

The FICFB - Gasification Process

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Abstract

A novel fluidized bed gasification reactor has been developed to get a product gas with a high calorific value (up to 15 MJ/Nm³) and nearly free of nitrogen. The gasification process is based on an internally circulating fluidized system and consists of a gasification zone fluidized with steam and a combustion zone fluidized with air. The circulating bed material acts as heat carrier from the combustion to the gasification zone. Gas mixing between these two zones is avoided by construction measures. Furtheron, the apparatus is characterized by a very compact design.

The development of the gasification reactor has been carried out step by step. First, a cold flow model was operated to study the fluid mechanics of the fluidization system. The second step was a laboratory scale test rig to study the main features of the reactor by varying different operating and geometrical parameters. After this step a pilot plant was constructed and has been successfully operated. The results attained came fully up to the expectations.

Keywords: Biomass, steam gasification, fluidized bed, compact reactor design, medium energy gas, low nitrogen content.

1 Introduction

In Europe, Austria is one of the leading countries in using bioenergy. The most common utilization of biomass for energy is the combustion for heating applications. Gasification could become a second important route especially for power production (Sipilä, 1995, Solantausta et. al, 1996).

Usually, biomass gasification is carried out using fixed or fluidized beds. As the overall gasification reactions are endothermic, the gasification process must be supplied with heat. The easiest way is to use air as gasification agent and to burn the biomass partially within the gasification reactor. In this case the product gas has a low calorific value (around 4-6 MJ/Nm³) and a high nitrogen content of 45-55 %.

A gas with a low nitrogen content and a higher calorific value (about 12 MJ/Nm³) can be produced with pure oxygen as gasification agent but the costs for the oxygen production are high. Another possibility is to supply heat with heat exchangers but here material problems due to the high temperature level will arise. The dilution of the product gas by nitrogen can also be avoided by using a dual fluidized bed system. In this case no oxygen generator is necessary and also no serious material problems due to high temperatures will appear. A good overview is given by Bridgewater (1995).

2 The Gasification Concept

The basic idea of the gasifier concept is to divide the fluidized bed into two zones, a gasification zone and a combustion zone. Between these two zones a circulation loop of bed material is created but the gases should remain separated. The circulating bed material acts as heat carrier from the combustion to the gasification zone (Hofbauer, 1983). The principle is shown graphically in Figure 1.

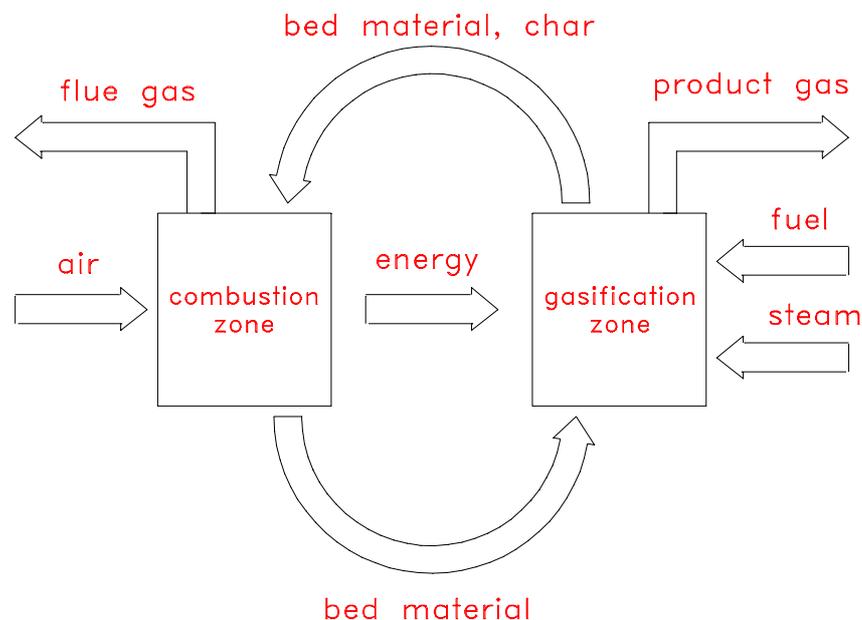


Fig. 1. Basic idea of the gasification process.

