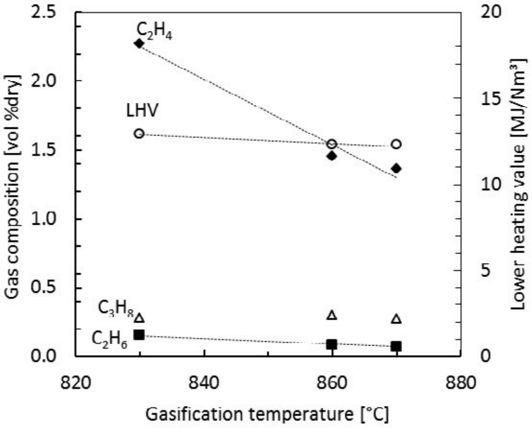

Fig. 4. Higher hydrocarbons and lower heating value vs. gasification temperature

The plot in Fig. 5 shows that the amount of produced syngas in total and per fuel input increased with higher gasification temperatures. This leads to the assumption that the chemical efficiency in the gasifier (cold gas efficiency) also increased, as shown in Fig. 6. This figure also displays the consumption of additional fuel in the combustion reactor. The amount of additional fuel also increased as a result of several inputs. The higher gasification temperatures forced the endothermic gasification reactions, causing more heat losses of the system, and by the improved gasification process there was less char left for the combustion reactor. The process efficiency, also shown in Fig. 6, includes the additional fuel power. Therefore, the net effect on the process efficiency is not that rigorous, it just slightly dropped.

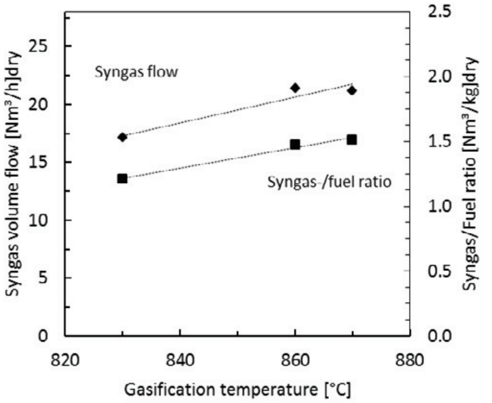

Fig. 5. Syngas flow rate and syngas-/fuel ratio vs. gasification temperature

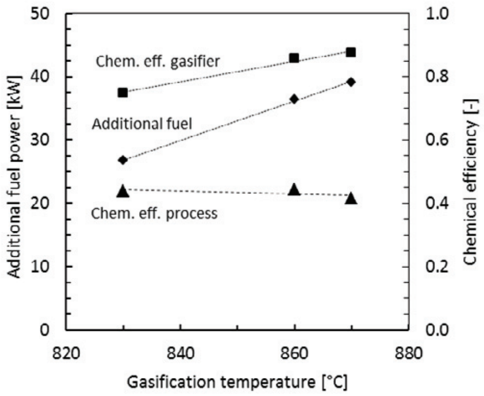

Fig. 6. Consumption of additional fuel and efficiencies of the process vs. gasification temperature

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