The fuel is fed into the gasification zone and gasified with steam. The gas produced in this zone is therefore nearly free of nitrogen. The bed material, together with some charcoal, circulates to the combustion zone. This zone is fluidized with air and the charcoal is partly burned. The exothermic reaction in the combustion zone provides the energy for the endothermic gasification with steam. Therefore the bed material at the exit of the combustion zone has a higher temperature than at the entrance. The flue gas will be removed without coming in contact with the product gas. With this concept it is possible to get a high-grade product gas without use of pure

oxygen. This process can be realized with two fluidized beds connected with transport lines (Schiefelbein, 1989; Paisley, 1993) or with an internally circulating fluidized bed. The latter one has the following advantages:

- simple reactor design
- low investment cost because of compact construction
- reduced energy losses because of efficient thermal household

3 The Test Rig and Pilot Plant

The gasification process has been developed step by step. Three steps are carried out already and a demonstration step will still follow:

- cold flow model
- laboratory test rig
- pilot plant

3.1 Cold Flow Model

At the beginning of the development a cold flow model was built to study and optimize the fluid mechanics of an internally circulating fluidized bed with a draught tube and a surrounding annular bed. Circulation rates of the bed material and gas leakage between the two zones were measured. The circulation rates are important for the heat transport. Further on the gas leakage must be minimized. The results were very promising therefore a laboratory scale test rig for gasification tests was constructed.

3.2 Laboratory Test Rig

The laboratory test rig was designed for a thermal output of 10 kW (Zschetzsche et. al. 1995). Fuel is fed into the annular bubbling bed by a double screw feeding system. The annular bed is fluidized with steam which also acts as gasification agent. The bed material together with the charcoal moves down towards a riser which is situated in the centre of the reactor. The particles are transported up by air through the riser where charcoal is partly burned. At the top of the riser the particles are separated from the gas. The particles fall down and come back to the gasification zone via an annular gap. This gap and the location of the steam and air inlets ensure, that the gas leakage between the two zones is lower than 5 % of the total gas input. Both zones have separated gas exits.

3.3 Pilot Plant

The next step was the construction of a pilot plant with a thermal output of about 100 kW based on the experience of the laboratory test rig. The circular-symmetric geometry was changed to a rectangular cross-section because of scale up consideration. A scheme of the pilot plant can be seen in Fig. 2. Now the riser (2) and the bubbling

level of the system without varying other operation parameters. With this installation parameter studies can be carried out very easily.

4. Results of Gasification Tests

Gasification tests were carried out using wood chips (<20 mm) as fuel. Table 2 contains the analysis of the wood chips.

Table 2. Fuel analysis (Analysis after DIN standards, dm ... dry matter)

wood chips		
water	w.-%	12.1
ash	w.-%	0.6
volatile matter	w.-%	73.3
fixed carbon	w.-%	14.0
C	w.-%, dm	51.5
H	w.-%, dm	6.3
O	w.-%, dm	41.3
N	w.-%, dm	0.22
S	w.-%, dm	<0.05
calorific value	MJ/kg	15.6

For start up purposes electrical air preheaters are installed which are able to heat up the fluidization gases up to 700 °C. During start up instead of steam air is blown into the gasification zone. As soon as the bed temperature exceeds 400 °C fuel feeding is started. After reaching the desired temperature the fluidization gas in the gasification zone is changed over to steam and the preheaters are switched off.

Figure 3 shows typical results attained with wood chips gasified in the 100 kW pilot plant. A lot of temperatures, pressures, volume streams and gas concentrations are measured continuously during gasification. This figure contains only a few of these data to improve overview namely the bed temperature in the combustion zone (T3), the bed temperature in the gasification zone (T6) and the concentrations of CO and H₂ in the dried product gas.

In this example the warm up was not recorded. The gasification was started when the fluidization gas was switched over from air to steam. Immediately the concentrations of CO and H₂ raise to a level of about 32 %. The temperatures in the combustion as well in the gasification zones decrease slightly and remain nearly constant after 25 minutes. According to the concept explained above the temperature in the combustion zone is about 100 °C higher than in the gasification zone. This means that the circulating bed material transports heat from the combustion to the gasification zone. After 1400 s a decrease in CO and H₂ concentrations can be observed because of changing the analysis channel for tar and water analysis of the product gas. The test was finished after 7000 s of operation because the whole system reached complete equilibrium.

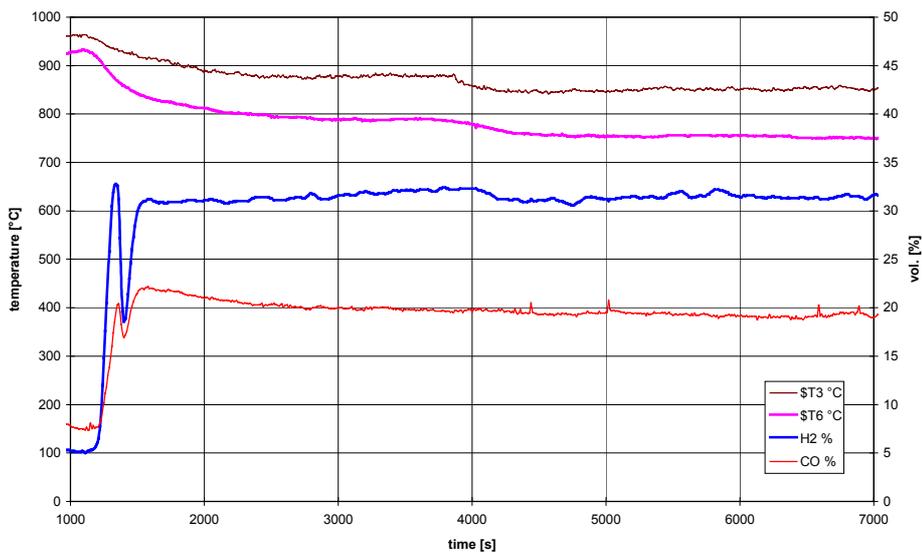


Fig. 3.

Pilot plant test run with wood chips (further data see Table 3)

In addition to the continuous analysis of the gas composition gas samples were taken and analysed with gas chromatography. A small part of the product gas is drained for analysis. This sample gas is cooled down to about 10 °C where most of the condensate and tar is removed. Further gas cleaning stages are a glass wool filter and a high-grade paper filter. Typical results of gas analysis from selected gasification tests for the wood chips can be seen in Table 3.

The nitrogen content is very low in the case of the test rig (< 2.5 %) and something higher in the product gas of the pilot plant (5 %). However, the content is small compared with air blown gasifiers (45 - 55 %). The calorific value is therefore much higher and lies above 13 MJ/Nm³ in any case.

The amount of tar produced during steam gasification has been quantified. In all experiments the tar amount did not exceed 1 g/Nm³ dry product gas although no catalytic bed material has been used up to now. Compared to air blown gasification the tar content is low. Experiments show that the tar content in this case is between 10 to 15 g/Nm³. This results are in agreement with literature (e.g. Rei et al., Baker et al.) and can be explained by steam reforming of the tar.

Table 3. Example of detailed analysis of the product gas (dry) using gas chromatography

<u>operation parameter</u>		
installation	-	pilot plant
type of fuel	-	wood chips
feed	kg/h	30
steam	kg/h	14.89
feed/steam	-	2.01
gasif. temp.	°C	754
comb. temp.	°C	845
<u>product gas analysis</u>		
<u>gas</u>	<u>vol. [%]</u>	<u>calorific value [kJ/Nm³]</u>
H ₂ [1,31]	31.50	3402
O ₂ [1,63]	0	0
N ₂ [1,71]	2.79	0
CO [2,54]	22.66	2865
CH ₄ [2,83]	11.21	4023
CO ₂ [5,87]	27.46	0
ethene [6,21]	3.52	2.095
ethane [7,07]	0.55	353
propene [9,90]	0.27	243
propane [10,35]	0.02	14
i-butene [11,67]	0.02	20
i-butane [12,16]	0.00	0
n-butane [12,97]	0.00	0
sum :	100.00	13015

The following variations of parameters were carried out in several measurements:
(Figure 4,5,6)

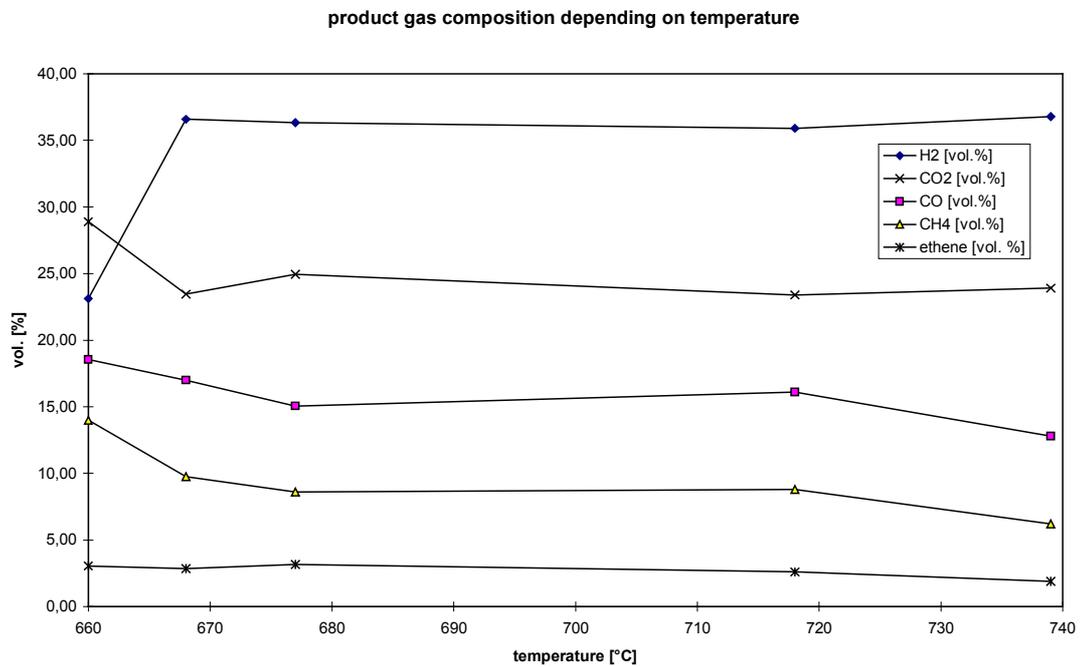


Fig. 4. Product gas composition depending on temperature

Figure 4 shows the product gas composition depending on temperature. In these experiments the fuel to steam ratio was held constant at about 1,1 as far as possible. It can be seen that the product gas composition does not change worth mentioning at temperatures above 670 °C.

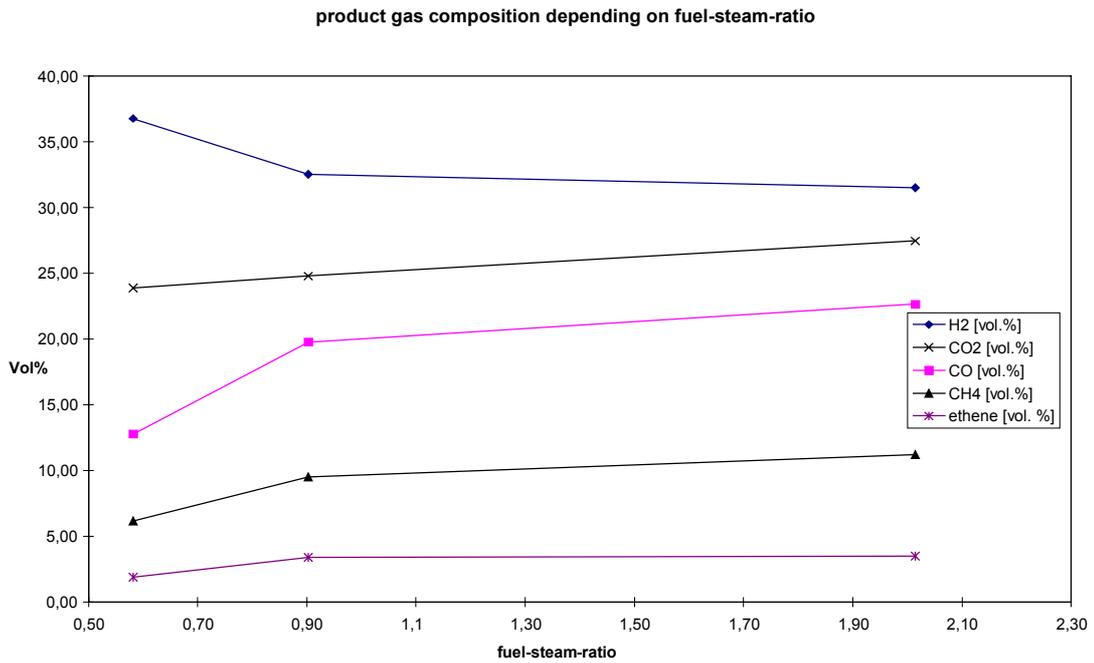


Fig. 5. Product gas composition depending on fuel-steam-ratio

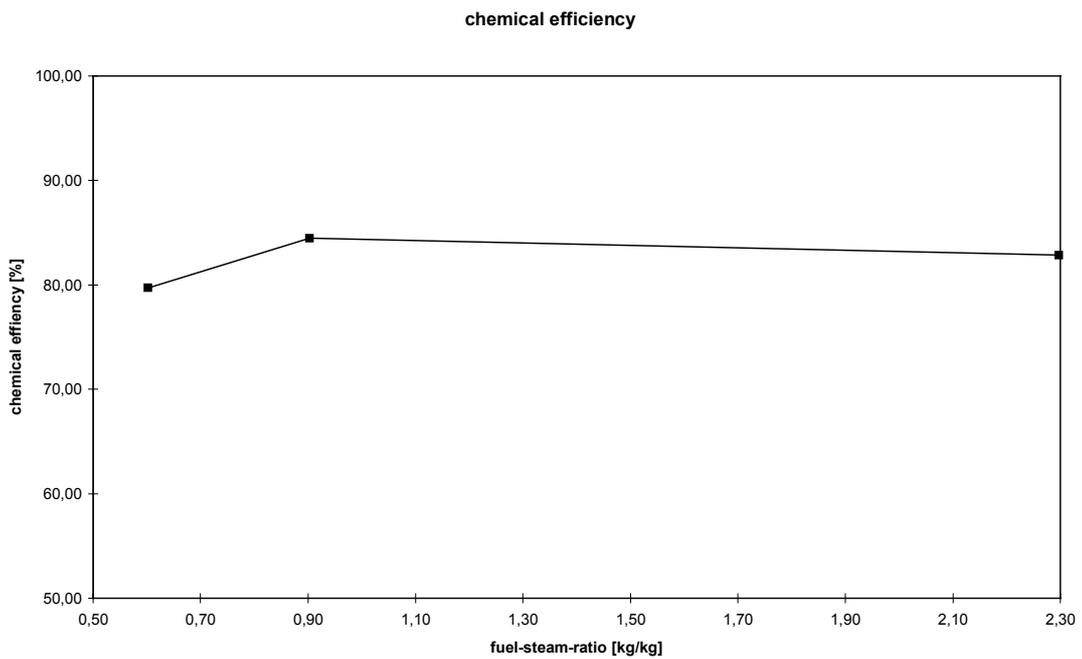


Fig. 6. Chemical efficiency of the process depending on fuel-steam-ratio

Figure 5 shows the product gas composition depending on the fuel to steam ratio. In these experiments the temperature was held constant at about 745 °C as far as possible. It can be seen that a decrease of H₂ goes hand in hand with an increasing CO value by increasing the fuel to steam ratio. All other components in this diagram increase

slightly with the fuel to steam ratio too. We are aware that too much steam is necessary to run this reactor and therefore the variation of the fuel to steam ratio shown in figure 5 is of less importance. In this reactor that high amount of steam is necessary to keep up fluidization but in the next step of development the reactor will be reconstructed to avoid this fact and to reach higher fuel to steam ratios.

Figure 6 shows the chemical efficiency of this process depending on the fuel to steam ratio. In these experiments the temperature was held constantly at about 740 °C as far as possible. It can be seen that the chemical efficiency is almost constant at a high level though changing the fuel to steam ratio.

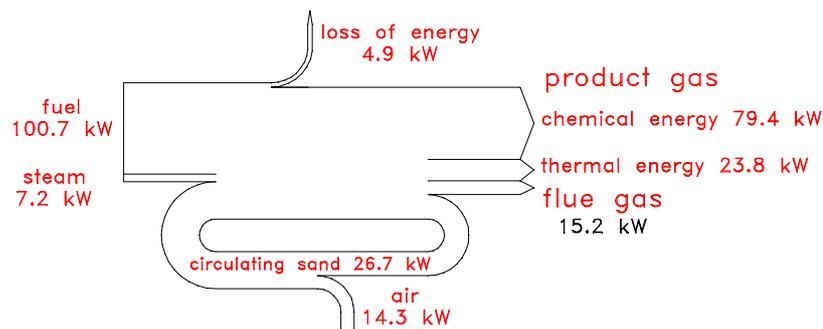


Fig. 7. Energy diagram of the FICFB pilot plant

Figure 7 shows an energy diagram of the pilot plant with energy input, energy output, energy losses and the amount of energy, which is circulating within the gasifier.

5. Conclusion

A novel gasifier was presented which has the following main advantages compared with an air blown gasifier:

- product gas nearly free of nitrogen
- calorific value higher than 13 MJ/Nm³
- very low tar content due to steam gasification
- gas quality is independent of water content in biomass feed
- the apparatus is very compact
- a wide range of feedstock can be gasified
- possibility to use a catalyst as bed material (regeneration of catalyst in combustion zone) to influence the gas composition and gasification kinetic in a more positive way

6. References

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